A LOW ENTHALPY GEOTHERMAL SYSTEM IN THE MOESIAN PLATFORM

Augustin TENU (1). Florin DAVIDESCU (1), Mario MUSSI (2), Paolo SQUARCI (2), Vasile VAMVU (3)

1) Nat. Inst. Meteo/Hydro., Sos. Bucuresti - Ploiesti 97, 71552 Bucharest, ROMANIA 2) Int. Inst. Geoth. Res, Piazza Solferino 2. 56126 Pisa. ITALY. 3) FORADEX **S.A.** Str. Milcov 5, 78741 Bucharest. ROMANIA

Key words : carbonate aquifer. thermal water. geochemistry, origin. utilisation.

Abstract

In the central part of the Moesian Platform . in Romania there is a Mesozoic carbonate aquifer whose water teinperatures are from 42°C to 80°C.
The goal ofthis paper is to describe the geothermal system - origin **of** the water. peculiarity of the hydrothermalism - and the stage of practical utilization.
The approach to these problems was by means of geochemical methods: hydrochemical analyses, specific conductivity and temperature measurements, environmental isotopic analyses (D, ^{18}O, ^{3}H, ^{14}C).

The main conclusions:
- the origin of the thermal waters ι almost exclusively meteoric:
- the reservoir has no high enthalpy potential.

1. INTRODUCTION

In the central part of the Moesian Platform. on the left side of the Danube. in Romania. in the Bucharest-Snagov area (Figure 1). drilling delineated the presence of a geothermal aquifer. The thermal waters are **linked** to Mesoroic (K+J3) carbonate formations of about 1000 m thickness that developed into monoclines. with an inclination froin south *to* north and many step-fault discontinuities. The teinperatures of these waters are **only** 42°C at Bucharest. but gradually become warme towards the north, reaching 80°C at Snagov.

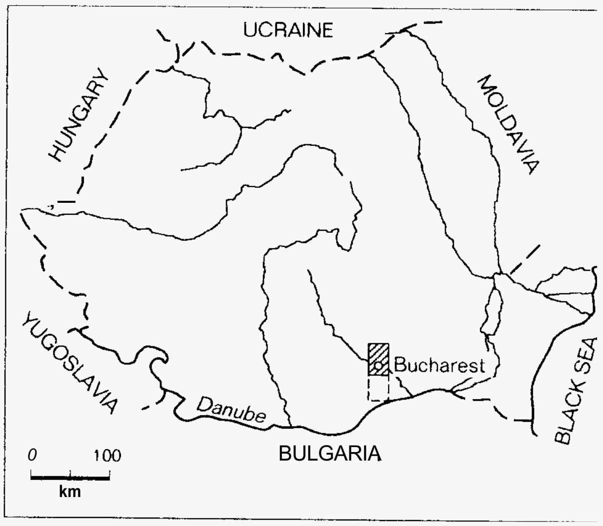


Figure 1 : Location of the study area

The goal *of* this paper is to report our knowledge of the Bucharest. Snagov geotherinal system (the origin of the thermal water. peculiarity of the hydrothermalism) of the area and the stage and the modality **of** practical utilization of the warm waters.

2. GENERAL CHARACTERIZATION

<u>*Geologically*</u> the Bucharest-Snagov area is situated in the north-central part **of** Moesian Platform. a region characterized by a gently N-ward dipping structure. I don't see any evidence of ***a*** monocline structure. For example. while the carbonate - Cretaceous complex is found at a depth **of** about 2750 m at Snagov and 1900 m at Bucharest (Figure 2). it outcrops on the hank ofthe Danube in the area of Giurgiu city. This structural continuity extended the studied area to the Danube in order to understand the hydrodynamic aspects of the K+J3 aquifer.

