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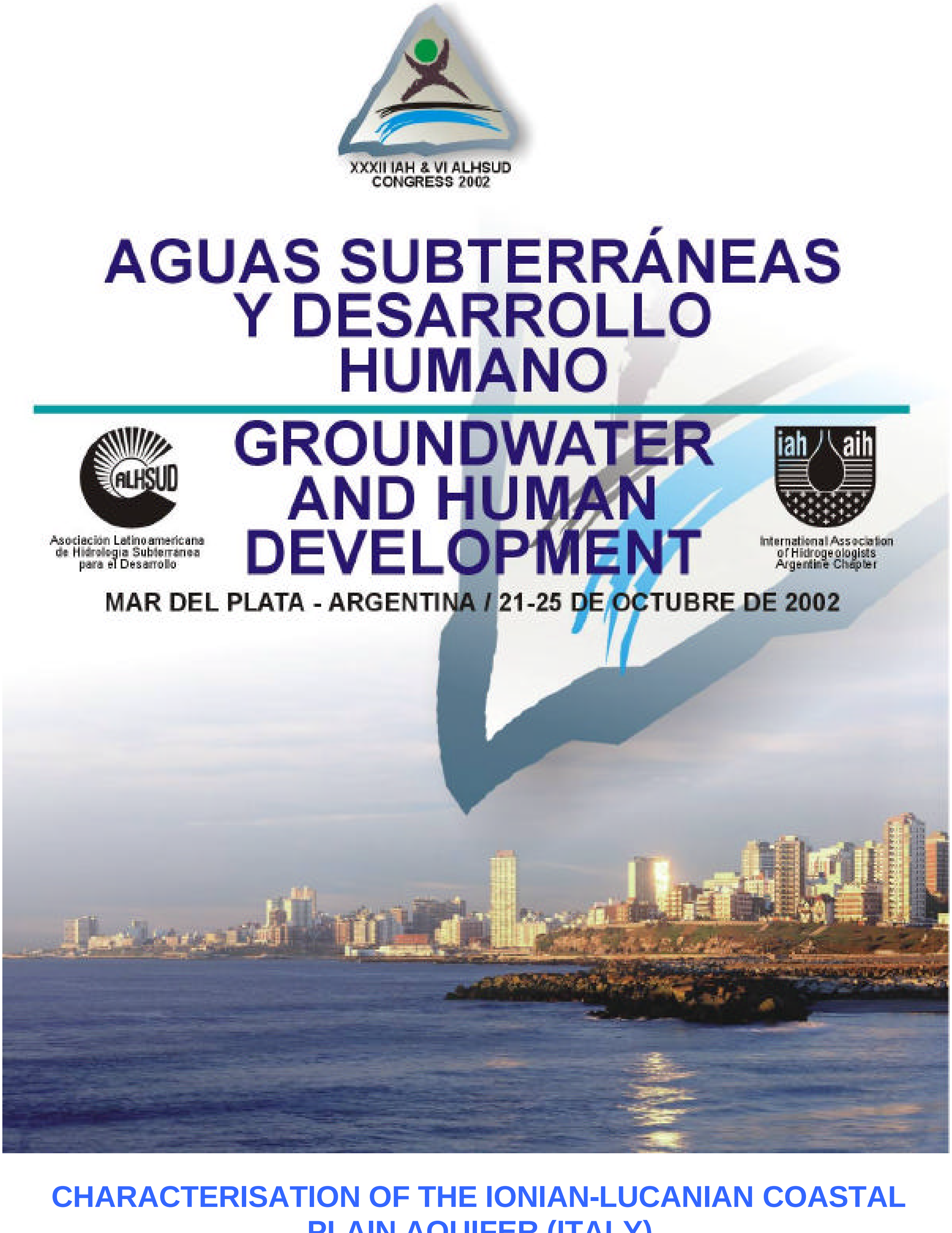

CHARACTERISATION OF THE IONIAN-LUCANIAN COASTAL PLAIN AQUIFER (ITALY)

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Abstract. This paper deals with a Southern Italy area, 40 km by 10 km wide, located where four river valleys anastomose themselves in the coastal plain. The geological and hydrogeological features of the study area and the chemical-physical groundwater characterisation have been inferred from the data analysis of 1130 boreholes. Some aquifers, connected among them, constituted by soils of different geological origin - marine terraces deposits, river valley alluvial deposits and alluvial and coastal deposits - have been considered. The coastal plain aquifer is the most interesting for practical utilisation. Groundwater flow is mainly unconfined in the marine terraces and in the river valleys while it becomes mostly confined in the coastal plain aquifer. An upper clayey layer overlies the sandy coastal aquifer characterised by a mean hydraulic conductivity value equal to 2.3 10^{-4} m/s. The bottom is a silty-clayey bed which lies under the sea level. Being the direct natural recharge extremely low, the recharge of this coastal aquifer is mainly guaranteed by the discharge from upward aquifers and from the river leakage. The new acquired knowledge permits to delineate scenarios useful for an optimization of the groundwater resources tapping and for pursuing the safeguard of them.

