Mem. Descr. Carta Geol. d'It.
LXXVI (2007), pp. 17-38
figg. 20- tabb. 8

Hydrogeological Features of the Enza River Alluvial Fan (Province of Reggio Emilia)

Aspetti idrogeologici della conoide alluvionale del torrente Enza (Provincia di Reggio Emilia)

BARBIERI S. (*), MARTINELLI G. (*)

ABSTRACT - The Enza River originates between the Giogo Pass (1.262 m a.s.l.) and Mount Palerà (1.425 m a.s.l.) in the Northern Apennines. The mountainous part of the hydrographic basin is markedly prone to slope instability and the the Enza River is strongly encased. At the valley outlet in the plain the gravelly river bed widens and the slope diminishes; the river course flows on the deposits of a large, flat alluvial fan. In this area numerous wells have been drilled for industrial and agricultural purposes, and for drinking water supply of the city of Reggio Emilia. Owing to the intensive groundwater withdrawal local aquifers water volume is slowly diminishing towards depletion.

A reconstruction of the geometry of the aquifers of the alluvial fan body was carried out on the basis of well stratigraphies provided by various Institutions and of geoelectric soundings. An isotopic survey has also been performed to better understand the origin, circulation and evolution in time of groundwater

The isotopic data relating to $\delta^{18}O$ and δD vary from -7.6 to -9.0 for $\delta^{18}O$‰ and between -51.2 and -61.1 for δD‰; Tritium values indicate a water residence time of 2-10 years.

A preliminary estimate has been performed on the water volumes stored in the three Aquifer Groups of the fan system, known as A, B and C, on the basis of hydraulic parameters known for the area.

A preliminary estimate has been made of the exhaustion time of the water volume stored in the alluvial fan system on the basis of the available information on the recharge of the aquifers from rainfall, river bed seepage, etc., and on the withdrawals for domestic, industrial and agricultural purposes.

The water balance of the aquifer system of the Enza River fan results to be significantly depleted, while the water-volume exhaustion time has been estimated at some decades unless structural interventions on the system of withdrawals are adopted in the meantime.

KEY WORDS: Enza River Alluvial Fan, Isotopes, Ground Water Monitoring, Hydrologic Balance, Land Subsidence.

RIASSUNTO - Il torrente Enza nasce tra il Passo del Giogo (1.262 m s.l.m.) e il M. Palerà (1.425 m s.l.m.) nell'Appennino Settentrionale. Il bacino idrografico presenta vaste zone caratterizzate da forte propensione per il dissesto idrogeologico. L'Enza ha caratteristiche tipicamente torrentizie nel tratto montano dove è fortemente incassato. Allo sbocco vallivo in pianura l'alveo ghiaioso si allarga e la pendenza diminuisce. Il corso fluviale scorre sul dorso della larga e bassa conoide alluvionale. In quest'area sono stati perforati numerosi pozzi per scopo industriale, agricolo e per l'approvvigionamento idrico civile della città di Reggio Emilia. A causa degli intensi prelievi delle acque sotterranee gli acquiferi locali stanno lentamente esaurendosi e il loro bilancio idrogeologico risulta essere negativo.

Sulla base di stratigrafie presenti negli archivi di numerose Istituzioni e di una campagna geoelettrica 3D è stata ricostruita la geometria degli acquiferi della zona di studio. Inoltre, è stata approntata una campagna di prospe-zione isotopica per meglio capire l'origine, la velocità di circolazione e l'evoluzione del tempo di residenza delle acque nell'area.

I dati isotopici relativi a $\delta^{18}O$ e δD variano tra -7.6 a -9.0 per $\delta^{18}O$‰ e tra il -51.2 ed il -61.1 per δD‰. I valori di Tritio indicano tempi di residenza delle acque compresi tra 2-10 anni.

Una stima preliminare sui volumi di acqua immagazzinata nel sottosuolo è stata compiuta sulla base di parametri idraulici conosciuti per quell'area e considerando i volumi di acqua presenti nei tre Gruppi Acquiferi comunemente detti A, B e C.

Sulla base delle informazioni disponibili sui processi di ricarica (per infiltrazione efficace da precipitazioni, infiltrazione da sub-alveo, etc.) e sui prelievi di acqua dal sistema idrogeologico della conoide del torrente Enza (per usi civili,

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(*) ARPA Emilia-Romagna, Sezione di Reggio Emilia, Via Amendola 2, 42100 Reggio Emilia. Corresponding Author: giovannimartinelli@re.arpa.emr.it

industriali e agricoli, etc.) è stata calcolata una stima preliminare del tempo di esaurimento del volume d'acqua immagazzinato all'interno degli acquiferi dell'area studiata.

Il bilancio del sistema acquifero della conoide del torrente Enza risulta essere significativamente negativo, mentre il tempo di esaurimento del volume d'acqua immagazzinato è stato stimato in alcuni decenni se non verranno nel frattempo adottati interventi strutturali sul sistema dei prelievi.

PAROLE CHIAVE: Conoide alluvionale del torrente Enza, Isotopi, Monitoraggio acque sotterranee, Bilancio ideologico, Subsidenza.

1. - INTRODUCTION

The alluvial fans of the Apennine rivers located in the *Emilia-Romagna* territory are particularly important as their subsurface waters are intensively exploited for domestic, agricultural and industrial uses. In the province of *Reggio Emilia*, $113.9*10^6$ m^3/year of water is withdrawn (RER-ARPA, 2003). A large amount, equal to $59.9*10^6$ m^3/year, is extracted in the area of the Enza River alluvial fan. Particularly intense withdrawals for domestic uses are carried out in the well-fields of Quercioli, Case Corti and Caneparini (≈450 l/s) in the Municipality of Cavriago. PELLEGRINI *et alii* (1976), PELLEGRINI & ZAVATTI (1980), CANEDOLI *et alii* (1994), provided a description of the main hydrogeological and geochemical characteristics of the aquifers of the Enza River alluvial fan. RER & ENI-AGIP (1998), and RER-ARPA (2003), described the structural characteristics and the recharge of the aquifers in the alluvial fan areas. In order to better understand the hydrogeological characteristics of the aquifers of the Enza River alluvial fan and to estimate the aquifers life-time stratigraphic, geoelectric, piezometric, chemical and isotopic data were collected.

2. - ENZA RIVER ALLUVIAL FAN AND AQUIFERS GEOMETRY

The geology of the Enza River valley has been previously reported by DE NARDO (1992), AMOROSI *et alii* (1996), CATANZARITI *et alii* (1999) and by VALLI *et alii* (2003). The Enza River rises between the Giogo Pass (1.262 m a.s.l.) and Mount Palerà (1.425 m a.s.l.) in the Northern Apennines; in its mountain stretch the river is strongly encased. At the valley outlet in the plain the river bed widens out and the slope diminishes. In this area the course of the river flows into the alluvial deposits of the broad ancient alluvial fan, encased between the steep ridges of the Pleistocene river terraces. The morphology does not change as far as the A1 motorway where the pebbly river-bed tapers and becomes sandy. Further north the Enza River bed shows a very small gradient (less than one per cent) and a meandering pattern (fig. 1) up to its confluence with the Po River.

The lithological variability that characterizes the hydrographical basin of the Enza River, i.e., the sandstones (Monte Ventasso Fm), sandy-marly (Bismantova Fm) and limestones (Monte Caio Fm) of the upper valley and the extensive silty and clayey rocks of the lower valley, determines high soil erosion rates.

During the Pleistocene glacial periods, the abundant solid transport gave rise to the typical fan deposition, characterized by vertical and lateral alternations of alluvial deposits of different grain size that reaches its maximum thickness, about 250 m, near the *Via Emilia* Road (AUTORI VARI, 1978).

The alluvial fan is triangular in shape, with its

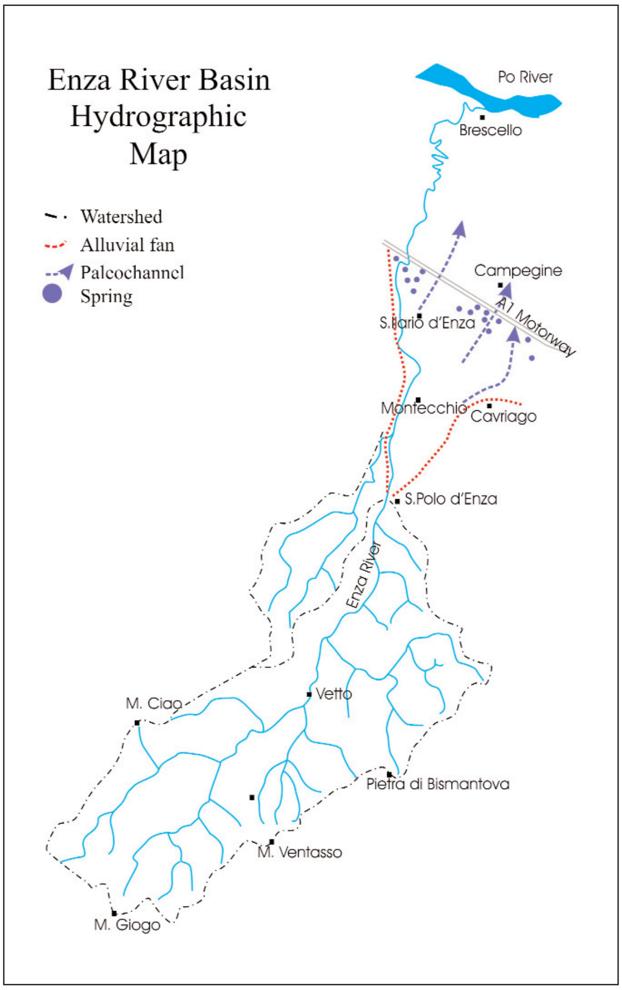

Fig. 1 - Hydrographic sketch map of the Enza River (after PEREGO, 1988, modified).
- *Corso fluviale del torrente Enza dal bacino montano fino alla confluenza con il fiume Po (da* PEREGO*, 1988, modificata).*

apex at San Polo d'Enza (about 200 m a.s.l.) and its front just northwards of the *Via Emilia* Road (40 m a.s.l.), where the transition between the more permeable sandy-gravelly deposits, and the silty-clayey and less permeable sediments of the middle plain takes place. The front of the alluvial fan is characterized by the occurrence of springs (resurgence line) in the zones of Caprara, Campegine, Laghi di Gruma and Corte Valle Re. The alluvial fan is bordered to the east by the slope of the terrace extending from San Polo to Cavriago and skirting Bibbiano and Barco (TAGLIAVINI *et alii*, 1990). These terraces of Middle Late Pleistocene age are made of gravelly alluvium affected by the formation of palaeosoils several dozens of centimetres thick. The terraces are suspended of about 10 m with respect to the Late-Holocene flat bottom of the valley.

The current course of the Enza River is the result of an evolutionary trend common to most of the water courses of the southern Po Plain (PELLEGRINI *et alii*, 1976; BURRATO *et alii*, 2003) which migrated (usually westwards) during the Holocene aggradation of the alluvial plains; currently, the Enza flows on the left margin of its Pleistocene alluvial fan.

Starting from San Polo d'Enza, heading northwards, the almost exclusively gravelly calcareous riverine deposits, site of water resources, get progressively thicker. The alluvial sediments pass from a few metres constituting a single undifferentiated layer to a few hundred metres (PELLEGRINI *et alii*, 1976) of alternating gravelly and silty-clayey beds; the importance of the latter is obviously increasing northwards whereas the relatively coarser sediments are confined in the first 100 m depth.

BERNINI & PAPANI (1987) identified two parallel tiers of buried imbricated structures, interrupted by a strike-slip left fault oriented north-east south-west, known as the Enza Line; this fault caused the differential uplift of the terraces locate west and east of the Enza River course.

As far as the Pleistocene marine substratum is concerned, an elevation of 80 m a.s.l. is registered near San Polo and rapidly merges northwards. At Montecchio a tight anticline uplifts the marine substratum at 70 m a.s.l. so that the alluvial cover presents a reduced thickness of 35-40 m; in correspondence of the *Via Emilia* road the marine top lies at a depth of about 400 m a.s.l.

The geometry of the marine substratum controls the geometry of the Aquifer Complexes with the exception of the A_1 complex, the most superficial one, which covers the Montecchio anticline and regularly thickens northwards of this structure.

The recharge of the alluvial fan is provided by the infiltration of rain waters and the seepage of the Enza River and minor waterways. In particular, PELLEGRINI & ZAVATTI (1980), by using the infiltration coefficient calculated by IDROSER (1976) in the range of 25-35%, estimated the contribution of meteoric waters at about 2 m^3/s and the seepage from the Enza River bed in the stretch San Polo-Sant'Ilario, where the river is generally loosing, at 0.5 m^3/s.

In the vulnerability map published by TAGLIAVINI *et alii* (1990), the depth of the top of the coarse deposits of the fan system is found in the first 5 m below the ground surface; the surficial fine deposits are thickening northwards and close to the *Via Emilia* road the top of the coarse deposits is more than 10 m deep. In the same study, many paleochannels have been identified; they are headed northeast in the direction Bibbiano-Cella-Cadelbosco, Montecchio-Calerno-Campegine and Sant'Ilario-Taneto-Praticello.

3. - HYDROGEOLOGICAL SECTIONS

The stratigraphic reconstruction of the water productive horizons, through the drawing of two hydrogeological sections longitudinal and transversal to the alluvial fan of the Enza River, includes the portion of the territory in which the AGAC (local Agency for water management) well-fields are located (fig. 2). The sections have been drawn using the water well stratigraphies from the archives of the Department of Earth Sciences (University of Modena and Reggio Emilia), the office of the *Emilia-Romagna* Enza River Technical Services and the AGAC archives. The latter provided detailed stratigraphic information useful for the for the correlations with the other stratigraphies. In the sections two basic lithologies are distinguished, characterized by very low-permeability, such as clays and muds, and by greater permeability, such as sands and gravels.

