Available online at http://geology.uaic.ro/auig/
Analele Stiintifice ale Universitatii "Al. I. Cuza" din Iasi
Seria Geologie 60 (1) (2014) 19–30

AUI GEOLOGIE

Establishment of the sanitary protection zone for the 110H Faraoani well, Bacău County

Mihai Remus Şaramet[1], Mihaela Stoicescu[2], Alexandru Stoicescu[2], Viorel Ionesi[1]

[1] "Alexandru Ioan Cuza" University of Iaşi, Department of Geology, 20A Carol I Blv, 700505 Iaşi, Romania
[2] SC Hidrogeoecotech SRL, Avram Iancu, 605200 Comăneşti, Bacău, Romania

Abstract

The aim of the present study lies in the analysis of the hydrogeological aquifer that supplies the 110h Faraoani well (Bacau County), in order to determine its sanitary protection zone.

Keywords: well field, aquifer, sanitary protection zone.

Introduction

In the context of current environmental legislation on natural resources and in order to establish the best possible protection methods for these resources, particular importance is given to the provision of water sources that are both "clean" in terms of quality, and, in direct correlation, quantitatively sufficient.

Taking into account the damaging effects of pollution over both surface water bodies and groundwater, it is necessary to improve water quality by all means possible, one of them being the delineation of protection zones around the structures that tap the aquifers used as drinking water sources.

From an administrative point of view, the Faraoani village is located in the centre of Bacău County (20 km from the city of Bacău), on the terraces and hills located on the right bank of the Siret River (Fig. 1). It covers an area of 39.6 km² and has a population of about 3,900 inhabitants. Morphologically, the study area is situated in the Siret Corridor, at the boundary between the Bârlad Plateau and the Pietricica Ridge (part of the Moldavian Subcarpathians). The Siret River floodplain includes ridges, aprons, lakes, meanders and secondary riverbeds called "sireţele." The transition from the floodplain to the Moldovian Subcarpathians is marked by river terraces in which the Faraoani groundwater-tapping wells were drilled.

Stratigraphically, in the study area, there are Sarmatian deposits, followed by Quaternary deposits (Fig. 2).

Corresponding author's e-mail: saramet@uaic.ro

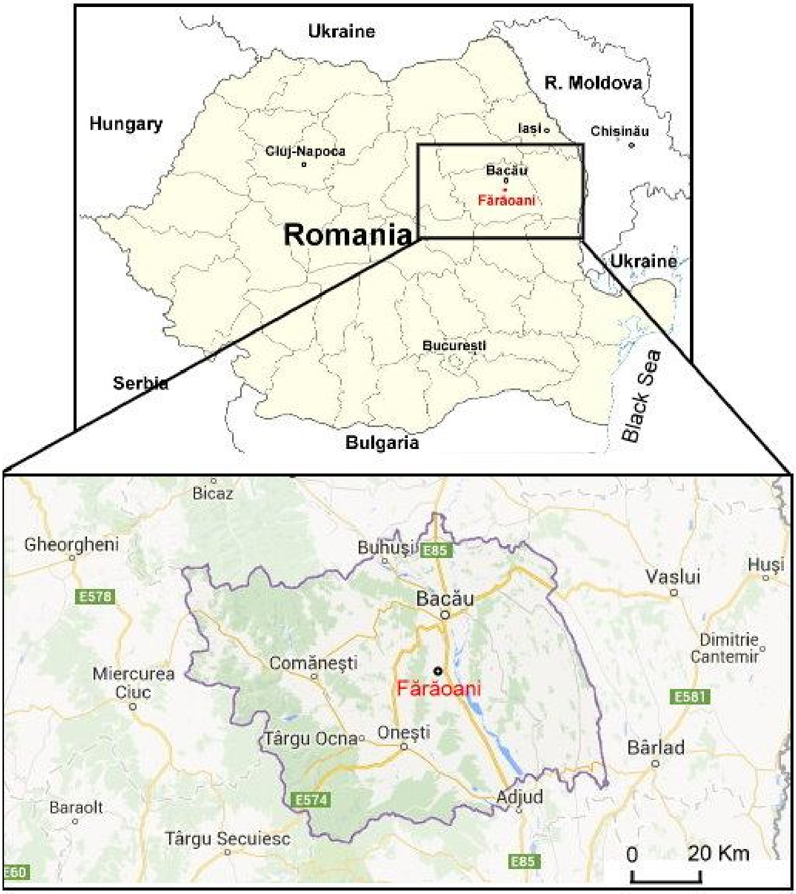


Fig. 1 Location of the Faraoani village.

According to Simionescu (1977), the Sarmatian thicknesses are estimated at 650–700 m for the Chersonian deposits, and 200 m for the Basarabian ones. Lithologically, the Sarmatian is composed of clays, silts and sands with thin intercalations of sandstone, oolitic limestone (oosparite), biosparite and arenitic limestone. Toward the west, between the platform and the Carpathian Molasse, the Sarmatian deposits accumulated in a deltaic facies, being composed of gravels and sands (Ionesi, 1994). In the Siret Valley, toward which the main watercourses in the area are directed, Pleistocene and Holocene alluvial accumulations composed of sands, gravels and loess are deposited.