Resumen. Este artículo trata el área sur de Italia, de 40 km por 10 km de ancho, donde cuatro ríos fluyen hacia la llanura costera. Los aspectos geológicos e hidrogeológicos del área de estudio y la caracterización químico-física del agua subterránea derivan del análisis de los datos de 1130 pozos. Han sido considerados algunos acuíferos, conectados unos con otros, constituido por rocas de origen geológico diferente: depósitos de terrazas marinas, depósitos aluviales de valles fluviales y depósitos costeros y aluviales. El acuífero de la llanura costera es el más interesante para la utilización de sus recursos hídricos. Las terrazzas marinas y los valles del río tienen un comportamiento hidrogeológico libre, mientras que la llanura costera tiene un carácter más confinado. El estrato superior arcilloso se sobrepone al acuífero costero arenoso caracterizado por un valor medio de conductividad hidráulica de 2,3 10^{-4} m/s. La parte baja es un lecho arenoso-arcilloso situado bajo el nivel del mar. Puesto que la recarga natural directa es extremadamente baja, la recarga de este acuífero costero se garantiza principalmente por la descarga de los acuíferos de la parte alta del área y de la infiltración del río. Los nuevos conocimientos adquiridos permiten la definición de escenarios útiles para la optimización de la explotación de los recursos hídricos subterráneos y para proceder a su protección.

Keywords: coastal aquifer, mixed waters, hydrogeological parameters, Southern Italy

INTRODUCTION

The study area is located in the southernmost part of *Basilicata* region (Southern Italy), so called also Lucanian region, stretching around the middle and the lower valleys of the Sinni, Agri, Cavone, Basento and Bradano Rivers (Figure 1).

Throughout the 20th century, land reclamation works, the construction of about ten dams and the introduction of modern irrigation systems have deeply modified the water cycle along the coastal plain. Moreover, the area is intensively farmed and the quality of the tapped groundwater is vital to the economic growth of the tourist and agricultural poles along the Ionian coastal plain.

Geological, hydrogeological, geotechnical and chemical-physical groundwater data coming from 1130 boreholes have been collected (Polemio et al., 2002a).

These boreholes, coming from different public sources, are widespread all over the study area. In detail, the stratigraphic and hydrogeological data are available for 71.9% of the wells whereas chemical-physical and geotechnical data are available respectively for 13.9% and for 5.6 % of the all wells.

The location, the altitude, the depth and the source of each well have been so gathered in a detailed database where stratigraphic, piezometric, chemical-physical groundwater data have been also reported.

Moreover, historical data have been also collected for estimating the groundwater use and the salt-related groundwater quality degradation.

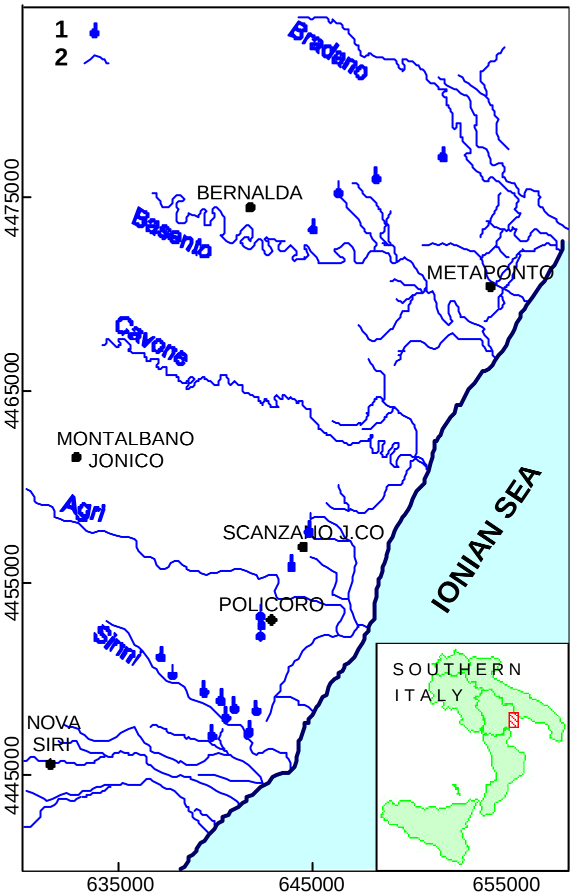

Figure 1: Location of the study area. 1: spring; 2: river.

A deep analysis of the all data, connected also to a hydrogeological survey, has allowed to define the geological and hydrogeological set-up of the study area. Besides, the hydrogeological features of aquifers lie in the area has been also pointed out.

The attention is focused on the shallow aquifer existing in the coastal plain as the most interesting for practical utilisation, as highlighted by Radina (1956). The features of this aquifer, such as its lithology, its depth above sea level, its thickness and that one of the unsaturated zone have been also investigated. The piezometric heights above sea level and the results obtained by pumping tests carried out in the study area have been analysed too.

The chemical-physical characterisation of the groundwater has been done, above all through the analysis of some major dissolved ions. Total dissolved solids, salinity, electrical conductivity, pH and temperature have been also assessed.

Moreover, the analysis of the all collected data has allowed defining the type of the groundwater flowing through the all study area. All acquired knowledge will be utilised to propose management guidelines to prevent the degradation of these groundwater resources, at the moment tapped without control.

GEOLOGICAL BACKGROUND

The study area is mainly located in the southernmost part of the Bradanic trough which is the narrow Pliocene-Pleistocene sedimentary basin, with a NW-SE trend, placed between the southern Apennines and the Apulian foreland (Figure 2).

The Bradanic trough is filled by a thick Pliocene to Pleistocene sedimentary succession (up to 2-3 km) whose upper part of Late Pliocene (?)-Late Pleistocene in age, widely outcrops in Southern Italy because of the intense Quaternary uplift occurred in the area (Ciaranfi et al., 1979; Tropeano et al., 2001).

This uplift was driven by the arrival at the subduction hinge of the thick buoyant south-adriatic continental lithosphere, which caused a lower penetration rate of the slab and a consequent buckling of the lithosphere (Doglioni et al., 1996).

