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PARAMETRIC STUDY REGARDING THE INTERACTION OF WATERWAYS LOCATED IN KARST FISSURE AREAS AND GROUNDWATER

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CONTENT

1. General characteristics of the natural and built environment in the area of waterways

1.1. Aquifers

The research area of the present paper is located in the North of Southern Dobrogea, in the region between the Capidava - Ovidiu and Rasova - Costinesti faults, the Danube and the Black Sea.

Provision of water supply in the localities in South Dobrogea, including those in the seaside area and in the Constanta city, have as a majority water sources fronts for catching with wells drilled. Water catchments exploit two hydrostructures with regional development: a free-level hydrostructure, embedded in calcareous formations of the Sarmatian age, called the upper Sarmatian aquifer and a lower hydrostructure partially free and predominantly under pressure, of medium depth, embedded in calcareous-dolomitic formations of Jurassic- Cretaceous age, called the Jurassic-Cretaceous lower aquifer complex.

The Sarmatian upper aquifer is a free-level, groundwater aquifer for South of Dobrogea, which suppply by rainfall and by diffuse water losses from irrigation systems. In general, surface water infiltrations penetrate through the loessoid superficial layers until they meet the Sarmatian limestone plate. In the southern part of South Dobrogea, there is a direct interaction between the aquifers, as the lower aquifer complex is free level, which favors communication with the upper aquifer. In the researched area (northern South Dobrogea), the lower aquifer complex is under pressure, and the upper aquifer is rare.

The Black Sea, through the existing lake system in the seaside area (Techirghiol, Tatlageac and Mangalia lakes) is the main drainage center of the upper aquifer. The secondary drainage center is represented by the Dunare-Marea Neagra waterway, which intercepts the aquifer for the last 5-6 km before the junction with the Black Sea.

The main flow directions of the upper aquifer are oriented East-West, with some exceptions:

- in the North-East area, due to two drainage components (one to the East - Black Sea and the other to the North), the major flow directions are South-West - North-East;

- in the areas adjacent to the Dunare-Marea Neagra waterway, lakes and valleys, which benefit from a continuous supply of water from the upper aquifer, the flow directions suffer local disturbances.

The quality of groundwater stored in Sarmatian deposits was significantly influenced by the existing hydrodynamic conditions. Predominantly, the groundwater contamination with substances from agricultural activities, in the category of pesticides, nitrates and nitrites, is caused by the aquifer recharging through infiltration from precipitation and irrigation. In the South-Eastern part of South Dobrogea, in the water catchments wells which are in exploitation, important contributions of the deep waters with inorganic hydrogen sulfide content were found.

The Jurassic-Cretaceous lower aquifer complex represents a unitary aquifer in relation to the entire southern Dobrogea territory. In large proportions, about 60% of the southern Dobrogea territory, the aquifer is under pressure, while in the vicinity of the Danube River and in the South, there is an area where this aquifer is with free-level and can be fed directly by infiltration of precipitation, irrigation channels and vertical drainage from the upper aquifer.

The general flow direction of the lower aquifer complex is oriented from South to North (from the border with Bulgaria) and becomes oriented East - West in the vicinity of the Capidava - Ovidiu fault. The Black Sea, through Siutghiol lake is the main natural drainage center of this lower aquifer.

The groundwater quality in the lower aquifer is adversely affected, especially in the southern areas, where it is free level and is in direct interdependence with the Sarmatian aquifer. In this area there is a water supply from the upper aquifer through descending vertical drainage and at the same time pollutants from the category of pesticides, nitrates and nitrites can infiltrate.

In the researched area, groundwater circulates in fissure-karst environments, which can also be formed from underground channels, with different widths. The circulation of water in these environments starts from one end of the underground channel, where water infiltrates from the surface of the limestone massif, and flows to the other end, where the drainage of groundwater occurs.

1.2. Waterways

1.2.1. Dunare – Marea Neagra waterway

The Danube - Black Sea waterway was built between the years in the '70s, was put into operation in 1983 and has a length, between the Danube at Cernavoda (km 299,3 on the river) and the Black Sea (Constanta Sud harbor), of 64,41 km.

The main constructive characteristics of the Danube - Black Sea waterway are:

- The waterway length between the Danube at Cernavoda (km 299.3 on the river) and the Black Sea (the Constanta Sud harbor) is 64.41 km.
- Two locks were provided in the construction scheme: Cernavoda, which ensures the connection of the waterway with the variable levels of the river and Agigea, in order to communicate with the Black Sea level, in the Constanta Sud harbor.
- The waterway consists of three sections:
  - Section I: located between the Danube and the upstream head of the Cernavoda lock, which has a length of 4,105 km;
  - Section II: located between the downstream head of the Cernavoda lock and the upstream head of the Agigea lock, which totals a length of 57,991 km;
  - Section III: located between the downstream head of the Agigea lock and the “0” point in the South Constanta harbor, with a length of 1,510 km.
- The characteristic levels, the depths and the transit capacity are summarized in Table 1.1., below:

Specifications	M.U.	Section I	Section II	Section III
Maximum level with1% insurance	rmBS	+12,00	+8,50	+0,50
Normal / medium level	rmBS	+6,50	+7,50*	-0,50
Minimum level	rmBS	+2,95**	+7,00	-1,10
Exceptional minimum level	rmBS	+2,75***	+6,00	-1,10
Waterway bottom level	rmBS	-1,50	+0,50	-7,50
The water depth - at normal / medium level - at minimum level	 rmBS rmBS	 +8,00 +4,45	 +7,00 +5,50	 +7,00 +6,40
Water transit capacity - at normal / medium level - at minimum level	 m³/s m³/s	 -500 250	 315 250	 315 250

* maximum operating level on section II = +8,00 rmBS
** level with 94 % insurance
*** level with 97 % insurance

Table 1.1. – Characteristic levels, depths and transit capacity of the Dunare – M. Neagra waterway

Throughout the waterway length, the depth at the normal level of exploitation is 7.00 m, the elevation of the waterway bottom is: on section I: -1,50 rmBS; on section II: +0,50 rmBS; on section III: -7,50 rmBS.

- The waterway functionality is also ensured with other constructions help:
    - a pumping station from Cernavoda, which has an installed flow of 211,50 m³/s and is located on the bypass waterway. This ensures the needed water in the waterway section II, in case the Danube levels at Cernavoda are lower than +7,50 rmBS;
    - the dam from the pumping station vicinity, which ensures the gravitational transit of the Danube flows in the section II in case the river levels exceed the level of +7.50 rmBS. The dam is located at km 2+188 of the waterway bypass;
    - the installations and galleries within the Agigea lock through which the transition of the flood flows from the hydrographic basin of the waterway to the sea and the maintenance of an optimal level of exploitation (+7,50 mrMB) in the waterway section II;
    - water pumping stations that come from drainage and flood prevention of some localities and lands.

1.2.2. Poarta Alba – Midia, Navodari waterway

The Poarta Alba - Midia, Navodari waterway was built between 1980 and 1987 and has a length of 27.5 km, from the intersection with the Dunare – Marea Neagra waterway, to the Midia harbor. The eastern branch of the waterway, which crosses Tasaul lake (Navodari), measures 5 km.

From a constructive point of view, the waterway is unsealed on the bottom, so that it intercepts the Jurassic - Cretaceous lower aquifer, on a sector with a 4 km length and a 12 m thickness, out of the 300 m total thickness of the aquifer in this sector.

During the execution of the Poarta Alba - Midia, Navodari waterway due to the dewatering works necessary for the excavations, decreases of groundwater levels were observed, including hydrodynamic levels from the observation wells and from the catchment wells of Constanta city.

When the construction was completed and put into operation, the waterway was filled with water and there were variations in the piezometric head caused by the waterway water level, discovered in observation wells. Currently, the waterway is in operation and it has been found that it has a general effect of supplying the lower aquifer (from the upstream section to the Ovidiu lock) with water from the Danube. Some of these flows that come from the waterway and supply the aquifer resource, are then drained by the waterway, but downstream of the lock (approximately 0,5 m^3 / s).

The main constructive characteristics of the Poata Alba – Midia, Navodari waterway are:

- the waterway follows Valea Adanca (Nazarcea), crosses the plateau from Ovidiu through the limestone quarry area, falls on the northern limit of Siutghiol (Mamaia) lake and flows into the Midia harbor.
- the waterway length from the detachment from the Dunare – Marea Neagra waterway, to the Midia harbor is 27,500 km. The eastern branch, which crosses Tasaul (Navodari) lake, measures 5 km.
- the construction scheme provides for the extension of the water level in the section II of the Dunare – Marea Neagra waterway, until after crossing the plateau area, at the Ovidiu lock, where this level drops from the level of +7.50 mrMB to the level of the average exploitation level of the Siutghiol (Mamaia) and Tasaul (Navodari) lakes of +1.25 rmBS. The branch that ensures the connection with the Midia harbor has a Midia - Navodari lock, through which the connection of the waterway with the Black Sea level is made.
- The waterway consists of three sections:
  - Section I: between the detachment from the section II of the Dunare - Marea Neagra waterway and the upstream head of the Ovidiu lock, with a 15,230 km length;
  - Section II: between the downstream head of the Ovidiu lock and the upstream head of the Midia - Navodari lock, with a 10,041 km length;
  - Section III: between the downstream head of the Midia - Navodari lock and the Midia harbor, with a 1,834 km length.

- the waterway section has a trapezoidal shape, except for the area of the Ovidiu plateau, where this section has a rectangular shape, being made between support walls.

The minimum width at the base of the waterway section at the upper level is:

- in the area with trapezoidal section and slope 1:4,5 and 1:4 36,00 m
- in the area with trapezoidal section and slope 1:2 and 1:1 42,00 m and 47,00 m
- in the area with rectangular section 50,00 m
- in the waiting ports of the locks, between the mooring constructions 90,00 m
- on Section III, at the connection with Midia harbor 90,00 – 150,00m.

- The characteristic levels, the depths and the transit capacity are summarized in Table 1.2., below:

Specifications	M.U.	Section I	Section II	Section III
Maximum level with1% insurance	rmBS	+8,50	+2,00	+0,50
Normal / medium level	rmBS	+7,50*	+1,25	-0,50
Minimum level	rmBS	+7,00	+1,00	-1,10
Exceptional minimum level	rmBS	+6,00	+1,00	-1,10
Waterway bottom level	rmBS	+2,00	-4,25	-6,60
The water depth - at normal / medium level - at minimum level	 rmBS rmBS	 +5,50 +5,00	 +5,50 +5,25	 +5,50 +5,00
Water transit capacity - at normal / medium level - at minimum level	 m^3/s m^3/s	 225 42	 51,0 38,2	 50,5 37,5

* maximum operating level on section II = +8,00 rmBS

Table 1.2. – Characteristic levels, depths and transit capacity of the Poarta Alba – Midia, Navodari waterway.

1.3. Interaction of watrerways with aquifers

From a geological point of view, the formations of sedimentary blanket (of which the store rocks of the two hydrostructures are part) are discordantly arranged on an old crystalline foundation. They present an uneven spatial distribution, which leads to the idea that their sedimentation took place in an active dynamic zone, of structural blocks with different positions (high or low), in different geological stages.

The geological and structural elements are shown in: Appendix 2 – Structural map of the investigated area, Appendix 6 – Hydrodynamic map of the Jurassic – Cretaceous lower aquifer, Appendix 7 – Hydrogeological section 1 – 1'.

The structure of the Jurassic – Cretaceous rocks is particularly complicated due to the existence of the system of vertical or subvertical faults (see the appendix drawings): Appendix 3 - Hydrogeological section 1-1' and 2-2' of the researched area, Appendix 4 - Hydrogeological section 3-3' and 4-4' of the researched area, Appendix 5 - Geological section 5-5' and 6-6' of the researched area), which divides it into tectonic blocks.

The faults were formed following the deposition of Jurassic limestones and were active throughout the Cretaceous and Paleogene formations deposits, most of which slowed to move before the Sarmatian formations deposition.

Over the Jurassic – Cretaceous permeable carbonate formations, which are buried to the west, reaching the vicinity of the Danube at a thickness of 1000 m and descend in steps to the east (coastal area), are deposited, more in the eastern half, packages of Senonian, Eocene and Badenian semipermeable rocks.

On the South Dobrogea scale, the aquifer store rock of the upper hydrostructure, represented by Sarmatian limestone, is in turn deposited over the formations presented above.

In the researched area in this paper, Sarmatian limestones are generally absent and therefore the upper hydrostructure may rarely occur.

The complex system of vertical and horizontal faults in the researched area generated a series of tectonic blocks, with variable dimensions and elevations. In the following, each tectonic block will be detailed.

The area between the **Capidava - Ovidiu fault and the Cernavoda - Constanta fault** includes a number of 5 tectonic blocks, delimited by means of vertical faults.

Block 1 (Cernavoda) is mainly composed of Jurassic – Cretaceous rocks, which have a thickness between 1000 and 1200 m. The upper limit quota of the complex is between +12 and -175 m. The cover / foundation quota is at -1200 m.

Block 2 (Tortomanu) is mainly composed of Jurassic – Cretaceous rocks, which have a thickness of 800 m. The upper limit quota of the complex is between -320 and -400 m. The cover / foundation quota is at -1130 m.

Block 3 (Castelu) is mainly composed of Jurassic – Cretaceous rocks, which have thicknesses greater than 1040 m. The upper limit quota of the complex is between +10 and -56 m. The cover / foundation quota is at -1180 m.

Block 4 (Poiana) is composed mainly of Jurassic – Cretaceous rocks, which have a thickness of 800 m. The upper limit quota of the complex is between +20 and -10 m. The cover / foundation quota is at -800 m.

Block 5 (Constanta) is composed mainly of Jurassic – Cretaceous rocks, which have a thickness of 500 m. The upper limit quota of the complex is between -15 and -47 m. The cover / foundation quota is at -500 m.

The area between the **Cernavoda – Constanta fault and the Rasova – Costinesti fault** includes a number of 8 tectonic blocks, delimited by means of vertical faults.

Block 6 (Ivrinezu - Pestera) is composed mainly of Jurassic - Cretaceous rocks, which have a thickness between 700 and 800 m. The upper limit quota of the complex is between 0 and -65 m. The cover / foundation quota is between -800 and -850 m.

Block 7 (Siminoc - Ciocarlia) is composed mainly of Jurassic - Cretaceous rocks, which have a thickness between 550 and 650 m, and, in some places, of Sarmatian rocks, which have a maximum thickness of 50 m. The upper limit quota of the complex is between +10 and -25 m. The cover / foundation quota is at -650 m.

Block 8 (Poarta Alba) is composed mainly of Jurassic - Cretaceous rocks, which have a thickness of 700 m. The upper limit quota of the complex is between +10 and -25 m. The cover / foundation quota is at -650 m.

Block 9 (Valul lui Traian) is composed mainly of Jurassic - Cretaceous rocks, which have a thickness between 700 and 800 m. The upper limit quota of the complex is between -80 and -120 m. The cover / foundation quota is at -800 m.

Block 10 (Siminoc - Ciocarlia) is composed mainly of Jurassic - Cretaceous rocks, which have a thickness of 500 m. The upper limit quota of the complex is between -200 and -260 m. The cover / foundation quota is at -800 m.

Block 11 (Poarta Alba) is mainly composed of Jurassic – Cretaceous rocks, which have a thickness of 250 m. The upper limit quota of the complex is between -115 and -170 m. The cover / foundation quota is at -400 m.

Block 12 (Straja) is not composed of Jurassic – Cretaceous rocks.

Block 13 (Eforie - Techirghiol) is not composed of Jurassic – Cretaceous rocks.

In general, the hydrotechnical works executed and in operation, such as waterways, irrigation channels and groundwater sources, lead to significant distortions of the flow regime and to changes in the groundwater quality. The analysis of the hydraulic relations between surface water and groundwater is performed by studying the hydrodynamic spectrum (after Moldoveanu V. 1998).

By analyzing the gradients and the flow directions of the groundwater, the supply and drainage areas can be established. In areas with rainfall deficit, the aquifers supply by water infiltration from irrigation systems, including artificial irrigation or waterways, is an important source of recovery of water resources affected by catchment wells for localities water supplies. (after Moldoveanu V. 1998).

In the case of fissure-karstic aquifers, in carbonated rocks, the karst network is formed by cracks, karstic gaps (channels) formed by the dissolution phenomena. Most of the ways of water penetration into the karst aquifer are capillary or supracapillary fissures and tectonic faults (after Moldoveanu V. 1998).

The continuous interaction between surface waters and groundwater embedded in karst-fissure aquifers presents specific elements, especially as they are adjacent to seaside areas:

- The main aquifer supplying areas and, implicitly, the formation of karst-fissure aquifers are determined by the favorable geological situations, where the carbonated rocks meet on the land surfac and allow the infiltration of precipitation directly into the layer or through the thalweg of valleys.
- The main aquifer discharge areas (drainage) are located in the marine coastal sectors or in natural lakes located near them.

