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Dynamics of the Felix – 1 Mai thermal aquifer (Bihor county, Romania)

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Abstract. The investigations performed indicate that all the wells in Felix-1 Mai area are in interference, supporting the idea that there is present a unique thermal aquifer in the Lower Cretaceous limestones. The vertical movement of the piezometric surface of the aquifer depicts a wave-like shape with an amplitude of about 2.5 m in 2015-2016 time interval and a periodicity being directed by the extension of the hydrological cycles. The thermal aquifer is fed from Pădurea Craiului and Bihor Mountains and the transit of cold mountains underground waters to the thermal reservoir is mainly through the regional drain represented by the Galbena fracture system. The thermal aquifer is confined and the oscillation of its surface has a complex state of motion influenced by natural factors, including the quantity and time distribution of precipitations and by anthropic factors, including the volume of thermal water extractions. The thermal aquifer has a karstic–fissured feature with very large local variations of transmissivity. The deformation of the thermal aquifer surface generated by the exploitation through wells is rapidly transmitted within the whole aquifer area, especially by fractured, fisured and karstified routes. The Ochiul Mare lake is in direct connexion with the thermal aquifer, is located on a main drainage axis of the reservoir and manifests rapidly the effects of natural recharge-discharge cycles and of drawdowns produced by wells development.

Key words: hydrogeology, thermal waters, piezometric surface, Peța lake

Introduction

The Peţa (Peţea) lake, or the so-called Ochiul Mare lake, is included within a Natura 2000 site coded ROSCI0098 since 2007. The site is the only place in Romania where a natural thermal ecosystem hosted several endemic or rare species, such as *Nymphaea lotus* var*. thermalis*, *Melanopsis parreyssi* and *Scardinius erythrophtalmus racovitzai*. A severe deterioration of the natural status of the Ochiul Mare protected area has been observed starting mainly from 2012.

To clarify, update and identify the actual status of geothermal resources in the area the National Agency for Mineral Resources (NAMR – ANRM), which is the governmental body managing and controlling the geothermal groundwater resources at national level, has entitled the Romanian Association of Hydrogeologists (RAH, AHR) with the design and the implementation of a hydrogeological study in the Felix-1Mai area.

The main objective of the RAH study was to provide the updated knowledge on the geothermal aquifer characteristics and its general behaviour in order to eventually conciliate the conflicting objectives of certain economic (commercial) entities on one side and the protection of the (thermal) groundwater dependent ecosystem i.e. the Natura 2000 ROSCI0098 site on the other side.

The thermal aquifer in Felix-1Mai area is the southern compartment of a larger geothermal aquifer system, namely Oradea – Băile Felix – 1Mai, that is hosted by dolomites and limestone of Triassic (Oradea area) and Cretaceous (Felix-1Mai) age(s).

The thermal aquifer of Felix-1 Mai area is located in lower Cretaceous limestones covered locally by calcareous mudstones and by Sarmatian – Panonian mostly impervious deposits with thicknesses up to 138 m in the South of Felix zone and only up to 12 m in the northern part of 1 Mai zone. The temperature of the water ranges between 32.1 and 47.1 ^{O}C.

The present paper will present and provide an interpretation of the data obtained in the field by following the evolution of the piezometric surface and temperature of the thermal aquifer by means of sensors introduced in the wells, as well as the contribution brought by these new data to the knowledge of the genesis of this reservoir. The results of the first investigations were previously published (Orăşeanu & Malancu 2016).

1. Historical data

The information about the evolution in time of the piezometric surface of the thermal aquifer is rare and it is mainly found in the reports of execution of the wells. The data about the flow-rates of water springs and boreholes are more numerous and their synthetic presentation was made in 1985 by G. Paal and I. Cohut based on the data collected by the County Office of Tourism Bihor, the authors underlining „the enhanced fall of the flow-rate potential of the sources from the hydrogeothermal perimeter Felix -1 Mai between 1983-1985" (Cohut & Paal 1985).

In its natural state, i.e. before 1885 when Balint well was drilled, the whole system was thought to be discharging through some springs, out of which the Ochiul Mare spring located in the Peţa Brook area was the most important one. The gradual development of the spa facilities exploiting the geothermal water at Felix-1 Mai through an increasing number of wells led to the continuous lowering of the hydraulic head in this compartment of the system. Subsequently, all the thermal springs in the area dried out.

A number of 21 exploitation wells were drilled in Felix – 1 Mai area before 1990 (Vasilescu & Nechiti 1964, Flamaropol 1975), while other 8 wells were more recently drilled, i.e. after 2002; out of which only 13 are still operational. After 1990 an unknown number of wells were also (unlawfully) drilled and presumably periodically operated but no NAMR (ANRM) licence has been requested by, or granted to their owners.

Between 1973-1987 the piezometric level of the thermal aquifer in Felix – 1 Mai area severely dropped with 8.8 m, followed by a more reduced decline of around one meter until 2015. The actual hydraulic head in the area is fluctuating above or below the (average) ground level, i.e. 154.5 m (Fig. 1).

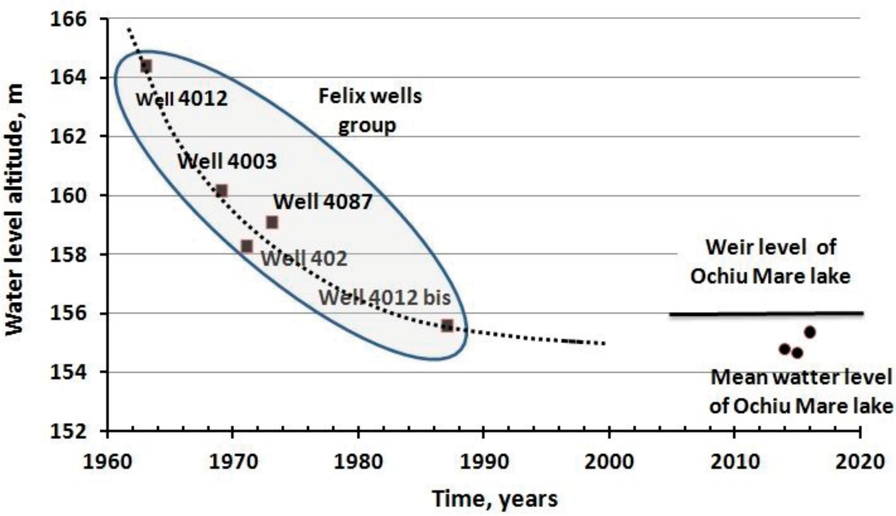


Figure 1. Decrease of the thermal aquifer piezometric level of Felix – 1 Mai zone as new boreholes were drilled.

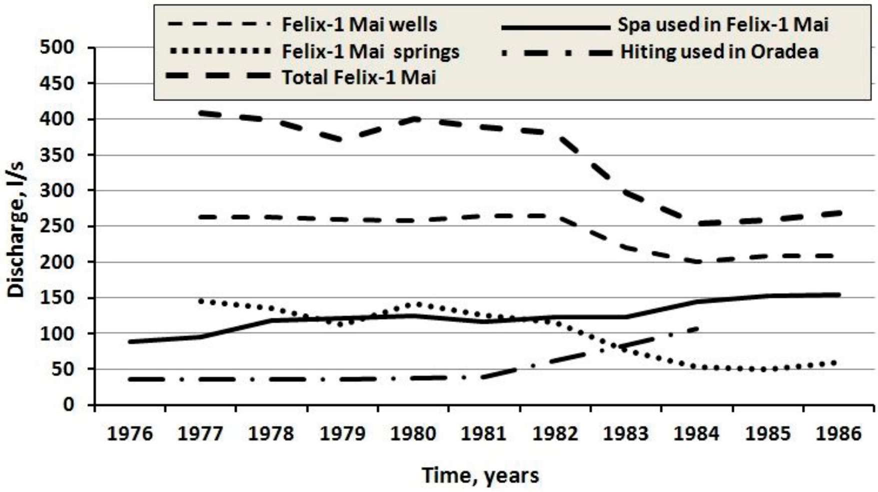


Figure 2. Flow-rates of water discharged from the thermal aquifer through springs and artesian wells, between 1977-1986. (After Cohut & Paal, 1985).

In 1963, by drilling the well 4005, thermal water was found in the subsoil of Oradea, (Vasilescu & Nechiti 1968), 10 more boreholes being drilled until 1993.

In 1985 Cohut & Paal presented the evolution of the flow rates of the springs and wells (all with free overflows) by means of which the thermal aquifer of Felix-1 Mai area is discharged. At the end of 1964, the thermal aquifer disharged freely at 398 l/s, 216 l/s through springs and 182 l/s through wells. In 1973 these values reached 449, 181, respectively 268 l/s. After 1976, the total flow discharged from the aquifer was constant around the value of 258-265 l/s until 1982, when there an enhanced decrease was noticed, reaching values of 86 l/s in 1984 (Fig. 2).

The fall of the flow rate potential of the thermal aquifer between 1982-1983 was attributed to the exploitation of thermal water from Oradea, and this is underlined by the above mentioned authors by the interpretation of the results of the interference tests between Oradea – Felix -1 Mai reservoirs, conducted in 1984. The period between 1982-1983 was critical from pluviometric point of view, the year 1983 being the most droughty in the last 50 years and that is the reason why we consider drought has played a significant part in the decrease of the flow rates of thermal waters from Felix -1 Mai area. This is illustrated in Fig. 3, where the evolution of the source discharges and the variation of precipitations (annual amounts) at two pluviometric stations, namely Stâna de Vale and Zecehotare, are illustrated.