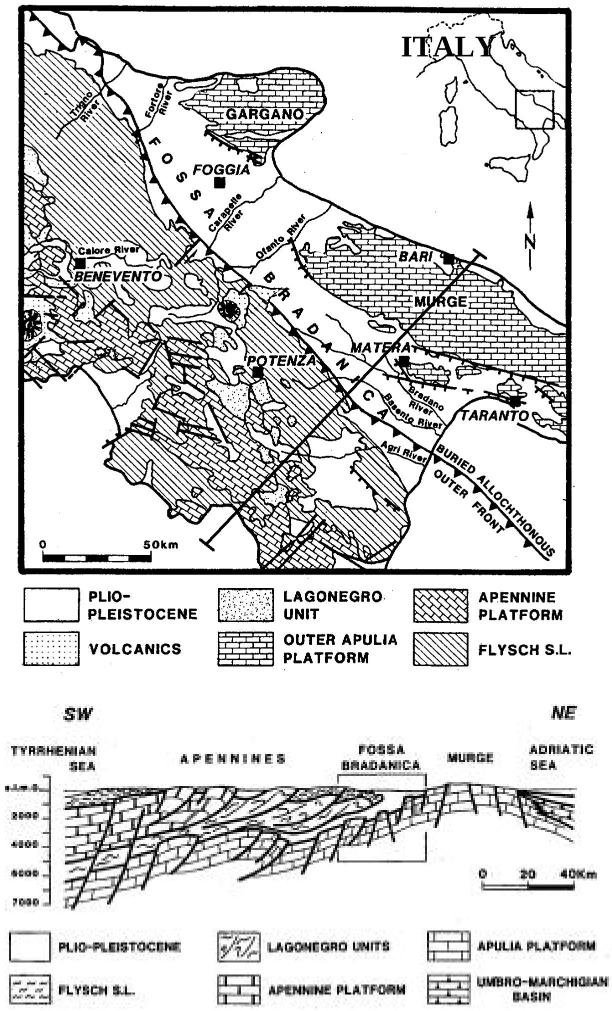

Figure 2: Schematic geological map and geological section of the southern Apennines (after Sella et. al., 1988).

The progressive uplift occurred previously in the northern sectors and afterwards in the southernmost ones. The uplift was higher in the western edge of the trough than in the eastern one, producing then a regional tilting towards the Adriatic sea of the geological formations deposited in the Bradanic trough (Tropeano et al., 2001).

The uplift is testified by the regressive trend of the sediments deposited in this trough since early Pleistocene which are represented by the following geological formation (Figure 3), from top to bottom: Marine Terraced Deposits (regressive deposits consisting of sands, conglomerates and silts of Middle-Upper Pleistocene in age, outcropping in the southern part of the trough), *Sabbie di Monte Marano* and *Conglomerato di Irsina* Formations (sands and conglomerates of Early-Middle Pleistocene in age outcropping in the northernmost and central sector of the trough) and *Argille subappenine* Formation (silty-clayey successions of Late Pliocene?-Middle Pleistocene in age, widely outcropping).

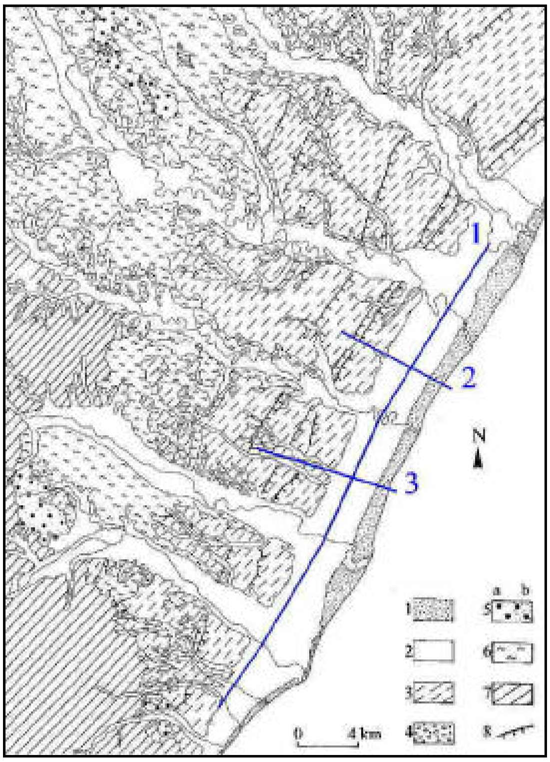

Figure 3: Schematic geological map of the study area: 1) coastal deposits; 2) alluvial, transitional and marine deposits; 3) marine terraces; 4) Conglomerato di Irsina Formation; 5) Sabbie di Monte Marano Formation (a) and Sabbie di Tursi Formation (b); 6) Argille subappennine Formation; 7) allochthon; 8) marine terraced scarps; the lines of the lithological sections in Figure 4 are reported.

Near the Apennines, thick Lower Pleistocene delta bodies are located at different depth in the *Argille subappennine* Formation (Figure 3) and they represent the *Sabbie di Tursi* Formation, constituted by sands with basal clayey intercalations and by sandstones with lens of polygenic conglomerates (Pieri et al., 1996). Moreover, the allochthon, cropping out in the westernmost sector of the study area (Figure 3), consists of marly-clayey, sandy-clayey and marly-calcareous successions, sandstones and limestones, belonging to the Apennines geological formations.

As regards the marine terraced deposits, eight orders of terraces have been recognised on the basis of morphological features. Their ages varies from 80,000 up to 650,000 years B.P. (Brückner, 1980). The flat top surfaces of these terraces are broken off both by the river valleys and by marked morphological steps, roughly parallel to the present coastline with a fairly fanwise trend, which should represent the ancient coastlines and so the phases of sea level standing (Parea, 1986).