- The existing interference between surface waters (rivers, valleys, lakes or lake systems bordering seaside areas, irrigation channels, waterways, etc.) and groundwater have produced important changes in the water flow regime. These can be rigorously observed by measurements and by drawing up hydrogeological maps with hydrodynamic spectrums.
- In the situation of the waterways exploitation, they may constitute: artificial supplying areas, for certain sectors where were executed and intersect the upper part of the karst-fissure aquifer or drainage areas, in areas where the waterway level quota is lower than the groundwater level quota.
- With the increase of hydrodynamic resources, given the relatively high flow rates of aquifers, there are high risks of occurrence of pollution phenomena coming from agricultural activities.

In general, the water level quota in the waterways imposes the flow regime in the karst-fissure aquifer in the area where it is located and, implicitly, it may create pollution risks if it supplies the aquifer to water.

2. Modeling of interaction between waterways and aquifers

2.1. The researched area

The research area of this paper includes two waterways: Dunare – Marea Neagra, respectively Poarta Alba - Midia, Navodari and is located in northern South Dobrogea, in the region between the Capidava - Ovidiu and Rasova - Costinesti faults, the Danube and the Sea Black.

2.2. Boundary conditions

Mathematical modeling performed through calculation programs, is a useful tool in the study and evaluation of groundwater aquifers, as well as in the design and increase of efficiency in operation of both groundwater resources and various hydrotechnical constructions.

The groundwater flow determination and the pollutants transport from aquifer systems can be done by numerical or analytical modeling of mathematical equations. These equations were taken with given initial conditions, at time t = 0 on the aquifer domain, as well as the boundary conditions given by the values of the functions (Diriclet type conditions) (after Moldoveanu V. 1998).

Groundwater flow and the pollutants transport in a hydrostructure can be described by the analytical or numerical integration of the fundamental equations of hydraulic diffusivity and hydrodynamic dispersion.

Hydraulic diffusivity equation:

$$\frac{\partial h}{\partial t} = a\ div\ grad\ h + \frac{w}{S}$$

where:

$h = z + \frac{p}{\gamma} + const.$ = piezometric head;
$a = \frac{KH}{S}$ = hydraulic diffusivity coefficient;
K = hydraulic conductivity;
w = uniform distributed flow;
$S = \frac{\partial(\gamma m_e H)}{\partial p}$ = storage coefficient.

Hydrodynamic dispersion equation:

$$\frac{\partial (C\rho)}{\partial t} = D\ div\ grad\ (C\rho) - \vec{v}\ grad\ (C\rho) + \frac{C}{m_e}$$

where:

C = concentration;
ρ = density;
D = hydraulic diffusivity coefficient;
$\vec{v}$ = effective velocity

m_e= effective porosity.

These equations require initial conditions and time functions on the aquifer horizon, as well as boundary conditions (at the limit), given by values of Dirichlet-type functions or its derivatives (Neuman-type conditions) on the development boundaries of the aquifer hydrostructure.

Based on the knowledge of the analytical methods for solving groundwater flow and pollutant transport, hydrodynamic spectrum of hydrostructure, based on groundwater level measurements in different time intervals, but also hydrogeological data, the conditions were defined at limit of the selected hydrostructures.

Thus, using the realized hydrodynamic spectrum, the boundary limits were drawn, which were of several types:

- Charged or dischargerd boundary conditions (drawn on potential lines);
- Potential line boundary conditions (drawn in the aquifer directions);
- Watertight boundary conditions (drawn on the basis of structural and geological elements, which prevent the groundwater circulation).

Initial conditions given by the values of the functions $h = h(t, P)$ and $Cp = Cp_0(t, P)$ at time $t = 0$ on the aquifer domain:

$$h(0, P) = h_0(P) \qquad \text{and} \qquad C\rho(0, P) = C\rho_0(P)$$

boundary conditions given by the values of the functions (type Diriclet):

$$h(t, P) \mid_{P \in \Omega} = f(t, P) \qquad \text{and} \qquad C\rho(t, P) \mid_{P \in \Omega} = g(t, P)$$

or of normal derivatives (Neumann type):

$$\frac{\partial h}{\partial n}(t, P) \mid_{P \in \Omega} = F(t, P) \qquad \text{and} \qquad \frac{\partial (C\rho)}{\partial n}(t, P) \mid_{P \in \Omega} = G(t, P)$$

or of a linear combination of their functions and normal derivatives (Fourier conditions):

$$A. h(t, P) + B \frac{\partial h}{\partial n}(t, P) \mid_{P \in \Omega} = \mathcal{F}(t, P) \qquad \text{and} \qquad A'. C\rho(t, P) + B' \frac{\partial (C\rho)}{\partial n}(t, P) \mid_{P \in \Omega} = \mathcal{G}(t, P)$$

on the Ω boundaries of the aquifer development domain (after Moldoveanu V. 1998).

2.3. Model representation

The numerical model was developed for the researched area and simulates the groundwater flow in the Jurassic-Cretaceous lower aquifer.

The studied area covers an area determined by: 68 km – length, respectively 32 km – width, discretized in a network of cells with variable dimensions depending on the areas of interest analyzed. Thus, the horizontal dimensions of the discretization cells are generally 1000 m x 1000 m, but they have a finer discretization of 500 m x 500 m in the groundwater catchments areas, for a greater accuracy of the results. The heights of the discretization cells are equal to the thicknesses of the Jurassic – Cretaceous lower aquifer, intercepted in observation wells, and are between 12.80 m and – 1205.33 m.

The cells dimensions of the discretization network are small enough to be considered the hypothesis that the parameters variation is continuous from one cell to another, and at the same time large enough to include fractured areas, and the model is regional scale, so the model flow can be considered an equivalent porous medium. (Dassargues, 1995).

The construction of the Jurassic-Cretaceous lower aquifer flow model was accomplished by introducing lithological data, boundary conditions, observation wells and catchment wells in the calculation program.

The lithology of the Jurassic – Cretaceous lower aquifer was determined by interpolation, using as base data the thickness of the aquifer detected in each observation well. Thus, the calculation program by means of the data presented in table 2.1. generated two surfaces, called the bed, respectively the roof, which delimit the aquifer researched in this paper.

Crt. No.	Locality	Well	Well depth [m]	Land quota [m]	Upper quota [m]	J-K aquifer thickness	Final well quota [m]	Bottom quota [m]
1	Basarabi (Murfatlar)	F 5035	501.20	15.88	-79.12	605.00	-589.12	-684.12
2	Poarta Alba	F 5036	500.70	23.07	5.07	1182.00	-1158.93	-1176.93
3	Poarta Alba	F 5037	500.00	27.33	-17.67	705.00	-677.67	-722.67
4	Valul lui Traian	F 1 (5039)	500.60	32.60	-91.40	576.00	-543.40	-667.40
5	Palas	F 5040	499.70	42.06	-111.94	596.00	-553.94	-707.94
6	Constanta Cismea I	F 5041	499.70	4.21	-46.29	499.50	-495.29	-545.79
7	Basarabi - capt	F 5042	700.00	18.00	-24.00	708.00	-690.00	-732.00
8	Tortomanu	F 5044	1187.70	33.00	-354.00	770.00	-737.00	-1124.00
9	Dunarea	F 5045	847.20	13.10	-155.90	678.00	-664.90	-986.90
10	Pestera	F 5046	700.00	43.67	-14.33	742.00	-698.33	-756.33
11	Siminoc	F 5052	743.40	50.00	-17.20	629.80	-579.80	-647.00
12	Castelu	F 5053	1200.30	20.97	-139.03	1090.00	-1069.03	-1229.03
13	Baraganu	F 5060	628.40	77.63	-140.37	247.50	-169.87	-387.87
14	Cernavoda	F 5061	1199.00	14.30	12.80	1190.50	-1176.20	-1177.70
15	Costinesti	F 5068	600.70	8.68	-437.82	453.50	-444.82	-891.32
16	Techirghiol	F 5069	609.80	15.50	-351.50	211.00	-195.50	-562.50
17	Cumpana	F 5070	650.20	48.88	-238.12	255.00	-206.12	-493.12
18	Medgidia - capt oras	F 5091	953.15	22.45	-2.55	790.00	-767.55	-792.61
19	Nazarcea capt.	F 1H	700.30	44.67	-3.33	1202.00	-1157.33	-1205.33
20	Nazarcea ISCIP	F 2	655.00	46.74	-5.74	1197.52	-1150.78	-1203.26
21	Rasova	F 2H	568.20	17.49	-36.51	846.00	-828.51	-782.51
22	Lazu	F 8H	726.20	14.29	-369.71	416.00	-401.71	-785.71
23	Ivrinezu Mare	F 1	188.00	13.72	-22.58	750.00	-736.28	-772.58
24	Medgidia - capt oras	F 1 (Car.)	550.00	13.28	-130.72	1056.00	-1042.72	-1186.72
25	Medgidia - SP Tortomanu	F 2	700.00	11.43	-408.57	787.00	-775.57	-1195.57
26	Valea Seaca	F 1	400.00	24.11	-90.89	585.00	-560.89	-675.89
27	Medgidia - capt CT	P 0	265.00	16.11	-19.95	779.00	-762.89	-798.95
28	Constanta	P 23	146.00	64.20	-52.80	432.36	-368.16	-485.16
29	Constanta	P 24	87.00	43.06	-29.94	477.00	-433.94	-506.94
30	Constanta Cismea I	P 25	66.00	15.92	-35.08	499.00	-483.08	-534.08
31	Constanta Nord	P 26	76.00	11.94	-53.06	485.00	-473.06	-538.06
32	Constanta Nord	P 27	80.00	3.22	-61.78	486.00	-482.78	-547.78

Table 2.1. – Lithological data of the Jurassic – Cretaceous lower aquifer

The boundary conditions imposed for the creation of the hydraulic model were determined by interpolation, based on the hydrodynamic map of the Jurassic – Cretaceous lower aquifer. In the numerical model, imposed load limit conditions were specified, specified in bellow table 2.2. The Nordic border, represented by the Capidava - Ovidiu fault, was considered a watertight border. Also, both the Siutghiol lake and the section of the waterway the Poarta Alba – Midia, Navodari, which is in direct contact with the Jurassic – Cretaceous lower aquifer (located between the Ovidiu lock, respectively 3 km upstream in the waterway) will benefit from a 1,25 m imposed potential.

Crt. No.	Border	Section	Length [m]	Potential type	Imposed potential
1	Northern	-	-	watertight	-
2	Western	1 - 2	4234	variable	9.2 - 9.0
		2 - 3	7076	linear	9
		3 - 4	3244	variable	9 - 12
		4 - 5	6640	linear	12
		5 - 6	2448	variable	12 - 10
		6 - 7	3528	variable	10 - 9.5
		7 - 8	8702	variable	9.5 - 9
3	Southern	8 - 9	3230	variable	9 - 10
		9 - 10	1802	variable	10 - 11
		10 - 11	2750	variable	11 - 12
		11 - 12	6282	variable	12 - 11.5
		12 - 13	7156	variable	11.5 - 12
		13 - 14	10032	variable	12 - 19
		14 - 15	8808	variable	19 - 21
		15 - 16	27278	variable	21 - 18.7
4	Easthern	16 - 17	16242	variable	18.7 - 18
		17 - 18	718	linear	18
		18 - 19	4802	variable	18 - 11
		19 - 20	18670	variable	1 - (-1)
		20 - 21	1062	linear	0
5	Siutghiol lake			linear	1.25
6	3 km sector in direct contact with the aquifer		3000	linear	1.25

Table 2.2. – Imposed boundery conditions

The observation wells data located in the researched area are centralized in table 2.3.

The 2D coordinates (x, y) for each observation well were determined by means of a local coordinate system located as follows:

- The origin of the coordinates system is on the Danube river, south - west of Rasova;
- The Ox axis is located in the direction of the Rasova - Costinesti fault;
- The Oy axis is located in the Danube river direction.

The levels of hydrostatic levels from the observation wells were determined following the measurements performed in 2018.

Crt. No.	Locality	Well	Local coordinates (model)		Land quota	NHs (2018)
			x [m]	y [m]	[m]	Quotas [m]
1	Basarabi (Murfatlar)	F 5035	37099.7666	13297.7436	15.88	7.1
2	Poarta Alba	F 5036	36537.8339	18090.6771	23.07	13.15
3	Poarta Alba	F 5037	37556.9580	19075.2914	27.33	9.6
4	Valul lui Traian	F 1 (5039)	42984.6574	15528.7713	32.60	5.82
5	Palas	F 5040	47493.1840	18578.3388	42.06	2.7
6	Constanta Cismea I	F 5041	49111.6481	26373.5305	4.21	0.57
7	Basarabi - capt	F 5042	36200.4523	14975.6964	18.00	9.82
8	Tortomanu	F 5044	15104.7347	21323.5673	33.00	8.80
9	Dunarea	F 5045	1450.8971	26676.9677	13.10	9.02
10	Pestera	F 5046	18142.6074	2535.9964	43.67	10.15
11	Castelu	F 5053	26773.8997	20373.3085	20.97	10.07
12	Baraganu	F 5060	41266.8374	6212.6580	77.63	16.75
13	Cernavoda	F 5061	1090.6785	14058.5439	14.30	12.01
14	Techirghiol	F 5069	56808.4853	11582.8823	15.50	14.01
15	Cumpana	F 5070	51621.6116	13809.2180	48.88	18.5
16	Medgidia - capt oras	F 5091	23417.9633	15069.3299	22.45	-
17	Nazarcea capt.	F 1H	35353.2144	21151.8841	44.67	10.15
18	Nazarcea ISCIP	F 2	35160.0076	20717.7792	46.74	10.8
19	Rasova	F 2H	1255.5474	1255.5474	17.49	9.12
20	Lazu	F 8H	54878.5903	16583.3787	14.29	-
21	Ivrinezu Mare	F 1	9328.8705	4165.0696	13.72	11.1
22	Medgidia - capt oras	F 1 (Car.)	24450.7068	15561.6760	13.28	9.81
23	Medgidia - SP Tortomanu	F 2	23698.4415	16915.4534	11.43	11.82
24	Valea Seaca	F 1	40934.3303	15499.6499	24.11	5.02
25	Medgidia - capt CT	P 0	23145.1936	15675.1893	16.11	11.68
26	Constanta	P 23	49711.2935	23106.0808	64.20	0.17
27	Constanta	P 24	49379.4343	24512.7633	43.06	1.42
28	Constanta Cismea I	P 25	49340.3607	25701.3087	15.92	0.12
29	Constanta Nord	P 26	49462.7947	27715.9392	11.94	0.83
30	Constanta Nord	P 27	49714.5058	28109.8365	3.22	0.41

Table 2.3. – Observation wells in the researched area

The exploited flows from the groundwater catchments located in the areas adjacent to the waterways, which supply the Constanța city, Medgidia town, Basarabi town and Valul lui Traian commune are expressed in table 2.4. presented below.

The values of the exploited flows were provided by the Raja Constanta water operator.

Crt. No.	Water catchment	Exploited flow	
		[m³/day]	[l/s]
1	Caragea Dermen	55119.74	637.96
2	Cismea I	133505.97	1545.208
3	Cismea II	29926.20	346.368
4	Constanta Nord	18066.24	209.1
5	Basarabi I	39391.49	455.92
6	Basarabi II	6092.93	70.52
7	Valul lui Traian	16321.00	188.9
8	Medgidia town	38880.00	450
9	Medgidia for Constanta city	17280.00	200

Table 2.4. – Exploited flows from the underground catchments

2.4. Model used / Performance

In the present research paper, based on the hydrogeological conditions presented in the first research report, a calculation model of the researched area was built and numerical simulations were performed for different flow scenarios using the GMS program.

Groundwater Modeling System (GMS) is a programs package that can be used to simulate groundwater flow in a three-dimensional environment. This package also includes the Modflow, Modpath and Mt3d programs, which were used for various simulations in this research paper.

Modflow is a complete program with an intuitive and easy-to-use interface that can simulate, two-dimensional (2D) or three-dimensional (3D) groundwater flow, as well as the pollutants transport. The program benefits from a logically structured menu, which can be easily accessed and allows:

- easy creation of the model grid and selection of measurement units;
- convenient allocation of model properties and boundary conditions;
- performing number simulations;
- model calibration using manual or automatic techniques;
- pumping flows optimization and wells location;
- results visualization in two-dimensional (2D) or three-dimensional (3D) form.

Modpath is a program from GMS package, through which you can determine the flow directions, pathlines and groundwater transit times, on each of the three directions (x, y, z).

Through the Mt3d program, simulations of pollutant transport through groundwater can be performed. It takes all the data from the flow model and starting from an initial concentration in the aquifer, depending on the sources of contamination and the processes of advection, dispersion, retardation, can determine the distribution of the concentration in the aquifer at any time during the simulation.

This model was created to evaluate the interaction between the Dunare – Marea Neagra and Poarta Alba - Midia, Năvodari waterways located in fissure - karst areas, with groundwater.

