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Specific hydraulics related to a groundwater catchment

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Abstract: The paper presents both, the study of a ground water flow towards a series of catchment drillings which are ran under different operational schedule, and a flow simulation along the pipes network and headrace supplying a small town of about 7200 inhabitants with fresh water under specific requirements. The steady state ground water flow numerical model considers a maximum captured discharge of 20.00 l/s, obtained from 6 running drillings out of 9 corresponding to several specific operation situations. A daily water demand distribution is assumed (the hourly variation ratios for the increased consumption interval considered from 0.51 to 1.37), which leads to a maximum water flow reached in the network of 1.64 m3/min. The hourly water volume required for the supply system is stored up by a reservoir placed about 12km from the catchment line. Several relative pumps rotation speed values are considered in such a way that the working parameters of the running system to be optimized.

Keywords: groundwater flow, underground water catchment, pipes network.

1. INTRODUCTION

The Salsig Groundwater Catchment is situated on S-W of the homonym village on the left bank of Somes River, specifically in the alluvial fan formed by the tributary Salaj Creek. The hydrotechnical study is based on general data regarding the geo-morphology and hydro-geology of the area corresponding to the nine catchment drillings in the Somes River flood plain. Specific data, such as soil permeability ratios – k in the vicinity, influencing operation radius – R, admitted water velocity – v_a, operation flows – Q_{exp} and drillings dislevelments – s, were estimated for the most unfavorable rainfalls circumstances along the year by considering the results of experimental pumping performed upon the nine drillings. These data values, referring actually to the year of 2011, are given by the table no.1.1.

Further on, technical information describing six out of nine drillings (F5, F7, F8, F9, F10 and F11) were employed together with the path topography along which the headrace to the reservoir lays down. Thus, the pipes network unsteady flow numerical simulation is considered with respect to specific results regarding the groundwater motion ("option O3", specifically). The catchment network is assembled from High Density PolyEthylene (PEHD) pipes of different lengths and diameters (from D-110mm to D-315mm) for which a roughness C = 150 of Hazen–Williams type was considered. Slide valves Dn140 and Dn300, butterfly throttles Dn150 and the group of six pumps of variable rotation speed (type A01905 SP 17–5 50 Hz, MS4000 engine) also endows the catchment system.

Table no.1.1

	A	B	C	D	E	F	G	H	I	J	K	L
1	Foraj	Adancime	Interval	Nivel de apa	Hcaptat	Diametru	k	R	Va	Q	Q	s
2		dupa	captat	de la sol		coloana				neinnisip	exploatare	exploatare
3		desnis. (m)	(m)	(m)	(m)	foraj (m)	(m/zi)	(m)	(m/s)	(l/s)	(l/s)	(m)
4	F3	12.05	2.0-9.0	4.85	4.15	0.30	152	95.00	0.002	7.800	4.80	1.600
5	F4	11.99	2.0-9.0	4.65	4.35	0.30	57	95.00	0.002	8.200	2.60	3.000
6	F5	12.23	2.5-9.0	5.00	4.00	0.30	123	89.00	0.002	7.500	4.10	1.800
7	F6	15.43	2.5-10.0	5.53	4.47	0.30	88	95.00	0.002	8.400	3.80	2.400
8	F7	15.37	2.5-10.0	5.30	4.70	0.26	36	88.00	0.002	7.600	2.10	3.400
9	F8	13.10	2.5-10.0	4.66	5.34	0.26	14	46.00	0.002	8.700	1.50	4.400
10	F9	14.80	2.0-10.0	4.98	5.05	0.26	104	100.00	0.002	8.200	4.50	2.400
11	F10	15.00	2.0-10.0	4.94	5.06	0.26	103	91.00	0.002	8.300	3.50	2.900
12	F11	13.70	2.5-9.0	4.94	4.66	0.26	90	108.00	0.002	7.600	4.30	2.000

2. NUMERICAL MODELING OF THE STEADY STATE GROUNDWATER MOTION TOWARDS THE CATCHMENT DRILLINGS

A 2D finite elements numerical modeling was considered in order to simulate the possible operation procedures that would lead to the working water levels (elevation levels or dislevelments - s) on the catchment drillings and to the operation flow - Q_{exp}, respectively. It is assumed that a number of six drillings out of nine would be in operation at a time, while the requirement regarding the total discharged flow stipulates that an amount of 20.00 l/s should be assured. The outlined plain view given by the figure 2.1 was generated, displaying all the nine drillings (marked as P3 … P11 in the numerical model).