From a hydrological point of view, the surface streams in the Faraoani village are the Faraoani, Clejuţa, Valea de Sus, Valea Dragă, Valea Mare and Siliştea brooks. These water bodies, which either spring or flow within the village, are tributaries of the Siret River, which, despite flowing across a short distance through the locality, is of great importance, as its waters are used for irrigation, fishing and entertainment.

The inhabitants of the village are provided with drinking water from wells that tap both deep aquifers and groundwater aquifers located on the terraces of the Siret River, near the Faraoani village (Fig. 3). Being unfit for drinking, the raw water from the 10 wells (101H, 102H, 103H, 104H, 105H, 106H, 106H-bis, 107H, 108H, and 109H) is treated before being distributed to local residents.

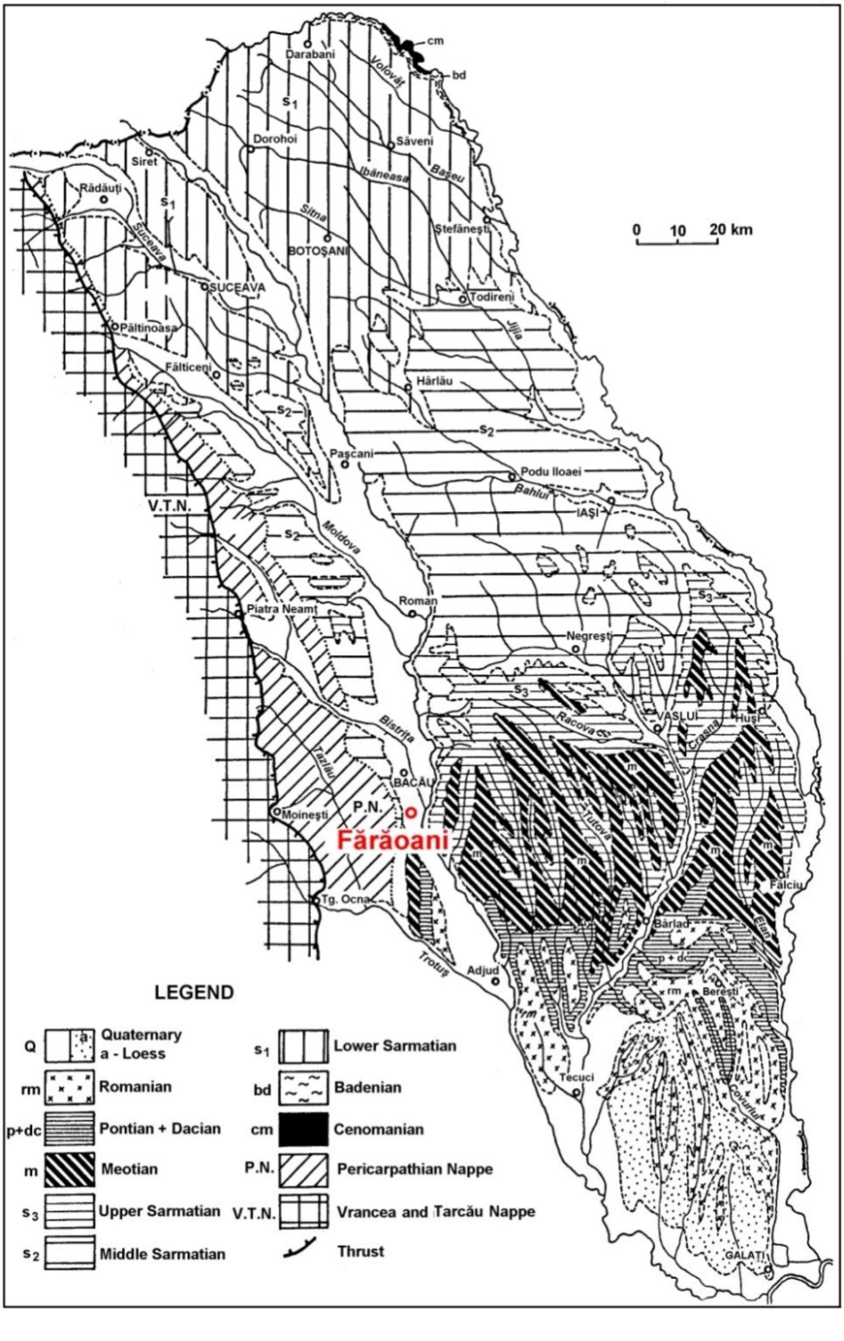


Fig. 2 Geological map of the Moldavian Plateau (after Ionesi, 1994).

