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figg. 9 - tab. 2

Anthropogenic Pressure on Ground Water Resources of the Benevento Alluvial Plain (Campania)

Effetti della pressione antropica sulle risorse idriche sotterranee della piana alluvionale di Benevento (Campania)

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ABSTRACT - Alluvial aquifers are characterized by an extremely complex ground water circulation depending on high lithologic as well as granulometric heterogeneity of deposits forming them. The possibility to encounter, either on surface or along vertical lines, levels at a lesser relative permeability, allows a splitting up of the ground water flow. The precise knowledge of Hydrostratigraphic Units forming an alluvial aquifer and the horizontal and vertical relations taking place among them allows to define mechanisms of aquifers recharge at different depths. This understanding also clarifies the processes ruling incidental spreading of pollutants in the aquifer.

KEY WORDS: Alluvial Plain, Hydrogeology, Hydrostratigraphic Unit, Vulnerability.

RIASSUNTO - Gli acquiferi alluvionali sono caratterizzati da una circolazione idrica sotterranea estremamente complessa legata all'elevata eterogeneità litologica e granulometrica dei depositi che li costituiscono.

La possibilità di rinvenire, sia arealmente sia lungo la verticale, la presenza di livelli a minore permeabilità relativa, determina la scomposizione del flusso idrico sotterraneo. Non a caso, a questi acquiferi è generalmente associata una circolazione idrica sotterranea che si realizza secondo lo schema delle falde sovrapposte interagenti a grande scala. L'esatta conoscenza delle Unità Idrostratigrafiche costituenti l'acquifero alluvionale e dei rapporti che fra di esse si realizzano, sia lungo l'orizzontale sia lungo la verticale, permette di definire i meccanismi di alimen-tazione dei diversi livelli acquiferi in profondità e di comprendere, pertanto, anche alla luce delle risultanze delle indagini idrogeologiche, i processi che regolano l'eventuale propagazione, in falda, di sostanze contaminanti. La ricerca condotta mostra, infatti, quali siano le ripercussioni, sia in tema di vulnerabilità all'inquinamento dell'acquifero, sia relativamente alla qualità chimico-fisica della risorsa, derivanti dalle considerazioni suesposte.

PAROLE CHIAVE: Piana alluvionale, Idrogeologia, Unità idrostratigrafica, Vulnerabilità.

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1. - INTRODUCTION

Alluvial aquifers are characterized by an extremely complex ground water circulation depending on high lithologic as well as granulometric heterogeneity of deposits forming them. The possibility to encounter, either on surface or along vertical lines, levels at a lesser relative permeability, allows a splitting up of the ground water flow.

It is not a chance if a ground water circulation is generally connected with these aquifers, which takes place according to superimposed water tables feature acting upon each other on a large scale. Very often monitoring piezometric levels does not permit to reconstruct ground water circulation considering the above mentioned complexity. Scarce knowledge of drilling depths as well as the impossibility of carrying out measurements in wells by means of canes drawing at different aquifer levels, leads us to reconstruct piezometric features referring to abstract flow patterns to be connected with single water tables (sole-water table levels), that are normally free. Thus, incidental differences among water table levels estimated in wells located at close distances, can only be hypothetically associated with presence, at a certain depth, of well differentiated or that can be differentiated aquifers; more often we are brought to associate such differences with trivial errors in measuring. What has been said is mainly applied when a detailed litho-stratigraphic reconstruction is lacking, which allows to draw the precise borders of one or more Hydrostratigraphic Units and of relations existing among themselves. This study shows how important it is to combine stratigraphic and hydrogeologic data in order to understand the presence of anomalies within estimated water loads and reconstructed piezometric features.

The precise knowledge of Hydrostratigraphic Units forming an alluvial aquifer and relations taking place among them horizontally as well as vertically also allows to define aquifers recharge at different depths thus understanding also, following hydrogeologic surveying results (with utmost reference to water loads within each other), the processes ruling incidental spreading of pollutants within the water table. On the base of these considerations the present research shows the consequences both on vulnerability to pollution and physical-chemical quality of water resources.

Raffaele Bruno worked upon gathering, elaborating and interpreting hydrogeologic and sedimentologic data. He also took part in writing out the text with Libera Esposito who also worked with Alessio Valente for combining hydrogeologic and sedimentologic features. Important corrections on the text have been made by Mario Valletta and Giuseppina Monacelli.

2. - GEOLOGICAL FRAMEWORK

The Benevento alluvial plain expands, for about 30 km^2, over the central part of Calore river valley (fig. 1). From a morphological view point, the territory is rather differentiated with remarkable height's variations (ranging from 10 to 80 m).

Within the surveyed areas it is possible to recognize lithostratigraphic units described in the following.

2.1. - Lagonegro Unit

Terranes attributed to such a Unit outcrop North of Benevento, along the orographic right hand of Calore river and North-East, over the area which falls between Calore river bed and the Cornacchie torrent (fig. 1).

Because of numerous tectonic phases that took place during Miocene-Pliocene times, such terranes originated chaotic successions organized in two distinct facies. The *clayey-marly* facies includes clays and marly clays, shales, sometimes well layered, compact, grey, red and green somewhere, alternating with marls and red calcareous marls and, subordinately, with layers of turbiditic calcarenites; in the upper part of the succession it is possible to find layers of soft grey quartz-lithic arenite including rare clayey levels, and layers of soft micaceous brown sandstone. Such terranes are characterized with a chaotic structural arrangement as well as disorganized folds of small radius. Such a facies is the relative aquiclude of the main aquifer.

The *calcareous-marly* facies, includes massive layers or just layers of calcarenites and bioclastic, turbiditic calcirudites, interbedded within marls and red clayey marls. Calcareous breccias can be found too, with significant red marly matrix. These lithotypes are to be found very often as calcareous olistoliths, ranging to several thousands of m^3, included and isolated within terranes belonging to the clayey facies.

Such lithologies have to be referred to Red Flysch formations, to Multicoloured Clays and, as far as sandstones are concerned, to the Tusa Tuffites (Zuppetta *et alii*, 1984) and to the Numidic Flysch; that is to say it is a matter of terranes deposited in the Lagonegro basin between Upper

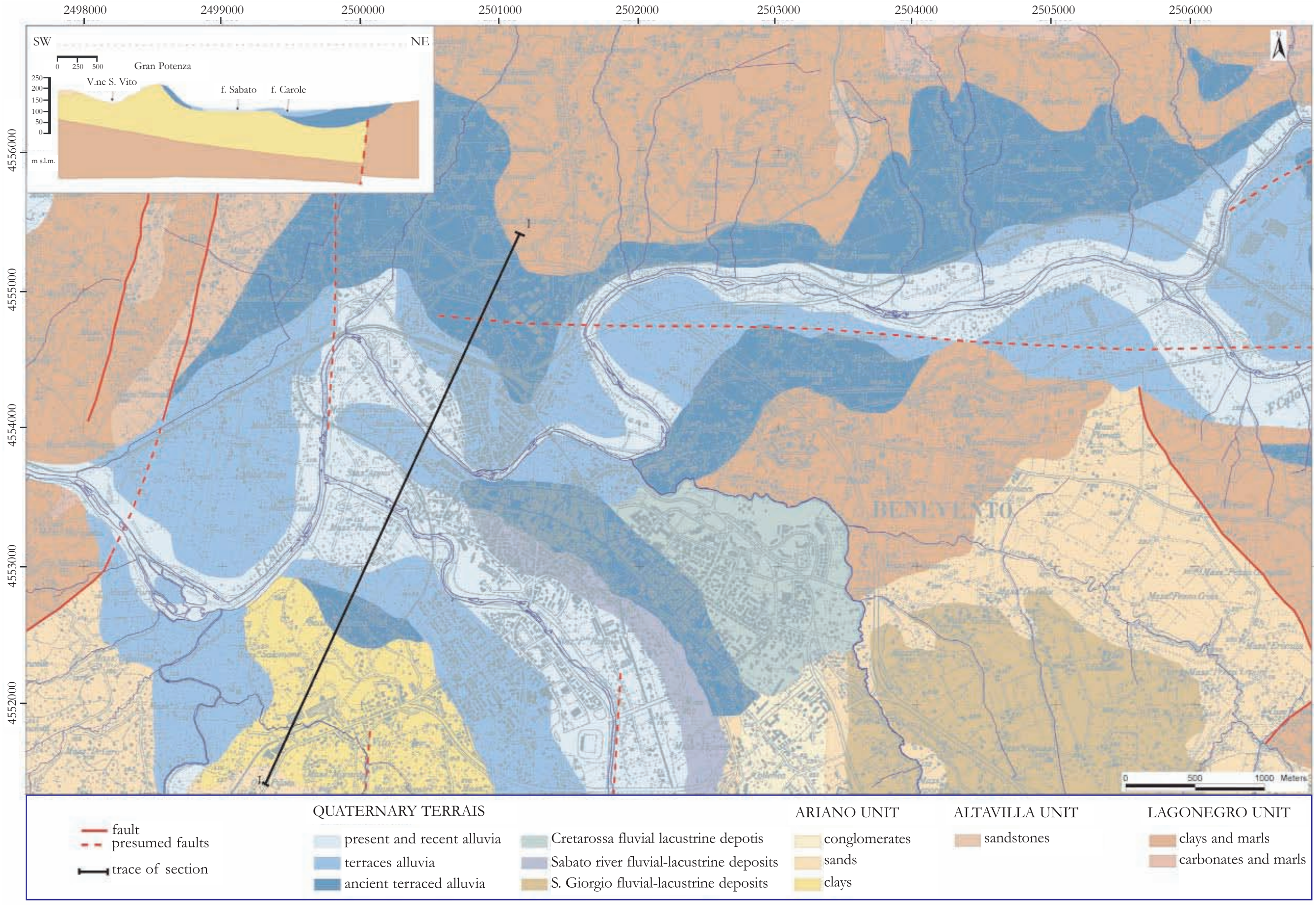


Fig. 1 - Hydro-lithological map and geologic cross-section of the study area.
- *Carta idro-litologica e sezione geologica dell'area di studio.*

Cretaceous and Miocene (PESCATORE *et alii*, 1996).