3.1. - SOUTH-NORTH LONGIUDINAL SECTION

Section 1, oriented southwest-northeast (fig. 3), lies entirely in the Municipal territory of Cavriago and develops for about 5 km in length roughly parallel to the aquifer streamlines. It comprises elevations ranging between about 110 and 45 m and crosses the town of Cavriago, the Case Corti AGAC well-field and the industrial settlement of Corte Tegge, near the *Via Emilia* road. Nine stratigraphies have been used, two of which belong to the well-field of Case Corti and reach depths of about 120 m and 160 m. In the southeastern portions of the section, silty-clayey sediments are

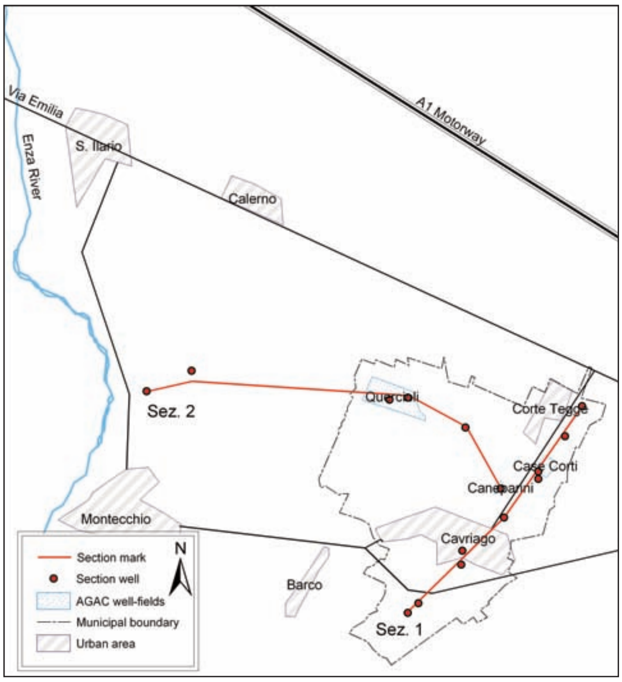

Fig. 2 - Location of hydrogeologic sections.- *Traccia delle sezioni idrogeologiche.*

present on the surface. Below that cover, in the first 60-70 m from the ground surface, the stratigraphies show three continuous and well developed large gravelly-sandy bodies. In the central portion of the section, proceeding northwards, in the first 25-30 m from the topographic surface there is a single undifferentiated gravelly layer, site of the aquifer, which extends as far as the Corte Tegge area, where a clayey cover appears. Below this gravel body, in particular near Case Corti, between 30 m and 100 m from surface alternations between gravelly and clayey beds can be observed. Hydraulically he superficial aquifers are probably laterally connected; the underlying ones can be considered confined aquifers owing to the presence of the clayey beds.

3.2. - East-West transversal section

Section 2, oriented east-west (fig. 4), cuts across the middle part of the Enza River alluvial fan. The section spans from the well-fields of Caneparini and of Quercioli to the present river-bed of the Enza River for an overall length of about 7.5 km, including elevations ranging from 60 to 70 m. To draw this section seven stratigraphies have been used, two of which from the well field of Quercioli (about 150 and 180 m deep) and one from the well field of Caneparini.

The first 30 m from the topographic surface are dominated by a single undifferentiated gravel body that tends to subdivide into distinct beds in the vicinity of Caneparini. Below these gravels the coarse deposits are separated by clayey beds and develop in the first 60-80 m from the ground surface; at Quercioli the gravel bodies are present at greater depths, also beyond 150 m.

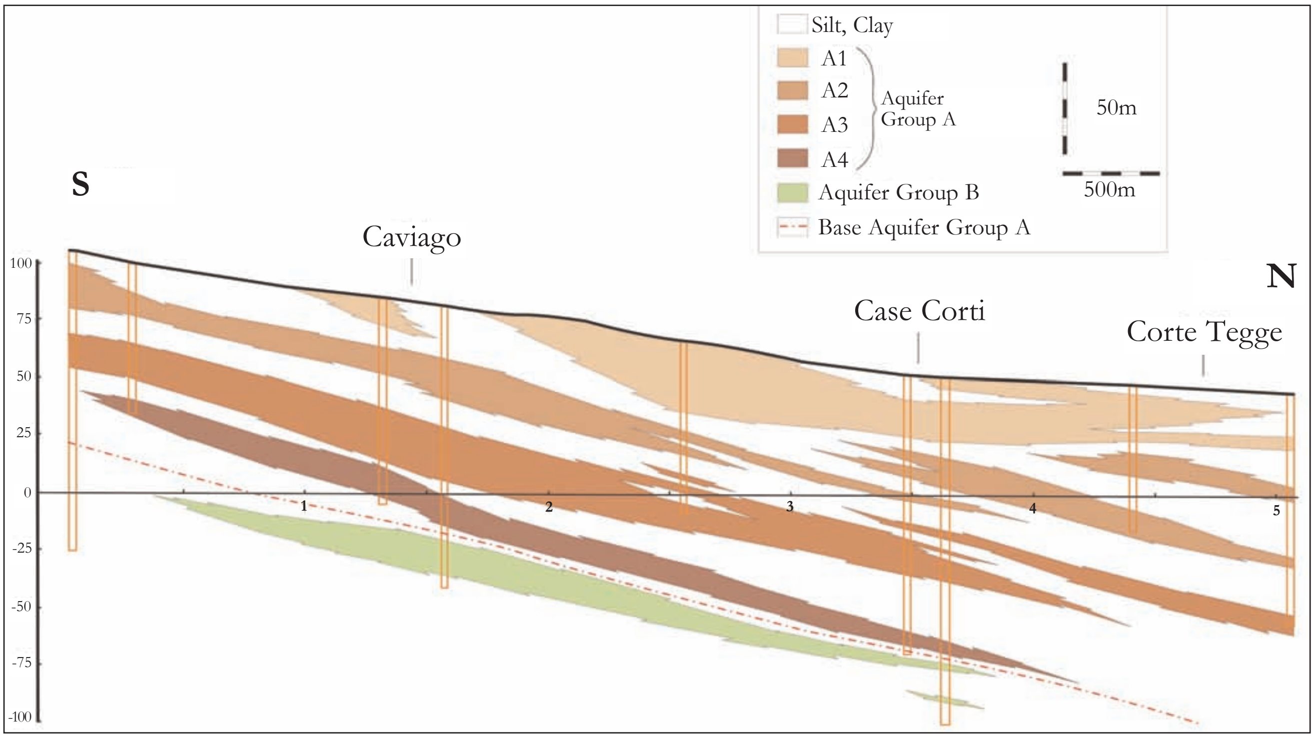

Fig. 3 - Hydrogeologic section of the study area oriented South-North. - *Sezione idrogeologica semplificata ad andamento Sud-Nord.*

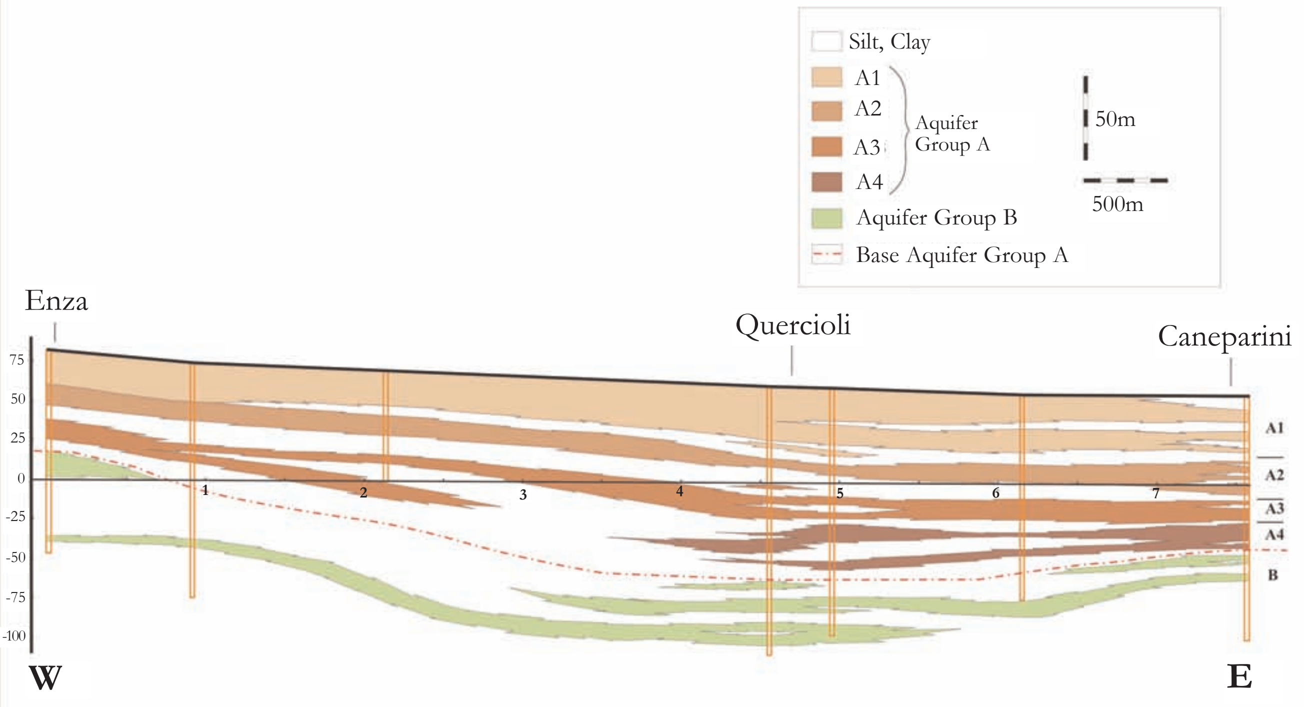

Fig. 4 - Hydrogeologic section of the study area oriented East-West.
- *Sezione idrogeologica semplificata ad andamento Est-Ovest.*

4. - GEOPHYSICAL INVESTIGATION IN THE WELL-FIELD OF QUERCIOLI

In order to improve knowledge on local hydrogeological features a 3D tomographic geo-electrical investigation within the area of the AGAC well-field of Quercioli has been carried out. This study fulfils a research agreement between the ARPA *Emilia-Romagna* Section of *Reggio Emilia* and the Institute of Methodologies for Environmental Analysis of the National Research Council (CNR- IMAA) of Potenza.

The experimental determination of the apparent resistivity values, through joint measures of the intensity of the electrical current, sent into the subsoil by means of a couple of electrodes fixed in the ground, and the tension at the heads of a second pair of electrodes, also in direct contact with the ground, allows for the reconstruction of the geometry and the geological-hydrogeological balance of the test site. For the investigations in the Quercioli well-field, a configuration of Wenner-Schlumberger type was used (electrodes arranged with the same inter-electrode spacing). The Quercioli well-field is located in the middle part of the Enza River alluvial fan. Stratigraphic researches evidenced a complex multilayered aquifer (Pagotto *et alii*, 1994) characterized by gravel situated below the soil up to 30 m in depth, resting upon a semi-permeable bed. Modest silty-clayey lenses are only locally present. This gravel body is generally unsaturated. A second aquifer, semi-confined as it receives supplies through the semi-permeable roof, ranges between 30 m and 60 m in depth. At between 60 m and 100 m in depth there is a third aquifer hosted in gravelly sediments. Between 100 m to 180 m below the topographic surface several confined aquifers occur. The repeated alternation of gravelly and clayey beds of similar thicknesses at depths up to 100 m hosts the main aquifer.

Measures have been performed by arranging five 780 m long parallel alignments spaced out 60 m from each other; for each alignment measures were performed with an inter-electrode spacing of 20, 30 and 40 m for an investigation depth of about 125 m. The performed 3D tomography is characterized by over 3.400 values of resistivity. The results of the tomographic study are in agreement with the hydrogeological data.

In particular, the 3D resistivity model (fig. 5) indicates the presence of a layer with resistivity > 50-60 Ohm m up to a depth of about 35-40 m that can be associated with the unsaturated gravelly-sandy body underneath the soil cover. Furthermore, one can observe a significant spatial variability in the resistivity values due to size heterogeneity and/or different water content within the gravelly-sandy body of above.

The relatively low values (resistivity <50 Ohm m) already detectable at about 40 m in depth, and above all from about 70 m onwards, can be asso-

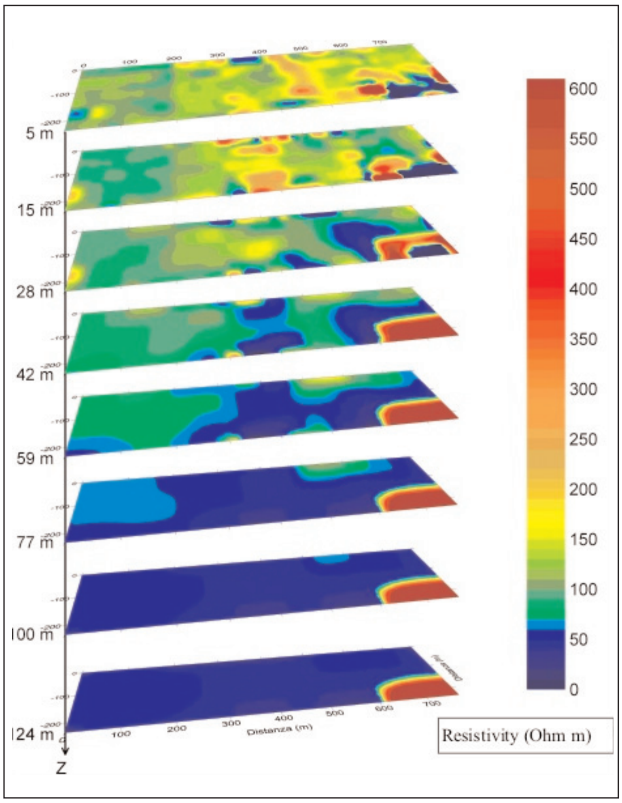

Fig. 5 - 3D Resistivity model of the Quercioli well field. Location in figure 2.
- *Modello 3D della resistività elettrica nel campo pozzi di Quercioli. Ubicazione in figura 2.*

ciated with clayey beds. It should be underlined that any further saturated gravelly bed alternating with these clays is not recognizable owing to its similar electrical behaviour (same resistivity values). The reconstruction, therefore, has provided reliable results in the first 60-70 m of depth in agreement with previous investigations by MAZZETTI *et alii* (2003) in an adjoining area of the Enza River alluvial fan.

