Hydrogeological map of the Monti Picentini Regional Park (southern Italy) at 1: 50,000 scale

A. Corniello[1], D. Ducci[1] and A. Aquino[2]

[1] Dipartimento di Ingegneria Idraulica, Geotecnica ed Ambientale, Napoli, Italy
[2] Engineering consultant

(Received: December 12, 2009; accepted: July 07, 2010)

ABSTRACT Calcareous and calcareous-dolomitic reliefs form the backbone of the Monti Picentini Regional Park. A possible subdivision of the groundwater bodies of the area into hydrogeological basins was proposed: for each basin the stratigraphy and structure as well as the scheme of groundwater circulation were drawn up. Many basins fall only partly within the park and most of their groundwater often ends up outside the area in question; the Terminio-Tuoro mountains, for example, feed large springs (Cassano Irpino group, Serino springs, etc.) that are all outside the park boundaries. Using integrated hydrogeological data analysis, we defined the main aspects of aquifer vulnerability to pollution and identified the factors that may locally increase the risk of resource contamination. Finally, the effective recharge of the various groundwater bodies was evaluated.

1. Introduction

The aim of this paper is to define the current hydrogeological knowledge for the area of the Monti Picentini Regional Park; it contains a synthesis of several studies carried out in this area (see references).

Calcareous and calcareous-dolomitic reliefs form the backbone of the Monti Picentini Regional Park. The presence of the karst network influences the groundwater flow, feeding large springs; the poljes, such as Piana del Dragone and Laceno, often carry surface waters into groundwater bodies, causing contamination problems (Celico *et al*., 1982, 1994; Aquino *et al*., 2006; Aquino and Aquino, 2007).

Data and information from the above cited studies were improved by our original research and unpublished field experience. Considerable effort was expended in situ both to verify certain situations of particular interest and to census all the more significant springs and boreholes falling within the park's domain.

On the basis of this information more products have been drawn up:

1. the hydrogeological map of the park at a scale of 1/50,000 (Plate 1) ;
2. the intrinsic aquifer vulnerability map of the park at a scale of 1:100,000 (left-hand side of Plate 1);
3. illustrative notes, represented by this paper, that summarize the knowledge about groundwater resources for each groundwater body (as required by Directive 2000/60/EC and as recognized in SOGESID, 2005) and their proposed subdivision into hydrogeological basins;

4. the evaluation of the effective recharge of the various groundwater bodies.

By necessity, the text of these illustrative notes has been condensed, although the size of the area and its hydrogeological complexity would have deserved a more extensive discussion. As a compromise, we have included an extensive bibliography which should be used if further information is required.

2. The groundwater bodies of the Monti Picentini Regional Park

The Picentini Mountains encompass four large mountain groups: Terminio/Tuoro, Cervialto, Polveracchio/Raione and Accellica/Licinici/Mai; they give rise to the rivers: Sabato, Calore Irpino, Ofanto, Sele, Tusciano, Picentino and Solofrana. The Picentini Mountains consist of limestones, dolomitic limestones and dolomites from the Upper Trias to the Upper Cretaceous. During the formation of the Apennine Range, these carbonate successions were overthrust upon the deep-sea deposits of the eastern areas. This event is well visible in the south-eastern part of the Picentini Mountains, in the Campagna tectonic window, where the fluvial erosion cut the carbonate succession, revealing these marine basinal sediments (Scandone *et al*., 1967; Turco, 1976; Ferranti and Pappone, 1992, 1995).

Carbonate sediments are covered by flysch-facies terrains consisting of interbedded sandstone, calcareous sandstone, marl and clay. These deposits crop out widely at the foot of the Picentini Mountains along the northern border and between the Cervialto Mountain and the Terminio-Tuoro group.

The various hydrogeological basins (described in sub-paragraphs, e.g., 2.1.1.) falling within the groundwater bodies (described in paragraphs, e.g., 2.1.) identified under the Campania Regional Authority's Water Protection Plan (SOGESID, 2005) are illustrated in Fig. 1.

2.1. Accellica-Licinini-Mai

2.1.1. Mts. Solofra

This area includes the mountains in the park's north-western sector bounded by the upper and middle valley of the Solofrana and, to the NE, by the River Sabato. Here, the main formation consists of limestones and dolomites (Upper Cretaceous-Lias) resting on Triassic dolomites. There are few springs fed by the perched water table: the most significant is called Bocche Soprane (12 l/s). Most of the actual infiltration reaches the main aquifer which, via the carbonatic substrate of the Solofrana middle valley, contributes to the feeding of the springs of S. Marina di Lavorate and S. Mauro (at least, as long as it was active) in the Sarno plain (Celico *et al*., 1995; de Riso and Ducci, 1992; Sarno River Basin Authority, 2004).

These mountains form part of a substantially independent hydrogeological basin within the more extensive Mts. Avella / Partenio / Pizzo d'Alvano groundwater body. The separation is thought to be located (de Riso and Ducci, 1992) along faults running continuously from Monteforte Irpino, west of M. Isca (Forino plain), Bracigliano, Siano and the small ridge at its foot where the S. Marina di Lavorate and S. Mauro springs are. All this derives from (Corniello, 2008):

- hydro-chemical diversity (Celico *et al*., 1980) between the S. Mauro and S. Marina di Lavorate springs and the remaining ones (S. Maria la Foce, Mercato and Palazzo, Cerola)

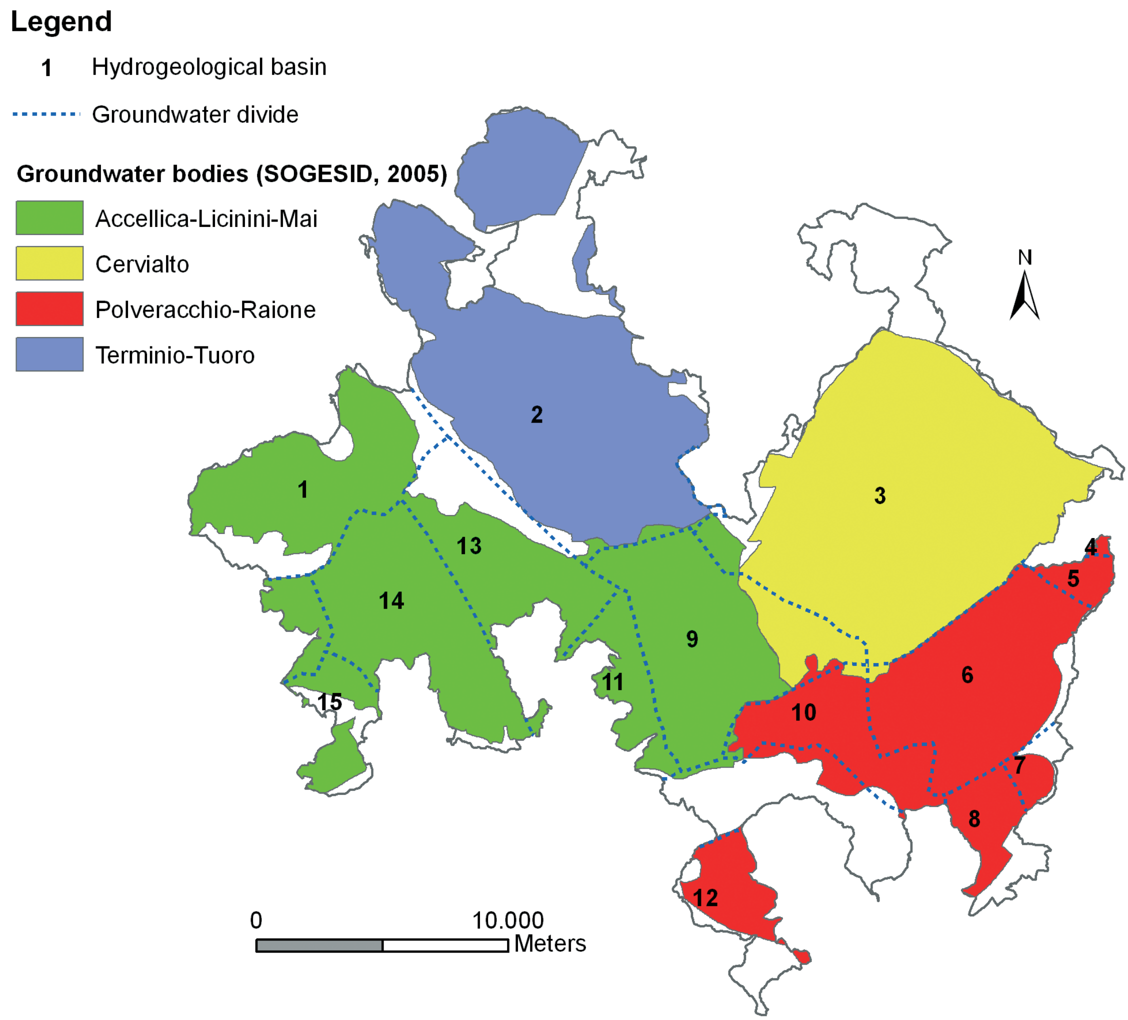

Fig. 1 - Groundwater bodies, as recognized in SOGESID (2005), and hydrogeological basins: 1) Mts. Solofra; 2) Mt. Terminio; 3) Mt. Cervialto; 4) Calabritto; 5) Mt. Antillo; 6) Mts. Magnone/Polveracchio; 7) Mt. Raia; 8) Mt. S. Salvatore; 9) Mt. Accellica; 10) Mt. Calvo; 11) Mt. Telegrafo; 12) Mt. Raione/Olevano sul Tusciano; 13) Mts. Licinici; 14) Mts. Mai; 15) Mts. Monna and Tobenna.

