CONSIDERATIONS CONCERNING THE POSSIBILITY OF CONTAMINATION IN THE AREA OF THE POARTA ALBĂ – MIDIA – NĂVODARI CANAL

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Abstract. Pollution of the Danube – Black Sea and Poarta Albă – Midia – Năvodari canals is possible due to various sources, such as wastewater from different industrial units, sewage water discharged directly in the canals or along the tributary valleys, navigation, pipelines for the transport of petroleum products. Groundwater flow modeling has provided a useful tool for the simulation of pollution events scenarios, in order to estimate their consequences on the canal water and drinking water sources. This paper presents the results of a local scale model, carried out in the Ovidiu zone, as well as those of a regional scale model, on the Upper Jurassic – Lower Cretaceous confined aquifer, that is in relationship to the Poarta Albă – Midia – Năvodari Canal.

Key words: canal, groundwater, numerical modeling, transport simulation, wellfield

INTRODUCTION

The Danube – Black Sea Canal is a human made waterway which was cut in order to shorten the navigation route for merchant shipping along the Danube. The Canal has one end in the area of Cernavoda town (on the Danube River, ~ km. 300 upstream the Danube mouths), cuts the Southern part of Dobrogea historical province on a general West – East direction and reaches the north-western Black Sea coast south of Constanta city. The Poarta Albă – Midia – Năvodari canal represents a north-east ramification of the Danube – Black Sea canal, which allow ships to reach Midia Harbour, also on the Black Sea coast, North of Constanta.

Pollution of the Danube – Black Sea and Poarta Albă – Midia – Năvodari canals is a complex issue, due to the various types of potential pollution sources.

For both canals, such potential pollution sources are (Barac *et al*., 2007): pipelines for the transport of petroleum products, purging stations and pumping stations for wastewater from Poarta Albă, navigation and harbour activities. Additional potential pollution sources for the main Danube – Black Sea canal are: the purging station, the pumping station and the industrial sewerage systems from Medgidia, the sewerage systems from Cernavodă, Medgidia and Basarabi, the dump ramp from Megidia, the Cernavodă Nuclear Power Plant. For the Poarta Albă – Midia – Năvodari canal, the dump ramp from Ovidiu can also be taken into account.

The purposes of the study are: 1) to estimate the impact of a possible contamination event of the Poarta Albă – Midia – Năvodari Canal water from a petroleum products transport pipeline in the Ovidiu area and 2) to analyze if the groundwater abstraction wellfields of Constanta City may be endangered by an accidental pollution of the Danube – Black Sea Canal.

Data concerning the unconfined aquifer in the Ovidiu area and the regional Upper Jurassic – Lower Cretaceous confined aquifer were integrated by numerical modeling. Groundwater flow models were simulated for both study areas. The available data on which the models have been based provide the distribution of the piezometric heads and hydrodynamic parameters and the main groundwater flow directions.

A local scale groundwater flow model was carried out on the unconfined loess aquifer in the Ovidiu area and several pollution scenarios were simulated.

A regional groundwater flow model was also carried out for the Upper Jurassic – Lower Cretaceous aquifer, in the area between the Danube – Black Sea and Poarta Albă – Midia – Năvodari canals, in order to estimate the influence of an accidental pollution of the Poarta Albă – Midia – Năvodari Canal on the abstraction wellfields of Constanța City. This paper presents the results provided by groundwater flow and transport modeling.

GEOLOGICAL FRAMEWORK

The structure of the geological deposits crossed by the Danube – Black Sea Canal is complicated, as they are affected by the regional NNE – SSW and ESE – WNW fault systems of the South Dobrogea area. A brief description of the geological formations cropping out along the canal is given in Tanislav *et al*., this volume.

A regional confined aquifer is located in the Upper Jurassic – Lower Cretaceous deposits, which are divided by the fault systems into tectonic blocks of limestone and dolomite formations, with variable thickness and different vertical jumps (Zamfirescu *et al*., 1994). This regional aquifer is bounded North by the Capidava – Ovidiu fault, which represents its natural boundary, as it separates the limestone deposits from impervious green schists deposits that make an impervious screen for the groundwater flow (Zamfirescu *et al*., 1994; Dinu, 1998).

The Ovidiu study area is located North of the Capidava – Ovidiu fault, in Quanternary loess deposits.

METHODOLOGY

To solve a problem of groundwater flow, by means of mathematical modeling, consists in computing the distribution in space and time of the state variables. These ones must satisfy the flow differential equation in any point of the domain, as well as the prescribed boundary conditions. The solution of the flow model is the piezometric head of the aquifer in any point of the represented domain. The direct problem of the potential is thus solved: starting from the characteristic parameters of the aquifer (hydraulic conductivity or transmissivity, storage coefficient, effective infiltration) the distribution of the piezometric head is determined.

Calibration of the model consists in the adjustment of the values and distribution of the input parameters until the obtained results, respectively the distribution of piezometric heads, are very close to the ones provided by the measurements.

After the calibration of the flow model, the transport of pollutants can be simulated. This involves the input of the parameters characterizing the mechanisms responsible for the transport of pollutants. The transport simulations provide the distribution of the pollutant concentrations in groundwater.

Numerical modeling in both study areas was performed using Visual Modflow code (Guiguer & Franz, 1996), which is based on the 3D finite difference method.

LOCAL GROUNDWATER FLOW MODEL IN THE OVIDIU AREA

One of the hot spots along the Poarta Albă – Midia – Năvodari canal is in the Ovidiu area, where there is a pipeline for petroleum products. Four boreholes were drilled in this hot spot, in order to study the risk of contamination of the canal if there is a leakage due to a damage in the pipeline.

A local scale groundwater flow model was carried out on the shallow aquifer, based on data provided by the four study boreholes (F24, F24B, F24C and F24D), on an area covering around 0.18 km^2. The represented unconfined aquifer is in loess deposits, with top elevations between 3 and 6 m and bottom elevations between - 4 and 1 m. The groundwater head elevations are between 0.92 m in F24C (located NE) and 2.95 m in F24D (located NW). The main groundwater flow direction is NW – SE. The horizontal dimensions of the grid are 10 m x 10 m and the height of the cells is equal to the thickness of the loess aquifer.

The constant-head boundary conditions were prescribed by interpolation, based on the measured hydrostatic heads. Along the western boundary, the prescribed groundwater heads are equal to the water elevations measured along the valley drained by the Poarta Albă – Midia – Năvodari Canal. On the southern boundary, the constant-head is equal to the water elevation in the canal, that is 1.65 m.

After calibration, the possible occurence of pollution by petroleum products was simulated in the area of the pipeline. This one is located along the main groundwater flow direction.

For the transport simulation, a steady-state groundwater flow regime was assumed for one year. The concentration of the dissolved petroleum product varied between 10 and 100 mg/l. The highest concentration could be an extreme, less probable value.

The longitudinal dispersivity of the aquifer (*aL*) varied between 5 and 25 m, plausible values for an unconfined aquifer (Carey *et al*., 2000).