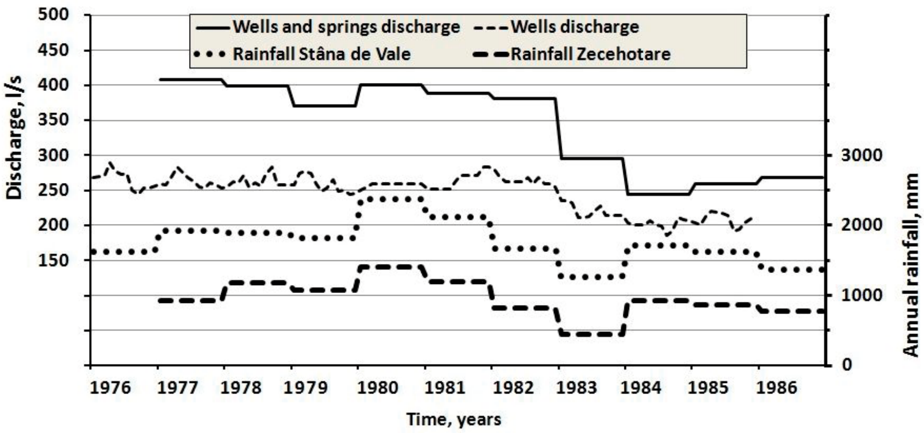


Figure 3. Evolution of the flowing potential of the thermal aquifer based on Cohut & Paal (1985), together with the annual amounts of precipitations at Zecehotare and Stâna de Vale between 1976-1986.

The feeding of the thermal aquifer with the precipitations fallen in the mountain zone developed to the East is supported by most researchers, among the first ones proposing this possibility being Paucă (1958) and Vasilescu & Nechiti (1968).

During the last period of 1986 until September 2014 no measurements were performed regarding the position of the piezometric surface level of the geothermal aquifer.

The exploitation of the thermal aquifer of Felix -1 Mai area is performed by 13 wells authorized by NAMR and by illegal drilling holes whose number and characteristics are not known. The development is carried out using suction and submersible pumps. 8 wells are exploited by SC Turism SA Felix, and the water volumes extracted by this company are measured. In the period September 2014 – October 2016 the volumes of water extracted from the other leased wells were also monitored.

2. Results

The hydrogeological investigation started in September 2014 with the installing of pressure and temperature sensors in the wells authorized by NAMR in Felix-1 Mai area (Table 1, Fig. 4), in the well 1730, Cihei from Oradea and in Ochiul Mare lake. In the piezometer drilled in 2015 near Ochiul Mare (Piezometer AHR), a sensor was also introduced. In a separate piezometer, situated near the AHR piezometer, the phreatic aquifer level was measured on a monthly basis too. The sensors record the pressure data (water column above the sensor + atmospheric pressure) and the water temperature. They were set to store the data every 1 hour, and for the correction of the deviations caused by the variation of the atmospheric pressure, a suitable sensor was installed. To verify the records, measured on a monthly basis, the level of the thermal aquiferous from all the monitored wells from Felix -1 Mai area were using a level meter. The data recorded by the sensors were downloaded and processed on a monthly basis.

Table 1. Characteristic data for the monitored wells

No.	Wells	Drilling	Co-ordinate, m			Depth,	Stratigraphic intervals	Open interval, m	T
		year	X, North	Y, East	Z	m			°C
1	Balint	1885	614526,9	270423,1	153,31	47,17	0,0-42,8, Pliocene; 42,8-47,17, K1	n.c.i.: 42,79-47,17	47,13
2	4011	1962	614998,3	270483,7	149,50	153,00	0,0-48,5, Pliocene; 48,5-153, K1	s.c.: 145-153	46,23
3	4003	1969	614553,2	270437,6	152,17	69,00	0,0-45, Pliocene; 45-69, K1	s.c.: 57-69	42,45
4	4087	1973	614117,0	270521,4	153,70	200,00	0,0-112, Pliocene; 112-200, K1	s.c.: 125-190	39,53
5	Fp2, Izbuc	1985	615233,9	272034,9	157,69	100,00	0,0-23, Pliocene; 23-100 K1	p.c.: 25-40; n.c.i.: 40-100	37,51
6	Fp3, Strand cu valuri	1986	614955,3	272467,3	161,20	500,00	0,0-20, Pliocene; 20-500, K1	p.c.: 190-247; n.c.i.: 253-500	32,09
7	Fp1, Venus	1986	615509,5	271288,7	157,66	500,00	0,0-70, Pliocene; 70-500 K1	p.c.: 230-298; n.c.i.: 300-500	37,47
8	4012 (Fp4), CFR	1987	615302,9	270488,0	152,41	650,00	0,0-106, Pliocene; 106-650 K1	n.c.i.: 300-650	40,26
9	SC ARCASIAN, Iulia Hotel	2002	615671,0	270876,0	150,08	102,00	22,5-77, Pliocene; 77-102, K1	n.c.i.: 82,5-102	38,60
10	F1 PSC Cordău, President Hotel	2003	613512,5	270762,2	155,16	172,00	6-72, Pliocene; 72-128, Sm; 128-172, K1	n.c.i.: 85-172	38,97
11	F2 PSC Cordău, Nicoleta Hotel	2003	613903,3	270766,1	157,94	92,00	5-70, Pliocene; 70-80, Sm; 80-92, K1	n.c.i.: 71-92	38,74
12	SC PRO QUADRIGA, Afrodita	2008	615720,2	270796,1	147,00	110,00	10-90, Pliocene; 90-110, K1	90-107, Plastic Johnson screen	40,60
13	F. Alin Bogdan, Perla Hotel	2014	615352,8	271888,3	162,41	100,00	6-23, Pliocene; 23-100 K1	n.c.i.: 96-100	36,13
14	Aqua, President Hotel	2014	613247,6	270713,0	157,19	160,00	12-87, Pliocene; 87-110 Sm; 110-160 K1	s.c.: 110-119,5; n.c.i.:120-160	35,89
15	AHR Piezometer	2015	615225,0	272216,0	158,10	70,00	6,9-9,5, Pliocene; 9,5-70, K1		32,20

s.c. = slotted casing; p.c. = perforated casing; n.c.i. = no casing interval; T=water temperature.

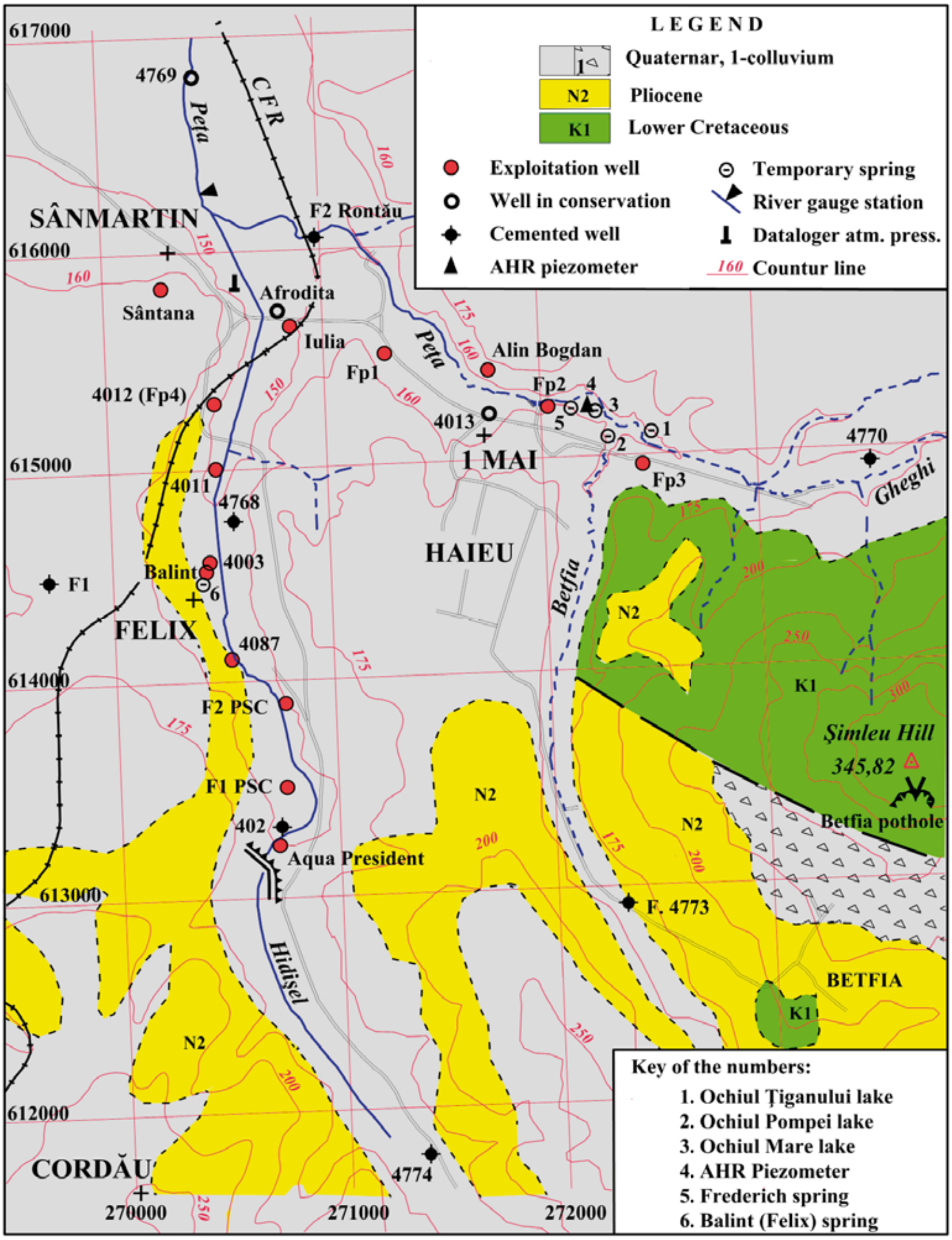


Figure 4. Geological map of Felix-1 Mai area (after Istocescu et al., 1967-1968)

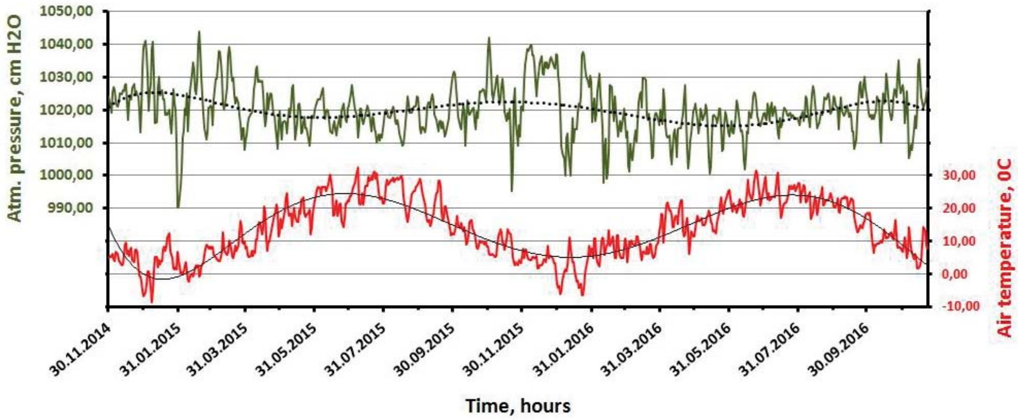


Figure 5. Evolution of the atmospheric pressure and air temperature within Felix -1 Mai area during the study period.