The thickness of these deposits has been estimated to attain at least a few hundreds of meters (PESCATORE *et alii*, 1996).

2.2. - ALTAVILLA UNIT

Terranes belonging to this Unit outcrop North-West of Benevento, in locality S. Vitale and North-East, in locality Piano Borea (fig. 1).

Altavilla Units sediments were deposited within basins of limited size situated upon advancing nappes of the chain, far from active fronts, over inside areas known as *piggy-back* basins. Deposits of this sedimentary cycle ranging from Upper Messinian to Low Pliocene (CIAMPO *et alii*, 1986), are resting, with disconformity, upon the Lagonegro terranes and are limited above by a transgression surface.

Starting from the most ancient terranes, the cycle consists of: 1) evaporites (gypsum does not outcrop on the area); 2) massive layers of sandstones and conglomerates including predominantly calcareous, multisized and well rounded pebbles; 3) soft sandstones and sands with clayey-silty levels.

Deposits belonging to this sedimentary cycle underwent a strong orogenic phase taking place between Low and Medium Pliocene. As a consequence basal terranes are notably strained; whereas towards the top, the succession shows more regular a structure featured with folds or break-thrusts having predominantly meridian axial directions and eastern vergence (COPPA DE CASTRO *et alii*, 1969). The succession can attain thicknesses of about 300 meters.

2.3. - ARIANO UNIT

Terranes attributed to Ariano Unit (D'ARGENIO *et alii*, 1973) outcrop extensively South of Calore river (fig. 1). They belong to a subsequent sedimentary cycle of Medium Pliocene (CIARCIA *et alii*, 1998), that is transgressive and unconformable over Miocene or Lower Pliocene and is sheared off at the top by pleistocenic deposits or by the present erosion surface.

Such a cycle consists of three lithologic items: 1) grey-light blue clays, well layered, interbedded with silty massive clays, outcropping in Gran Potenza zone and Sabato river valley (fig. 1). Such deposits have been attributed to an offshore and not very deep depositional environment (CIARCIA *et alii*, 1998). This lithologic item, along with the clayey-marly Lagonegro Unit, forms the aquiclude of the alluvial aquifer in the southern section South of Calore river; 2) massive layers or just layers of clayey yellowish sands, interbedded with very thin layers of grey-light blue silty clays including rare shells of lamellibranchia and gasteropoda. They outcrop in locality Torre Alfieri and on the orographic right hand of S. Nicola torrent (fig. 1, 3) polygenetic conglomerates, including multisized spheroidal or tilelike pebbles, inside a sandy matrix; frequently found in the area included between Monte Guardia and locality Pacevecchia (fig. 1). From the structural point of view, the above mentioned terranes, also deposited according to piggy-back basin like process, originate monoclines, with slightly dipping layers, directing towards North North-East. The succession can attain thicknesses of about 250 meters.

2.4. - QUATERNARY DEPOSITS

Quaternary deposits, the site of the studied aquifer, express several units as described in the following.

Ancient terraced alluvial deposits. The ancient terraced alluvial deposits flank Calore river where it directs East-Westwards (fig. 1), forming a terrace 70-80 meters high with regard to the present river bed; they are lacking in sections of meridian orientation instead, where the valley becomes notably narrower (fig. 1). These deposits consist of conglomerates with massive structure, interbedded with lenticular sands and clayey reddish *silts*; they show polygenetic (predominantly calcareous), multisized, well rounded clasts, included within a significant sandy matrix carrying evident marks of oxidation and organic substances. Very often a calcareous cement gives a stone-like consistency to the deposit; cementation is missing on the surface, where the conglomerate, being altered, appears loose.

As shown in paragraphs 4.1 and 4.2, these deposits are of paramount importance to the structure of the alluvial aquifer.

S. Giorgio fluvial-lacustrine deposits. They outcrop South-East of Benevento, between S. Nicola and Cornacchie torrents (fig. 1). The succession, of fluvial-lacustrine origin, consists of compact, muddy brown-yellowish clays, alternating with layers of polygenetic, multisized, got close pebbles, included within a significant sandy matrix; thicknesses very often attain 40 meters.

Sabato river fluvial-lacustrine deposits. Terranes belonging to this sedimentary unit do not outcrop because they are covered with debris and colluvium, however their existence is witnessed by means of analyses carried out during several geognostic surveys (PESCATORE *et alii*, 1996). The succession, of fluvial-lacustrine origin, originated following ancient terraced alluvial deposits, along the western border of the hill where is located the historical centre of Benevento and which subsequently has been almost entirely dismantled by erosional activity of Sabato river (PESCATORE *et alii*, 1996). It deals with gravels and pebbles gathered together, in a sandy matrix, turning towards the top into very compact grey muddy clays, including sandy-muddy interbeddings which show organic substance as well as peaty and rusty levels. In the whole these terrains do not exceed a thickness of 50 meters.

Cretarossa fluvial-lacustrine deposits. Geognostic drillings (PESCATORE *et alii*, 1996) have also pointed out, where Cretarossa fluvial-lacustrine deposits outcrop (fig. 1), a rather heterogeneous succession covered with several meters of debris, colluvium and weathered pyroclastic rocks. Such a complex, resting upon pliocenic terrains or ancient terraced alluvial deposits, originates a further terrace rising 70-80 meters above the present Calore river bed. Layers attaining several meters in thickness of brown-yellowish compact clays are interbedded with very thin sandy levels and at times lenses of gravel or multisized, polygenetic pebbles, included within significant sandy matrix. Organic remnants and patinas carrying manganese or limonite occur very frequently. Thicknesses do not exceed 20 meters.

Terraced alluvial deposits. They outcrop as outliers forming fluvial terraces located at about 20 meters above Calore and Sabato river beds (fig. 1). They are characterized with gravels enclosing polygenetic, multisized, rounded pebbles, within a sandy-muddy matrix, interbedded with lenses of sands and muds. Campanian Ignimbrite (39.000 y BP; DE VIVO *et alii*, 2001) rests upon such deposits.

Modern and Recent alluvial deposits. They are made up with loose gravels and multisized, polygenetic pebbles, enclosed within a significant sandy-muddy matrix, interbedded with lenses of muddy sands and sandy-muddy clays. These deposits give rise to the most recent terrace attaining 8 meters above Calore and Sabato river beds. Reworked pyroclastic rocks are resting upon them (PESCATORE *et alii*, 1996).

Debris and colluvium. Detrital deposits are made of multisized, generally closely gathered gravels, within a sandy-muddy matrix. Often reworked levels of pumices of Vesuvian origin can be found within them (Avellino pumices, LIRER *et alii*, 1973).

Colluviums, on the contrary, are made of loose sands and clayey muds, which are very soft and brown, with polygenetic and multisized stony inclusions; muddy material is mostly due to weathering and erosion of volcanic products that can be attributed to the Campanian Ignimbrite. In some instances pyroclastic rocks are filling paleo-gaps attaining several meters in thickness. (PESCATORE *et alii*, 1996).

From a morphological point of view it is possible to point out three zones that might interest: the alluvial plain area s.s., slope zones and terraced alluvial deposits (fig. 2). Such a featuring is to be considered directly depending on Calore and Sabato rivers which are the main denudation agent of the landscape. The most visible results of such an activity are represented by several orders of terraces (ranging from I to IV), which we have already mentioned, running alongside the valleys of the two rivers. The prevailing, within the area, of non-conservative lithotypes has fostered erosional processes that have partly dismantled terraced surfaces making them difficult to recognize.

Alluvial terraces of first and second order, located at a height of 70-80 meters above the heights of the present Calore and Sabato river beds are resting upon ancient alluvial deposits of Calore river and upon fluvial-lacustrine deposits of Sabato and Cretarossa rivers. They are referred to formation mechanisms of tectonic type which originated the alternation of strain phases, responsible for events of partial damming and thereafter for overflooding of river beds, followed by phases of general filling of the area which induced gapping within deposited sediments.

An example of damming of Calore fluvial stream is shown by miocenic ridge of Toppa Pallotta-Monte S. Angelo (located West of Calore-Sabato junction; fig. 1).

Terraces of third and fourth order scattered along the rivers, at a height of 20 and 8 meters above the present river beds respectively, originated following successive base level's variations most likely due to events of climatic nature (glacial-eustatic variations; PESCATORE *et alii*, 1996).