The retardation mechanisms taken into account are the ones characterizing the fate of petroleum products in the porous media: sorption, characterized by a distribution coefficient *Kd* of 0.1 m^3/kg (Teutsch *et al*., 1998), and degradation, characterized by the linear degradation constant λ of 0.05 day^{-1} (Carey *et al*., 2000).

REGIONAL MODEL OF THE UPPER JURASSIC – LOWER CRETACEOUS AQUIFER ON THE ZONE BETWEEN THE DANUBE – BLACK SEA AND POARTA ALBĂ – MIDIA – NĂVODARI CANALS

This model was considered useful for the estimation of the contamination hazard of the groundwater abstraction wellfields of Constanta City, in case of an accidental pollution of the Poarta Albă – Midia – Năvodari Canal, and was based on the available data.

The Upper Jurassic – Lower Cretaceous confined aquifer is in direct relationship to the Poarta Albă – Midia – Năvodari Canal approximately between the Nazarcea and Capidava – Ovidiu faults.

The modeled domain is the sector bounded NW and N by the Poarta Albă – Midia – Năvodari Canal, NE by the Lake Siutghiol, SW and S by the Danube – Black Sea Canal and E by the Black Sea.

The horizontal dimensions of the grid cells are 500 m x 500 m and 250 m x 250 m in the zones of the wellfields. The heights of the grid cells are equal to the intercepted thicknesses of the Upper Jurassic – Lower Cretaceous aquifer, between 350 and 650 m.

As the dimensions of the grid cells are large enough to include fractured zones and, at the same time, small enough to consider the variation of parameters as continuous from one cell to another, the fractured medium can be assimilated to an equivalent porous medium (Dassargues, 1995).

The groundwater flow model was calibrated in steady-state regime, based on the piezometric heads measured in 1986. It was not possible to update these measurements, as many wells are not in function anymore. The boundary conditions are of prescribed constant-head and prescribed flux types. The constant-heads were prescribed based on the piezometric map of the Upper Jurassic – Lower Cretaceous aquifer (Fig. 12).

The water elevation of 1.25 m, measured downstream the lock, was prescribed on the northeastern section of the Poarta Albă – Midia – Năvodari Canal, where this one is in direct relationship with the aquifer. The same water elevation of 1.25 m was prescribed on the sector representing the Lake Siutghiol. The rest of the constant-heads along the Poarta Albă – Midia – Năvodari and Danube – Black Sea canals, were prescribed by interpolation, based on the piezometric map of the Upper Jurassic – Lower Cretaceous aquifer (Fig.12). On these sections, the canals are in contact with Senonian deposits, so they are not in direct relationship with the aquifer anymore.

Along the boundary with the Black Sea, the constant-heads were prescribed also by interpolation, based on the groundwater heads measured in wells. The strong hydraulic gradient north of the Danube – Black Sea Canal is due to the presence of tectonic blocks without limestone and dolomite formations, located south of the Lazu – Cumpăna fault, where the hydraulic continuity of the aquifer is provided by Cenomanian deposits (Moldoveanu, 1998).

The prescribed flux boundary conditions are represented by the abstraction rates of the Constanţa and Valul lui Traian wellfields. The Basarabi abstraction wellfield is located on the western boundary of the modeled domain. Therefore, its effect on the aquifer was represented by constant-heads equal to the dynamic head elevations. This was necessary because the zone influenced by this wellfield exceeds the boundary of the modeled domain.

The abstraction rates of the wellfields that exploit the Upper Jurassic – Lower Cretaceous aquifer are:

- Cişmea I wellfield (Constanţa): 1500 l/s;
- Cişmea II wellfield (Constanţa): 500 l/s;
- Caragea Dermen wellfield (Constanţa): 700 l/s;
- Constanţa Nord wellfield: 450 l/s;
- Valul lui Traian wellfield: 100 l/s.

The wellfields of Constanţa city are located South of the Lake Siutghiol (Fig. 12).

Calibration of the model was achieved by the trial-and-error method, by adjusting the values of hydraulic conductivity until the calculated heads became as close as possible to the measured heads, in all the observation points. Calibration of a flow model is usually considered well done when the differences between the calculated and measured groundwater heads are less than 1 m in all the observation points.

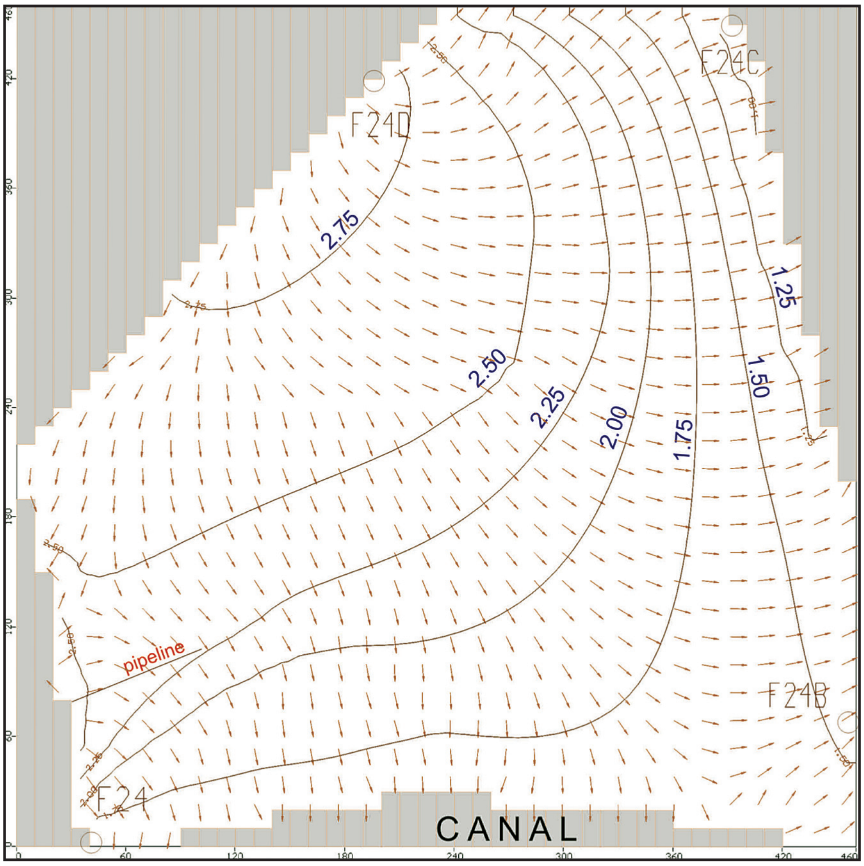

Fig. 1 Piezometric map and groundwater flow directions in the shallow aquifer from Ovidiu zone

RESULTS

1. Local groundwater flow model in the Ovidiu area

The hydraulic conductivities resulted after the calibration of the model are between 1 m/day, on the widest area of the domain, and 10 m/day (NW). Fig. 1 shows the piezometric map resulted after the calibration, as well as the groundwater flow directions, that are mainly NW – SE and W – E. In the southeastern part of the modeled domain, the Poarta Albă – Midia – Năvodari Canal supplies the shallow aquifer, which has lower groundwater heads (1.46 m in the borehole F24B).