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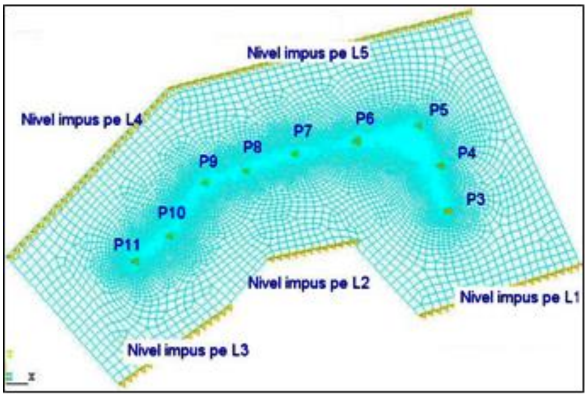


Fig. 2.1 Numerical model of the catchment area:
mesh and boundary conditions on edges and at the nine drillings

The considered extent was meshed by employing quadrangle finite elements of different sizes, clogged towards the catchment drillings.
The geometrical and hydraulic searched parameters of the numerical model were determined based on the estimated data given by table 1.1, with values as presented in table 2.1.

In order to develop the 2D meshed model that cares about the level of the underground water, the average hydraulic permeability ratio was considered of about k = 0.000993m/s and, since the mean groundwater height was estimated at a value of about 4.5m, the hydraulic transitivity (K = k·h) of the water bed was considered of about K = 0.00447m^2/s.
Taking notice at the drillings P5 … P11, one can find that the groundwater levels show a hydraulic slope of about 0.2%, being similar to the value towards the P3 … P5 drillings. Thus, the possible rising of the water levels along the model sides L1 … L5 were consequently estimated and enforced for the numerical model. The main principle considered for modeling the steady state motion of the ground water towards the catchment drillings is the analogy [2,3,4] between the thermal exchange (T) and the hydraulic specific flow (K).

Table no.2.1

	A	B	C	D	E	F	G	H	I	M	N	O	P	Q
1		Hcaptat	d(m)	k(m/zi)	k(m/s)	T=k*h (m^2/s)	Qc (l/s)	Qc (mc/s)	Qc (mp/s)	Teren	Marna	Nivel hidro.	Nivel foraj	s (m)
2	F3	4.15	0.30	152	0.001759	0.00730	4.8	0.00480	0.001156627	167.00	157.00	161.15	159.55	1.60
3	F4	4.35	0.30	57	0.00066	0.00287	2.6	0.00260	0.000597701	166.40	156.40	160.75	157.75	3.00
4	F5	4.00	0.30	123	0.001424	0.00569	4.1	0.00410	0.001025000	166.70	156.70	160.70	158.90	1.80
5	F6	4.47	0.30	88	0.001019	0.00455	3.8	0.00380	0.000850112	167.40	157.40	161.87	159.47	2.40
6	F7	4.70	0.26	36	0.000417	0.00196	2.1	0.00210	0.000446809	167.40	157.40	162.10	158.70	3.40
7	F8	5.34	0.26	14	0.000162	0.00087	1.5	0.00150	0.000280899	166.70	157.70	163.04	158.64	4.40
8	F9	5.05	0.26	104	0.001204	0.00608	4.5	0.00450	0.000891089	167.12	158.12	163.17	160.77	2.40
9	F10	5.06	0.26	103	0.001192	0.00603	3.5	0.00350	0.000691700	167.10	158.10	163.16	160.26	2.90
10	F11	4.66	0.26	90	0.001042	0.00485	4.3	0.00430	0.000922747	167.20	157.40	162.06	160.06	2.00
11					Tmediu=	0.00447								

Considering a single drilling working at a time for a specific running level given according to table no.2.1, several successive numerical simulations were performed in order to set up the hydraulic model for the steady state regime. The transitivity ratio (K ≐ T) along the specific drilling contour consequently changes until the calculated average value of the captured discharge in the setting model reaches the value required by the supply system, moment at which the K value is saved.
Four groups of six drillings possible to work simultaneous were studied by the help of numerical model, each group needing to ensure the total supplying discharge of about 20.00 l/s. These working possibilities marked as “***option Ox***” are further on presented.
Option O1: covering the catchment combination of drillings *P3*, *P4*, *P5*, *P6*, *P7*, *P8*, that represents an exceptional situation since the total reached water discharge is of about 18.90 l/s.
Thus, the situation aims to reveal the groundwater levels interface for the successive drillings P3 … P8. The considered hydraulic head for each of these drillings are: *P3 → 159.55 mSL*, *P4 → 157.75 mSL*, *P5 → 158.70 mSL*, *P6 → 159.47 mSL*, *P7 → 158.70 mSL*, *P8 → 158.64 mSL*.
Option O2: covering the catchment combination of drillings *P3*, *P5*, *P6*, *P7*, *P8*, *P9*, situation that lead to a total discharge of 20.80 l/s.

The considered hydraulic head were: *P3 → 159.55 mSL*, *P5 → 158.70 mSL*, *P6 → 159.47 mSL*, *P7 → 158.70 mSL*, *P8 → 158.64 mSL, P9 → 160.22 mSL*.
Option O3: covering the catchment combination of drillings *P5*, *P7*, *P8*, *P9*, *P10*, *P11* (presented as an example by figure 2.2), situation for which the total discharge of 20.00 l/s was reached.