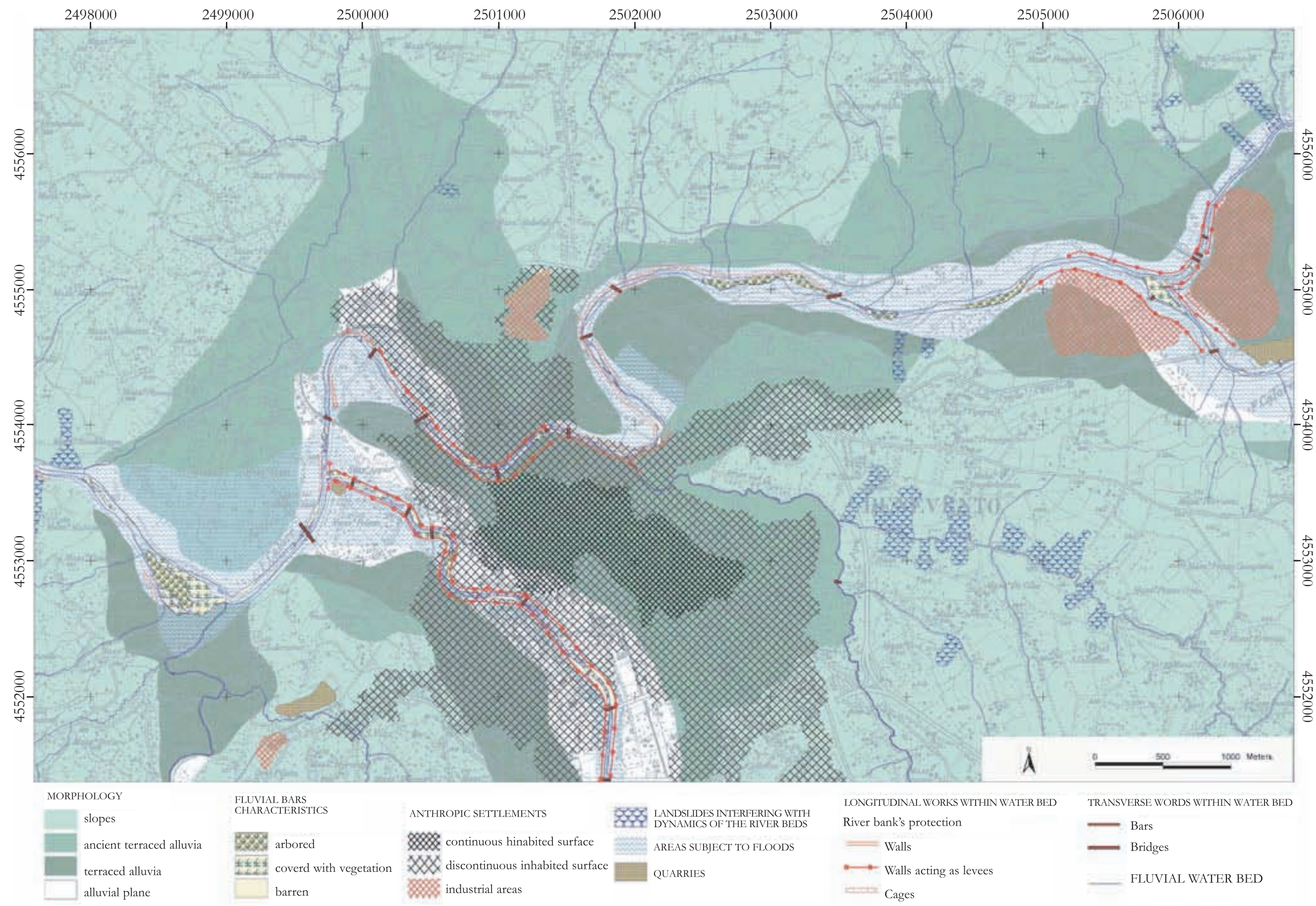


Fig. 2 - Map of the morpho-sedimentary and anthropogenic features.
- Carta dei caratteri morfologico-sedimentari ed antropici.

The hydrographical pattern appears to point out the existence of a structural control of the area, also proved by subsequent rivers and by fault slopes that can be found along Sabato river valley. Two main structural patterns are recognizable (PESCATORE *et alii*, 1996; BOUSQUET *et alii*, 1990): the first one directing East-West (fig. 1), consisting of faults which differentiate several monoclinal neotectonic structures where, within depressed zones, quaternary continental deposits have piled up; the second one, with meridian direction (fig. 1), consisting of a series of faults disengaging from the differential movement amongst different structures.

3. - HYDROGEOLOGY

Referring to lithologic characteristics of present deposits and in the light of the transmissivity data (T, in m^2/s) which have been worked out by means of some pumping tests (about 10) carried out within alluvial deposits (CELICO *et alii*, 1998; tab. 1) it was possible to associate to each lithotype a different type and degree of permeability.

- Deposits belonging to the marly-clayey facies of Lagonegro Units and to the clayey member of Ariano Unit are characterized with permeability of a matrix-depending type having a rather low water circulation (permeability degree being quite low; $K<1,0x10^{-7}$ m/s) which develops essentially within surface levels (circulation of "epidermal" type), at the most dealing with the first 5÷6 meters of loosened weathering sheets (CASTRACANI *et alii*, 1993). Water table's morpho-logy, as it will be shown by specific piezometric reconstructions, tends to follow the topographic pattern; consequently, water table flow gathering points are represented by the alluvial complex, located in the most depressed zones of the plain and by the most gapped water beds of the drainage.

- Deposits belonging to the sandy element of Ariano Unit show a type of permeability as to porosity and fissure and a ranging from medium to low degree of relative permeability ($K\approx3,0x10^{-7}$m/s). Frequently recurring interbeddings of clayey-silty nature characterizing this pliocenic sedimentary cycle, give often rise to small springs for permeability limit having discharges below $1,0x10^{-3}$ m^3/s (CELICO *et alii*, 1998).

- Arenaceous-marly lithotypes belonging to Altavilla Unit are characterized with a type of permeability as to porosity associated to a relative permeability degree ranging from medium to low.

Tab. 1 - *Results of the pumping tests. T = transmissivity calculated in the lowering phase; T' = transmissivity calculated in the rising phase; Saq = thickness of the saturated aquifer.*
- Risultati delle prove di emungimento. T = trasmissività calcolata con i dati di abbassamento; T' = trasmissività calcolata in risalita; Saq = spessore dell'acquifero saturo.

Well n.	Dischange (x 10^{-3} m^3/s)	T (m^2/s)	T (m^2/s)	Saq (m)
1	102	$1,77x10^{-1}$		97
2	5	$1,00x10^{-2}$	$1,10x10^{-2}$	42
3	1	$2,60x10^{-2}$		55
4	3	$9,71x10^{-4}$		15
5	3	$1,97x10^{-3}$	$2,14x10^{-3}$	13
6	6	$9,47x10^{-3}$	$8,74x10^{-3}$	58
7	2	$1,41x10^{-5}$		51
8	1	$1,10x10^{-3}$		3
9	3	$5,49x10^{-2}$		14
10	2	$4,88x10^{-4}$		3
11	1	$1,14x10^{-4}$		2

Hydrological importance of such deposits is of a strictly local type, since circulating waters feed springs with modest discharge and also wells of large diameter, not over 20 meters deep, used for domestic purposes.

- Stony lithotypes, of calcareous nature, belonging to Lagonegro Units are characterized by a medium permeability degree due to fissure. They too outcrop isolately forming reliefs of reduced extensions; consequently, they take on a limited interest giving rise to springs of very low discharge depending on the frequent marly interbeddings which hamper the ground water runoff's deepening.

- Ancient terraced alluvial deposits, terraced alluvial deposits, recent and present alluvial deposits, besides fluvial lacustrine deposits belonging to S. Giorgio, Cretarossa and Sabato river Units have been considered, in the set, having uniform permeability in the whole, of the type prevalently depending on matrix, of a medium-high degree (K≈5,0x10^{-4} m/s), in spite of terranes presenting significant variations, as to granulometric assortment and cementation degree, due to the depositional nature of sediments.

Consequently, as anticipated, clayey-marly elements belonging to Lagonegro Unit as well as grey-light blue clays belonging to Ariano Unit represent the aquifer's basal aquiclude resting within alluvial deposits. Lithologic and granulometric variety of them fosters a complex ground water circulation that follows the pattern of "superimposed water tables" interacting on a large scale. From a geometric point of view, the aquifer, within the analysed area, spreads over an East-West direction, covering a surface of approximately 34 km^2. Its thickness, reconstructed through the interpretation of available stratigraphic maps (CELICO, 1998) and of the General Town Planning Scheme of Benevento (Piano Regolatore Generale del Comune di Benevento, 1984), seem to vary progressively from the borders towards the axial zones of the valley where they are, nearby Benevento Central Station (fig. 3), about 110 meters deep. Data resulting from the above mentioned pumping tests are very interesting because they have shown that the highest values of transmissivity (ranging from 1,77x10^{-1} to 9,47x10^{-3} m^2/s) are proper to the areas of Benevento and its Industrial Zone, where alluvial aquifers thick-nesses attain higher values and where gravely-conglomeratic deposits are the most frequent ones. On the other hand, the lowest values (ranging from 1,97x10^{-3} to 1,14x10^{-4} m^2/s), can be found within the bordering zones of the plain, coinciding with reduction of thickness and granulometry of those deposits which originate the alluvial aquifer. Minimum values (1,14x10^{-5} m^2/s) characterize, to conclude, sheets covering arenaceous-sandy complexes bordering the alluvial plain. Obviously, it is a matter of merely indicative values, given the extreme complexity of the plain hydrostratigraphy.