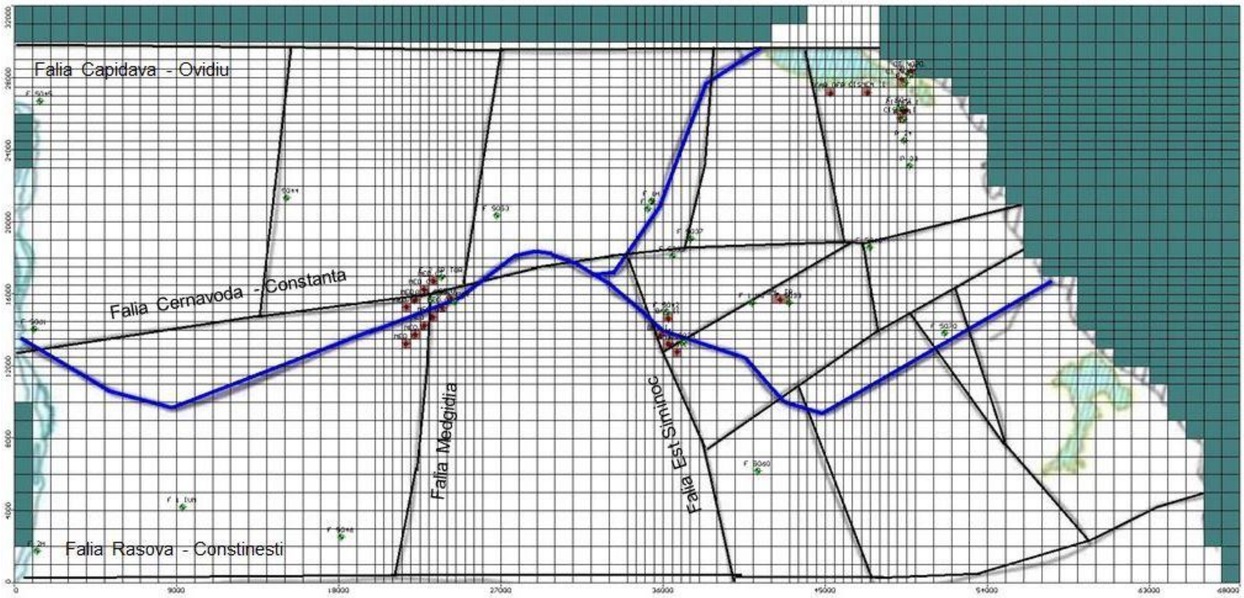


Figure 2.1. – Jurassic – Cretaceous lower aquifer model

2.5. Model calibration

The calibration of the flow model was performed in permanent flow regime, based on the quotas of hydrostatic levels from observation wells, measured in 2018. The boundary conditions used were of the imposed potential type and imposed flow type. The imposed potential type conditions were established by interpolation based on the piezometric map of the Jurassic - Cretaceous lower aquifer, while for the imposed flow type conditions, the data provided by the Raja Constanța water operator were used.

The water level quotas in the Dunare – Marea Neagra and Poarta Alba – Midia, Navodari waterways have different values depending with the provisions of the operating and maintenance regulations of waterways. On the north-eastern section of the Poarta Alba - Midia, Navodari waterway, in the area where the waterway is in direct contact with the lower aquifer, the quota of the water level measured after the Ovidiu lock is 1,25 m. The same quota of 1,25 m was introduced in the Siutghiol lake area. Along the two waterways, Dunare – Marea Neagra, respectively Poarta Alba – Midia, Navodari, except for the section where the waterway is in direct contact with the lower aquifer, the imposed piezometric head were established by interpolation based on the piezometric map of the Jurassic - Cretaceous lower aquifer. In the southern area, there is a significant hydraulic gradient north of the Lazu - Cumpana fault. This is due to the lack of carbonate formations south of the Lazu - Cumpana fault. In this area, the hydraulic continuity of the aquifer is ensured by the Cenomanian deposits (after Moldoveanu V., 1998).

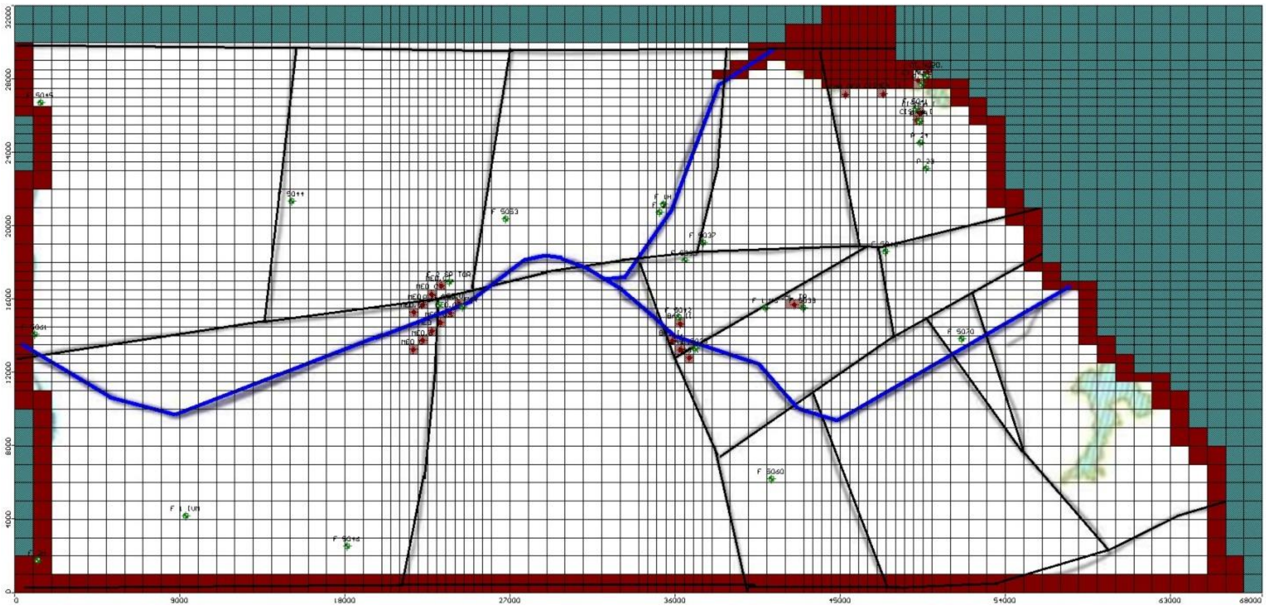


Figure 2.2. – Boundary conditions imposed on the model

The imposed flow boundary conditions are expressed by the flows catched from the lower acfiver. In the numerical model, the water catchments of the Constanta city, Murfatlar and Medgidia towns, but also the Valu lui Traian commune catchment were represented by the pumping wells from which various flows are extracted (figure 2.1.).

The model calibration process was performed by the method of successive tests, by adjusting the values of hydraulic conductivity until the time when the calculated levels in all the observation wells were close to the measured levels.

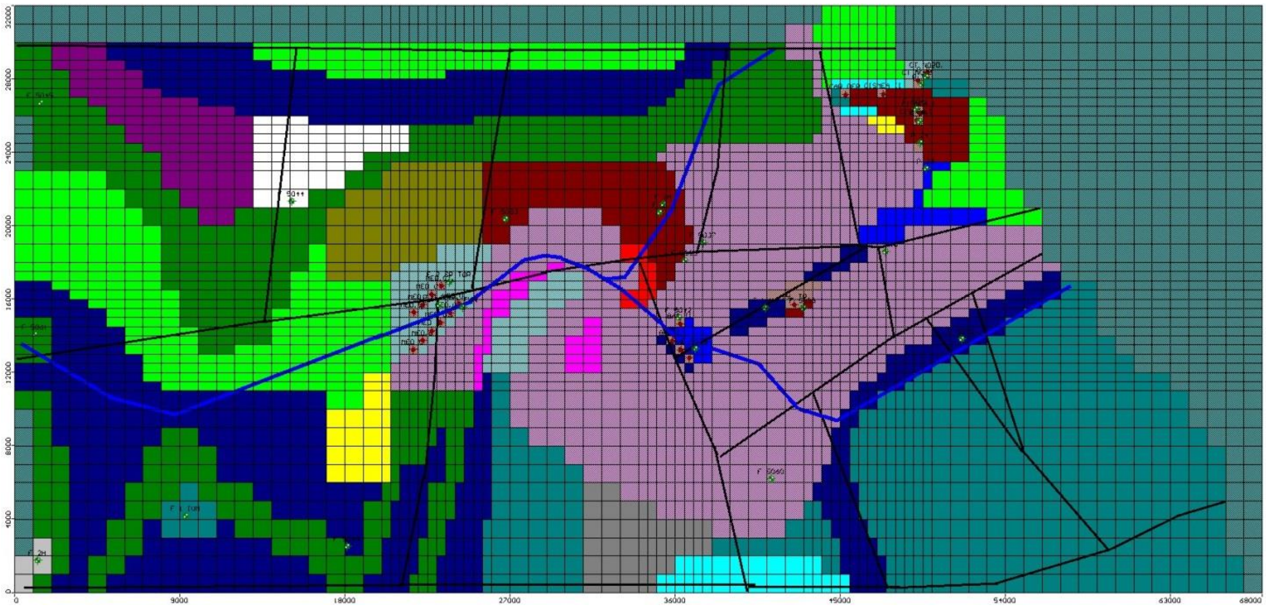
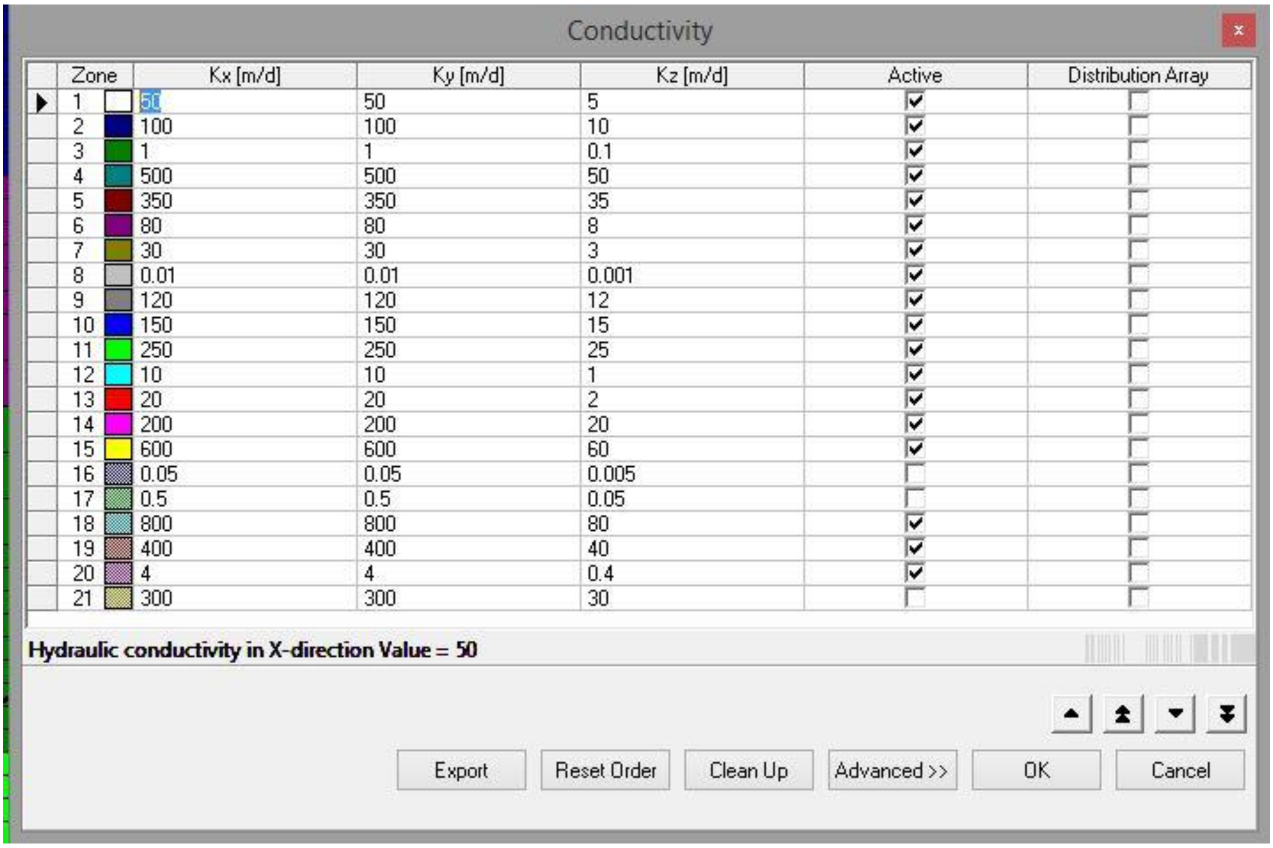


Figure 2.3. – Distribution of hydraulic conductivities used for model calibration



Conductivity

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]	Active	Distribution Array
1	50	50	5	☑	☐
2	100	100	10	☑	☐
3	1	1	0.1	☑	☐
4	500	500	50	☑	☐
5	350	350	35	☑	☐
6	80	80	8	☑	☐
7	30	30	3	☑	☐
8	0.01	0.01	0.001	☑	☐
9	120	120	12	☑	☐
10	150	150	15	☑	☐
11	250	250	25	☑	☐
12	10	10	1	☑	☐
13	20	20	2	☑	☐
14	200	200	20	☑	☐
15	600	600	60	☑	☐
16	0.05	0.05	0.005	☐	☐
17	0.5	0.5	0.05	☐	☐
18	800	800	80	☑	☐
19	400	400	40	☑	☐
20	4	4	0.4	☑	☐
21	300	300	30	☐	☐

Hydraulic conductivity in X-direction Value = 50

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Figure 2.4. – Hydraulic conductivities values used for model calibration

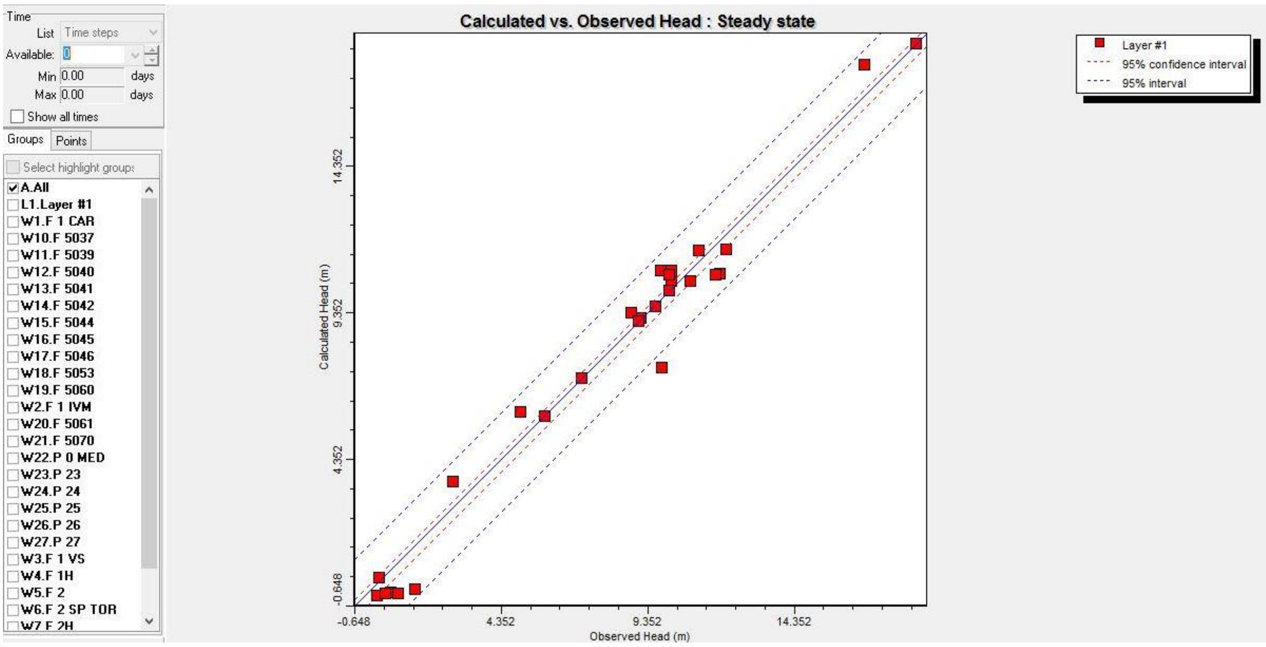

Figure 2.5. – Calculated levels vs measured levels graph in observation wells after model calibration

In general, a numerical model is considered to be well calibrated if the difference between the calculated and measured levels in all observation wells is at most 1,0 m. In this model, differences greater than 1,0 m were found between the calculated and measured levels, in two observation wells (F 5042 Basarabi – 2,33 m and F 24

Constanta – 1,47 m). However, given that this model was created for research purposes, on a regional scale (68.000 m x 32.000 m), and some measurements may have small uncertainties, the model can be considered calibrated.

After the completion of the model calibration process, the distribution of the hydraulic conductivities of the aquifer resulted (figure 2.3.), whose values are between 0.01 m/day, locally, on a portion around the F 2H Rasova well and 800 m/day in the area of the Medgidia town, especially in the area of the water capture fronts of the Medgidia town, respectively Medgidia for the Constanta city. The high values of the hydraulic conductivities in the researched area indicate the idea that it is strongly karstified.

The system of vertical and horizontal faults in the researched area generated a series of uneven tectonic blocks in terms of hydraulic conductivity.