The atmospheric pressure was recorded using a sensor located to the Northern–Western side of 1 Mai locality, and it recorded the air temperature, too. In Fig. 5 the variations of the daily means of the two parameters are represented for the two year monitoring period, together with their polynomial trends of order 6. The two parameters indicated a reverse cyclic variation, the atmospheric pressure decreasing during the hot seasons and increasing during the cold ones and reaching maximum values in the middle of the winter. The maximum variation gap of the atmospheric pressure was about 55 cm H_2O.

Related to the amplitude of the oscillation of the piezometric level of the thermal aquifer recorded in the period of our monitoring activity (about 2.5 m) at a first estimation, it can be said that the variation of the atmospheric pressure could be responsible for about 20 % of it.

The sensors were introduced in wells beneath the maximum unevenness obtained during pumping operations, the hydraulic head recorded by them comprising the pressure of the water situated above them and the atmospheric pressure. The pressure of the water column is obtained by deducting from the total pressure the atmospheric pressure recorded by a separate sensor (Fig. 6).

2. 1. Evolution of the piezometric surface of the thermal aquifer

The wells drilled in the Felix -1 Mai area have the bottom in Lower Cretaceous limestones, except for the borehole 4768 which crossed through these deposits down to 1300 m followed by Jurassic deposits down to 1904 m and Triassic down to 3196 m. The borehole drilled in 1975 was abandonned.

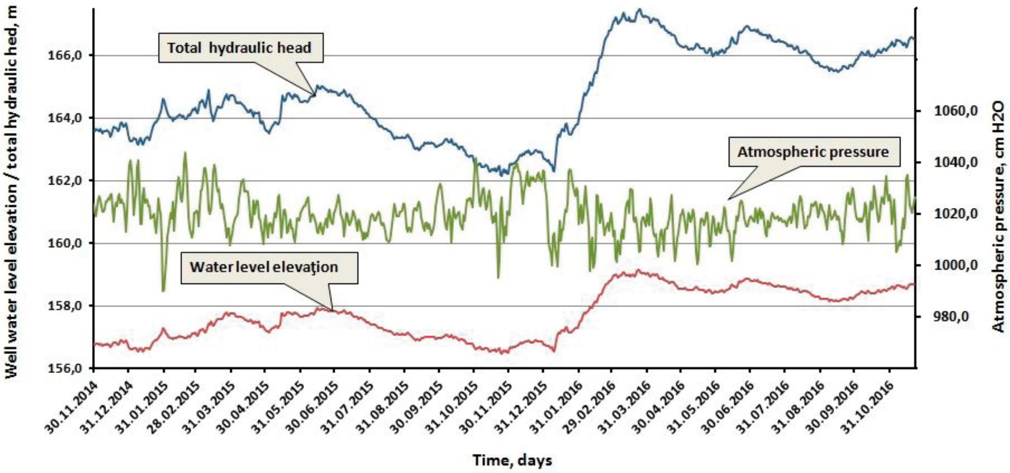


Figure 6. The total and measured heads in Afrodita well and atmospheric pressure at station 1 Mai for november 2014 to november 2016 time period.

The investigations performed indicated that all the wells are in interferrence no matter the level where they open the Lower Cretaceous reservoir, supporting the idea that a unique aquifer is present in the Lower Cretaceous limestones and covered localy by calcareous mudstones and by Pliocene deposits.

The Afrodita well, situated at the North-West end of Felix-1Mai perimeter is in conservation stage, the records of the level oscillations are not influenced by its exploitation and are suggestive to illustrate the dynamics of the piezometric surface of the whole Lower Cretaceous thermal aquifer (Fig. 7). They will be taken into account as milestones in the currrent presentation. Fig. 7 also presents the evolution of the piezometric water level in the conservation well 1730 Cihei, situated to the East side of Oradea. For both boreholes, the evolution of surfaces was averaged by using the polynomial trend method (order 6).

The movement of the piezometric surface of the aquifer of Felix -1 Mai area is a wave-like shape with an amplitude of about 2.5 m in 2015-2016 and a periodicity of about one year. The maximum levels occur during May–June, and the minimum ones in December –January, their position being directed by the extension of the hydrological cycles. The thermal aquifer is fed from Pădurea Craiului and Bihor Mountains, while the seasonal distribution of the precipitations generate oscillations of the underground water level within the feeding zones translated through the pressure waves recorded in the wells.

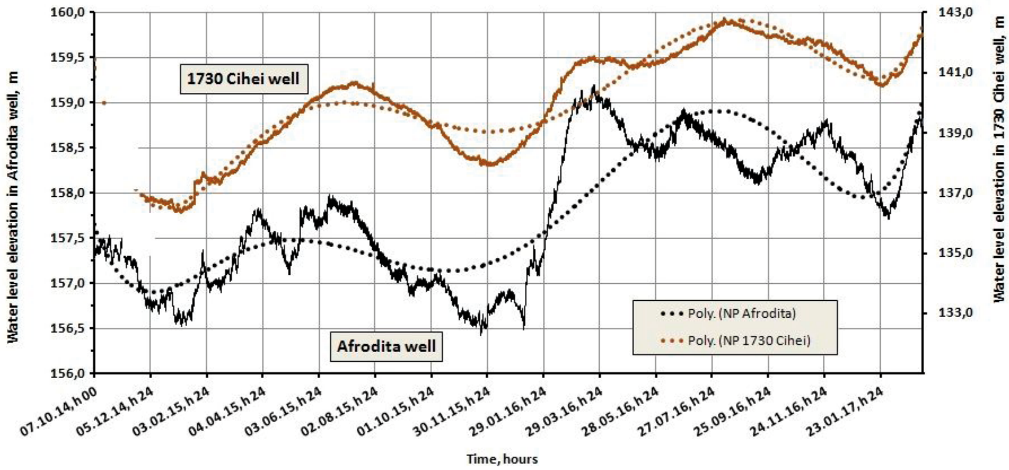


Figure 7. Fluctuations of the thermal aquifer level recorded in Afrodita and 1730 Cihei wells.

The hydrographers of the rivers are a direct indicator of the distribution of the precipitations and of the position of the piezometric surface of underground waters in the respectiv watershed. The crossed correlations performed between the flow rates of Crişu Pietros at Pietroasa and Vida stream at Luncasprie and the levels of the piezometric surface of the thermal aquifer measured in Afrodita borehole (rows of daily values for the period XI. 2014-XII. 2015) are highly reliable (0.357, respectively 0.25), reaching maximum values after 59 respectively 51 days, values interpreted as minimum transit times of high flows between the watersheds and the thermal aquifer of Felix -1 Mai area (Orăşeanu 2016). The transit of cold, mountain underground waters to the thermal water reservoir is mainly through the regional drain represented by Galbena fracture system (Orăşeanu 2015).

The oscillation of the thermal aquifer surface has a complex shape, influenced by natural factors, quantity and time distribution of precipitations and by anthropic factors, such as the volume of thermal water extractions. Each exploitation well causes pointwise trough of the piezometric surface and such depressions are rapidly transmitted within the whole aquifer area.

The impact of thermal water exploitation on the piezometric level between 07.10-18.11.2014 is shown in detail in Fig. 8. The time scale is expressed in days, the beginning of the weeks being marked by specifying the date. The minimum levels are recorded at the end of each week as these are the periods when the tourists' influx is maximum, and the pumped flow-rates are likewise. The levels

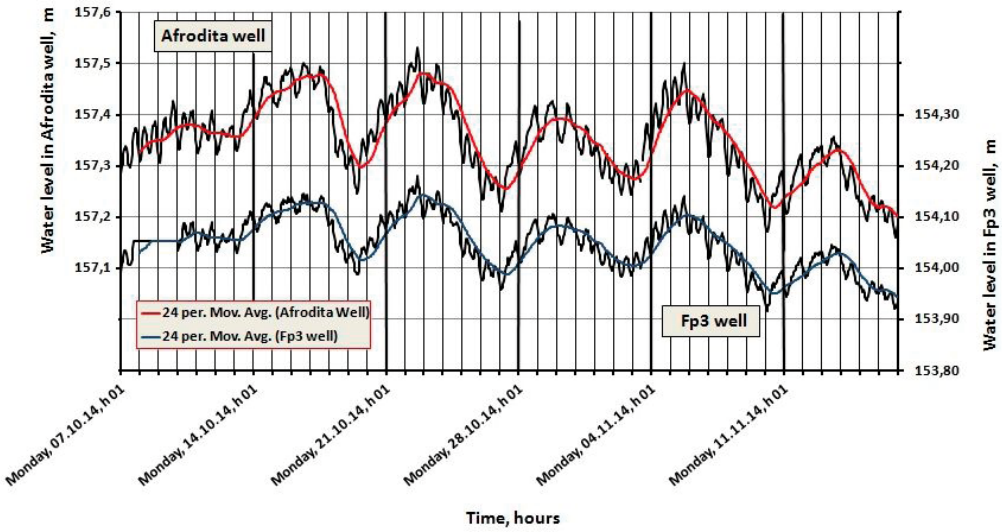


Figure 8. Weekly fluctutations of the thermal aquifer level measured in Afrodita and Fp3 wells.

increase then, in the first days of the week by reducing the pumped flows, their diminution by the end of the week being repeated. The amplitude of the weekly oscillations generated by aquifer exploitation is about 30 cm in Afrodita well and about 20 cm in Fp3 well. The drawdowns produced in the exploited wells are quickly driven also in the Ochiul Mare lake, the lake surface exhibiting fluctuations with amplitudes up to 30 cm.