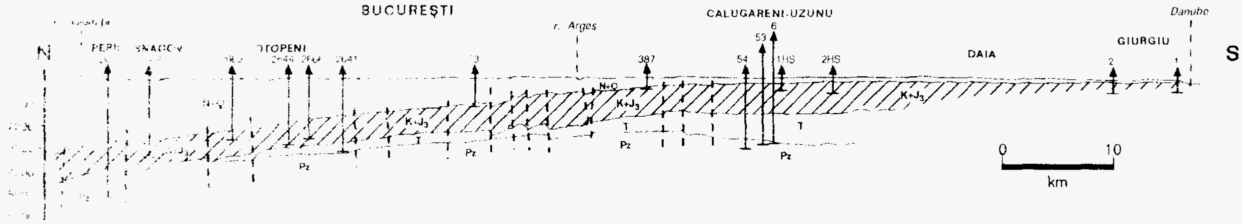
The <u>*hydrogeologic*</u> inforination on the Moesian Platform, primarily obtained from oil wells. **has** been completed during the last feu years by drilling geothermal wells in the Bucharest - Snagov area. All these boreholes have had K+J3 formation.; as their target.
Some water supply wells. between Bucharest and the Danube, where also used to identify the regional flow-pattern. estimate some of the hydrogeological parameters and determine the origin of the thermal waters.
Figure 3 and Table 1 show the position and the main parameters obtained with these horeholes.

As regards the <u>*geothermal*</u> aspect, compared with the regional thermal background value **of** about 2°C 100 m. in the northern and eastern part of Bucharest, there is an anomaly with average geothernial gradients of up to 3.5°C/100 m.
The calculated temperatures at the bottom of tlie Jurassic limestones indicate an increase froin south to north. in agreement with the increasing depth **of** Mesozoic formations: froin 60°C-70°C north of Bucharest they reach about 100°C in tlie area of Snagov
It is iinportant to **note** that in some wells. after penetrating the limestones of tlie K+J3 complex . a disctitdance was observed between the calculated and recorded temperatures and even thermal inversions. This can be explained by the predominant convective therinal transfer associated with an active circulation of waters in the K+J3 fractured and karstified horizons.

Table 1: Geological and hydraulic parameters of deep water wells from the Moesian Platform

Well/year	Elev./deep	AQUIFER		HYDRAULIC PARAMETERS			
	masl (m)	Interval (m)	Age	NHs (m)	NHd (m)	Q (l/s)	T* (°C)
1-Giurgiu Uz Apă/1976	18 0/600	260-600	$K+J_3$	6.0	18.0	16	14
2-Giurgiu Nord 1980	19 0/625	415-625	$K+J_3$			70	14
2-HS Uzunu/1991	88 8/ 660	234-651	K	772	78 2	39	30
2641-Bucuresti/1982	91 6'3520	2540-2704	J_3	7x5	110.0	21	42
2664-Otopeni/1982	94 1/2774	2053-2774	$K+J_3$	75.0	840	33	55
2666-Otopeni/1987	94 9/3101	2188-3103	$K+J_3$	74.0	121 0	28	57
2663-Otopeni/1987	03 7/2800	2001-2800	$K+J_3$	72 5	830	22	62
2662-Otopeni/1987	93 7/2762	2101-27hl	$K+J_3$	81.0	105 0	31	62
2644-Int Airport/1982	94 0/3000	2333-2847	$K+J_3$	67.0	75 5	34	66
2667-Int Airport/1987	Y4 912790	2347-2790	$K+J_3$	68 0	io 5	26	65
2672-Balotesti/1989	YX 1/3204	2256-3204	$K+J_3$	**	**	15	70
2669-Balotesti/1990	94 5/3304	2414-3304	$K+J_3$	68.0	**	28	73
2676-MoaraVlăsiei/1989	84.3/3028	2289-3028	$K+J_3$	68.0	70.0	21	76
2680-Moara Vlăsiei/1990	89.8/2829	2237-2829	$K+J_3$	71 0	**	35	78
2682-Snagov/1990	92.5/3273	2738-3273	J_3	70 0	**	20	80

* - measured at emergence
** - variable. becouse of gas bubbles



cross section Key N+Q - Neogene and Quaternary. K+J3 - Cretaceous and Upper **Jurassic,** T - Triassic; Pz - Paleozoic

