CREATION OF NUMERICAL MODEL OF TBILISI GEOTHERMAL DEPOSIT

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The geothermal reservoir of Tbilisi is the most promising one; thus assessment of its conditions should be regarded as the most important task. This paper summarizes the geothermal potential of Tbilisi region. Based on existing and newly obtained geologic, hydrogeological and geophysical data, 3D model of thermal region was created. As a result of modeling work, the 10 year perspective of thermal deposit of Tbilisi was assessed for present conditions of exploitation.

Keywords: Tbilisi geothermal deposit, numerical modeling.

Introduction

Urban centre of Tbilisi is of a particular importance with its multilateral and dimensioned consumer existence, thermal waters resources, unlimited perspective of development and a population of 1.5 million inhabitants. Tbilisi thermal waters' deposit as a result of historical and research works' chronology, conditionally has been divided in 3 exploitation sections: central or balneology resort and baths section, Lisi-Saburtalo section and Samgori-Sartichala oil field section, which is related to the same Middle Eocene thermal water horizon, unlike two previous ones. Up-to-date hydrodynamical relations of these 3 regions (Lisi, Central and Oil) are not well investigated, and it is impossible to conduct environmentally and economically optimized exploitation of balneological and thermal waters without detailed monitoring of hydrologeological regime. Use of heat energy of ground hydrothermal resources for therapeutic and heating aims is traditional worldwide and detailed research of hydrodynamic and hydrochemical characteristics of exploitation area is significant. Commonly, for such hydrothermal resource we need three dimensional model construction for both hydrodynamic and thermal regime. It is well known that three dimensional digital modeling, hydrodynamic and thermal gradients' selection is of big importance for estimating proper regime of low thermal-consisting hydrothermal pools' with ecologically proved exploitation conditions. As a rule, in such environment, ground water flow is related not only to the hydrodynamic gradient, but to the temperature gradients as well, which can govern density changes in the flow as well as its movement. The modeling studies will use existing data and those obtained from boreholes.

Establishment of boundary conditions for targeted area and creation of conceptual model

The modeling have been fulfilled by software Feflow 5.3, which enables computing a 3D thermal model of the region. For this purpose, a 3D geometric model was prepared beforehand by the software ArcMap 9.2 and ArcView 3.2a.

Based on analysis of geologic and hydrogeologic data a conceptual model was created. This model assumes that Upper Eocene water-horizon of Tbilisi hydrothermal basin is water impermeable, what creates conditions for pressuring of underground water. It is assumed that there is little hydrodynamic connection between Tbilisi Central district and Lisi district. Several factors convince that this is true: hydraulic gradients in "Lisi" thermal field are much stronger and larger compared to the Central district, what points to the low permeability, though the depth of aquifer is the same at both sites (Fig. 1).