The high oscillations in Fig. 8 are accompanied by low oscillations generated by the earth tides. In the presented period Afrodita and Fp3 wells were not exploited. The averaging of the trends of the oscillations of the piezometric surface by means of the moving averages with a 24 hours period cut off the oscillations caused by the earth tides, underlying their semi-diurnal nature.

The deformation of the thermal aquifer surface generated by the exploitation through wells is variable because of the lack of homogeneity of the hydraulic characteristcs of the collector and the varied regime of exploitation (flow-rates, periods and pumping times), and the amplitude of unevenness is not proportional to the extracted flow. For illustration purpose we elaborated the maps with the isopiestic aspects of the thermal aquifer within two distinct periods. In February 2015, the maximum depression of the piezometric surfaces has developed around the well PSC2 (Fig. 9), and in July 2015 around the 4011 well (Fig. 10).

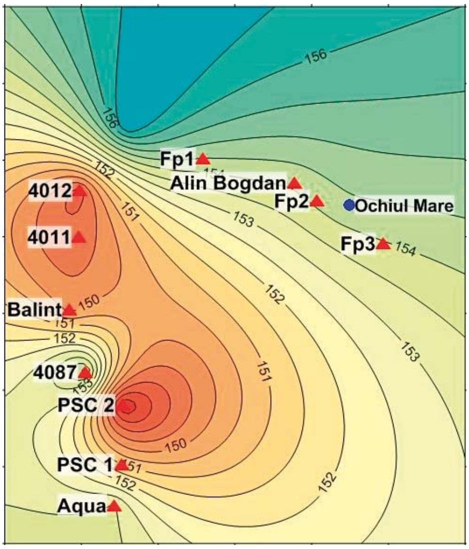


Figure 9. The spectrum of the thermal aquifer isopiezis between 23-28 February 2015

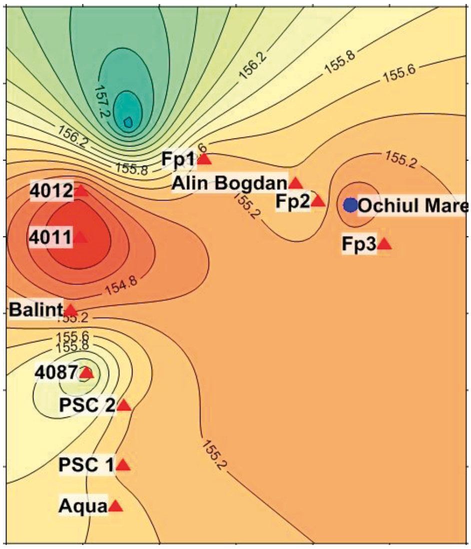


Figure 10. The spectrum of the thermal aquifer isopiezis in the period 16-25 July 2015

Taking into account only the above mentioned aspect, we could draw wrong conclusions. The dynamic level of underground waters is very different because of the karstic – fissured feature of the aquifer with very large local variations of transmissivity. Some wells pump 25 l/s, generating drawdowns lower than 1 m, while others must pump with a drawdown of 7-8 m in order to extract 5 l/s (Fig. 11). Finally, the exploitation impact on the whole piezometric surface is proportional to the volume of water extracted from the well and not with the drawdown produced.

The map of the specific flow-rates (drawdown / discharge) indicate the lack of area uniformity of the hydrogeological parameters of the thermal aquifer, the most „productive" zones being revealed by the wells Fp2 (Izbuc), Alin Bogdan and PSC1 (Fig. 12).

The area distribution of the values of the hydrogeological parameters presented in Figs 9-12 is only indicative of the interpolation method considering the aquifeorus an homogenous and continuous environment. Actually, the aquifer of Felix -1Mai area, of fissure – karstic type, is heterogenous and discontinue, with a drainage axis oriented along the fault systems. The existence of two systems oriented along the valleys of Hidişel and Peţa streams is presumable.

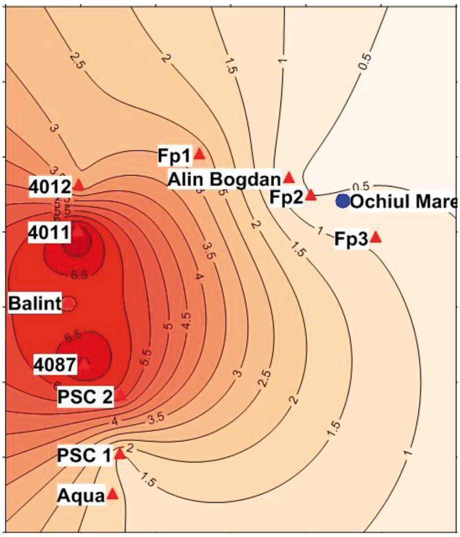


Figure 11. Area distribution of the unevenness of the piezometric surface between 16-25 July 2015

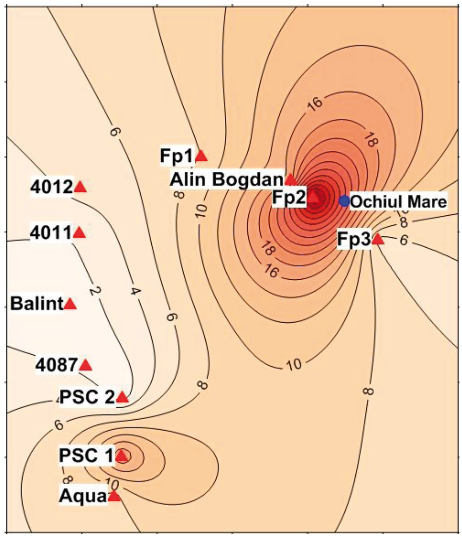


Figure 12. Area variation of the specific flow-rates, l/s/unevenness meter for the period 16-25 July 2015

In a quasi-stationary system, in Felix zone the level of the thermal aquifer is situated a little above the ground, and in 1 Mai zone is beneath the ground level by about 1 m, this being revealed by the diminution of the water level in Ochiul Mare lake („ochi" means a small pond formed by a sublacustrine spring).

The level oscillations of Ochiul Mare lake water (Fig. 13) reflect as a whole the oscillations of the thermal aquifer level to which it is connected through a fissure /karstic void continuing to the surface with a discontinuity of the deposits clogged by permeable detritus. The oscillations generated in the lake by the oscillations of the piezometric surface of the thermal aquifer are „disturbed" by the water contributions from the phreatic aquifer developed in the detrital deposits, by the temporary surface course of Peţa stream and the uneven supply of thermal water pumped from well Fp2 (Izbuc) or AHR piezometer to support the thermophylic flora and fauna.

To know the level of the thermal aquifer of the lake perimeter, a piezometer hole of 70 m deep was drilled at 42 m West from the staff gage placed in the middle of the lake, called „AHR piezometer" (Fig. 14). The drill hole crossed through the peat layer with intercalations of black clays (2.0-3.8 m), sapropelic mud (4.0-6.8 m), greenish clay (6.8-7.0 m), coarse sand (8-8.5 m), blackish plastic clay (8.5-

9.5 m), blackish calcareous mudstones (9.5-25.0 m), white and gray limestones (25.0-43.0 m) and compact limestones (47.0-60.0 m). At the m 70 level, in the gray limestones, a highly fractured zone with thermal water circulation was intercepted. To measure the phreatic aquifer level, a perforated plastic tube was placed, attached to the drill hole tubing.

In the middle of Ochiul Mare lake a staff gage is placed with the „0" level placed at 156.1 m above sea level. The evolution of the level and temperature of the water from Ochiul Mare lake was monitored with a diver type sensor immersed at the bottom of the lake using a plastic tube perforated at the base attached to the staff gage in the middle of the lake. The sensor records were carried out until 22.04.2016. On the occasion of the field trip on 29.06.2016 the sensor was taken out of the tube. The level of the lake water is read on daily basis on the staff gage by an employee of the Țării Crişurilor Museum and we could have access to these records due to the kindness of the above mentioned institution.

Based on the proposal made in 1965 by G. Vasilescu and G. Nechiti, to limit the thermal water losses of the aquifer through Ochiul Mare in the Peţa brook (200 l/s, 32^{o}C), at about 310 m downstream Ochiul Mare, near the Rontău metal culvert, a concrete notch weir was built with a spillway situated at 156 m level. At present, beneath the spillway there are permanent infiltrations, their values ranging between 5 and 10 l/s. The spillway is rarely overflown when there are high water flows. The infiltrations are supplied from Ochiul Mare by passing through the alluvial deposits which are clogging the Peţa stream route downstream the lake. The rehabilitation of the weir seal is limiting these losses.

In 2015 the level of the lake water was permanently beneath 156 m reaching the minimum value (153.6 m) at the end of the said year and beginning of the next one and during this period the water surface on the botttom of lake cone temporary froze (Fig. 15). In case of heavy precipitations, the Ochiul Mare area is flooded by Peţa stream water for a short time as these waters infiltrate rapidly in the thermal aquifer through the alluvial material from lake bottom. Most of the year Peţa stream is dry.