2. Transport simulations in the Ovidiu zone

The figures 2 - 11 show the concentration distribution in the aquifer, for differing values of the concentration *C* and of the longitudinal dispersivity *aL*. The pollutant plume spreads more for higher concentration (Figs. 2 and 3) and higher dispersivity (Figs. 4 and 5).

Simulations were made considering the retardation mechanisms as well. First, both sorption and degradation were introduced, then only sorption. In both cases, the plume stays in the vicinity of the pipeline after one year, regardless of the concentration or the dispersivity values.

If only degradation is taken into account, the plume extends more along the groundwater flow direction, but doesn't reach the Poarta Albă – Midia – Năvodari Canal during one year (Figs. 9 and 11).

In the absence of retardation, the plume reaches the Poarta Albă – Midia – Năvodari Canal during one year, except for the situation where *C* = 10 mg/l and *aL* = 2 m. But, even in this case, pollution reaches the canal after more than one year.

The higher are the pollutant concentration and the dispersivity, the shorter is the time that pollution needs to reach the canal.

The results of the transport simulations in the Ovidiu zone are synthesized in Table 1.

Pollution of the Poarta Albă – Midia – Năvodari canal, due to damage of the petroleum products pipeline in the Ovidiu zone, may be less serious than shown by these simulations, as the sorption process may occur. Unfortunately the specific parameters of this process are not known. Thus, we don't know at what extent the petroleum product can be sorbed to the solid phase and naturally atenuated in this way. Therefore, damage to the petroleum products pipeline in this zone leads to the more or less serious pollution of the Poarta Albă – Midia – Năvodari Canal.

Table 1 Results of the transport simulations for the case of pollution from the pipeline for petroleum products

Pollutant concentration *C* (mg/l)	Longitudinal dispersivity a_L (m)	Observations	
		No retardation	With retardation
10	2	The pollution plume extends along the groundwater flow direction, towards the canal.	Only sorption or sorption + degradation: after 1 year the pollution plume stays in the zone of the pipeline Only degration: after 1 year the pollution plume extends a little around the source, mainly on the groundwater flow direction, towards the canal. After 1 year the plume doesn't reach the canal yet.
	5	Pollution reaches the canal after 1 year.	
	10	Pollution reaches the canal after 300 days.	
	20	Pollution reaches the canal after 250 days.	
20	2	Pollution reaches the canal after 1 year.	
	5	Pollution reaches the canal after 300 days.	
	10	Pollution reaches the canal after 250 days.	
	20	Pollution reaches the canal after 200 days. After 1 year the pollutant concentration is over 0.5 mg/l in the vicinity of the canal.	
50	2	Pollution reaches the canal after 300 days. After 1 year the pollutant concentration is over 0.1 mg/l in the vicinity of the canal.	
	5	Pollution reaches the canal after 250 days. After 1 year the pollutant concentration is 0.5 mg/l in the vicinity of the canal.	
	10	Pollution reaches the canal after 200 days. After 1 year the pollutant concentration is 1 mg/l in the vicinity of the canal.	
	20	Pollution reaches the canal after 150 days. After 1 year the pollutant concentration is over 1 mg/l in the vicinity of the canal.	
100	2	Pollution reaches the vicinity of the canal after 250 days. After 1 year the pollutant concentration is 0.5 mg/l in the vicinity of the canal.	
	5	Pollution reaches the canal after 200 days. After 1 year the pollutant concentration is 1 mg/l in the vicinity of the canal.	
	10	Pollution reaches the canal after 200 days. After 1 year the pollutant concentration is over 1 mg/l in the vicinity of the canal.	
	20	Pollution reaches the vicinity of the canal after 120 days. After 1 year the pollutant concentration is 5 mg/l in the vicinity of the canal.	

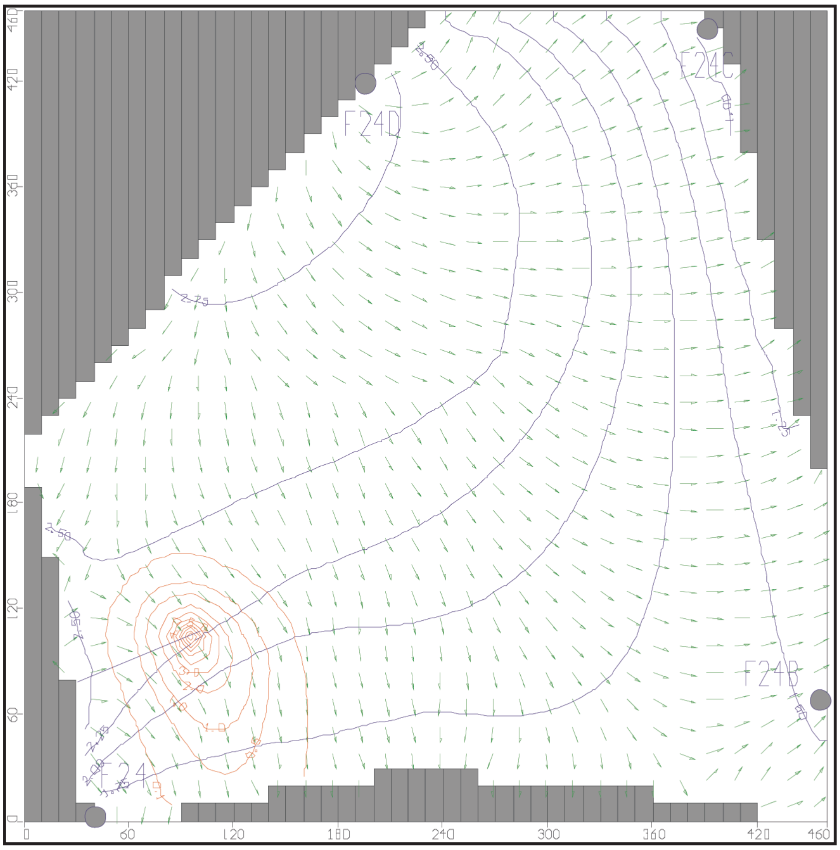

Fig. 2 Concentration distribution (mg/l) after one year, for $C = 10$ mg/l and $aL = 20$ m

