HEAD AND TEMPERATURE CHANGES INDUCED BY EARTH-TIDE IN FELIX - 1 MAI – ORADEA THERMAL AQUIFER (BIHOR, ROMANIA)

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Abstract: Head of karstic confined thermal aquifer in Felix-1 Mai and Oradea areas present oscillations of up to 20 cm generated by the earth – tides. Their main components were identified by processing of the time hourly series of the piezometric surface levels. The temperature series values depict harmonic frequencies too. The shape and amplitude of the harmonic oscillations is strongly altered by the unevenness of the piezometric surface generated by the exploitation of the aquifers.

Key words: Earth-tide, piezometric surface, thermal aquifer, Felix- 1 Mai - Oradea, Romania

Introduction

The earth tides are produced by the gravitational attraction forces of the Moon and the Sun on the Earth. They occur as rythmic rises and falls of the earth surface.

The amplitude of the gravitational forces is periodical with the time, like the movement of the celestial bodies which it generates. This results in the presence of a high tidal potential, the earth surface oscillations forming a sum of sinusoids (harmonic) with different frequencies and phases called tidal constituents or components, (Agnew, 2005). The frequency of the earth tides is identical for the whole terrestrial globe, but their amplitude and phase being specific to each place on the Earth. Five tidal components (M2, S2, N2, K1 and O1) totalize 95% of the tidal potential (Hsieh et al, 1988, Melchior, 1964, table 1).

The oscillation of the Earth induced by tides presents components with a period of almost 12 hours highlighting the semi-diurnal character. They are mainly lunar (M2 and N2).

The gravitational attraction forces exercised on the Earth's crust show varyable rythmic intensities and produce fluctuations of the water pressure in the pores and fissures of the aquifers represented by variations of the levels/flow-rates in wells, (Merritt, 2004).

Similar short-term oscillations of the aquifer surfaces are also produced by the daily cyclic variations of the atmospheric pressure, (Spane, 2002).

Table 1. Harmonic components of tides, after Wilhelm et al., 1997, Merritt, 2004 and NOAA Tides Online. (Tva-tipical vertical amplitude; Cr- coefficient ratio, m=100)

	Symbol	Angular Freq. (rad/hr)	Frequency, cycles/day	Period, (hours)	Tva, mm	Cr	Description
Semi-diurnal	M2	0,50586804	1,93227356	12,420602	108	100	Main lunar semidiurnal
	S2	0,52359878	2,0	12,0	25,05	46,6	Main solar semidiurnal
	N2	0,49636693	1,89598199	12,658348	10,31	19,2	Lunar elliptic
	K2	0,5250322	2,0055152	11,967	6,082	11,97	Solar-lunar semidiurnal
Diurnal	K1	0,26251618	1,00273794	23,934469	32,01	23,93	Lunar-solar diurnal
	O1	0,24335189	0,92953574	25,381934	22,05	25,82	Main lunar diurnal
	P1	0,2610825	0,9972575	24,066	10,36	25,0	Main lunar diurnal

Thermal Reservoir

The thermal water reservoir of Felix-1 Mai, is situated in the Western side of Apuseni Mountains at the crossing point of Galbena crustal faults system with the fracture system along which Panonic Basin subsidence occurred (I. ORĂŞEANU, 2015, 2016). The thermal groundwater are hosted in Lower Cretaceous (Lower Aptian - Neocomian) fissured and karstified limestones covered locally by calcareous mudstones (Aptian) and by Pliocene sandstones and sands of 20-128m thick over the entire area. Sarmatian sandy conglomerates are present in the lowered compartments.

The thermal aquifer is confined and opened by wells up to depths of 25-650m. The water temperature is ranging between 32,1- 47,1^{o}C. The waters are ascensional through the wells and the piezometric level is situated close to the topographic surface (average level 155m). In some wells the aquifer is arthesian. The aquifer is of fissure – karstic type with drainage axes along the fracture planes. It has high transmissivity, the drawdowns of the piezometric surface produced by the pumping wells are rapidly transmitted and blurred in the whole aquifer mass.

In the Lower Triassic dolomites and limestones of Oradea town area there is located a hyperthermal aquifer opened through several wells and exploited to be used for heating the dwellings. The aquifer is intercepted at an average depth of 2,000 m while its hydrodynamic relations with the Upper Cretaceous aquifer from Felix-1 Mai are not entirely clarified.