5. - PIEZOMETRIC MONITORING

In order to reconstruct the main hydrodynamic characteristics of the aquifer system, such as the aquifer flow direction, the identification of the recharge areas and feeding, and the areas subjected to intensive withdrawal, a piezometric monitoring network has been specifically set up. The distribution of the measurement points falls within an area limited by the alignments Montecchio-Barco to the south and Cavriago Corte Tegge to the east, by the Enza River to the west and the A1 motorway to the north (fig. 6). The highest density of measurement points lies in the municipality of Cavriago, with a density close to 2 wells for km^2.

Sixty-six wells were identified (tab. 1) mainly designed for domestic or breeding purposes. Some of them are irrigation wells and two belong to the Quercioli and Caneparini AGAC well-fields and are part of the *Emilia-Romagna* control network set up in 1976 and managed by ARPA.

Most of the wells of the control network have a depth ranging from 50 to 80 m, except for some wells with depths over 100 m and some others that do not reach 50 m depth.

5.1. - PIEZOMETRIC CAMPAIGN 2002

The piezometric campaign for the reconstruction of the equipotential surface was performed in the period from March to April 2002. The selected measures were processed by means of an automatic interpolation software (Surfer 7.0).

Thus, the map of the 2002 piezometric surface was drafted (fig. 7) by means of equipotential lines traced every metre indicating the pressure present in the aquifer under static conditions. The trend of piezometry is strongly conditioned by the permeability of the alluvial deposits, by the degree vof confinement of the water-bearing bodies, and in particular for the zone to the north of the town of Cavriago, by the intense water withdrawal evidenced by the cone-like piezometric depressions. On a large scale the natural flow in the aquifer tends to occur in the southwest-northeast direction, in accordance with the dip of the Pliocene marine substrate.

Along the Montecchio-Barco alignment there is a constant and uniform lowering of the piezometric surface (fig. 7). This trend is coincident with the orientation of the culmination of the buried sincline described above (TAGLIAVINI *et alii*, 1990). The equipotential lines range between values of 30 and 90 m above sea-level, and the subdivision of the study area in two zones having a different hydraulic gradient is evident.

The high, uniform hydraulic gradient of the southern portion of the study area changes into low hydraulic gradient (0.002) in proximity of the *Via Emilia* road due to increasingly marked conditions of confinement of the aquifer. These low values, lower than those of the topographic gradient, explain the occurrence of springs further north near the A1motorway. In the surroundings of S. Ilario the morphology of the equipotentials are strongly affected by the course of the present Enza River and groundwater tends to flow in the west-east direction, practically parallel to the *Via Emilia* road (fig. 7).

Summarizing, the equipotential lines tend to maintain a parallel trend from the Apennine margin to the town of Cavriago. Northwards the hydraulic perturbations generated by the intense

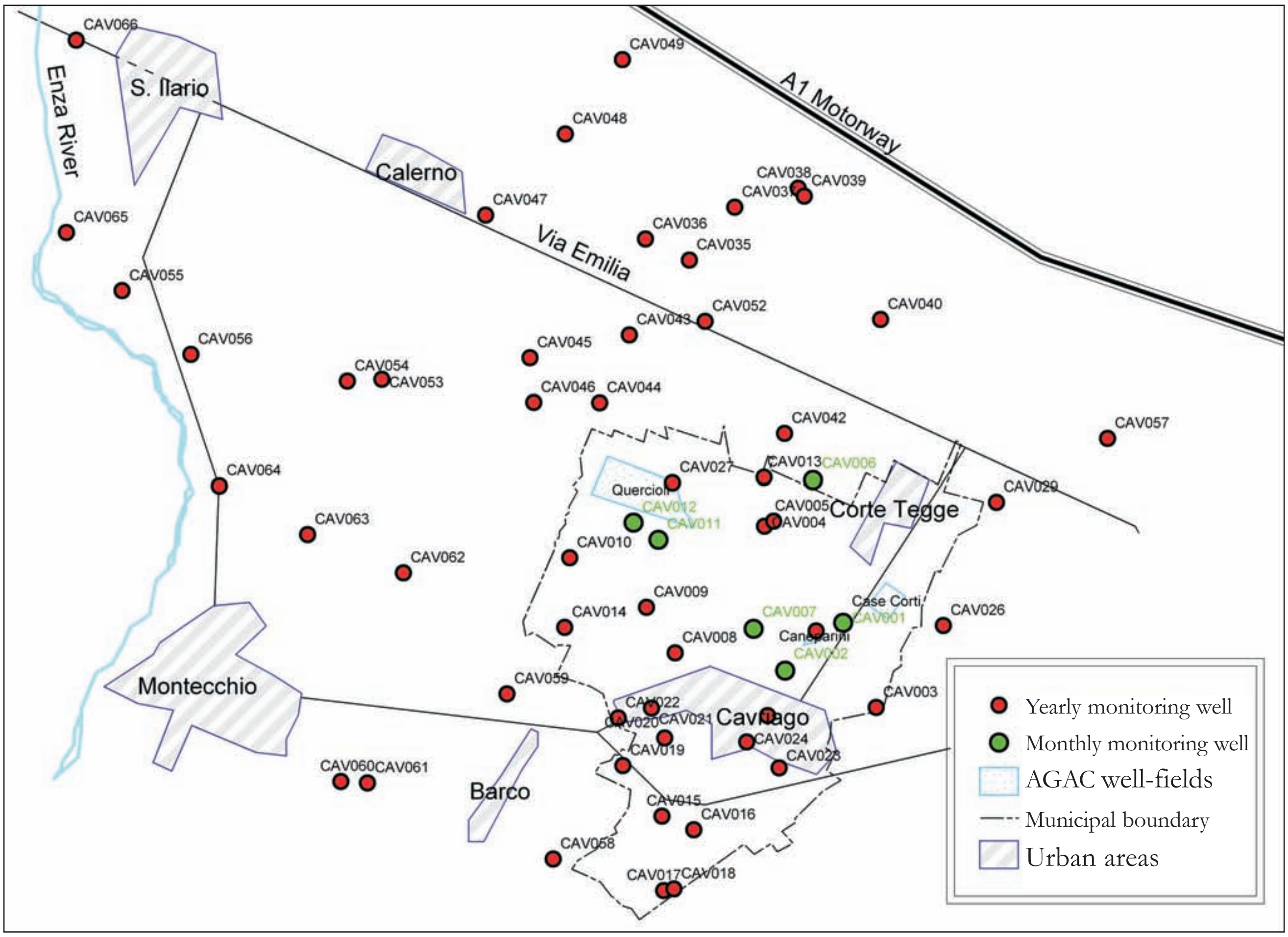

Fig. 6 - Location of wells utilized to monitor piezometry and chemical parameters.
- *Ubicazione dei pozzi utilizzati per la carta della piezometria e per il monitoraggio mensile.*

water withdrawal in the AGAC well-fields and in the industrial settlement of Corte Tegge, are displayed through two circular piezometric depressions (fig. 7). The intense exploitation determines a groundwater flow converging upon these two areas with contributions both from adjacent and remote areas.

The subsurface watershed that separates the two depression cones (Quercioli to the west, and Caneparini/Case Corti and Corte Tegge to the east) is thus to be considered a fake. Its presence derives from the interaction and the reciprocal influence of the two depression cones and its position thus migrates in time in relation to the increase or the decrease in the water withdrawals from one area or the other.

Hydraulic interaction between superficial and ground waters is evident only on the right bank of the Enza River which, in the reach between Montecchio Emilia and S. Ilario, looses water to the water table.

The comparison with the 1987 piezometric campaign (TAGLIAVINI *et alii*, 1990), shows a precise coincidence as regards the morphology of the groundwater surface and a general negative variation of about 7 m of the piezometric level.

5.2. - MONTHLY MONITORING

An additional piezometric control network of detail was set up for a better understanding of the flow dynamics in the area subject to the highest withdrawal; a monthly piezometric survey was carried out on the network, made up of six wells: CAV001, CAV002, CAV006, CAV007, CAV011 and CAV012 (fig. 6), for the period February 2002-October 2003. The diagrams (fig. 8) show a lowering of the groundwater surface in the months of July 2002 and 2003. This is due to the start-up of numerous irrigation wells in the month of June. In particular, July 2003 was a month characterized by a reduction in the piezometric level that was far higher than in July 2002; this deepening of the piezometric level was in the range of 7-8 m and almost 10 m for the CAV002 e CAV007 wells.

Tab. 1 - *List of wells utilized for piezometric and physical-chemical monitoring.*
- Elenco dei pozzi della rete di monitoraggio piezometrico e chimico fisico.

Well code	Ground surface (m a.s.l.)	Well depth	Water depth (m b.g.l.)	Piezometric level (m a.s.l.)
CAV001	55	80	-25	30
CAV002	68	54	-33,5	34,5
CAV003	63,2	/	-6,7	56,5
CAV004	55	100	-23,3	31,7
CAV005	54,5	49	-22	32,5
CAV006	48	70	-14,6	33,4
CAV007	62,5	79	-22,7	39,8
CAV008	71,2	100	-28,9	42,3
CAV009	70,5	90	-32,7	37,8
CAV010	70	60	-33,8	36,2
CAV011	63,5	55	-32,8	30,7
CAV012	63,3	64	-34,8	28,5
CAV013	50,8	64	-19,5	31,3
CAV014	77,4	/	-24,1	53,3
CAV015	96	48	-12,5	83,5
CAV016	117,2	65	-34,3	82,9
CAV017	124	64	-37,9	86,1
CAV018	124	55	-38,1	85,9
CAV019	94,1	70	-23,8	70,3
CAV020	89	70	-34,5	54,5
CAV021	85,5	70	-34,9	50,6
CAV022	89,4	76	-37	52,4
CAV023	83,5	128	-24,6	58,9
CAV024	83	74	-24	59
CAV025	77	90	-29,1	47,9
CAV026	53	/	-20,1	32,9
CAV027	59	160	-28,5	30,5
CAV028	60	150	-26,6	33,4
CAV029	45	60	-15,7	29,3
CAV030	49,5	/	-3,5	46
CAV031	48,2	/	-3,6	44,6
CAV032	43	12	-2,3	40,7
CAV033	42	15	-3,3	38,7
CAV034	39,9	12	-1,6	38,3
CAV035	45,3	40	-11,6	33,7
CAV036	42,2	100	-11,8	30,4
CAV037	42	70	-7,3	34,7
CAV038	39	78	-5,2	33,8
CAV039	40	100	-6,6	33,4
CAV040	38,1	/	-6,2	31,9
CAV041	41,7	35	-2,1	39,6
CAV042	45	32	-13,8	31,2
CAV043	50	40	-17,6	32,4
CAV044	56,5	/	-23,1	33,4
CAV045	55,9	/	-21,6	34,3
CAV046	57,5	55	-23,3	34,2
CAV047	51,5	100	-14,6	36,9
CAV048	43,3	35	-8,1	35,2
CAV049	39,8	/	-4,9	35,1
CAV050	33,5	47	spring	spring
CAV051	57,4	70	-28	29,4
CAV052	46,8	80	-13,7	33,1
CAV053	66	70	-26	40
CAV054	67	100	-25,1	41,9
CAV055	69	22	-20,2	48,8
CAV056	73	50	-19,1	53,9
CAV057	40,7	45	-7,6	33,1
CAV058	104,5	74	-13	91,5
CAV059	87,5	70	-30,1	57,4
CAV060	99,5	60	-5	94,5
CAV061	99,3	30	-5,1	94,2
CAV062	79,8	70	-32,1	47,7
CAV063	81	70	-33,6	47,4
CAV064	80,9	64	-31,1	49,8
CAV065	65	51	-18,3	46,7
CAV066	56,7	60	-11,7	45

6. - COMPARISON WITH THE *EMILIA-ROMAGNA* CONTROL NETWORK

In the study area there are two wells of the *Emilia-Romagna* control network, namely the RE-25-00 and RE 26-00 located in the AGAC well-fields of Quercioli and Caneparini, respectively. The piezometric measures of the static levels refer to the whole period ranging between 1977 and 1999 (fig. 9). For each year four seasonal measures are available: months of January, April, July and October.

From the diagrams of the period 1977-1984 a general lowering of the piezometric level of about 17 m, up to values of 30 m, can be observed. After a period of instability in the mid 8Os the trend was once again negative and was characterized by a rapid lowering of the piezometric level with a new minimum in the summer-autumn of 1990. The first half of the following decade was characterized by a rise of the piezometric level followed in the subsequent 5 years by a lowering until values close to the current ones were reached.