Besides the above-mentioned geological formations, alluvial, transitional, coastal and marine deposits outcrop widely in the coastal plain (Figure 3) which include the mouths and the deltaic systems of the Sinni, Agri, Cavone, Basento and Bradano Rivers, rising in the Apennines. Briefly, the alluvial and marine deposits with the lower sediment thickness of a transitional environment are thick probably more than 60 m and they consist mainly of silty-clayey layers and sandy strata. The sedimentation of these deposits has been deeply influenced by the glacioeustatic fluctuation and the consequent coastline changes occurred since the end of Tyrrhenian (Cotecchia et al., 1971).

Finally, the Ionian littoral is defined mainly by sandy beaches, from 10 up to 100 metres wide and average value of the particle-size between 500 and 300 micron, but moving towards the Sinni area, the Ionian beaches become gravely-sandy or sandy with pebbly lens (Cocco et al., 1975). The beaches are limited inland both by marshy areas and by coastal dunes. The latter, parallel to the coast, are made up of sands, packed and weakly cemented, and they may be as high as 12 m.

Lithological set up of the study area

The analysis of the lithological logs, obtained by some of the boreholes realised in the area, has allowed to elaborate the lithological set up of the upper portions of the Ionian coastal plain and of the marine terrace outcrops.

In the area of the marine terraces, below the topsoil, three units have been identified (Figure 4). The upper unit is constituted by pebbles, locally cemented and dispersed mainly in a sandy matrix, and by sands and silty-clayey levels of different thickness. These are arranged in the space in different ways and the gravelly intervals could be substituted by sandy, clayey or silty-clayey strata. The thickness of the pebbly intervals changes from a few metres up to around 10 metres. Below the upper coarse-grained unit, there is a sandy unit, fine-grained to coarse-grained whose thickness is up to around 40 metres. Different clayey and silty-clayey strata, sandstone levels and gravely lens are also widespread in this sandy unit. The thickness of these strata or levels changes from a few centimetres up to 10 m. The third unit is represented by a clayey and silty-clayey succession.

As regards the Ionian coastal plain, below the topsoil (about 1-4 m thick), four principal units have been distinguished (Figure 4). The upper one consists of grey and/or yellow clays and exists above all, even if with a discontinuous trend, in the sector of the plain from the Cavone River towards the Sinni River, where it reaches the thickness of around 10 meters. Below the clayey unit a sandy unit exists. This unit shows an almost subhorizontal arrangement gently dipping towards NE.

The maximum depth of the bottom is nearly 45-50 meters from ground level. It reaches the present-day sea-level in the plain close to the coast in the Sinni sector and far from the coast in Basento and Bradano area, as shown by Figure 5. The bottom surface gently goes down from inland to the coast. The lithological features of this unit are rather heterogeneous with a typical arrangement of a transitional environment, where the rivers and sea interacting between themselves. Silty-clayey and clayey levels, gravely sands and locally cemented pebbly lens are widespread in this sandy unit, above all in the area lying from the Cavone River towards the Sinni River. Anastomosed by heteropic phenomena, the thickness of the levels or of the lens are deeply variable, from few centimetres up to less than 10 meters. The third unit consists essentially of grey silty-clays and clays. A few pebbly lens, locally cemented and less than 6 meters thick, exist mainly in the upper part of this unit and hardly ever inside it. Except for a few, the analysed boreholes have been stopped when they have reached this unit therefore, it is not possible to define accurately its thickness which changes approximately from some meters up over 30 meters. The greater thickness seems to exist in the Basento and Bradano Rivers area. The fourth unit consists of grey sands, from fine-grained up to coarse-grained and it has been reached only by some boreholes because of their low depth.

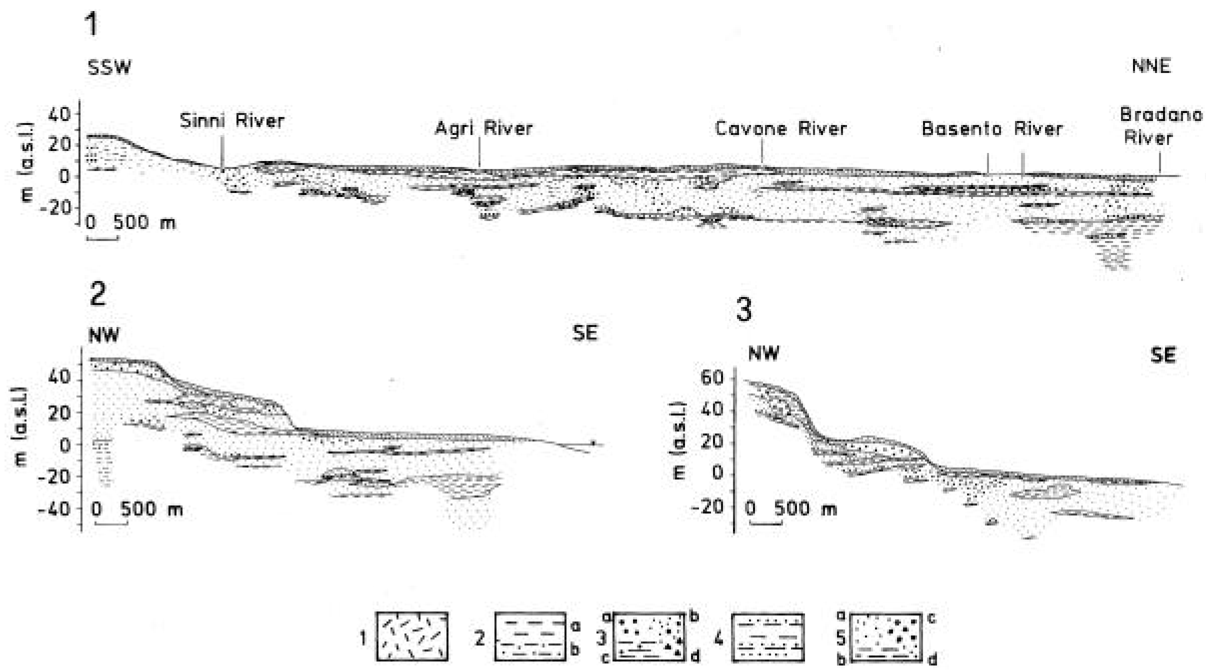

Figure 4: Schematic lithological sections (for the location see Figure 3). Legend: 1) soil; 2) yellow, brown or grey clays or silty clays (a) and locally sandy clays (b); 3) pebbles (a) in a sandy (b) or clayey matrix (c); pebbles locally cemented (d); 4) grey sands with clayey strata; 5) grey or yellow sands and silty sands (a), locally clayey sands (b) or with gravels (c), locally sandstone strata (d).