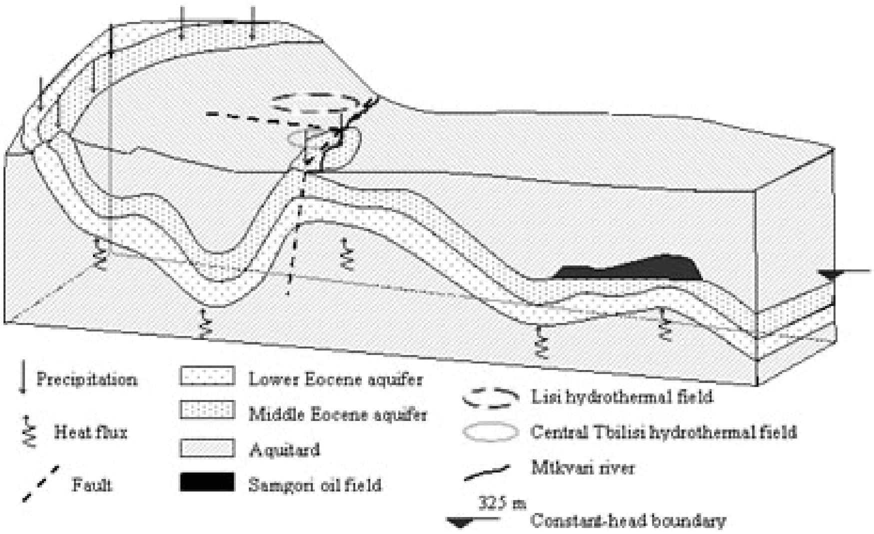

Fig. 1. Block diagram of conceptual model

Low values of transmissivity might be caused by the large depth of "Lisi" aquifer because lithostatic pressure of upper rock formation leads to decrease of cracks' openings and decrease of their total volume and accordingly, of permeability. Decrease of pressure in the Central district leads to opening of cracks and thus to increased permeability.

Piezometric maps, mineralization and thermal profiles point to regional West-East flow of underground waters. In other words ground waters flow from mountainous recharge area with low mineralization to the deepest horizons in the west, where underground fluids (water and oil) have much higher temperatures and mineralization.

In the model, North and South boundaries of hydrothermal basin are confined by narrow impermeable belt, because there are no manifestations of thermal water beyond this belt. Similar boundary could be proposed for the East boundary of oil field, what leads to the hypothesis on existence of deep faults here, which represents physical boundary for aquifer. In any case these boundaries are not crossed by water, they coincide with flow direction and thus are considered as water impermeable. Boundaries of water containing horizon in the model were defined as is shown in Fig. 2, where boundary westward to Mtkvari coincides with the recharge area of aquifer and lateral boundaries (North and South) follow aforementioned water impermeable belts. East boundary was set up conditionally in 40 km from thermal districts.

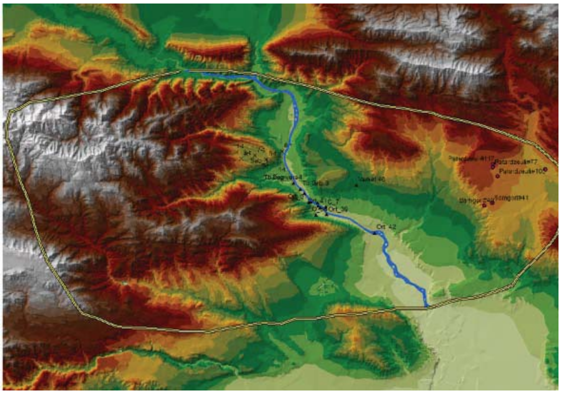

Fig. 2. Boundary of Tbilisi Thermal region.

Outcrop zone of Middle and Lower Eocene represents the main recharge source for water containing horizon. Consequently this zone is considered as a constant boundary for the descending water flow. The area of outcrops of Middle Eocene rocks of Lisi district is 87.7 km² and the total area of outcrops of recharge area at the Central district is 126 km². The mean value of precipitation is 550 mm per year, only part of which reach depth and its amount is calculated below (Fig. 3).

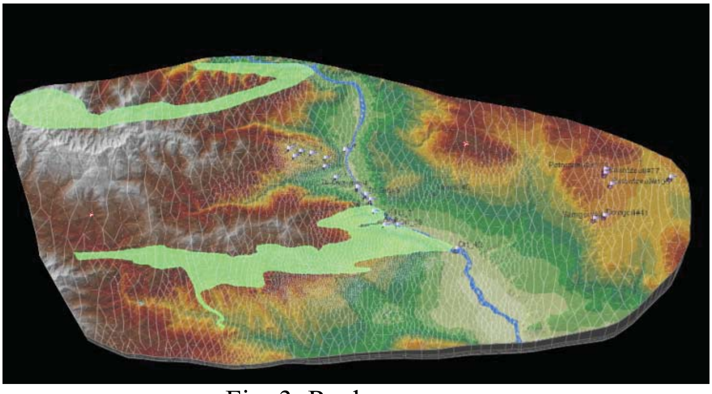

Fig. 3. Recharge areas

Total area of the model region was 2037 km^2. Difference in the heights of profile was 9.4 km.