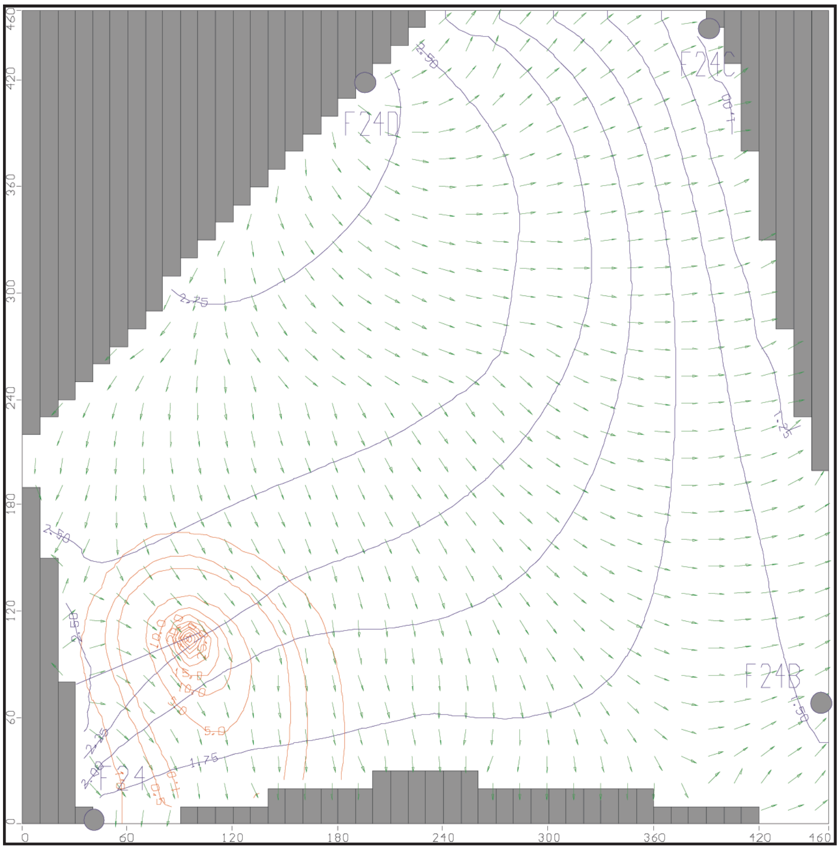

Fig. 3 Concentration distribution (mg/l) after one year, for $C = 50$ mg/l and $aL = 20$ m

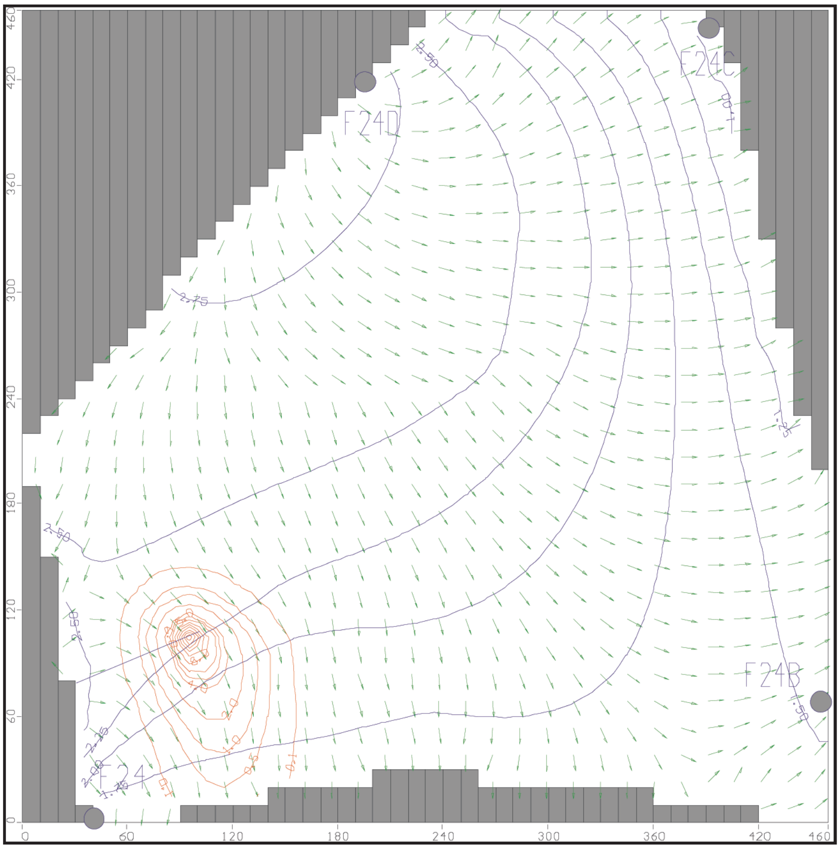

Fig. 4 Concentration distribution (mg/l) after one year, for $C = 20$ mg/l and $aL = 10$ m

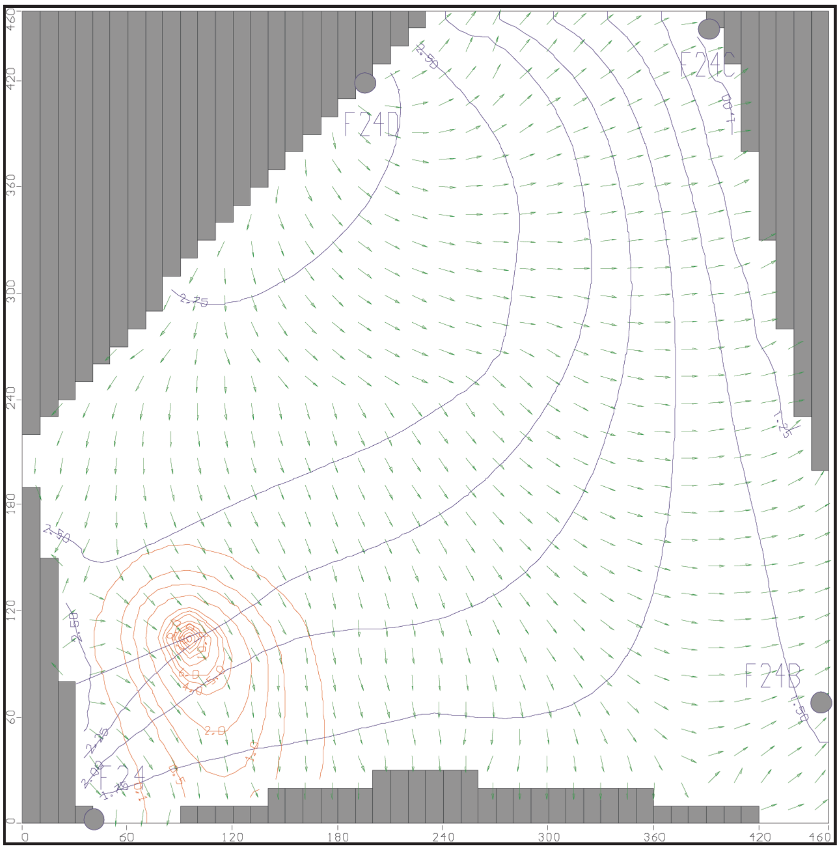

Fig. 5 Concentration distribution (mg/l) after one year, for $C = 20$ mg/l and $aL = 20$ m

