Quantitative and Qualitative Assessments of Groundwater into the Catchment of Vaslui River

GHEORGHE ROMANESCU[1,2], ELENA PAUN[3], ION SANDU[2,4*], IONUT JORA[5], EMILIAN PANAITESCU[5], OVIDIU MACHIDON[6], CRISTIAN STOLERIU[1]

[1]Alexandru Ioan Cuza University of Iasi, Faculty of Geography and Geology, Department of Geography, 20A Carol I , 700505, Iasi, Romania

[2] Alexandru Ioan Cuza University of Iasi, ARHEOINVEST - Interdisciplinary Platform, Laboratory of Scientific Investigation and Conservation Cultural Heritage, 22 Carol I Blv., Corp G, 700506, Iasi, Romania

[3] Hyperion University of Bucuresti, Faculty of History and Geography, 169 Calea Calarasilor 169, Bucharest, Romania

[4] Romanian Inventors Forum, 3 Sf. Petru Movila St., Bl. L11, Sc. A, III/3, 700089, Iasi, Romania

[5] Prut Water Headquarters, Iasi, 10 Vascauteanu Str., Iasi, Romania

[6] Moldova Regional Meteorological Centre, 10 Vascauteanu Str., Iasi, Romania

The Vaslui river, a left hand tributary of Barlad, is located in the eastern part of Romania. The monitoring of groundwaters, within water bodies, records information in view of a long term tendency evaluation, both as a result of changes in the natural conditions and as an effect of anthropic activities. The hydrographic network of Vaslui is in deficit, in regard to surface water reserves. The groundwater reserves are richer, but that is of local importance only, as they are often salinized. The main subterranean waters are accumulated in cracks and cavities of the calcareous-sedimentary complex, as well as in the sand of the interfluvial surfaces. The water body GWPRO3, specific to the hydrographic network Vaslui, is a "qualitative risk water body" and its quantity is directly influenced by the quantity of rain. The subterranean waters register a relative flow rate stability, but the reserves are scarce, compared to the rest of the country. The GWPRO5 water body is a cross-basin and cross-border one and it is used in compliance with the European principles for the exploitation of subterranean resources. The qualitatively deteriorated phreatic aquifer consists of alluvial deposits in the waterside and terraces of Vaslui, but also at the bottom of the loess deposits within the interfluvial network. From a hydrological point of view, the Vaslui basin is of low importance. As it is geographically located in the poorest department of the EU, that area is under intense study. Therefore, the hydro-geologic studies represented a priority, in order to emphasize the water reserves. Due to their high flow rate and proper quality, the deep groundwaters are exploited and they can supply the necessary water for certain urban and rural areas.

Keywords: groundwater exploration, groundwater management, injection wells, Romania, water supply

A precise survey of the groundwater network of Romania, and implicitly of the Vaslui network, was done relatively late, after 1970, during the development of the hydro-geological state network, managed by the Waters Office Prut Iasi, within the National Administration "Romanian Waters". Based on the field measurements and the laboratory results obtained, they tried to synthesize the data in regard to the resources and quality of groundwaters of the hydrographic network Vaslui, an area with a serious deficit of surface waters. That was the first such study in Romania, based on individual and institutional observations. The relatively long list of observations and measurements (over a period of 25 - 35 years) led to a conclusive analysis in regard to the groundwaters and could fulfill the numerous requests for capturing new sources of water, superior in quality to the existing ones.

Aside from the general study made by University of Iasi on the phreatic and deep aquifer of the hydrographic basin Barlad, the present study analyzes for the first time, in detail, the characteristics (quantitative and qualitative) of the groundwaters in the Vaslui hydrographic network. Such a study was imperious to the field of agriculture, as the Vaslui county became a real wheat source for Romania, due to the state of the art methods used in agriculture, in compliance with the European requirements. Thus, the additional necessary water can be supplied from underground reserves, or from areas with surplus water supply (the Oriental Carpathians). Unfortunately, the surface sources that supply in excess are at a long distance and involve additional costs. Recent works, in regard to the quantity and quality of groundwaters in Romania and in other regions of the world, were published in various renown international publications [1-13].

Geographical location and borders

The Vaslui river, a left hand tributary of Barlad, is located in the eastern part of Romania. The surface of the Vaslui hydrographic basin represents 9.58% of that of Barlad, which has the largest and longest basin of all the tributaries of Siret (fig. 1). The amount of water supplied is not proportional to the surface of the basin, as it is a typical forest-steppe river, with a very low flow rate, mainly due to the physico-geographical conditions. It wells out under the Repedea-Paun plateau, at an altitude of 340m and merges into the Bârlad river at an altitude of approximately 83m.

The hydrographic basin of the Vaslui river is bordered to the west by the basins of the Rebricea and that of the Telejna rivers and to the east by that of the Crasna river. To the north, the area under study is bordered by the hydrographic basins of the rivers Bahlui and Jijia. Morphologically, the Vaslui hydrographic basin is situated

* *email: sandu_i03@yahoo.com*

Fig. 1. The position of the Vaslui hydrographic basin in Romania

in the central-eastern area of the Moldavian Plateau, more precisely, in the central north-eastern part of the Central Moldavian Plateau, in the Barlad Plateau.

Mathematically, the 47°05'57" parallel, northern latitude, marks the most northern point of the basin (27°40'13" eastern longitude), in the Paun hill (407.2m) and that of 46°31'45" indicates the most southern point of the basin, situated in the confluence area (27°48'34" eastern longitude). The eastern extreme point is represented by the 27°52'30" meridian, in Dealul Schitului (371.1m) (46°52'05" northern latitude) and the western extreme is the 27°34'59" meridian, in Dealul Schitului (342.0m) (47°00'42" northern latitude). From a social-administrative point of view the Vaslui hydrographic basin stretches over an area belonging to the Iasi and Vaslui counties.