on the Sarno side;

- several years ago, the disappearance of the S. Maria la Foce and S. Mauro springs which were, respectively, at a higher and lower altitude: a result which can be interpreted simply by two substantially distinct basins.

The hydrogeological basin of Mts. Solofra is the northward limit marked by contact with fairly impermeable clayey-marly arenaceous sediments. Eastwards the boundary may be pushed as far as the eastern foot of the Mt. Garofano group, whose water table (situated at about 200 m AMSL; Celico, 1979; Sarno River Basin Authority, 2004) is much lower than that feeding the Serino springs Acquaro/Pelosi (370 m AMSL) in the nearby Sabato Valley. Southwards the hydrogeological basin is bounded by the tectonic line Materdomini-Pellezzano according to studies reported by Celico *et al*. (1977). The south-eastern boundary is less clearly defined and reference should be made to studies of a regional nature (Budetta *et al*., 1994; Sarno River Basin Authority, 2004; SOGESID, 2005).

2.1.2. Mts. Licinici / Mai/ Telegrafo

The mountains rising north of Giffoni Vallepiana constitute several hydrogeological basins which, however, only partly fall within the Picentini Regional Park. The carbonatic succession is tectonically overlaid by thrust faults on Lagonegro Units consisting of flinty limestones and siliceous schists, outcropping in a tectonic window along the River Picentino and the Rio Secco and Capodifiume torrents (Ietto, 1963a, 1963b, 1965).

The northern boundary of these mountains coincides with the important fault of the upper valley of the Sabato. Westwards, the Mts. Licinici basin may be considered sufficiently buffered by outcrops of the impermeable substrate of Lagonegro Units and by tectonic phenomena (where the channel of the Rio Secco sits). To the SE the hydrogeological boundary, which actually separates the basins of Mts. Licinici and Mt. Telegrafo, probably coincides with the faults followed by the course of the Capo di Fiume and the Picentino. Along this tectonic phenomenon, we may also observe: a) outcropping (in a tectonic window) of the impermeable marly-siliceous calcareous substrate in the area of Giffoni Vallepiana and b) the presence of fairly impermeable marly limestones within the dolomitic succession.

The main springs of the Mts. Licinici basin are:

- the springs called Cocchiaduro (131 l/s, close to the confluence of the streams Capo di Fiume and Infrattata) and Chieve (25 l/s);
- widespread groundwater outlets along the channel of the Infrattata (about 121 l/s) and Rio Secco.

The basin of Mts. Mai (rising west of Rio Secco) feeds the springs of the Fosso Prepezzano (springs known as Aretina and the Tornola group).

The groundwater of Mt. Telegrafo (Piscopo *et al*., 1993), beyond the limits we have indicated, meets significant barriers to its eastward flow along the faults of Vallone dell'Oglio. The groundwater appears as widespread springs along the course of the Capo di Fiume. However, the main groundwater outlet is far away from the park, namely the springs known as S. Benedetto and Acqua Fetente (180 m AMSL) about 6 km SW of the town of Montecorvino Rovella.

SW of the Fosso Prepezzano the thrust faults limit the Mts. Monna and Tobenna, whose groundwater flows into the Fosso La Sordina channel.

2.1.3. Mt. Accellica

The hydrogeological basin of Mt. Accellica also comprises the hills that stretch SE towards Toppo della Faragna and the Acerno Plain (see below). Northwards, the basin is divided from that of Mt. Terminio by the fault of the upper course of the River Calore. Along this tectonic discontinuity, a difference in piezometric level of at least 100 metres between the water table in the two neighbouring basins has been recorded (Piscopo *et al*., 2001).

Westwards, the hydrogeological boundary (separating this basin from that of Mt. Telegrafo, see sub-paragraph 2.1.2) runs along the faults of the Vallone dell'Oglio. Moreover, within the Toppo della Faragna, soundings detected the water table at above 530 m AMSL, hence not compatible with the groundwater of Mt. Telegrafo which has springs at 180 m AMSL. The southern limit of the Mt. Accellica basin consists in the Montecorvino Rovella/Calabritto fault (at times compressive) which ensures a clean hydraulic break with the Mt. Polveracchio basin (Celico and Civita, 1976; Celico, 1978, 1983; Budetta and de Riso, 1982; Piscopo *et al*., 1993). Lastly, to the west, the hydrogeological basin is bounded by the faults on the eastern edge of the Acerno plain.

The water infiltrating into the hydrogeological basin of Mt. Accellica feeds a perched water table flowing towards some springs (Ferranti, 1993; Piscopo *et al*., 2001; Sciumanò and Genco, 2007), but most water ends up in the Acerno plain, in a main aquifer feeding:

- the Ausino, Ausinetto and Avella springs (global flow about 600 l/s; the right bank of the Isca Serra);
- increases in flow along the above river (about 100 l/s);
- the Olevano spring (about 300 l/s; the right bank of the Tusciano, south of Acerno);
- considerable flow increases along the Tusciano channel (about 450 l/s; upstream of the Olevano spring - this is currently being extracted).

2.1.4. The Acerno Plain

This depression (extending north and south of the River Tusciano) was once occupied by lake Acerno. The area is currently filled with detritic, fluvial and lacustrine deposits. Sedimentation began about 0.75 Ma, terminating in 0.35 Ma (Capaldi *et al*., 1988), and resulted in a global depth of 100-150 metres. Study of pollen trapped in the lake sediments has led to the history of this ancient lake being reconstructed, often characterised by warmer climate conditions than the present day (interglacial period). In these deposits, the fossilized bones of Elephas antiquus, a particularly widespread species during warm climate periods, were also found. The emptying of the lake was caused by the erosional deepening of the gorge which the River Tusciano carved in the slopes of Mt. Raione, due mainly to the uplift of the massif with respect to the Sele River plain.

The fluvial-lacustrine deposits of the depression rest on a carbonatic substrate (dolomites, dolomitic limestones), identified on the basis of geophysical and stratigraphic data (Budetta and de Riso, 1982), and consist, starting from the top, of:

- well welded breccias with dolomitic elements in a calcite matrix;
- andy silts with frequent, and at times wholly prevalent, levels of grey silts with a varved structure and lignite bands;
- welded breccias (as above).

As stated above, the groundwater of the main aquifer of Mt. Accellica and neighbouring mountains reaches the Acerno plain through various outlets. The Avella-Ausino-Ausinetto group of springs lies along the Isca Serra valley between 565 and 570 m AMSL. Here, the dolomitic substrate is relatively shallow (about 50 metres) and this enables the groundwater, which flows under pressure, to open up a breach through the lacustrine deposits. The Olevano spring gushes on the right bank of the Tusciano at 555 m AMSL at the foot of a high ridge formed by bands of welded breccias of the fluvial-lacustrine deposits. The spring is a further outlet of the groundwater that feeds the Avella-Ausino-Ausinetto group, also because along the River Tusciano major faults make the southward groundwater flow difficult (Celico and Civita, 1976;

Table 1 - Main features of the hydrogeological sub-basins of Mt. Polveracchio.