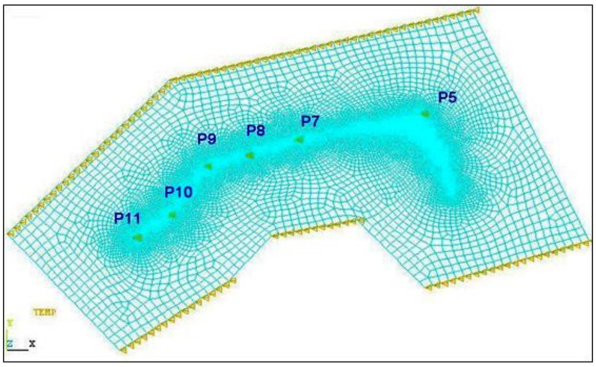


Fig. 2.2 Drillings considered by “option O3”

The hydraulic head for each of the drillings were considered as: *P5 → 158.70 mSL*, *P7 → 158.70 mSL*, *P8 → 158.64 mSL*, *P9 → 160.22 mSL*, *P10→ 160.26 mSL*, *P11 → 160.06 mSL*.
Option O4: covering the catchment combination of drillings *P45*, *P6*, *P8*, *P9*, *P10*, *P11*, situation for which the total discharge of 20.00 l/s was also reached.

The hydraulic head for each of the drillings were considered as: *P4 → 157.75 mSL, P6 → 159.47 mSL, P8 → 158.64 mSL, P9 → 160.22 mSL, P10→ 160.26 mSL, P11 → 160.06 mSL*.

By analyzing the total hydraulic flows related to contour joints of each drilling of the situation, the followings were revealed:

• the total running discharge for "option O1"
Q_{total}^{O1} =4.27+2.38+3.68+3.26+2.29+1.69=17.58 l/s, facing the total aimed discharge from "option O1"
Q_{total}^{aimed} =4.48+2.60+4.10+3.80+2.10+1.50=18.90 l/s that lead to the *overall efficiency* =17.58/18.90= **0.93** for the simultaneous drillings catchment;

• total running discharge for "option O2"
Q_{total}^{O2} =4.48+3.80+3.31+2.26+1.63+4.86=20.34 l/s, total aimed discharge from "option O2"
Q_{total}^{aimed} =4.80+4.10+3.80+2.10+1.50+4.5=20.80 l/s meaning an *overall efficiency* of **0.978**;

• total running discharge for "option O3"
Q_{total}^{O3} =4.08+2.32+1.62+4.52+3.53+4.67=20.74 l/s, total aimed discharge from "option O2"
Q_{total}^{aimed} =4.10+2.10+1.50+4.50+3.50+4.30=20.00 l/s meaning an *overall efficiency* of **1.037**;

• total running discharge for "option O4"
Q_{total}^{O4} =2.59+3.60+1.64+4.56+3.54+4.67=20.60 l/s, total aimed discharge from "option O4"
Q_{total}^{aimed} =2.60+3.80+1.50+4.50+3.50+4.30=20.20 l/s meaning an *overall efficiency* of **1.0198**.

As output examples, figures 2.3 and 2.4 present the equipotential level lines obtained for the working possibility corresponding to the drillings group "***option O3***", and the water discharges for one of the six drillings (e.g. drilling P11), respectively.