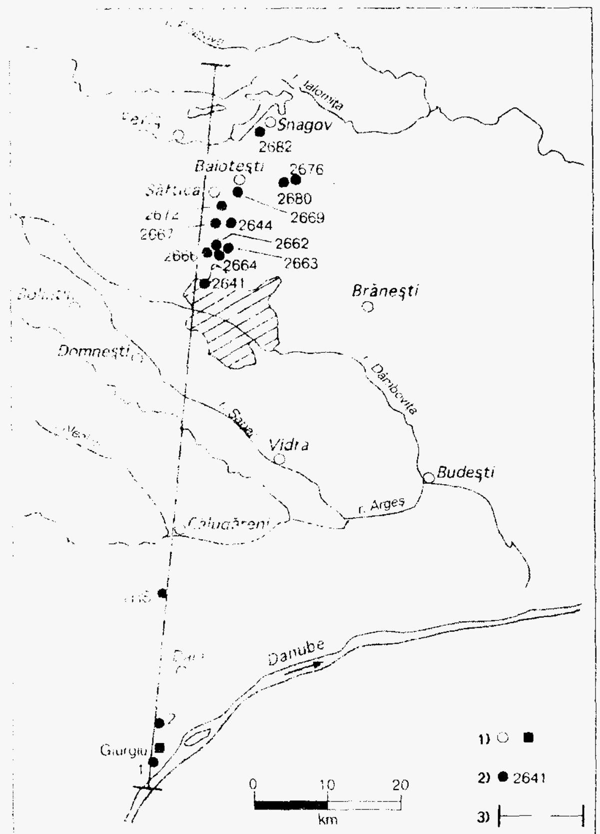


Fig. 3 Map of studied area. Key: 1) Localities; 2) Deep boreholes; 3) Geological cross section.

3. EXPERIMENTAL DATA

3.1. Presentation

The experimental data available consist of:

- representative hydrochemical analyses of the main indicators (Table 2) carried out after drilling or made in different periods till August 1993;

'**Table 2:** Chemical composition (mg/l) of groundwaters

Well	TDI	CATIONS				ANIONS		
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl	SO_4^{2}	HCO_3^{-}
2-Giurgiu Nord	601	72	30	41	3	25	27	403
2-HS Uzunu	1123	85	48	193	10	325	100	370
2641-Bucuresti	1375	75	39	386	15	471	66	323
2664-Otopeni	1707	119	45	376	30	660	86	391
2666-Otopeni	1516	104	55	326	17	624	87	306
2663-Otopeni	1868	123	57	424	30	**794**	111	329
2662-Otopeni	1870	115	42	451	26	762	96	378
2644-Int. Airport	1921	101	28	579	27	853	138	195
2667-Int. Airport	2052	146	61	463	34	840	152	356
2669-Balotesti	2147	60	53	581	44	1035	42	**232**
2676-Moara Vlasiei	1778	104	29	456	26	723	196	**244**
2680-Moara Vlasiei	1644	88	29	439	20	752	48	268
2682-Snagov	1882	114	37	442	24	658	331	**276**

- anion analyses for F-. CL- Br-. NO_3^-, PO_4^{3-}- . and SO_4^{2-} carried out in 1993 by chromatography with a DIONEX multi QIC;

- measurements of specific conductivity and temperatures;

- environmental isotope analyses (D. ^{18}O, ^{3}H. ^{14}C) only in the southern part of the study area.

3.2 Discussion and intrrpretation.

Regarding the *hydrochemical data*, it is important to note that the waters of the K+J3 aquifer clearly differ from tlie aquifers above and below *and* from zone to zone. Whereas the mineralisation ut' the Mesozoic aquifer is low, 0.h-7.2 g/l, the Triassic and Sarmation waters have concentrations of 3 to 100 g l.

A standard trilinear/Piper diagram (Figure 4) reveals a continuous evolution in hydrochemistry from south to north; froni tlie bicarbonate waters, located next io rhe Danube (7 Giurgiu N), to the mixed waters in the median region (2 HS Uzunu) and finally to the chloride-sodium water north of Bucharest. In this last area, in particular, there is no correlation between hydrochemical content and well spacing, despite the fact that the cation diagram to show an approximatly continuous evolution. Thus, the highest percentage of Na and Cl can be found in wells 2644 International Airport and 2669 Nalotesti, but not in tlie area Of Snagov, as might have been expected.