Hydrogeological sub-basin	**Notes**
Mt. Calabritto	Supplies fairly small springs along the channel of the Rio Zagarone
Mt. Antillo	The aquifer feeds Acquara-Ponticchio springs at the NW margin at about 675 m AMSL (discharge about 175 l/s)
Mts. Magnone/Polveracchio	Supplies (to the SE) the Piceglie/Abazzata group (average discharge 300 l/s distributed in an altitudinal belt between 480 and 520 m AMSL) and the Acqua Bianca springs (average discharge 40 l/s – height 450 m AMSL). Farther from the margin of the massif (to the SE) there is the S. Nicola group (average discharge 190 l/s – 330 m AMSL) and still farther SE the hot mineral springs of Contursi Bagni and the springs of Contursi Terme (average discharge 600 l/s – height 60-110 m AMSL) (Celico *et al.*, 1979b)
Mt. S. Salvatore	The main aquifer, which is supplied by that of Mts. Magnone/Polveracchio along the Vallone Trientale/Piano di Montenero faults, feeds the springs of the Contursi Terme group decidedly further away (in proximity of the River Sele) and lower (60-110 m AMSL)
Mt. Raia	The aquifer of this basin feeds conspicuous springs (Acqua di S. Pietro, Acqua di Oronzo, Calovedda – average total discharge 100 l/s) distributed at variable elevations from 550 to 585 m AMSL
Mt. Calvo	Chiefly dolomitic, is bounded towards S (and at the base) by rather impermeable calcareous-siliceous-marly sediments. The main water table, maintained at high elevations by an impermeable substrate at low depth, emerges Eastward at the Rainosa group springs – average discharge 15 l/s and height about 140 m AMSL). To the W, the aquifer drains towards the River Tusciano, feeds some small springs in the Astratto Valley (a few tens litres/s) and the Acqua Bona spring (about 80 l/s at 450 m AMSL). This groundwater flowing in opposing directions are caused by the groundwater divide most likely resulting from local uplift of the impermeable substrate.

Celico, 1978, 1983; Budetta and de Riso, 1982; Piscopo *et al.*, 1993).

East of the Olevano spring, the Consorzio dell'Ausino ascertained the presence of significant flow increases in the River Tusciano (about 400-450 l/s and in a partial exploitation phase) stemming from the northern sector (thus connecting it to the main aquifer of Accellica) (de Riso, 1996, unpublished report).

2.2. Polveracchio-Raione

Only the southernmost parts of the Mt. Polveracchio basin do not fall within the boundaries of the Monti Picentini Regional Park. The hydrogeological limits of Mt. Polveracchio are all connected (Celico and Civita, 1976; Celico 1978, 1983; Celico *et al.*, 1987) to faults. Along the northern and north-eastern margin, the limit consists in an important fault between Acerno and

Calabritto: its buffering role is also confirmed by the fact that there are no groundwater outlets along the Rio Zagarone (downstream of the town of Calabritto) which is the lowest point of potential outlet of the main aquifers of Mts. Cervialto and Polveracchio. The Mt. Cervialto groundwater emerges further north, close to Caposele, at about 420 m AMSL while, for Mt. Polveracchio, the local groundwater outlet is at the Acquara-Ponticchio springs at about 675 m AMSL. Along the eastern margin, in the upper valley of the River Sele, the boundary consists in a tectonic thrusting front (Cocco *et al.*, 1974; Celico and Civita, 1976; Perrone and Sgrosso, 1982; Pescatore, 1986). The Polveracchio groundwater reaches, through a carbonatic substrate covered by terrigenous deposits, springs (Contursi Terme and Contursi Bagni springs outside the park) situated a few kilometres away from the surveyed area.

Along the western margin, the boundary is represented by the system of faults on which the Tusciano River rests, separating Mt. Accellica from Mt. Polveracchio. Further south, the Polveracchio basin is effectively buffered by fairly impermeable lithotypes of the Lagonegro Units which outcrop in Campagna's tectonic window (Scandone *et al.*, 1967; Turco, 1976; Ferranti and Pappone, 1992).

In the context of Mt. Polveracchio, several partly inter-communicating secondary hydrogeological basins are identified, with different groundwater springs (Celico, 1978, 1983; Celico *et al.*, 1987) (Table 1).

As regards groundwater physical and chemical characteristics, the presence of a Ca-Mg bicarbonate facies has been ascertained (Celico *et al.*, 1979a; 1979b; 1979c; 1981), except for some springs in Contursi Bagni (outside the park) which fall within the domain of calcium sulphate waters. This difference in the chemistry, besides the water temperature, should be correlated with the presence of various groundwater circuits in the main aquifer. The aquifer's more superficial flows lead to less mineralised water (group of Acquara-Ponticchio, Abbazzata, etc; electrical conductivity of about 280 μS/cm), while the deeper groundwater circuits feed more mineralised springs (Contursi Bagni; electrical conductivity reaching about 6,000 μS/cm). All the more mineralised waters also have low O_2 levels and high H_2S and CO_2 contents (1,300 mg/L), whose origin is definitely inorganic (Panichi and Tongiorgi, 1975). The high sodium chloride component in such waters is further confirmation of the presence of deep groundwater circuits.

The south-western foothills of the Mt. Raione/Olevano sul Tusciano hydrogeological basin fall within the Picentini Park. Groundwater flows towards SW in the alluvial detritic deposits on the Eboli plain.

2.3. Terminio-Tuoro

2.3.1. Mt. Terminio

The Mt. Terminio and Tuoro massif chiefly consists of limestones and dolomites from the Cretaceous, as well as Triassic-Jurassic dolomites. Within the massif, south of the town of Volturara Irpina, layers of arenaceous-clayey-marly deposits occur, tectonically overlaid by outcropping limestones (Civita, 1969). Similar sediments have also been found in boreholes both along the southern margin of the Dragone Plain (Celico, 1988) and in the tectonic-karstic area of the Verteglia Plain (Allocca, 2004).

Mt. Terminio-Tuoro is bounded (Civita, 1969; Celico, 1978, 1983) towards:

- north and NE by the tectonic thrust of limestones and dolomites on fairly impermeable

Table 2 - Discharge data of the main springs of the Mt. Terminio (from Aquino *et al*., 2006); (*) including groundwater discharge to the upper Calore River; (**) groundwater inflow from the Sabato river alluvial sediments.

<table>
<tr><th colspan="2" rowspan="2">Spring</th><th rowspan="2">Elevation (m AMSL)</th><th colspan="3">Q (m^3/s)</th></tr>
<tr><th>max</th><th>med</th><th>min</th></tr>
<tr><td colspan="2">Scorzella Springs (*)</td><td>983÷800</td><td>-</td><td>0,36</td><td>-</td></tr>
<tr><td colspan="2">Candraloni</td><td>1190</td><td>-</td><td>0,07</td><td>-</td></tr>
<tr><td rowspan="3">(**)</td><td>Acquaro</td><td>376</td><td rowspan="2">1,60</td><td rowspan="2">1,00</td><td rowspan="2">0,10</td></tr>
<tr><td>Pelosi</td><td>380</td></tr>
<tr><td>Urciuoli</td><td>330</td><td>1,70</td><td>1,30</td><td>1,0</td></tr>
<tr><td rowspan="4">Cassano Irpino Group</td><td>Bagno della Regina</td><td>478</td><td rowspan="4">4,80</td><td rowspan="4">2,5</td><td rowspan="4">1,7</td></tr>
<tr><td>Fontana del Prete</td><td>475</td></tr>
<tr><td>Peschiera</td><td>474</td></tr>
<tr><td>Pollentina</td><td>475</td></tr>
<tr><td rowspan="2">Sauceto Group</td><td>Sorbo Serpico</td><td>462</td><td rowspan="2">-</td><td rowspan="2">0,14÷0,20</td><td rowspan="2">-</td></tr>
<tr><td>Salza Irpina</td><td>486</td></tr>
<tr><td colspan="2">Baiardo</td><td>446</td><td>0,48</td><td>0,25</td><td>-</td></tr>
</table>

sediments;

- SW by the fault (on which the River Sabato valley has developed) which leads to the contact, below the valley's alluvial deposits, between the carbonatic rocks and impermeable clay sandstone deposits (Esposito *et al*., 2000);
- south by tectonic contact between the chiefly limestone rocks of Mt. Terminio and the less permeable dolomites of Mt. Accellica and by the raising of the substrate of the latter, consisting of marly, siliceous and calcareous parts of the Lagonegro Units (Turco, 1976; Ferranti and Pappone, 1992);
- east by the tectonic discontinuity marked by the course of the River Calore Irpino, as well as contact with less permeable sediments.