The minimum levels of the water in Ochiul Mare were recorded in February 2015, a month when precipitations actually were absent. The significant precipitation amounts fallen in January and February 2016 in the whole mountain area led to the raise of the thermal aquifer levels and water level in Ochiul Mare lake by 2,26 m, from 154,14 m on 27.12.2015 to 156.4 m on 24.02.2016, and after that the lake level slowly decreased and stabilized at 155.95 m until 22.04.2016, which is the date of the last record. At 155.8 m level the thermal water spillage enhanced a string influx of air bubbles marking at the lake surface, the vertical of the access

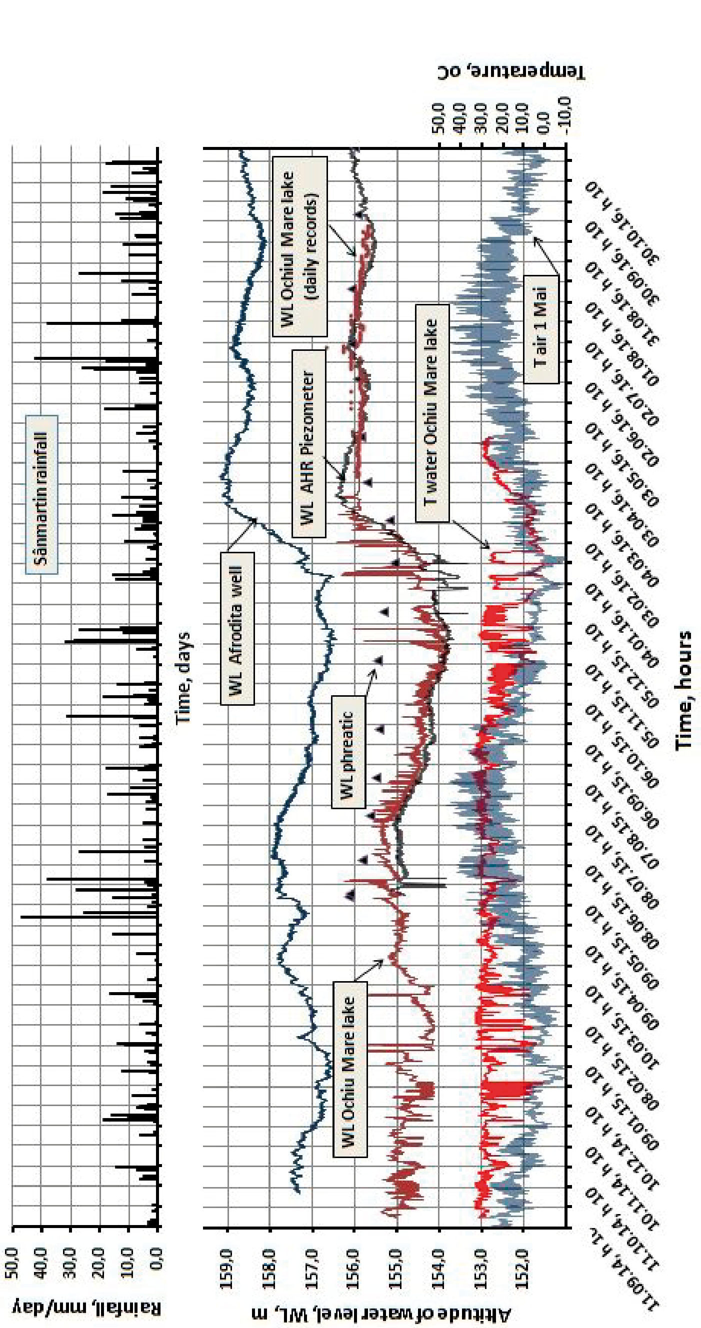


Figure 13. Fluctuation of the water level and temperature in Ochiul Mare lake and representation of the parameters obtained from other investigated points.

Figure 14. Aspects from the execution of the AHR piezometer in April 2015

Figure 15. Ochiul Mare lake at different stages of filling on 20 Jan, 2015 (up), 25 April, 2015 (middle) and 19 Jan, 2016 (bottom)

place of the thermal waters through its bottom The time of the upward thermal water flowing starting through the connection channel with the thermal aquifer is marked by the start up of the lake water heating, this reaching the maximum value of 29.7 ^{O}C on 17.04.2016. On 22 April 2016 the thermal water outflow from the Ochiul Mare was supplying Peţa stream with a 8.0 l/s flow-rate, the shallow course being dry upstream the lake.

On 10 March 2016 the thermal aquifer in the AHR piezometer reached the maximum level of 156.47 m. It is also noticeable that on 18.03.2016 the level of the thermal aquifer from the piezometer was by about 0.6 m above the level of the water in the lake. After reaching the maximum level, the level of thermal aquifer slowly decreased so that on 21 April 2016 its level was at the same level with lake surface (155.93 m), very close to the phreatic aquifer level (155,89m).

The increase of the thermal aquifer level resulted in:

- Filling of the depression basin of Ochiul Pompei and reactuation of the water flowing; it stopped in April 2016;
- On 21.04.2016 at the bottom of the hexagonal basin of the spring with „*Rana dalmatina*" (so called by Slăvoacă and Feru in 1961), there was a water layer 10 cm deep, situated at 125 cm beneath the Southern border of the basin. Usually the basin is dry;
- Actuation of Frederich spring;
- Increasing the flow-rate of Felix spring of the Felix resort, its surface being agitated by significant influxes of water and air bubbles.

The increase of the piezometric level of the thermal waters at the beginning of 2016 (Fig. 13) is attributed to the high amounts of precipitations fallen in January and February 2016 in the mountain zone, as the regime of the exploitation of the thermal aquifer did not justify such increase (Fig. 16). Between January and February 2016 at Luncasprie there fell 189,2 mm precipitation compared to 95.6mm in January–February 2015, at Pietroasa 220.2 vs 90.9 mm, at Călăţea 164.1mm vs 91.5 mm, and at Sânmartin 123.4 vs 74.5 mm. The correlation between the cumulated values of the precipitations fallen at Luncasprie and the increase of the thermal aquifer level in Afrodita borehole is linear and indicates a very high reliability (R^2=0.98), underlining the significant impact of precipitations on the thermal aquifer level (Fig. 17).

The water level of the phreatic aquifer of the lake was measured on a monthly basis (Fig. 13). It is in a permanent supply – drainage relation with the Ochiul Mare lake (Fig. 12). Until 05.02.2016 the phreatic supplied the lake, its piezometric level decreasing slowly as a result of rainfall deficiency. After that date until the end of April 2016 the lake water infiltrated in the phreatic aquifer, and further on the le-

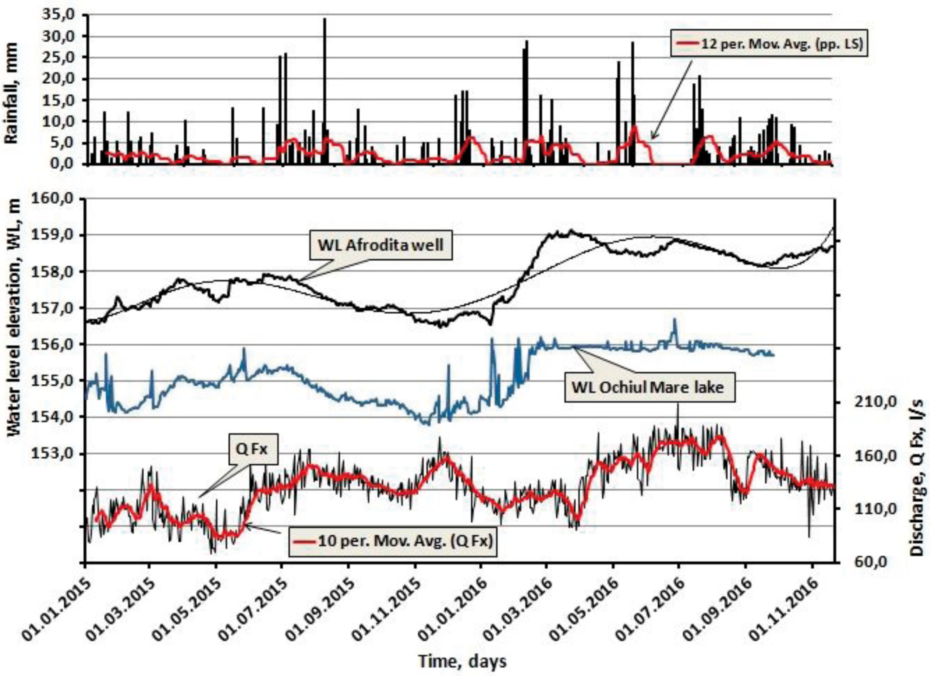


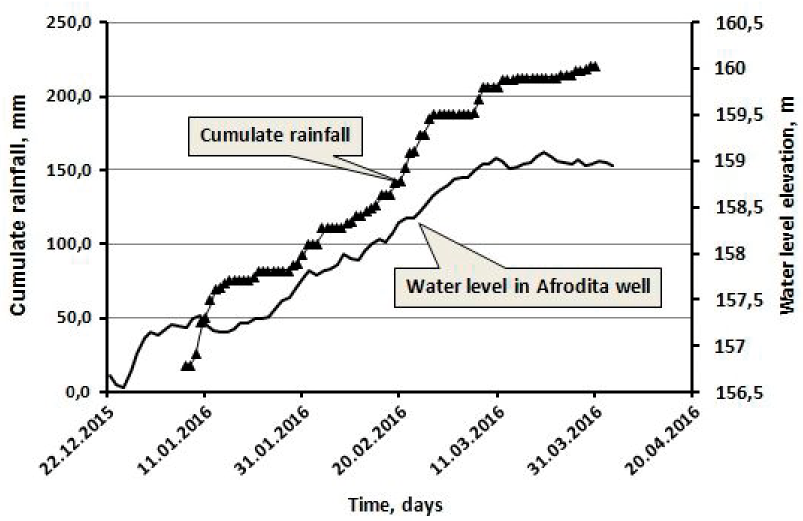
Figure 16. Distribution of precipitations at Luncasprie, variation of the thermal aquifer level in Afrodita well and of Ochiul Mare lake surface as well as the daily flow-rates extracted from the aquifer at Felix -1Mai (Q Fx), through the wells licensed in the period January 2015 - November 2016.

vels of the lake water, the thermal and phreatic aquifer are situated at close levels.

