

Assessment of Geothermal Water and Energy Resources of Lower Jurassic Formations in the NW Part of Polish Lowland (Szczecin Trough)

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ABSTRACT

The paper presents results of PhD dissertation aiming at estimation of geothermal water and energy resources accumulated in Lower Jurassic formation in Szczecin Trough as well as indication of the areas which are characterized by favourable geothermal conditions that would justify their industrial usefulness. Szczecin Trough is located in NW part of Polish Lowland where the highest exploitation water temperatures in Poland were documented (87°C).

Water resources were estimated by means of dynamic hydrogeological modeling. Numerical model was created on the basis of conceptual model. The foundations of the conceptual model were interpreted well log data, which enabled separation of water bearing formations within Lower Jurassic sediments together with their petrophysical parameters. As the result of dynamic modeling water circulation system was established as well as water mass balance. Geothermal resources were calculated in respective categories according to methodology accepted by European Union countries. Assessment procedure was preceded by analysis of hydrogeological and petrophysical parameters which was carried out by means of numerical methods. Range and amounts of disposable geothermal energy resources determinates areas where geothermal plants could be constructed. The final result and summary of the study was presented in the form of map indicating optimal areas for development of geothermal resources in NW part of Polish Lowland. All interpretation and calculations were done using specialized software (Landmark Graphic Cooperation interpretation package, Visual Modflow) which enables application of numeric data processing methods.

1. INTRODUCTION

The research area occupies NW part of Polish Lowland (Szczecin Trough), between coordinates 52°00' - 54°00' latitude and 14°00' - 17°15' longitude. Total area of research covers 16 910 km², which constitutes 6,2% of the Polish Lowland territory and 5,4% of the territory of Poland (fig.1).

Analyses were carried out for the Lower Jurassic aquifer which is the most perspective Mesozoic aquifer in the Szczecin Through.

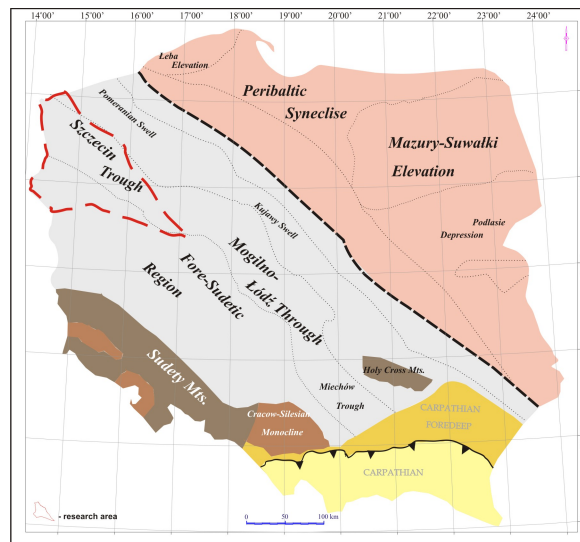


Figure 1: Localization map of research area.

Dynamic hydrogeological model was created using Visual MODFLOW 4.3 software. Interpretation of geothermal system parameters and quantitative calculations were run with Z-MAP Plus software, which enables interpretation of data with three-dimensional spatial grid (GRID). The software uses advanced, mathematical and geostatistical methods of data inter- and extrapolation with the application of several built-in algorithms as well as an option for interpretation of geological discontinuities. Selection and operation modes of interpolation algorithms varied and depended on types and amount of available data. For estimation of geological parameters Least Squares algorithms are used, what allows to obtain most objective interpretation models. Presentation of structural and parametric maps of geothermal aquifers was accomplished with the Albers Equal Area projection based upon Krassovsky's ellipsoid (1940) (central meridian 19°).

2. DYNAMIC HYDROGEOLOGICAL MODEL

2.1 Conceptual Model

Numerical model was prepared on the basis of conceptual model, which was created with well logs interpretation support (fig.2). Log interpretation allowed to indicate hydrogeothermal aquifers as well as petrophysical parameters of these aquifers.