The main springs are all outside the park's territory (Table 2); within the massif there are perched water tables with conspicuous flows, e.g.: in the southern sector of the Dragone Plain (Celico, 1981) and in the tectonic-karstic area of the plains of Verteglia, d'Ischia, Campolaspierto, Acquenere, etc. (Calcaterra *et al*., 1994; Allocca, 2004).

Various factors affect the presence of these resources lying at higher altitudes than the main aquifer: karstic phenomena (Calcaterra *et al*., 1994), the structure of the massif (Bellucci *et al*., 1982; Celico, 1988) and the different degree of relative permeability which may be found within the same carbonatic complex (Allocca, 2004).

As regards the groundwater circulation in the main aquifer, more than one groundwater basin may be identified (Civita, 1969; Celico, 1978, 1983; Coppola and Pescatore, 1989; Coppola *et al*., 1990) whose boundaries, albeit not acknowledged unequivocally, correspond to precise tectonic alignments. First of all, the fault line bordering the southern sector of the endorheic basin of the Dragone Plain, constitutes a structural element separating the carbonatic massif into two distinct hydrogeological basins (Celico, 1978, 1983). Northwards, the main groundwater basin feeds the springs of Sorbo Serpico-Salza Irpina and Baiardo. In the southern sector, the complex system of tectonic discontinuities, between Volturara Irpina and Mt. Accellica, separates the basin feeding the Acquaro-Pelosi and Urcioli springs, to the west, from that of the Cassano Irpino springs, to the east. What also contributes to supplying the Cassano Irpino springs is the secondary infiltration water intercepted by the Dragone Plain (Celico and Russo, 1981; Celico *et al*., 1982; Galasso *et al*., 1991; Aquino and Aquino, 2007). The basin of the Mt. Terminio feeds the upper valley of the Sabato (to the west) and the plain north of the town of Montella (eastwards) through groundwater inflows.

The groundwaters of Mt. Terminio-Tuoro are oligo-mineral with calcium bicarbonate (Corniello, 1996; Aquino *et al*., 2001; Esposito, 2001; Romeo, 2005). There are contamination risks for the Cassano Irpino springs due to their connection with the swallow-hole mentioned above; the major well field of Volturara Irpina could also be at risk (Galasso *et al*., 1991) due to the proximity of the swallow-hole.

In the panorama of the main springs, special mention should be made of the Baiardo spring (NW of Cassano Irpino). It is not a natural outlet, but emerged inside a tunnel (Nicotera and Aquino, 1995) built in the 1930s for the Società Meridionale del Sannio when, a substratum consisting of calcareous rocks was intercepted at about 466 m AMSL; this substratum is hydraulically connected to the Terminio-Tuoro massif and buried below the outcropping flyschoid cover.

Finally, it is worth recalling that, during the earthquake on November 23, 1980, major increases in spring flows were recorded at the springs of Cassano Irpino and Serino. This phenomenon was also observed in many other springs on Campania's carbonatic massifs (e.g., Sanità di Caposele) (Celico, 1981, 1983, Celico *et al*., 1981; Cotecchia and Salvemini, 1981; Cotecchia *et al*., 1986, 1990; Celico and Mattia, 2002).

2.4. Cervialto

2.4.1. Mt. Cervialto

Characterised by a carbonate succession, Mt. Cervialto constitutes a hydrological basin sufficiently independent of the neighbouring massifs, and falls almost entirely within the park. It is bounded (Celico and Civita, 1976; Celico, 1978, 1983) towards:

- NW, by contact with scarcely permeable sediments;
- NE, by tectonic overlay on fairly impermeable materials;
- SW, by the raising of the rather fractured dolomitic substrate, which prevents any connection between Mt. Cervialto and Mt. Accellica;
- SE, by the Acerno-Calabritto fault; at least in its NE part, it shows clear evidence of reverse fault.

Groundwater flows from SW to NE. The aquifer's only major outlet consists of the Sanità di Caposele spring (Table 3) as well as surface water inflows (Tredogge spring).

The piezometric gradient is rather low, approximately 0.2-0.3%. The average altitude of the water table in the massif varies between 450-500 m AMSL (Bellucci *et al*., 1983). The average temperature of the Sanità spring water is 9-10 °C (Celico *et al*., 1979a, 1979b); hydraulic conductivity is low (about 290 μS/cm) and the facies is of calcium bicarbonate.

One of the best-studied karst systems of Mt. Cervialto is the one that connects the large

Table 3 - Discharge data of the main springs of Mt. Cervialto (from Aquino *et al.*, 2006).

Spring	Elevation (m AMSL)	Q (m^3/s)		
		max	max	max
Sanità di Caposele	420	6.7	4.0	2.8
Tredogge	415		0.07	
Tronola	1115		0.015	

endorheic basin of the Laceno Plain (with its homonymous lake) with the Bocca del Caliendo resurgence (Bellucci *et al*., 1983; Giulivo, 2002).

3. Aquifer pollution vulnerability

Intrinsic aquifer vulnerability of the Monti Picentini Regional Park was drawn up at a scale of 1:100,000, following zoning in homogeneous areas with the GNDCI-CNR method (Civita, 1990, 1994), and is reproduced on the left-hand side of the hydrogeological map (Plate 1).

In some areas of the Picentini Park (Mts. Avella-Partenio-Pizzo, Terminio-Tuoro Mountain) aquifer vulnerability maps drawn up by different methods have already been published (Celico *et al*., 1994, 1995; Celico and Piscopo, 1995; Aquino *et al*., 2006). These maps were not used *in toto* due to problems of scale and lack of method homogeneity; nevertheless, their comparison with the vulnerability map presented herein gave satisfactory results.

The GNDCI-CNR method (Civita, 1990, 1994), recognizes 20 hydrogeological standard settings (e.g., karst aquifers, volcanic aquifers, alluvial aquifers with or without protection, etc.) linked to 6 degrees of intrinsic vulnerability in the Mediterranean countries. The settings are based on:

- hydrogeological features of the aquifer and the vadose zone;
- depth to groundwater;
- aquifer conductivity and type of groundwater flow.

These factors are not strictly quantified, but have to be identified for each representative site. The 6 vulnerability degrees are reported in the legend of the map.

Evaluation of aquifer vulnerability concerns only the main aquifers and does not take into account any poor shallow aquifers.

The aquifer vulnerability map shows that the less vulnerable areas are in Mts. Accellica-Licinici-Mai and in Mts. Polveracchio-Raione, where low vulnerability is due to the widespread presence of dolomitic rocks. In the rest of the park area, excluding a small sector with low vulnerability due to the presence of impervious sediments, aquifer vulnerability is generally high, very high or extremely high: most vulnerable areas correspond to Mts. Terminio and Cervialto, where the very high conductivity of the limestone aquifers (severely fractured and karstified) prevents the depuration, despite the high depth to water. Locally, the degree of vulnerability decreases due the presence of less pervious sedimentary or pyroclastic deposits filling the karstic polje.

The Solofrana and Sabato valleys are also highly vulnerable due to the presence of highly