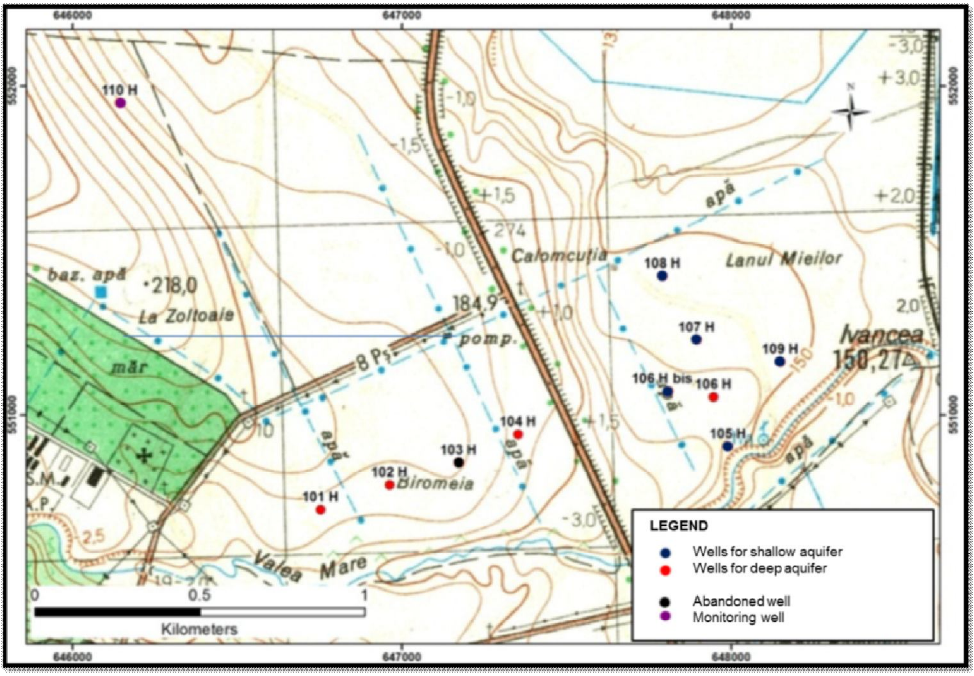


Fig. 3 The location of the Faraoani well field and the 110H well, by type of aquifer intercepted (Stoicescu et al., 2013).

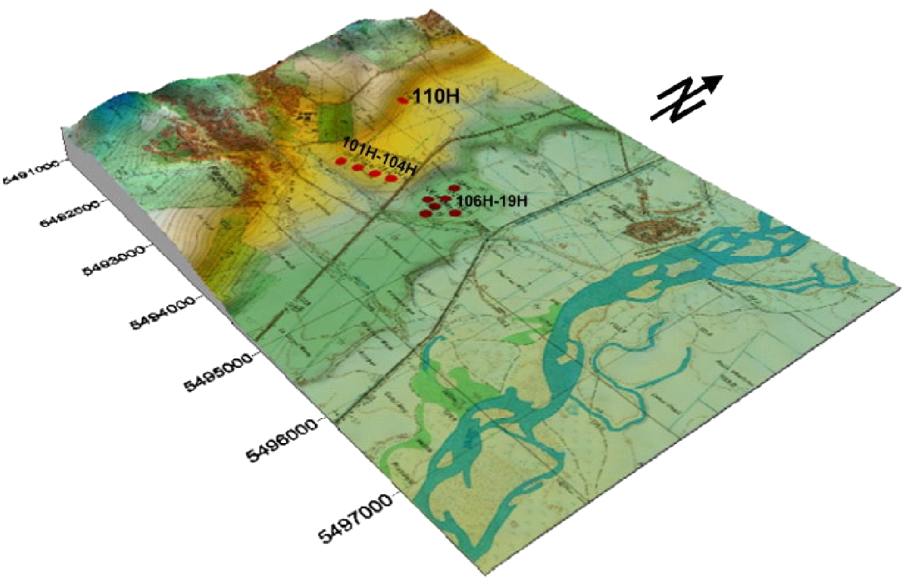


Fig. 4 Spatial projection of the morphological map with the location of the well field and the Faraoani 110H well.

The F110H well (Figs. 3 and 4) is located in the north-west, being an isolated point outside the Faraoani well field, at the contact between the Bârlad Plateau and the Sub-carpathian hills.

The well has intercepted sedimentary rock deposits typical for terrace areas (Fig. 5), represented by a sequence of sands, clays and silts. The aquifers, with a total thickness of 24 m, have been identified in the following ranges: 87.0–103.5 m, 128.0 m, and 148.0–123.5–151.0 m. The yield of the well is 1.5 l/s in artesian regime, at a hydrostatic level of 0.5 m above ground level.