Methodology

The monitoring of groundwaters, within water bodies, records information in view of a long term tendency evaluation, both as a result of changes in the natural conditions and as an effect of anthropic activities. During this stage, the supervision monitoring of the groundwaters must provide enough information to allow a classification of groundwaters, both quantitatively and qualitatively. An important problem of quantitative and qualitative monitoring is the periodic testing of all aspects of the deep probes in the hydrologic state network. Due to technical difficulties, which involve complex equipment and high costs, those probes were only pumped (hydro-geologically tested) during their initial setup. Monitoring their behaviour in time only involved the fluctuations of the hydrostatic levels. Thus, the water samples, which were taken at random, have no relevance, because they were taken only from the upper side of the probes, from waters that had been stagnant for years.

The extension and intensification of water exploitations in deep aquifers may cause significant modifications, especially in quantity, in the natural development of groundwaters. The tap sizing and proper calculation of optimal exploitation flow rates can only be done by exact knowledge of the behaviour in time of the source. All the arguments above determined the relevant authorities to start a program of experimental pumping for the deep probes. Those experimental pumping procedures, which are actually groundwaters flow rate measurements, will be followed by water sampling for physico-chemical and bacteriologic analysis, which should prove relevant under the current conditions.

The groundwater monitoring of the Vaslui hydrographic basin consisted of "classical" measurements in the hydro-geological wells network. The measurements were:

- measurements of the piezometric level at intervals of 3, 6 and 15 days for the phreatic waters and quarterly for deep groundwaters;
- periodic flow rate measurements at the experimental pumps;
- taking samples to determine the physico-chemical properties of groundwaters and also during the experimental pumping procedures.

According to Frame Directive 60/2000/E.C., the water bodies in the Vaslui hydrographic basin were identified based on geologic criteria, hydro-dynamics and their quantitative and qualitative state. In parallel with the "classical" monitoring, starting in 2006, there also functions the system of the Frame Directive 60/2000/E.C. Starting in 2005 the low depth hydro-geological probes were equipped with automatic level and temperature measurement stations.

Results and discussions

The groundwater bodies and their main characteristics

The identification and delimitation of the groundwater bodies in the Vaslui hydrographic basin was done in compliance with the Frame Directive 60/2000/E.C. In the Vaslui hydrographic basin they identified and delimited 2 groundwater bodies, named as follows:

- GWPR03 - the riverside and terraces of Barlad and its tributaries (including Vaslui), of a phreatic type.
- GWPR05 - The Central Moldavian Plateau, an underground cross-basin and cross-border water body (fig. 2).

The code of the groundwater bodies has the following structure: GW = groundwaters; PR = the Prut hydrographic basin; 03 = the number of the water body within the Prut hydrographic basin. Even though the Barlad river belongs to the Siret hydrographic basin, the code contains the name of the Prut hydrographic basin due to the reference of the Barlad hydrographic basin to the Prut-Barlad Basin Water Administration. GWPRO3 is a quaternary groundwater body of the porous-permeable type, which developed in the riversides and terraces of Barlad (including Vaslui) and of its tributaries. It represents the main phreatic water reserve of the Vaslui hydrographic basin.

The aquiferous deposits consist of sands with rare gravel elements, with clay insertions. The permeable deposits are 2 - 5m thick, not thicker than 10m. The hydrostatic level can be reached, on average, at a depth of 3m. The phreatic aquifer is supplied by precipitation with an infiltration of 15 - 63mm/year. The surface of the entire water body in the Barlad basin is $1033km^2$.

GWPRO5 is a groundwater body of the porous-permeable type, which stored in Sarmatian age deposits with a cross-basin and cross-border character. That water

Fig. 2. The groundwater bodies belong to the Prut-Barlad Basinal Water Administration and the phreatic water quality monitoring

body stretches over the territories of Neamt, Bacau and Vaslui counties and over to The Republic of Moldova.

The Sarmatian deposits are disposed concordantly over the Volhinian deposits, which spread over the northern part of the Moldavian Platform. The first porous-permeable interpolations within that body occur at a depth of 40 - 50m and the last at 250m. The surface of the deep groundwater body is 12531km^2. The probing drills made in that water body investigated all the aquifer networks encountered and the flow rates recorded during experimental injection represent the cumulated value of the aquiferous possibilities in different hydro-structural units.

More than half of the deep water body surface is on Romanian territory, hence the good exploitation perspective. The water circulation in the aquifer is relatively good, because the entire pack of rocks is porous and the covering layers are thin. It is known that phreatic waters have no pressure, while the deep groundwaters do (table 1).

The use of water in various domains is relatively different for the two water bodies (table 2) The main polluting agents are the usual and they affect groundwaters in different degrees: phreatic waters are more affected than groundwaters. At the same time, phreatic waters may be subject to a qualitative risk. The groundwaters of the Vaslui basin (phreatic and deep) have hydro-geologic parameters that allow limited exploitation (table 3).

Table 1
CHARACTERISTICS OF DEEP GROUNDWATER AND PHREATIC BODIES (PART I)

Code/name	Area (km^2)	Geologic/ hydro-geologic characterization		
		Type	Under Pressure	Covering layers (m)
1	2	3	4	5
ROPR03 – Riversides and terraces of Barlad and its tributaries (including Vaslui)	1,033	P	Yes	2.0 – 5.0
ROPR05 – Central Moldavian Plateau (including Vaslui)	12,531/ 21,626	P	No	40.0 – 60.0

Legend: Surface (km^2): numbering - the surface of the body on Romanian territory; naming - the entire surface of the body; Type: P – porous.