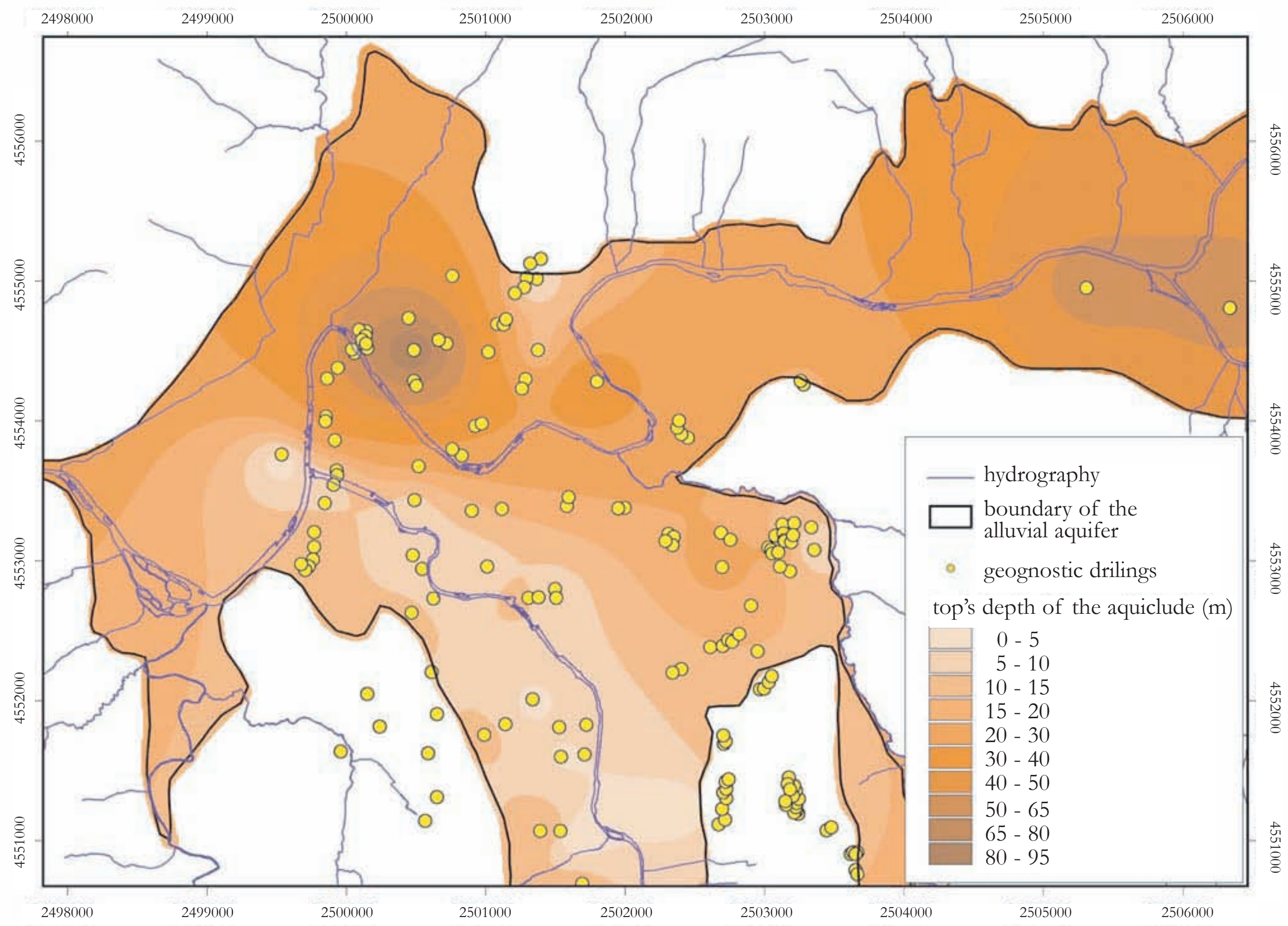


Fig. 3 - Depth of the top of the aquiclude.
- Carta della profondità del tetto del substrato impermeabile.

4. - DATA ACQUISITION, PROCESSING AND INTERPRETATION

4.1. - Hydrostratigraphic reconstruction

The research on the hydrostratigraphic arrangement of the area has been carried out by interpreting about 170 geognostic drillings (Celico, 1998; Piano Regolatore Generale del Comune di Benevento, 1984), of a depth ranging from 10 to about 100 meters and scattered mainly over the area interesting the inhabited centre of Benevento (fig. 3).

By interpreting stratigraphic maps it was possible to work out a series of hydrostratigraphic sections perpendicularly and longitudinally to the Calore fluvial stream as well as the consequent determination of lithological types building up the alluvial Hydrostratigraphic Unit. This last one, as one can see from hydrostratigraphic section shown in fig. 4, is formed by polygenetic and multisized conglomerates alternating one another, including frequent psammitic-pelitic interbeddings.

The sedimentary evolution of the basin has, presumably, caused the making up of two well differentiated depositional systems: the Calore river system that develops in the Northern section of the studied area, with thicknesses attaining at least 100 meters (Celico, 1998; fig. 3) and the Sabato river depositional system interesting the Southern section of the area, with much more trivial thicknesses which depend on the local ascent of the aquiclude (about 10-20 m; fig. 3 and 4).

The two depositional systems, both resting on the clayey aquiclude (Aquitard System), can be reasonably put together to form a Hydrostatrigraphic Unit, that is to say *"one formation or one group of formations, with homogenous hydrologic characteristics or distributed in such a way to allow an internal subdivision in aquifers and associated confining layers"* (Domenico & Schwartz, 1990). More in detail, within Calore river depositional system,