Piezometric data in the zones of Quercioli and Case Corti have been available since the late-1950s; the graphs of figure 9 show that in the 1950s the piezometric level was closer to the ground surface (-7 m and -9 m) and had a negative trend up to 1976 (Quercioli). The comparison of these data with the ones registered in 2003 shows that the piezometric level lowered of over 20 m for the area of Quercioli and 15 m for that of Case Corti.

7. - CHEMICAL-PHYSICAL MONITORING

Some sampling campaigns have been performed for the chemical-physical characterization of a part of the wells used for drafting the piezometric map (fig. 7). The first sampling was performed in June 2002. In 39 wells the main chemical-physical characteristics of the waters were measured in the field by means of a multiparametric probe (pH, temperature and specific electrical conductivity; tab. 2) and samples for laboratory analyses were collected (Payne *et alii*, 1964).

PH: The values detected are in the range 6.7-7.5 units pH. The maximum values are recorded near the Enza River and precisely north of Montecchio, where the course of the river shifts north-west. pH values lower than 7, were recorded between the towns of Montecchio Emilia and Cavriago with a minimum of 6.7 units pH at Barco. The spatial distribution of pH values and their near-perfect overlap with the piezometric data indicates seepage from the Enza River bed.

Temperature. Temperature data commonly

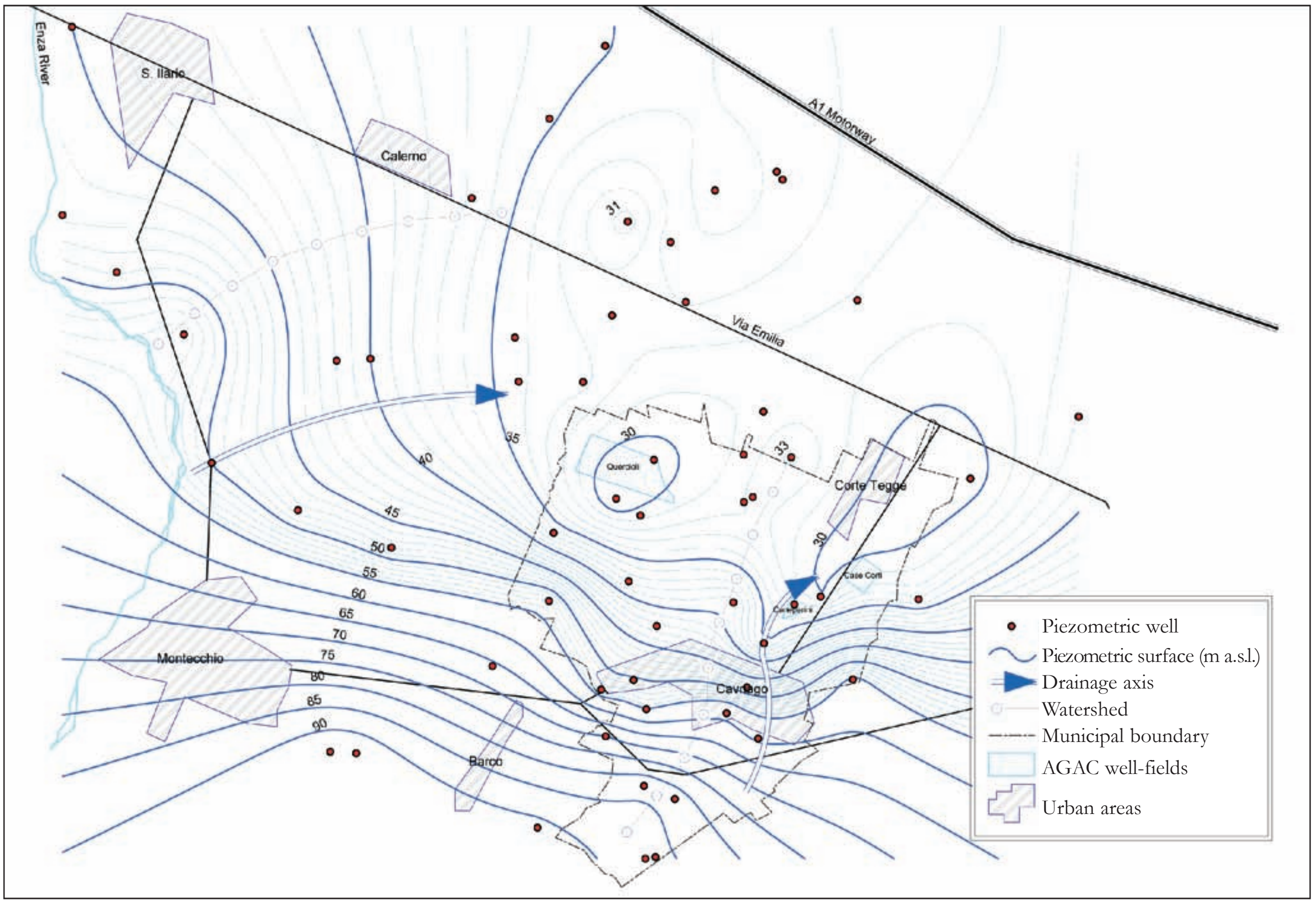

Fig. 7 - Piezometric surface in 2002. - *Superficie piezometrica della falda (m s.l.m.) nell'anno 2002.*

range between 14 and 14.8°C, with an average value of 14.5°C.

Specific Electric Conductivity. Being conductivity a parameter sensitive to temperature, both the specific electrical conductivity and the conductivity at 25 °C (microS/cm (c)) were measured; the latter normalized value was used for comparisons. The extreme values are 489 and 1106 microS/cm; the highest values were found south-east of Cavriago in the Apennine foothills. The majority of measures (28 out of 39) are in the range 700-900 microS/cm. The trend of groundwater electrical conductivity values can be used to verify the possible local seepage of the waters of the Enza River characterized by a low degree of mineralization (s.e.c. < 700 microS/cm); the low conductivity values and their correlation with the trends of pH and piezometry confirm the role the Enza River bed in the aquifer recharge.

8. - CHEMICAL ANALYSES

The main cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, Cl^-, SO_4^{2-}, NO^{3-}) of the waters of the 12 wells were analyzed.

The data (tab. 3) have been processed and mapped through isoconcentration lines. The Langelier-Ludwig diagram (fig. 10) indicates that the waters are all of a markedly Ca-bicarbonate nature; the reservoir is indeed made up of mainly calcareous clasts reflecting the calcareous rocks vastly outcropping in the Enza drainage basin.

Nitrate. Nitrate is the indicator of pollution as it derives from the organic nitrogen and the chemical nitrogen of industrial fertilizers (e.g. ZAVATTI, 2001).

The mean value observed is of about 25 mg/l even if in proximity of the *Via Emilia* road the CAV045 and CAV052 wells reach values of 40 and 46 mg/l, respectively. In general, concentrations are above 15 mg/l, except near the Enza River where the CAV056 well, with 10 mg/l of nitrate, probably benefits from dilution by the Enza surface waters (fig. 11).

M*agnesium*. Mg^{2+} is present with an average concentration of 16.5 mg/l. Its area distribution indicates that the minimum values are in proximity of the zones of piezometric depression. In such zones, water that is probably not chemically equilibrated with the host sediments is withdrawn (fig. 12). Low values are also present in the CAV056 well in proximity of the Enza River.

Calcium. The average concentration of Ca^{2+} in the 12 wells is 129 mg/l; lower values have been

Tab. 2 - *Physical-chemical parameters measured in the field.*
- Parametri fisico-chimici misurati sul campo.

Well code	**pH**	**°C**	**s.e.c. (i S/cm(c))**	**s.e.c. (i S/cm)**
CAV001	6,9	14,2	991	789
CAV002	7,2	14,4	1106	957
CAV004	6,8	14,3	784	627
CAV006	6,8	15,6	750	615
CAV008	7,1	14,5	760	625
CAV009	7,1	14,1	860	683
CAV010	7	13,6	777	616
CAV011	7	14,5	922	738
CAV012	7,1	14	805	636
CAV013	6,9	15,2	817	665
CAV014	6,9	19,6	795	712
CAV016	7,1	15,7	1055	869
CAV017	7,1	15,4	827	676
CAV020	6,8	15,3	887	722
CAV022	7	14,3	679	540
CAV024	7	14,6	1054	846
CAV025	6,9	14,8	1011	818
CAV029	6,8	15,9	903	747
CAV037	6,8	14	878	695
CAV038	7	15,6	827	678
CAV042	6,9	14,3	838	667
CAV043	7	14,1	789	625
CAV044	6,8	14,1	742	587
CAV045	6,7	15,5	863	704
CAV046	6,8	14,4	749	598
CAV047	7	13,8	637	501
CAV048	7,1	15,6	820	674
CAV052	6,8	15,1	898	729
CAV053	6,8	14	790	624
CAV056	7,5	14,7	489	393
CAV058	6,7	15,9	909	753
CAV059	6,8	14,4	867	692
CAV060	7	14,6	835	669
CAV061	6,8	21,1	860	797
CAV062	7,1	20,8	825	760
CAV063	6,9	14,4	840	672
CAV064	7,2	17,9	688	595
CAV065	7,5	14,5	644	515
CAV066	7,4	13,2	774	601

recorded in correspondence with the zone fed by the Enza River (fig. 13) where the CAV056 well is characterized by the minimum values of 66 mg/l. Higher concentrations have been recorded in the eastern portion of the study area.

Bicarbonate. The distribution of HCO_3^- is similar to that of the calcium ion. The lowest values of 189 mg/l has been recorded in the CAV056 well (fig. 14). The average bicarbonate concentration is 407 mg/l and the maximum is 490 mg/l. The relatively high concentration of Bicarbonates is mainly due to dissolution of calcareous rocks by meteoric waters.

Chloride. Chloride, whose mean concentration is 29 mg/l, reaches its maximum value in the CAV001 well (90 mg/l) between Cavriago and Corte Tegge (fig. 15); from here concentrations diminish radially suggesting that this value could represent an anomaly due to local pollution.

Sulphate. Sulphate (fig. 16) is present with concentration below 50 mg/l. According to ANNOVI & SIMONI (1993) they partly derive from superficial waters washing the rocks in the hydrographic basins upstream of the study area.

Sodium. The trend of Na^+, whose mean value is 18 mg/l, is similar to that of Chlorides. Its low concentration (fig. 17) is coherent with the Ca-bicarbonate nature of the examined waters. The Potassium ion, having extremely low concentrations (1-3 mg/l), has been ignored.

In general, the results of the chemical analyses do not show significant differences in the chemistry of the sampled waters as compared with previous data by AUTORI VARI (1978) and CANEDOLI *et alii* (1994). Specifically, the increase in Nitrate, from 30 to 46 m/l, is recorded in the centre of the study area near the *Via Emilia* road.

9. - ISOTOPIC MONITORING

9.1. - $\delta^{18}O$ AND δD

In June 2002 the first sampling campaign was performed on 20 wells (tab. 4); the isotopic data on $\delta^{18}O$ and δD vary from –7.6 to –9.0 for $\delta^{18}O$‰ and between –51.2 and –61.1 for δD‰ (fig. 18). The ratios $\delta^{18}O/\delta D$ of the 20 samples, line $\delta D‰ = 7.2\delta^{18}O‰ + 4.3$, show a good correlation with the Local Meteoric Water Line $\delta D‰ = 7.7\delta^{18}O‰ + 9.4$ calculated by LONGINELLI & SELMO (2003).

In the Emilian plain $\delta^{18}O$ values of about –7.6 were recorded in the precipitation (LONGINELLI & SELMO, 2003), and seasonal variations in the precipitation comparable to -3,2 $\delta^{18}O$ found by CARLIN *et alii* (1975), in the waters of the Reno River were also observed (DADOMO & MARTINELLI, 2004). The altitude can generate depleted local precipitations in $\delta^{18}O$ equal to about – 8.5 at ca 1.000 m and about –9.5 at ca 2.000 m altitude. From the data obtained it can be hypothesized for the area characterized by more negative values of $\delta^{18}O$ (-8,9) a supply by Apennine meteoric waters, precipitated probably at the altitude of about 500-1000 m.