Water level monitoring

Between 2014-2017 the Romanian Association of Hydrogeologists conducted studies within Felix -1 Mai zone funded by the National Agency for Mineral Resources, the water level monitoring constituting a part of this program.

The piezometric surface of the thermal aquifer of Felix-1 Mai zone depicts a complexe dynamics generated by natural recharge – discharge hydrologic cycles and by anthropic exploitation, proceses developed on long term (I. Orășeanu, F. Malancu, 2017). The surface exibit as well hourly variations induced by the earth tides, short time fluctuations that make the object of the present paper.

The evolution of the thermal aquifer surface level was monitored by placing pressure sensors at most of the wells of Felix-1 Mai zone, in the preservation wells 1730 Cihei, 1715 Oradea and 1720 Sânandrei (Fig. 1). The records were carried out at hourly interval.

In all wells of Felix-1 Mai zone (Cretaceous collector) and from Oradea zone (Traissic collector), the short term trend of the piezometric surface show rythmic semi-diurnal oscillations with amplitudes up to 20 cm, (Fig. 2), with maximum values during the periods of New Moon and Full Moon and minimum values during the first and last quarter. Their allure is altered by the thermal water exploitation (Fig. 3).

The hourly series of the water levels were corrected to remove the barometric loading and analyzed using Fast Fourier Transform highlighting the main components of the tides, their periodicity and amplitude (Table 2).

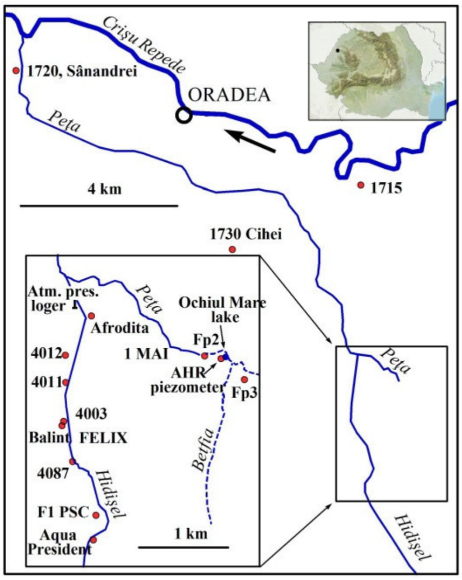


Fig. 1. Location of the monitored wells

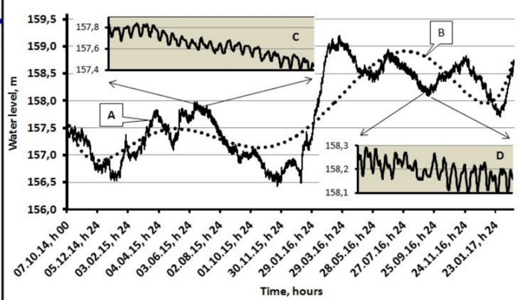


Fig. 2. Evolution of the piezometric surface level of the thermal aquifer in Afrodita well between 2014-2017, (A). Polynomial trendline, order 6, (B). Oscilation of water surface induced by tides: 10-31.07.2015 period, (C) and 01-16.09.2016 period, (D).

The atmospheric pressure was monitored with a sensor (absolute gauge transducer) located in 1 Mai resort. Its density spectrum for a 2 year period indicate two maximum values with periodicities of 24,016 and 12 hours attributed to the solar components S1 and S2, (table 2). The components of the atmospheric pressure S1 and S2 have frequencies identical with K1 and S2 components of earth tides.

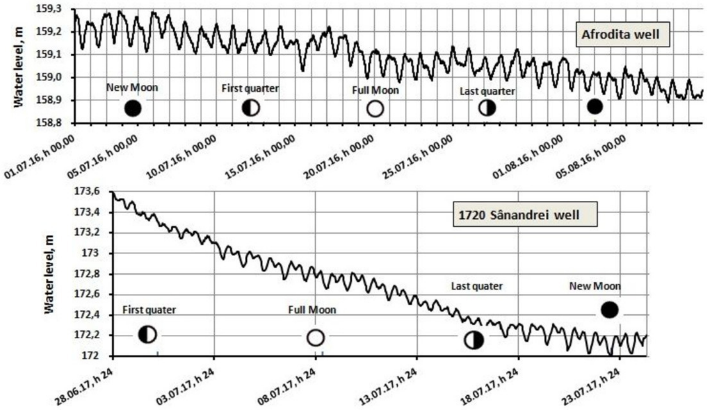


Fig. 3. Evolution of piezometric level in Afrodita and in 1720 Sânandrei wells. The amplitude of the oscillations of the level is influenced by the Moon phases