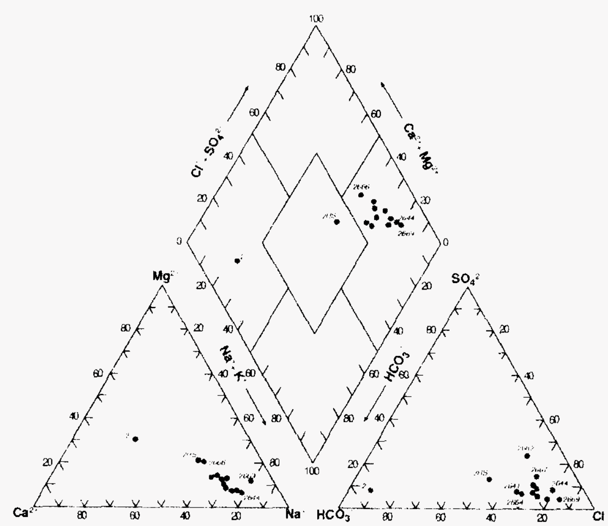


Fig. 4 Piper diagram of deep (cold and warm) groundwaters. The numbers correspond to **the** wells in Table 1.

The composition diagranis (Figure5) show a good positive correlation between TDI and Na+K, and TDI and Cl, and also the same tendency for Ca, Mg and SO4. These correlations seem to represent the classic case of a progressive mixing of two types of water: a fresh water, represented in our case by the well 7 Giurgiu and a saline water that can be found in higher proportions in the well 2669 Balotesti.

In the case of a large aquifer such as that under study, a mixing model **of** this type implies the acceptance **of** a conceptual hydrogeological inodel with various inputs of saline fluids from depth throughout the area.

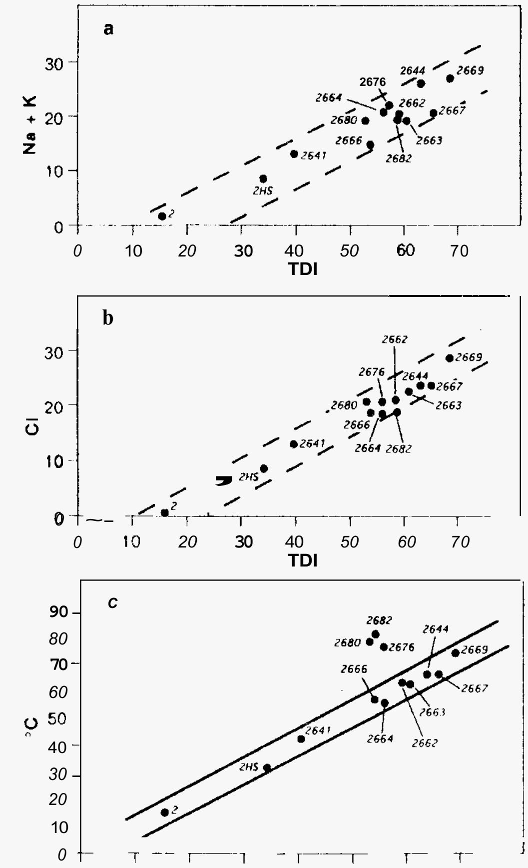


Figure 5: Composition diagrams of deep (cold and warm) groundwaters. The concentrations are given in meq/l TD! = total dissolved ions, the sum of dissolved cations and anion?. The numbers correspond to tlie wells in Tahle 1.