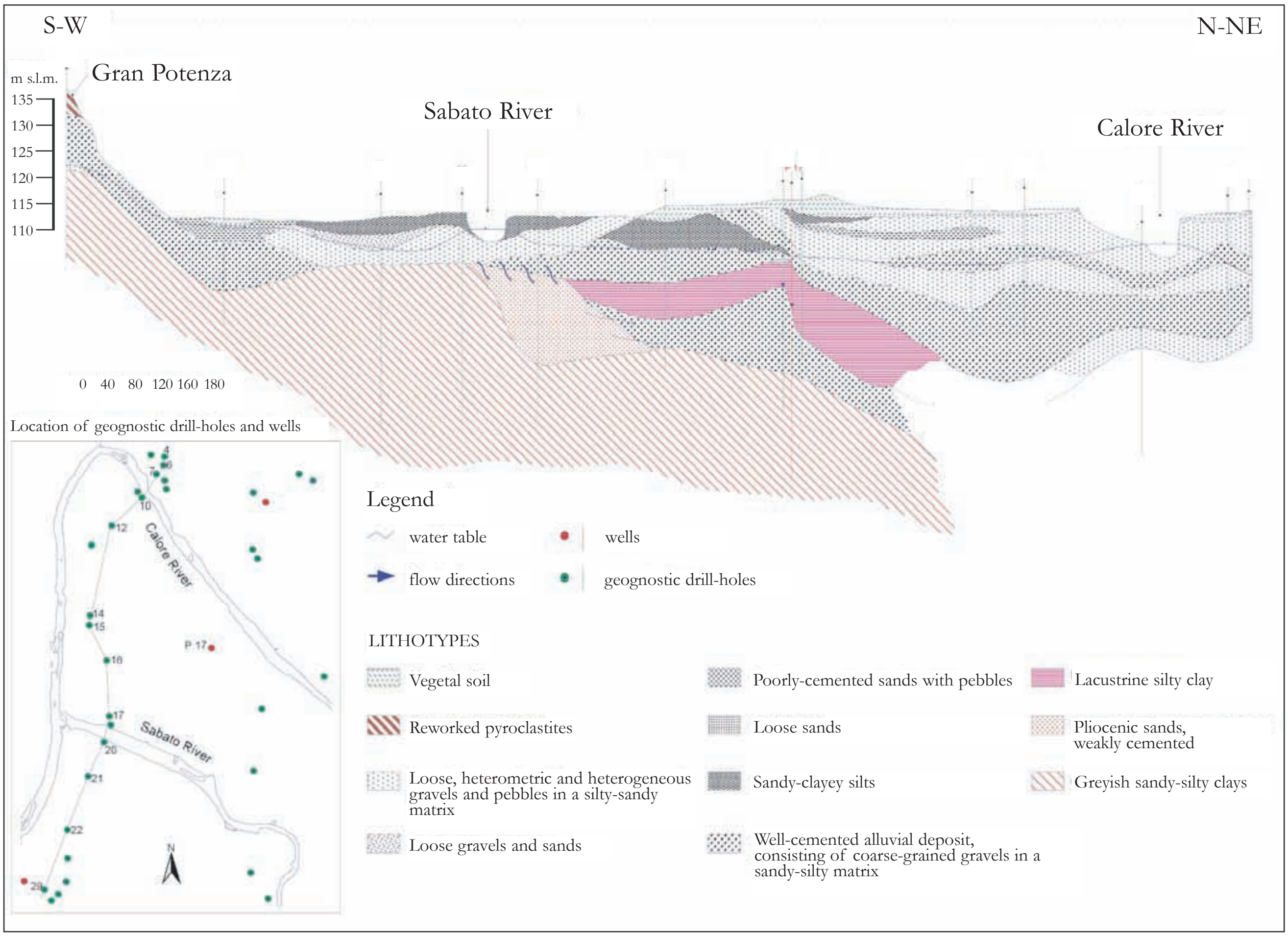


Fig. 4 - Hydrostratigraphic section.
- *Sezione idrostratigrafica.*

close to junction with Sabato river, it is mandatory to point out the existence of one level of muddy clays (fig. 4), connected with deposits belonging to the fluvial-lacustrine Unit of Sabato river, which locally tends to deepen under Calore river bed (fig. 4). The above mentioned level, attaining a medium thickness of about 5 meters, is interbedded between two horizons of well cemented conglomerates of coarse gravels within a sandy-muddy matrix (fig. 4). The low relative permeability that characterizes it, makes the above said level to take on a particularly important role with regard to the aquifers structure and the consequent vertical pattern of ground water flows in this specific section of the analysed Hydrostratigraphic Unit. As a matter of fact, it carries locally a surface water table of phreatic type and represents also the impermeable top of the deepest water level in bordering conditions. Technically, it is possible to recognize two water levels, which are well distinguished and that can be distinguished; they are set within gravely-sandy and conglomeratic deposits, with different cementation degree, representing the most permeable elements of the aquifer. The confined water level is fed by the surface water table through processes of vertical drainages and through pouring-offs occurring in the residual outlier of pliocenic sands, weakly cemented, upon which laterally ends a level of fluvial-lacustrine clays (fig. 4).

4.2. - Reconstruction of ground water circulation

Utilized data for reconstruction of ground water circulation of the analysed area are referred to measurements of the water table piezometric level carried out during low water periods and reloading beginning, in the year 2002 (fig. 5).

Piezometric measurements were carried out over a 155 water points net, made up of 108 wells, located over the plain as well as on the adjacent elevated zones, along with 47 measurements of hydrometric level carried out over Calore, Sabato and Tammaro rivers (fig. 5). Thus, if we consider the studied area (about 94 km^2), it has been obtained a sampling density equal to 1,6 control points per km^2. Such results have been interpreted referring to hydrogeologic characterization of the outcropping lithotypes.

Piezometric measurements interpolation has allowed to recognize, on a large scale, one sole phreatic water table, located within deposits originating the alluvial aquifer. Flow directrixes converge towards Sabato river and Calore river or, most likely, towards one of its possible paleoriver-beds taking on, consequently, the role of underground drainage axis (fig. 5). However, it is to be pointed out that along Calore river one could come across a localized inversion of the river-water table relationship: this can be inferred, besides specialistic bibliography (Celico, 1998), by comparing hydrometric levels with piezometric levels measured within wells next to fluvial stream (fig. 4). The above said inversions are to be associated only with anthropic activities, with a special reference to emunctory processes having mainly agricultural purposes.

Piezometric gradient varies according to the thickness and the aquifers nature, according to the above mentioned transmissivity data. It is, however, included within a range attaining 5-7 %, along the plain's borders, and 0,5-3 % in axial zones next to the inhabited area of Benevento and the Industrial Area of Ponte Valentino (fig. 5). The highest values of the hydraulic gradient, referred to the bordering band, must be attributed to the alluvial aquifer changing into the one made of clayey-marly deposits (fig. 1). Within these last ones, as anticipated, it is possible to recognize a ground water flow which is concentrated into the surface-weathered sheet, adapting itself to the outside morphology, with ultimate discharge towards the plain's aquifer, through mechanisms of ground water pouring off. Therefore, we deduce that the plain Hydrostratigraphic Unit is mainly fed by the seepage rate directed towards it (about 2,67x10 m^3/year, from Celico, 1998), and, subordinately, by the ground water contributions of the adjacent aquifers, estimated around 1,21x10 m^3/year (Celico, 1998).

To conclude, with regard to the deep water level, which can be locally found below the layer of muddy clays, we must underline that the insufficient number of measure-sites relative to that did not allow the reconstruction of its piezometric contours lines. However, by comparing subjacency data referred to surface water table with those ones measured within wells by means of canes drawing under the above said relative aquiclude (muddy clays), one can see that, in the period of low water (August 2002 measurements), there is a small difference between the two levels (+ 5 m); such a difference is obviously reduced during the discharge period (about + 2 m). Following these data one can assume that the deep water table is fed by surface water table, even through vertical seepage flows, directed from top to bottom, with serious repercussions upon the vulnerability of the deep aquifer.