In the South-West area, the value of hydraulic conductivity is generally 100 m/day, except for some very fine paths that bypass the observation wells from Ivrinezu Mare (F 1) and Pestera (F 5046) and stop near the Medgidia town. In the Central - Western area, especially in the area of the Cernavoda - Constanta fault, the hydraulic conductivity has the value of 250 m/day.

In most of the area in the Central - Eastern area, the hydraulic conductivities have relatively small values, between 1 m/day and 4 m/day, which indicates an area with a strong hydraulic gradient. In the South - Eastern area of the model, more precisely in the tectonic blocks 12, respectively 13, there are no rocks of Jurassic - Cretaceous lower age.

In the northern area of the domain, the values of hydraulic conductivities vary between 1 m/day (towards the domain center) up to 250 m/day (in the area of the Capidava - Ovidiu fault).

3. Case study

Following the model calibration resulted the hydrodynamic map of the Jurassic - Cretaceous lower aquifer, presented in figure 2.6.

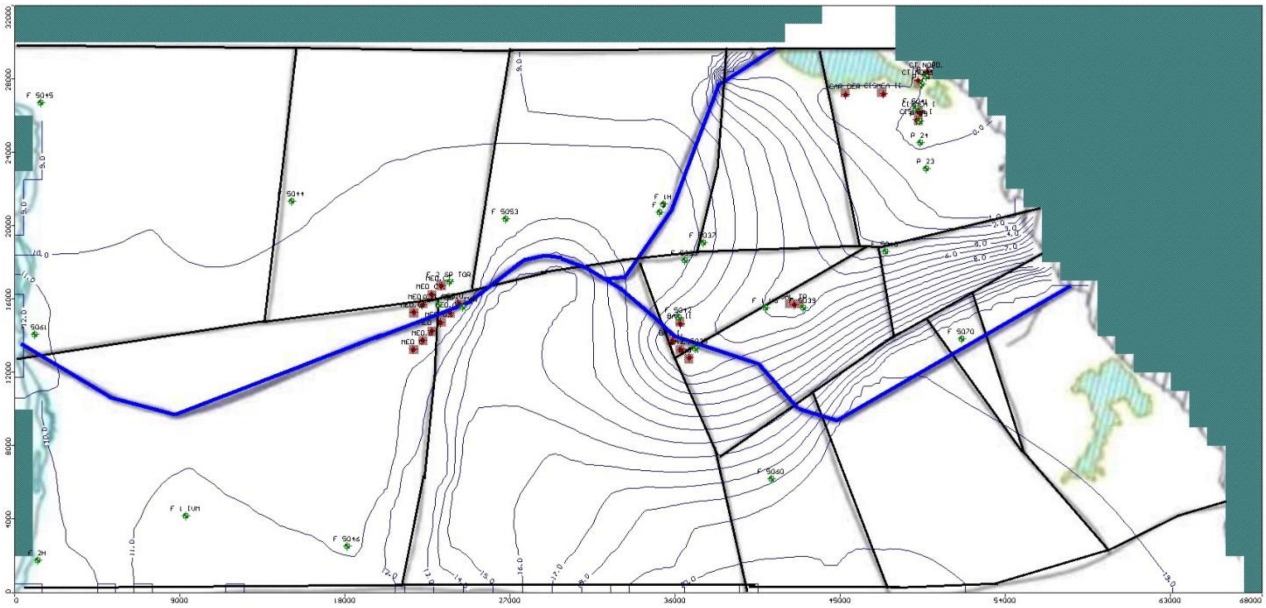

Figure 2.6. – Hydrodynamic map of the calibrated model

The flow directions resulting from the model calibration are mainly oriented South-West - North-East, according to Figure 2.7. Locally, in the area delimited by the Lazu - Cumpana and Cernavoda - Constanta faults, the hydraulic conductivities have low values, and the flow directions are oriented South - North. At North of the Cernavoda - Constanta fault, the flow directions return to the South-West - North-East.

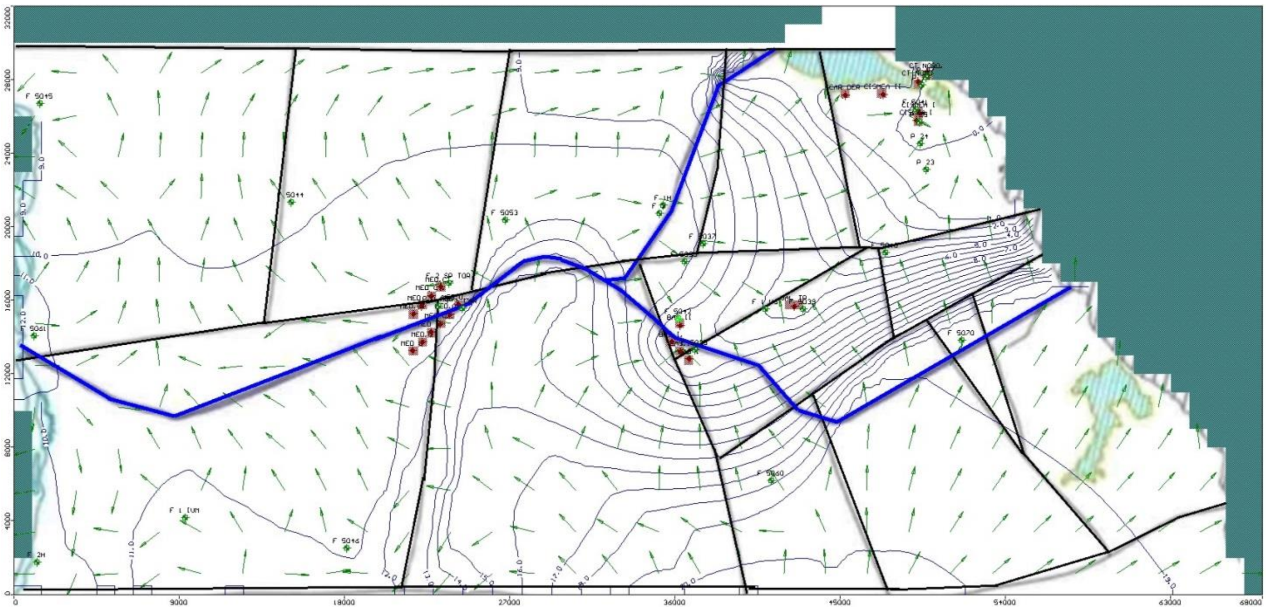

Figure 2.7. – Flow directions through the calibrated model

In the area of Ovidiu lock, on the Poarta Alba - Midia, Navodari waterway, a local disturbance was observed, determined by the direct hydraulic connection between the water in the waterway and the aquifer. Also, there were disturbances in the Constanta, Basarabi, Valul lui Traian and Medgidia groundwater catchments areas.

Subsequent to the model calibration procedure, particles were introduced into the cells corresponding to the groundwater catchments, and these generated the supply areas of the wells. This procedure is called "backward-tracking" and is used to determine the supply areas of the wells. In figure 2.8. it can be seen that most of the catchment wells are supply from the southern border of the domain, except for the wells from the Constanta Nord, Cismea II and partially Cismea I groundwater catchments, which are supply from the northern border and sometimes from Siutghiol lake.

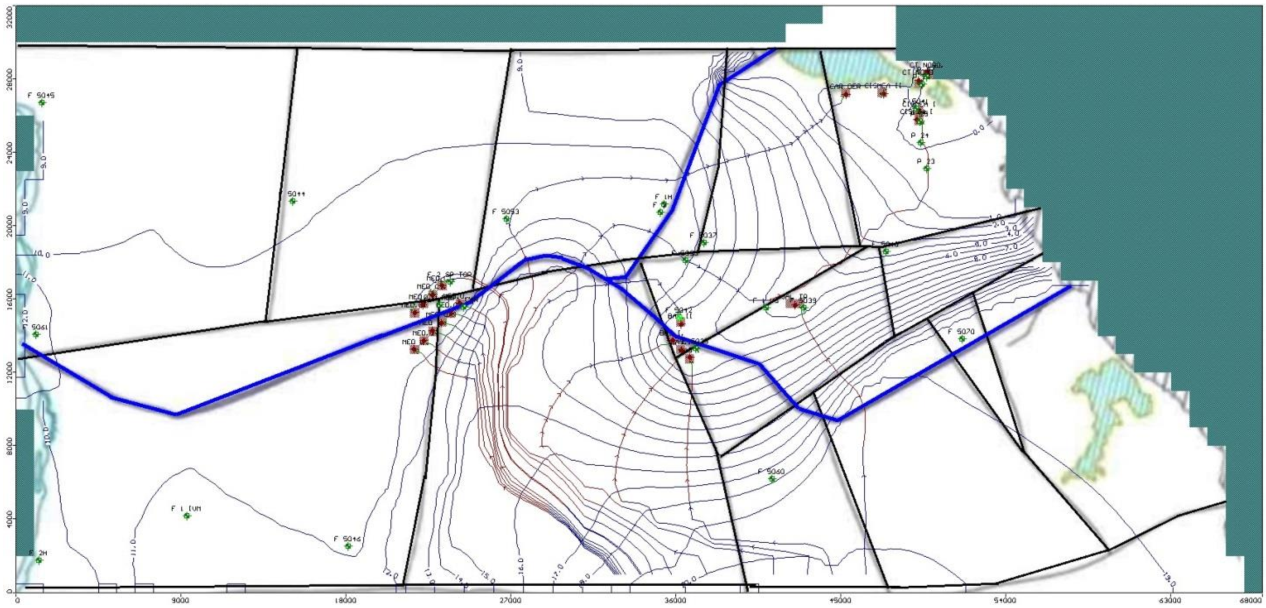

Figure 2.8. – Supplying areas for the catchment wells

As shown in figure 2.8. if the hypothesis of an advective pollutant transport is adopted, respectively the pollutant displacement is realized only after its the water flow, the model shows that in present there is no danger of contamination of the catchment wells with water from the Poarta Alba - Midia, Navodari waterway.

Based on the calibrated model, certain areas were drawn on the eastern, southern and western borders to create a balance sheet. Thus, in table 2.5. there are shown the inflow and outflow values in the areas with constant level (Siutghiol lake and section between Ovidiu lock and 3 km upstream), in catchments and in each delimited zone (Figure 2.9.).

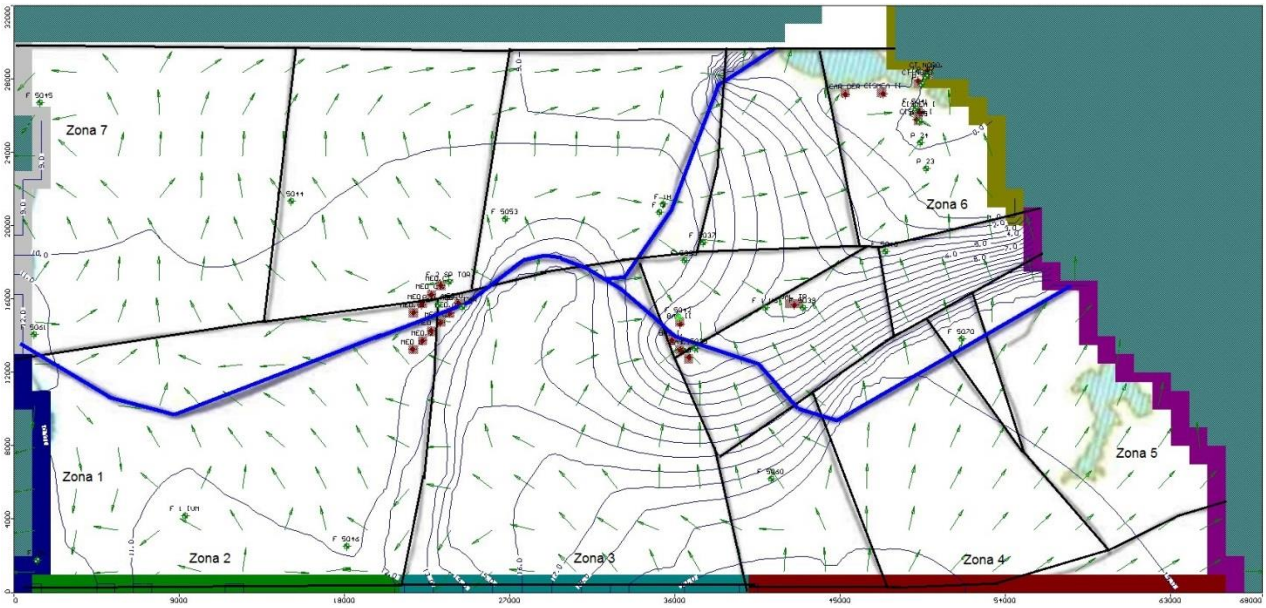

Figure 2.9. – Delimited areas for the determination of the balance sheet

Crt. No.	Border	Inflow m³/day	Outflow m³/day
1	Siutghiol lake + section in direct contact with the lower aquifer	91180	21014
2	Groundwater catchments	0	345550
3	Zone 1	75296	10133
4	Zone 2	39667	53862
5	Zone 3	483650	348500
6	Zone 4	474800	0
7	Zone 5	12840	366340
8	Zone 6	152160	939070
9	Zone 7	287610	353520

Table 2.5. – Balance sheet for the calibrated model

3.1. Hypotheses studied

This calibrated model was further used to simulate two hypotheses:

- Hypothesis 1: increasing the catchment flows from the Constanta city catchments from 2740 l/s (currently) to 4000 l/s;

- Hypothesis 2: transport of pollutants from upstream of the Ovidiu lock.

3.1.1. Hypothesis 1 – increase of the catchment flows

Due to the fact that during the summer, water consumption is very high in the seaside area and the exploited flows from the Constanta catchments can reach very high values, the evolution of the Jurassic - Cretaceous lower aquifer in the situation of increased exploited flows was studied. Thus, it was imposed that the sum of the flows extracted from the Caragea Dermen, Cismea I, Cismea II, Constanta Nord catchments reach 4000 l/s, compared to the flows currently exploited, which together reach approximately 2740 l/s

After applying hypothesis 1 and running the model, the hydrodynamic map of the Jurassic - Cretaceous lower aquifer, shown in figure 2.10, resulted.

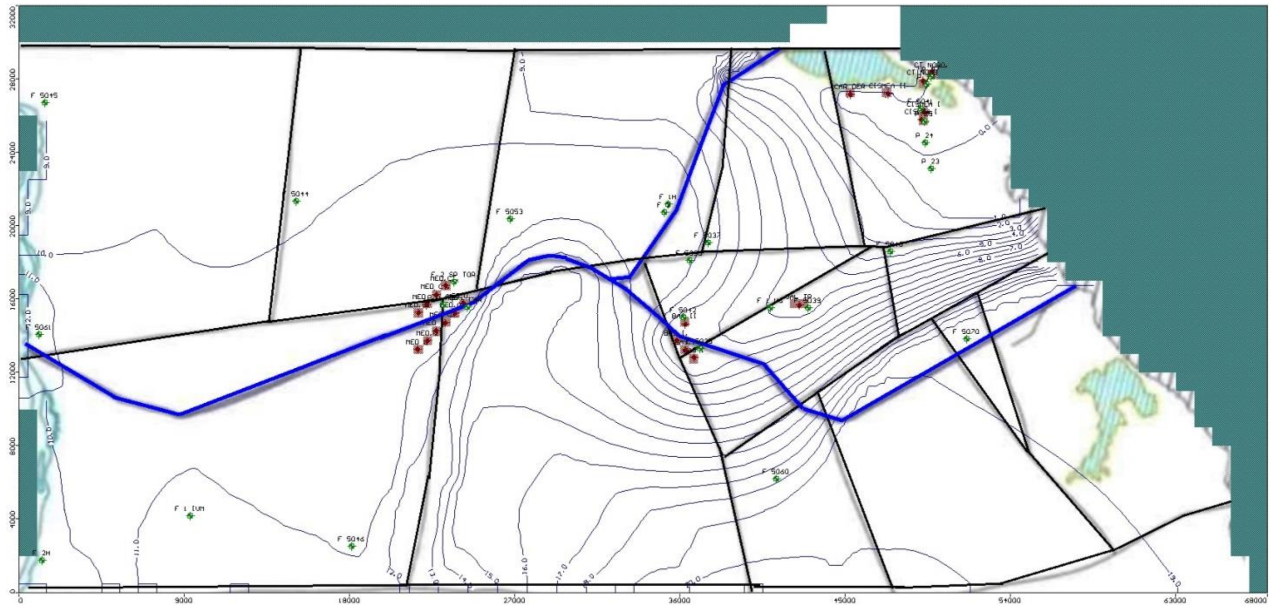

Figure 2.10. – Hydrodynamic map of the model simulated with hypothesis 1

The flow directions resulting from the model calibration are mainly oriented South-West - North-East, according to Figure 2.11. Locally, in the area delimited by the Lazu - Cumpana and Cernavoda - Constanta faults, the hydraulic conductivities have low values, and the flow directions are oriented South - North. At North of the Cernavoda - Constanta fault, the flow directions return to the South-West - North-East.