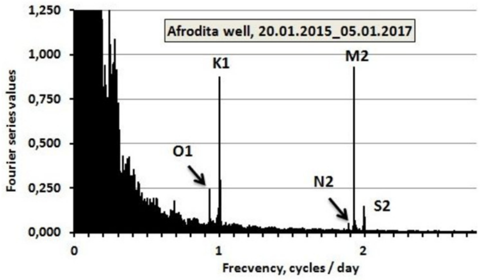
The periodograms of the harmonic frequencies elaborated for the hourly series of piezometric surface levels measured in Afrodita and Cihei wells indicate the complete view of the tide constituents being highlighted by the large value of the Fourier M2 and K1 components amplitude (table 2, fig. 4 and 5).

The tidal oscillations of the thermal aquifer surface are also visible in Ochiul Mare lake which is connected to it through a fissure providing a permanent recharge – drainage relationship with the aquifer (table 2). It represents a piezometer of the thermal aquifer.

Tablel 2. Principal tide constituents of Felix-1 Mai-Oradea thermal aquifer head.

Site	Symbol	Angular freq. (rad/hr)	Frequency, (cycles/day)	Period (hours)	Ampl.
Baro. pres. (20.01.2015-28.01.2017)	S1	0,26162214	0,999333777	24,016	1567,372
		0,26197664	1,000917508	23,978	767,608
	S2	0,52359878	2,00000000	12,000	1699,576
Afrodita well (20.01.2015-05.01.2017)	M2	0,50581250	1,93205603	12,422	0,933
		0,50500000	1,930657228	12,431	0,358
	K1	0,26204304	1,000917508	23,978	0,877
		0,26240851	1,002338791	23,944	0,629
		0,26167756	0,999541877	24,011	0,620
	O1	0,24376946	0,931134821	25,775	0,244
	S2	0,52372060	2,000500125	11,997	0,150
	N2	0,49631024	1,895734597	12,660	0,054
1730 Cihei well (20.01.2015-05.01.2017)	M2	0,50584223	1,932211577	12,421	2,220
	K1	0,26257459	1,002967111	23,929	0,981
	S2	0,52374504	2,000500125	11,997	0,570
	O1	0,24326764	0,92922410	25,828	0,395
	N2	0,49636427	1,89597184	12,658	0,072
Afrodita well (1-27.12.2014)	K1	0,26200000	1,00000000	24,000	0,042
	M2	0,50400000	1,92585460	12,462	0,048

Site	Symbol	Angular freq. (rad/hr)	Frequency, (cycles/day)	Period (hours)	Ampl.
AHR Piezometre (17.05.2015-03.08.2016)	K1	0,26253852	1,002823264	23,932	3,074
		0,26194721	1,000564653	23,986	1,764
	M2	0,50556404	1,931112366	12,428	0,723
		0,50615534	1,933370977	12,414	0,813
	S2	0,52364792	2,000187705	11,999	0,233
		0,52330312	1,998870695	12,007	0,195
Ochiul Mare lake (11.09.2014-21.04.2016)	K1	0,26275712	1,003658274	23,913	3,233
		0,26185573	1,000215193	23,995	2,492
		0,26230642	1,001936733	23,954	2,285
		0,26320782	1,005379815	23,872	1,599
	M2	0,50564725	1,931430211	12,426	0,318
		0,50609791	1,933151628	12,415	0,218
	S2	0,52277255	1,99684407	12,019	0,261
		0,52457522	2,00372974	11,978	0,365
1720 Sânandrei well, (22.06-25.07.2017)	K1	0,26179939	1,00000000	24,00	4756,3
	M2	0,50670849	1,93548387	12,40	9605,1
	S2	0,52359878	2,00000000	12,00	2056,8



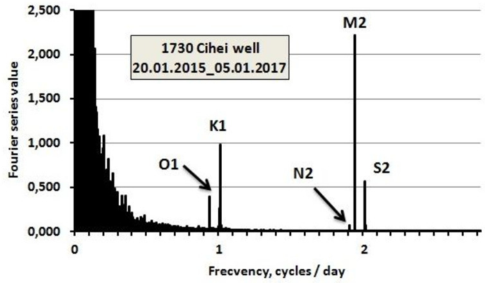


Fig. 4 and Fig. 5. Periodogram of harmonic frequencies present in head data of Afrodita and 1730 Cihei wells.