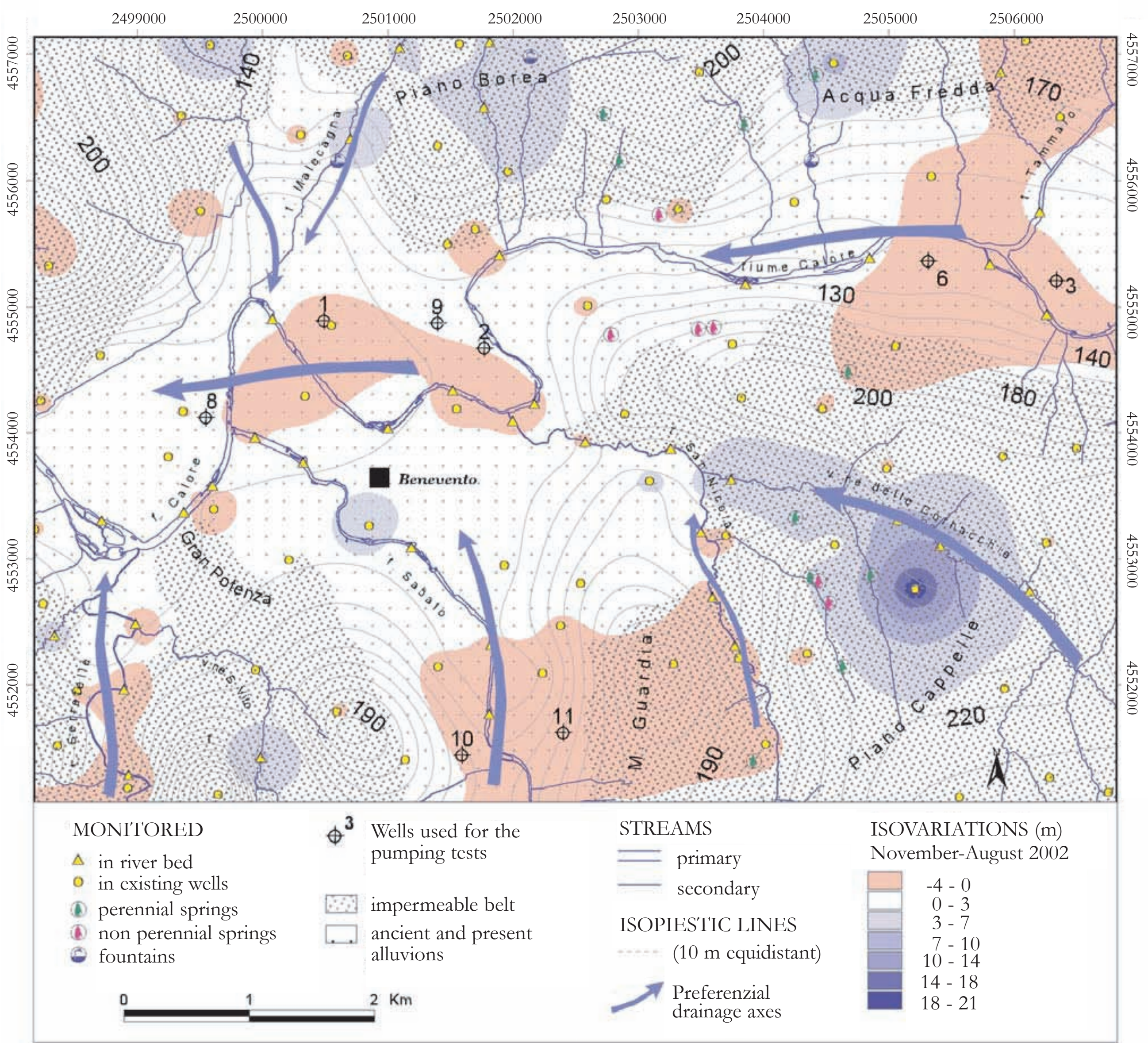


Fig. 5 - Hydrogeological scheme.
- *Schema idrogeologico.*

4.3. - Evaluation of intrinsic and integrated vulnerability

It was possible to determine the intrinsic and integrated vulnerability to pollution by means of the experimental SINTACS method (Civita & De Maio, 1997), only for the surface aquifer. The worked out thematic map (fig. 6) shows that zones with higher intrinsic vulnerability are those adjacent to river flows. That is due to low subjacency of the water table (very seldom above 3 m), to the minimum values of acclivity (0,5-3%), to the high transmissivity (1,8x10^{-1} m^2/sec), to the high values attributed to the potential seepage coefficient (always > 80%) and to the poor self clearing power acted upon by lithologies making up the saturated and not-saturated aquifer. The overlapping of the above said thematic map with more than 250 elements (punctual, linear and areal) suitable to define integrated vulnerability (Civita, 1990, 1994) makes even more alarming the described situation. Just within the most depressed zone of the plain coexist the main real and potential producers of pollution, as well as the potential absorbers and subject to the pollution. It is inferred, therefore, that the most vulnerable section of the plain due to "natural" factors is also the one where take place the activities which are more exposed to probable mechanisms of chemical pollution of the ground water resource. Such a section partly coincides with the aquifers section where it is possible to recognize a deep water table level. As it is clearly seen, the reduced number of quantitative data representing this last one, mainly when referring to subjacency parameter, does not allow an analogous working out of the vulnerability degree. After suggestions supplied by DAC method (CELICO, 1996), one could reach the following considerations: 1) the confined water table is vulnerable because it is fed by the surface one; 2) the vulnerability degree of the deep water level is certainly lower than the surface water table one, because of higher subjacency of the water table and of the self clearing role due to muddy clays which consent its confinement. What has been said could result truthful if the deep water tables feeding were granted only by vertical seepage flows through the relative aquiclude. But, how it has been anticipated, the confined water level is also fed by water flows, coming from the surface and pouring off into the pliocenic sands contacting the gravely-sandy-conglomeratic deposits hosting the deep water table (fig. 4). These sandy deposits, due to the higher relative permeability characterizing them, take on a secondary role in the self clearing processes compared with that concerning muddy clays. Thus it is likely to associate with the deep water table an intrinsic vulnerability degree to the pollution which differs not much or not at all from the surface aquifer's vulnerability degree. On the other hand, though the relationship between vulnerability and resources quality does not result univocally proved (CELICO *et alii*, 1997; BRUNO *et alii*, 2003), chemical-physical researches, carried out also upon samples representative of the deep aquifer, indicate present chemical polluting processes which can be associated with anthropic activities.

4.4. - GROUND WATER QUALITY

In order to evaluate ground water quality, special hydrogeochemical researches have been carried out, including chemical-physical field evaluations as well as sample gatherings for subsequent lab-tests. Such researches were carried out during December 2002 over a net of 15 wells that were uniformly scattered on the territory (fig. 7). Sampling depths were ranging from 6 to 100 meters so to acquire knowledge of the qualitative condition of the ground water resource hosted within the whole plain Hydrostratigraphic Unit. On table 2 a synthesis is shown of analysed chemical pollution indicators. Concentrations plots according to Piper's classification diagram made it possible to define the sampled waters as bicarbonate-calcic waters (fig. 8).

Significative indication has been obtained by comparing concentrations of dissolved substances with depths of sampled wells. In diagrams shown on figure 9 we see, in fact, a good correlation of Cl^- F^- and SO_4^{--} percentages with the sampling's depth. The progressive lowering of their concentrations as depth increases, would make us suppose a likely surface origin for the penetration mechanisms of the above said substances into the ground water circuits. It is also to be considered that the above mentioned substances are included within the so called chemical polluting indexes, that is to say, within those parameters which can be easily ascertained and scientifically quantified by means of chemical-physical analyses, to which one generally refers when evaluating possible polluting events that are in progress or have already occurred, no matter if they are of a domestic, industrial, agricultural or zootechnical type.

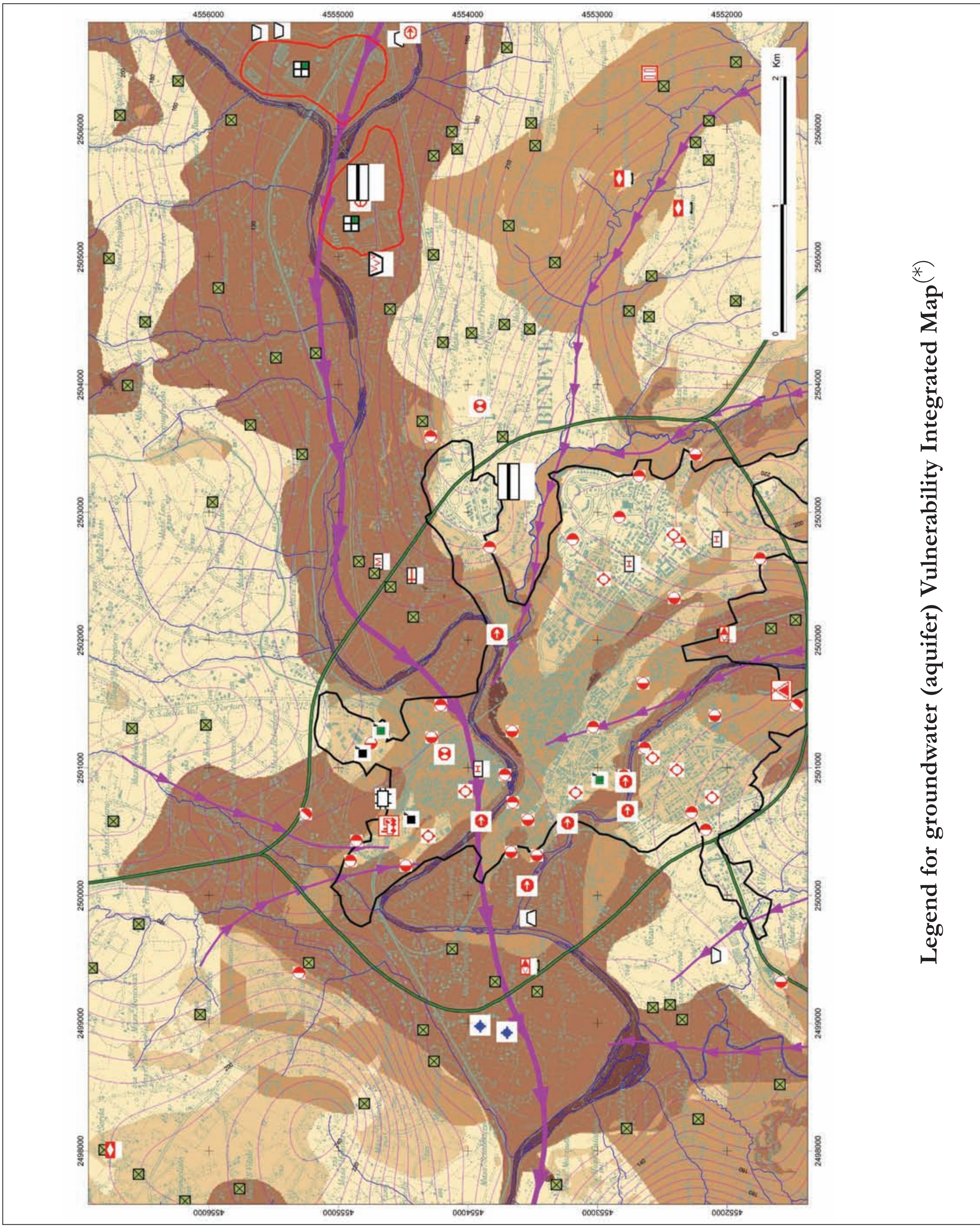
Obviously, such parameters should be interpreted not only separately but also as a function of other quantities which they could depend on or with which they might interact. Within this context, given the introductory and incomplete nature of the carried out analyses, it is possible to associate with the proved surface origin of the above said substances a possible influence of anthropic character.

By comparing thereafter the carried out analyses with maximum admissible concentrations (MAC) which are established by the present regulation ruling the use of waters for human purposes (D.P.R. of May 24, 1988, n. 236), a situation of diffused pollution due to fluorides and nitrates has been ascertained. Fluorides percentage , as a matter of fact, are by far above the MAC, fixed at 1,5 mg/l, in all of tested wells, and sometimes they double such a value (tab. 2)

Nitrates concentrations are above the maximum admissible ones (50 mg/l), extensively within the area North-West of Benevento (locality S. Vitale) and the morphologic reliefs of Piano Borea and Piano Cappelle forming those zones feeding local ground water circulation. Figure 7 shows how the concentrations of nitrates, sulphates, chlorides and fluorides, are distributed, pointing out wells where MAC are exceeded.

We also have to underline that chlorides concentrations, even though they never exceed the indicative limit of 200 mg/l, they are constantly above 25 mg/l, established by law as a guide value (GV), at which waters designated to exploitation for human purposes should be aimed.

The scanty quantity of data obviously does not allow cartographic mappings of results through hydrogeochemical charts showing isovariation curves of the single parameters. However, considerations of



Legend for groundwater (aquifer) Vulnerability Integrated Map(*)