Table 2
CHARACTERISTICS OF DEEP GROUNDWATER AND PHREATIC BODIES (PART II)

Code / name	Use of water	Pollution agents	Global protection degree	Risk		Cross-border / country
				Qualitative	Quantitative	
1	6	7	8	9	10	11
ROPR03 – Riversides and terraces of Barlad and its tributaries (including Vaslui)	PO, I, Z	I, A	PU, PM	Yes	No	No
ROPR05 – Central Moldavian Plateau (including Vaslui)	PO, Z	-	PVG	No	No	Yes / Republic of Moldova

Legend: PO - potable water supply; I - industrial water supply; zootechnic water supply; polluting agents: I - industrial; A - agricultural; Global protection degree: PU - unsatisfactory; PM - average; PVG - very good.

Table 3
CHARACTERISTIC HYDRO-GEOLOGIC PARAMETERS OF THE GROUNDWATER BODIES

Name of the groundwater body	K (m/day)	T (m^2/day)	Q (L/s/m)
ROPR03 – Riversides and terraces of Barlad and its tributaries (including Vaslui)	10 – 50	10 – 500	1.0 – 1.5
ROPR05 – Central Moldavian Plateau (including Vaslui)	3 – 10	15 – 20	0.5 – 5.0

Legend: K - average filtration ratio; T - transmission ratio; Q - specific average flow rate.

Phreatic hydro-structures

The phreatic aquifer is influenced directly by climatic and hydrologic factors. Moreover, the relief factor, especially by geo-morphologic processes, influences the natural hydro-geologic development of the area. Economically, phreatic groundwaters only have local importance, as they cannot supply long-term exploitable flow rates for large industrial objectives and neither for irrigation. The aquifer reserve is relatively constant and the natural development is apparently not influenced by anthropic factors.

Underground phreatic water was found both in plateau deposits, or in the area of slopes, where it oozes or wells out, and in alluvionary deposits of water courses. In the case of the first mentioned formations, there are no proper aquifer layers, as the water circulates preferentially and the reserve regeneration and the supply of wells depends on precipitation. Still, in the river side area, groundwater is stored in a relatively well individualized aquifer layer, with a continuous spread, supplied both by precipitation and by hydro-dynamic exchange with the river.

In 1971 the alluvionary aspect of the main river bed of Vaslui, near Moara Grecilor, was subject to a hydro-geologic study based on existing bores and there were made 3 bore holes, each to a depth of 10m. The bores were aligned perpendicular on the water course and oriented East-West. The total length of the profile was 836m. During the works they encountered the Sarmatian and the Quaternary (fig. 3). The Sarmatian was found 7m underground and consisted of dark bedrocks with insertions of sand, while the quaternary, represented by Holocene, consisted of a suite of successive clay and sand layers, as follows:

- in the base - a layer of gravel in the mass of coarse sand, or coarse sand with little gravel;
- intermediary - a layer of medium and fine yellow sand, of shell fragments;
- upper layer - a layer of black clay or dust, with the vegetation soil above.

In the area of the F2 bore hole there is a lens of sandy gray mud. The total thickness of quaternary deposits caries between 7.0 and 7.8m. Within that complex, the layers of gravel and coarse sand are those that hold water.

The aquifer layer was found at variable depths, from 2.7 to 7.8m and consists of medium and coarse sands, gravel and pebbles. The thickness of the aquifer varies between 1.6 and 4.3m. According to analysis bulletins, the elements in the aquifer layer are found in the following proportions: sand (56 - 74%), gravel (6 - 40%), pebbles (4 - 22%).

The piezometric levels were established after finalization to 1.50m in the F1 bore, 0.00m in F2, 0.50m in F3. Those values were confirmed by the isobats map, which established that in the hydrologic section Moara Grecilor the groundwater depth varies between 0 and 2m.

After bore finalization they performed experimental and sand removal injections. The maximum flow rates were obtained at the F1 bore hole, out of the coarse sand layer

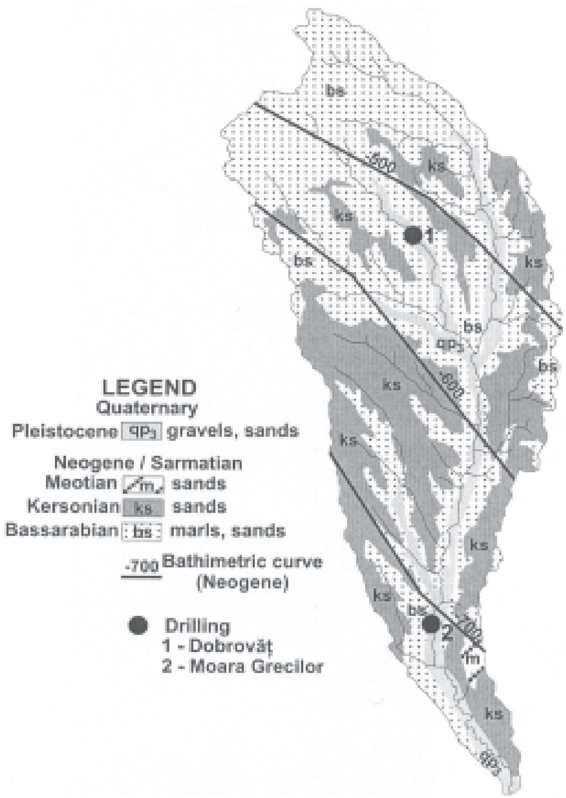

Fig. 3. Geologic map of the Vaslui hydrographic basin

with rare gravel elements (3.3 L/s) and the minimum flow rate at the F3 bore hole (0.7 L/s). According to the results obtained during experimental injection, they established the filtration ratio (K), the influence radius (R) and the physico-chemical characteristics, by using the Dupuis and Dupuit-Forchheimer formulae [14] (table 4, 5).