Well Code	Ground Level	Depth	Feb-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02	Oct-02	Nov-02	Jan-03	Feb-03	Mar-03	Apr-03	May-03	Jun-03	Jul-03	Aug-03	Sep-03	Oct-03
CAV001	55,00	80,00	-25,00	-25,50	-25,70	-27,70	-27,45	-25,50	-24,50	-24,30	-23,15	-22,37	-21,54	-21,37	-21,20	-23,80	-28,90	-29,45	-29,63	-29,40
CAV002	68,00	54,00	-33,50	/	-33,90	-35,97	-36,96	-34,90	-33,60	-33,30	-31,96	-31,15	-30,07	-29,74	-29,20	-32,92	-38,62	-38,81	-39,29	-38,98
CAV006	48,00	70,00	-14,60	-14,75	-15,05	-15,70	-16,30	-15,35	-14,76	-14,65	-13,36	-12,98	-12,50	-12,13	-11,90	-15,99	-18,30	-18,60	-18,83	-18,70
CAV007	62,50	79,00	-22,70	-22,90	-23,20	-24,00	-29,39	-25,90	-22,14	-22,15	-22,63	-21,93	-20,04	-19,86	-19,54	-25,87	-32,28	/	/	/
CAV011	63,50	55,00	-32,80	-32,10	-32,55	-33,10	-33,39	-31,90	-32,28	-32,10	-30,07	-29,87	-29,60	-29,35	-28,67	-31,75	-34,90	-35,63	-36,73	-36,59
CAV012	63,30	64,00	-34,80	-34,50	-34,40	-35,35	-35,60	-34,00	-33,87	-33,86	-31,10	-31,23	-31,40	-30,75	-29,77	-32,27	-36,04	-36,71	-37,57	-37,27

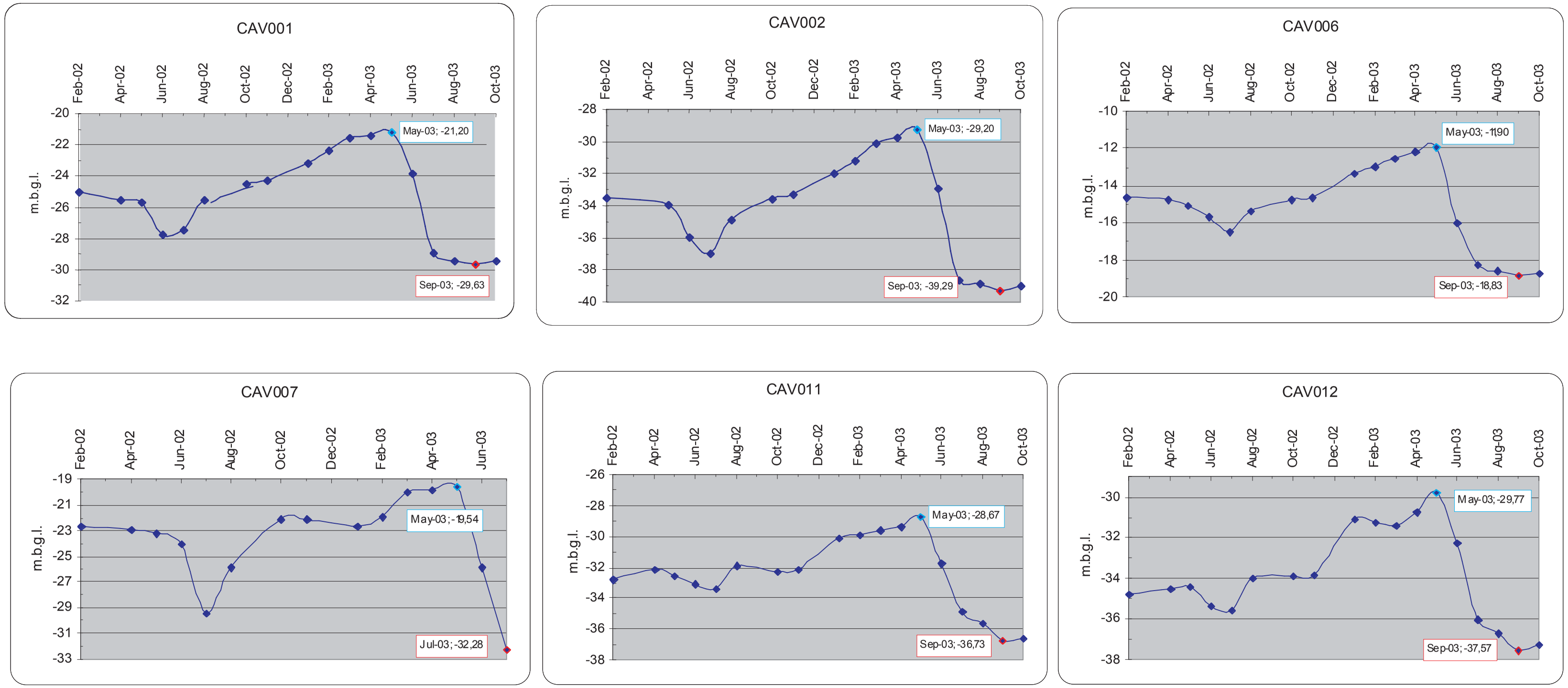

Fig. 8 - Piezometric data (period February 2002-October 2003) and related graphs.
- *Tabella delle misure piezometriche mensili e relativi grafici della soggiacenza.*

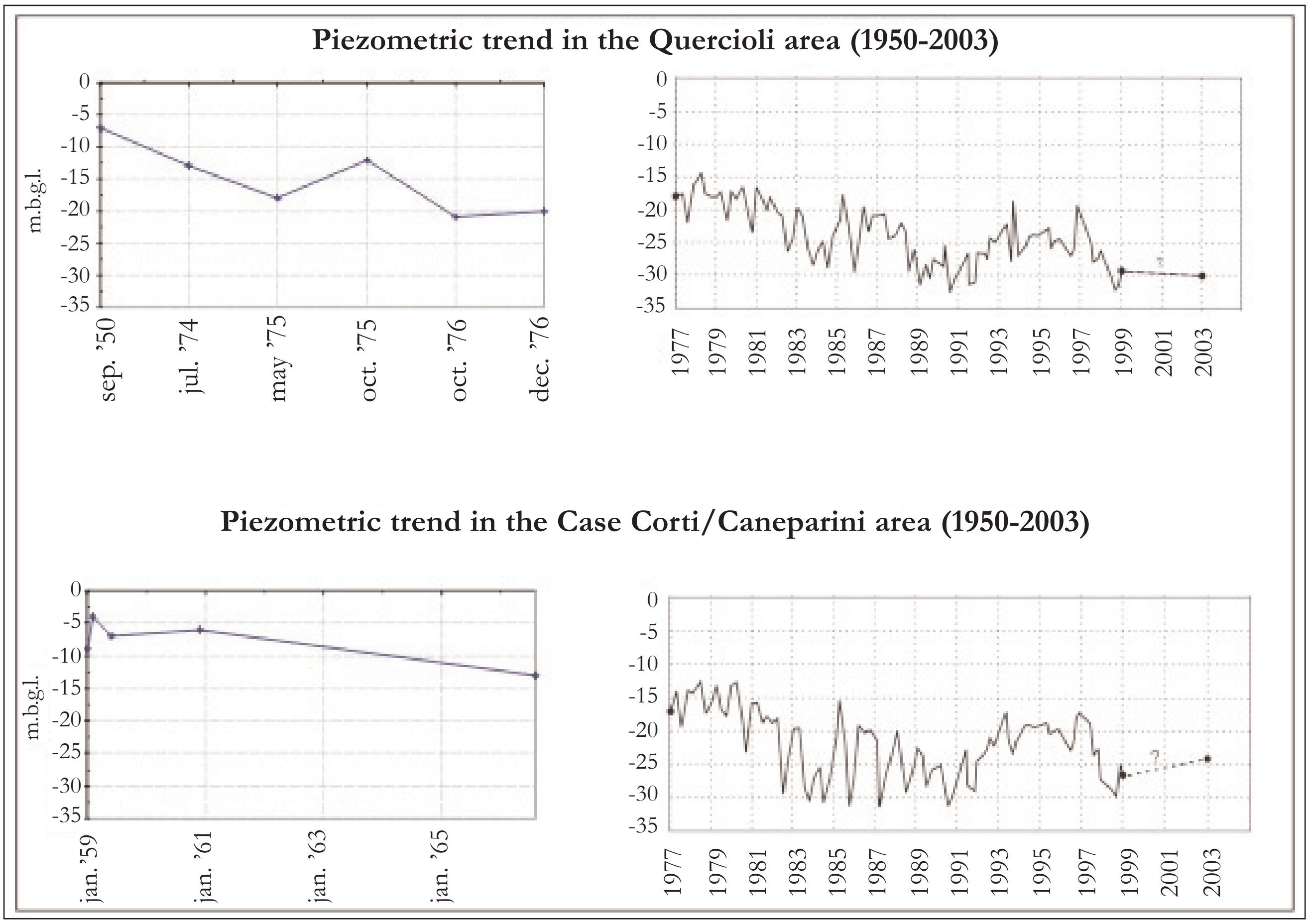

Fig. 9 - Piezometric trend in the Quercioli area (period 1950-2003) and in the Case Corti/Caneparini area (period 1959-2003). Courtesy of AGAC-ARPA. Locations in figure 2.
- *Andamento piezometrico nel periodo 1950-2003 nell'area di Quercioli e nel periodo 1959-2003 nell'area di Case Corti/Caneparini. Dati AGAC-ARPA. Ubicazioni in figura 2 .*

The isovalue maps of $\delta^{18}O$ and δD in the study area show two zones characterized by significantly different groundwater flow dynamics; the area close to the Enza River is characterized by minimum relative values of –7.6 $\delta^{18}O$ and of –51.5 δD, while the southeastern portion of the study area is characterized by maximum relative values of –9.0 $\delta^{18}O$ and –61.1 δD.

In March and June 2003 two further samplings were performed on a smaller number of wells;

Tab. 3 - *Analytical data of sampled ground water (mg/l).* - Analisi chimico-fisiche espresse in mg/l.

Well code	pH	°C	c.e.s.	Calcium	Magnesium	Potassium	Sodium	Bicarbonate	Nitrate	Sulphate	Chloride
CAV001	6,9	14,2	991	151	12,9	1,6	29,5	400	15,2	29,7	90,6
CAV006	6,8	15,6	750	129	13,3	1,3	13,4	420	17,1	28	13,9
CAV012	7,1	14	805	137	14,9	1,1	18,7	425	25,3	37,3	22,4
CAV017	7,1	15,4	827	134	18,8	2,1	17,3	490	17,6	35,2	20,1
CAV029	6,8	15,9	903	136	22,4	1,4	20,8	430	31,4	47,8	31,7
CAV038	7	15,6	827	133	21,1	1,2	12,7	440	30,2	34,3	16,7
CAV045	6,7	15,5	863	140	17,2	1,8	18,6	430	39,9	37,6	22,8
CAV047	7	13,8	637	97,8	15,3	1,4	14,7	325	16,1	13,2	32,5
CAV052	6,8	15,1	898	143	21,7	2,8	17,1	460	45,7	39,9	21,6
CAV056	7,5	14,7	489	66,1	11,3	1,6	15,8	189	10,6	2,7	37,5
CAV060	7	14,6	835	142	15,8	1,3	16,3	445	24,2	43,3	17,2
CAV063	6,9	14,4	840	140	13,5	2,4	21,5	435	25	38,3	29,5

table 5 shows that the data obtained in these campaigns are practically identical to the ones of June 2002. The arithmetic mean of the δ^{18}O values of each of the three samplings campaign results -8.37, -8.38 and -8.33, respectively. Also in the study of CHAHOUD *et alii* (2002) the wells sampled inside the Municipality of Cavriago did not show any significant variations in the value of

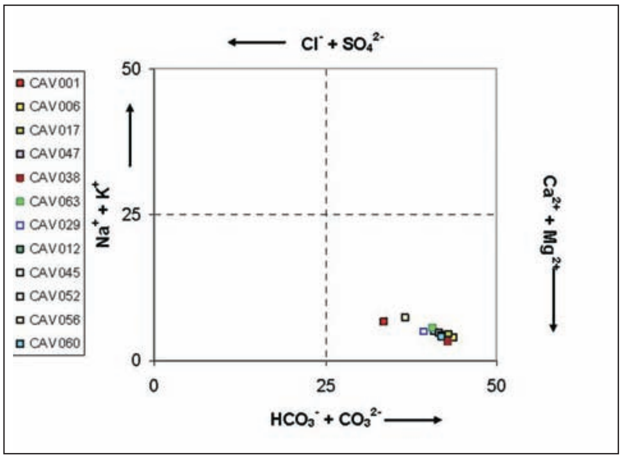

Fig. 10 - Langelier-Ludwig diagram of sampled ground waters.
- *Classificazione delle acque campionate tramite il diagramma di Langelier-Ludwig.*

Tab. 4 - *δ^{18}O, δD and Tritium in sampled ground water (June 2002).*
- Analisi isotopiche δ^{18}O, δD e Tritio (TU) del Giugno 2002.

Well code	^{18}O	D	Tritium
CAV001	-8,9	-59,6	6,4
CAV002	-8,9	-61,1	
CAV006	-8,7	-57,2	12,2
CAV012	-8,2	-52,8	6,2
CAV016	-8,7	-59,1	
CAV017	-9	-58,4	4,7
CAV029	-8,5	-57,5	9,7
CAV038	-8,5	-57	14,5
CAV042	-8,3	-55,5	
CAV045	-8,1	-52,6	6,3
CAV047	-8,6	-58,8	11
CAV048	-8,5	-55,7	
CAV052	-8,1	-53	7,1
CAV056	-7,8	-52,3	6,4
CAV058	-8,6	-57,9	
CAV060	-8,3	-55	7,5
CAV063	-8,5	-56,9	7
CAV064	-7,6	-51,2	
CAV065	-7,9	-51,6	
CAV066	-8,1	-53,7	