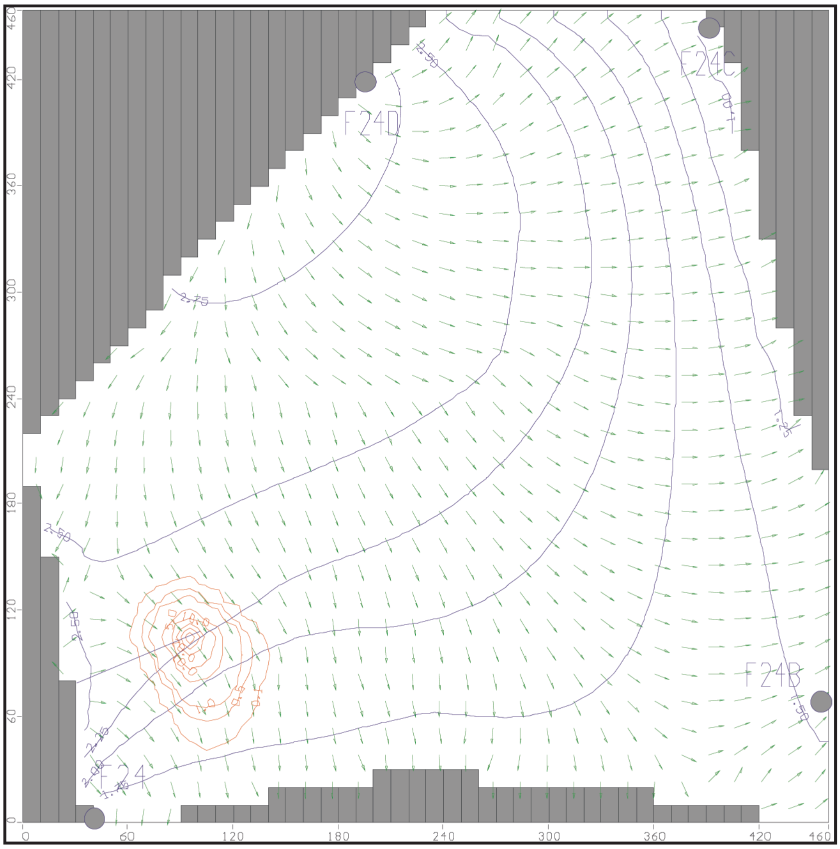

Fig. 6 Concentration distribution (mg/l) after 120 days, for $C = 50$ mg/l and $aL = 10$ m

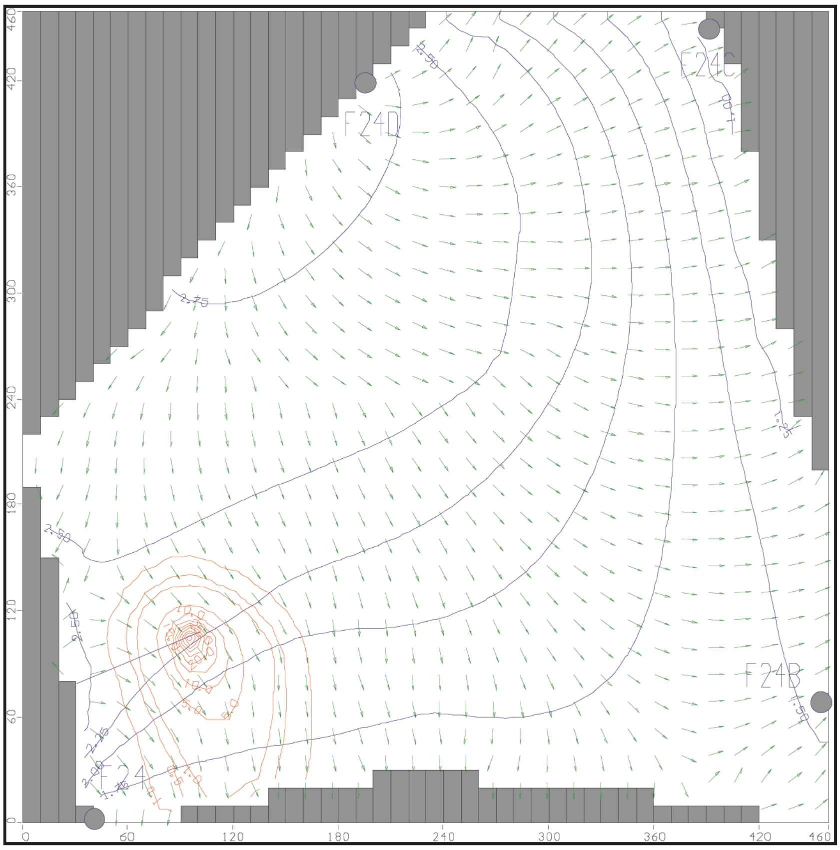

Fig. 7 Concentration distribution (mg/l) after one year, for $C = 50$ mg/l and $aL = 10$ m

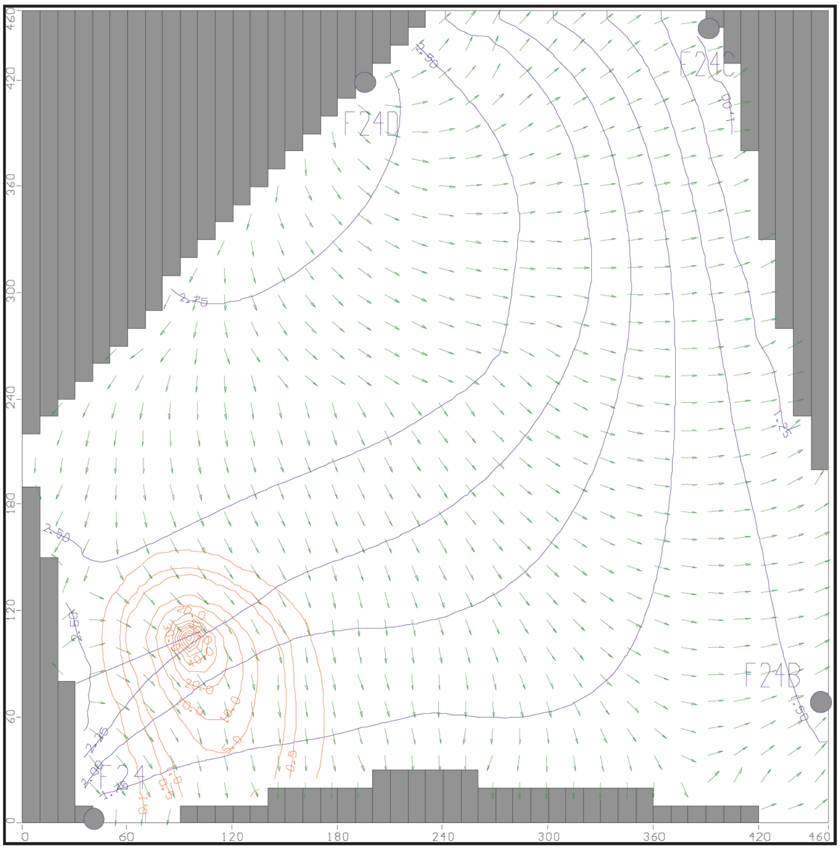

Fig. 8 Concentration distribution (mg/l) after one year, for $C = 100$ mg/l and $aL = 10$ m