The Filtration ratio (Kmed) varies between 6.6 and 27.6m/day and represents the equivalent of the circulation speed of a groundwater current driven by a unitary hydraulic gradient through a unitary section within a saturated porous environment. That parameter is a quantitative notion that indicates the ease with which water can circulate and pass through a more or less permeable layer. The influence radius (Rmax) registered values of 35.4 - 172.0m and represented the distance in the flow direction of the underground current towards the bore hole, measured horizontally on the axis of the bore hole to a point where the dynamic effect ceases. They are important for the proper assessment of the location of exploitation wells in an intake front.

In order to assess the chemical properties of the groundwater, they took a set of samples for analysis. They found that the samples from the bores F1 and F2 fall within the category of magnesium and sodium bicarbonated waters and those from bore F3 within the sulphatic sodic category. In 1974 in the water side of Dobrovat, in Dobrovat

Table 4
RESULTS AFTER EXPERIMENTAL INJECTION IN THE BORES OF THE HYDRO-GEOLOGIC STATION MOARA GRECILOR

Bore	Stage	Flow rate Injected		Level oscillation (S)	Radius of influence	Filtration rate with level under medium	Filtration rate pressure intake
		L/s	m^3/day	m	m	m/day	
F1	I	1.6	138.2	1.07	58.9	30.3	27.6
	II	2.5	216.0	2.02	105.0	27.2	
	III	3.3	285.1	3.03	152.0	25.3	
F2	I	0.8	69.1	1.75	59.7	11.7	12.3
	II	1.6	138.2	3.32	124.0	13.4	
	III	2.0	172.8	5.10	172.0	11.7	
F3	I	0.7	60.5	1.50	35.4	5.6	6.6
	II	1.5	129.6	3.00	79.7	7.6	
	III	2.2	190.1	4.80	124.0	6.7	

Analyzed Elements	U.M.	F1	F2	F3	Maximum allowed concentration
pH	pH units	7.8	7.8	7.8	6.5–9.5
NH_4	mg/L	0.5	4.5	21.5	0.5
Na		109	217	265	200
K		39	10	10	-
Mg		146	44	55	50
Ca		68	36	180	100
Cl		86	23	38	250
SO_4		354	344	650	200
HCO_3		732	464	708	-
Total hardness	^0G	42	15	38	min 5
Fixed residue	mg/L	1,170	917	1,585	100–800
O_2		5.1	7.5	6.7	min 6
Total mineralization		1,534	1,143	1,928	-

Table 5
PHYSICO-CHEMICAL CHARACTERISTICS OF THE GROUNDWATER AT THE HYDRO-GEOLOGIC STATION MOARA GRECILOR, AFTER BORE HOLES FINALIZATION

village, they bored to a depth of 8m. The alluvionary deposits of the flat lands are approximately 5 m thick on top of Sarmatian deposits consisting of gray clay.

According to the lithology of the Dobrovat river reception basin, to the lithology revealed by the bore in the Dobrovat hydrologic station and to the profile oriented transversally on the direction of the valley, we concluded that the old river bed of Dobrovat, with coarser elements, gravel, or Sarmatian sand stone fragments, was not intercepted. The aquifer layer, with a thickness of 2.2m, is situated between 3.1 and 5.3m and the piezometric level, after finalization, was assessed to be 1.4m.

A vertical variation in the granulometry was observed in the upper part, with a 1.4m thick layer of fine sand, over fine to medium sand. The granulometric curve drawn for a sample taken from a depth of 5m revealed the following proportions for the various granulometric fractions: coarse sand (8%); medium sand (36%); fine sand (56%). The cover of the aquifer layer consists of a clay powder layer 1.5m thick, under dusty clay and the groundlevel. The bed drilled over a thickness of 2.7m to a relative level of 8m, consists of compact gray clay, with yellow Sarmatian traces. The aquifer layer within the alluvionary deposits of the flat land is under pressure. The piezometric level (measured during injection) registered 2.4m above the cover.

In the area of the Dobrovat hydro-geologic station the link between surface and ground water is reduced, as the river bed is carved in low permeability deposits. Upstream from Dobrovat village, the supply of the phreatic horizon is done from the slope area or from the river. During the experimental injections, the maximum flow rate registered after finalization of the works was 0.941L/s. To the favorable hydro-geologic parameters (the filtration ratio = 15.7m/day; influence radius = 86m) there corresponds a transmission rate of 32.3mm^2/day. That parameter represents the conventional potential of a aquifer layer and is expressed by multiplying the average filtration ratio by the thickness of the aquifer layer (table 6). A water sample was taken, to determine the physico-chemical properties of the phreatic water stored in the Dobrovat flat land, in the village with the same name. The analyzed water was magnesium bicarbonated, undrinkable, according to the Scholler-Berkaloff diagram, due to its high concentration of magnesium (table 7).

Deep aquiferous structures

In the Central Moldavian Plateau the deep aquifer is stored almost exclusively in Sarmatian hydro-structures. The study thereof was done based on several bore holes in the state hydro-geological network, but also on other bore

Bore	Stage	Flow rate Injected		Level oscillation (S)	Radius of influence	Filtration rate with level under medium	Filtration rate pressure intake
		L/s	m^3/day	m	m	m/day	
F1	I	0.330	28.5	0.83	23.0	13.0	14.8
	II	0.677	58.5	1.69	53.0	15.6	
	III	0.941	81.3	2.52	86.0	15.7	

Table 6
RESULTS AFTER EXPERIMENTAL INJECTION IN THE BORES OF THE DOBROVAT STATION

Analyzed elements	U.M.	F1	Maximum allowed concentration
pH	pH units	7.0	6.5–9.5
NH_4	mg/L	0.0	0.5
Na		39	200
K		7	-
Mg		127	50
Ca		38	100
Cl		97	250
SO_4		96	200
HCO_3		663	-
Total hardness	^0G	35	min 5
Fixed residue	mg/L	1,028	100–800
O_2		6.3	min 6
Total mineralization		1,068	-