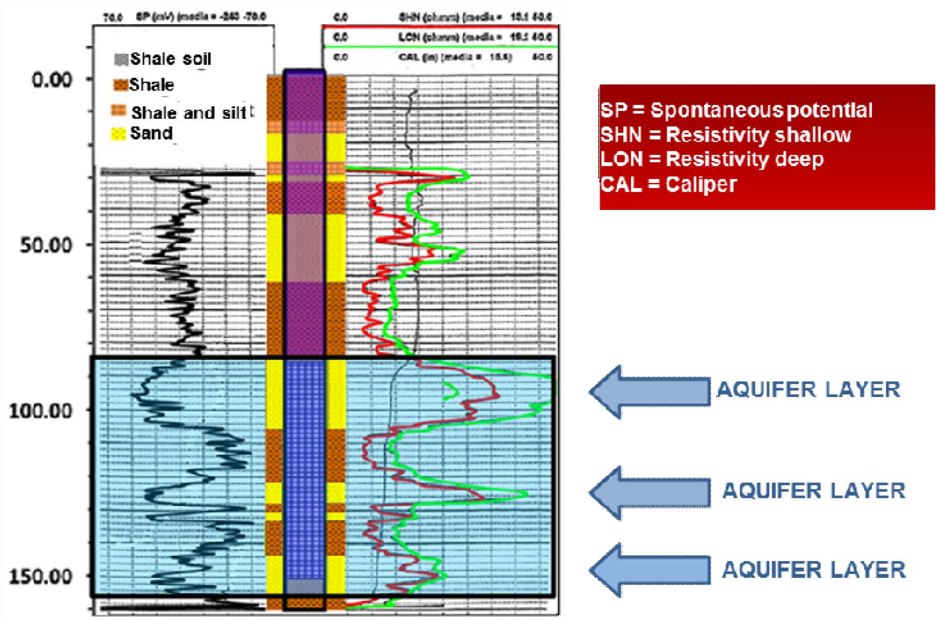


Fig. 5 110H-Faraoani well.

Based on the analysis of geophysical well-logging results, Stoicescu et al. (2013) have carried out a correlation between the lithological characteristics of the rocks intercepted by the F110H well and those of the rocks intercepted by drilling in the Faraoani well field, as shown in Figure 6.

The similarity between the 104H well and the 110H well suggests that the wells have tapped the same deep aquifers. However, since the110H well displays artesian behaviour, while the 104H well is only ascending, there is no hydrodynamic communication between them (Figs. 7 and 8).

If there were communication between the two wells, the 104H well would display the same artesian character, since it is positioned at a lower elevation. Consequently, the 110H well has features that differentiate it from the other wells of the Faraoani well field.

In order to determine the hydrogeological characteristics of the aquifer tapped by the 110H well, experimental pumping was performed in four steps with constant flow (Q_1, Q_2, Q_3 and Q_4), and the corresponding drawdown ($\mathbf{s}_{01}$, $\mathbf{s}_{02}$, $\mathbf{s}_{03}$, and $\mathbf{s}_{04}$) was recorded. The results of the experimental pumping are summarized in Table 1.