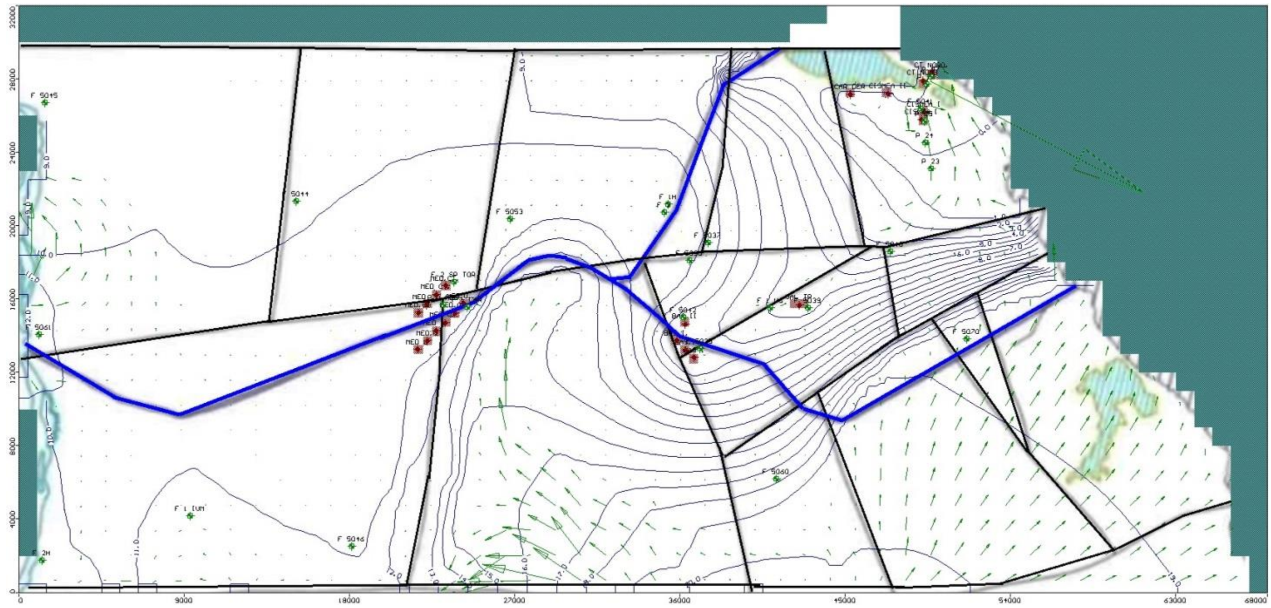

Figure 2.11. – Flow directions through the model simulated with hypothesis 1

Subsequently, particles were introduced into the cells corresponding to the groundwater catchments, and the model generated their paths in the opposite direction to the flow to the stop. In figure 2.12. it can be seen that most of the catchment wells are supply from the southern border of the domain, except for the wells from the Constanta Nord and Cismea II catchments, which are supply from the northern border and sometimes from Siutghiol lake.

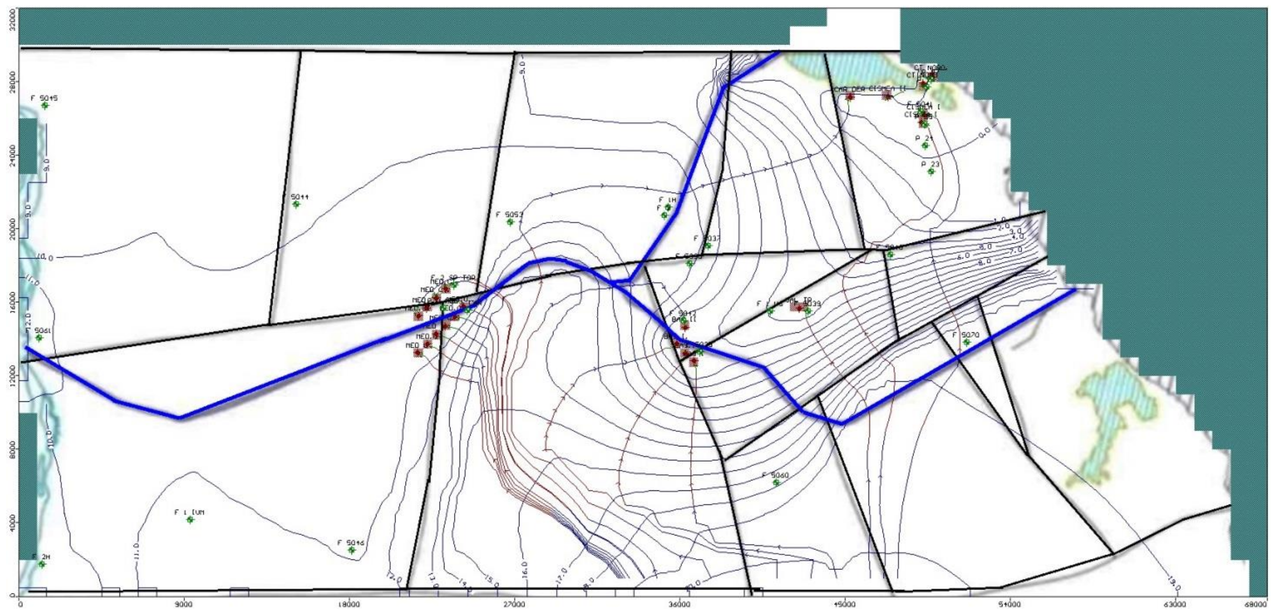

Figure 2.12. – Supplying areas for the catchment wells after hypothesis 1 simulation

After increasing the extracted flows from the catchments of Constanta city, table 2.6 was shown up which synthetically presents the input and output flows values in the areas with constant level (Siutghiol lake and upstream of the Ovidiu lock), catchments and in each area delimited according to figure 2.13.

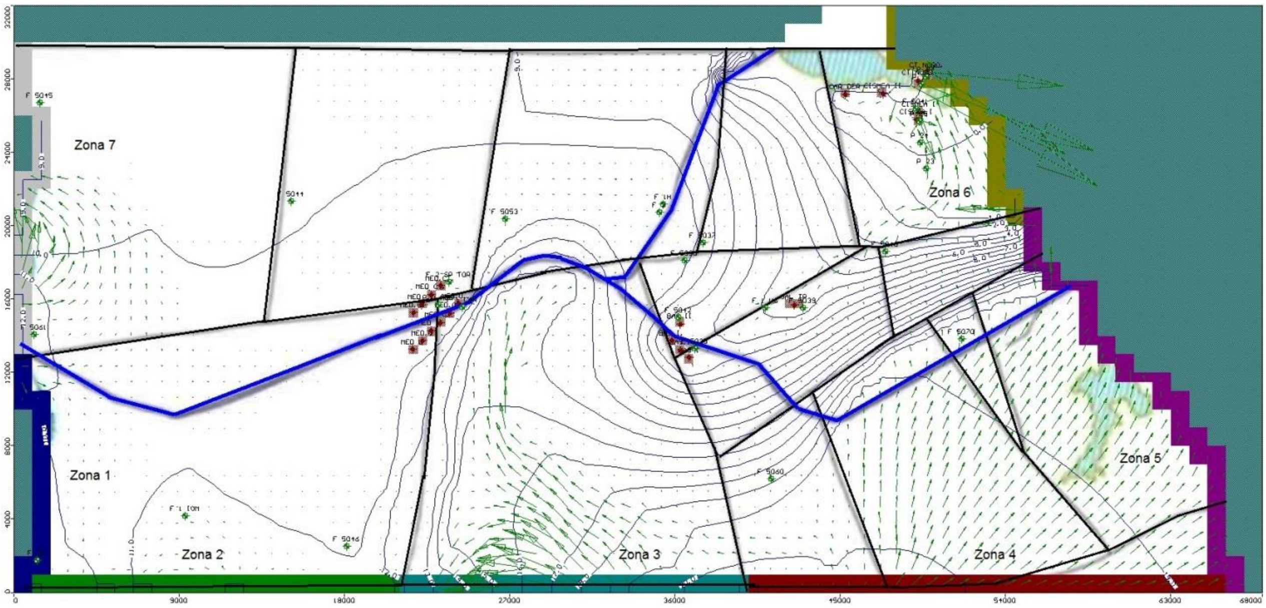

Figure 2.13. – Delimited areas for the determination of the balance sheet after hypothesis 1 simulation

Crt. No.	Border	Inflow m^3/day	Outflow m^3/day
1	Siutghiol lake + section in direct contact with the lower aquifer	961330	20911
2	Groundwater catchments	0	450420
3	Zone 1	75322	10129
4	Zone 2	39675	53843
5	Zone 3	483710	348450
6	Zone 4	474880	0
7	Zone 5	12852	366280
8	Zone 6	172540	904470
9	Zone 7	287650	353450

Table 2.6. – Balance sheet after hypothesis 1 simulation

3.1.2. Hypothesis 2 – pollutants transport

The numerical model developed was further used to simulate the pollutants transport, taking into account the dispersion. Several scenarios of accidental pollution were simulated, in which a pollutant was introduced in the area of the Ovidiu lock, from the Poarta Alba - Midia, Navodari waterway. The pollutant transport simulations were performed in this area because on the section between the Ovidiu lock, respectively 3 km upstream on the Poarta Alba - Midia, Navodari canal, the Jurassic - Cretaceous lower aquifer is in direct contact with the waters from the waterway. The simulations were made for a maximum period of 30 years, considering the quasi-stationary flow regime, while the operating flows from underground catchments had both a variant with the values provided by the RAJA Constanta operator and another variant with the values calculated according Hypothesis 1. The pollutant investigated had a concentration of 100 mg/l, while the dispersivity of the medium was varied.

The results of the pollutant transport simulations for the calibrated model are presented at different exposure times in Figures 2.14 - after 10 days, 2.15 - after 1 year, 2.16 - after 10 years and 2.17 - after 30 years.

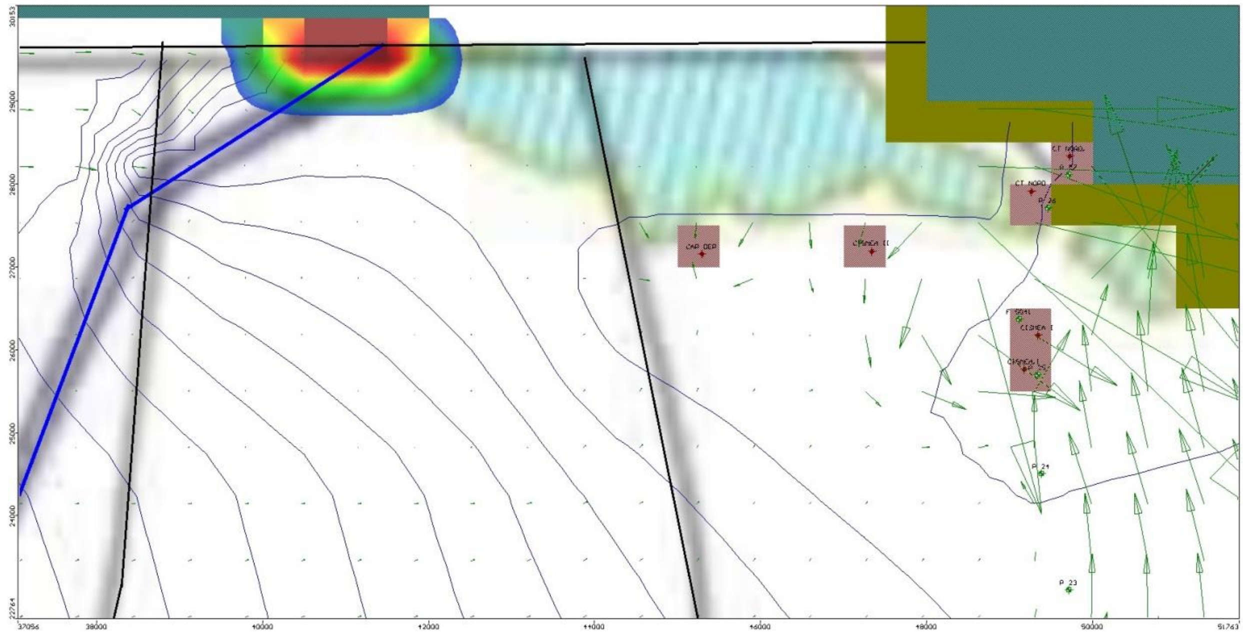

Figure 2.14. – The contaminated area by the pollutant after an exposure time of 10 days in the calibrated model

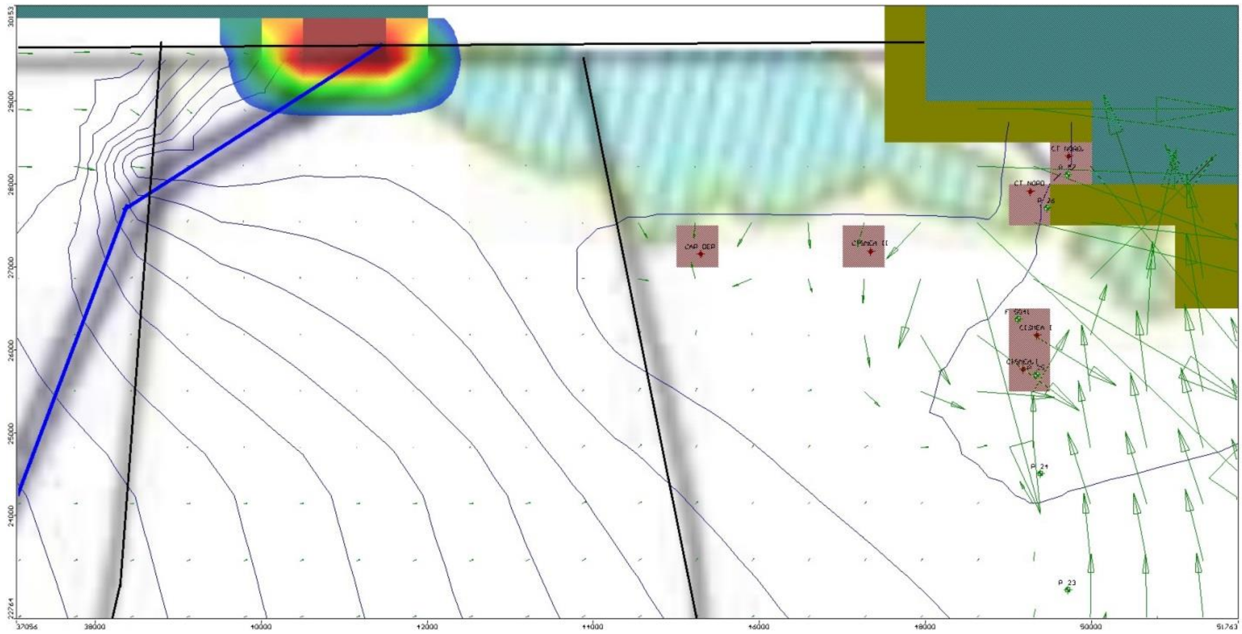

Figure 2.15. – The contaminated area by the pollutant after an exposure time of 1 year in the calibrated model

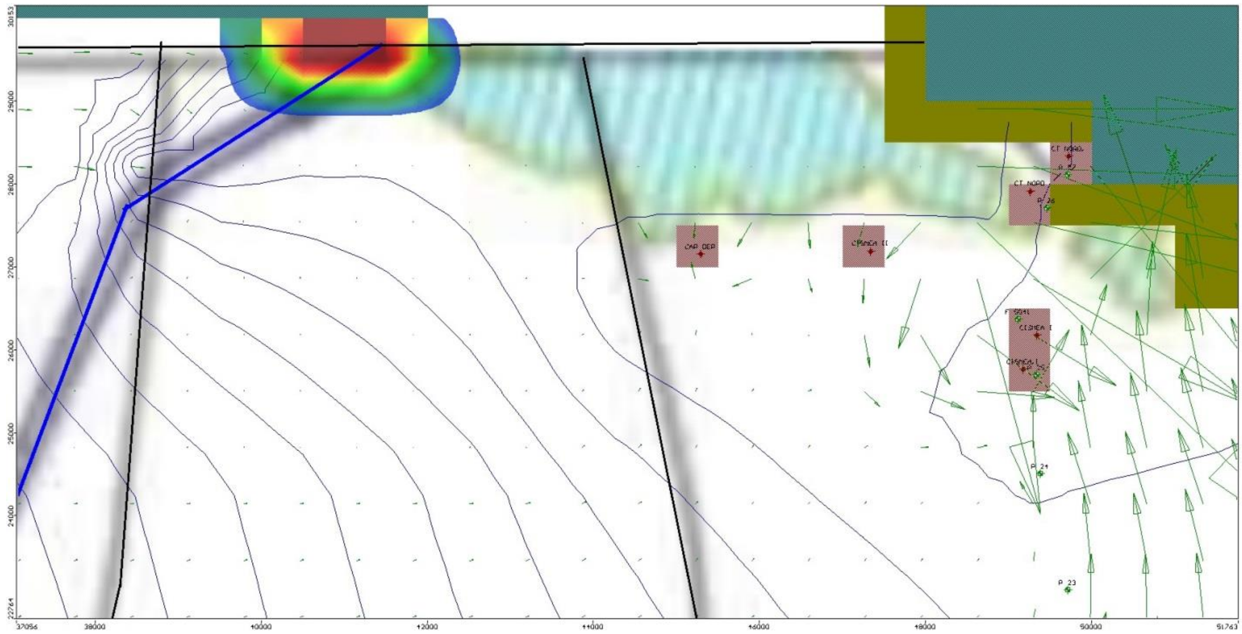

Figure 2.16. – The contaminated area by the pollutant after an exposure time of 10 years in the calibrated model