Table 7
PHYSICO-CHEMICAL CHARACTERISTICS OF THE GROUNDWATER AT THE DOBROVĂT HYDRO-GEOLOGIC STATION, AFTER BORE HOLES FINALIZATION

Stage	Flow rate Injected		Level oscillation (S)	Radius of influence	Filtration rate with level under medium	Filtration rate pressure intake
	L/s	m^3/day	m	m	m/day	
I	4.78	413.0	3.0	55.0	3.74	4.27
II	8.15	704.2	5.0	105.0	4.22	
III	13.75	1,188.0	8.0	193.0	4.85	

Table 8
RESULTS AFTER EXPERIMENTAL INJECTION IN THE FA SOLESTI DEEP BORE

Analyzed elements	U.M.	FA Solesti	Maximum allowed concentration
pH	pH units	7.0	6.5–9.5
NH_4	mg/L	4	0.5
Na	mg/L	510	200
K	mg/L	5	-
Mg	mg/L	2.4	50
Ca	mg/L	16	100
Fe	mg/L	1.5	0.2
Cl	mg/L	230	250
SO_4	mg/L	260	200
NO_2	mg/L	0.2	0.5
NO_3	mg/L	2	45
HCO_3	mg/L	707	-
Total hardness	^{0}G	2.8	min 5
Fixed residue	mg/L	1,400	100–800

Table 9
PHYSICO-CHEMICAL CHARACTERISTICS OF THE GROUNDWATER AT THE FA SOLESTI DEEP BORE

holes. The result analysis revealed important qualitative and quantitative differences according to area. The quantitative differences were found horizontally and were determined by the different granulometry of he Sarmatian deposits, consisting mainly of sand and gravel in the West, at the contact area with the Carpathian orogen, and the finer granulometry in the East.

The differences in marine facies (saline, weak saline and sweet) of the Bessarabian or Kersonian deposits also determine qualitative differences. In the Bessarabian deposits they identified two layers with freshwater mollusk fauna. The first one, consisting of sand and clay, clay, limestone, which is located under the "Repedea Limestone", is known as "The clays and sands of Barnova". The second layer consists mainly of clay and sand varieties [15].

In the Vaslui hydrographic basin they performed 2 deep exploration-exploitation bores for the state hydro-geologic network. In 1994, north of Solesti village, on the left shore of the Vaslui river, downstream from the confluence with the Dobrovat river, they performed the deep bore hole FA Solesti. Geologically, the bore hole is located in the area of Sarmatian formations.

The analyses performed on the samples taken from 25 m intervals revealed a micro-fauna poor in foraminifera and ostracoda, but also fragments of unidentified lamelibranhiata. Based on that micro-fauna and on the descriptive lithologic data, they assessed that the intercepted formations are from the following period:

- between 0.15 - 15.0 belong to the Quaternary;
- between 15.0 - 100.0 belong to the Kersonian;
- between 100.0 - 200.0 belong to the Bessarabian;

The upper half of the suite belongs to the Sarmatian and the lower interval to the middle Sarmatian [15]. The roofs and beds of the 4 aquifer layers carrying water consist of marnic clays and compact gray clay marns (impermeable). Hydro-geologically, those layers were treated globally, in a complex, given the short distance between them and their common age.

The piezometric level is artezian, as the aquifer layers are under pressure. The results of the experimental injections revealed the following hydro-geologic characteristics and parameters: piezometric level (Np) = 0.0m; maximum level oscillation (Smax) = 8.0m; maximum flow rate (Qmax) = 13.75L/s; maximum influence radius (Rmax) = 193m; medium permeability ratio (Kmed) = 4.27m/zi; transmission rate (T) = 155.85m^2/day; physico-chemical characteristics (table 8, 9).

Chemically, the water is hydro-carbonated and chloride-sulphato-sodic. The interpretation of the ionic concentration on the Scholler - Berkaloff analysis diagram indicates a water whose ion content exceeds the allowed limit by far, the water being undrinkable. In 1990, in order to investigate the structure of the middle and superior Sarmatian in the Vaslui county area and to identify the productive aquifer layers necessary to supply water, they made the FA Vaslui deep bore. The bore is located on the main river bed of the Vaslui river, approximately 600m East of the Vaslui-Iasi national road, near the pumping station. The micro-paleontologic analysis of the samples taken from the bore at intervals of 25m, revealed a fauna specific to the Bessarabian. They captured 5 aquifer layers, consisting mainly of dusty sand. The results of the experimental injections revealed the following: piezometric level (Np) = 1.30m; maximum level oscillation (Smax) = 4.1m; maximum flow rate (Qmax) = 8.0L/s; maximum influence radius (Rmax) = 127m; medium permeability ratio (Kmed) = 9.64m/zi; transmission rate (T) = 173.5m^2/day (Table 10). The chemical analyses revealed the fact that the water is carbonated-sulphato-chloride-calcium-magnesian-sodic. The results of the experimental injections revealed the following hydro-geologic characteristics and

Analyzed elements	U.M.	FA Vaslui	Maximum allowed concentration
pH	pH units	7.0	6.5–9.5
NH_4	mg/L	0.35	0.5
Na		68	200
K		14	-
Mg		41	50
Ca		92	100
Fe		0.7	0.2
Cl		56	250
SO_4		182	200
NO_2		0.022	0.5
NO_3		12.5	45
HCO_3		329	-
Total hardness	^0G	22.4	min 5
Fixed residue	mg/L	667	100–800

Table 10
PHYSICO-CHEMICAL CHARACTERISTICS OF THE GROUNDWATER AT THE FA VASLUI DEEP BORE

Stage	Flow rate Injected		Level oscillation (S)	Radius of influence	Filtration rate with level under medium	pressure intake
	L/s	m^3/day	m	m	m/day	
I	2.7	233.3	1.37	32.6	8.62	
II	5.3	457.9	2.74	77.0	9.72	9.64
III	8.0	691.2	4.10	127.0	10.57	

Table 11
RESULTS AFTER EXPERIMENTAL INJECTION IN THE FA VASLUI DEEP BORE

parameters: piezometric level (Np) = 1.30m; maximum level oscillation (Smax) = 4.10m; maximum flow rate (Qmax) = 8.0L/s; maximum influence radius (Rmax) = 127m; medium permeability ratio (Kmed) = 9.67m/zi; transmission rate (T) = 173.5m^2/day (table 11).