The well 1730 Cihei is situated at the East side of Oradea at about 4.2 km North-West from the Afrodita borehole in 1 Mai resort. The depth of the borehole is 2,800 m and opens the Triassic collector with a slotted casing over the interval 2080-2750 m. The borehole is in preservation stage and indicates low methane release. The pressure sensor introduced in the borehole indicates a wave-like variation of the opened aquifer level, similar to the Lower Cretaceous aquifer of Felix -1 Mai area, but with double amplitude (Fig. 7).

The similar shape of the pressure waves recorded at the two previous wells indicates the location of their feeding zone in the same mountain areas, but with different altimetry positions, with a similar temporary distribution of precipitations. Both in Pădurea Craiului mountains and in Bihor mountains, the Triassic deposits are at higher altitudes, with superior values of precipitations.

In all monitored wells, the opened aquifers are under pressure and indicate



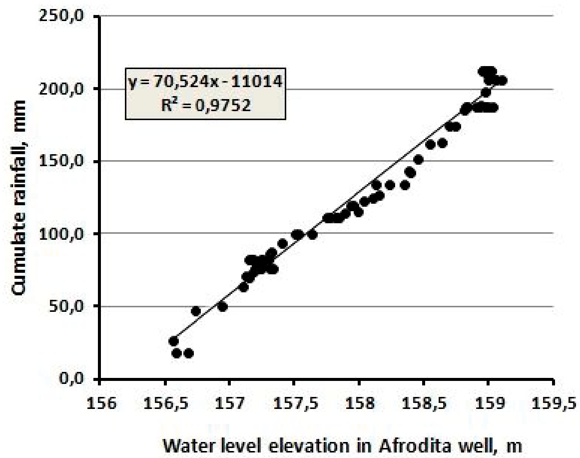


Figure 17. Time distribution of the precipitations cumulated at Luncasprie and of the thermal aquifer level in Afrodita borehole (left). To the right, there is the correlation between the rows of values mentioned.

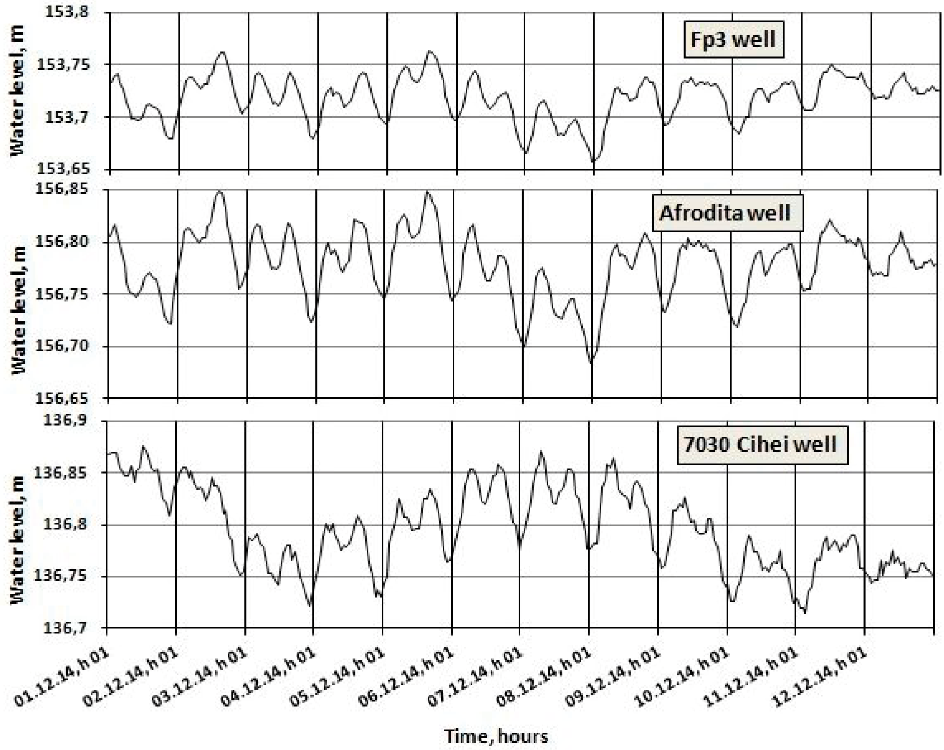


Figure 18. Fluctuations of the thermal aquifer level caused by earth tides.

rhythmic oscillations of the thermal aquifer elevation level because of the earth tides. The amplitude of 5-6 cm is found at Fp3 well, reaching 10 cm in Afrodita and 1730 Cihei wells (Fig. 18). The graphics illustrate the semi-diurnal nature of the tides. The period between two successive records of the levels is one hour.

The earth tide harmonic oscillations of thermal aquifer level are recorded also at the surface of Ochiul Mare lake, with an amplitude of 10 cm and a distorted shape produced by nearby exploited wells.

2. 2. Thermal water temperature

In the monitoring wells, the thermal aquifer is under pressure, and the depth where it is intercepted by the wells varies between 20 and 128 m. The pressure and temperature sensors are introduced in the wells casing below the limit of the exploitation dynamic level, which is situated at maximum 8-9 m from the ground surface. The water circulates through the casing only during exploitation (either by pumping or by aspiration), and during this period the actual temperature of the thermal water is recorded. During the repose periods the water is stationary on the column and its temperature slowly decreases to the temperature of the contiguous rock temperature. Table 2 presents the characteristics recorded by the sensors introduced in the boreholes in the period of observations, namely Sept. 2014 – Nov. 2016. The temperature values of the thermal waters pumped from the aquifer are considered as belonging to the maximum temperature value range.

Table 2. Average, minimum and maximum termperatures recorded by the sensors introduced in thermal water wells.

	Fp1	**Fp2**	**Fp3**	**Alin Bogdan**	**4012**	**4011**	**4003**	**Balint**	**4087**	**F2 PSC**	**F1 PSC**	**Aqua Presid.**
Media	33,73	36,47	22,75	35,36	35,75	44,66	41,85	46,05	38,84	37,73	38,86	35,08
Min.	24,10	36,12	19,53	33,20	34,48	44,03	41,55	45,39	38,52	32,72	38,37	33,12
Max	37,47	37,51	32,09	36,13	40,26	46,23	42,45	47,13	39,53	38,74	38,97	35,89
Avedev	3,72	0,10	3,43	0,26	0,87	0,33	0,12	0,31	0,11	0,57	0,06	0,14

The temperature of the thermal waters extracted from the wells indicates a significant variation in the area. The water with the highest temperature is coming from Balint (47.1 ^{O}C) and 4011 (46.2 ^{O}C) wells, the temperatures decreasing radially, with the minimum values encountered to the East end of 1 Mai zone (table 2 and Fig. 19). For the elaboration of the map in Fig. 19 we used the data acquired during the period September 2014–February 2016 and the data from the exploration drilling contiguous to the investigation zone.

Fig. 20 presents the evolution of the temperature of the water pumped from the wells that continuously operated for longer periods of time. As the pumping period increase, the water temperature indicates a constant trend of increases at some wells and decrease at others. The increase of the water temperature was recorded at Balint (+0.369 ^{O}C/year), 4003 (+0.277 ^{O}C/year) and 4087 (+0.231 ^{O}C/year) wells. The increase trends of the pumped water temperature occurred at Aqua President and F1 PSC wells, too. The most significant decrease of the water temperature was recorded at wells 4011 (-0.554 ^{O}C/year), followed by Alin Bogdan (-0.277 ^{O}C/year) and Fp2 (-0.231 ^{O}C/year). It is to be underlined that the wells where the temperature of thermal pumped water increased are situated at the center of Felix resort along the alignment of 4003-Balint-4087-Aqua President, considered the main ascending way of thermal waters to the surface.

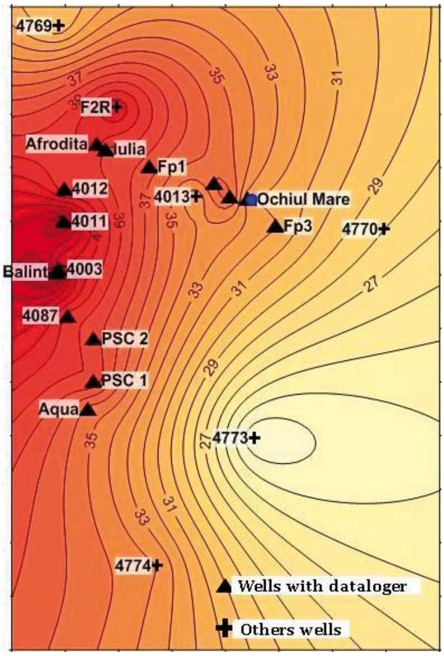


Figure 19. Area distribution of the temperature of thermal waters extracted through the wells in Felix -1 Mai area between September 2014 – February 2016.

No time relation has been noticed between the oscillations of the piezometric level of the Lower Cretaceous thermal aquifer of Felix -1 Mai area and the temperature of the thermal waters extracted from the wells.

During exploitation of Balint borehole between March–April 2015, the water temperature varied between 46 and 47 ^{O}C, the pumping periods being accompanied by the decrease of water temperature (Fig. 21). In the summer season of 2015 the pumping operation was actually a permanent one with variable flow-rates, the water temperature ranging around 45.7 ^{O}C.

At borehole 4011, which is permanently pumping with varyable flow-rates, the weekly fluctuations of water temperature during the above mentioned period can be found but their amplitude is 0.2-0.3 ^{O}C (Fig. 21). During summer season of 2015 the water temperature decreased by about 0,2 ^{O}C below the mean value of 45 ^{O}C. Since the fall of 2015 a constant decrease of the temperature of the pumped water was recorded, namely up to 44.03 ^{O}C in November 2016.