HYDROGEOLOGICAL SETTING

The Ionian coastal arch (Figure 2) features weather conditions which do not favour the build-up of water resources. The mean annual temperature estimated for the study area ranges between 16°C and 17°C. As regards the estimated rainfall regime, the mean annual rainfall value varies from 535 mm up to 591 mm. Besides, the minimum of mean monthly rainfall occurs in July and the peak is in November. An annual water surplus of 101 mm from December to March has been calculated on a water storage capacity of 100 mm, using the traditional Thornthwaite-Mather method. The climate of the area is then semiarid.

In the study area 28 springs are known (Figure 1). The flow rate is generally low but greater than 0.1 l/s. If the spring flow rate is considered, the unique interesting springs are located along the Sinni River (Figure 1). These are connected to the river water leakage and so they have substantially disappeared as an effect of dam construction upward.

The hydrogeological features of the study area are directly connected to its lithological and structural set-up, previously described. Therefore, the aquifers could be distinguished in two types.

The former encloses aquifers constituted by marine terraces deposits and alluvial river valleys deposits. The marine terraces aquifers show hydraulic conductivity from medium to high but their continuity across the area is regularly broken by river valleys. The aquifers of river valleys, except for Sinni River, show hydraulic conductivity from low to medium and do not permit the accumulation of relevant groundwater resources.

The second type of aquifer includes the aquifer constituted by coastal plain deposits on which is focused the attention. The coastal plain aquifer is the most interesting for practical utilisation, as it is pointed out in the following, not for its hydraulic conductivity, which is not so high, but for its extension and continuity across the area, to be recharged by remaining aquifers and, not secondly, because is located where higher is the water demand.

As regards the coastal plain, known as *Piana di Metaponto* (Figures 1 and 3), the aquifer is more or less large 40 km and long no more than 10 km (along the main groundwater flow direction, almost orthogonal to the present-day coastline). Its transversal continuity is partially reduced by the deep riverbeds of the different rivers flowing into the Ionian Sea.

The groundwater of the coastal plain flows in a multilayered aquifer connected to the lithological set up of the area, where sandy and permeable strata are confined by impermeable levels of various extension and thickness (Figure 4), deposited in a marine and/or transition environment. In particular, the shallow sandy aquifer stratum, coinciding with the above-mentioned sandy unit lying below the upper clayey unit, is generally the only one exploited for any kind of practical utilisation and it is the one that has been deeply analysed in this following. The particle-size distribution in this sandy aquifer is extremely variable, as a matter of fact the gravel fraction is in the range 0-11%, the sand fraction changes from 0 up to 96 % with a mean value of 48%, the silt fraction is in the range 4 -99%, with a mean value equal to 38% and finally the clay fraction varies from 0 up to 55%, with a mean value of 14%. Moreover, the sand fraction is higher for the samples collected in the coastal plain extended between the Cavone and Basento Rivers.

If the total thickness of effective pervious strata of aquifers is determined neglecting silty or clayey levels, Figure 5 can be drawn. So it can be observed the unique aquifer the thickness of which is generally higher than 10 m is the coastal aquifer. The total effective thickness increases from inland to the coast with some exception, as between Agri and Cavone River.

Coinciding with the sandy unit's bottom, the bottom of this aquifer is below the sea level near the coast (Figure 6).

The gradient of this bottom surface is not null coming from Sinni to Bradano River (NNE): the bottom appears so to decrease. This hydrogeological feature is confirmed by the analysis of the chemical physical groundwater data, as described afterwards.

The coastal aquifer does not outcrop everywhere due the widespread presence of the upper almost impervious stratum, 3 up to 10 m thick and constituted by silty-clays. In particular, where this stratum exists the aquifer is confined otherwise it becomes unconfined. Generally the latter type is more present nearby the coast and also in some areas around the Basento River.

The coastal aquifer is bounded downward (SE) by Ionian Sea and it passes upward (NW) to the aquifers belonging to the marine terraces or to the alluvial deposits of river valleys. The groundwater in the marine terraces is not confined everywhere, due to the not homogeneous distribution of the low hydraulic conductivity strata or levels existing in these deposits (Figure 4).

A recharge boundary between the coastal and the upper aquifers is not everywhere well defined and it becomes a discharge limit mostly near

Policoro villages, where some springs are located (Figure 1). In fact the clayey strata outcrop in this area directly under the pebbly unit, at the foot of the slope of the marine terraces.

The piezometric map shows rivers generally can to cause a drainage effect on river valley aquifers (Figure 7). This effect gradually decreases, ceases or is inverted from where rivers start to flow in the coastal plain to the coast. This change is more evident in some areas as in the case of Sinni and Bradano rivers.