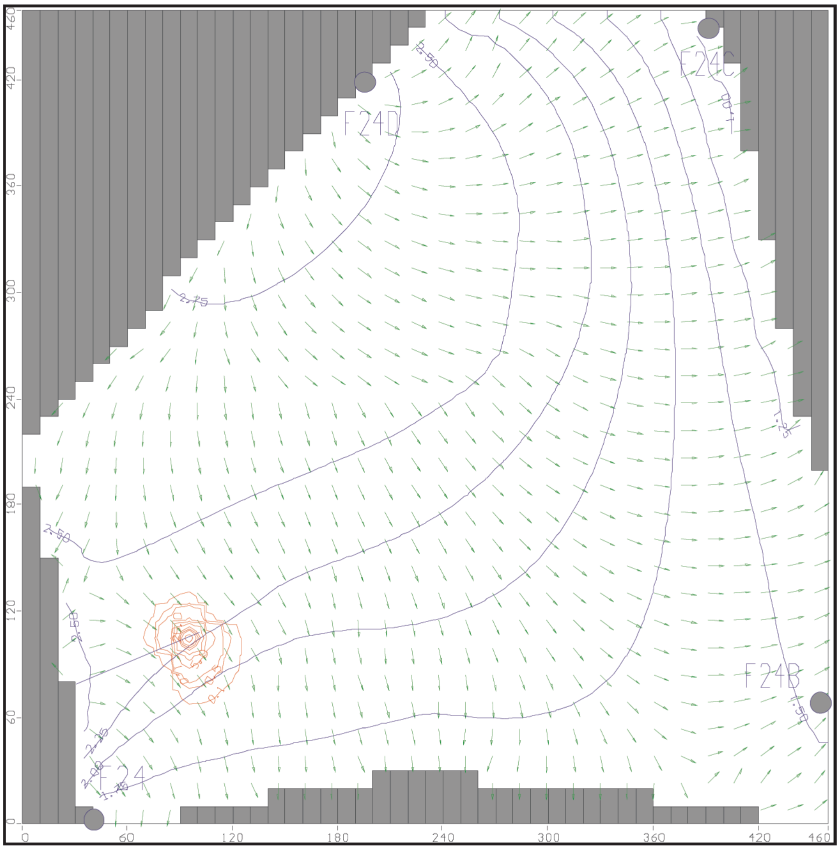

Fig. 9 Concentration distribution (mg/l) after one year, for $C = 100$ mg/l and $aL = 10$ m, with degradation

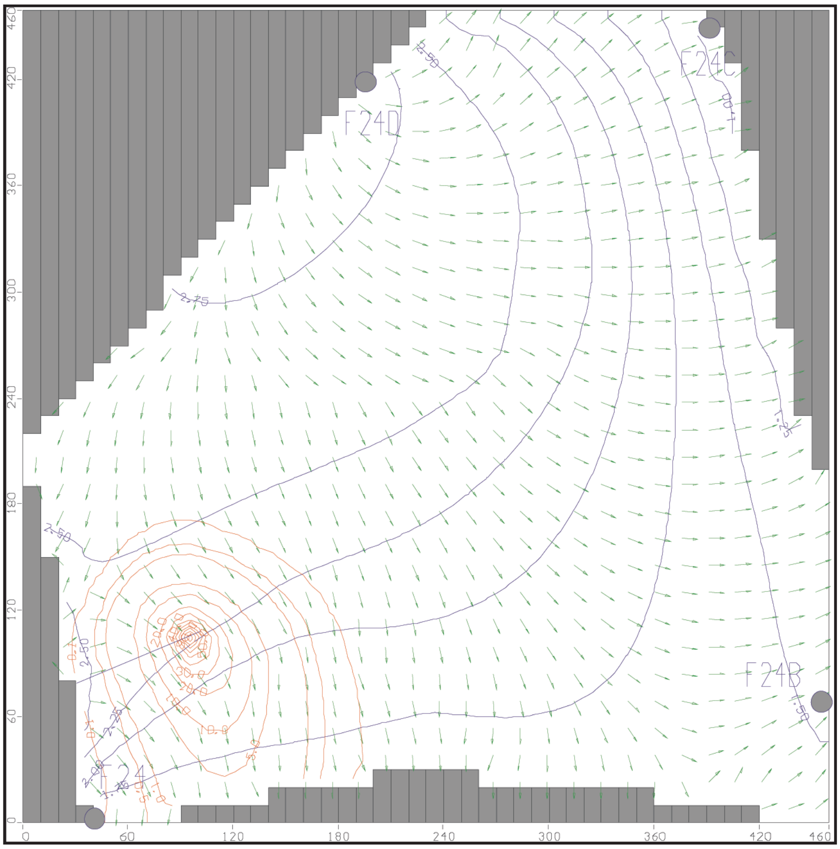

Fig. 10 Concentration distribution (mg/l) after one year, for $C = 100$ mg/l and $aL = 20$ m

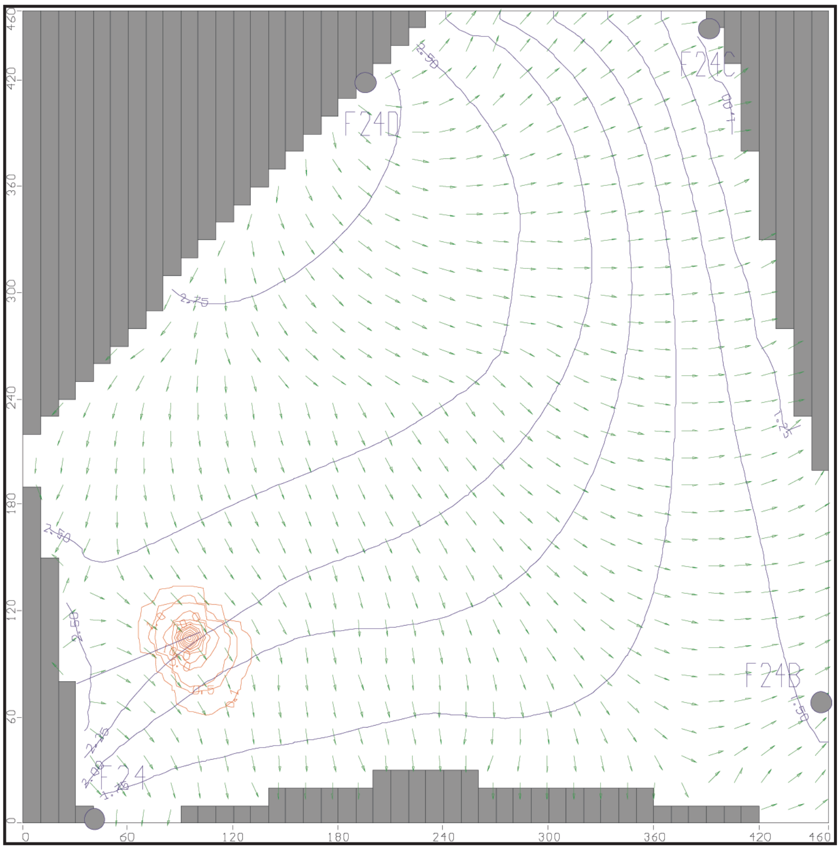

Fig. 11 Concentration distribution (mg/l) after one year, for $C = 100$ mg/l and $aL = 20$ m, with degradation

3. Regional model of the Upper Jurassic – Lower Cretaceous aquifer on the zone between the Danube – Black Sea and Poarta Albă – Midia – Năvodari canals

The differences between the calibrated and measured piezometric heads exceed 1 m in two observation points : 1.08 m in P5 and 1.3 m in P6, wells located in the northern part of the modeled domain, close to the Poarta Albă – Midia – Năvodari Canal. But, taking into account the regional scale of the model, its simplicity and the uncertainty of some of the measurements, the calibration can be considered good.