The diagram in Figure 5c shows the existence of a very good linear correlation between TDI and temperature. It must also be noted that all the points in this diagram plot in a sequence, reflecting the position of each point along the cross-section in the interval between Giurgiu and Balotesti. This observation supports the hypothesis of the above-mentioned gradual mixing model and also highlights, for the entire interval Giurgiu-Balotesti, a unifonn temperature increase linked to the deepening of the aquifer. The fact that the three wells *in* the northern Moara Vlasiei - Snagov zone (2676, 2680. 2682) yield waters with the highest temperatures hut with much lower TDI contents reflects, on the one hand. the structural situation of the Mesozoic carbonate rocks and also a local hydrochemical situation linked to the ascent of a sulphate water with a lower salinity and total mineralization from the Triassic.
The analyses in Table 2 allow a tentative application of chemical geothermometers.
We have first chosen the Na-K-Mg-Ca geothermometer of GIGGENBACH (1988). Most o! the problems in its application stem from the use of unsuitable samples.
It is known that the most ionic solute geothermometers "work" only if used with close-to-neutral waters containing chloride as the major anion. These two conditions are fulfilled for all our warm waters.
Theoretically, for an evaluation of the Mater temperatuie at depth. we must take into special consideration the cation contents in the reservoir. This evaluation is carried out by calculating the "maturity index" (MI) of waters, according to the formula:

$$Mi = 0.315\ Lkm - Lkn \qquad (1)$$

in which

$$Lkm = \log(C_K^2/C_{Mg}) \qquad (2)$$

$$Lkn = \log(C_K/C_{Na}) \qquad (3)$$

where C_i represents the ionic concentrations in mg/kg

All the thermal waters ot our area have shown values of this index between 1.5 and 1.K. bur the applicability condition of the Na-K-Mg-Ca geothermometer is to have MI 2 However. this fact may be interpreted as reflecting tlic low temperatures that can be found even at depth in the reservoir

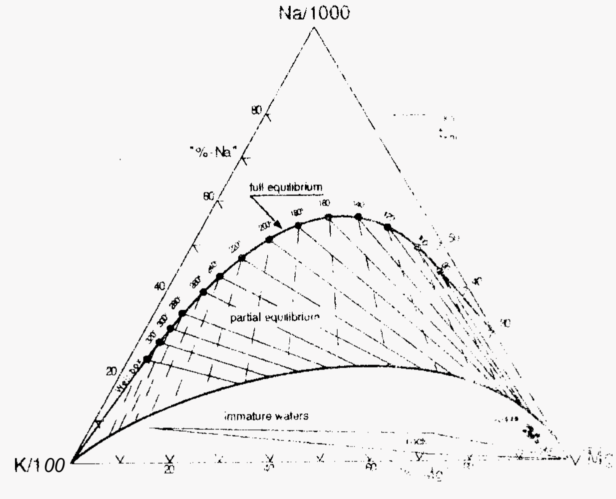


Figure 6: Giggembach diagram for evaluation of the Na-K and K-Mg equilibration temperatures.

Despite this conclusion, we have constructed the Na-K-Mg diagram (Figure 6) using the corresponding values for the Bucharest-Snagov area. As the points are grouped in the Mg corner this figure confirms that all the waters in our area are immature. However this diagram reveals that the same processes, roughly of the same intensity, have regulated the underground flow and mixing determining the hydrochemical composition of all the thermal waters.

Analyzing the application requirements of other geothermometers as regards:

- the available experimental data and their validity
- the nature of the matrix,
- the possibility of sampling a reservoir water with unchange chemical composition;
- the maximum supposed temperatures.

we have concluded that, in our case only the K-Mg geothermometer (GIGGENBACH *et al.*, 1983) can supply a correct reservoir temperature estimate. Application of this geothermometer gives calculated values ranging from 60°C (2641 Bucuresti. 2666 Otopeni) to 82°C (2669 Balotesti), which are very similar to temperatures measured at wellhead.
The isotopic data are shown in Table 3.