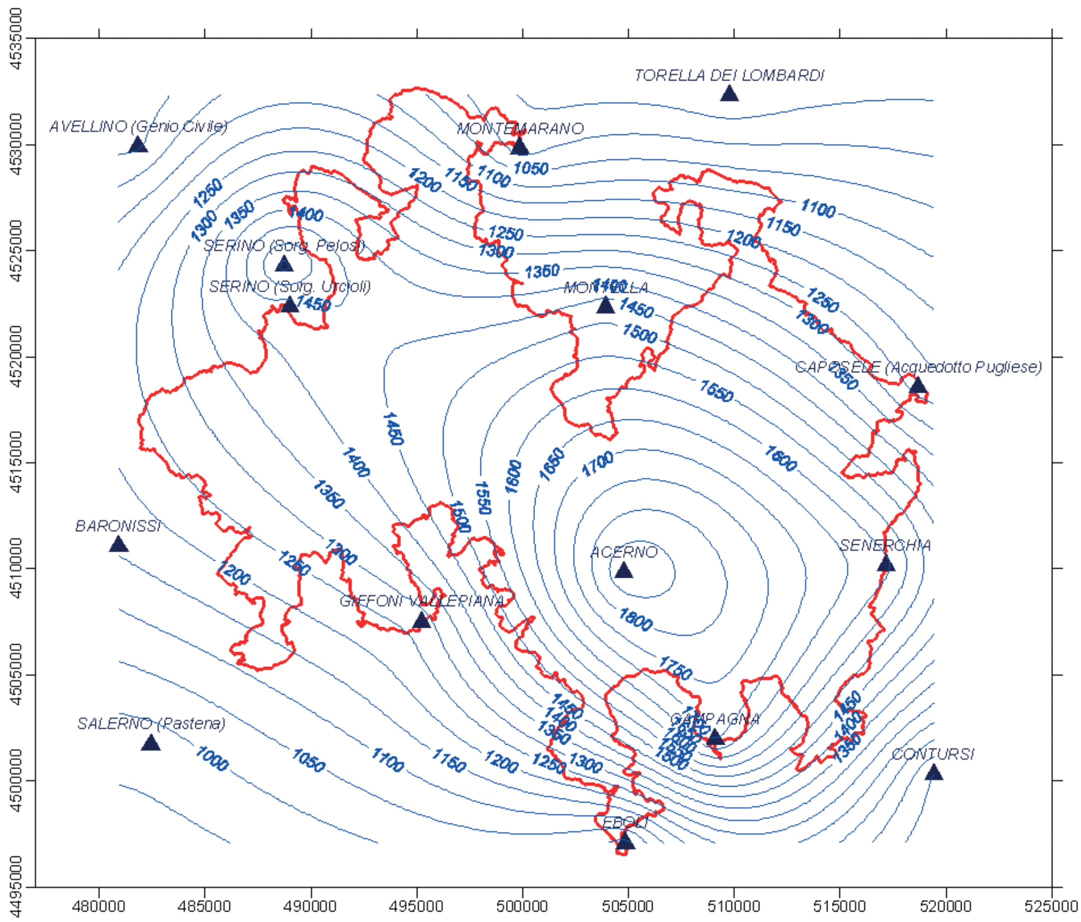

Fig. 2 - Raingauge stations (triangles) and mean annual rainfall (1980-1999). In red the park area.

permeable alluvial and talus sediments and to the low depth to the groundwater.

4. Groundwater resource evaluation

Mean annual recharge of the Picentini Regional Park area was evaluated by deducting the actual evapotranspiration rate and the runoff from the rainfall rate, following the procedures indicated below.

4.1. Rainfall

Input data included mean monthly and annual precipitation data for the years 1980-1999 from rain gauges in the park area or nearby (Hydrographic Service). The distribution of the 15 rain gauges in the area is shown in Table 4 and in Fig. 2, which also shows the mean annual rainfall for the period.

Rainfall distribution shows a spatially irregular distribution: the rainiest area is a sector of the

Table 4 - Raingauge stations and mean annual rainfall (1980-1999).

Rain Gauge Station	Elevation m AMSL	X	Y	Yearly mean rainfall mm
		UTM33 - ED50		
Acerno	725	504783	4509853	1892,4
Avellino (Genio Civile)	383	481848	4529928	1041,9
Baronissi	220	480933	4511079	1158,4
Campagna	300	509108	4501994	1708,7
Caposele (Acquedotto Pugliese)	426	518693	4518571	1228,4
Contursi	97	519420	4500318	1045,1
Eboli	173	504862	4497088	982,5
Giffoni Vallepiana	198	495259	4507510	1273,5
Montella	500	503932	4522341	1475,5
Montemarano	821	499882	4529833	976,5
Salerno (Pastena)	30	482458	4501732	975,5
Senerchia	600	517167	4510149	1614,7
Serino (Pelosi Spring)	374	488739	4524292	1568,1
Serino (Urcioli Spring)	351	489017	4522379	1425,8
Torella dei Lombardi	652	509773	4532337	905,1

park, facing NW-SE, with a peak, in the Acerno area, of almost 1900 mm/year. Another high rainfall area is Mt. Terminio with about 1500 mm/year. Lower precipitation occurs on the other side of the Apennine watershed (towards east), where rainfall is below 1000 mm/year. Overall, the correlation between precipitation and elevation is low; on the contrary, a linear relation was found between rainfall and distance from the Tyrrhenian coast and a non-linear relation between rainfall and the main watersheds.

All the weather stations reported marked seasonal cyclicity, with a unimodal distribution; the rainy period occurs in December (in some cases November), while the dry period is in June and July. For the rain gauge stations with a large and continuous data set (from 1951; Avellino, Caposele, Giffoni Vallepiana, Salerno, and Torella dei Lombardi), the rainfall time-distribution indicates a trend of decreasing rainfall, especially in the period 1980-1999.

Rainfall variability was observed by comparing the mean yearly map of the period 1951-1979 (Fig. 3) and that of the period 1980-1999 (Fig. 2); the comparison highlights a rainfall decrease which is more evident in the western sector and at the foot of the mountains. However, the rainfall decrease from 1951-1979 to 1980-1999 is evident because the total mean yearly rainfall value, evaluated with GIS for the whole park area, ranged from 1467 mm/year to 1421 mm/ year, with a decrease of 3% (about 30 Mm^3/year). This decrease recorded since the 1980s is in line with the region-wide decrease in Campania reported by Ducci and Tranfaglia (2008).

4.2. Evapotranspiration

To estimate the evapotranspiration the FAO Penman-Monteith (Allen *et al.*, 1998) method was

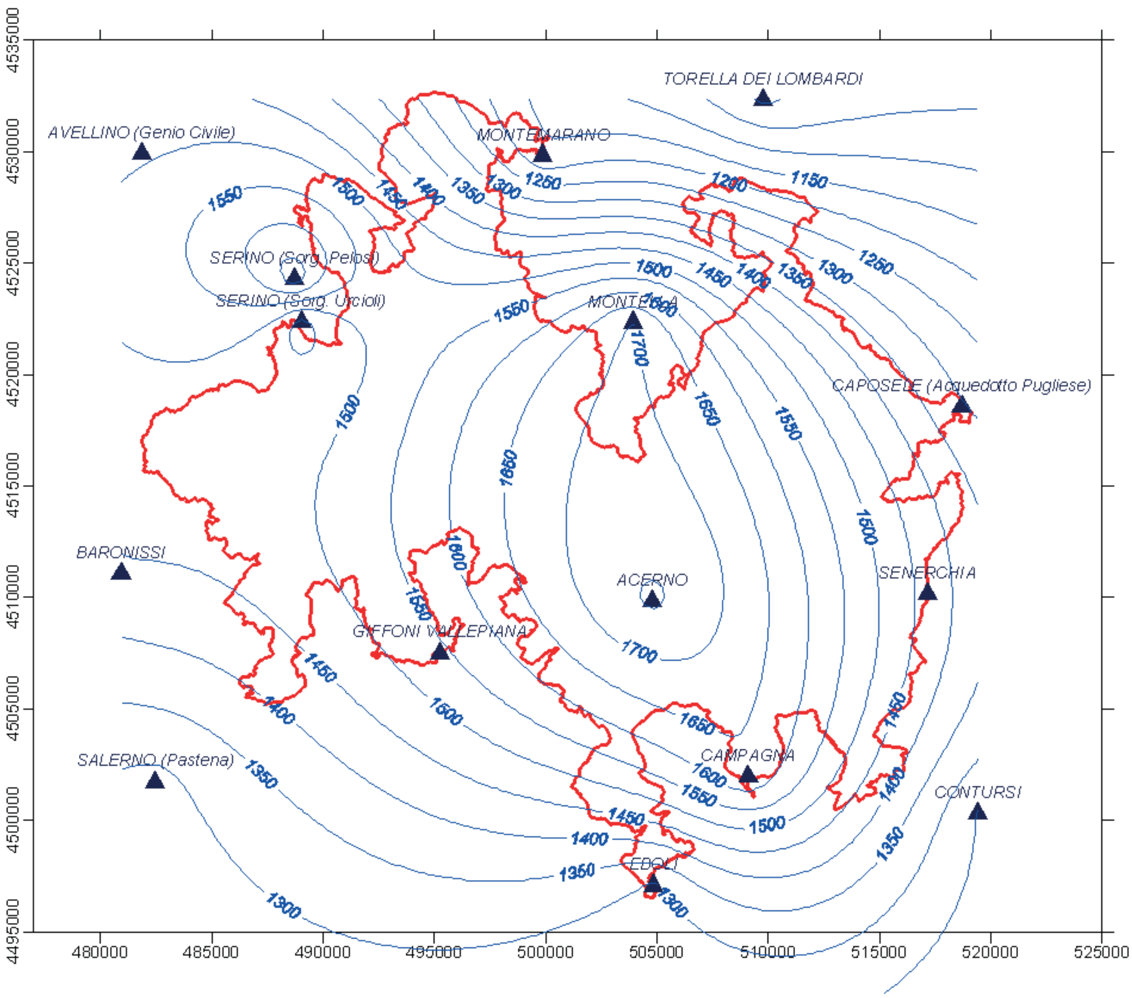

Fig. 3 - Mean annual rainfall (1951-1979). In red the park area.

considered. This method, used to estimate ET_0, is given by

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}$$

where ET_o = reference evapotranspiration (mm day^{-1}),
R_n = net radiation at the crop surface (MJ m $^{-2}$ day $^{-1}$),
G = soil heat flux density (MJ m $^{-2}$ day $^{-1}$),
T = mean daily air temperature at 1.5 to 2.5 m height (°C),
$u2$ = wind speed at 2 m height, (m s $^{-1}$),

Table 5 - Recharge coefficients (CIP) assigned to the outcropping rocks, as defined in the hydrogeological map (see # in Plate 1), and to the urbanized areas.