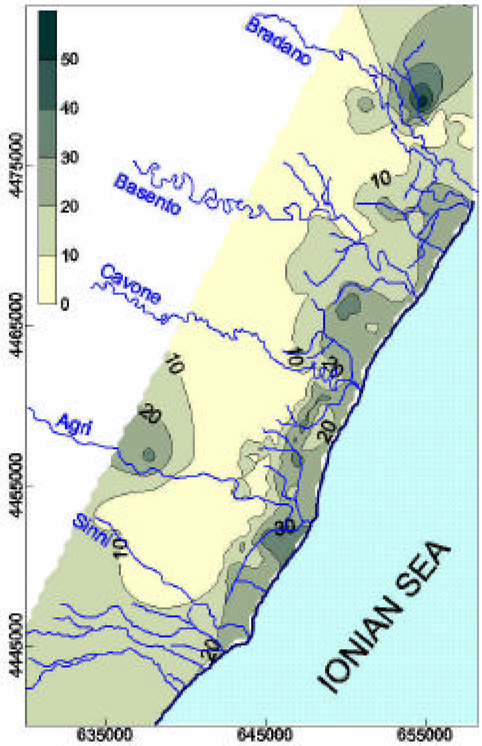

Figure 5: Thickness (m) of the shallow coastal aquifer.

Piezometric contour lines are quite straight and almost parallel to the coastline and to boundary between the upper marine terraces and the coastal plain where this boundary is crossed (Figure 7). The spatial trend of the piezometric contour lines confirms groundwater of upward aquifers, particularly these constituted by terraced deposits, recharges coastal aquifer.

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This contribution must be relevant as the direct natural recharge of the shallow coastal aquifer is extremely low due both to the low actual rainfall and mainly to the low hydraulic conductivity of the topsoil and the soil at the top of the coastal aquifer. Being the first 3 up to 10 m from the ground surface almost impermeable, as described before, the recharge of the shallow aquifer is mainly guaranteed

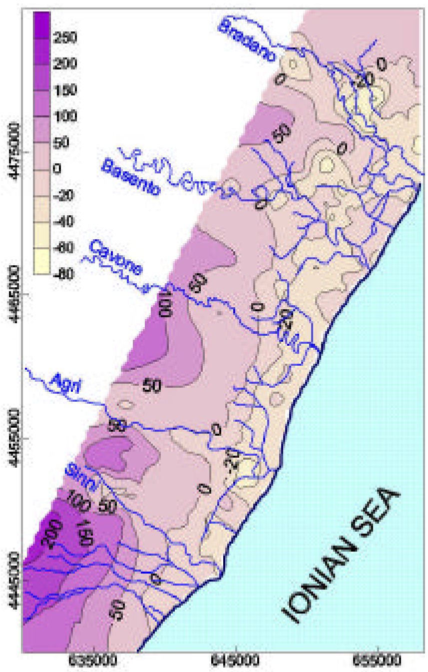

Figure 6: Approximate trend of sandy unit's bottom nearby the coastal plain (m a.s.l.).

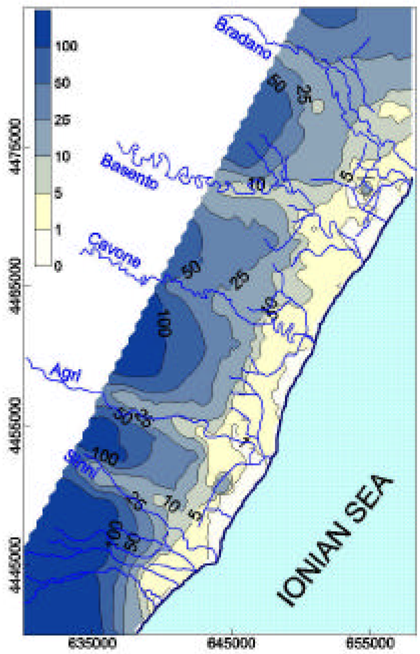

Figure 7: Piezometric map (m a.s.l.).

by the discharge from the upward aquifers of the marine terraces and from the river leakage. As a matter of fact, as shown in Figure 4, the riverbeds are deep enough to cut outcropping soils of low hydraulic conductivity, where they exist. If the river water height dominates the piezometric height it depends from the point but somewhere also from the river flow stage, that is subject to a relevant seasonal effect.

Moreover, the piezometric surfaces are clearly influenced by the river paths upward (Figure 7): this effect is particularly evident for the Basento and the Agri Rivers. In any case, as for the Sinni River, the downward concavity of the piezometric contour lines is not exactly superimposed on the present riverbed but it could be correlated to the buried riverbed.

The minimum hydraulic conductivity value of the study coastal aquifer, obtained by the analysis of different wells, is equal to $3.47\ 10^{-6}$ m/s which is due to a well yield equal to 0.8 l/s as a drawdown effect of 25.9 m. On the contrary, the mean value is equal to $2.28\ 10^{-4}$ m/s and the median one is $6.53\ 10^{-5}$ m/s. The maximum value of the hydraulic conductivity is equal to $5.69\ 10^{-3}$ m/s, connected to a well yield equal to 2.3 l/s as a drawdown effect of 0.2 m.

Besides, the riverbed paths do not seem to affect the spatial trend of the hydraulic conductivity in the coastal aquifer, as highlighted by the hydraulic conductivity map (Figure 8). In detail, the hydraulic conductivity decreases moving both from inland to the coastline and from the Sinni to the Bradano areas.

CHEMICAL AND PHYSICAL FEATURES OF GROUNDWATER

A chemical and physical characterisation of groundwater flowing into the study area has been carried out. This analysis has been inferred from the tests performed on different groundwater samples: number 47 tapped by marine terraces deposits and number 162 by alluvial and coastal deposits. All these samples have been taken from 158 wells uniformly distributed within the study area. Several public bodies (Polemio et al., 2002a) according to Italian standard methods carried out the utilised laboratory analyses. Due to different purpose of these monitoring campaigns, a validation analysis was preliminarily realised (Polemio et al., 2002a).