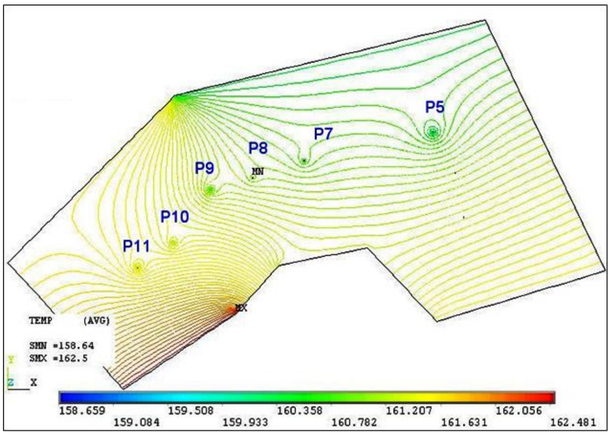
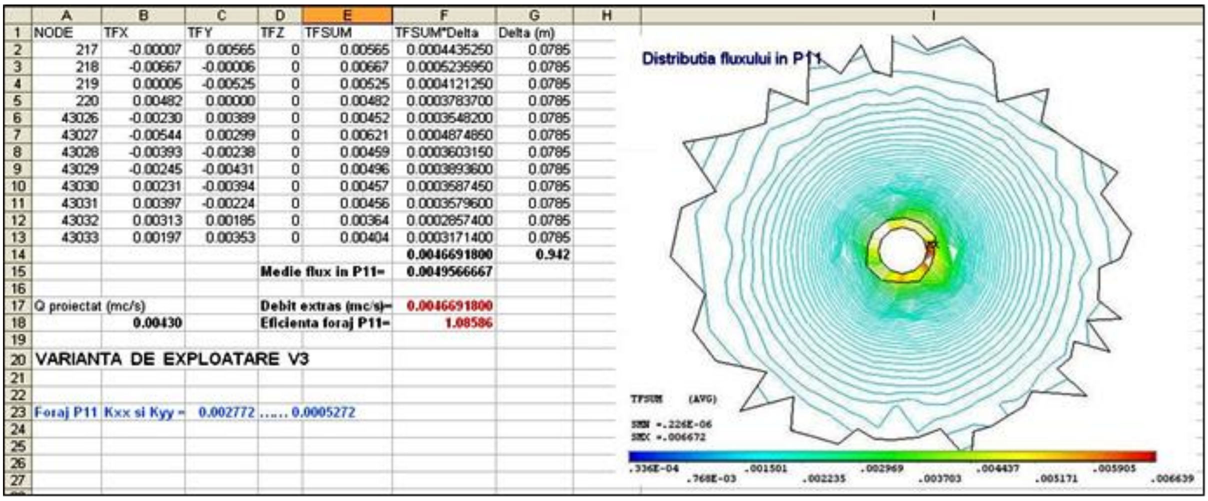


Fig. 2.3 Groundwater level development corresponding to "option O3"



	A	B	C	D	E	F	G
1	NODE	TFX	TFY	TFZ	TFSUM	TFSUM*Delta	Delta (m)
2	217	-0.00007	0.00565	0	0.00565	0.0004435250	0.0785
3	218	-0.00667	-0.00006	0	0.00667	0.0005235950	0.0785
4	219	0.00005	-0.00525	0	0.00525	0.0004121250	0.0785
5	220	0.00482	0.00000	0	0.00482	0.0003783700	0.0785
6	43026	-0.00230	0.00389	0	0.00452	0.0003548200	0.0785
7	43027	-0.00544	0.00299	0	0.00621	0.0004874850	0.0785
8	43028	-0.00393	-0.00238	0	0.00459	0.0003603150	0.0785
9	43029	-0.00245	-0.00431	0	0.00496	0.0003893600	0.0785
10	43030	0.00231	-0.00394	0	0.00457	0.0003587450	0.0785
11	43031	0.00397	-0.00224	0	0.00456	0.0003579600	0.0785
12	43032	0.00313	0.00185	0	0.00364	0.0002857400	0.0785
13	43033	0.00197	0.00353	0	0.00404	0.0003171400	0.0785
14						**0.0046691800**	**0.942**
15				**Medie flux in P11=**		**0.0049566667**	
16							
17	Q proiectat (mc/s)			**Debit extras (mc/s)=**		**0.0046691800**	
18		**0.00430**		**Eficienta foraj P11=**		**1.08586**	
19							
20	VARIANTA DE EXPLOATARE V3						
21							
22							
23	Foraj P11	Kxx si Kyy =	0.002772	..... 0.0005272			
24							
25							
26							
27							

Fig. 2.4 Water discharge distribution around drilling P11, corresponding to "option O3"

By analyzing the results corresponding to the 4 running options, each considering a specific group of 6 out of 9 drillings working simultaneously in order to accomplish a maximum discharge of 20.00 l/s, one can notice that the water demand is fulfilled by choosing to run the system according to situations marked as "option O2", "option O3" and "option O4". As about the running situation given by "option O1", it represents an exception which doesn't fulfill the required captured discharge.

3. NUMERICAL MODELING OF THE UNSTEADY WATER FLOW IN THE CATCHMENT'S PIPES NETWORK AND THE SUPPLY SYSTEM'S HEADRACE

The given running parameters of the employed type of pump are presented by figure 3.1.

In order to simulate a feasible running situation with the goal of reaching the parameters of an unsteady state, a numerical model of the pipes network and headrace was assembled [1,5]. The average running discharge $Q_{run\ av}$ = 20.00 l/s = 1.20 m^3/s was considered to be delivered by a group of 6 pumps working simultaneously.

A given path was followed, while the employed hydraulic parameters were those established by the ground water motion numerical modelling corresponding to "option O3" – situation considering the catchment drillings F5, F7, F8, F9, F10 and F11 running simultaneously (as shown by figure 2.2), presenting an overall efficiency of 1.037.

Figure 3.2 shows the schematic spread of the water supply system indicating the elements denomination (joint J-x, pipe P-x, valve TCV-x, reservoir R-x, pump PMP-x, drilling F-x) and geometrical characteristics (section length L=:x and diameter D=:x).