#	Hydrogeological Units	CIP %
1	Alluvial Unit	70
2	Debris Unit	70
3	Pyroclastic unit	60
4	Conglomerate Unit	60
5	Clayey-marly-arenaceous Unit	40
6	Marly-calcareous-clayey Unit	30
7	Clayey Unit	20
8	Limestone Unit	90
9	Dolomitic Limestone Unit	80
10	Upper dolostone Unit	70
11	Marly – calcareous Unit	35
12	Lower dolostone Unit	70
13	Calcareous-siliceous-marly Unit	35
-	Densely Urbanized Area	10
-	Discontinuous Urbanized Area	20

e_s = saturation vapour pressure at 1.5 to 2.5 m height (KPa),
e_a = actual vapour pressure at 1.5 to 2.5 m height (KPa),
e_s-e_a = saturation vapour pressure deficit (KPa),
Δ = slope vapour pressure curve (KPa °C^{-1}),
g = psychrometric constant (KPa °C $^{-1}$).

Clearly, this method requires a significant amount of data including net radiation, air temperature, wind speed and relative humidity. Hence the ET_0 values published in Perini *et al.* (2007) for the whole of Italy on a 8 km · 8 km cell grid were utilized, converting 10-day values into monthly averages.

Crop Evapotranspiration (Et_c) evaluates the differences in ET_0 rates across seasons and regions related to crops. The crop coefficient *Kc* multiplied by the reference *ET* value yields the crop *ET*:

$$ET_c = Kc * ET_0 .$$

The crop coefficients *Kc* used in this research for each crop and for every month were established on the basis of the large number of crop coefficients reported in the FAO publication (Allen *et al*., 1998). The existing crops were obtained from the Corine Land Cover (CLC) map drawn up by the Monti Picentini Regional Park (http://www.parcoregionalemontipicentini.it/web/monti/home).

Calculated crop evapotranspiration ET_c represents the potential evapotranspiration. Recharge only occurs when monthly rainfall $P>ET_c$ and actual evapotranspiration ET_a is equal to the ET_c.

Table 6 - Mean annual recharge for the period 1980-1999 (carbonate groundwater bodies as recognized in SOGESID, 2005).

Carbonate Groundwater Bodies	**Surface (in the Park area)**	**Recharge**		
	Km²	**mm**	**Mm³/y**	**l/s**
Polveracchio-Raione	93,8	909	85,3	2704
Accellica-Licinini-Mai	165,4	746	123,4	3914
Terminio-Tuoro	104,6	874	91,4	2900
Cervialto	117,9	1014	119,6	3793

When $P \leq Et_c$, the whole amount of P will evapotranspire plus the available soil water in the previous month.

In order to assess the actual evapotranspiration rate a monthly hydrological balance of the soil was performed using GIS. The depth of the soil undergoing evapotranspiration may be fixed at H = 70 cm (field capacity), deriving from pedological characteristics, as evaluated in Perini *et al*. (2004, 2007). In the moderate flow period (assumed to occur in March), the soil is saturated and the height of the available water is equal to the field capacity.

Using the hydrological balance we evaluated the actual evapotranspiration, excess rainfall (positive balance) for each month, when $ET_a > Et_c$, and the deficit storage (negative balance), when the sum of the rainfall and the water available in the soil cannot satisfy crop evapotranspiration requirements. The deficit occurs from June to August, while the excess in the winter period. Due to the soil topography, in some months it is possible to have, at the same time, excess in some sectors and deficit in other sectors of the Park. The resulting annual actual evapotranspiration is 577 mm/year as against 1421 mm/year of rainfall.

4.3. Runoff and Recharge

The map of annual total flow (runoff + recharge) was obtained from the difference between precipitation and actual evapotranspiration. This map almost coincides (differences less than 1%) with the map obtained by summarizing the excess of every month. This is confirmation of the reliability of the soil balance.

Recharge was estimated as a percentage of the total flow as a function of the permeability of the outcropping rocks. This recharge coefficient (CIP) ranges from 10–20 % in impervious rocks to 90 % in karstified limestone, as shown in Table 5. Changes were made to the hydrogeological map (Plate 1), adding the urbanized areas (extracted from the Corine Land Cover map), where recharge is almost absent.

The recharge rate ranges between 85 and 1490 mm/year, with the highest values on the carbonate mountains (see Table 6). These values are definitely lower than those determined for previous years, especially for some groundwater bodies, like Mt. Terminio (Calcaterra *et al*., 1994). Mean recharge in the period 1980-1999 for the whole park area is 775 mm/year, corresponding to a total recharge of about 500 Mm^3/year.

Despite their significance for the amount of groundwater resources in the Monti Picentini

Regional Park, these values could be integrated with the underflow data of the adjacent aquifers and verified on the basis of natural and anthropogenic outflow (pumping, spring flows, etc.).

5. Conclusions

In the Monti Picentini Regional Park a lot of copious springs outflow: Acerno springs, Caposele springs, Senerchia springs, etc.; some other springs, outflowing outside the park area, have their recharge areas (or part of them) inside the park: Urciuoli/Pelosi springs, Cassano Irpino springs and Quaglietta springs.

The Hydrogeological Map of the Monti Picentini Regional Park, the Vulnerability Map and the resource evaluation described in this paper represent a crucial tool for the protection and management of the groundwater resource.

Peculiarly, in the park area, aquifer vulnerability to contamination is high, due to the very high conductivity of the limestone (severely fractured and karstified); the less vulnerable areas are where dolomitic rocks outcrop.

The amount of groundwater resources in the Monti Picentini Regional Park is significant, but definitely lower than those determined for previous years, especially for some groundwater bodies: mean recharge in the period 1980-1999 for the whole park area is 775 mm/year, corresponding to a total recharge of about 500 Mm^3/year. These values could be verified on the basis of natural and anthropogenic outflow (pumping, spring flows, etc.) and of the underflow data to/from the adjacent aquifers.

Acknowledgements. This study was partially funded by the research project PRIN 2007 (Nitrate Contamination in Groundwater: main causes of contamination and impact of climatic trends) National Coordinator and Leader of the Operative Unit: A. Corniello. This paper was presented at the Geoitalia 2009 meeting, session A2 (Integrated hydrogeological, hydrogeochemical and geophysical data: a tool for aquifer management), Convenors: Dimitra Rapti-Caputo & Giovanni Santarato.

REFERENCES

Allen R.G., Pereira L.S., Raes D. and Smith M.; 1998: *Crop evapotranspiration: guidelines for computing crop water requirements.* FAO Irrigation and Drainage Papers **56**, 290 pp.

Allocca V.; 2004: *Analisi sperimentale dei meccanismi di interazione tra acque sotterranee e contaminanti microbici in idrostrutture carbonatiche dell'Italia Meridionale*. In PH.D. Thesis IN Geologia Applicata ed Ambientale, Facoltà di Scienze MM. FF. NN., Università degli Studi di Napoli "Federico II", Napoli, 160 pp.

Aquino S. and Aquino A.; 2007: *Analisi della qualità ambientale dei bacini endoreici del Dragone e del Laceno e la loro influenza sulle risorse idriche sotterranee dei massicci carbonatici dei Monti Terminio e Cervialto (Parco Regionale dei Monti Picentini).* In: Del Prete S. and Maurano F. (eds), Atti del I Conv. Reg. di Speleologia "Campania Speleologica", Oliveto Citra, Salerno, pp. 217-226.