The temperature of the thermal water from wells had actually maintained constant since the time of their drilling until 1985. The average temperatures measured in the period IX.2014-II.2016 are lower by about 2 ^{O}C compared to those of 1985 (Table 2).

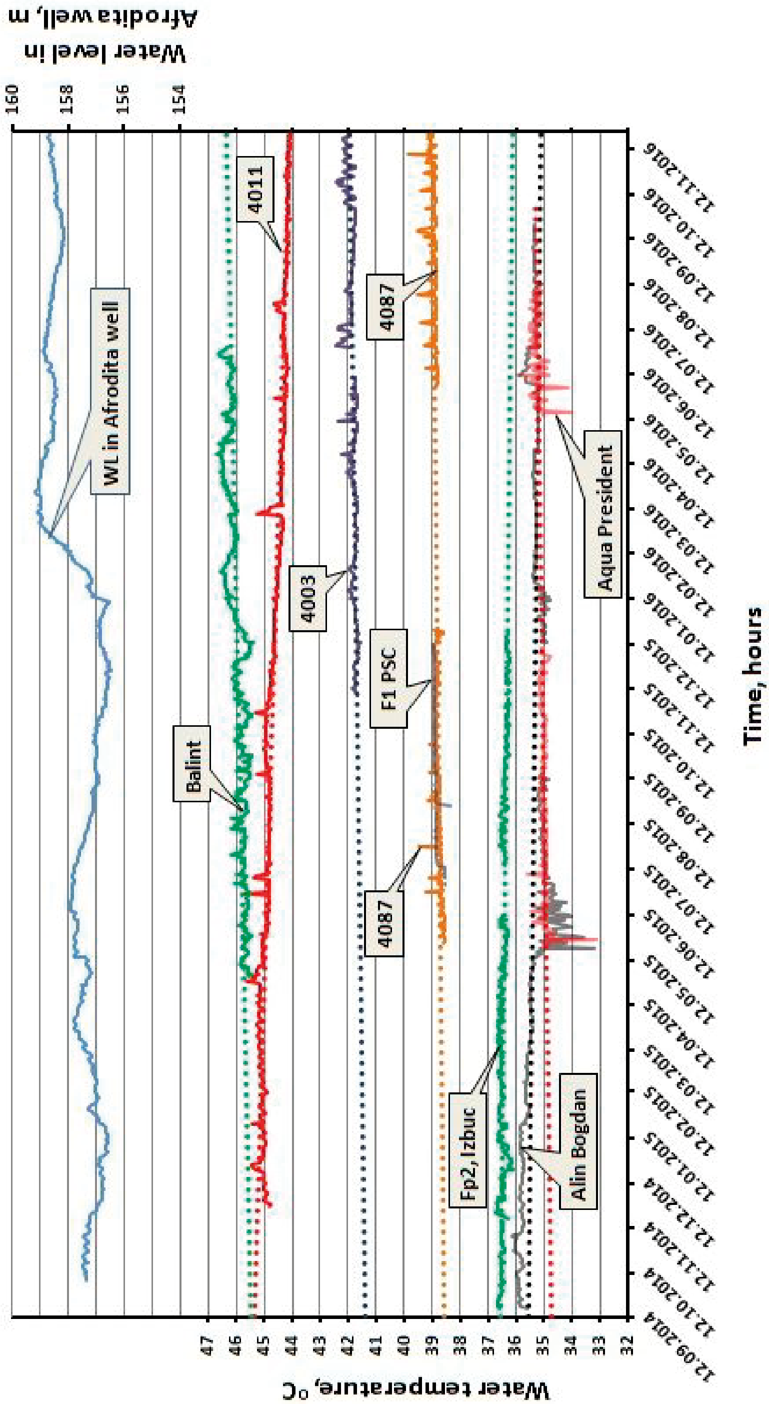


Figure 20. Evolution of thermal water temperature from some wells with continuous pumping.

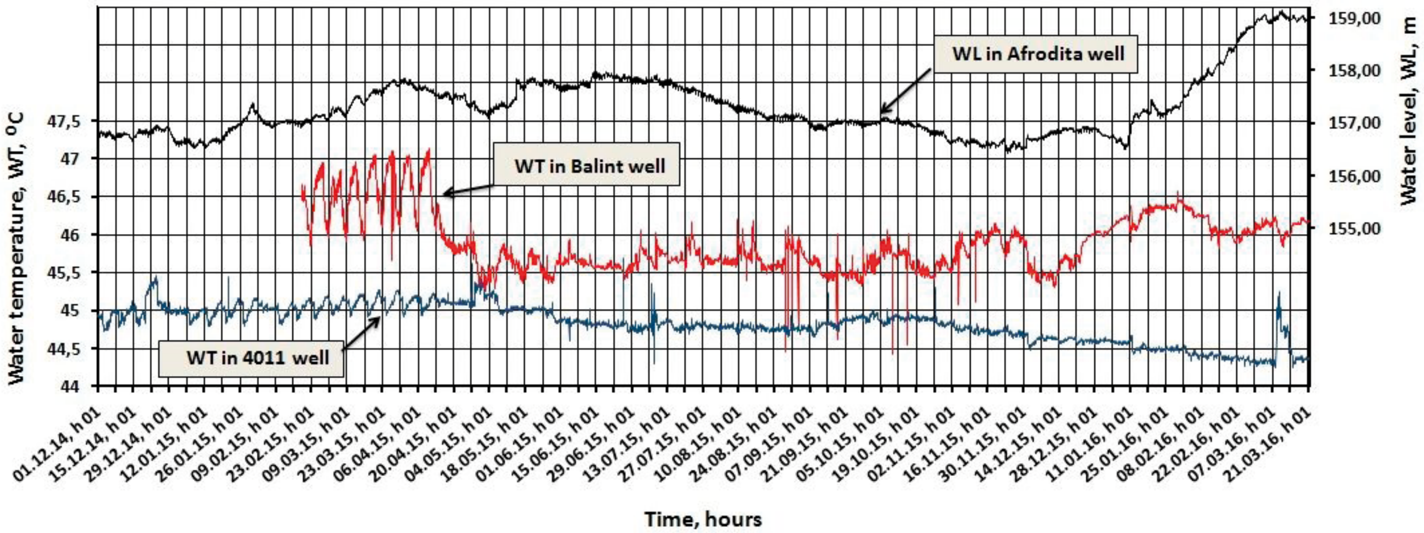


Figure 21. Evolution of the temperature of the thermal water pumped from Balint and 4011 wells and of the piezometric surface in Afrodita well.

Table 3. Evolution with the time of the temperature of thermal water discharged from wells.

No.	Well	Vasilescu, Nechiti 1965	ISPIF		A. Ţenu, 1975			Cohut, Paal 1985	AHR IX.2014-XI.2016
			II.1966	IV. 1966	V. 1969	IX.1969	VII.1971		
1	Balint	49	49	49	49	49	47,8	49	47,1
2	Izbuc	42	42	42	40	40	39,4		37,5
3	4011	49			49	49	48	49,5	46,2
4	4012	39						39	40,3
6	4003				45	45	43,6	45	42,4
8	4087							42	39,5

3. Considerations regarding the interference test of 1984

The processing of the row of precipitations fallen in Pădurea Craiului Mountains and Bihor Mountains and of the piezometric surface levels of the thermal aquifer in Felix-1 Mai area indicated that the aquifer is supplied from this area, the magnitude of the aquifer level fluctuation being directly related to the precipitation regime. On the other hand, the thermal water exploitation generates significant unevenness of these surfaces, the piezometric level representing the difference between the contributions made by the precipitations and the magnitude of these exploitations.

After the discovery of the Triassic thermal aquifer from Oradea, the investigations were focused on the clarification of the existence or non-existence of the hydrodynamic relations with the Lower Cretaceous aquifer from Felix -1 Mai, the supply route and heating method of the two aquifers.

In order to verify the hypothesis regarding the presence of a hydrodynamic connection between Oradea and Felix-1 Mai reservoirs, in 1984 an interference test was conducted consisting in the closure, on 27 August, of all the wells from Oradea zone for 28 days and in the monitoring of the flow-rates of the sources from Felix-1 Mai (Cohut & Paal 1985). Before the test period, the thermal water was pumped from the wells of Oradea at a flow rate of 93,7 l/s, whereas in May–June 1984, the flow rate was reduced by 55 l/s. At the end of September 1984 an increase by 35 l/s (about 20%) of the delivery potential of the sources which discharge the Lower Cretaceous aquifer of Felix-1 Mai was recorded, this increase being explained by the authors as an effect of the interference with the Triassic collector of Oradea (Fig. 22).