According to hydrologic conditions the model is divided into three parts (Fig. 4). Area of North-West part of model is 493 km^2, that of central part 842 km^2 and the area of Samgori Patardzeuli oil field 700 km^2. The former is divided by the fault and consists of two parts - Northern and Southern parts (255 km^2 and 445 km^2 accordingly).

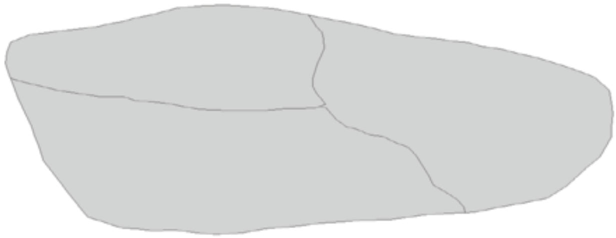

Fig. 4. Contours of three thermal districts.

It is assumed that there is little hydrodynamic connection between Tbilsi Central district and Lisi district. Several factors convince that this is true:

Below (Table 1) hydraulic (piezometric) heads are provided for Lisi-Saburtalo and Central district, what confirms essential differences between them.

Table 1. Elevation of boreholes in Tbilisi area

Name	Altitude above sea level in meters	Hydraulic head in meters(for open wells)	Hydraulic head in meters (for closed wells)
	Lisi district		
1-Sab	532	598.08	661.10
4-t	454	527.80	693.70
5-t	656	659.09	666.90
6-t	434	555.60	666.60
7-t	653	662.28	669.94
8-t	639	652.10	666.00
	Central district		
Botanic Garden	415	413	413

As it follows from Table 1, hydraulic head of Lisi wells are similar and they are self (gravity) flowing, though hydraulic head of well in Botanic Garden is smaller by 250 m and has a negative level, 2 m below day surface. This could be caused by presence of tectonic fault between these two districts. Two deep faults are established within the area of Tbilisi hydrothermal deposit, correct account of which has fundamental importance for hydrodynamic and thermal conceptual model. Namely, the lateral fault has been revealed along river Mtkvari. It is partially discharge area for Central district and same time as recharge area for oil field. This of course decreases movement ability of underground water. Moreover, by geophysical investigations, including seismic ones, the long West-East lineament has been established, which separates Lisi district from the Central district. This lineament is assumed as having low permeability and weak hydrodynamic connection between separate districts can be explained by its presence (Buntebarth et al., 2009).

Table 2. Water level and discharge data of Tbilisi wells

Well #	Q in m^3/day	T in °C	P in atmosphere
	Lisi district		
1 sab	280	65	
4-T	480	68	
5-T	1684	60	
6-T	480	70	
7-T	294	60	
8-T	96	56	
	Central district		
25	28.5	33	
1 bot	432	-	
27	380.16	33	1.5
30	86.4	45	-
31	630.72	51	0.6
48	86.4	41	-
39	146.88	24	-

Debit and temperature of water horizons have been evaluated by data obtained from self-flowing wells in Lisi and Central district (Table 2).

Description of model boundary conditions

In order to involve both recharge and high pressure (Samgori oil field) areas the regional scale modeling has been carried out. This enables to set the boundary conditions, which as a rule are impermeable and coincide with physical boundaries of hydrothermal basin and to investigate influences of separate stresses, e.g. exploitation of hot water and oil (Fig. 5).