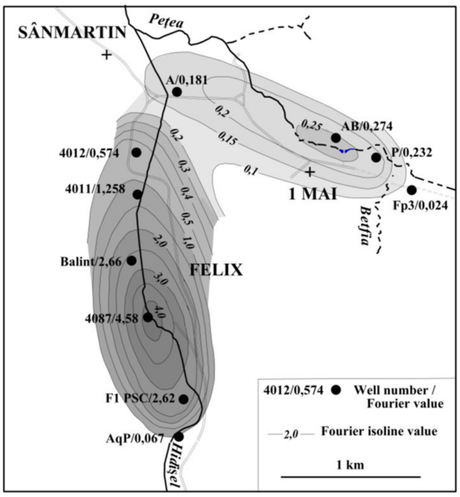


Fig. 6. Area variation of the Fourier amplitude of the M2 earth-tidal component

In fig. 6 there is shown the area variation of the Fourier amplitude of M2 tidal constituent calculated for the interval between 16.06-13.09.2015, when we took advantage of the datalogger records at all the monitored wells of Felix -1 Mai area It is revealed the presence of the maximum values along the alignment of F1 PSC-4087-Balint wells, equivalent to the maximum thermal water pathway outflow.

The exploitation of the thermal aquifer from Felix-1 Mai is carried out with varyable weekly intensities required by the number of tourists. The minimum levels of the piezometric levels are recorded in the wells at the end of each week, when the tourists inflow is maximum and the exploitation of the thermal aquifer reaches the highest values. The weekly cyclicality of the intensity of the exploitation of the wells, (Fig. 7), is well revealed by the spectrum of the harmonic components of the oscillations of the piezometric level of the thermal aquifer at Afrodita well (Fig. 8, left).

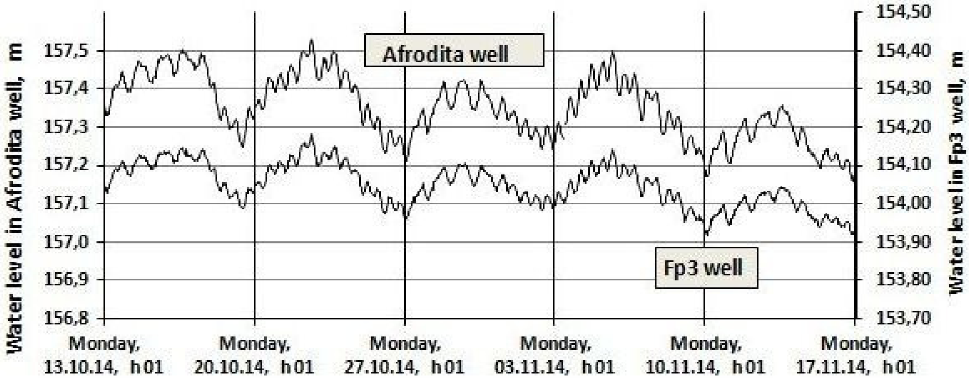


Fig. 7. Weekly evolution of the thermal aquifer level of Felix -1 Mai zone revealed at Afrodita and Fp3 wells

The piezometric surface of the thermal aquifer opened through the well 1720 Sânandrei is embroided by oscillating movement caused by the tides with amplitudes of up to 20 cm (fig. 3), the harmonic component spectrum being dominated by the mainly lunar semi-diurnal component M2 (fig. 8, right and table 2).