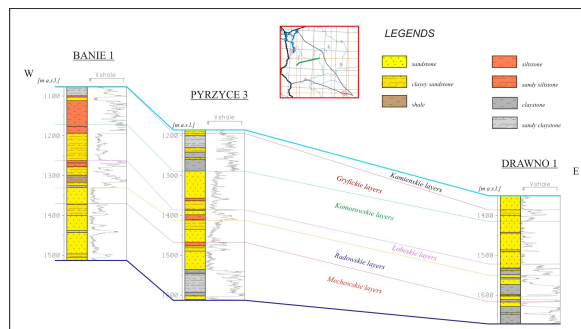


Figure 2: Correlation of selected profiles of Lower Jurassic in Szczecin Trough area.

The Lower Jurassic water-bearing formations are covered by younger Mesozoic formations. Only on a small, fragment in the north part of analyzed area the Lower Jurassic sediments are laying directly below Cenozoic formations. There is no Lower Jurassic outcrops on the area of research. Recharge area is situated on the Pomerania Anticlinorium, while drainage zones constitute Baltic Sea in the north and Odra valley in the south (Szklarczyk, Łapinkiewicz, 1995).

Because model boundary should be similar with hydrodynamical boundary (Szczepański, 2008) analyzed area was widened to boundary of underground water section.

2.2 Numeric Model

For the purpose of the project the interpolation grid 1 000 x 1 000 m was applied, which reflects distribution of 57,500 interpolation nodes. 16,739 of these nodes were inactive while 40,761 were active. Area of the Szczecin Through (16,910 km²) constitutes 41.5% of total analyzed area (40,761 km²). Model consist of seven layers (fig.3): six regional layers of Lower Jurassic formation and one Cenozoic layers only in places where Lower Jurassic formation was laying directly below Cenozoic sediments. Structure of the model is as follow:

- Layer No 1 – Cenozoic - water-bearing layer,
- Layer No 2 – Lower Jurassic – kamienskie layers - water-bearing layer,
- Layer No 3 – Lower Jurassic - gryfickie layers,
- Layer No 4 – Lower Jurassic – komorowskie layers - water-bearing layer,
- Layer No 5 – Lower Jurassic - lobeskie layers,
- Layer No 6– Lower Jurassic - radowskie layers - water-bearing layer,
- Layer No 7 – Lower Jurassic - mechowskie layers - water-bearing layer.

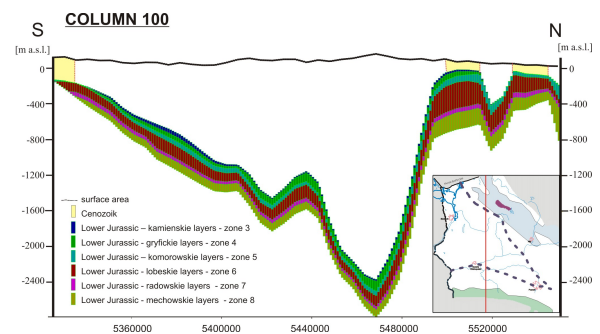


Figure 3: Outline of geological background applied in the model.

Filtration coefficient was established as:

- Layer No 1 – Cenozoic- 1×10^{-5} m/s,
- Layer No 2 – Lower Jurassic – kamienskie layers- 2×10^{-6} m/s,
- Layer No 3 – Lower Jurassic - gryfickie layers – 1×10^{-10} m/s,
- Layer No 4 – Lower Jurassic – komorowskie layers - 1×10^{-5} m/s,
- Layer No 5 – Lower Jurassic - lobeskie layers - 1×10^{-10} m/s,
- Layer No 6– Lower Jurassic - radowskie layers - 2×10^{-5} m/s,
- Layer No 7 – Lower Jurassic - mechowskie layers - 4×10^{-5} m/s.