The water demand, characterizing only the ending joint J-6 (reservoir), varies along the time period – 24 hours – considered by the model being represented by the total average running flow corrected by the hourly variation ratio 0.51 ÷ 1.37 along one day given by figure 3.3. Consequently, figure 3.4 gives the water demand behavior along the time period, while the limit values for required flow are Q_{run_min} = 0.61 m^3/min and Q_{run_max} = 1.64 m^3/min, respectively.

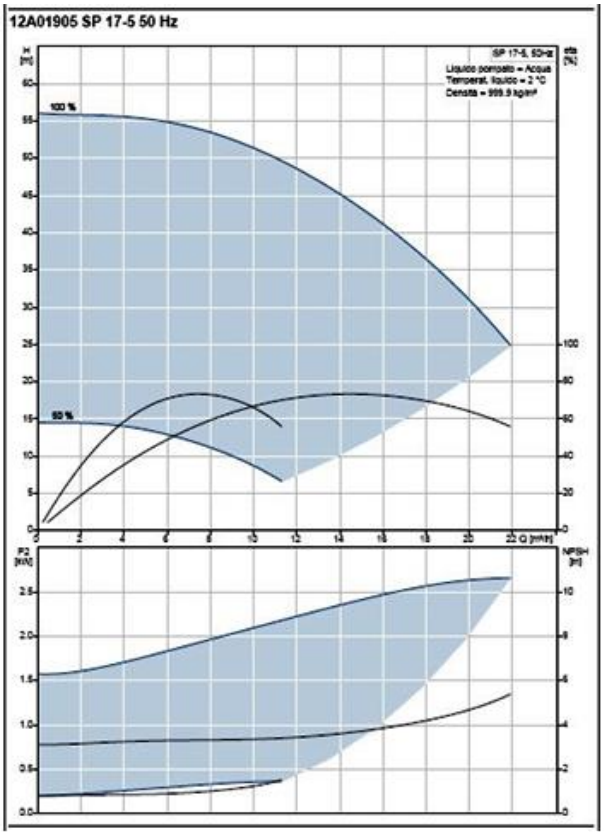


Fig. 3.1 MS4000 pumps characteristics

The boundary conditions considered on a data base in order to solve the equations system generated by the numerical model regard the minimum water levels in catchment drillings area (PMP-1 → H_a=158.7m, PMP-2 → H_a=158.7m, PMP-3 → H_a=158.64m, PMP-4 → H_a=160.22m, PMP-5 → H_a=160.26m and PMP-6 → H_a=160.06m) and in the same time the running conditions assigned to the pumps by the relative rotation ratio for an optimal work (minimum power consumption).

All running parameters corresponding to the considered group of six simultaneous working pumps were obtained through the numerical simulation. As an output example, figure 3.5 presents the water flows through the components of the system formed by the headrace and the pipes network for one specific situation, i.e. the one developed at the maximum consumption moment of 19:30.

The minimum water demand, happening at 04:00, is 0.61 m^3/min, the pumped discharge at PMP-5 and PMP-6 being 0.06 m^3/min, while PMP-3 is turned off. As regarding the maximum water demand at 19:30, the water flow at the reservoir entrance is 1.64 m^3/min, while at the 6 pumps, all working, the water discharges are as follows: PMP-1 → Q = 0.27 m^3/min, PMP-2 → Q = 0.27 m^3/min, PMP-3 → Q = 0.27 m^3/min, PMP-4 → Q = 0.28 m^3/min; PMP-5 → Q = 0.28 m^3/min, PMP-6 → Q = 0.28 m^3/min.

The pumped water discharge aside of hydraulic head behavior in time for the simultaneous working group of 6 pumps along a 24 hours time period is given by figure 3.6. Further on, figure 3.7 presents power consumption development for the considered time period and the hydraulic head produced at ending joint J-6 (reservoir entrance), respectively.