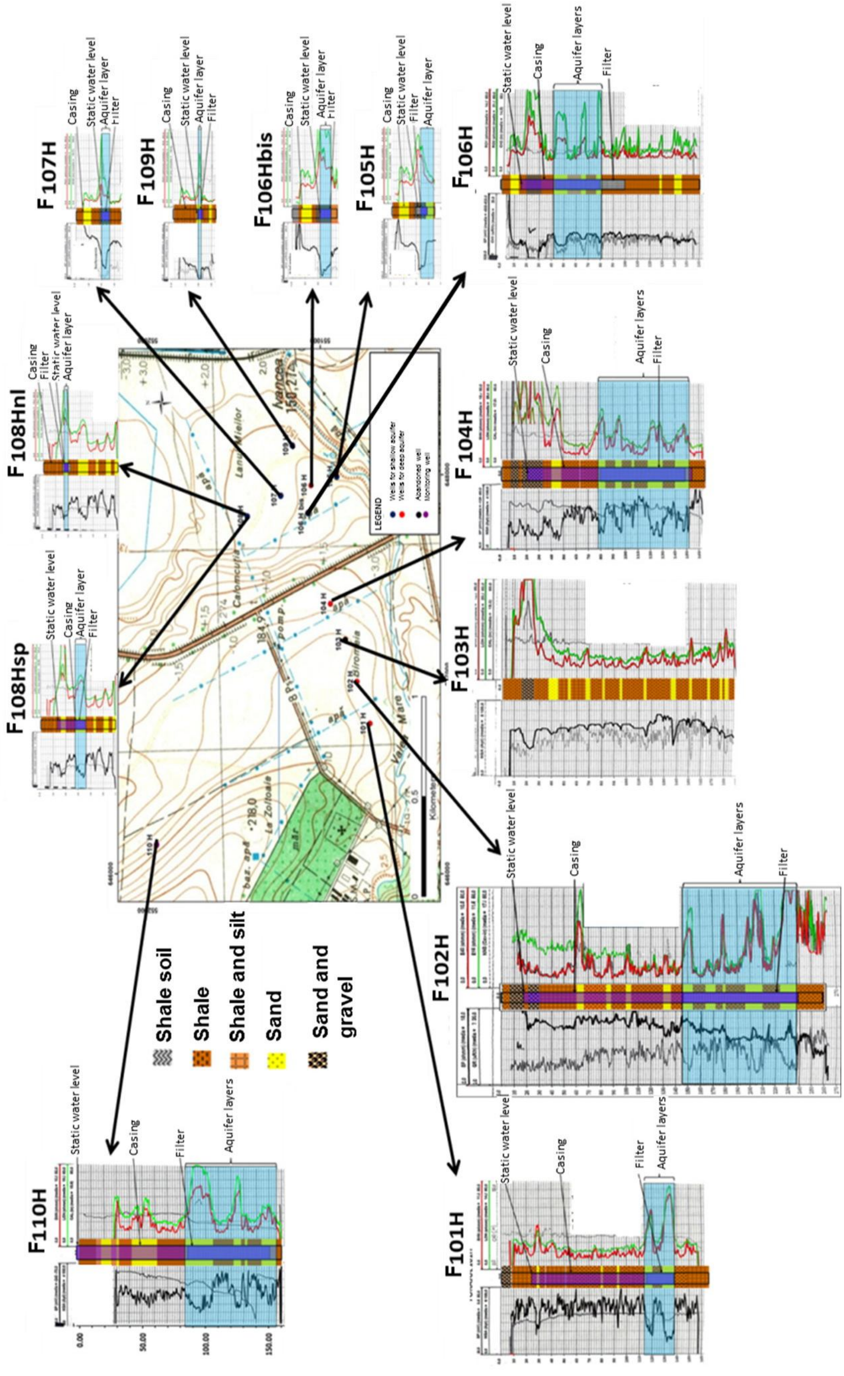


Fig. 6 Correlation between the wells from the Faraoani well field and the 110H well (Stoicescu et al., 2013).

By plotting the specific drawdown (S_{01}/Q_1, S_{02}/Q_2, S_{03}/Q_3 and S_{04}/Q_4,) according to flow (Q_1, Q_2, Q_3 and Q_4), points arranged around a straight trend line were obtained, whose analysis suggests that the aquifer is captive and under pressure (as proven by the artesian character of the well). The linear regression equation (eq. 1) is represented in Fig. 9.

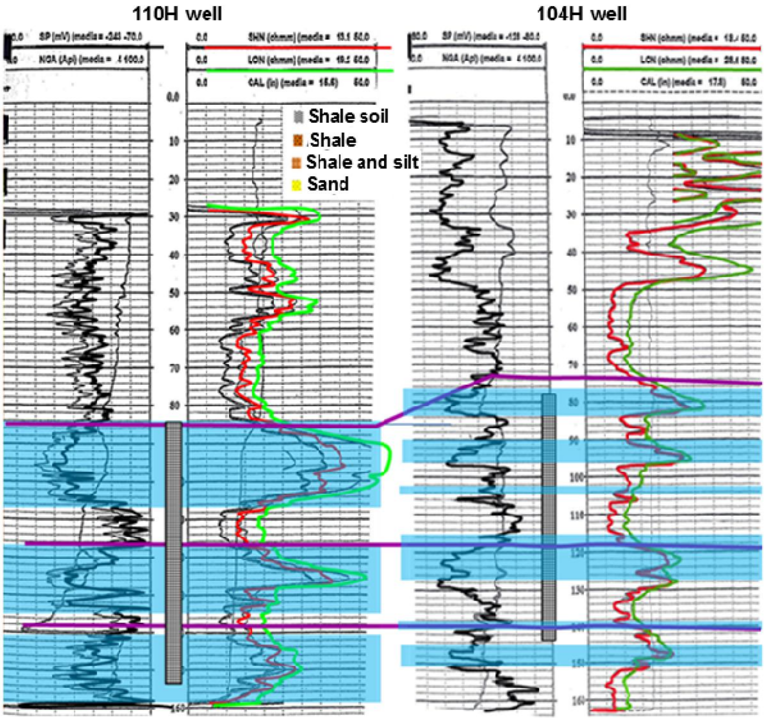


Fig. 7 Well log correlation between the 110H well and the 104H well.

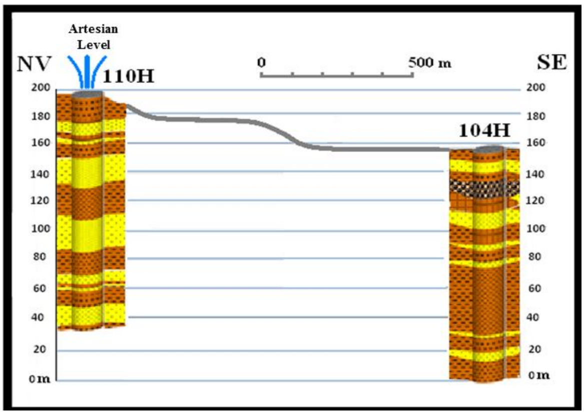


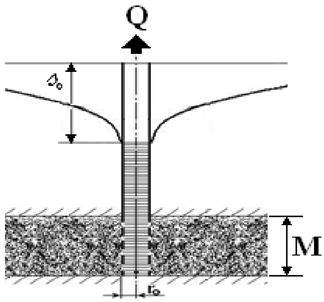
Fig. 8 Lithological column correlation between wells 110H and 104H.

$$S_0/Q = A + B \cdot Q \ \ [s/m^2] \qquad (1)$$

where:
A = 14152 is ordered in origin;
B = $4 \cdot 10^6$ – the slope of the straight line and the tangent of the angle between the straight line and the horizontal, respectively.