Groundwater development

The aspects regarding groundwater development, according to the interpretation and processing of levels, only apply to the phreatic aquifer [16-20]. According to the level measurements done in the hydro-geologic bores the following issues were considered:

- the study of the natural development of phreatic waters;
- the assessment of the phreatic waters status;
- the assessment of the fluctuations in the phreatic water reserves.

To assess development of groundwaters involves the analysis of their variation in time and their interdependence, with all the causes that influence that variation, in different geologic and hydro-geologic conditions. The natural development of levels may be influenced by two categories of factors:

- constant factors (the geologic structure and the lithologic arrangement), that determine the conditions in which level oscillations occur, by limiting their volume and duration;
- variable factors (climatic, hydrologic, bio-pedologic factors, anthropic activities, biotic and physical-chemical processes etc.).

The most important variable factors are: precipitation, evapo-transpiration, air temperature variation, superficial flow and anthropic activities. The modifications of the variable factors reflect the permanent changes of the phreatic water levels. Therefore, to make a thorough characterization of the development of groundwaters, one must take a long enough period to analyze, with as many observations as possible (at least 10 - 15 years), for levels and other parameters.

Moreover, the relevant elements in that type of study play an important role in the characterization of groundwater development. The must also be monitored dynamically and in time. The levels depend on the surface of the area. The analysis of the general elements in regard to phreatic water development must be correlated with the dynamic and diachronic evolution of flow rates and levels. According to the dynamic aspect of the underground flow, the elements of the development can be divided in two main groups:

- the daily annual and multi-annual flow (in that situation the analysis will be done based on daily piezometric levels recorded over one month, one year, or a longer period);
- the monthly annual and multi-annual flow (the analysis starts from monthly levels, that is, the average of daily levels registered over one month).

The analysis of daily values are of interest for agriculture, where the presentation of maximum daily annual, multi-annual, as well as the period and the duration of piezometric levels have an important role in irrigation schedule, or land draining. In view of supplying water to certain objectives the analysis of the flow should be made according to the developments elements that characterize the monthly annual and multi-annual flow. The development of the average annual piezometric levels recorded during the 1983 - 2009 period varied from 112 to 28 cm at F1, 115 - 27cm at F2, 125 - 20cm at F3 for the hydro-geologic station Moara Grecilor (fig. 4) and at F1 Dobrovat between 263 and 42cm (fig. 5).

The amplitude between the maximum and minimum daily multi-annual piezometric levels (Δh) recorded at F1 Moara Grecilor was 118cm. The underground reserve (Δhr) which represents the difference between the piezometric level at the beginning of the interval (the average piezometric level for January 1983) and the piezometric

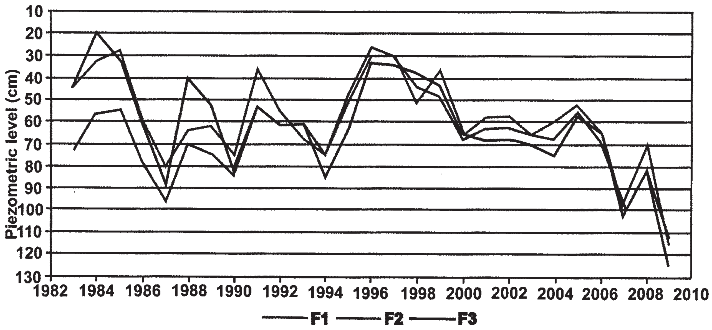

Fig. 4. Piezometric level variation annual average for the bores (F1, F2, F3) in the Moara Grecilor hydro-geologic station

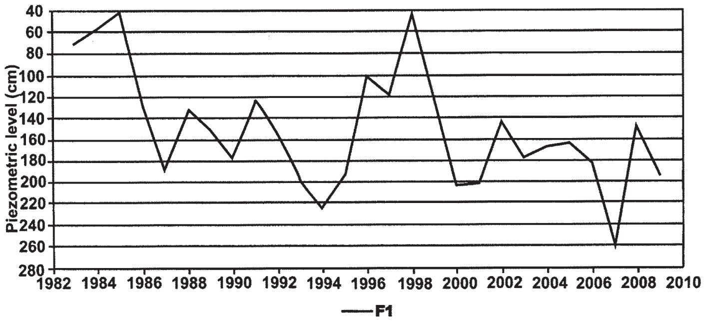

Fig. 5. The variation of annual medium piezometric levels at the F1 bore of the Dobrovat hydrometric station

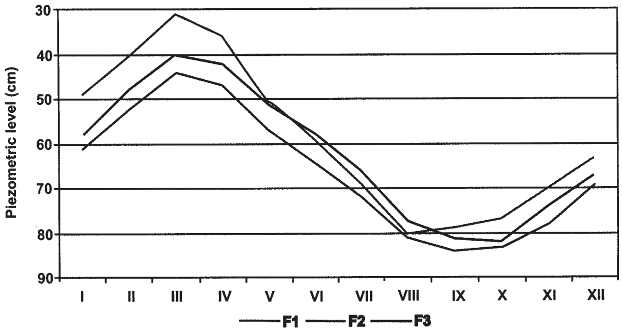

Fig. 6. Monthly multi-annual average piezometric level variation for the bores (F1, F2, F3) in the Moara Grecilor hydro-geologic station