As regards the groundwater temperature, it ranges between 12°C and 20°C. This finding has to be cautiously assessed as it was yielded by a plethora of apparatuses and methods. Notwithstanding this, some considerations about the temperature trend in the study area could be pointed out. The temperature seems to increase towards the coastline as shown in Figure 9.

It is possible to highlight a gradual increase of

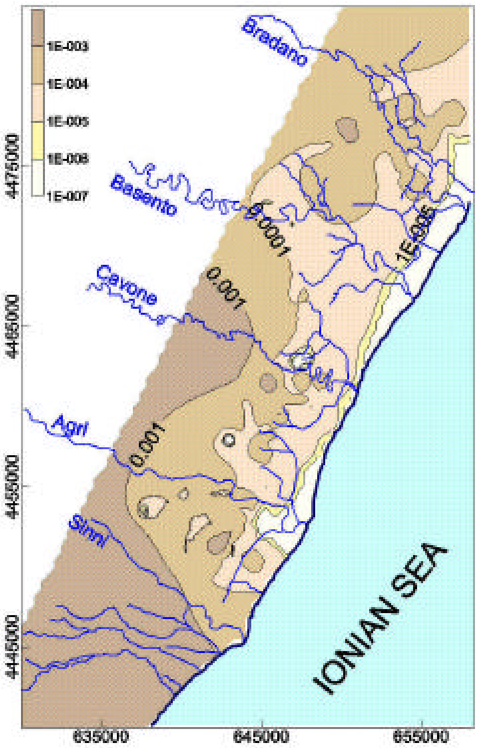

Figure 8: Hydraulic conductivity map (m/s).

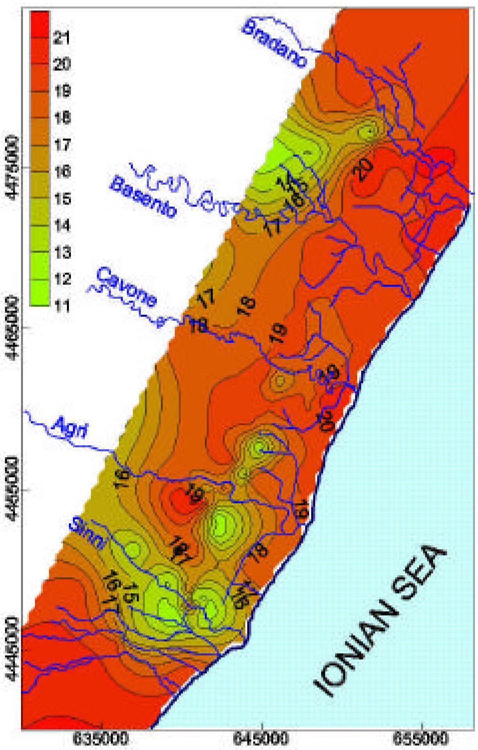

Figure 9: Groundwater temperature map (°C).

the groundwater temperature from the recharge areas, located inland where the marine terraces outcrop and collect direct recharge of rainfall infiltration, to the receiving areas corresponding to spring zones, to the coastal plain aquifer and to the sea (Figure 9).

River paths do not seem to be relevant for the spatial groundwater trend except for the Sinni River area where can be observed the effect of the leakage of cold river water.

Flowing toward the coastline, where the direct infiltration of rainfall water is modest, the groundwater residence time –a parameter for which no quantitative data are available– would increase and reach its peak near the coast, where no recharge action is exerted by the rivers. The progressive increase of groundwater temperature can be explained as the result of the progressive heat exchange between groundwater and storage soils and also, in addition, close to the coastline, as the effect of the sea on the groundwater temperature.

The minimum, the maximum and the mean values of each chemical parameter and the classification according to the outcropping lithotype are shown in Table 1.

The groundwater pH values range from 6 up to 8 and they tend to increase along the coast. The distribution of this parameter seems to be influenced by the river action.

The concentrations of the calcium and the bicarbonate ions in the groundwater are highest inland and lowest along the littoral. In detail, the concentration of calcium ion ranges between 50 and 125 mg/l, whereas that of bicarbonate ion varies between 250 and 450 mg/l. The waters coming from the rivers seem also to affect the concentration of the calcium ion in the groundwater system, though with a lesser extent comparing to the pH trend.

The magnesium content ranges between 25 and 50 mg/l and it increases along the coastline, especially in the coastal sector between the Bradano and the Cavone Rivers.

The concentrations of the major ions estimated for each sample are plotted in the Piper diagram shown in Figure 10. Even if they are extremely dispersed, two dominant types of groundwater have been distinguished: the bicarbonate-alkaline-earthy type and the sulphate-chlorinate-alkaline type. The former is typical of groundwater flowing in the marine terraces and in the alluvial deposits while the latter is characteristic for the samples taken in the coastal plain deposits. The other facies highlighted in the Piper diagram (Figure 10), such as the bicarbonate–alkaline type and the bicarbonate-alkaline-earthy type, are less documented by the examined water samples. In particular, the sulphate-chlorinate-alkaline-earthy type has been recognised for groundwater flowing in the area surrounding the Basento river and it seems to be due to pollution phenomena occurred in this area. The pollution is due to leakage of river water into the coastal aquifer. The sources of pollution are waste water discharge into the Basento River in the basin of which the highest percentage of population and industrial activities are located.

The variability of major ions contents is related to many factors such as the different lithologies of the aquifers, the seawater intrusion, the mixing with river water and the impact of intensive farming.