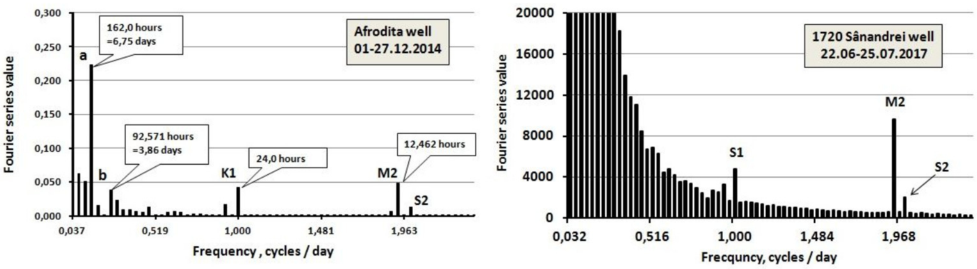


Fig 8. Periodogram of harmonic frequencies present in heads data of Afrodita and 1720 Sânandrei wells

Water temperature

The real temperature of the thermal water is recorded by sensors during the well exploitation. The intense pumping periods revealed by the lowering of the dynamic level of water in the wells are accompanied by the increase of their temperature. The fig. 9 presents the evolution of the previously mentioned parameters at well 4011. The weekly variation cuve of the temperature is „parasitized" by small semi-diurnal oscillations caused by the tides.

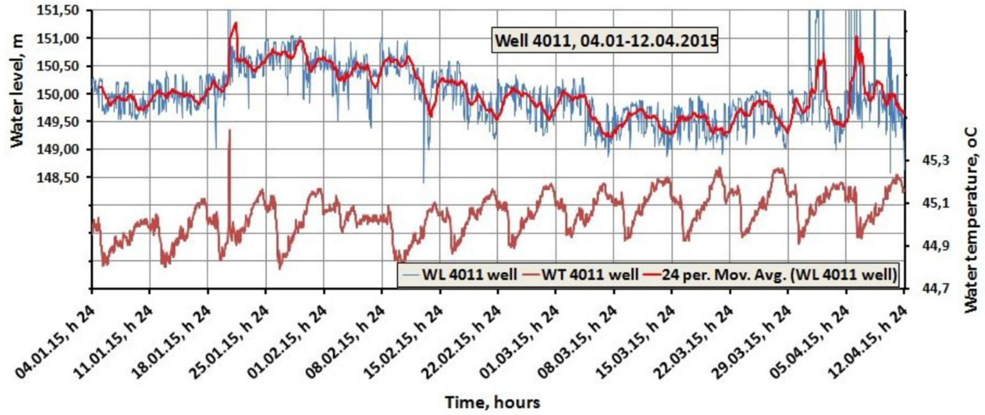


Fig. 9. Evolution of the piezometric level and temperature of the pumped water of the well 4011 during the period January –April 2015

The processing of the hourly temporary series of levels and the temperatures recorded at well 4011 throughout its exploitation provide information about the presence of some periodicities in their development. The periodicities are revealed both in the oscillations of the piezometric surface levels (fig. 10, left) and in those of the water temperature, (fig. 10, right). There are observed the weekly, semi-weekly and 8 hours periodicities generated by the exploitation program of the neighbouring wells and the presence of the tidal lunar-solar diurnal K1 and mainly solar semi-diurnal S2 and P1.

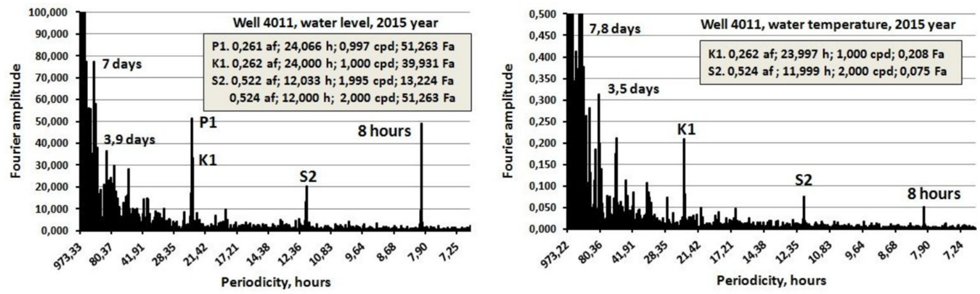


Fig. 10. Periodogram of harmonic frequencies present in the head (left) and water temperature (right) data of 4011 well in 2015 year interval.(af=angular frequency in rad/hour; h=period in hours; cpd= frequency in cycles per day; Fa=Fourier amplitude.

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