Tab. 1 Results of the experimental pumping from the 110H well

Test	Yield Q		Drawdown s_o	s_o/Q
—	l/s	m^3/s	m	$m/(m^3/s)$
I	0.95	0.00095	16.43	17294.74
II	1.15	0.00115	21,60	18782.61
III	1.40	0.00140	27.80	19857.14
IV	1.75	0.00175	35.70	20400.00



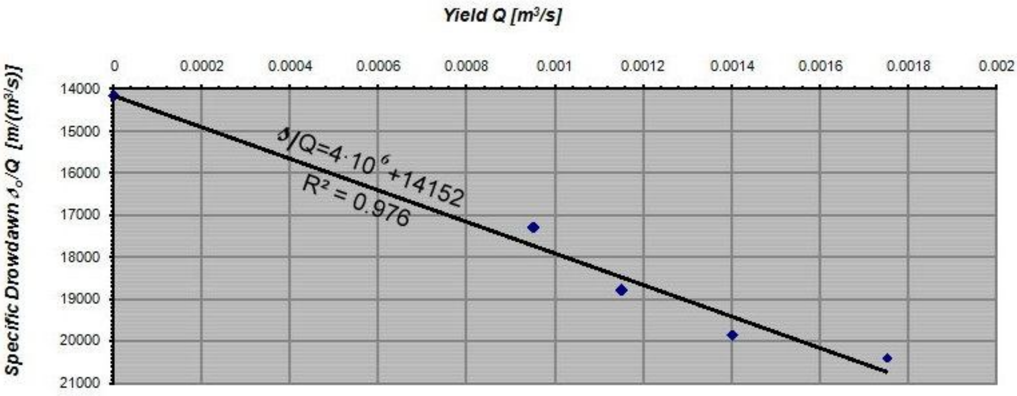


Fig. 9 Specific drawdown vs. yield for the 110H well.

Based on these values, calculations were made using the relations of Zamfirescu (1995), and then centralized in Table 2. The assumptions for the calculations were the following: captive aquifer, conservative continuous plane-radial flow, and non-linear flow rate in the proximity of the borehole.

The permeability values (k) obtained from the calculations carried out for the four pumping stages (Tab. 2) suggest a lithology of the aquifer composed of fine sands and silts, which would explain the reduced flow (even at considerable drawdown within the well). On the other hand, the flow is influenced by the presence of a zone in which the water passes from the linear flow regime (Dupuit) to a nonlinear regime of the Forchheimer type.

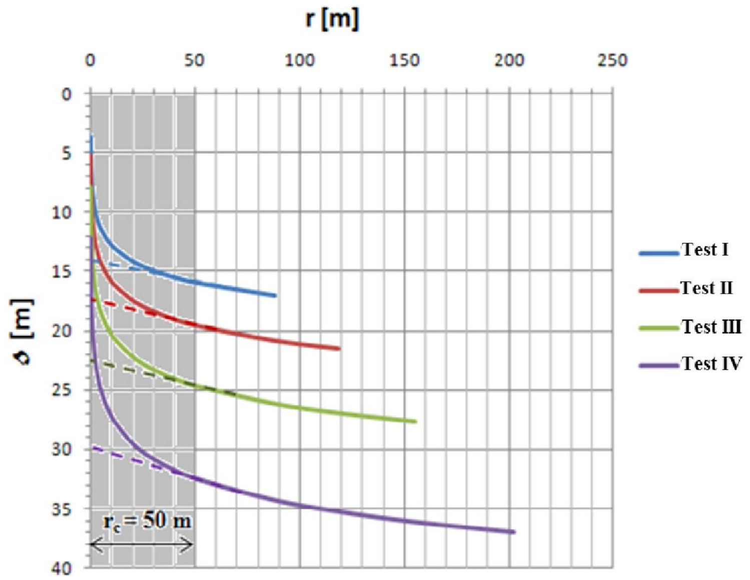


Fig. 10 Representation of drawdown variation (s) versus distance (r) from the well axis.

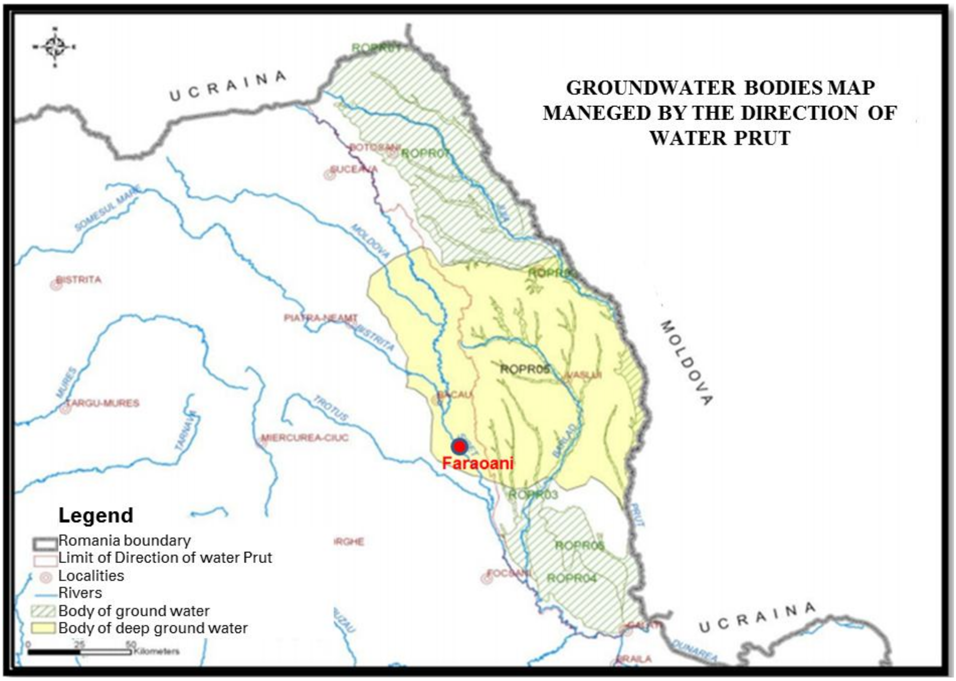


Fig. 11 Groundwater Body ROPR05 (RO-Romania, PR-Prut River, 05-order number).