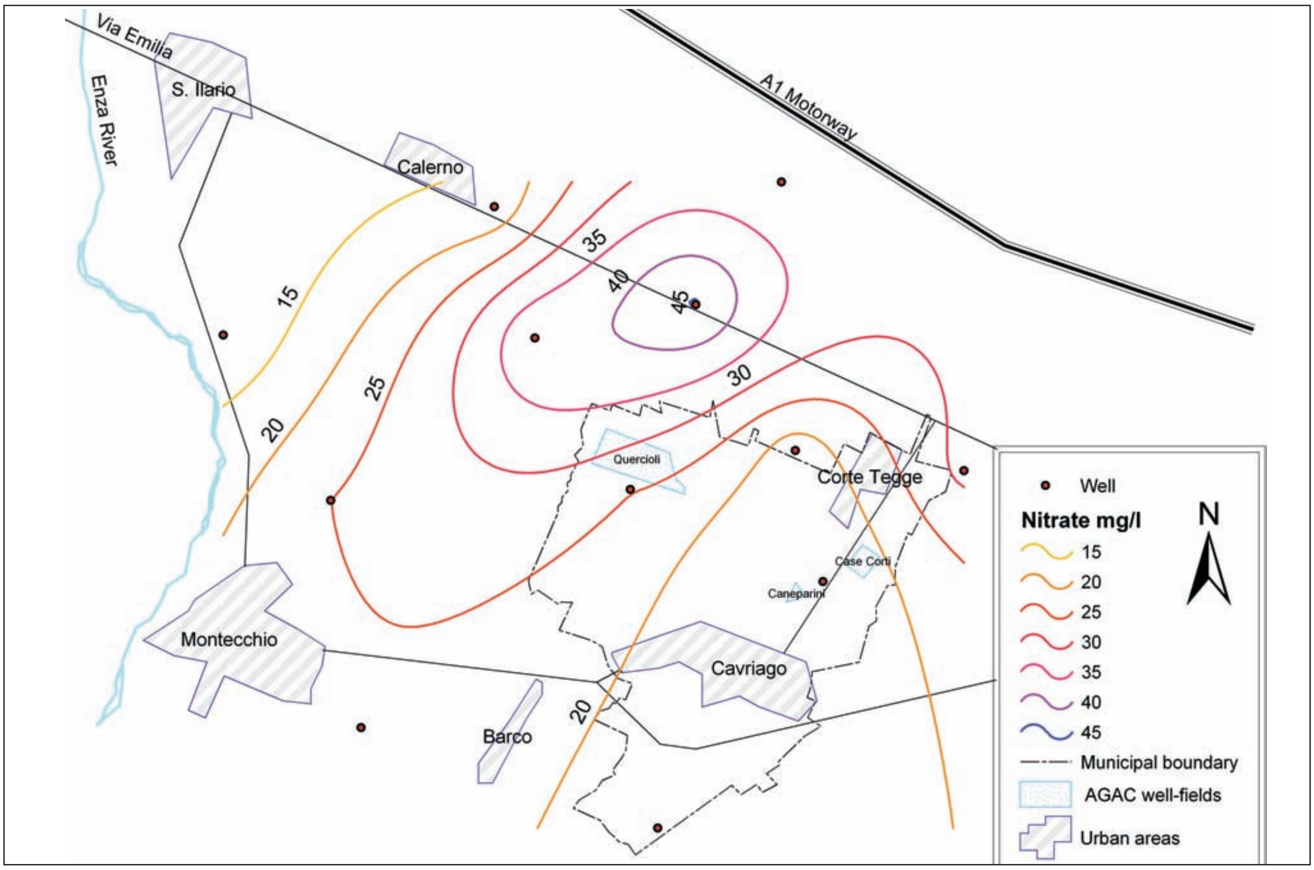

Fig. 11 - Nitrate concentration in ground water of the study area in June 2002.- *Isocone (mg/l) dei Nitrati nelle acque sotterranee dell'area di studio (Giugno 2002).*

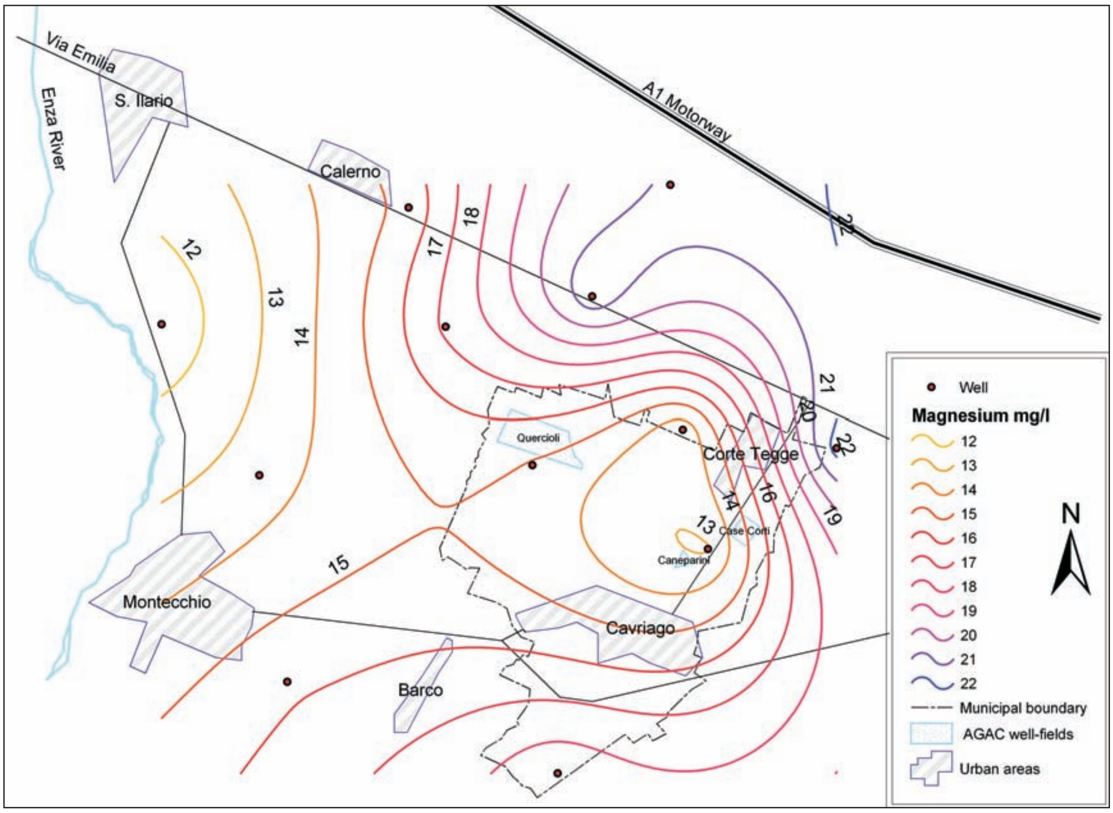

Fig. 12 - Magnesium concentration in ground water of the study area in June 2002.
- Isocone (mg/l) dello ione Magnesio nelle acque sotterranee dell'area di studio (Giugno 2002).

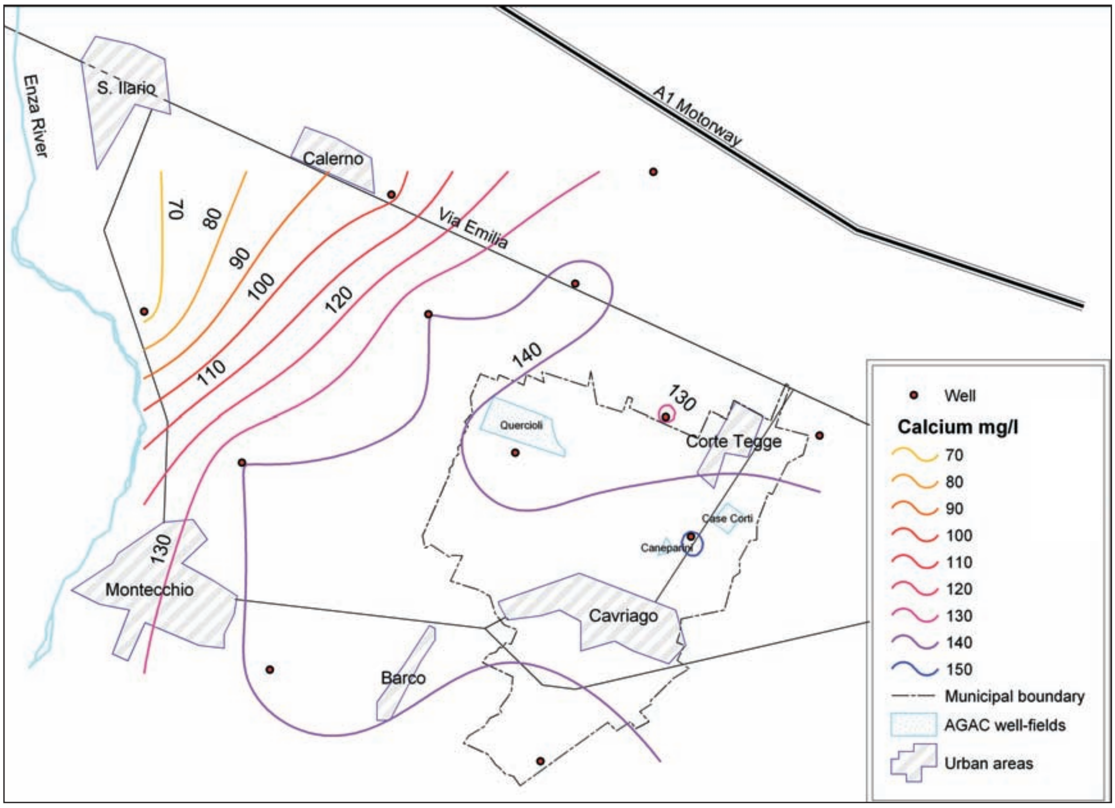

Fig. 13 - Calcium concentration in ground water of the study area in June 2002.
- Isocone (mg/l) dello ione Calcio nelle acque sotterranee dell'area di studio (Giugno 2002).

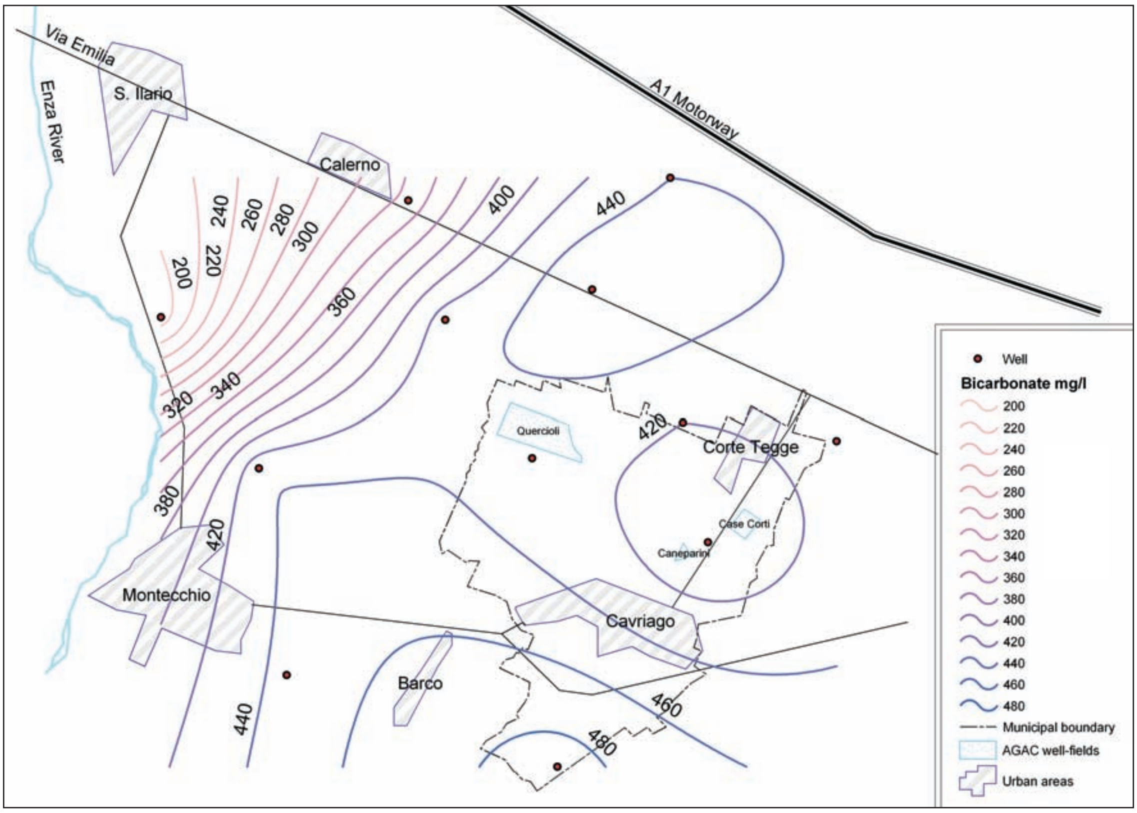

Fig. 14 - Bicarbonate concentration in ground water of the study area in June 2002.
- Isocone (mg/l) dello ione Bicarbonato nelle acque sotterranee dell'area di studio (Giugno 2002).

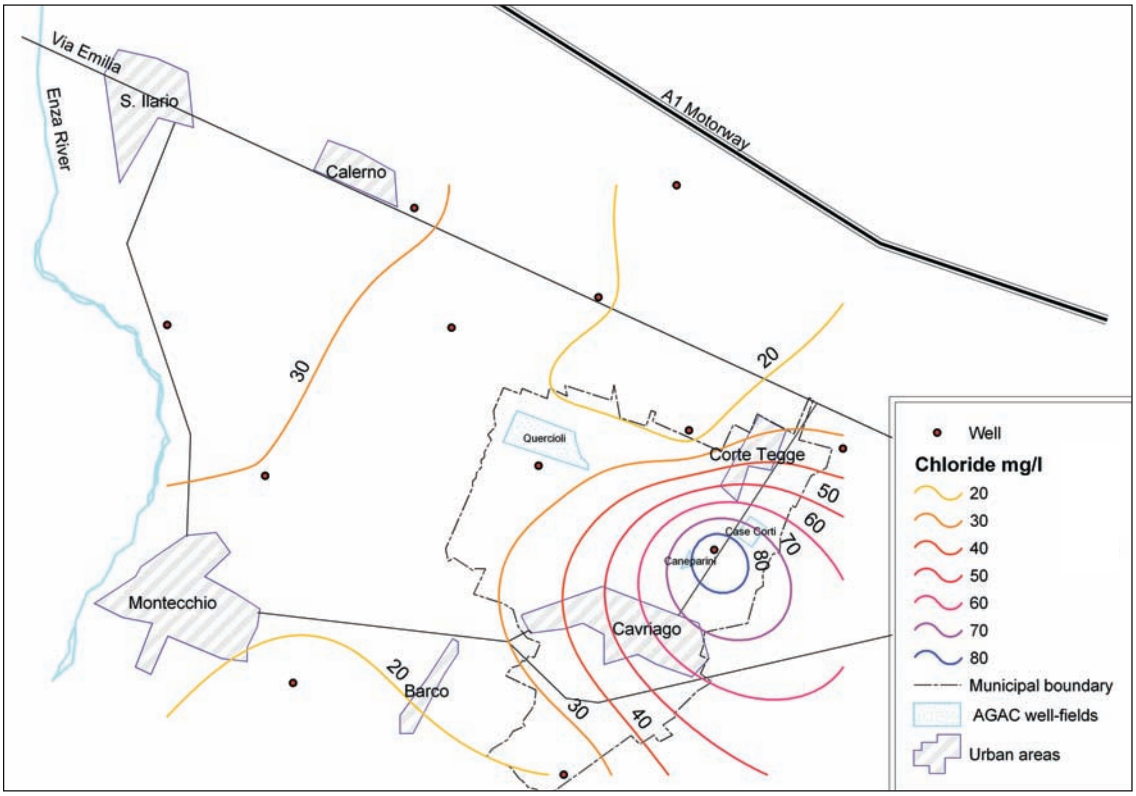

Fig. 15 - Chloride concentration in ground water of the study area in June 2002.
- Isocone (mg/l) dello ione Cloro nelle acque sotterranee dell'area di studio (Giugno 2002).