The hydraulic conductivities of the Upper Jurassic – Lower Cretaceous aquifer, resulted from the calibration of the model, are between 0.01 m/day, on a restricted area around well P7, in the northern zone of the represented domain, and 800 m/day, in the zone of the Cernavodă – Constanța fault and in the zone of the well F5037 (Fig. 13). The high values of hydraulic conductivity correspond to zones with higher degree of karstification.

On the widest part of the domain, the hydraulic conductivity is 50 m/day. Between the Cernavodă – Constanța and Lazu – Cumpăna faults, the hydraulic conductivities are relatively low, between 0.2 and 10 m/day. These values correspond to the zone with strong hydraulic gradient.

The groundwater flow directions, resulted from the calibration of the model, are mainly W – E and SW – NE (Fig. 13). Perturbations occur in the zone of the wellfields of Constanța city but also locally, in the zone of the wellfield from Valul lui Traian village and in the zone of the lock from the Poarta Albă – Midia – Năvodari Canal. The zone with low hydraulic conductivities located north of the Lazu – Cumpăna fault is responsible for the deviation of the groundwater flow direction, which becomes mainly S – N, then turning to W – E north of the Cernavodă – Constanța fault (Fig. 13).

After calibration, particles were introduced in the cells corresponding to the abstraction wellfields and backward-tracking simulations were performed, in order to determine the zones they come from. It can be noticed that all the wellfields are supplied from the western boundary of the modeled domain (Fig. 14), located in the vicinity of the Poarta Albă – Midia – Năvodari Canal. In this sector, the canal is in direct relationship with Senonian deposits, not with the Upper Jurassic – Lower Cretaceous aquifer. Therefore, if we consider only the advective transport, the model shows that the abstraction wellfields cannot be contaminated by water from the Poarta Albă – Midia – Năvodari Canal.

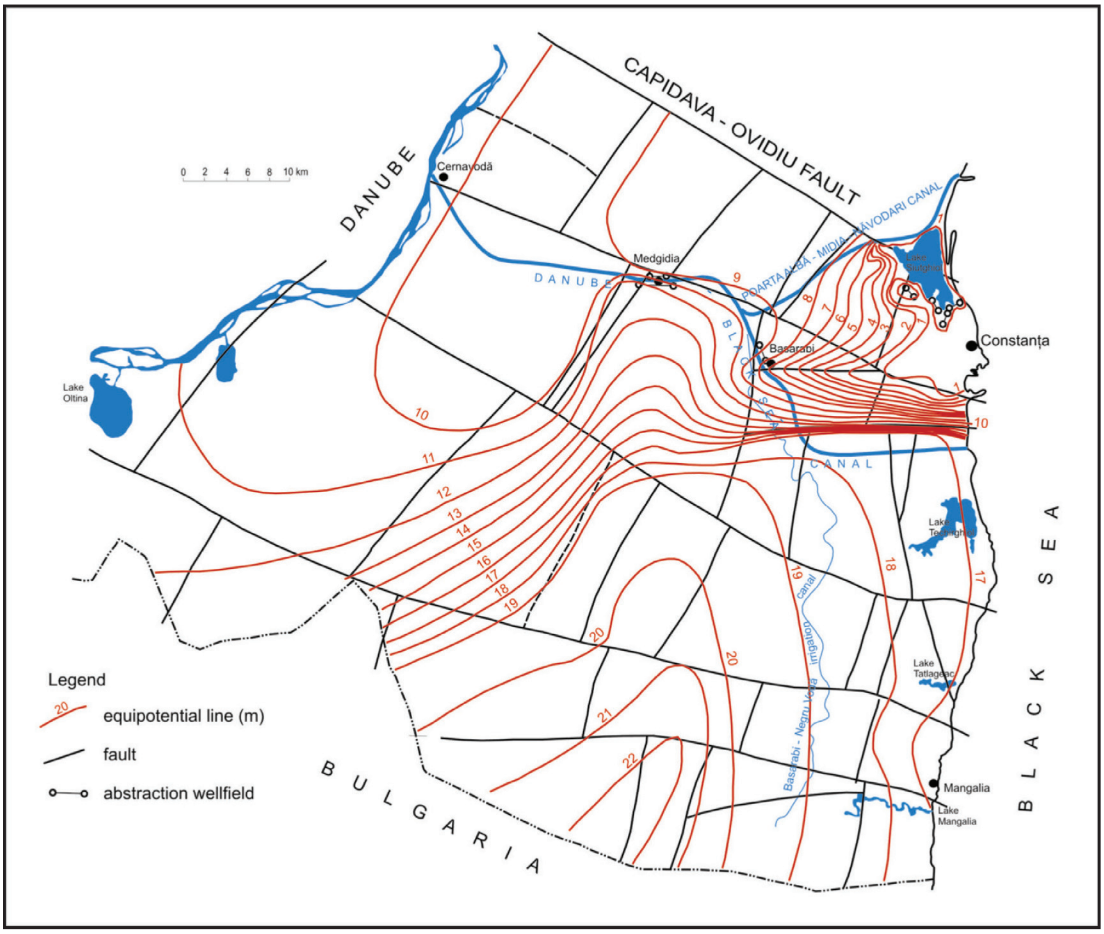

Fig. 12 Piezometric map of the Upper Jurassic – Lower Cretaceous aquifer (modified after Moldoveanu, 1998)

The transport of pollutants was also simulated by considering dispersion. A hypothetic pollutant was introduced in the zone of the Poarta Albă – Midia – Năvodari Canal and the groundwater flow regime was considered as steady-state for 20 years, the abstraction rates being constant. Of course this is a very simple approach, but the available data have not allowed transient modeling. For the transport simulations, different values were introduced for the pollutant concentration and the aquifer dispersivity. The transport model showed that, regardless of the concentration and dispersivity, after 20 years, the pollution effect only occurs on a restricted area, around the pollution source. Finally, pollution was introduced on the whole length of the Poarta Albă – Midia – Năvodari Canal. Even in these conditions and for high dispersivities, of 20 and 30 m, the simulations showed that, after 20 years, the pollution effect only occurs on a narrow section, along the canal. This is the consequence of the hydrodynamic conditions.

The transport simulations show that an accidental pollution on the Poarta Albă – Midia – Năvodari Canal does not endanger the quality of the water provided by the abstraction wellfields, which represent the drinking water source of Constanța City.

CONCLUSIONS

Data concerning the shallow aquifer in the Ovidiu area, as well as data concerning the Upper Jurassic – Lower Cretaceous regional aquifer have been integrated by numerical modeling. Transport simulations have been performed in order to estimate the effects of accidental pollution.