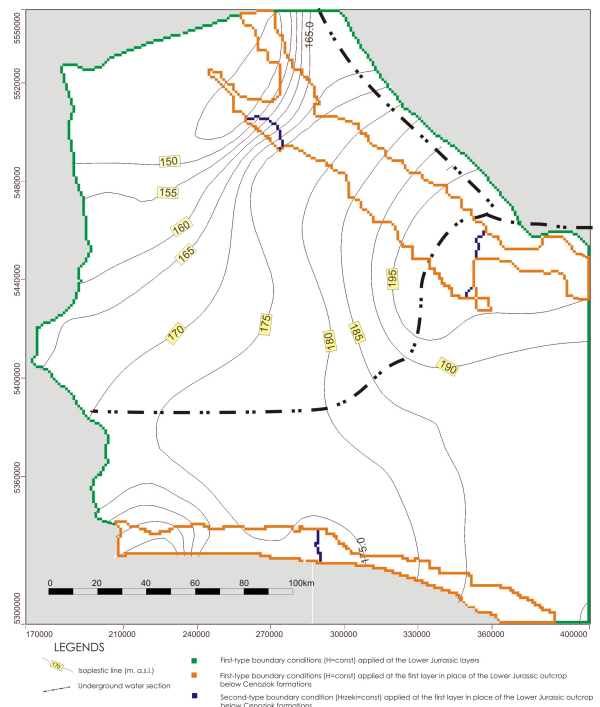


Figure 4: Sketch of boundary conditions.

Boundary conditions are shown on figure 4. First-type boundary condition was applied for the first layer of the model (Quaternary) in a regions where Quaternary sediments lie directly on Lower Jurassic formation and another layers at the boundary of the model ($H=\text{const}$).

Second-type boundary condition was applied for the first layer as an effective infiltration. Value of infiltration coefficient depended on Cenozoic formations' lithological type and varied from 0.08 to 0.25. The average annual rainfall was set as 600 mm (according to IMiGW). Rivers were allowed for third-type boundary condition.

2.3 Model Verification

The largest problems were associated with model check out. Verification were carried out through analyses of hydrodynamical accordance of computer simulation effects with empirical hydrogeological model. Filtration coefficient was the main property subjected to verification. Filtration coefficient after model checking was established from 5×10^{-7} m/s to 2×10^{-5} m/s. As a result of dynamic modeling of water circulation system was established as well as water mass balance (fig.5).

In the Szczecin Through area two main direction of water circulation are observed. In the central and north part of this area water circulation runs from SE to NW direction, where Baltic Sea is a drainage zone. In south part of the Szczecin Through water flow have direction from NE to SW, where drainage zone are Odra valley in area of Lower Jurassic outcrops.

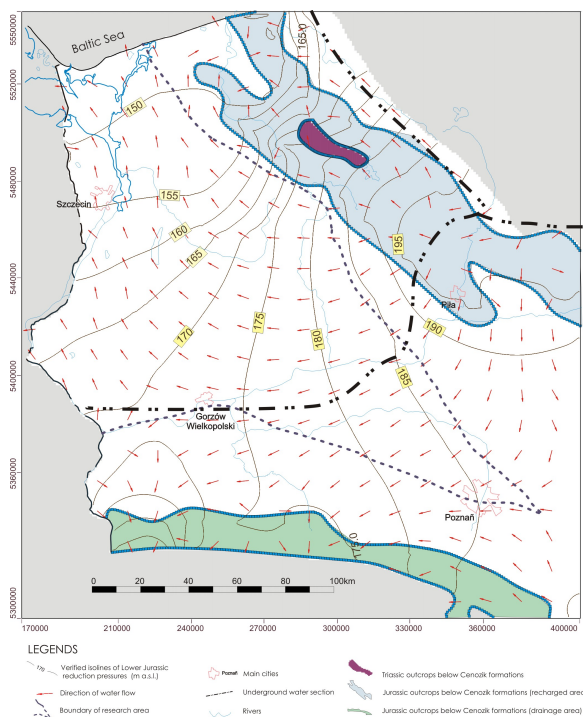


Figure 5: Map of Lower Jurassic water level on the model.