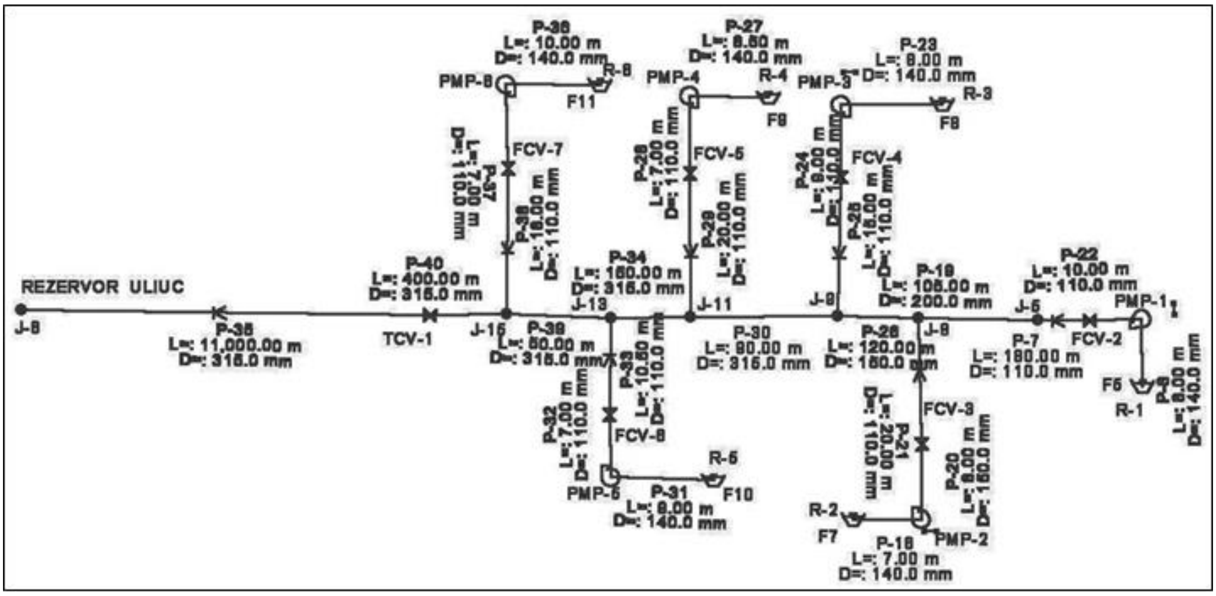


Fig. 3.2 Water catchment system: pipes network and headrace [5]

As regarding the time development of the hydraulic head, one can notice that at the minimum consumption moments the pumps head upper limit reaches about 41.00m and then dropping towards the lower limit of about 33.00m, while at the maximum consumption moments the head goes for the upper limit of about 48.00m and drops at about 40.00m.

As a representative situation, figure 3.8 brings the characteristic curves – the pump hydraulic head and the system head vs. discharge – of two pumps (PMP-1 and PMP-4) working simultaneously at the maximum consumption hour 19:30.