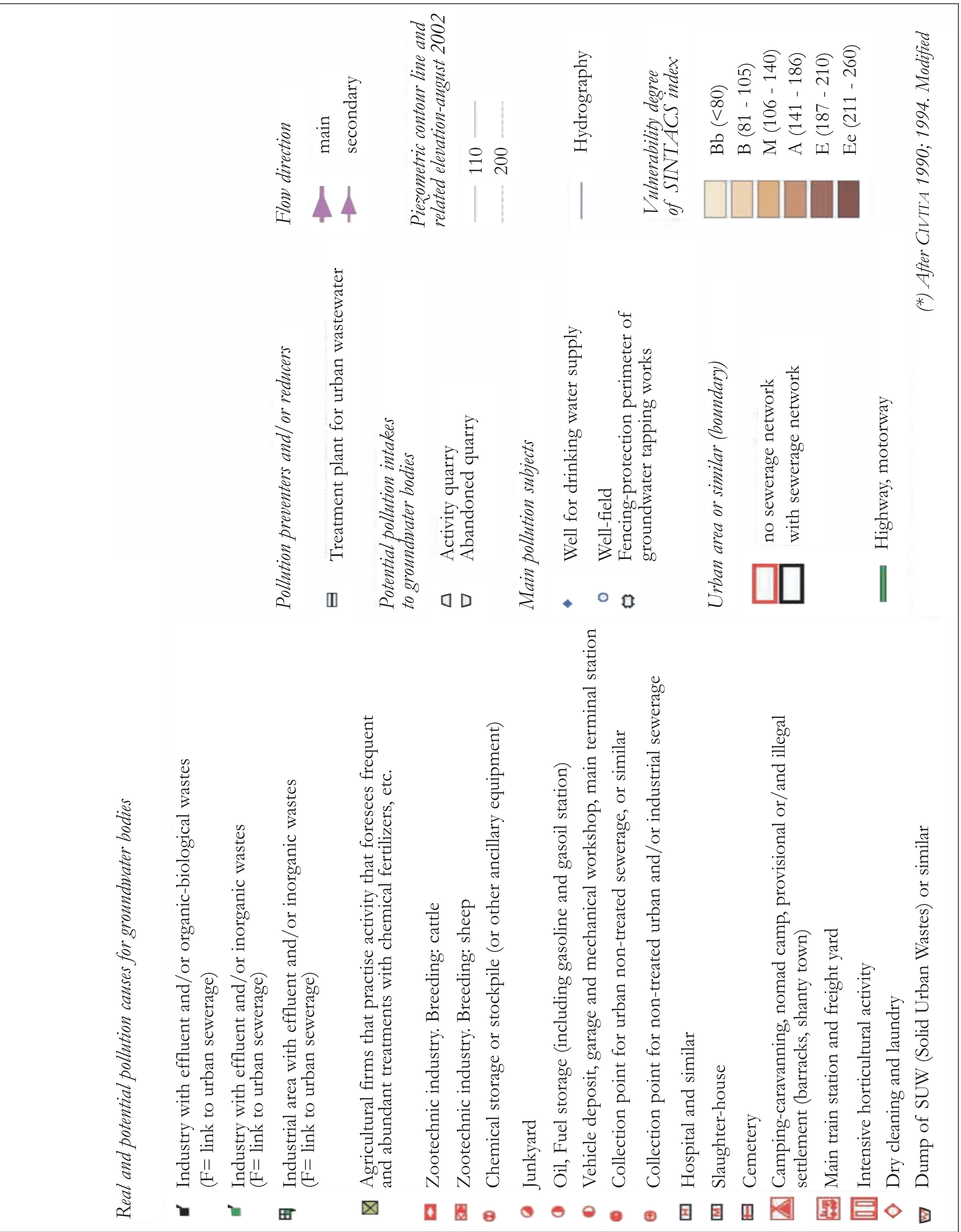


Fig. 6 - Intrinsic and Integrated Vulnerability map. - *Carta della Vulnerabilità Intrinseca ed Integrata.*

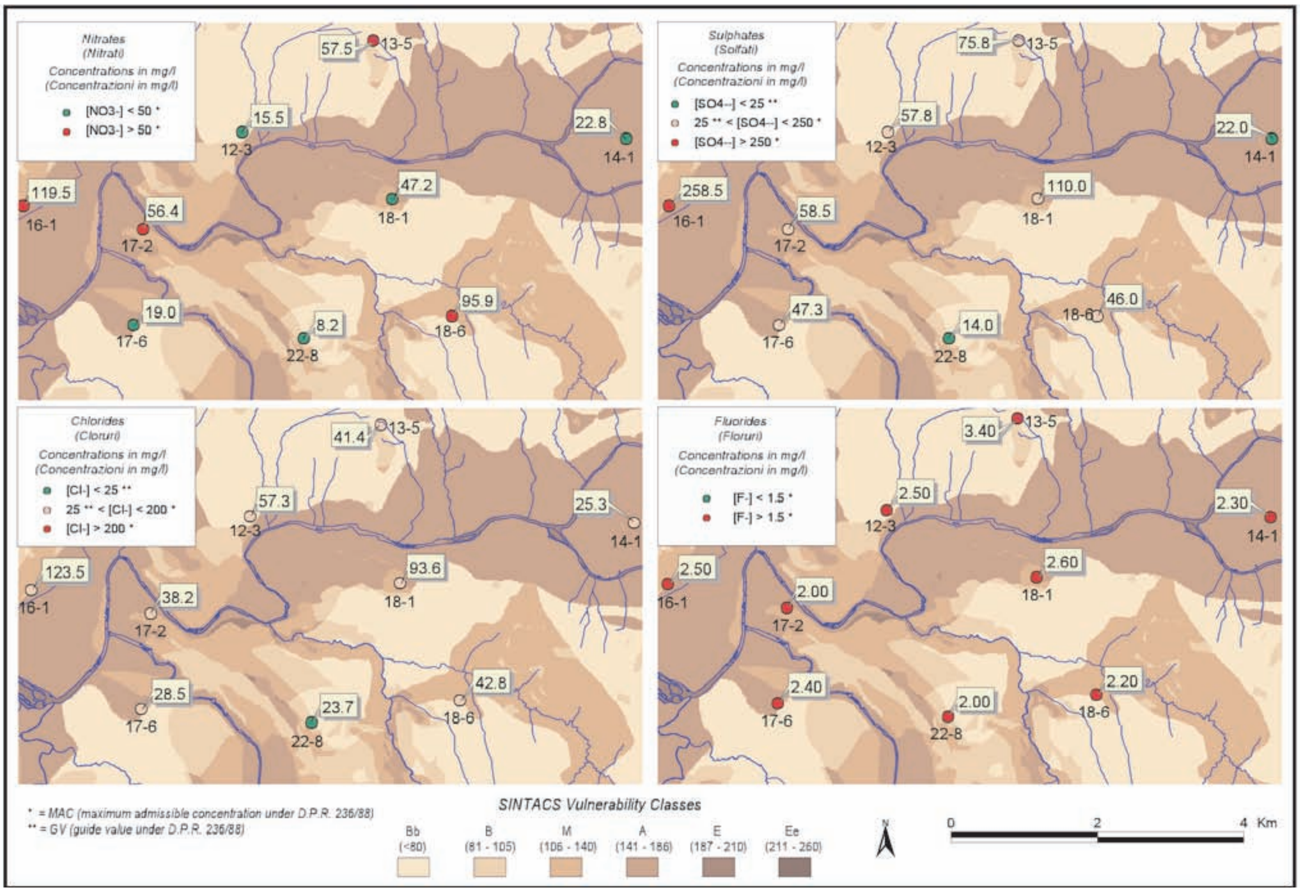


Fig. 7 - Punctual representation of ground water quality with regard to parameters: Nitrates, Sulfates, Chlorides, Fluorides.
- *Rappresentazione puntuale della qualità delle acque sotterranee con riferimento ai parametri: Nitrati, Solfati, Cloruri, Fluoruri.*

Tab. 2 - *Concentrations (mg/l) of some analysed chemical pollutants.*
- Concentrazioni (mg/l) di alcuni indicatori chimici di inquinamento.

Sample	Na^{++}	K^{+}	Ca^{++}	Mg^{++}	Sr^{++}	Cl^{-}	HCO_3^{-}	SO_4^{--}	NO_3^{-}	F^{-}	SiO_2
12-3	47,0	12,5	124,5	11,8	0,57	57,3	404,8	57,8	15,5	2,50	3,65
13-5	78,3	22,7	128,0	20,8	0,59	41,4	519,5	75,8	57,5	3,40	4,20
13-11	105,0	18,2	78,0	11,5	0,58	34,6	423,7	50,9	5,4	2,80	3,98
17-2	40,0	49,0	108,5	16,3	0,26	38,2	380,4	58,5	56,4	2,00	4,31
17-6	27,5	10,7	137,0	16,0	0,45	28,5	458,5	47,3	19,0	2,40	3,12
22-5	36,2	19,5	138,5	18,7	0,48	40,2	447,5	56,3	54,3	2,30	4,50
11-6	46,2	38,4	188,5	19,3	0,79	89,8	374,3	124,1	177,6	2,40	5,60
16-3	63,7	7,6	132,5	18,6	0,68	35,2	396,9	53,1	157,9	2,20	4,70
16-1	90,0	24,2	205,0	30,5	0,96	123,5	509,7	258,5	119,5	2,50	6,78
21-10	35,0	14,7	128,0	31,6	0,70	44,2	545,7	37,6	3,7	2,00	3,60
14-1	27,5	19,6	110,5	10,3	0,36	25,3	312,1	22,0	22,8	2,30	3,10
18-1	80,0	24,7	162,5	14,9	0,57	93,6	512,7	110,1	47,2	2,60	4,50
18-6	32,5	23,1	138,5	12,1	0,43	42,8	405,4	46,0	95,9	2,20	4,20
19-4	77,5	28,3	137,0	22,2	0,62	49,0	568,2	103,9	25,3	2,80	3,98
22-8	55,0	5,4	75,0	14	0,32	23,7	418,2	14,0	8,2	2,00	3,66

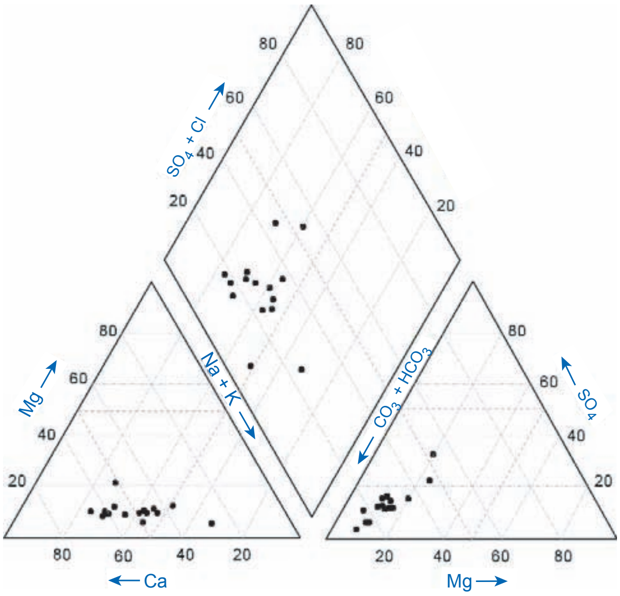


Fig. 8 - Classification of sampled waters according to PIPER (1944).
- *Classificazione dei campioni d'acqua attraverso il diagramma di* PIPER.

general character along with some useful correlations, made it possible to recognize, as to the studied area, a situation of rather diffused pollution due to nitrates and fluorides, including contamination mechanisms depending on other important chemical indexes such as chlorides and sulphates.