The simulations carried out in the Ovidiu zone show that the time needed by the dissolved petroleum products to reach the Poarta Albă – Midia – Năvodari Canal depends on their concentration and on the dispersivity of the shallow aquifer. If only advection and dispersion occur, the pollutant plume extends more as the aquifer dispersivity is higher or as the pollutant concentration is higher. If sorption and degradation or only sorption are taken into account, the pollutant plume stays in the zone of the pipeline. If only degradation is taken into account, the plume doesn't spread as much as in the absence of retardation. The retardation parameters are unknown, thus we don't know at what extent the petroleum products can be sorbed on the solid phase.

Therefore, the damage of the pipeline for petroleum products in the Ovidiu zone may lead to the more or less serious pollution of the water of the Poarta Albă – Midia – Năvodari Canal.

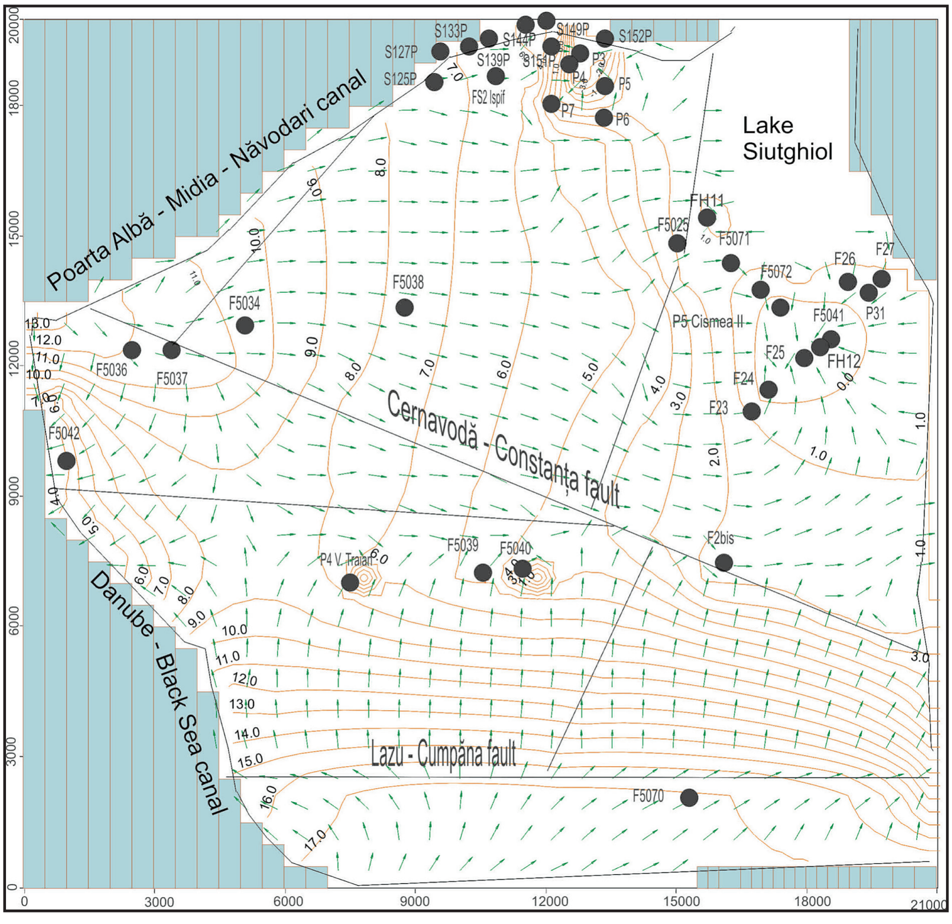

Fig. 13 Piezometric map and groundwater flow directions in the Upper Jurassic – Lower Cretaceous aquifer, resulted from the calibration of the model

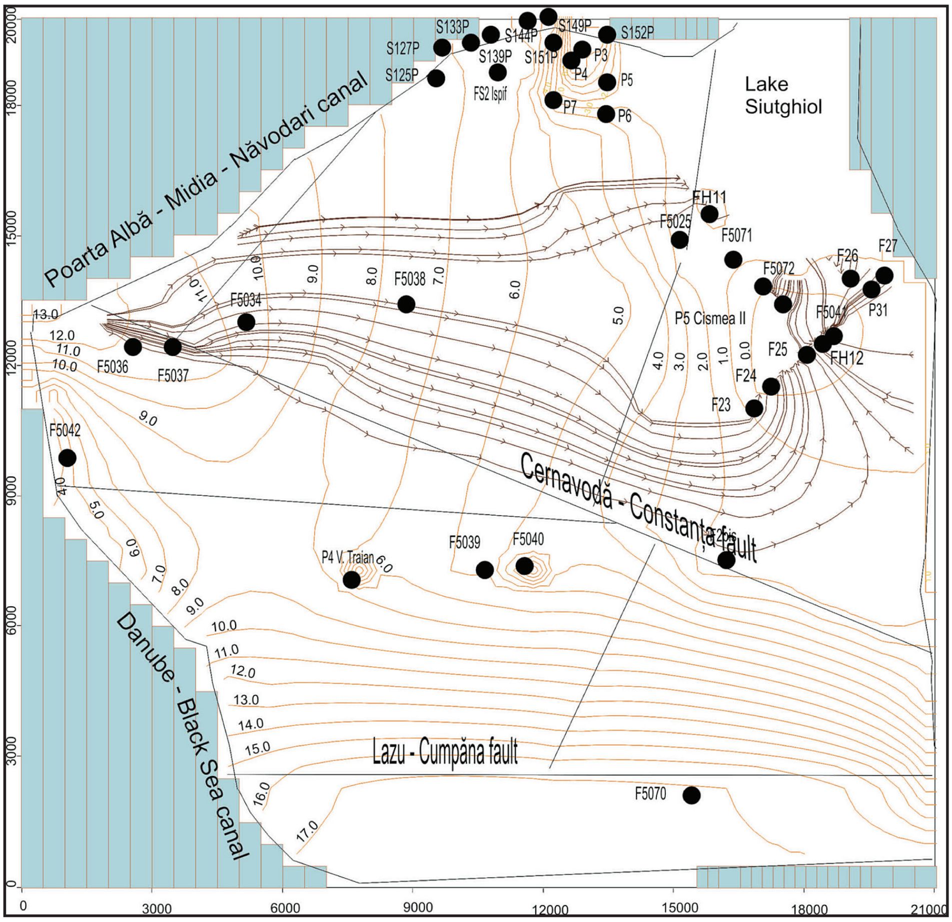

Fig. 14 Piezometric map and pathlines in the Upper Jurassic – Lower Cretaceous aquifer, resulted from the calibration of the model, emphasizing the supply zones of the wellfields of Constanța city

The groundwater flow model of the Upper Jurassic – Lower Cretacous confined aquifer is simplified, but reflects the general flow tendencies. The results provided by the transport simulations show that an accidental pollution of the Poarta Albă – Midia – Năvodari Canal does not endanger the quality of the groundwater exploited by the abstraction wellfields of Constanta City. This is due to the hydrodynamic conditions, that are mainly determined by the geological structure.

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