Aquino S., Allocca V., Esposito L. and Celico P.; 2006: *Risorse idriche della Provincia di Avellino (Appennino meridionale, Italia).* Arti Grafiche Cinque srl, Avellino, 120 pp.

Aquino S., Esposito V., Aquino A.M. and Fabbrocino S.; 2001: *Idrogeologia del massiccio carbonatico del Terminio-Tuoro (Campania).* Atti Programma Operativo Multiregionale 940026/l/1, Febbraio 2001, 94 pp.

Bellucci F., Brancaccio L., Celico P., Cinque P., Giulivo I., Santo A. and Tescione M.; 1983: *L'evoluzione geomorfologica, carsismo e idrogeologia della grotta del Caliendo (Campania).* Le Grotte d'Italia, Bologna, **11**, 371-385.

Bellucci F., Capasso G., Celico P., Dell'Aversana L., Giulivo I., Santo A. and Tescione M.; 1982: *Il significato della grotta del Sambuco nell'idrogeologia del Monte Terminio (AV).* Notiziario Club Alpino Italiano, Napoli, **36**, 80-88.

Budetta P. and de Riso R.; 1982: *Studio idrogeologico delle sorgenti di Acerno (M. Picentini).* Mem. e Note Ist. Geol. Appl., Napoli, **16**, 1-27.

Budetta P., Celico P., Corniello A., De Riso R., Ducci D. and Nicotera P.; 1994: *Carta idrogeologica della Campania 1:200.000.* In: Atti IV Geoengineering International Congress: Soil and Groundwater Protection, Geda, Torino, pp. 565-586.

Calcaterra D., de Riso R., Ducci D., Santo A. and Aquino S.; 1994: *Analisi dell'idrodinamica di massicci carsici mediante uso integrato di dati: un esempio nel settore SE del M.Te Terminio (Appennino Meridionale).* In: Atti IV Geoengineering International Congress: Soil and Groundwater Protection, Geda, Torino, **2**, pp. 587-596.

Capaldi G., Cinque A. and Romano P.; 1988: *Ricostruzione di sequenze morfoevolutive nei Picentini meridionali (Campania, Appennino Meridionale).* Suppl. Geogr. Fis. Dinam. Quat., **1**, 207-222.

Celico F. and Mattia C.; 2002: *Analisi degli effetti indotti dal sisma del 23/11/1980 sugli equilibri idrogeologici della sorgente Sanità (Campania), mediante simulazione ragionata delle dinamiche di ricarica e di esaurimento.* Quad. Geol. Appl., **1**, 5-18.

Celico F. and Piscopo V.; 1995: *Idrodinamica sotterranea e vulnerabilità all'inquinamento delle piane del Sarno e del Solofrana (Campania).* Quad. Geol. Appl., **2**, 407- 414.

Celico F., Celico P. and Aquino S.; 1994: *Vulnerabilità all'inquinamento dell'acquifero carbonatico del Terminio-Tuoro (Campania).* In: Atti IV Geoengineering International Congress: Soil and Groundwater Protection, Geda, Torino, **2**, pp. 385-394.

Celico F., Piscopo V. and Daniele L.; 1995: *Gli acquiferi del Sarnese (Campania): vulnerabilità all'inquinamento di una realtà idrogeologica complessa.* Quad. Geol. Appl., **1**, 153-161.

Celico P.; 1978: *Schema idrogeologico dell'Appennino carbonatico centro-meridionale.* Mem. e Note Ist. Geol. Appl., Napoli, **14**, 1- 97.

Celico P.; 1979: *Considerazioni sull'idrogeologia di alcune zone dell'Italia centro-meridionale alla luce dei risultati di recenti indagini geognostiche.* Mem. e Note Ist. Geol. Appl., Napoli, **15**, 1- 43.

Celico P.; 1981: *Relazioni tra idrodinamica sotterranea e terremoti in Irpinia (Campania).* Rend. Soc. Geol. It., **4**, 103-108.

Celico P.; 1983: *Idrogeologia dei massicci carbonatici, delle piane quaternarie e delle aree vulcaniche dell'Italia centro-meridionale (Marche e Lazio meridionale, Abruzzo, Molise e Campania)*. Quaderni CASMEZ, 4/2, Roma, 225 pp.

Celico P.; 1988: *Falda in rete sospese nel massiccio carbonatico del monte Terminio (Campania) ed implicazioni idrogeologiche.* L'Appennino Meridionale, Napoli, **2**, 99-112.

Celico P. and Civita M.; 1976: *Sulla tettonica del massiccio del Cervialto (Campania) e le implicazioni idrogeologiche ad essa connesse.* Boll. Soc. Natur., **85**, 555-580.

Celico P. and Russo D.; 1981: *Studi idrogeologici sulla Piana del Dragone (Avellino)*. Boll. Soc. Natur., **90**, 37-50.

Celico P., Civita M., Macchi A. and Nicotera P.; 1977: *Il sistema idrogeologico dei monti calcareo-dolomitici di Salerno; idrodinamica, riserve globali e loro degradazione a seguito dello scavo della galleria ferroviaria S. Lucia.* Mem. e Note Ist. Geol. Appl., Napoli, **13**, 1- 44.

Celico P., de Gennaro M., Ferreri M., Ghiara M.R., Russo D., Stanzione D. and Zenone F.: 1980. *Il margine orientale della Piana Campana: indagini idrogeologiche e geochimiche.* Period. di Mineralogia, **49**, 241-270.

Celico P., de Gennaro M., Ferreri M., Ghiara M.R. and Stanzione D.; 1979a: *Ricerche geotermiche nell'alta valle del fiume Sele (Salerno): indagini idrogeologiche, strutturali e geochimiche.* In: Atti del I Seminario Inform. Progetto Finalizzato "Energetica" - Sottoprogetto "Energia Geotermica", CNR, 18-21 dicembre, Roma, pp. 519-526.

Celico P., de Gennaro M., Ferreri M., Ghiara M.R., Stanzione D. and Zenone F.; 1979b: *La composizione chimica ed isotopica delle acque sotterranee dell'alta valle del F. Sele in relazione all'idrodinamica delle falde*. Mem. e Note Ist. Geol. Appl., Napoli, **15,** 1-40.

Celico P., de Gennaro M., Ghiara M.R. and Stanzione D.; 1979c: *Le sorgenti termominerali della Valle del Sele: indagini strutturali, idrogeologiche e geochimiche.* Rend. Soc. It. Miner. e Petr., **35**, 389-409.

Celico P., de Gennaro M., Ghiara M.R. and Stanzione D.; 1981: *Variazioni geochimiche nelle acque della valle del Sele dopo l'evento sismico del 23.11.80 in Irpinia.* Rend. Soc. Geol. It., **4**, 137-139.

Celico P., Guadagno F.M., Luise G., Tescione M. and Vallario A.; 1987: *Idrogeologia del Monte Polveracchio - Monte Raione (Monti Picentini - Campania).* Mem. Soc. Geol. It., **37**, 341- 362.

Celico P., Mangano F. and Monaco L.; 1982: *Prove di colorazione nel massiccio carbonatico del Monte Terminio - Monte Tuoro (Avellino).* Notiziario Club Alpino Italiano, Napoli, **36,** 73- 79.

Civita M.; 1969: *Idrogeologia del Massiccio del Terminio-Tuoro (Campania).* Mem. e Note Ist. Geol. Appl., Napoli, **11**, 1 - 92.

Civita M.; 1990: *Legenda unificata per le carte della vulnerabilità all'inquinamento dei corpi idrici sotterranei/Unified legend for the aquifer pollution vulnerability maps.* Quaderni di Tecniche di Protezione Ambientale, Sezione "Protezione delle Acque Sotterranee", Studi sulla vulnerabilità degli acquiferi, 1 (Appendice), Pitagora Editrice, Bologna, 13 pp.

Civita M.; 1994: *Le carte della vulnerabilità degli acquiferi all'inquinamento: teoria e pratica.* Quaderni di Tecniche di Protezione Ambientale, n. 31, Pitagora Editrice Bologna, 325 pp..

Cocco E., Cravero A., Ortolani F., Pescatore T., Russo M., Torre M. and Coppola L.; 1974: *Le unità Irpine nell'area a nord del monte Marzano, Appennino meridionale*. Mem. Soc. Geol. It., **13**, 607-654.