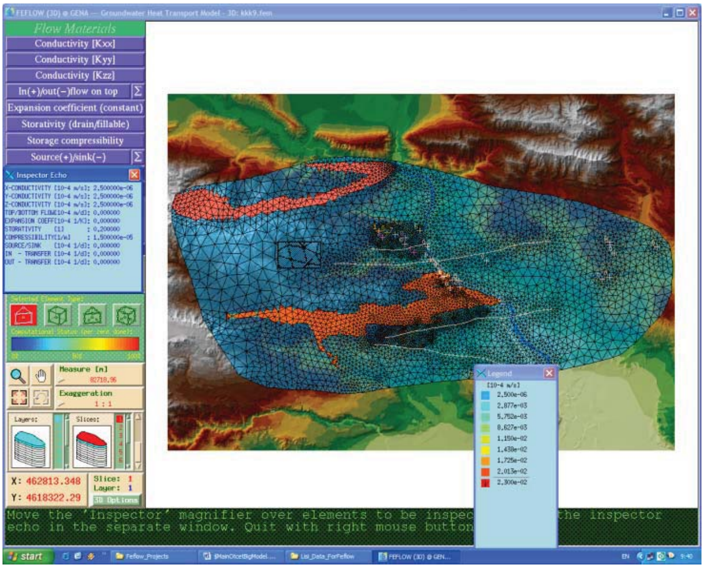

Fig. 5. Model with boundary conditions and fault system

Before vertical partitioning of the model the digital map of region has been created by ArcMap 9.2 and model boundaries have been contoured. The digital net of regional relief and its Z coordinates as shp files has been generated from space images.

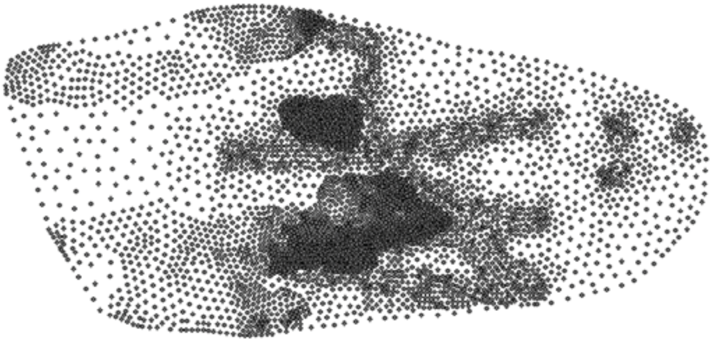

Fig. 6. Digital net of model surface.

This surface and its absolute heights were used as reference points for vertical partitioning of horizons. In the model three vertical zones have been defined corresponding to layers of practically impermeable Lower and Middle Eocene.

Input of hydrodynamic and temperature parameters

At first, for all layers, initial values of hydraulic pressure (piezometric levels) have been entered. Conditionally it corresponds to relief height for all layers. After analysis of real data, following hydraulic parameters were entered in the model:

Table 3. Values of hydrodynamic parameters

Lisi district	(Conductivity) Kx (m/s)
Upper Eocene	$2.5*10^{-6}*10^{-4}$
Middle Eocene	$0.137*10^{-4}$
Lower Eocene	$0.137*10^{-4}$
Central district	Conductivity Kx (m/s)
Upper Eocene	$2.5*10^{-6}*10^{-4}$
Middle Eocene	$5.7*10^{-3}*10^{-4}$
Lower Eocene	$5.7*10^{-3}*10^{-4}$
Patardzeuli district(North part)	Conductivity Kx (m/s)
Upper Eocene	$2.5*10^{-6}*10^{-4}$

Middle Eocene	$2.8*10^{-5}*10^{-4}$
Lower Eocene	$2.8*10^{-5}*10^{-4}$
Patardzeuli district(Southern pat)	Conductivity Kx (m/s)
Upper Eocene	$2.5*10^{-6}*10^{-4}$
Middle Eocene	$3.19*10^{-2}*10^{-4}$
Lower Eocene	$3.19*10^{-2}*10^{-4}$

Values of temperature parameters have been entered in special section of model, so called "transport data", where initial temperature distribution (Jimsheladze et al., 2008), rock thermal characteristics and thermal flow source values have been indicated. Their parameters were measured in laboratory (Sakvarelidze et al., 2008, 2009).