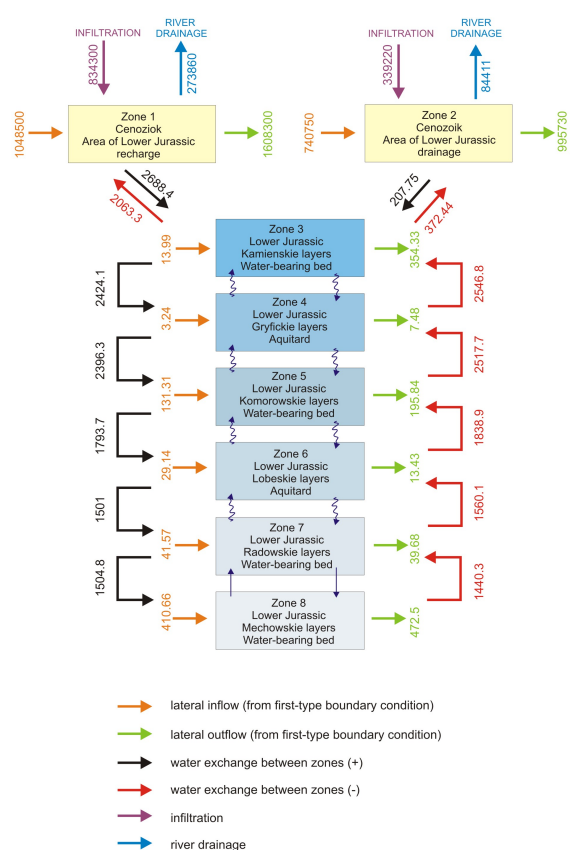


Figure 6: Balance zones for the whole area of model.

In order to show amount of water circulation to individual layers, zones with particulars balance were created. At the beginning balance zones for whole model were calculated (fig. 6). Total inflow to the model equals 2 963 375.63 m³/day and total outflow amount to 2 963 368.81 m³/day. As the result, model verification achieves balance divergence 6.82 m³/day, what is an equivalent of 0.000227781%.

In order to calculate water balance for the area of Szczecin Through additional zones were created. The structures of zones are shown on figure 7.

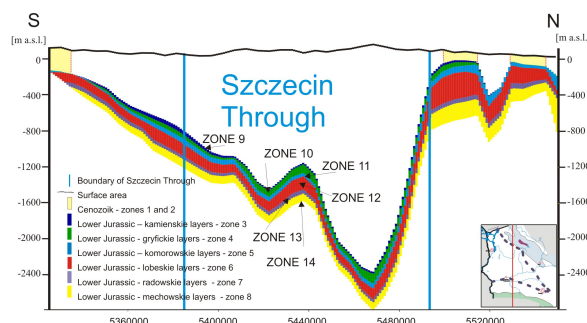


Figure 7: Balance zones in the Szczecin Through area.

The results of calculation allow to assess water balance only for the Szczecin through area. Total inflow to the zones of the Szczecin Through area equals 1 186.5 m³/day and total outflow amount to 1 169 m³/day. As the result of model verification balance divergence of 16.9 m³/day was achieved, what is an equivalent of 1.4%.

WATER MASS BALANCE		
	Inflow to the model [m ³ /day]	Outflow from the model [m ³ /day]
Lateral inflow and outflow (from first-type boundary condition)	76.8	-161.1
Water exchange between balance zones	1109.7	-1008.5
Sum	1186.5	-1169.6
Balance divergence	16.9 [m³/day] (1.4%)	

Figure 8: The Szczecin Through water mass balance (m³/day).

3. THE LOWER JURASSIC GEOTHERMAL RESOURCES OF SZCZECIN THROUGH

The numerical data processing and resources calculation methods were developed at the Department of Fossil Fuels in the 1990-ties (Gorecki et al., 1993 and Gorecki (editor), 1995) and improved in succeeding research projects and expert reports. The methodology of geological resources calculation was based upon available EU standards (Haenel & Staroste 1988; Hurter & Haenel 2002). Calculations of geothermal energy resources were based upon the volumetric model (Muffler & Cataldi, 1979) with the application of digital mapping methods.

Calculations of resources were carried out in respective categories, in particular static geothermal energy resources (amounts of free geothermal water hosted in pores, fractures or caverns of given hydrogeothermal horizon), static recoverable geothermal resources (which constitute only a part of the static resources diminished by the recovery index Ro,) and disposable geothermal reserves (classification according to Górecki & Hajto 2006). The result of geothermal resources calculations are following:

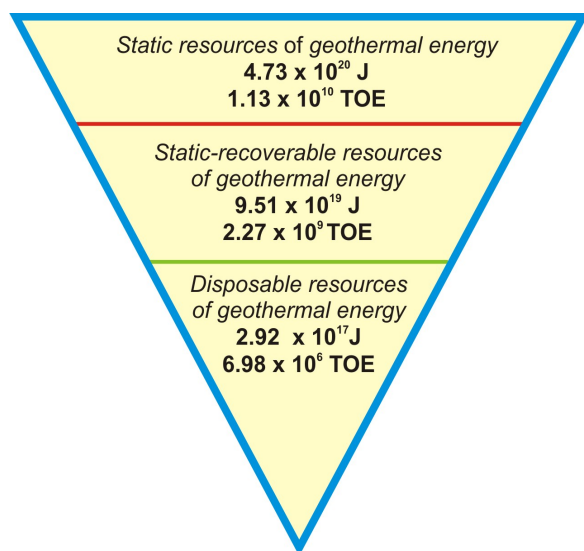


Figure 8: The amount of geothermal resources of Lower Jurassic aquifer in the Szczecin Through.