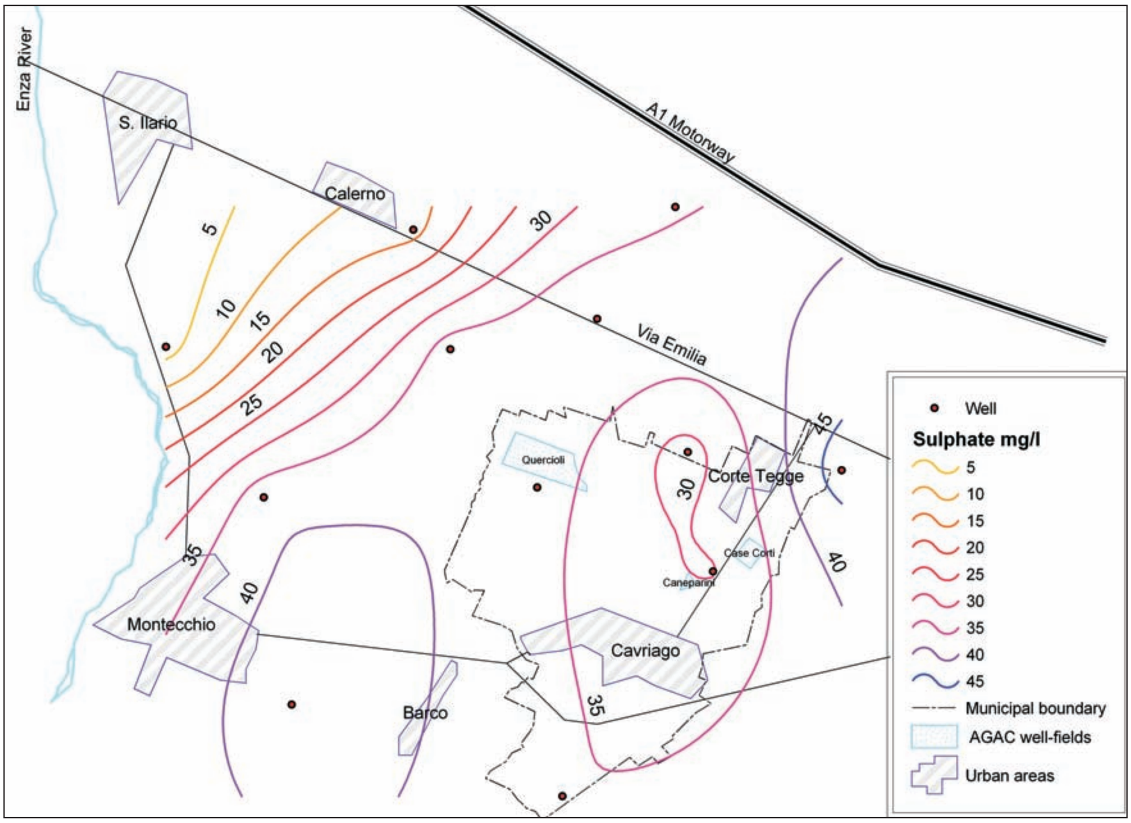

Fig. 16 - Sulphate concentration in ground water of the study area in June 2002.
- Isocone (mg/l) dello ione Solfato nelle acque sotterranee dell'area di studio (Giugno 2002).

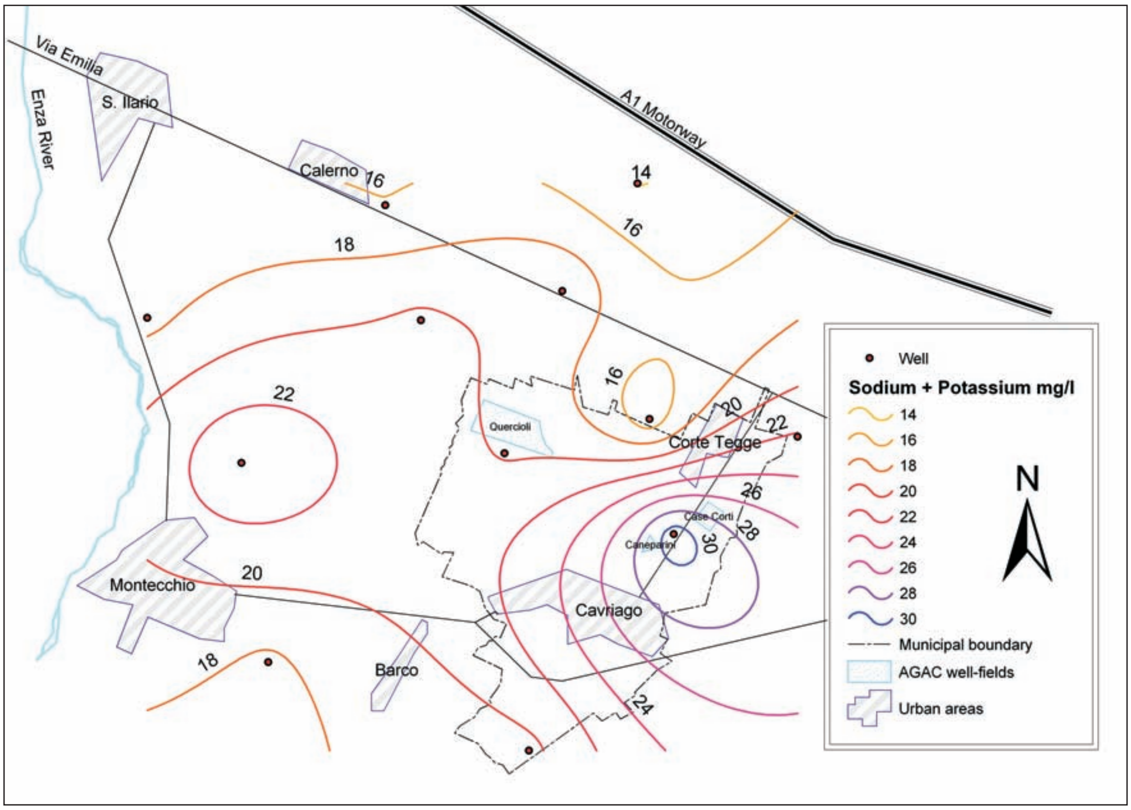

Fig. 17 - Sodium and potassium concentration in ground water of the study area in June 2002.
- Isocone (mg/l) dello ione Sodio nelle acque sotterranee dell'area di studio (Giugno, 2002).

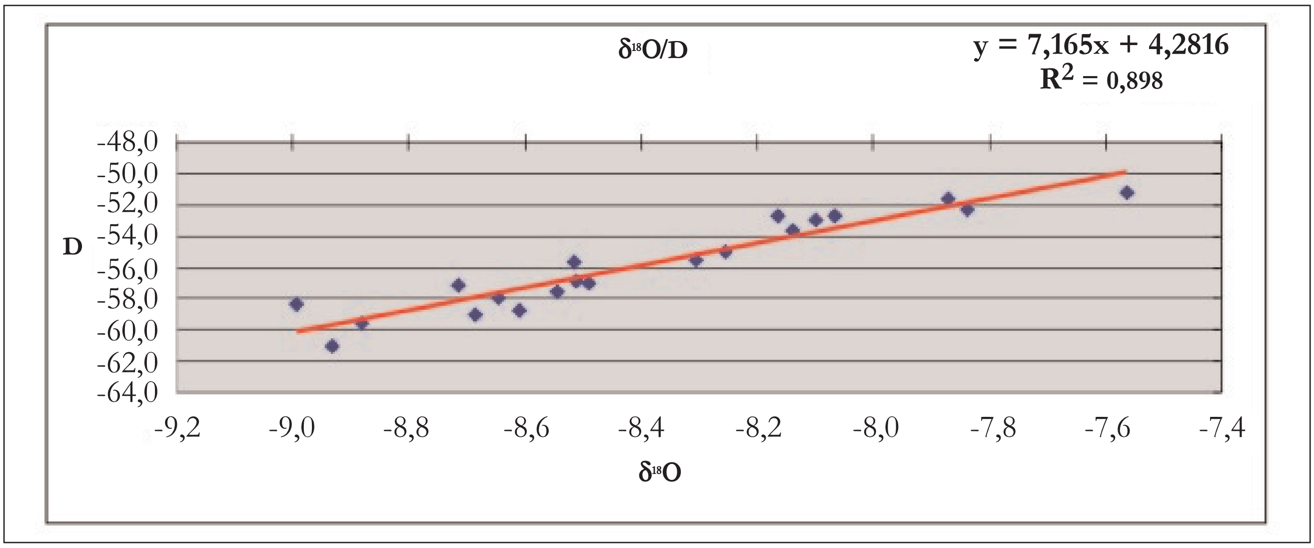

Fig. 18 - $\delta^{18}O/\delta D$ correlation of sampled ground waters.
- *Retta di correlazione $\delta^{18}O/\delta D$ ottenuta con i dati dei 20 campioni analizzati.*

$\delta^{18}O$ between the first (June 2001) and the second (March 2002) samplings.

The reasons for not detecting the $^{18}O/^{16}O$ expected (winter-summer) seasonal variations equal to about –3.2 $\delta^{18}O$ are probably due to: 1) the relatively high amount of water stored in sediments compared to the volume of the recharge, 2) the mixing of waters favoured by the relative abundance of coarse sediments and 3) the aquifer homogenisation induced by intense withdrawals.

CHAHOUD *et alii* (2002), assign to the recharge phenomena of local waters the values of $\delta^{18}O$ ranging between -7 and -8.5 and to the recharge of Apenninic waters the values of $\delta^{18}O$ ranging between -8.5 and -9.5. These workers identified significant variations in the isotopes of Oxygen and Hydrogen, between one sampling and the other, mainly in Tritium-bearing aquifers with relatively high groundwater circulation velocities; these variations represent the seasonal signal of the aquifer recharge and are generally detected in the intermediate portion of the alluvial fan. The values of $\delta^{18}O$ and δD that do not show significant variations between the two subsequent samplings are typical of confined or semi-confined aquifers, usually located in the middle and lower alluvial plain; their recharge is extremely slow or absent and therefore shows Tritium values equal or close to 0.

9.2. - TRITIUM

In the samples collected June 2002 Tritium values range between 4.7 and 14.5 T.U., with a minimum of about 5 T.U., in the areas close to the Enza River and the town of Cavriago and the maximum north of the *Via Emilia* Road (fig. 19). These values are in good agreement with the precipitation of the Genova rain gauge (IAEA-WMO, 2004). Also the Tritium data of CHAHOUD *et alii* (2002), relating to two wells (RE 01 and RE 02) inside the study area are in agreement with the ones here obtained. The relatively high values of Tritium here presented are typical of waters of recent meteoric infiltrations and characteristic of alluvial fan areas with a high rate of hydrologic renewal.

Previous studies by CALESTANI *et alii* (1999), in the comparable hydrogeological conditions of Collecchio area, south of Parma, showed values of

Tab. 5 - *Oxygen 18/16 data in ground water of the study area; no significant difference is shown in the period 2002-2003.*
- Comparazione dei risultati dei campionamenti di $\delta^{18}O$; non si apprezzano differenze significative nel periodo 2002-2003.