Table 3: Results of isotopic analyses (1)

Water body/well	Conductivity µS cm^{-1}	δD‰ vs.V-SMOW	$\delta^{18}O$‰ vs.V-SMOW	^3H (TU)	^{14}C (pMC)
Danube, Giurgiu	310**	-79.0 -72.0	-11.20 -10.02**	25 [illegible]	
? Giurgiu. Uz Apà	960 725**	-66.3 -69.8**	-10.15 -11.00**	12 ± 2	62.2 ± 1.8
2 Giurgiu Nord	635 640**	-65.8 -71.6**	-9.93 -10.00**	6 ± 2	49.0 ± 1.6
2 HS Uzunu	1520 1505	-73.0* -73.5**	-10.02* -10.38**	<5*	21.4 ± 0.7*
2641 - Bucuresti	2060 1935**	-86.9 -87.1**	-11.80 -11.85**	<5	4.2 ± 1.0
2664 - **Otopeni**	2540			<5	10.7 ± 0.?
2662 - Otopeni	2920			<5	3.0 ± 0.7

(1) Obtained in: 1988, 1991 (*) and 1993 (**), respectively

Tritium has been found only in the first two wells in the neighbourhood of the Danube, during a study period in spring-summer 1988. when the Danube had an average of 25 TU. From Uzunu to Otopeni. as was to be expected because of the great depth of the aquifer. the tritium content is below the significant level for the liquid scintillation method (5 TU).
These results. of particular importance for the boundary condition of the conceptual hydrogenlogic model. demonstrate the presence of a direct hydrodynamic link. more exactly a recharge of the Mesozoic aquifer by the Danuhe.
Radiocarbon analyses carried out for the interval Ciiurgiu-Otopeni confirm the information given by tritium on recharge from the Danube. Except for well 2664 Otopeni. all the values decrease constantly as one moves away from Danube. This arrangement shows an aging of waters and hence suggests a groundwater flow fiom south to north.
The same results also made it possihle to globally evaluate some useful hydrogeological parameters. The average values calculated for many intervals of the geologic cross-section (TENU *et al.*, 1994) are the following:

- actual flow velocity, $V_r = 3$ m/year;
- effective porosity. me = 15%.

The above-mentioned actual velocity, however, must he considered the highest possible value, as one cannot omit two possibilities for an artificial decrease of radiocarbon content by mixing with older/saline waters and by isotopic exchange with the calcareous inatrix. Thcsc arc considered to he only limited the calcareous matrix. These are considered to be only limited ineans of artificially decreasing ^{14}C contents, because. in the interval Giurgiu-Otopeni, the temperatures of the waters are low and the maximum upward input of saline was evaluated at a maximum of 3%.
With regard to the stable isotopes, deuterium and oxygen-18, the last analyses, performed on samples taken in August 1993, have been utilized for a inore detailed discussion by Tenu *et al.*, 1994. These values, as well as their areal distribution along the cross-section, confirm the hydrogeological features already revealed by tritium and radiocarbon. Thus:

- the similarity between the stable isotope coinposition of the Danube water and the groundwater froin the adjacent zone, suggests the existence of a local surface-water recharge of the Mesozoic aquifer ;

- the regional values of groundwater. which become more negative with distance from the Danube, show a gradual change in their genetic conditions. which seems to be in a good agreement uith the radiocarbon contents/ages.

4. UTILIZATION

The calculated hydrothermal potential of the Bucharest-Snagov area (18 wells) is evaluated ai about 500 Gcal/day. Only 20% of thia potential is now being exploited, especially for house heating, balneology and swimming pools.
Table 4 shows the stage and the modality for using all the 12 wells drilled so far in this area.

5. CONCLUSIONS

The most important conclusions of this study may be divided in two categories:
Regional hydrogeological conclusions, which may be considered as elements for a future elaboration of a conceptual model. and also useful for understanding the genetic and hydrodynamic processes of the thennal waters fiom the Bucharest-Snagov area. The main conclusions of this category are:

* in the Mesozoic aquifer there is an important groundwater flow;
* the flow direction is froin south to north;
* the Danube undoubtedly recharges the aquifer, is a at least in the area of Giurgiu city;
* in the interval Ciiurgiu-Otopeni, the average actual velocity of the aquifer is ainax. of 3 m/year and the effective porosity is a inin. of 15%.