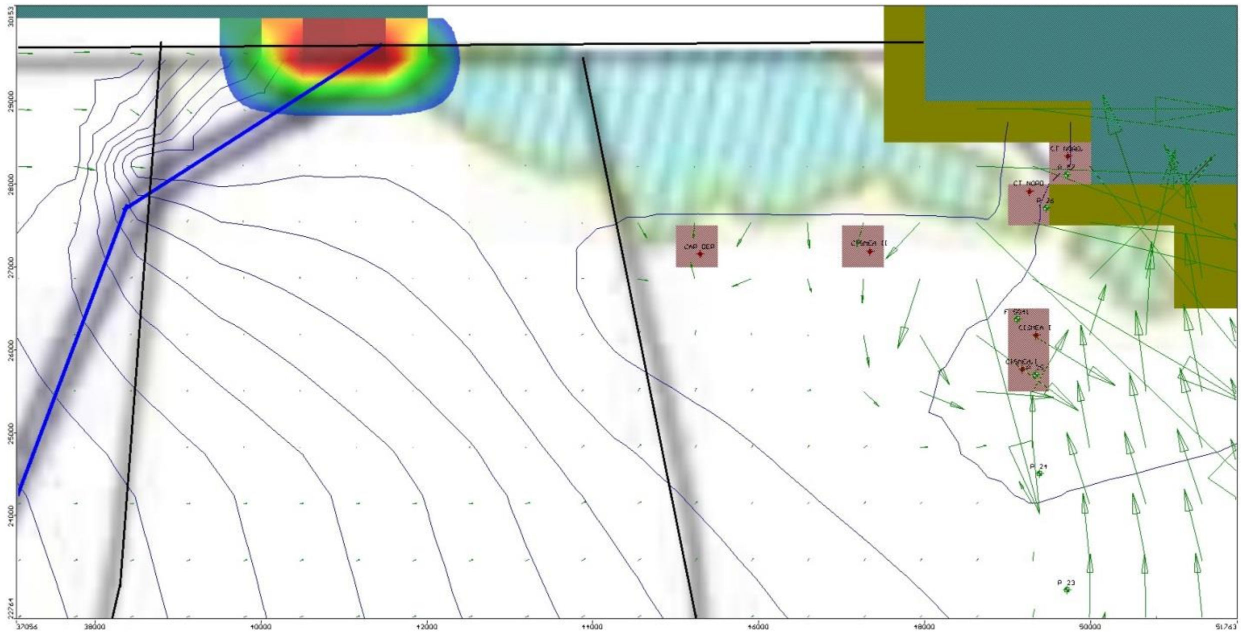

Figure 2.17. – The contaminated area by the pollutant after an exposure time of 30 years in the calibrated model

The pollutant transport simulation for the calibrated model showed that, regardless of the concentration value (up to the limit of 100 mg/l nitrogen) and dispersibility, after 30 years, the pollution effect is manifested only on a restricted area around the pollution source. The pollutant was introduced even along the entire length of the section from the Poarta Alba - Midia, Navodari waterway, in direct contact with the Jurassic - Cretaceous lower aquifer. Even in these conditions and for high dispersivities (20 m and 30 m), the simulations performed showed that, after 30 years, the effect of pollution is felt locally, on a small area. This is due to the hydrogeological conditions in the area (small hydraulic gradients to the catchments and Siutghiol lake).

Subsequently, the same simulations were repeated, modifying the operating flows according to hypothesis 1 (the sum of the catched flows from the Constanta city sources should be 4000 l/s).

Thus, the results of the pollutant transport simulations after the application of hypothesis 1 are presented at different exposure times in figures 2.18 - after 10 days, 2.19 - after 1 year, 2.20 - after 10 years and 2.21 - after 30 years.

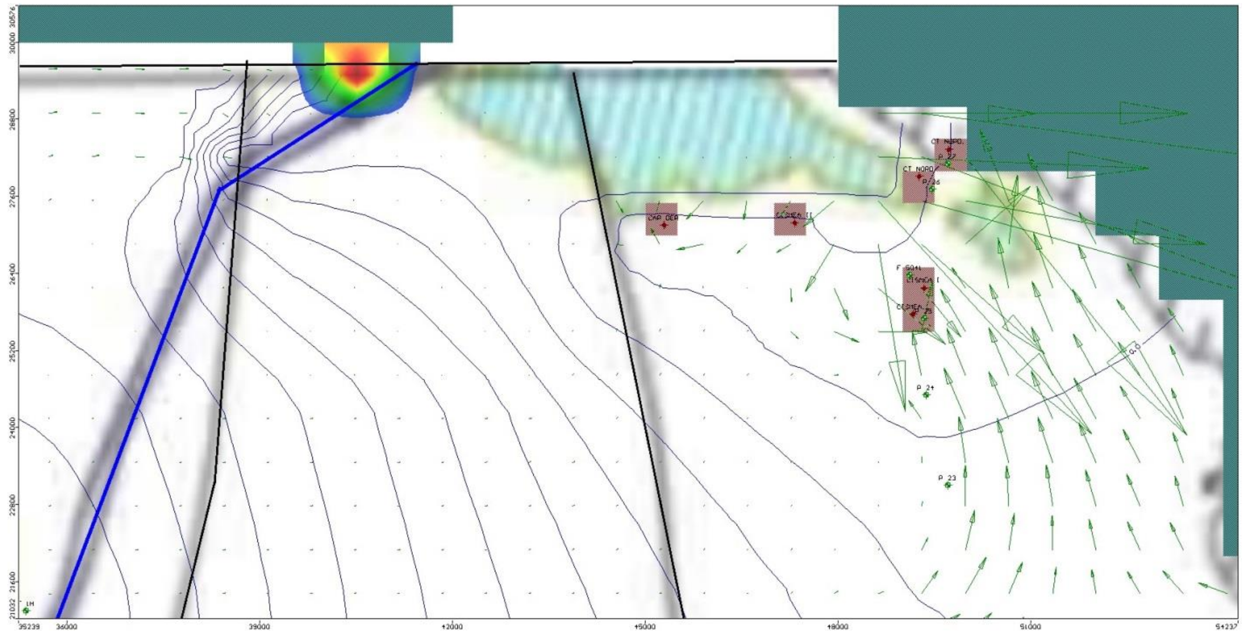

Figure 2.18. – The contaminated area by the pollutant after an exposure time of 10 days in model after hypothesis 1 application

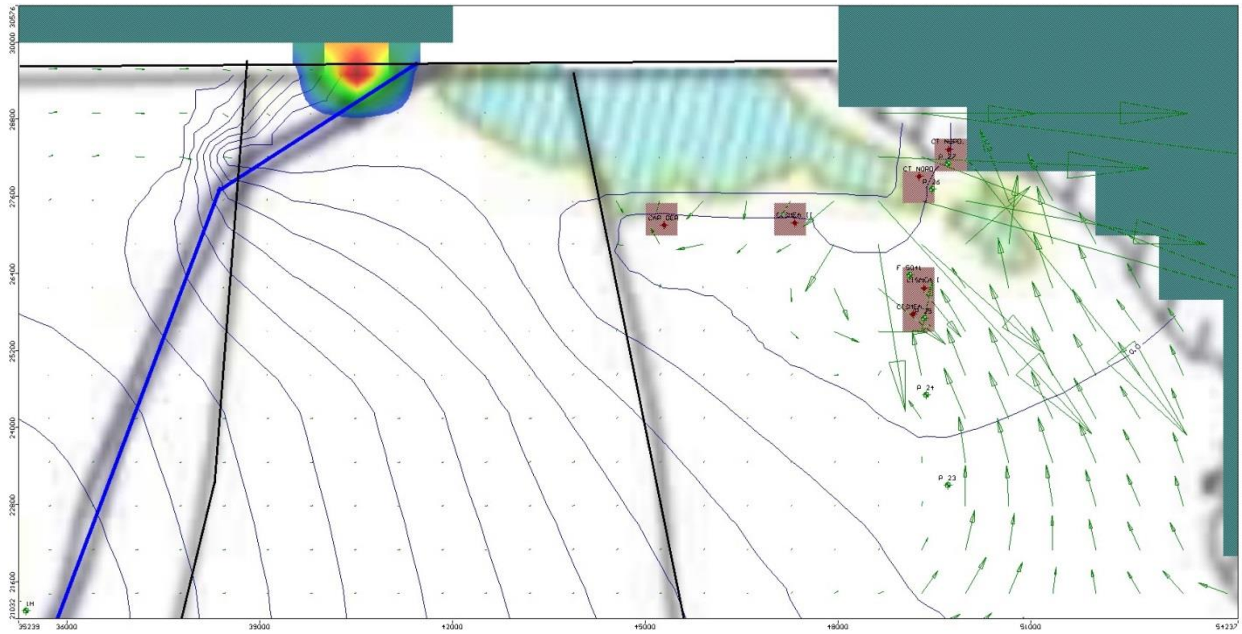

Figure 2.19. – The contaminated area by the pollutant after an exposure time of 1 year in model after hypothesis 1 application

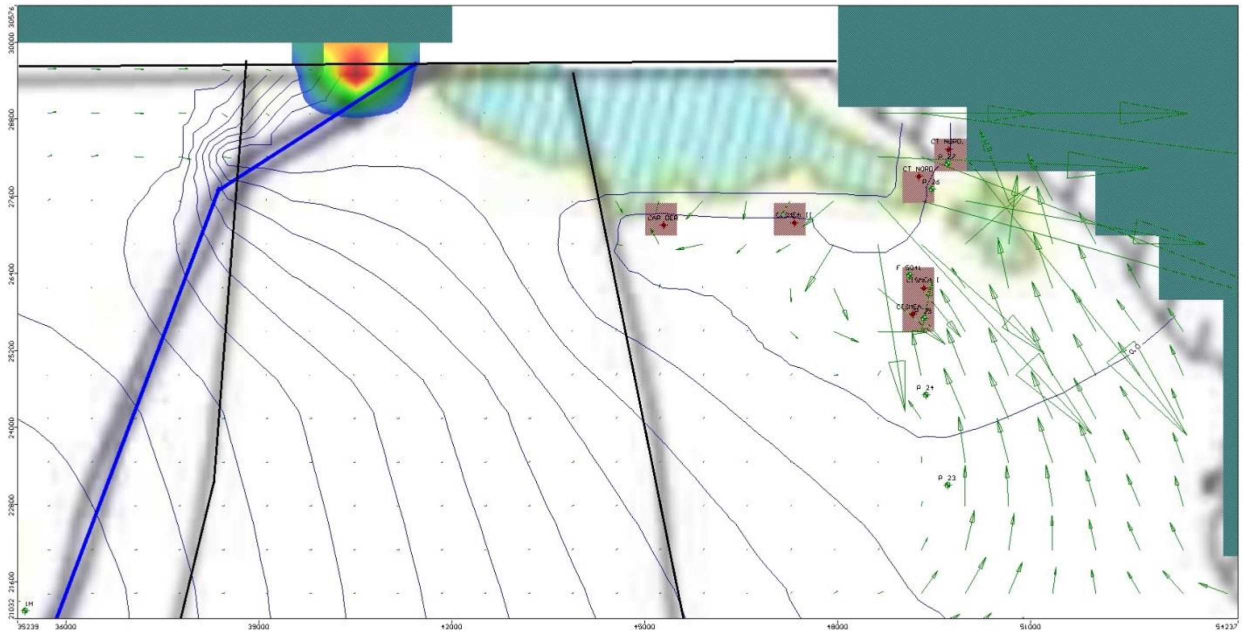

Figure 2.20. – The contaminated area by the pollutant after an exposure time of 10 years in model after hypothesis 1 application

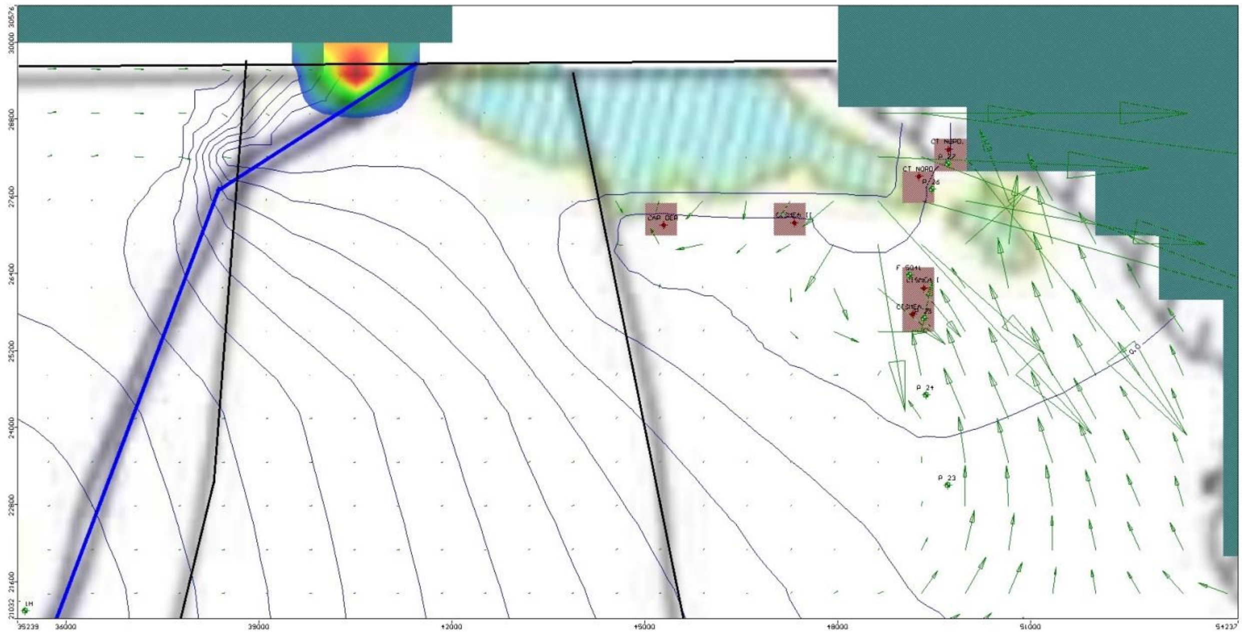

Figure 2.21. – The contaminated area by the pollutant after an exposure time of 30 years in model after hypothesis 1 application

The transport model after increasing the operating flows according to hypothesis 1, showed that, regardless of the value of concentration (up to the limit of 100 mg/l nitrogen) and dispersibility, after 30 years, the effect of pollution is manifested only on a small area of around the source of pollution. The pollutant was introduced even along the entire length of the section from the Poarta Alba – Midia, Navodari waterway, which is in direct contact with the Jurassic - Cretaceous lower aquifer. Even in these conditions and for high dispersivities (20 m and 30 m), the simulations performed showed that, after 30 years, the effect of pollution is felt locally, on a small area. This is due to the hydrogeological conditions in the area (small hydraulic gradients to the catchments and Siutghiol lake).

The simulations performed show that an accidental pollution in the Poarta Alba - Midia, Navodari waterway does not extend in the Jurassic - Cretaceous lower aquifer, but is felt locally, in the area of direct contact with the aquifer. Also, the quality of the water exploited through the catchment fronts of Constanta city is not altered even in the conditions of a total flow extracted from the catchment fronts increased by approximately 45% compared to the current exploitation regime.

4. Conclusions

The aim of the research carried out in this paper is to evaluate the impact of hydrotechnical works of waterway type (in this case the Dunare – Marea Neagra and Poarta Alba - Midia, Navodari waterways) on a karstic aquifer system and implicitly of groundwater catchments located in the vicinity of waterways, in operation for cities water supply.

The researched area is located in the north of South Dobrogea, limited to the west by the Danube and to the east by the Black Sea, and from a structural point of view it is comprised between the Capidava - Ovidiu (north) and Rasova - Costinesti (south) faults.

The arranged waterways transport water from the Danube (Cernavoda) and ensure the connection with the Black Sea through locks in the Agigea and Navodari sectors, respectively. In some sectors, waterways have been dug in the some water store rocks, without any sealing measures, and this can have an impact both quantitatively and qualitatively on groundwater.

At the scale of South Dobrogea (Constanta County) are presented two karst aquifer systems with regional extension, located in limestone rocks:

- the lower aquifer system, cantoned in limestone rocks of Jurassic - Cretaceous age, with extension on the whole territory of South Dobrogea;
- the upper aquifer system, encamped in limestone rocks of Sarmatian age, extending in the middle and southern area of South Dobrogea.

In the researched area (northern South Dobrogea) is found the lower aquifer system, located in limestone rocks of Jurassic - Cretaceous age, under pressure. Therefore, it is not vulnerable to pollution on a regional scale and is intensively used as a groundwater resource for drinking water supplies of large cities in Constanta County.

The upper aquifer system, located in limestone rocks of Sarmatian age, is relatively low in the south of the researched area, but is well developed in the middle and southern area of South Dobrogea. It is vulnerable to pollution (being free level and acting as a groundwater aquifer), and currently the trend of major pollution with chemicals used as fertilizers in agriculture has been detected. Therefore, the lower aquifer system, located in Jurassic - Cretaceous limestone rocks, is of vital importance for drinking water supplies in the area. In order to protect the lower aquifer, research is required to assess the risks for possible pollution phenomena.