This transition during flow leads to an additional loss of pressure, as reflected by the substantial drawdown within the well and flow reductions of up to 30%. In order to specify where this transition occurs, the drawdown variation was calculated by assigning different values for the distances (r) measured from the axis of the well for the four pumping stages (Table 3).

Table 2 Centralization of the hydrogeological parameters calculated

Parameter	Relation	No	S.I.	Value			
				Test I	Test II	Test III	Test IV
Permeability	$k = \dfrac{ln\frac{R}{r_0}}{2 \cdot \pi \cdot M \cdot A}$	(2)	m/s	$3.1890 \cdot 10^{-6}$	$3.3271 \cdot 10^{-6}$	$3.4541 \cdot 10^{-6}$	$3.5797 \cdot 10^{-6}$
Radius of influence	$R = 3000 \cdot s_0\sqrt{k}$	(3)	m	88.0	118.2	155.0	202.6
Transmissivity	$T = k \cdot M$	(4)	m^2/s	$7.654 \cdot 10^{-5}$	$7.985 \cdot 10^{-5}$	$8.290 \cdot 10^{-5}$	$8.591 \cdot 10^{-5}$
Additional hydraulic resistance	$\xi_0 = \dfrac{Q}{2 \cdot \pi \cdot T} \cdot \dfrac{\alpha \cdot k^2}{g \cdot r_0}$	(5)	-	1.827	2.308	2.917	3.779
Theoretical drawdown in Dupuit assumption of linearity filtering law	$s_0^0 = \dfrac{Q}{2 \cdot \pi \cdot T} \cdot ln\dfrac{R}{r_0}$	(6)	m	13.44	16.27	19.81	24.77
Supplementary drawdown in Forchheimer assumption of nonlinearity filtering law	$\Delta s_0 = \dfrac{Q}{2 \cdot \pi \cdot T} \cdot \xi_0$	(7)	m	3.61	5.29	7.84	12.25
Total drawdown	$s_0 = s_0^0 + \Delta s_0$	(8)	m	17.05	21.56	27.65	37.02
Yield calculation in the linear Darcy flow	$Q = \dfrac{2 \cdot \pi \cdot T \cdot s_0}{ln\frac{R}{r_0}}$	(9)	l/s	0.95	1.15	1.40	1.75
Yield calculation in the nonlinear flow	$Q_c = \dfrac{2 \cdot \pi \cdot T \cdot s_0}{ln\frac{R}{r_0} + \xi_0}$	(10)	l/s	0.75	0.87	1.00	1.17
Yield decreasing due to blocking up in drilling	$100 \cdot (1 - \frac{Q_c}{Q})$	(11)	%	21.2	24.5	28.4	33.1

The graphic representation of the results (Fig. 10) indicates that, regardless of the level, there are “hydraulic jumps” within the well, and the water flow transition from the linear to the nonlinear regime occurs at 50 meters (r_c = 50 m).

Summary

(i) the 110H well has tapped a deep captive aquifer of the ascending type;

(ii) the aquifer has a good degree of protection due to the thickness of the waterproof rock that caps it;

(iii) the 110H well does not communicate hydrodynamically with the other 10 wells of the Faraoani well field;

(iv) the aquifer, which has a low permeability ($3–3.6 \cdot 10^4$ cm/s), is divided into three reservoirs composed of silts and fine sands;

(v) close to the wellbore, at r_c = 50 m, the aquifer transitivity and permeability decrease substantially due to water passing from a linear flow regime to a nonlinear regime. This passage leads to a remarkable decrease in water flow (up to about 30 %);

Tab. 3 Simulation of water drawdown (**s**) at different radii (r) measured in the aquifer from the axis of the 110 well

r [m]	Drawdown **s** [m]			
	Test I	Test II	Test III	Test IV
0.098	3.61	5.29	7.84	12.25
0.100	3.66	5.35	7.91	12.33
0.200	5.03	6.94	9.77	14.58
0.300	5.83	7.87	10.86	15.89
0.400	6.40	8.53	11.93	16.83
0.500	6.84	9.04	12.23	17.55
1.000	8.21	10.63	14.10	19.80
2.000	9.58	12.21	15.96	22.04
3.000	10.38	13.14	17.05	23.36
4.000	10.95	13.80	17.82	24.29
5.000	11.39	14.31	18.42	25.01
10.000	12.76	15.90	20.29	27.26
20.000	14.13	17.49	22.15	29.51
30.000	14.93	18.42	23.24	30.82
40.000	15.50	19.08	24.01	31.76
50.000	15.94	19.59	24.61	32.48
88.000	17.05	20.89	26.13	34.31
118.200		21.56	26.92	35.27
155.000			27.65	36.15
202.600				37.02

(vi) as indicated by the water analysis report No. 6479/01.12.2005, that water from the well is not drinkable due to the presence of ammonia and manganese above the limits allowed by Law. 458/2002 on groundwater quality (amended by Law no. 311/2004 and GO no. 11/2010). It can be used only after prior treatment.