By calculation of initial values of thermal distribution the following scheme was used. At the model (day) surface the temperature was set as 15ºC, for all bottom surfaces the following formula has been used:

$$Tp=Tk+(q/\lambda)*H,$$

where Tp is the bedding temperature, Tk is the layer roof temperature, H is depth of layer, q is thermal flow, λ is coefficient of thermal conductivity of layer. For the whole model q=0,041 W/м^2.

Table 4. Heat capacity for each water-horizon.

Name	heat capacity per unit volume in J/ m^3
Upper Eocene	$3.32*10^6$
Middle Eocene	$2.55*10^6$
Lower Eocene	$3.06*10^6$

Model necessitates heat capacity values in J/ m^3. K, what is equal to W/m.K.

Table 5. Thermoconductivity for Lisi-Saburtalo district.

Name	heat capacity per unit volume
Upper Eocene	1.53
Middle Eocene	1.91
Lower Eocene	2

Table 6. Thermoconductivity for Central district.

Name	heat capacity per unit volume
Upper Eocene	1.75
Middle Eocene	1.86
Lower Eocene	2.09

Table 7. Thermoconductivity for Patardzeuli district.

Name	heat capacity per unit volume
Upper Eocene	1.3
Middle Eocene	1.56
Lower Eocene	1.9

Main source of heat in model is the thermal flow coming from the depth. In average it equals -2500 J/m^2.day (or 25 mWt/m^2). The minus in the software mean flow direction. Some literature data assumes it equal to 50 mWt/m^2, though by calibration at real values of temperatures in wells software necessitates flow value equal to 32011 J/m^2.day. The second source of energy is source+/sink- of solid equal to 0.108 J/m^3.day (or $1.25e^{-6}$ W/m^3). One more source of energy is constant temperature areas shown as blue points in the recharge area, where T equals C15°. By the program request we enter also values of porosity of building rocks which is 0.25 for Upper Eocene and 0.14 for Lower Eocene.

Calibration

Model has been calibrated by comparing to piezometric map, which was build on the basis of closed wells data. Also, for calibration of temperature flow, the temperature distribution map was built, based on data from the same wells. According to above formulas, pressure and temperature depend on the same physical parameters; consequently they have been calibrated simultaneously by the variation of such parameters as coefficient of water yield, flow amount in recharge area and thermal conductivity. Water yield remained constant for each hydrothermal area during model verification because existing hydrodynamic information do not enable to propose how it may vary for different areas. Mean flow value also was set as constant.

Created model of pressure distribution was tested for real field data - data from open wells (Table 3). Values of hydrodynamic parameters providing best fit to model, assures that water yield coefficient at Lisi district is smaller than for Central district. It is worth to say that there are few data on pressure distribution on both sides of fault. Field measurement of well discharge data also do not allow to compute conductivity in the fault zone. This is why we set arbitrary as step, which corresponds to low conductivity.

Realization of digital modeling

The created model enables any type of simulation for investigated thermal area - balance evaluation, recognition of perspective areas, prognosis of well exploitation results, etc. At first, prognostic evaluation for Tbilisi deposit was carried out, assuming present conditions of exploitation, and thermal water balance for 10 years period has been computed. As it follows from Fig. 7., in future the subsidence of horizon is expected, in other words water pressures will decrease at all wells. Balance calculation shows energy loss from the thermal field boundaries and negative balance for the whole deposit.