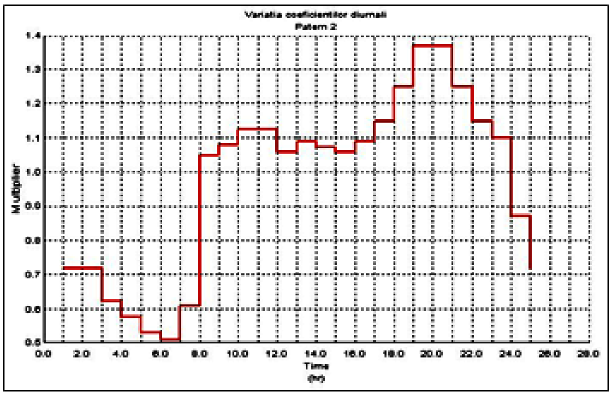


Fig. 3.3 Water demand hourly variation ratio along one day

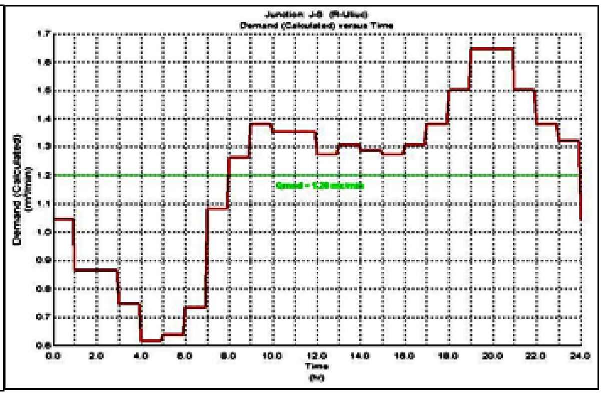


Fig. 3.4 Water demand behavior along one day at joint J-6

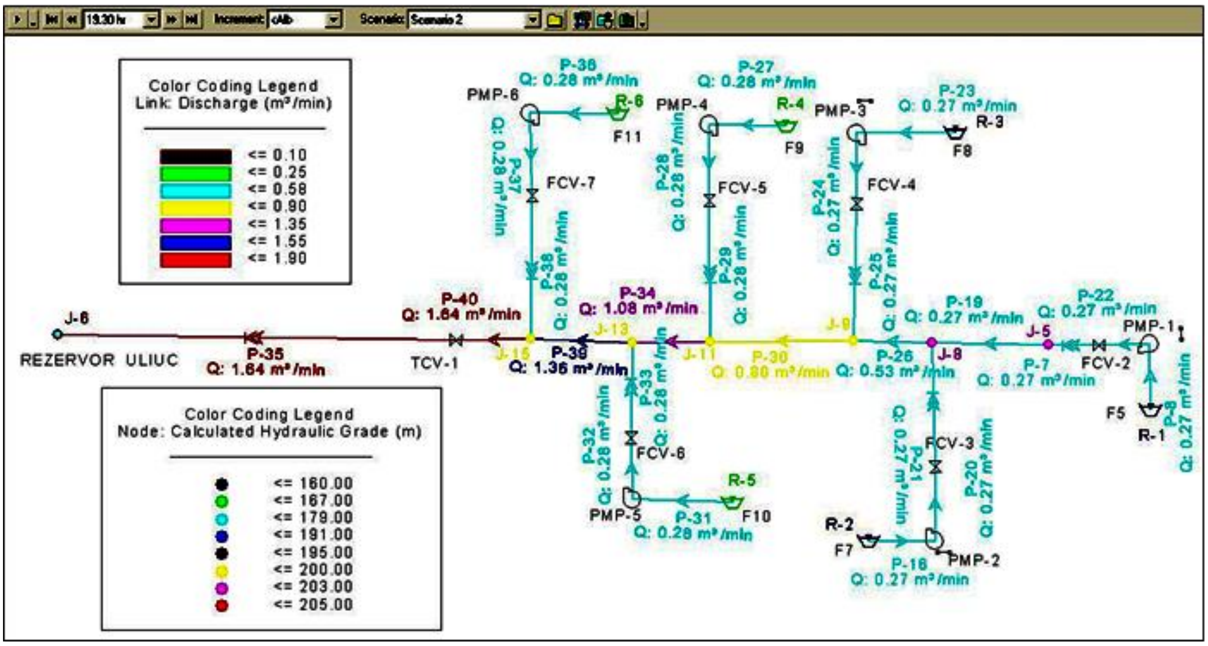


Fig. 3.5 Water flow development at two specific moments: top – h04:00, below – h19:30

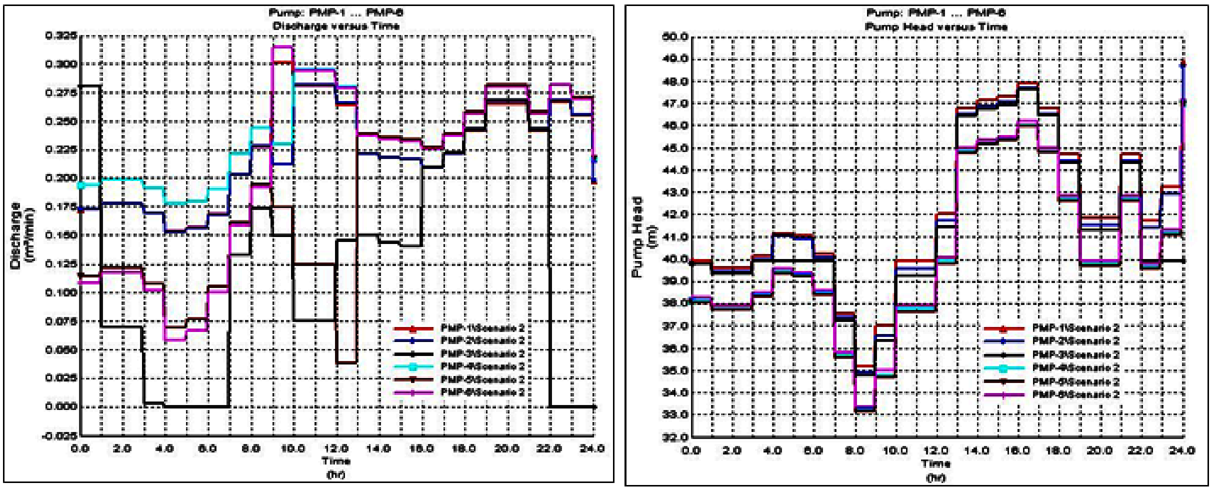


Fig. 3.6 Pumps water discharge (left) and hydraulic head (right) behavior for the 24 hours time period

By studying the results and the processed graphic outputs, the followings can be found:

- the head loss along the longest path of the scheme at the moment of maximum consumption is 5.94m (the drop from 200.56 to 194.62 in figure 3.9);
- the hydraulic head of the system ending point - reservoir entrance section - at the most demanding moment, 19:30 hours, when the maximum supplied discharge is of 1.64 m^3/min, reaches the minimum level of 194.62m, a value still above the maximum water level in this storing basin (192.00m) with 2.62m;
- at the moment of maximum consumption each pump runs near the point of optimum work (BEP);
- the power consumed by each pump along the running period of 24 hours leads towards an optimum cumulated value;
- since the pumps endowing the catchment drillings (P5, P7, P8, P9, P10, P11) work in their optimum

running domain, their type assignment was properly achieved;

- the pipes network and headrace present properly established geometrical parameters, the system head losses being placed below accepted limit and all demands asked by running operations being satisfied.