The following aspect must be stressed, as well: according to *The management plan for the Prut- Barlad hydrographic area* (Fig. 11), the deep aquifers of Faraoani belong to the ROPR05 (RO-Romania, PR -Prut, 05-order number) groundwater body, accumulated in the permeable Sarmatian rocks of the Neamt, Bacau and Vaslui counties (after Macaleţ et al, 2006). Given that a “body” is defined as a distinct volume of groundwater consisting of one or more aquifers that communicate between one another, the deep aquifer at Faraoani tapped by the 110H well cannot be regarded as being part of the water body mentioned above because, as previously mentioned, this well does not communicate hydrodynamically with other wells in the area. As a result, both the defining of a groundwater body and the inclusion of a captive deep aquifer must be carried out with caution.

In conclusion, in the case of the Faraoani 110H well, which taps a deep aquifer well isolated from the soil surface, the severe regime sanitary protection zone coincides with the restriction regime area, and the protection perimeter will form a circle, with the well as the centre and a radius of 10 m.

Notations:
A = 14152 and B = $4 \cdot 10^6$ – constants of the regression line in Fig. 9;
h – pumping water level at distance ″r″ from well;
h_0 – static water level;
H – pumping water level at the natural contour of the aquifer;
k – aquifer permeability coefficient;
M = 24 m – aquifer thickness;
NHs – hydrostatic water level;
Q – yield;
Q_C – yield in the nonlinear flow;
r – distance (radius) as measured from the axis of the borehole;
r_0 = 0.0975 m – borehole radius;
r_C – radius of nonlinear flow;
R – radius of well influence;

S – drawdown at distance r;

$\mathbf{S}_0$ – total drawdown at r_0;

$\mathbf{S}_0^0$ – theoretical drawdown in Dupuit assumption of linearity filtering law;

$\Delta\mathbf{S}_0$ – supplementary drawdown in Forchheimer assumption of nonlinearity filtering law;
T – transmissivity;
$\alpha = 4 \cdot \pi^2 \cdot M^2 \cdot g \cdot r_0 \cdot B = 8.7 \cdot 10^{10}$ – constant which takes into account the non-uniformity of flow in the aquifer;
ξ_0 – additional hydraulic resistance encountered by water at wellbore entry;
ln – natural logarithm.

Acknowledgments

The authors would like to express their gratitude toward the institutions that have kindly provided data from papers published on the topic and information on the workings of the Faraoani wells (Bacău County), namely the Siret Water Basin Administration, the Water Management System Bacău, Eng. Viorica Ignat and Dr. Petre Olariu, in particular.

References

Babskow, Al., Mălureanu, I., 1995. Geophysics, vol. II. Editura Imprimex, Ploieşti. (In Romanian).

Ionesi, L., 1994. Geology of platform units and the North Dobrogea Orogene. Editura Tehnică, Bucureşti. (In Romanian).

Macaleţ, R., Munteanu, T., Drăguşin, D., Coarnă L., Dumitraşcu G., 2006. Analysis of the Central Moldavian Plateau Sarmatian aquifer. Hidrogeologia, **7,** 33-34. (In Romanian).

Simionescu, Th.,1977. Geological survey of the Sarmatian and Meotian of Bistriţa Valley and Răcăciuni Valley (Bacău). Anuarul Inst. Geol. Geofiz., **LI**, 225–262. (In Romanian).

Stoicescu, M., Stoicescu, Al., Şaramet M., 2013. Lithostratigraphical characterization of the exploited aquifers from the Faraoani well field (Bacău County). Analele Ştiinţifice ale Universităţii "Alexandru Ioan Cuza" Iaşi, Geologie, **LIX**, 61–68.

Zamfirescu, Fl., 1995. Hydrogeology. Groundwater dynamics. Editura Universităţii Bucureşti. (In Romanian).

Zamfirescu, Fl., 1997. Basics in groundwater dynamics. Editura Didactică şi Pedagogică. (In Romanian).

*** 2000. Water Framework Directive 2000/60/EC of the European Parliament and the European Commission, European Community Official Journal.

*** 2005. Government Decision no. 930/02.09.2005 – for special norms on the character and size of sanitary protection zones and hydrogeological protection perimeters. (In Romanian).

*** Law no. 458/08.07.2002 on drinking water quality, issued by the Romanian Parliament, published in the Official Gazette, Part I, no. 552 of 29.07.2002. (In Romanian).

*** Order of the Ministry of Environment and Forests no. 1278/20.04.2011 – guidelines on the designation of sanitary protection zones and hydrogeological protection perimeters (In Romanian).