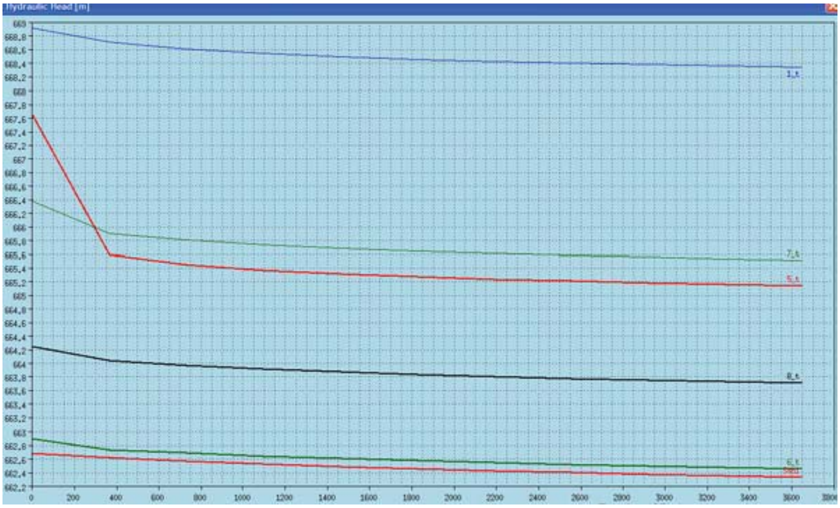

Fig. 7. Variation of pressures for 10 year

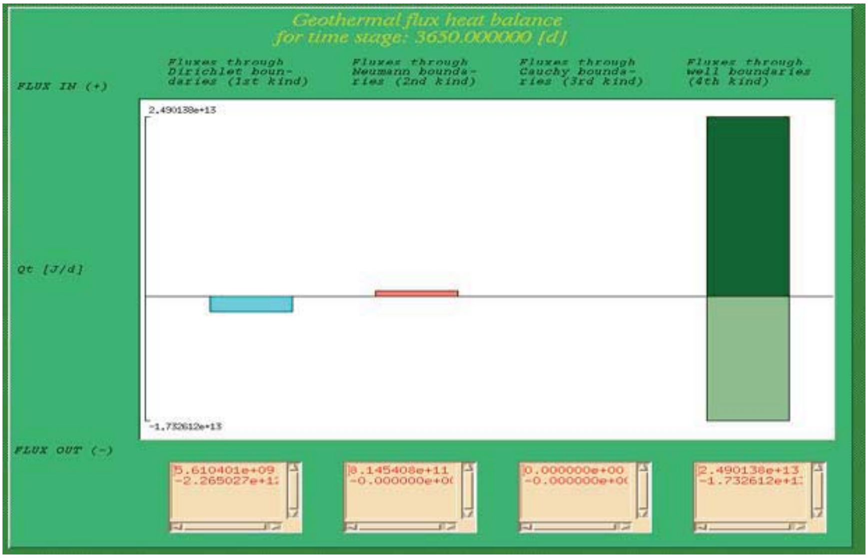

Fig. 8. Thermal balance for re-injection case during 10 years

At the next stage possible effect of exploitation, in case used thermal water will be re-injected back to the deposit was analyzed, i.e. in the case of geothermal circulation at “Lisi” district. Namely, reinjection of hot water from well 5 to well 1 was simulated and its effect for 10 years period was calculated. In “Lisi” well water pressure decrease is moderate (comparing to previous situation) and there is some increase of water temperature in well # 5

Consequently total thermal balance for “Lisi” district, where reinjection was simulated, becomes positive.

Main results

As a result of modeling the 10 years perspective of thermal deposit of Tbilisi was assessed for present conditions of exploitation.

For example in the whole region subsidence of horizon is expected; only for Lisi district, if mean yearly discharge is preserved, pressure drops to 2-5 m and released thermal energy decreases from $5.5*10^{20}$ to $1.578*10^{17}$ J.

The case of geothermal circulation system was simulated by the software, when used water from well 5 (1690 m³/daily) at 300 °C is pumped back to the well 1 with negative level. In this case according to the model, ‘cooling of horizon and subsidence’ tendency become slower. Therefore, in future we recommend implementation of geothermal circulation system. This will help to achieve economical and ecologically stable exploitation of geothermal resources.

At the same time capabilities of digital modeling are not restricted by this. Exactly, if make detail model will be possible to select necessary regimes of exploitation of Samgori oil field, Lisi-Saburtalo and Central district to minimize their interdependence. It is possible to use model for selection of optimal areas for drilling new wells.

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