As regards the influence of the sea intrusion on the chemical composition of the groundwater, the major concentrations of the ions present in seawater, such as potassium, sodium, sulphates, chlorine, have been estimated. The analysis of the concentration maps of these ions and of ratios of the concentrations as of maps of TDS and of groundwater electrical conductivity have delineated a coherent scheme of seawater intrusion in the area.

As an example, the roles played both by seawater intrusion and the exchanges occurring between the rivers and the groundwater system has been extensively confirmed by the values calculated for $(Na+K+Cl+SO_4)/(Ca+Mg+HCO_3)$, which is the characteristic ratio proposed by Cotecchia and Magri (1966). As a matter of fact, the values of this ratio exceeding the unit, which generally indicate seawater contamination, have been found along a strip of land stretching for 2.5-3 km from the coastline inwards (Figure 11). These data confirm the hypothesis about the existence of seawater intrusion along the Ionian coastline, highlighted by previous investigations such as those carried out in the study area (Radina, 1956, Polemio et al., 2002b) and in the portion of the coastal aquifer between the Bradano Cavone rivers (Polemio and Mitolo, 1999).

CONCLUSIONS

Hydrogeological aquifer features and main characteristics of groundwater flow have been determined for a wide coastal area lying in the Southern Italy, subjected to a semiarid climate and dramatically damaged by drought at the present time.

The geological and hydrogeological set-up shows the relation exiting between the coastal aquifer and the others inland aquifers. Mainly for the former, the spatial trend both of the geometrical aquifer characteristics and of the hydrogeological

		A	B	C	D	E	F	G	H	I	L	M
Terraced marine deposits	Min	16.0	6.7	271	348	19	9	27	3	20	1	40
	Max	22.0	8.6	2310	4000	208	102	549	76	805	372	807
	Average	19.3	7.2	868	1333	98	38	142	1	167	127	372
Alluvial deposits	Min	16.3	2.9	179	211	6	2	14	4	17	2	11
	Max	22.3	8.8	3410	9031	160	153	2175	38	2645	804	1251
	Average	19.3	7.6	940	1786	54	40	180	15	268	123	334
Coastal deposits	Min	19.0	6.8	261	446	12	9	33	49	30	37	124
	Max	20.2	8.3	1487	15052	192	251	2700	71	3000	163	763
	Average	19.5	7.7	805	3190	87	64	510	60	661	101	405

Table 1:- Statistical outline, listing the minimum, the maximum and the mean values of each chemical parameter and the classification according to the outcropping lithotype. Legend: A) T (°C); B) pH; C) TDS at 110°C (mg/L); D) Electrical Conductivity at 25°C (?S/cm); E) Ca^{2+}(mg/L); F) Mg^{2+}(mg/L); G) Na^{+}(mg/L); H) K^{+}(mg/L); I) Cl^{-} (mg/L); L) SO_4^{2-}(mg/L); M) HCO_3^{-}(mg/L).

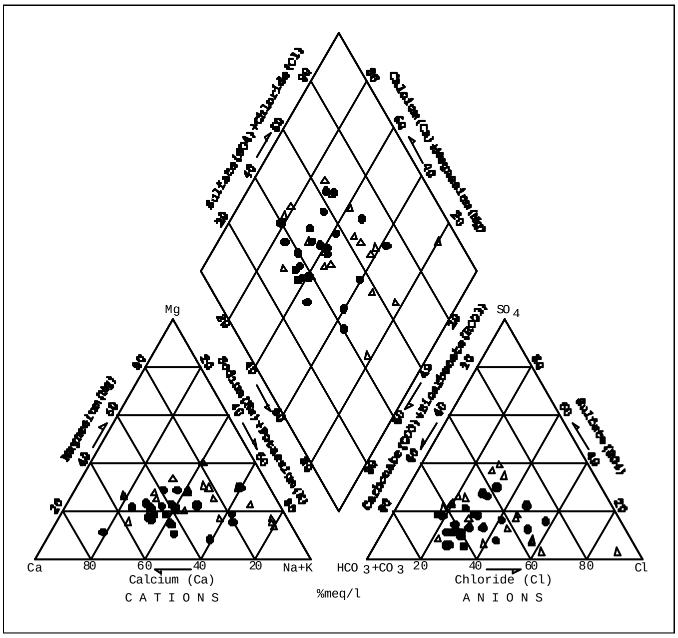

Figure 10: Piper diagram. Legend: ?) groundwater sample of terraced marine aquifer; ☆) groundwater sample of the coastal aquifer.

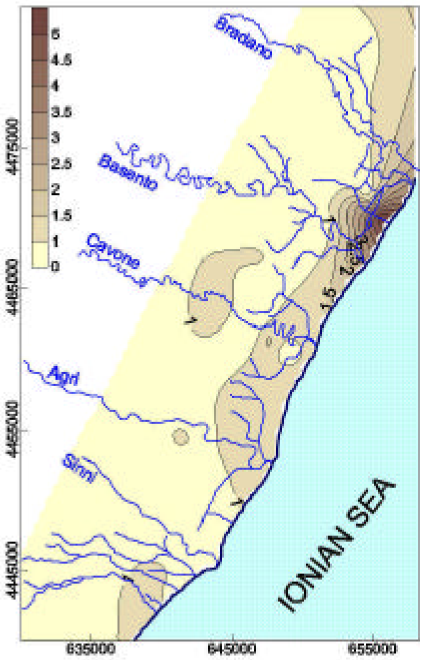

Figure 11: Map of characteristic ratio (Na^{+} + K^{+} + Cl^{-} + SO_4^{2-})/(Ca^{2+} + Mg^{2+} + HCO_3^{-}) (as epm ratio).

parameters were described.
These results highlight both the opportunity to continue and to strengthen the research activity on these aquifers and the utility to establish management criteria of groundwater resources and generally of the water cycle.

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