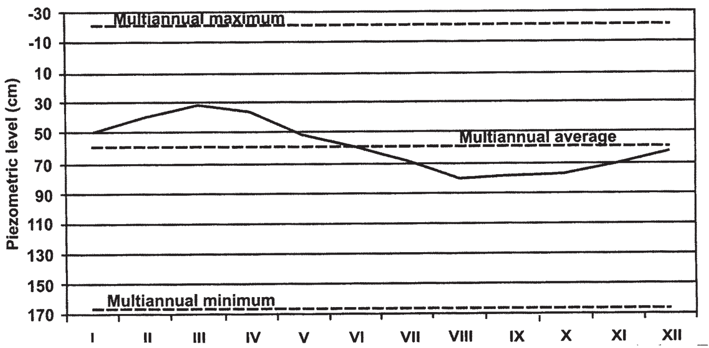

Fig. 7. Monthly multi-annual maximum and minimum piezometric level variation for the bore F1 at the Moara Grecilor

level at the end of the interval (the average piezometric level for December 2009), is -101cm. In that case t/T = 1.05 and represents the report between the period with high levels (t) and that with low levels (T), reported to the graph of the medium multi-annual level. At bore F2 Moara Grecilor: Δh = 185 cm, Δhr = -66 cm, and t/T = 0,88; at fore F3 Moara Grecilor: Δh = 202cm, Δhr = -103cm, iar t/T = 0,96; and at bore F1 Dobrovat: Δh = 332cm, Δhr = -249cm, and t/T = 0,90.

On the whole, the evolution of the average monthly multi-annual piezometric levels at the 3 bores from Moara Grecilor has a similar character (fig. 6). The levels kept increasing from October to March, then decreased constantly. The evolution has two cycles: one with increasing levels and one with decreasing ones. A similar evolution was registered for the average monthly multi-annual levels at the Dobrovat F1 bore, the only difference being that the levels increased until April.

The average monthly multi-annual level at the Moara Grecilor F1 bore oscillates between 40 and 45cm. The maximum amplitude between the minimum and maximum values of the monthly piezometric level is approximately 190cm (fig. 7). The average monthly multi-annual level at the Moara Grecilor F2 bore oscillates between 35 and 40cm. The maximum amplitude between the minimum and maximum values of the monthly piezometric level is approximately 175cm (fig. 8). The average monthly multi-annual level at the Moara Grecilor F3 bore oscillates between 40 and 42cm. The maximum amplitude between the minimum and maximum values of the monthly piezometric level is approximately 190cm (fig. 9). The average monthly multi-annual level at the Dobrovat hydro-geologic bore oscillates between 90 and 100cm. The maximum amplitude between the minimum and maximum values of the monthly piezometric level is approximately 340cm (fig. 10). The physico-geographical conditions specific to the area of the Vaslui hydrographic basin affect the level oscillations of the phreatic waters.

The Vaslui hydrographic basin is located in a continental temperate climate area with excessive nuances. That means that the average precipitation quantity is approximately 590-600mm/year and the evapo-

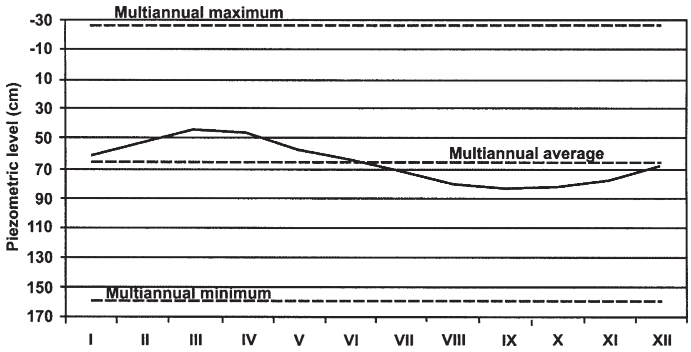

Fig. 8. Monthly multi-annual maximum and minimum piezometric level variation for the bore F2 at the Moara Grecilor

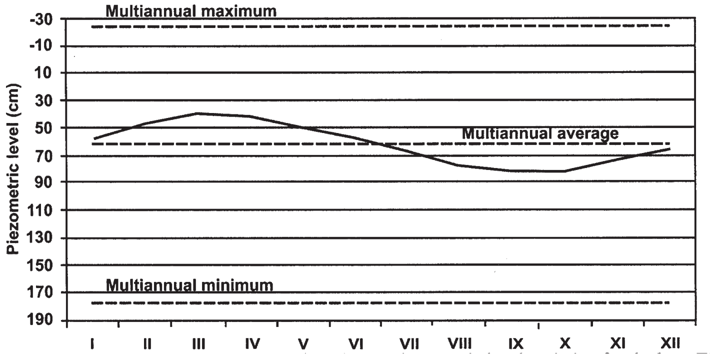

Fig. 9. Monthly multi-annual maximum and minimum piezometric level variation for the bore F3 at the Moara Grecilor

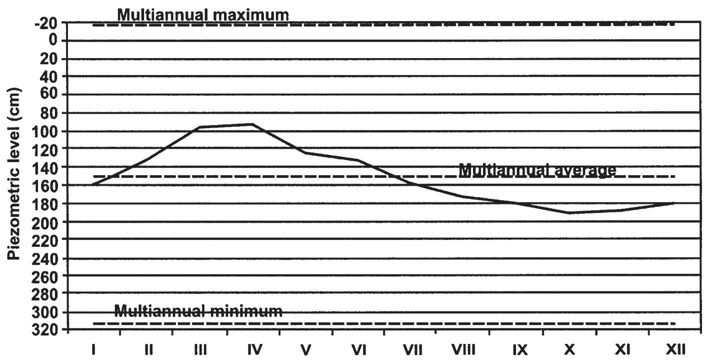

Fig. 10. Monthly multi-annual maximum and minimum piezometric level variation at the Dobrovat hydro-geologic station

transpiration above 700mm/year. The underground supply causes the formation of permanent rivers. The phreatic waters in the river side are directly influenced by precipitations and the water level in the minor river bed.