Simultaneous existence of the above said parameters in high concentrations, along with the ascertained surface origin of some of them, led us to conclude that the likely anthropic cause of such phenomenon could be associated with the intensive agricultural exploitation of the studied area.

The high percentages of nitrates and sulphates are often attributable to intensive coltural treatments carried out by using phytopharmaceuticals, nitrogenous fertilizers and chemical composts. The totally absence of sewerage, in rural areas, punctually replaced by dispersion wells, adds to the worsening of the ground water resources. This could explain the Cl^- high concentrations which, as it is known, are found in domestic liquid sewage as sodium chloride, as well as in industrial dumping and some pesticides.

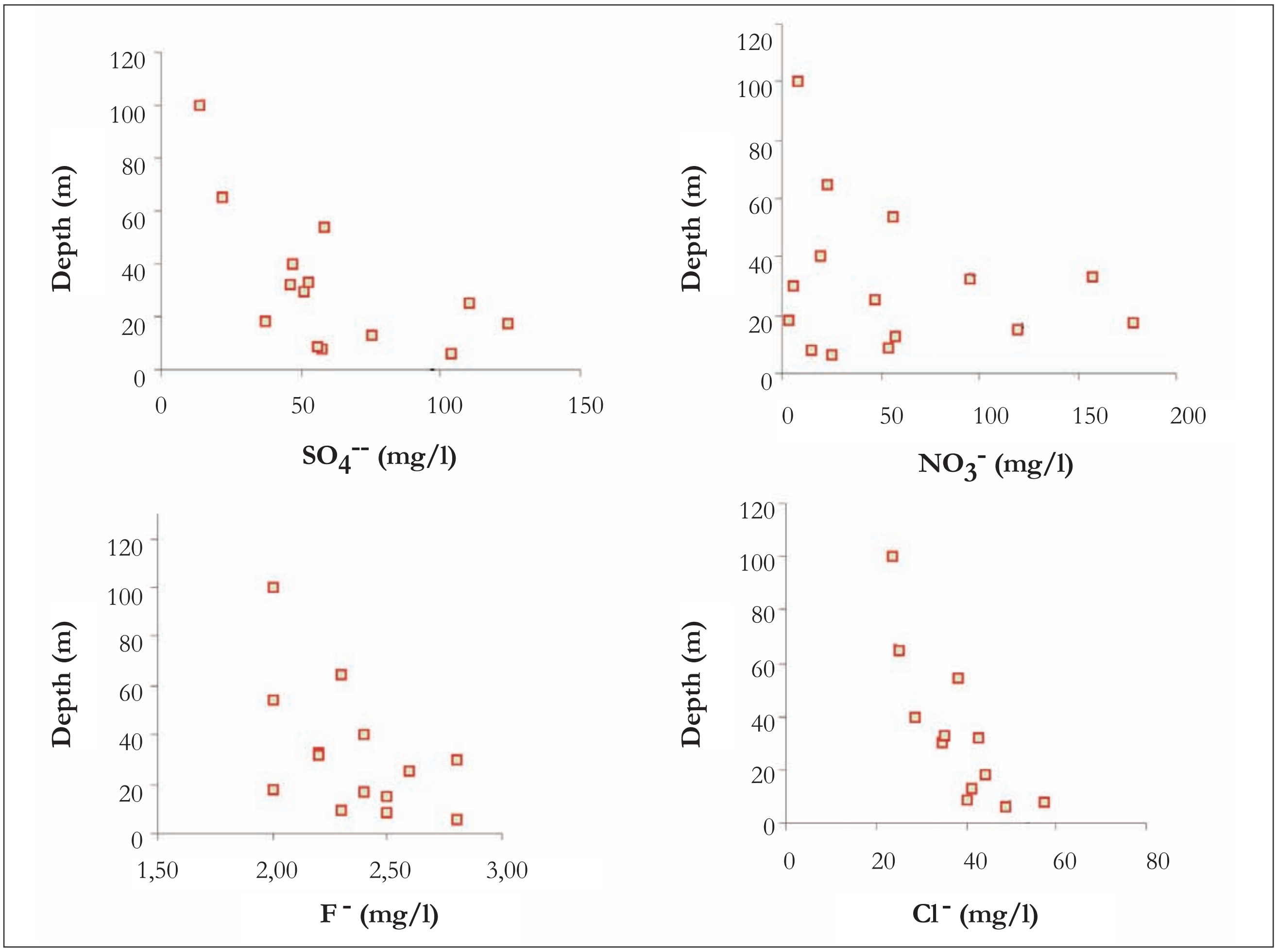


Fig. 9 - Wells depths compared with SO_4^{--}, F^-, Cl^- concentrations.
- *Comparazione tra profondità dei pozzi e concentrazioni di* SO_4^{--}, F^-, Cl^-.

To conclude, pollution due to fluorides, since there are no particular geological conditions which could cause its natural enrichment, has also to be associated with likely seepage of flowing back waters full of chemicals characterizing the common cleaning products.

5. - CONCLUSIONS

Hydrogeologic and stratigraphic pattern characterizing the alluvial plain of Benevento, which has been described in the previous paragraphs, created the ideal conditions for the making up of an alluvial aquifer characterized by high productivity (T = $1,77 \times 10^{-1}$ m^2/sec) along with remarkable thicknesses (up to 100 m), thus making it the main reservoir for the local potable water supplying. The aquiclude's pattern, made of clayey-marly elements of the Lagonegro Unit on the North and the grey-light blue clays of the Ariano Unit on the South, is a condition for the reservoir's geometry with decreasing thicknesses starting from the plain borders towards the axial zones.

Sedimentologic-depositional processes, proper to the alluvial areas, have determined the existence of rather complex stratigraphic features varying within depositional basin. However the analysis and interpretation of a remarkable number of stratigraphic logs has allowed us to single out two depositional systems connected with activity of the main streams: Calore and Sabato rivers. The hydrogeological interpretation of some purposely carried out hydrostratigraphic sections (of the type shown in fig. 4) has allowed to recognize on a large scale a freatic water table, directed towards the axis of valley, feeding either surface streams or underground drainage axes, interpretable as paleo-river-beds. The relationships with the main streams appear to vary locally as well as periodically (seasonal variations). More in detail, Sabato and Calore rivers' sections next to inhabited centre of Benevento city are feeding the water table prevalently during low water period, while the fluvial sections upstream of inhabited centre appear to be fed by the water table yearly round.

Near the Calore-Sabato junction zone we can point out the conditions also necessary to the existence of a deep water table subjacent to a level of muddy clays, attaining a medium thickness of about five meters, connected with the terrains of the fluvial-lacustrine unit of Sabato river. This unit is fed by the surface water table through seepage and lateral pouring off processes. Analysis of vulnerability carried out on the surface water table has given anything but positive answers. Terrains forming the alluvial aquifer are characterized with intrinsic vulnerability degrees ranging from "high" to "extremely high". Furthermore, the anthropic impact potentiality evaluated through census as well as the location of the danger centres (which are punctual and diffused), all synthesized within the map of integrated (fig. 6) vulnerability, shows rather critical a situation. An immediate checking of quality conditions of the water resource, carried out through a hydro-chemical research upon a considerable number of wells (figg. 7, 8, 9; tab. 2), which draw both from surface water table and deep water table, has proved the existence of contamination mechanisms and, in some instances, of pollution of ground water tables with regard to the considered parameters (nitrates, sulphates, chlorides and fluorides). Sufficiently symptomatic are hydro-chemical data relative to well 17-2 (fig. 4) drawing from the deep water table. Water samples gathered from this well have nitrates concentrations (56,4 mg/l) and fluorides concentrations (2,0 mg/l) above the maximum admissible concentrations established by the D.P.R. 236/88 for the use of potable water; have concentrations of sulphates (58,5 mg/l) and chlorides (38,2 mg/l) which are above guide values advised by the same decree. This, unfortunately, shows that the deep water table is in no way shielded from polluting phenomena acting within the surface water table, given the insufficient self-clearing activity on behalf of the pliocenic sands (fig. 4).

The situation appears far more serious if we consider that those wells used for potable water supply in the city of Benevento, are drawing water from the deep water table and were in the past subject to drastic interruption of supply because of nitrates pollution.

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