Well code	$\delta^{18}O$ June 2002	$\delta^{18}O$ March 2003	$\delta^{18}O$ June 2003	Difference June 2002/Mach 2003
Cav 1	-8,88	-8,93	-8,88	0,05
Cav 6	-8,72	-8,72	-8,75	0
Cav 29	-8,54	-8,56	-8,56	0,02
Cav 38	-8,49	-8,51	-8,48	0,02
Cav 45	-8,06	-8,04	-8,02	-0,02
Cav 52	-8,1	-8,08	-8,06	0,07
Cav 56	-7,84	-7,88	-7,83	0,04
Cav 60	-8,25	-8,22	-8,17	-0,03
Cav 63	-8,51	-8,51	-8,29	0

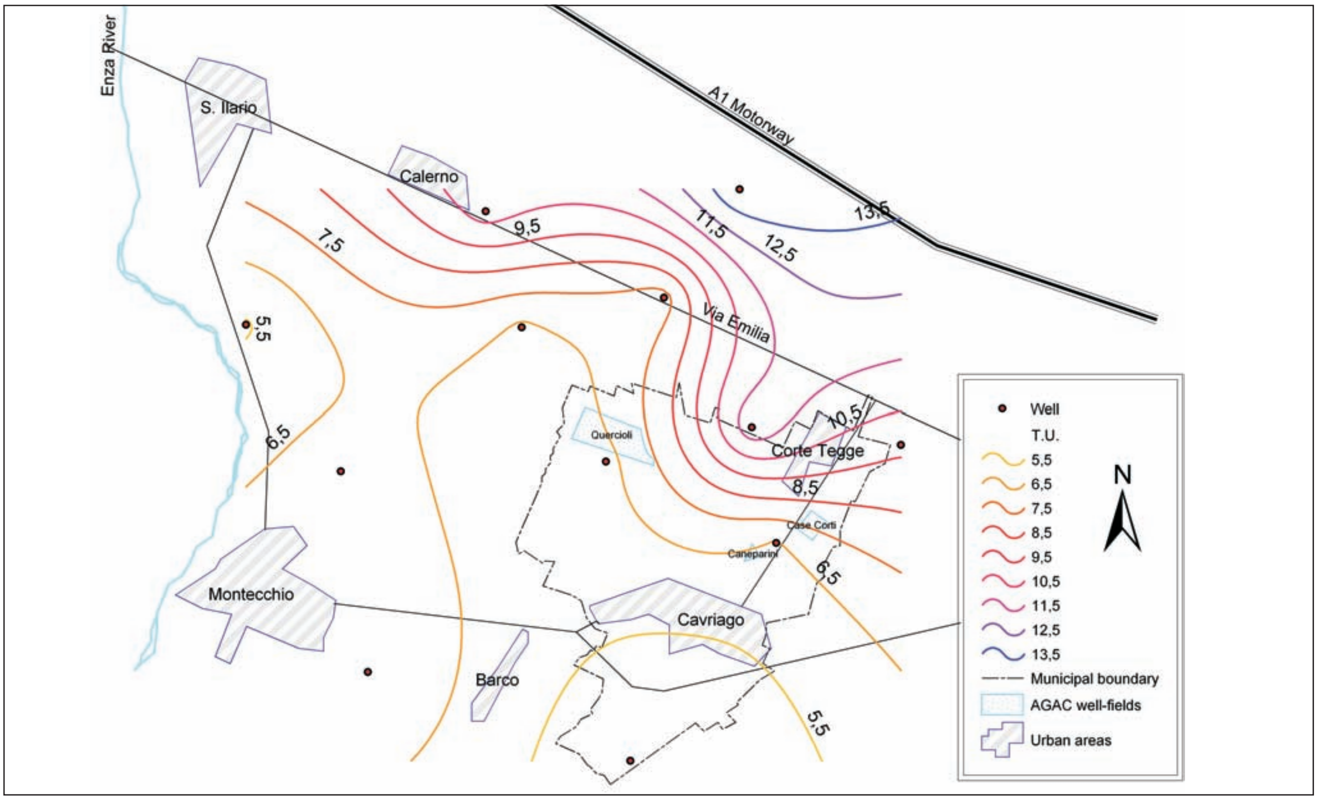

Fig. 19 - Tritium map of sampled ground water in the study area in June 2002.
- Isocone delle Unità Tritio nel mese di Giugno 2002.

Tritium of about 16 T.U. PELLEGRINI *et alii* (1998), have measured values ranging between 5.2 and 14 T.U. in the waters of the unconfined aquifer of the plain north of Parma and values close to 0 for the underlying confined aquifer. VICARI & ZUPPI (1990), in a isotopic hydrology study of the alluvial plain around Modena, identified at a depth of 70-100 m waters of Apenninic origin characterized by a low Tritium content in a $^{18}O/^{16}O$ ratio ranging between about -8.5 and -9. Such waters differ from those of local origin characterized by values of Tritium of about 10 T.U. and values in the $^{18}O/^{16}O$ ratio ranging between -7 and -8 (LONGINELLI & SELMO, 2003). VICARI & ZUPPI (1990) estimated a residence time of 25-50 years for the waters of the Secchia River alluvial fan.

The sampling of June 2002 was followed by two samplings in March and October 2003 (tab. 6), which involved a smaller number of wells located in the areas subjected to high piezometric lowering, including two wells (Que 9 and Que 10) of the Quercioli well-field. The results were compared with previous samplings, amongst which the March 2002 sampling by CHAHOUD *et alii* (2002), on the same wells; the variation in the Tritium values in all these different samplings is not significant (tab. 6) and such values indicate water ages ranging between 2 and 10 years.

10. - THE ENZA RIVER ALLUVIAL FAN RESERVOIR

The alluvial fan aquifer system is characterized by a superficial aquifer, strongly impoverished, playing the role of a seasonal water reservoir, and a deep aquifer, i.e. the lower part of Aquifer Group A in figures 3, 4, characterized by a recharge time of more than one year. Owing to the intense withdrawals this deep aquifer is slowly becoming impoverished as demonstrated by the trend of the piezometric levels in the past 50 years.

The alluvial fan system is characterized by the anisotropy of its sedimentary units and the non-homogeneity of its porous bodies and tends to homogenize different waters with the consequence that the flow of water inside it can only be described by a pure mixing model (e.g. KENDALL & MCDONNELL, 1998).

The intense water exploitation in the study area is accompanied by the phenomena of subsidence; in the close-by areas of figure 20 subsidence is correlated to piezometric variations. It is well known that subsidence is particularly effective when the hydrological system is characterized by confined aquifers. Such a condition is fully expressed in the aquifers B and C whereas, from the isotopic standpoint, aquifer

Tab. 6 - *Tritium concentration (TU) measured in ground water of the study area in the period March 2002-October 2003; no significant variation is shown in the period 2002-2003.*
- Sintesi dei valori del Tritio (TU) rilevato nelle acque dei pozzi dell'area studiata; non si notano differenze significative nel periodo 2002-2003.

Well code	**March 2002** **Chahoud** ***et alii, (2002)***	**June 2002**	**March 2003**	**October 2003**
Cav 1		6,4 ± 1,1	8,2 ± 0,9	6,8 ± 1,0
Cav 6		12,2 ± 1,1	12,3 ± 1	11,5 ± 1,5
Cav 38		14,5 ± 1,5	12,3 ± 1,4	14,5 ± 1,6
Cav 45		6,3 ± 1,1	8,1 ± 1,2	7,3 ± 1,1
Que 9	8,6 ± 1,0		9,2 ± 1,4	7,2 ± 1,2
Que 10	8,1 ± 1,2		8,5 ± 0,9	7 ± 1,0

A appears to be characterized by conditions of prevalent semi-confinement or non-confinement. Prolonged pumping of the confined aquifers of Groups B and C, constituted by large volumes of porous sediments, causes a progressive reduction in the internal interstitial pressures with dramatic subsidence rates (RER-ARPA, 2001; Carminati & Martinelli, 2002).

10.1. - Water volumes stored in the alluvial fan

For a preliminary estimate of the water stored in the subsurface the knowledge of some characteristics of the considered aquifer is needed. These are: the geometry of the saturated aquifer (area, thickness) and the Effective Porosity (n_e). The Water Volume stored in the aquifer (W) is:

$W=V*n_e$

where V= Volume of the saturated reservoir.

In the Enza River alluvial fan waters are stored in three Aquifer Groups named A, B and C (RER & ENI-AGIP, 1998). The "useful or main aquifer", that is the most exploited aquifer intercepted by almost all the wells drilled for domestic, industrial and irrigation purposes can be solely traced back to the Aquifers of the A and partly to the B Group (fig. 3, 4). In particular, the A Group is the only one presenting direct hydraulic contacts with surface waters that can infiltrate from the outcrop areas in the Apennines front and the Enza River bed seepage. On the contrary the B and C Groups (RER & ENI-AGIP, 1998) do not present hydraulic connections with the surface water courses and their recharge is mainly due to the drainage phenomena through semi-confining strata.

The indicative estimate of the underground water storage has been performed over an area, triangular in shape, corresponding to the whole alluvial fan of the Enza River with its apex at San Polo d'Enza and its front near the A1 motorway, where natural springs can be found, for a total area of about $131*10^6$ m^2 (fig. 1, 6).

Using the range of thickness of the porous sediments deduced from the isopay maps of the Aquifer Groups A, B and C (RER & ENI-AGIP, 1998) it was possible to calculate volume of the porous-permeable sediments for each Aquifer Group considered. By multiplying the volumes found for an average Effective Porosity (n_e) of 20%, for the A Group, and of 16%, for the B and C Groups (RER & ENI-AGIP, 1998) the volume of water stored in each of the three Aquifer Groups was determined, and from their sum, equal to $2123.2*10^6$ m^3 ±20%, the total volume of water stored in the Enza alluvial fan body was calculated (tab. 7).

11. - EXHAUSTION TIME OF THE WATER RESERVOIR

After calculating the volume of the water reservoir, knowing the water input (recharge by infiltration, seepage from the river bed, etc.) and output (withdrawals for domestic, industrial, irrigation and other uses), an estimate of the exhaustion time of the water reservoir can be done.

The inputs to the aquifer system can be traced back to:

1) recharge by infiltration, estimated by the Regione Emilia-Romagna equal to 200 mm/year (22% of total rainfall) by means of the CRITERIA model (Marletto *et alii*, 1993); this would correspond to a volume of $26.2*10^6$ m^3/year for the whole study area;

2) Recharge by the Enza River bed seepage (stretch S.Polo-S.Ilario), estimated by several researchers, e.g. Autori Vari (1978), Pellegrini & Zavatti (1980), RER-ARPA (2003), to be in the range 0.3-0.5 m^3/s, corresponding to $15.7*10^6$ m^3/year;

3) Recharge by irrigation waters (Celico, 1986), estimated equal to $3.5*10^6$ m^3/year, 15% of the groundwater withdrawal for irrigation.

The sum of the inflows, totalling $45.4*10^6$ m^3/year, must be subtracted by the outflows due to total withdrawals, corresponding to about $60*10^6$ m^3/year (RER-ARPA, 2003). Hence, the water balance of the Enza alluvial fan aquifer system presents a $14.6*10^6$ m^3/year deficit (tab. 8).

The exhaustion time of the water volume stored in the Enza alluvial fan can be estimated

Tab. 7 - *Calculation of the volume of water of the Enza River alluvial fan reservoir. Reference data after* RER & *ENI-AGIP (1998).*
- Calcolo del volume d'acqua contenuto nella conoide alluvionale del torrente Enza. Cartografie di riferimento da RER & ENI-AGIP (1998).

Aquifer Group	**Porous-permeable sediment (m^3)**	**Effective porosity (n_e)**	**Stored water (m^3)**
Group A	$4835 * 10^6$	20%	$967 * 10^6$
Group B	$2604 * 10^6$	16%	$416.6 * 10^6$
Group C	$4623 * 10^6$	16%	$739.6 * 10^6$
Groups A+B+C	$12062.7 * 10^6$	17.6%	$2123.2 * 10^6$

Tab. 8 - *Calculation of the exhaustion time of the Enza River alluvial fan water reservoir.*
- Calcolo del tempo di esaurimento del volume d'acqua contenuto nella conoide alluvionale del torrente Enza.

Recharge by infiltration (m^3/y)	$26.2 * 10^6$
Recharge by the Enza river bed seepage (m^3/y)	$15.7 * 10^6$
Recharge by irrigation (m^3/y)	$3.5 * 10^6$
Whithdrawals (m^3/y)	$60 * 10^6$
Water balance (m^3/y)	$-14.6 * 10^6$
Exhaustion time of Aquifer A (y)	66
Exhaustion time of the whole Aquifers (A+B+C) (y)	145

equal to 145 years considering the published values for the thicknesses of the porous media and the effective porosity (tab. 8). The aquifers of the Enza River alluvial fan have been subjected to intensive exploitation since the 1970s (fig. 20). It is thus possible to imagine that in consideration of the estimated time of exhaustion of the aquifer such intensive exploitation will be interrupted within a few decades.

12. - CONCLUSION

The results of this research can be summarized as follows.

1. Water average residence time in the upper part of Aquifer Group A is about 2-10 years while more prolonged residence times are estimated for the underlying aquifers.
2. Intense water withdrawal induced ongoing significant land subsidence.
3. Based on present withdrawals, the estimated exhaustion time of the alluvial fan aquifer system is 145 years, a figure consistent with the strong piezometric lowering measured locally.
4. To avoid exhaustion, the intense withdrawals initiated after 1974 should be interrupted within a few decades.

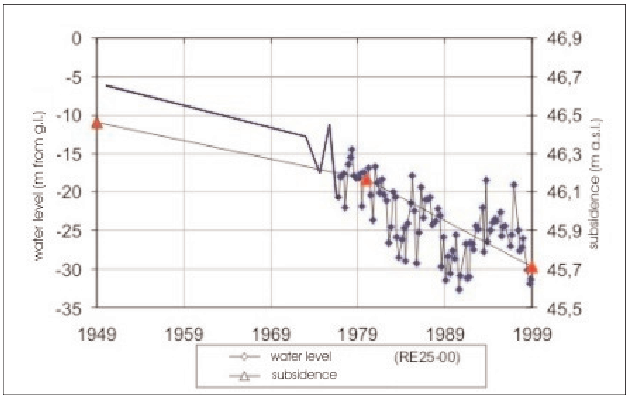

Fig. 20 - Piezometric level and land subsidence in the period 1949-1999 in the Pieve Modolena benchmark site located close to the study area. Courtesy of IGM and ARPA.
- *Confronto tra l'andamento della soggiacenza (periodo 1950-1999) e la subsidenza (periodo 1949-1999) presso il caposaldo Pieve Modolena prossimo all'area di studio. Dati IGM e ARPA.*

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