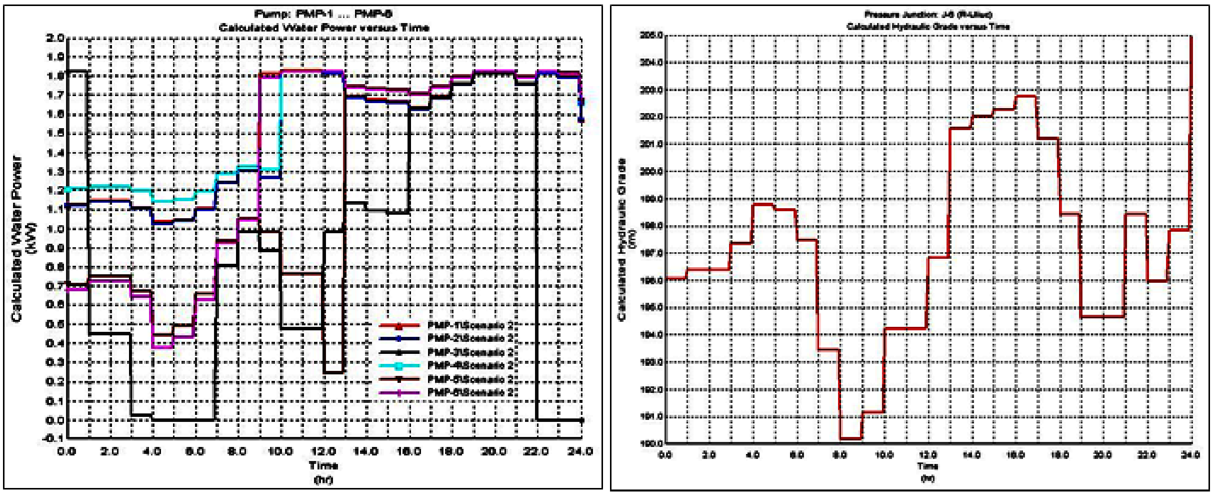


Fig. 3.7 Power consumption (left) and ending joint J-6 hydraulic head (right) development along the considered 24 hours time period

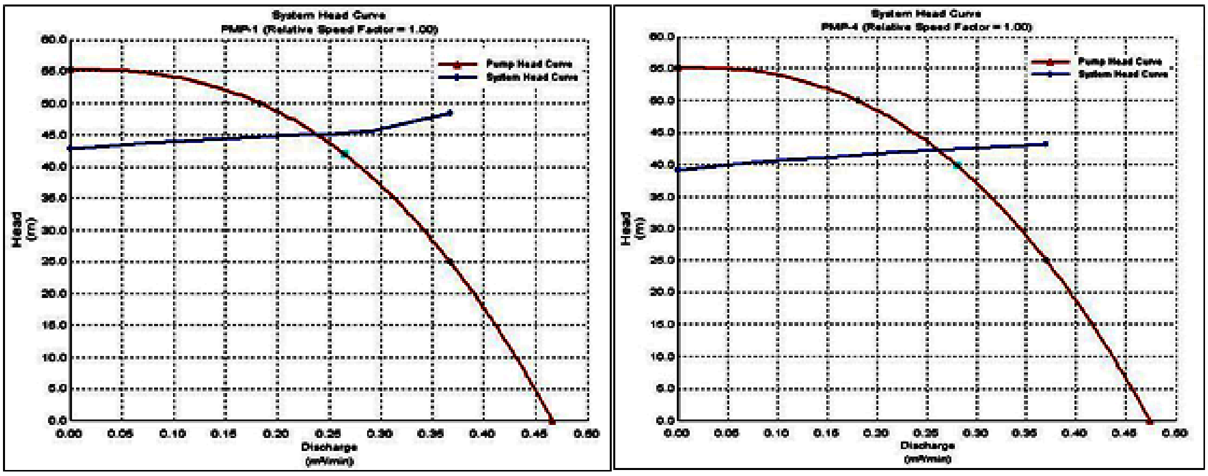


Fig. 3.8 Pumps characteristic curves – pump hydraulic head and system head vs. discharge – at the maximum consumption hour 19:30

4. CONCLUSIONS

The main goal of the ground water motion modeling was to explore the possibilities of running the specific catchment line, comprised of 9 drillings of 0.26 / 0.30 m in diameter and 4.00 – 5.35 m in depth. The system is considered to be endowed with 9 pumps of variable rotation speed, ran by MS 4000 engine type A01905 SP 17–5 50 Hz.

As about the catchment overall efficiency, three out of four running situations present an estimated value slightly above one. Thus, in case of an unfavorable situation given by the groundwater level variation in the catchment area (six drillings employed to run simultaneously, out of nine) there are still three running options that are going to ensure the demanded discharge for fresh water supply.

As about the unsteady water flow model, there is appreciated that the analyzed catchment system and its adjoined headrace have proper assigned running parameters, which ensure in optimized conditions the fresh water requirement along the entire standard considered running time period of 24 hours.

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