It is interesting to recall a similar case that was studied by isotopic methods in South Dobrogea (TENU *et al.*, 1975), a nearby region with the saine Mesozoic carbonate aquifer. The similarity of conclusions suggest that a correct and complete knowledge of the hydrogeological model requires a more global approach, in our case the entire Moesian Platform.

Hydrogeothermal conclusions. First of all, the hydrochemical and, in particular. the isotopic data demonstrate that the origin of the thernial waters in this aquifer is almost exclusively meteoric. Although the entire aquifer, and especially the area Oropeni-Balotesti. receives saline. prevalently chloride. upward inputs through the system of fractures. the volume of these waters can be evaluated only at about 1-3% of the entire volume of water stored in the aquifer.
As regards hydrothermalism. new elements emerging from this study can be suniinarized as follows:

- the correlation of hydrochemical and thennal data has demonstrated that the increase in groundwater temperatures from south to north is a gradual phenomenon, mostly due to the deepening of the Mesozoic reservoir, and that the role of the geothermal anomalies is only of secondary importance;

- both the hydrochemical data, through the tentative application of the Na-K-Mg-Ca geothermometer, and the isotopic data, because of a lack of stable isotope modification phenomena characteristic of high enthalpy geothermal waters, confirmed that the geothennal potential of this reservoir is based only on a low enthalpy system.

Utilization conclusions. As we said earlier, only 20% of the energy potential of this system is new being exploited. Investments should be made in surface plants that utilize the potential available in space heating. balnealogy and swimming-pools.

Table 4: The use of thermal waters in Bucharest-Snagov area

Well	Optimum energetic rate (Gcal/day)	Use
2641 Bucuresti		Balneology and reacreation
2664 Otopeni	---	Reinjection well collecting the effluent water from 2662, 2663 arid 2666 boreholes.
2666 Otopeni	35	Heating and preparation of domestic hut water for the households in the tuwn of Otopeni
2663 Otopeni	40	The same use.
2662 Otopeni	40	The same use
2644 Internat	80	Under conservation. It will be used fur heating and preparation of domestic hot water for Otopeni Airport.
2667 Internat	---	Under conservation. It will be used as reinjection well for the water extracted from 2644 and 2672 boreholes
2672 Balotesti	40	Under conservation. It will be used for heating and preparation of sanitary hot water
2669 Balotesti	70	Under conservation. It will he used by a textile factory: heating and industrial water.
2676 Moara Vlasiei	---	Under conservation. It will he used as reinjection well for the water extracted from 2680 well (geothermal doublet).
2680 Moara Vlasiei	115	Under conservation. It will he used for a poultry hreeding heating.
2682 Snagov	80	Under conservation. It will he expoitcd for heating. balneology and recreation in connection with 2683 (to be drillcd) as a geothermal doublet.

Acknowledgements.

This research was carried out in the International Institute for Geothermal Research of Pisa, Italy, and was financially supported by the Commission of the European Communities as part of the Community's Action for Cooperation in Sciences and Technology with Central and Eastern European Countries.
We would like to thank E. Calvi. C. Corsi. R. Dall'Acqua, G. Del Chicca and E. Gherardi for their technical assistance.

REFERENCES

Giggenbach, W., (1988). *Geothermal solute equilibria. Derivation of Na-K-Mg-Ca geoindicators.* Geochim. Cosmochim. Acta, vol. 52, pp. 2749-2765.

Giggenbach, W., Gonfiantini, R., Jangi, B.L., Truesdell, A.H., (1983). *Isotopic and chemical composition of Parbati Valley geothermal discharges, north-west Himalaya, India.* Geothermics, vol. 12, pp. 199-222.

Tenu , A., Davidescu, F., Mussi, M., Squarci, P., Vamvu, V., (1994) *Hydrodynamic and genetic aspects of athermal-thermal Mesozoic aquifer from central part of Valachian Platform.* Proc. of Intern. Hydrogeol. Symp., Constantza-Romania, pp. 536-556.

Tenu, A., Noto, P., Cortecci, G., Nuti, S., (1975). *Environmental isotopic study of the Barremian-Jurassic aquifer in South Dobrogea (Romania).* Journ. Hydrol., vol. 26, pp. 185-198.