After the execution and entry into operation of the waterways, local changes of the flow regime in the lower aquifer were found, which were presented in the research report no. 1. From 1987 until now, the flow regime is stationary - conservative, a phenomenon that was taken into account for the elaboration of the conceptual model and the construction of the numerical model in the present research report.

After the numerical model was done and its calibration, the calculated hydrodynamic map of the Jurassic - Cretaceous lower aquifer, the flow directions and the supplying areas of the wells in the catchments were obtained. Also, the model generated a flow balance sheet in the areas with constant imposed potential (Siutghiol lake and the section between the Ovidiu lock and 3 km upstream), in the groundwater catchments and on each marked area.

The supply areas of the catchment wells generally come from the southern border. It is noted, however, for the catchment wells from the Cosntanta Nord, Cismea II and partially Cismea I sources, the supply areas also come from the northern and southern border, and sometimes from Siutghiol lake for excess exploitation flows.

In the Poarta Alba - Midia, Navodari waterway, on the sector between the Ovidiu lock and upstream 3 km, the Jurassic - Cretaceous lower aquifer is intercepted by the waterway. This allows direct communication between surface waters, represented by the waterway, rainwater and the lower aquifer.

The water quality from the lower aquifer system and from the catchment wells is significantly influenced by the waters in the waterways. The only exception is the Medgidia Nord catchment, in which the water quality of the wells is not influenced by the waters of the waterway. This is due to the wells construction, which have depths between 350 - 400 m, and the final columns perfectly insulate by cementing (about 150 m) communication with groundwater aquifers.

The numerical model developed was further used to simulate the transport of pollutants, taking into account the dispersion. Several accidental pollution scenarios were simulated. In essence, a pollutant was introduced in the area of the Ovidiu lock, in the Poarta Alba - Midia, Navodari waterway, on the section which is in direct contact with the Jurassic - Cretaceous lower aquifer.

The simulations were made for a maximum period of 30 years, considering the quasi-stationary flow regime, while the operating flows from underground catchments had both a variant with the values provided by the RAJA Constanta water operator and another variant with the values calculated according Hypothesis 1. The pollutant investigated had a concentration of 100 mg/l, while the dispersivity of the medium was varied.

The pollutant transport simulation for the calibrated model showed that, regardless of the value of concentration (up to 100 mg/l nitrogen) and dispersibility, after 30 years, the pollution effect manifests itself locally, only on a restricted area around the source. pollution. This is due to local hydrogeological conditions (small hydraulic gradients towards catchments and Siutghiol lake).

Subsequently, the same simulations were repeated, modifying the operating flows according to hypothesis 1 (the sum of the flows catched from the Constanta city sources should be 4000 l/s).

And in these conditions, the effect of pollution after 30 years is also manifested locally, only on a small area around the source of pollution theoretically located.

Analyzing all this information and simulations, it is found that there are interferences between the waters of the Poarta Alba - Midia, Navodari waterway, upstream of the Ovidiu lock and the groundwater in the area of the underground catchments of Constanta city. Moreover, interference is observed, including in the groundwater that supply Siutghiol lake through the bottom. However, there is a small influence in terms of quantity and quality.

The water from the waterway that supply the lower aquifer in the sector upstream of the Ovidiu lock, is drained in a major proportion towards the eastern component, that is towards the Black Sea.

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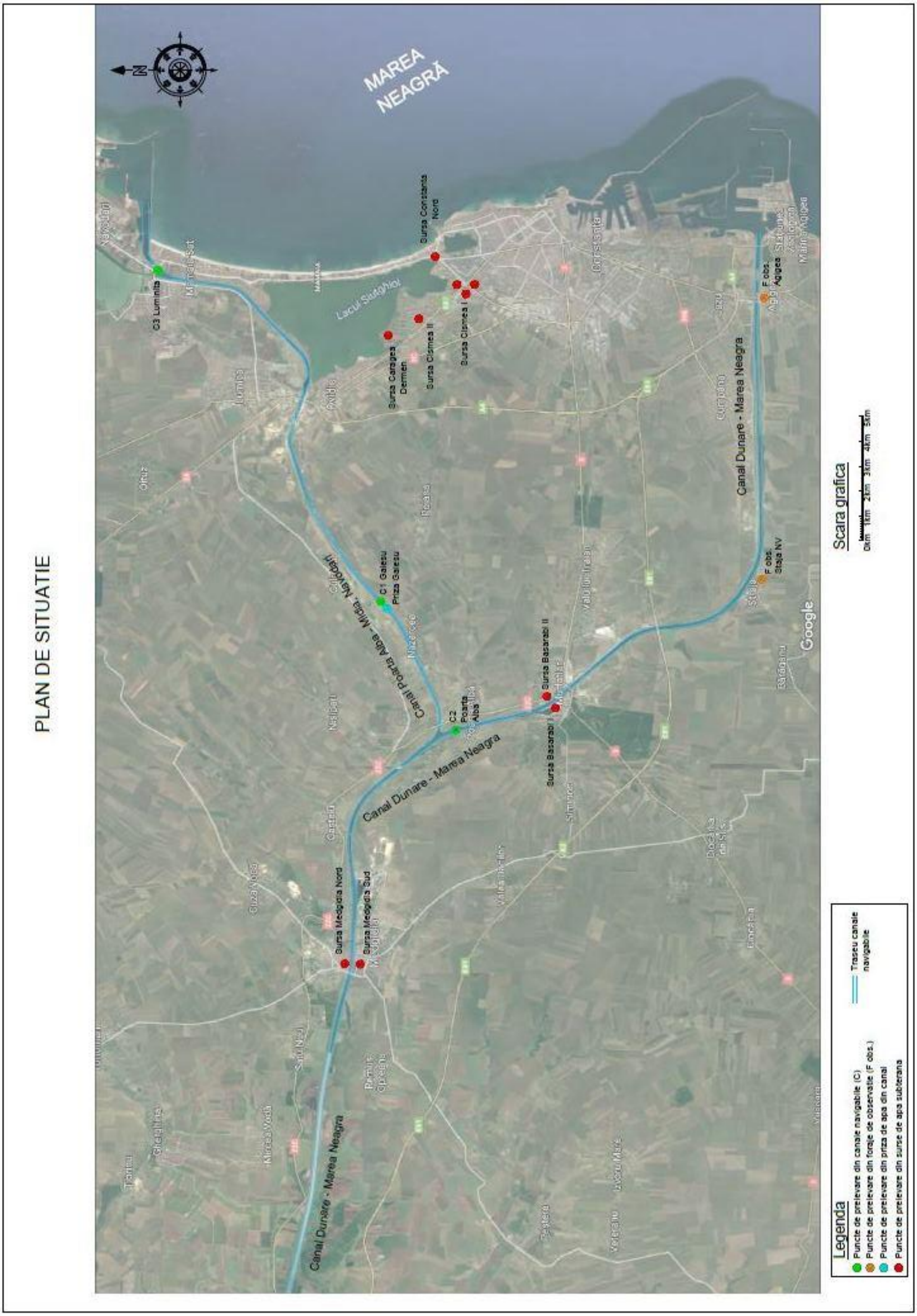
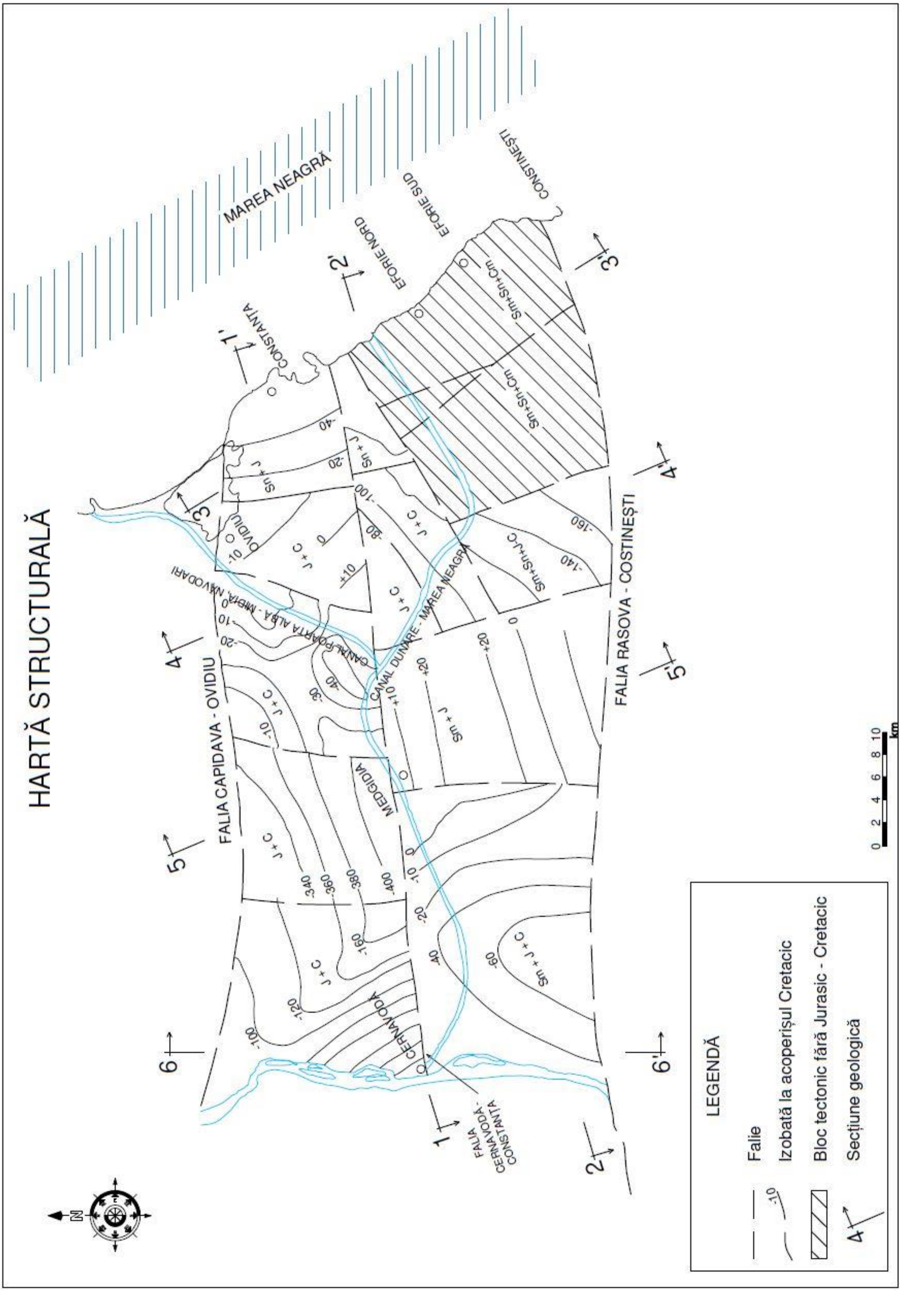
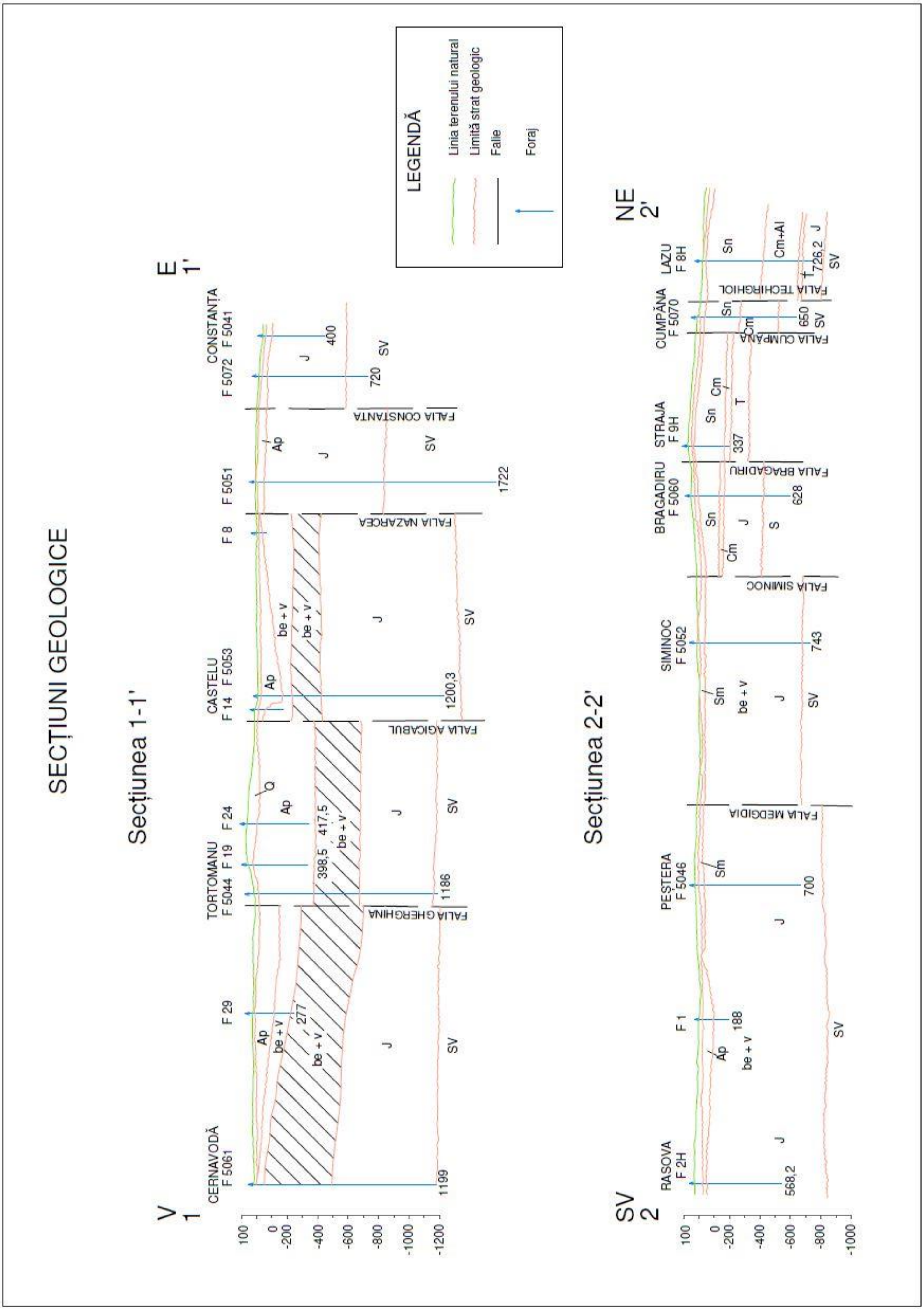


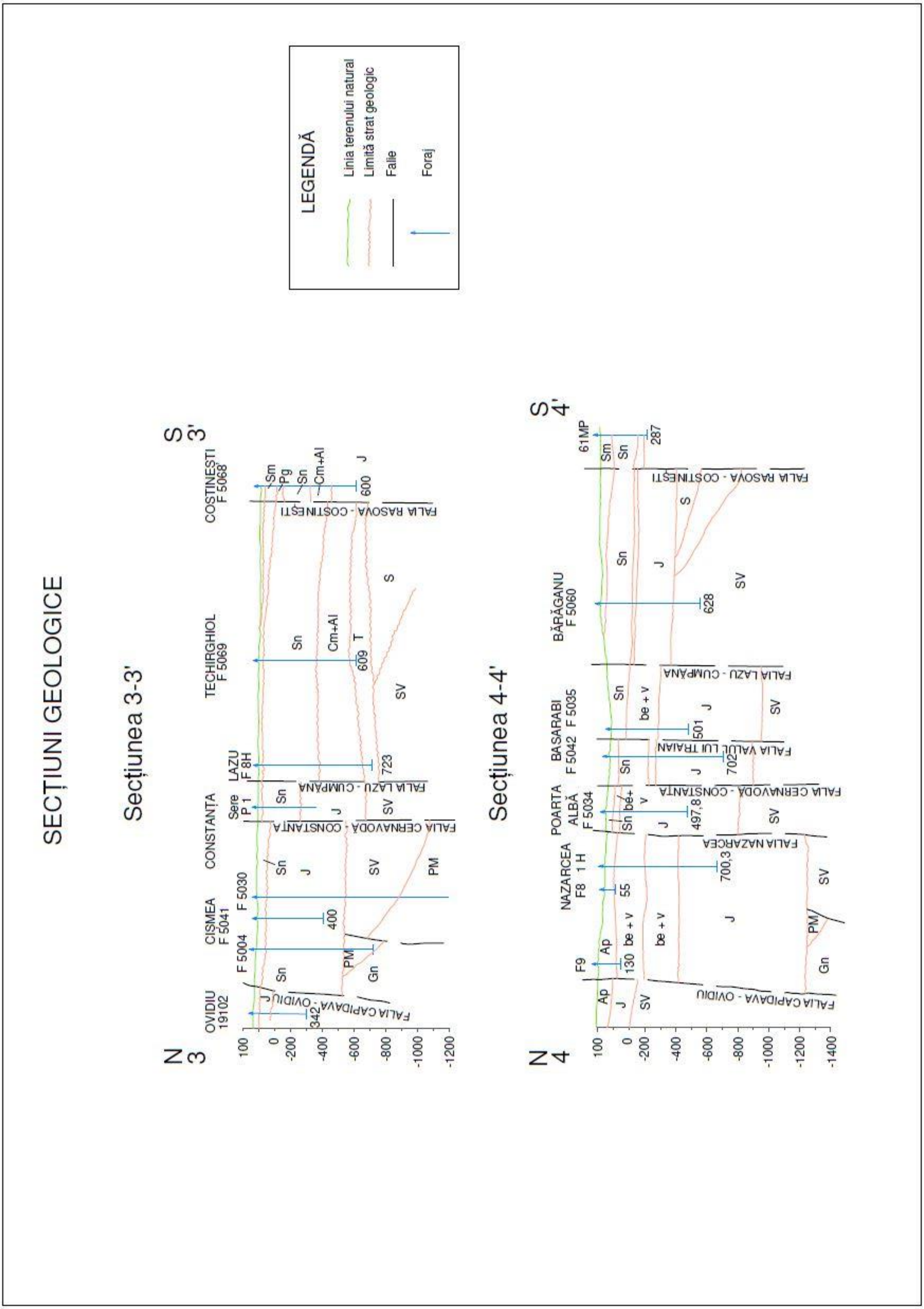
Appendix 1 – General layout of the investigated area