Unfortunately, the surface of deep hydro-structures is not known well enough due to insufficient data. That is why a precise evaluation of deep aquifer resources is currently not possible for each structure, as there are important areas that could not be investigated. The cross-basin and cross-border character of deep aquifer structures and the undifferentiated manner of investigation are elements that make it difficult to evaluate the aquifer reserve for each hydro-structure separately [15]. The deep aquifer resources have a series of characteristics and features that make them differ from phreatic waters:

- they are supplied through the extremes of the layer, from aquifers located at upper levels;
- the influence of the climatic factors (precipitation) is very weak, or absent;
- the dynamic exchange of water with the surface aquifer only occurs at the layer ends, where the contact surfaces overlap;
- the separation of the aquifer layers by the the aquilude strata (especially to the south of the Barlad hydrographic basin) allows the neighboring aquifer hydro-structures to regain correspondence;
- the exploitable flow rates are considerably higher, which makes their exploitation preferable to the phreatic ones;
- the anthropic influences are weak or absent, which confers advantages in regard to the exploitation.

The deep aquifer structures are located, most of the time, under the base level of the valley. The profound hydro-structures are usually intercepted in exploration bores, rarely in exploration-exploitation ones. The deep hydro-structures are usually thick multi-layered aquifers with waters under pressure that may manifest in an artezian way and their pressure increases constantly from north to south.

The deep aquifer reserves are significant quantitatively and offer optimal conditions for exploitation. Most of the time, those reserves are proper physico-chemically and are naturally protected from a hydro-geologic and sanitary point of view. The maximum allowed concentration is only slightly exceeded in the case of CCOMn and NH4. As more than half of the water body is on Romanian territory, the water resource can be used intensely in agriculture (the only economic field with relatively good results in the area).

The deep groundwaters have relatively high flow rates and their quality complies with home, agricultural and industrial use requirements. The resources are poorly exploited due to the lack funds for extraction and distribution to the main locations. In addition to the lack of water, the Vaslui hydrographic basin is the poorest area in the EU.

Even if the phreatic waters are of interest only locally, they are intensely exploited and risk permanent exhaustion of the Vaslui river flow rate. All the localities, except for the town of Vaslui, are supplied with water through wells from the phreatic. During the summer, though, when wide areas of land are irrigated, most of the wells dry, or get to supply extremely low flow rates.

In the phreatic of Dobrovat, upstream, they registered the maximum amplitude of the average annual piezometric levels (221cm). At Moara Grecilor, downstream, the highest amplitude was registered at the F3 bore (105cm). In that case the supply of the phreatic in the inferior basin is much better and the water reserve much more reliable.

In the evolution of the annual average piezometric levels our attention is drawn by the minimum values, which were registered in 2009 at the bores of the hydro-geologic station Moara Grecilor and in 2007 at Dobrovat. The average maximum annual piezometric levels were registered in 1984 at F3 Moara Grecilor, in 1985 at F1 Dobrovăt and F1 Moara Grecilor and in 1996 at F2 Moara Grecilor.

During the period under analysis (27 years) there are only few intervals in which the annual average piezometric levels did not oscillate significantly. The tendency for the annual average piezometric levels is to decrease at all 4 bores, except for the F2 bore at Moara Grecilor. The highest average monthly levels were registered in March and April and they decrease in August and September. They are influenced by climatic factors. The most constant flow rates were registered in the lower course, where the main river bed of Vaslui takes the form of an alluvial field.

The study of groundwaters in the Vaslui hydrographic basin, in the context of a relief unit with extremely scarce natural resources, reveals a relatively modest hydro-geologic potential, partially exploited and not entirely identified [11]. A proper exploitation of the underground water resources may by done if authorities join efforts and with proper financial support to stimulate economic growth and an enhanced quality of life in that basin. Since groundwaters are relatively poorly developed and surface waters are usually temporary, the North-Eastern Region of Romania is considered the poorest area in the EU. Therefore deep groundwaters must be intensely exploited and an additional supply must be provided from areas with excess resources, especially from the eastern part of the Oriental Carpathins.

Conclusions

From a hydrologic point of view, the Vaslui basin is of low importance. As it is geographically located in the poorest department of the EU, that area is under intense study. Therefore, the hydro-geologic studies represented a priority, in order to emphasize the water reserves. As the industrial domain is almost absent, the only solution to the economic issue is agriculture. Unfortunately, that field requires significant water quantity, especially in the eastern sector of Romania, where there are frequent droughts.

It should be noted that the Vaslui county, located over the hydrographic basin with the same name, is also very populated. Even if lately the average precipitation quantity slightly increased, the lack of water is felt more acutely. That situation was caused by the chaotic, torrential distribution of precipitation during the summer and the lack of precipitation during autumn and winter.

The lack of deep wells causes some villages to lack water during summer, for periods that can last 3 to 5 months. Most of the time water is transported in cisterns to supply the poor population that cannot afford to buy bottled water from stores. By boring some deep wells, even if the water is almost undrinkable, the department of Vaslui could ensure the necessary supply of drinkable, industrial and agricultural water.

There is only one agricultural company that gets its necessary water for irrigations from groundwaters (especially in the sectors of the main river bed). The other companies rely on surface water and the rewards are minimum. Unfortunately, many agricultural lands are small private properties and are exploited with antiquated techniques. Due to the lack of funds the peasants cannot rely on groundwater supplies, even if it were exploited on a large scale. The water in the Vaslui basin must be subsidized.

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