The most important are the disposable geothermal water and energy resources which means the amounts of free (gravitational) geothermal water within the horizon or other calculation unit, which can be developed under given conditions but without detailed localization as well as technical and economic specification of an intake. Deployment and amounts of disposable geothermal energy resources indicate areas where geothermal plants could be constructed.

The area of the occurrence of disposable resources in the Lower Jurassic aquifer in the Szczecin Through is equal to 16,340 km² which corresponds to 97% of the research area.

Disposable resources of geothermal energy in the Lower Jurassic aquifer are 9.51×10^{19} J (95 100 PJ), what is an equivalent of 2.27×10^9 TOE.

The values of unit disposable resources vary from several to over 40 MJ/m². Although, disposable resources were identified in the whole area that was analyzed, the most perspective zones are located in central part of the Szczecin Through, where unit disposable resources exceed 35 MJ/m². Highest values were encountered in the vicinity of Stargard Szczeciński, Dobrzany and Chociwel. Lowest values (<10 MJ/m²) are observed in the area of Gorzów Wielkopolski.

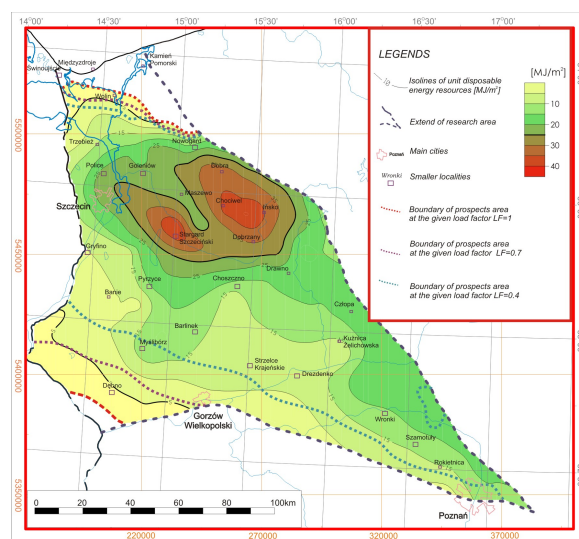


Figure 9: Map of unit disposable geothermal energy resources of Lower Jurassic aquifer in Szczecin Through.

3. CONCLUSION

The results of calculations allow to asses water balance for the Szczecin through area. Total inflow to the zones of the Szczecin Through area equals 1,186.5 m³/day and total outflow amount to 1,169 m³/day. As the result of model verification balance divergence of 16.9 m³/day was achieved, what is an equivalent of 1.4%.

In the Szczecin Through area two main direction of water circulation are observed. In central and north part of this area water circulation runs from SE to NW direction, where Baltic Sea is drainage zone. In south part of the Szczecin Through water flow from NE to SW, where drainage zone are Odra valley in area of Lower Jurassic outcrops.

Total disposable resources of geothermal energy in the Szczecin Through accumulated in Lower Jurassic geothermal aquifers equals 9.51×10^{19} J/year (95,100 PJ/year), what is an equivalent of 2.27×10^9 TOE.

Assuming the recovery of 1.5 - 2.5% of disposable resources (Górecki et al., 2006), the exploitable resources of geothermal energy are estimated at 4.38×10^{15} - 7.3×10^{15} J (4.38-7.3 PJ), which corresponds to 1.05×10^5 - 1.75×10^5 TOE. Such a resources are sufficient for supply of 9 - 14 geothermal installations, each producing annually the energy of 500 TJ.

This energy constitutes 0.06% of static geothermal energy resources of Lower Jurassic aquifer in the Szczecin Trough and 0.3% of static recoverable geothermal resources accumulated in Lower Jurassic aquifer in this area. Such an amount of energy corresponds to 10% of primary energy obtained in 2007 in Poland.

ACKNOWLEDGEMENTS

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