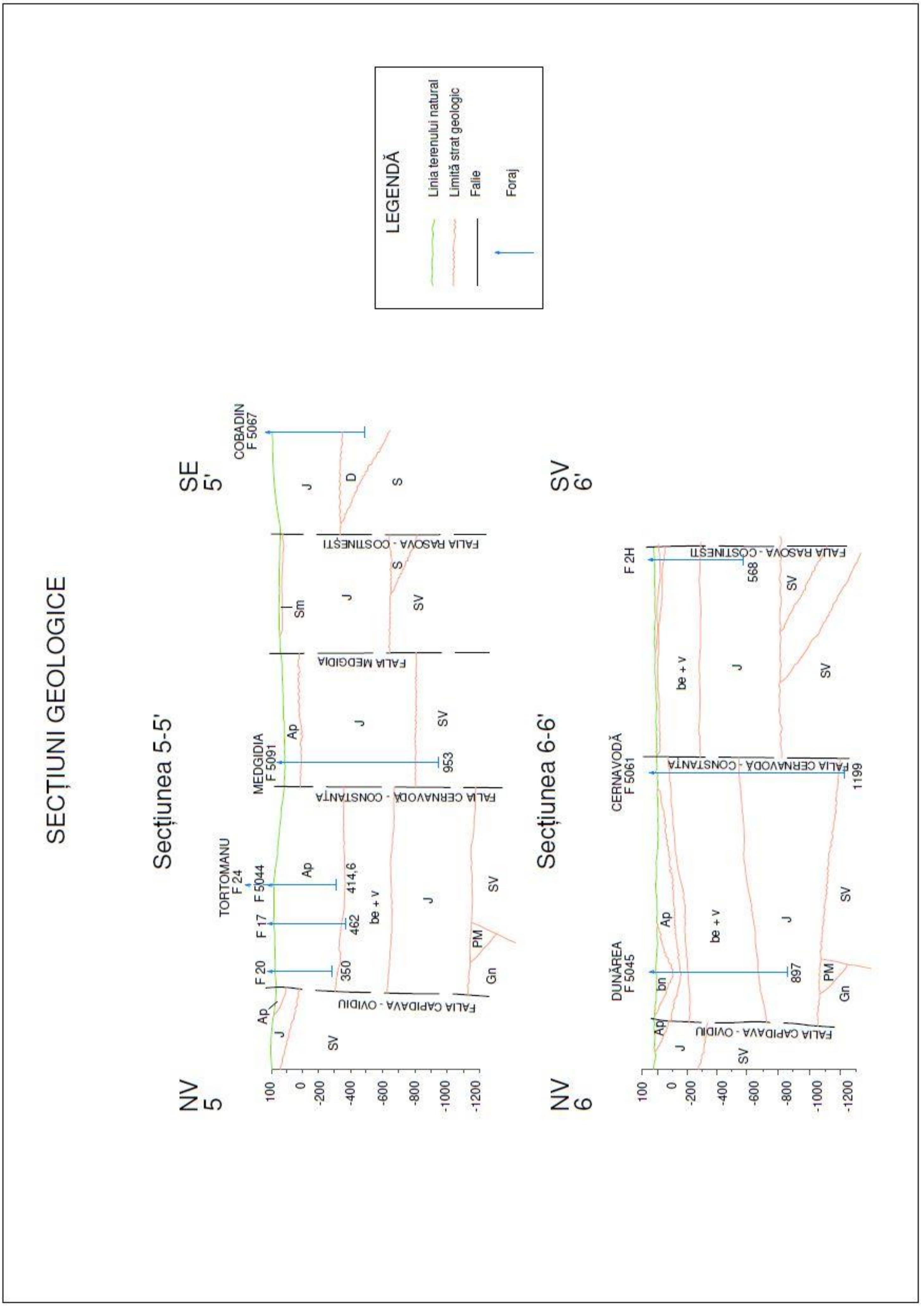
Appendix 2 – Structural map of the investigated area



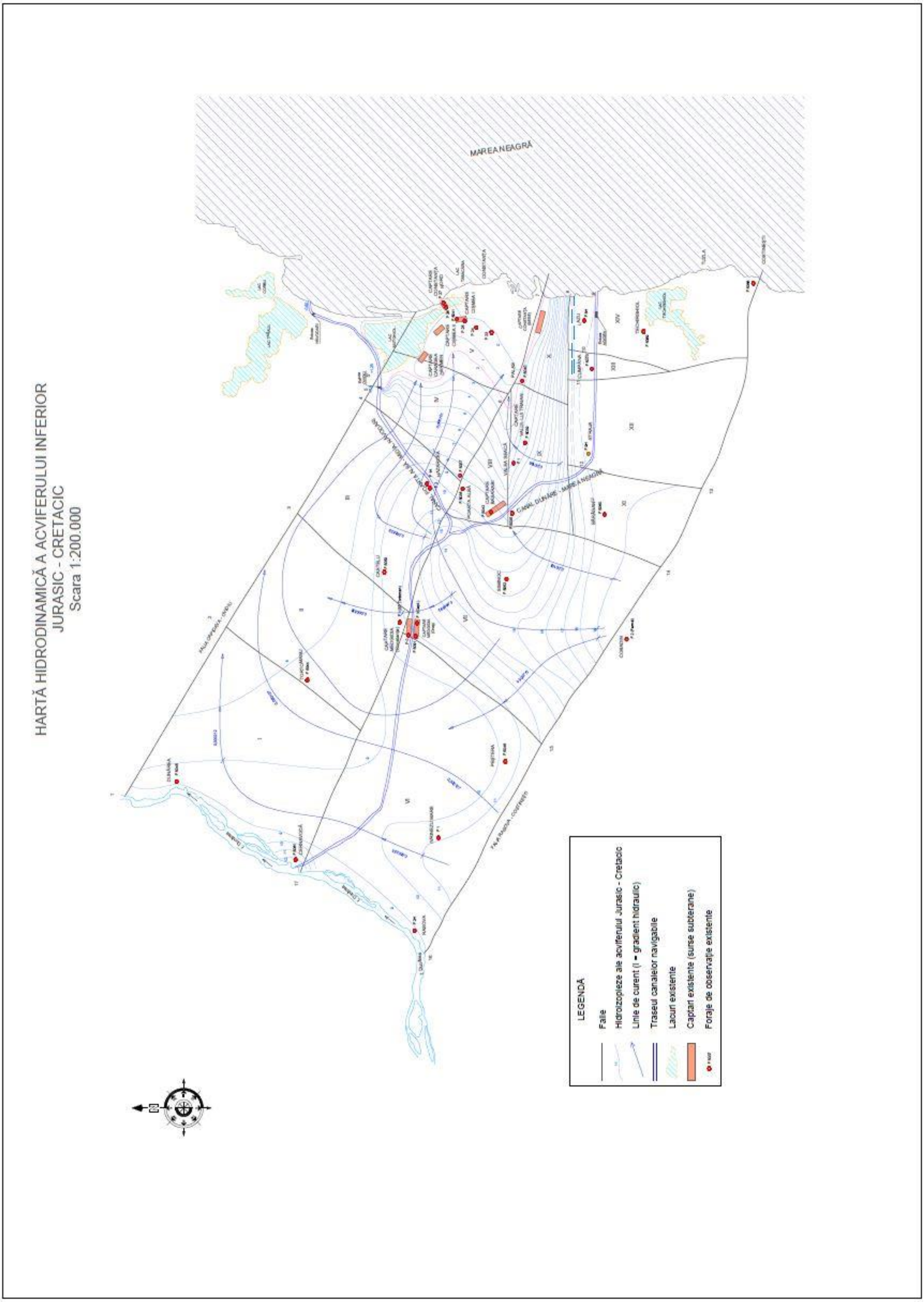
Appendix 3 – Geological sections 1-1' and 2-2' of the researched area



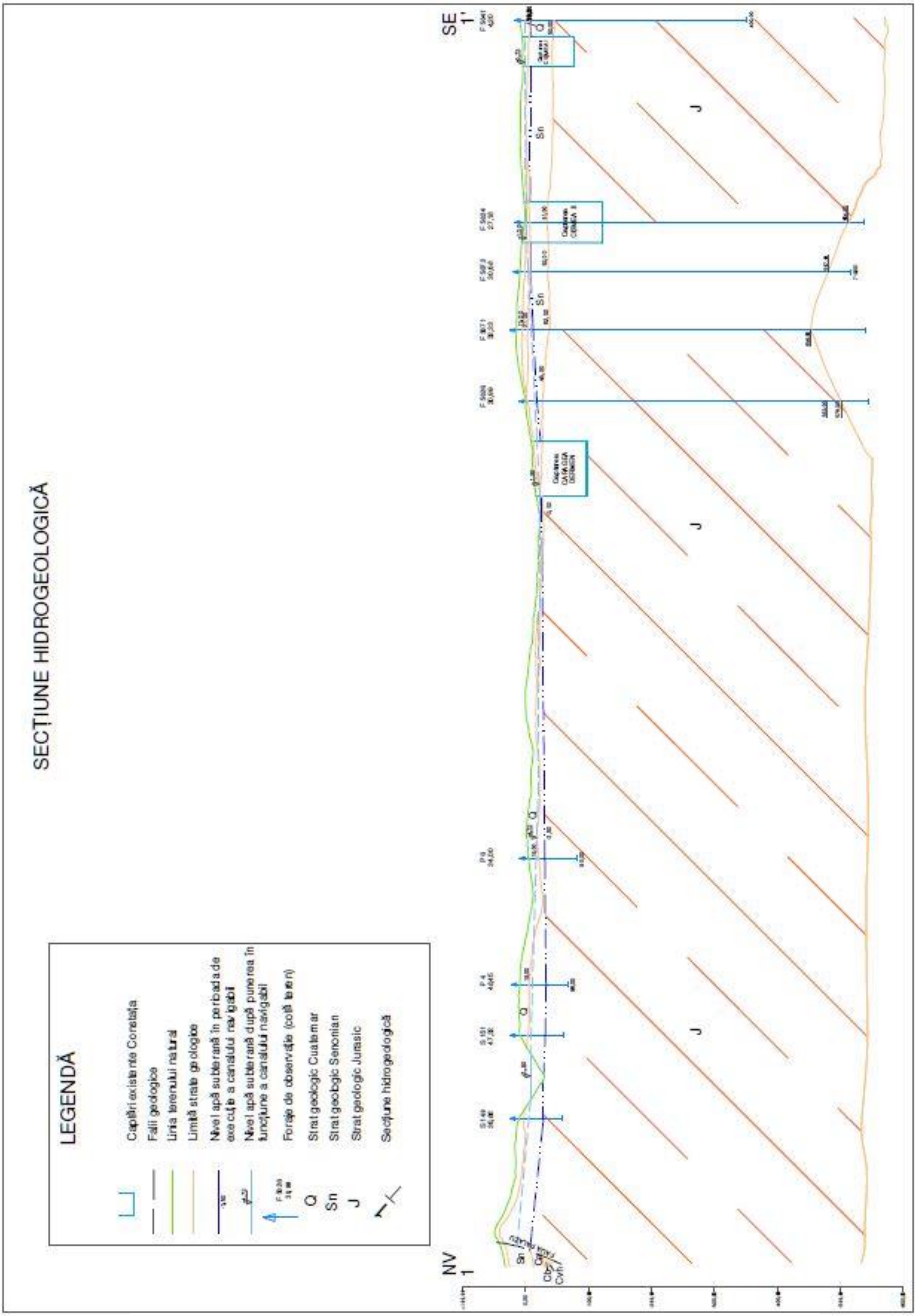
Appendix 4 – Geological sections 3-3’ and 4-4’ of the researched area



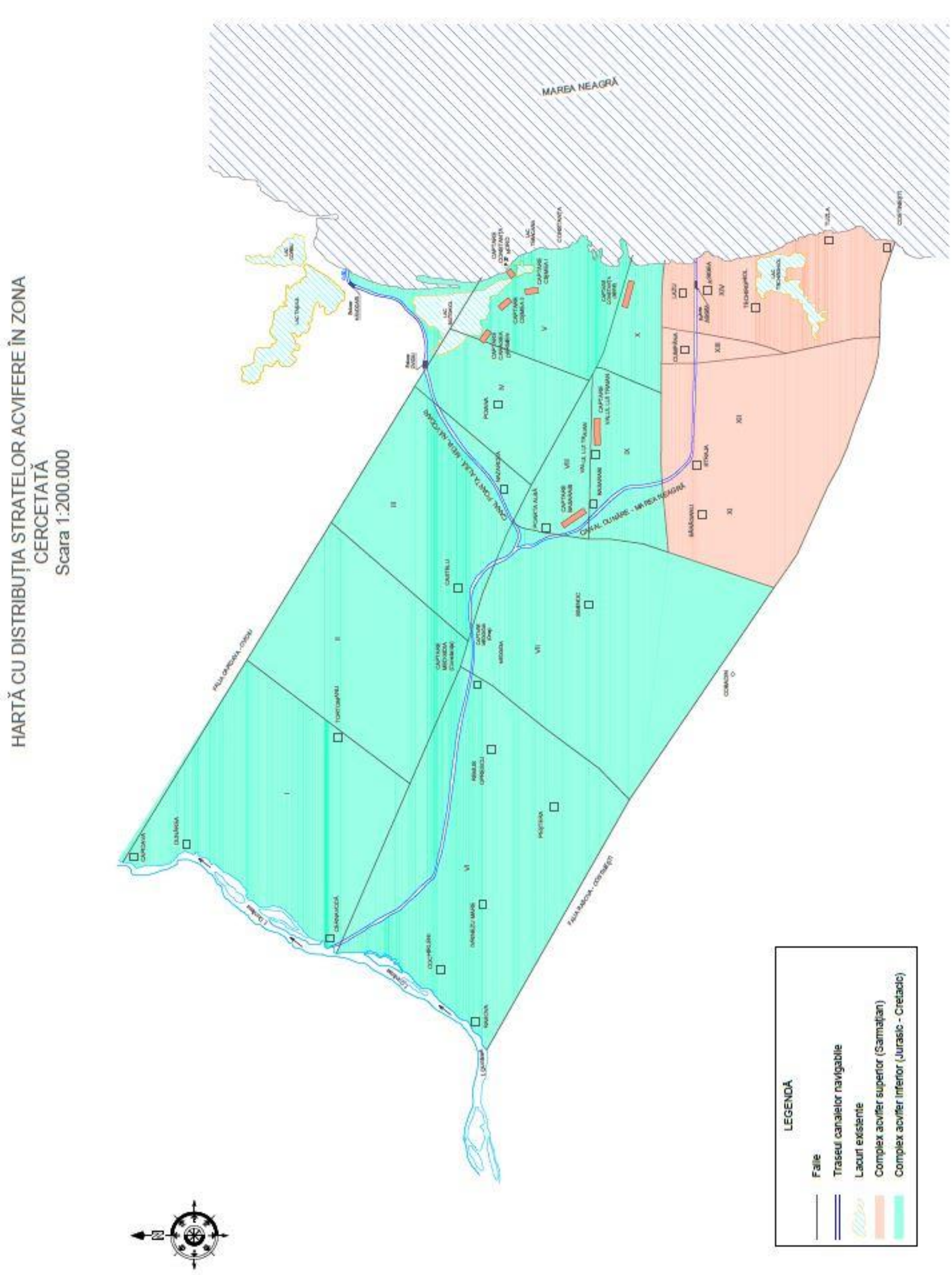
Appendix 5. – Geological sections 5-5’ and 6-6’ of the researched area



Appendix 6 – Hydrodynamic map of the Jurassic – Cretaceous lower aquifer



Appendix 7 – Hydrogeological section 1 – 1'



Appendix 8 – Map with the aquifers distribution in the researched area