Coppola L. and Pescatore T.; 1989: *Lineamenti di neotettonica dei Monti del Terminio-Tuoro, Cervialto e Marzano (Appennino Meridionale).* Boll. Soc. Geol. It., **108**, 105-119 .

Coppola L., Cotecchia V., Lattanzio M., Salvemini A., Tadolini T. and Ventrella N.A.; 1990: *Il gruppo delle sorgenti di Cassano Irpino (Avellino - Italia Meridionale): regime idrologico ed analisi strutturale del bacino di alimentazione.* Geol. Appl. e Idrog., **24**, 227-260.

Corniello A.; 1996: *Lineamenti idrogeochimici dei principali massicci carbonatici della Campania*. Mem. Soc. Geol. It., **51**, 333-342.

Corniello A.; 2008: *Approfondimento delle conoscenze idrogeologiche in taluni settori del bacino del F. Sarno.* Autorità di Bacino del Sarno, Relazione inedita.

Cotecchia V. and Salvemini A.; 1981: *Correlazione fra eventi sismici e variazioni di portata alle sorgenti di Caposele e Cassano Irpino, con particolare riferimento al sisma del 23 novembre 1980.* Geol. Appl. e Idrog., **16**, 167-192.

Cotecchia V., Nuzzo G., Salvemini A. and Ventrella N.A.; 1986: *Sanità Spring at Caposele (Avellino, Southern Italy): hypotheses on flow-changes caused by 23 November, 1980 earthquake and boundary-barrier stabilty problems.* In: Proc. Int. Symp. on "Engineering Geology Problems in Seismic Areas", Italian Group of IAEG, Bari, **2**, pp. 317-331.

Cotecchia V., Salvemini A. and Ventrella N.A.; 1990: *Interpretazione degli abbassamenti territoriali indotti dal terremoto del 23 novembre 1980 e correlazioni con i danni osservati su talune strutture ingegneristiche dell'area epicentrale irpina.* Rivista Italiana di Geotecnica, **4**, 145-158.

de Riso R. and Ducci D.; 1992: *Schema idrogeologico dell'Alto Sarno (T. Solofrana - Campania).* Geologia Tecnica e Ambientale, **3**, 29 - 38.

Ducci D. and Tranfaglia G.; 2008: *The Effect of Climate Change on the Hydrogeological Resources in Campania Region (Italy).* In: Dragoni W. (ed), Groundwater and climatic changes, Geological Society, London, Special Publications, **288**, pp. 25-38.

Esposito L.; 2001: *Delimitazione "ragionata" delle aree di salvaguardia delle sorgenti di Serino (Avellino - Italia).* Geologia Tecnica e Ambientale, **1**, 1–14.

Esposito L., Fabbrocino S. and Aquino S.; 2000: *Idrodinamica sotterranea e potenzialità idrica dell'acquifero carbonatico del Terminio-Tuoro.* Geologia Tecnica e Ambientale, **4**, 47-55.

Ferranti L.; 1993: *La grotta dello Scalandrone nel quadro dell'assetto strutturale e dell'evoluzione morfologica del massiccio dell'Accellica (Monti Picentini, Appennino meridionale).*). Le Grotte d'Italia, Istituto Italiano di Speleologia, Bologna, **4**, 41-58.

Ferranti L. and Pappone G.; 1992: *Nuovi dati sui rapporti tettonici tra i terreni lagonegresi quelli della piattaforma carbonatica Campano-Lucana nei dintorni di Campagna (Salerno – Appennino meridionale).* Rend. dell'Accademia Sc. Fis. e Mat., serie IV, **59**, 103-119.

Ferranti L. and Pappone G.; 1995: *Thrust tectonics in the Picentini mountains, Southern Apennines, Italy.* Tectonophysics, **252**, 331-348.

Galasso M., Lanzetta E., Manganiello D. and Aquino S.; 1991: S*tudio di un bacino endoreico: effetti e rischi delle attività umane sulla qualità delle acque profonde.* Inquinamento, **33**, 88-92.

Giulivo I.; 2002: *La Grotta di Caliendo (Monti Picentini, Bagnoli Irpino - Avellino).* In: L'Irpinia illustrata, 3, Elio Sellino

Editore, Avellino, **2**, 138-167.

Ietto A.; 1963a: *Rapporti tettonici tra scisti silicei e dolomie nei dintorni di Giffoni Vallepiana (Salerno).* Mem. Soc. Geol. It., **4**, 1049-1068.

Ietto A.; 1963b: *Nuovi aspetti della tettonica della serie calcareo-dolomitica mesozoica del salernitano.* Boll. Soc. Natur., **62**, 31-44.

Ietto A.; 1965: *Su alcune particolari strutture connesse alla tettonica di sovrascorrimento dei Monti Picentini.* Boll. Soc. Natur., **74**, 65-85.

Nicotera P. and Aquino S.; 1995: *Una captazione "sui generis" per la sorgente Baiardo nel massiccio del Terminio (Campania).* Riv. It. Geotecnica, **29**, 37-62.

Panichi C. and Tongiorgi E.; 1975: *Carbon isotopic composition of CO_2 from springs, fumaroles, mofettes and travertines of Central and Southern Italy: a preliminary prospection method of geothermal area.* In: Lawrence Berkley Lab. (ed), Proc. 2nd ymp. on Development and Utilization of Geothermal Resources, San Francisco, pp. 815-825.

Perini L., Beltrano M.C., Dal Monte G., Esposito S., Caruso T., Motisi A. and Marra F.P.; 2004: *Atlante Agroclimatico - agroclimatologia, pedologia, fenologia del territorio italiano.* ISBN: 88-901472-0-2, CRA-UCEA, Roma, 64 pp.

Perini L., Salvati L., Ceccarelli T., Motisi A., Marra F.P. Caruso T.; 2007: *Atlante Agroclimatico - Scenari di cambiamento climatico.* ISBN 88-901472-8-8, CRA-UCEA, Roma, 82 pp.

Perrone V. and Sgrosso I.; 1982: *Bacino pre-irpino: una nuova unità paleogeografica miocenica dell'Appennino meridionale.* Rend. Soc. Geol. It., **4**, 365-368.

Pescatore T.; 1986: *Evolution of a flysch basin during continental collison: Irpinian Basin, Southern Italy.* Giorn. di Geol., Serie 3, **48**, 25-43.

Piscopo V., Aquino S., Genco S. and Sciumanò E.; 2001: *Sulla presenza di falde sospese nel rilievo carbonatico del Monte Accellica (Campania).* Mem. Soc. Geol. It., **56**, 235-241.

Piscopo V., Cavallaro G., Pace G., Vitiello P. and Aquino S.; 1993: *Schema idrogeologico dei Monti Accellica e Licinici (Campania).* Geol. Appl. e Idrogeol., **28**, 611-617.

Romeo A.; 2005: *Studio geologico e geochimico del Massiccio carbonatico Terminio-Tuoro.* Tesi di Laurea Sperimentale (Triennale), Università degli Studi di Napoli, Corso di Laurea in Scienze Ambientali.

Sarno River Basin Authority (Autorità di Bacino del Sarno); 2004: *Piano Stralcio di Tutela delle Acque (art. 17 L. 183/89, L.R. 9/84, D. Lgs. 152/99 e s.i.m.).*

Scandone P., Sgrosso I. and Vallario V.; 1967: *Finestra tettonica nella serie calcareo-silico-marnosa lucana presso Campagna (Monti Picentini, Salerno).* Boll. Soc. Natur., **76**, 3-10.

Sciumanò E. and Genco S.; 2007: *La grotta dello Scalandrone in relazione alla presenza di falde sospese nel rilievo carbonatico di monte Accellica (M. Picentini, Salerno).* In: Del Prete S. and Maurano F. (eds), Atti del I Conv. Reg. di Speleologia "Campania Speleologica", Oliveto Citra, Salerno, pp. 279-287.

SOGESID; 2005: *Regione Campania – Attuazione dell'art. 44 del D. Lgs. 152/99 e s.i.m.: Piano di Tutela delle Acque.* Napoli.

Turco E.; 1976: *La finestra tettonica di Campagna (Monti Picentini, Salerno).* Boll. Soc. Natur., **85**, 639-652.

Corresponding author: Daniela Ducci
Dipartimento di Ingegneria Idraulica, Geotecnica ed Ambientale
Università degli Studi Federico II di Napoli
Piazzale Tecchio 80, 80125 Napoli, Italy
phone: +39 0817682165; fax: +39 0817682162; e-mail: daniela@unina.it