Reviewing the rainfall data recorded in the mountain zones contiguous to Felix-1 Mai resorts during the test performance of 1984, a similitude was found with those of the January–February 2016 period when heavy precipitations determined the increase of the thermal aquifer level, implicitly of the flow-rates discharged

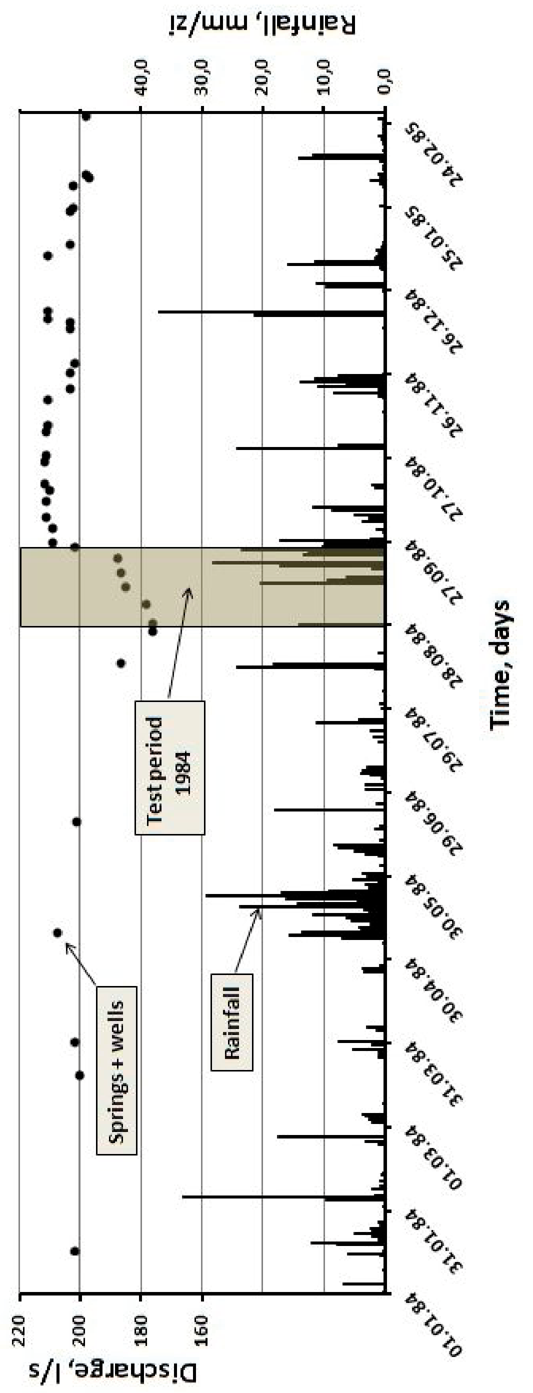


Figure 22. Evolution of the cumulated flow-rate of sources from Felix -1 Mai area and of precipitations fallen at Luncasprie in 1984

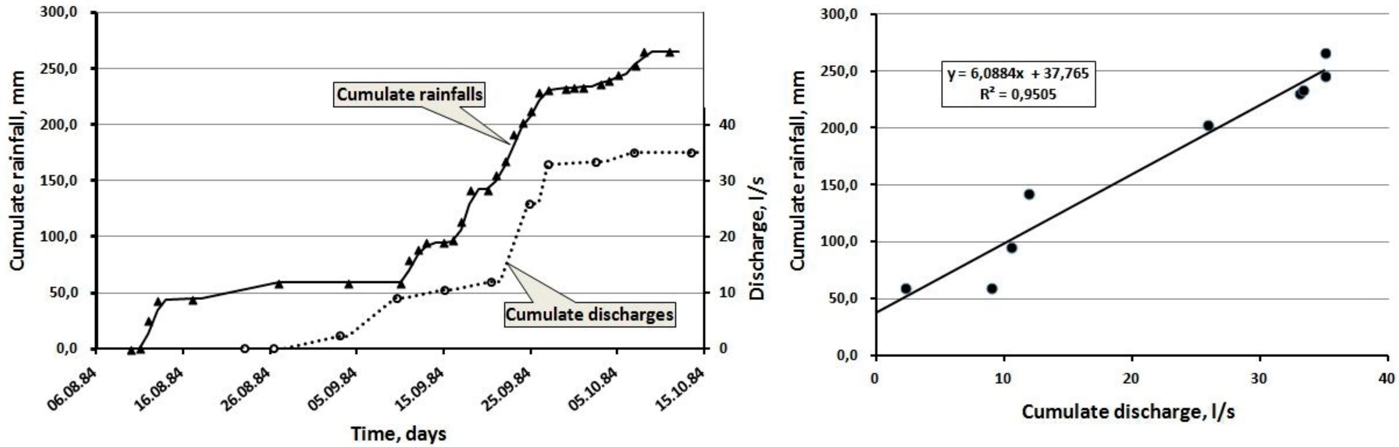


Figure 23. Distribution in time of the precipitations cumulated at Luncasprie and the growth of flow-rate of thermal water sources throughout the test of interference in 1984. To the right the correlation between the mentioned values rows is shown.

from it. In September 1984 at Luncasprie the precipitations totallized 174,4 mm (Fig. 22), the increase curve of the flow-rates of the thermal waters indicating a trend similar to the curve of the cumulated values of the precipitations (Fig. 23, left), and the correlation between the two rows of values having a high reliability (Fig. 23, right).

The increase of the flow-rates of the sources from Felix–1 Mai during the period when the wells exploitation from Oradea stopped can be explained by the high values of precipitations fallen in the mountain area, thus the interference with the boreholes from Oradea is not sustained in this case.

The results of the test conducted in 1984 together with the information offered by the isotopic determinations presented by Ţenu (1975) constituted the basis of the hypothesis issued in relation with the supplying zones, heating and discharging zones of Oradea–Felix–1 Mai thermal aquifer waters (Ţenu 1981, 2015; Cohut 1986, 2013; Paal 2013), summarized by Paal în 2013 as follows: „The aquifer of Băile Felix-1Mai represents the natural area of discharge of the hydrothermal convective system developed in the Triassic rocks from Oradea sub-soil".

The find of the Galbena fracture system playing the part of a regional dra-in for supplying cold waters to the thermal aquifer (Orăşeanu 2015) introduced a new component and implicitly new interpretations regarding its supply zone (Ţenu 2016).

Considering the particular importance of the clarification of the genesis of thermal waters of Oradea–Felix–1 Mai area for their reasonable exploitation it is necessary to do again the test under the current technical conditions of monitoring the pressure and flow-rates values.

Conclusions

The hydrogeological field investigations conducted in Felix–1 Mai area by the Romanian Association of Hydrogeologists between September 2014 – November 2016, by introducing pressure and temperature sensors in most of the wells with thermal water, involve new contributions to the knowledge on the dynamics of the piezometric surface and on the temperature distribution within the thermal aquifer area. The thermal aquifer is located in Lower Cretaceous karstic and fissured limestones. The calcareous mudstones and Sarmatian–Pliocene deposits cover the limestones providing a confined status to the thermal aquifer. All the wells drilled in the reservoir are in a hydraulic connection and the aquifer is a unique one.

The presence of the thermal aquifer was initially suggested by Balint spring of Felix resort and the bunch of springs from Peţa stream and further on, by Balint well, drilled in 1885. The exploitation wells drilled between 1962-1990, all with free overflow, determined the decrease of the piezometric level of the aquifer, the decline of the flow-rates of the sources and the drying out of most springs from Peţa stream (Cohut & Paal 1985). The drilling of new holes resulted in the continuation of the descending trend of the piezometric surface, an event enhanced between 2014-2015 by the rainfalls deficiency and revealed by the dramatic decrease of Ochiul Mare lake level.

During the study period the movement of the aquifer piezometric surface of Felix -1 Mai area is wave-like with an amplitude of about 2,5 m and a periodicity of about one year. The maximum levels occured between May–June 2015, while the minimum ones in December 2015–January 2016, their position being directed by the extension of the hydrological cycles. The thermal aquifer is supplied from Pădurea Craiului and Bihor Mountains, seasonal distribution of the precipitations producing fluctuations in the level of the underground waters within the supplying zones, reflected by the pressure waves recorded in the wells.

The transit of cold underground waters to the thermal reservoir is mainly carried out through the regional drain represented by the Galbena fracture system (Orăşeanu 2015). The average transit duration of the underground waters between the watersheds drained underground by the Galbena system and the thermal aquifer reached minimum 2 months for the watershed of Crişu Pietros stream (Orăşeanu 2016).

The oscillation of the thermal aquifer surface has a complexe shape and is influenced by natural factors, quantity and time distribution of precipitations and by anthropic factors, such as the volume of thermal water extractions. Each production well produces pointwise unevenness of the piezometric surface, an unevenness rapidly transmitted and dimmed or blurred in the whole aquifer area. The aquifer is of fissure – karstic type, heterogenous and discontinue, with drainage axes oriented along the fissure system.

The fluctuations of the level of Ochiul Mare lake water reflect the fluctuations of the thermal aquifer level to which it is connected through a fissure/karstic cavity continued towards the surface by a discontinuity of the deposits clogged with pervious detritus. In the Quaternary - Pliocene deposits contiguous to the lake, a phreatic aquifer is located, in supplying – drainage permanent relation with the lake.

To know the level of the thermal aquifer within the lake perimeter a piezometer hole of 70 m deep was drilled at 42 m West from the lake center.

The minimum levels of water in Ochiul Mare lake were recorded in December 2015. The precipitations fallen in January and February 2016 in Pădurea Craiului and Bihor Mountains determined the increase of the thermal aquifer level and implicitly of the water level in Ochiul Mare lake overflowing in the surface flow. The water level in the lake reached the maximum value in March 2016 and then a slow decrease was noticed.

The increase of the thermal aquifer level was a result of the rains fallen at the beginning of 2016, which determined the actuation of Ochiul Pompei and Frederich springs and the increase of the water level in the catching basins of ”*Rana dalmatina”* and Balint springs.

The temperature of the thermal water extracted from the drill holes indicates a significant variation. The water with the highest temperature is provided by the Balint (47.1 ^{O}C) and 4011 (46.2 ^{O}C) wells, the temperatures radially decreasing, with minimum values found to the East end of 1 Mai zone. For the wells where pumping operation lasted longer, a slow increase in time of the water temperature is noticed for those situated along the 4003-Balint-4087-Aqua President alignment (considered as the main ascending way of thermal waters towards the surface), and a slow decrease for those situated in the periphery zones.

The increase of the source flow-rates discharging the Lower Cretaceous aquifer of Felix -1 Mai area interpreted within the interference test in 1984 as being caused by the the fact that the exploitation of the Triassic aquifer of Oradea was stopped (Cohut & Paal 1985) can be also supported by the large contributions of the precipitations fallen in the Eastern contiguous mountain zones, an event similar to that monitored by us at the beginning of 2016. Considering the particular importance of the clarification of the genesis of the thermal waters from the area for their reasonable explotation, a reprise of the interference test in Oradea–Felix–1 Mai is needed under the current technical conditions of pressure and flow-rate monitoring.

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