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AN INTEGRATED APPROACH FOR THE DELIMITATION OF A GROUNDWATER BASIN: THE CASE STUDY OF THE CONCA DI ACERNO (CAMPANIA, SOUTHERN ITALY)

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EXTENDED ABSTRACT

L'individuazione delle aree di alimentazione delle sorgenti rappresenta un problema chiave dell'Idrogeologia. In tale contesto si inserisce questo studio sulle sorgenti della Conca di Acerno (Campania) che si basa sia su dati pregressi riguardanti le varie captazioni (l'ultima eseguita nel 1999), sia su indagini piezometriche, idrochimiche ed isotopiche (^{18}O e ^{2}H) condotte dagli Autori. Tutti questi dati hanno consentito di definire i vari aspetti connessi all'origine delle sorgenti e al loro bacino di alimentazione.

La Conca di Acerno è un graben intra-appenninico nel settore sud-occidentale dei Monti Picentini (SA) limitato, a nord-ovest, dal Monte Accellica (1660 m s.l.m.). La Conca era sede di un esteso lago (datato Pleistocene medio) poi colmato da depositi fluvio-lacustri a loro volta incisi dal Fiume Tusciano e dal Torrente Isca della Serra (suo principale affluente di destra); l'abitato di Acerno è situato su una delle superfici terrazzate così formate.

I Monti Picentini sono costituiti da una successione carbonatica (Piattaforma carbonatica Appenninica) che vede dolomie (Trias) alla base di calcari dolomitici (Giura) e di calcari (Giura-Creta); la successione è tettonicamente sovrapposta ai depositi del bacino Lagonegrese.

Nell'area in esame affiorano prevalentemente i termini dolomitici, mentre quelli calcarei e calcareo-dolomitici si rilevano nella parte alta del M.te Accellica. In corrispondenza della Conca *s.s.*, le dolomie sono ricoperte dai sedimenti fluvio-lacustri con (alla base) un orizzonte (di circa 10 metri) di conglomerati cui segue una facies lacustre (sabbie siltose con lenti di argilla e lignite) e un'altra di conoide-delta lacustre (ghiaie grossolane e sabbie). In prossimità dell'abitato di Acerno l'insieme di questi depositi ha uno spessore di circa 120 metri che va decrescendo verso nord.

All'interno della Conca, in prossimità dell'abitato di Acerno, sono localizzati due importanti gruppi di sorgenti captati dal Consorzio idrico dell'Ausino. Il primo gruppo che comprende le sorgenti Ausino, Ausinetto e Avella (Q tot ~ 500 L/s) è distribuito lungo l'alveo del Torrente Isca della Serra. Le sorgenti Olevano e Nuova Olevano (Q tot ~ 530 L/s) sono invece in prossimità dell'alveo del F. Tusciano.

In corrispondenza del primo gruppo di sorgenti le dolomie si ritrovano a circa 50 metri dal p.c. e sono ricoperte da depositi lacustri *s.l.*, poco permeabili. La falda delle dolomie presenta carattere artesiano e alimenta le sorgenti in quanto l'erosione, operata dal torrente Isca della Serra sui terreni di copertura, consente la risalita delle acque di falda. I dati acquisiti per la sorgente Olevano mostrano invece, a tetto del substrato dolomitico, il livello conglomeratico inferiore al cui interno si attesta la falda dell'acquifero dolomitico, qui con carattere freatico: la sorgente, in questo caso, è determinata dal tamponamento laterale dei conglomerati ad opera delle alluvioni del F. Tusciano. Il gruppo Nuova Olevano (formato da diverse scaturigini) presenta un'origine analoga ma quote topografiche più basse verosimilmente per la presenza di travertini molto permeabili giustapposti ai conglomerati. Gli studi relativi a questo ultimo gruppo (che praticamente è a ridosso del F. Tusciano) hanno altresì permesso di accertare che la sua alimentazione proviene nettamente dal versante in destra del fiume, cosa che di fatto induce a riconsiderare quanto fin qui noto sulla circolazione idrica sotterranea nell'opposto versante.

Le analisi chimiche, isotopiche e piezometriche confermano che tutte le sorgenti sono di fatto venute a giorno (con modalità diversificate) della falda del basamento dolomitico della Conca di Acerno.

Il bacino idrogeologico dell'Acerno ha dunque in questo substrato il principale serbatoio idrico sotterraneo. I limiti di tale bacino, essenzialmente riconducibili a condizionamenti tettonici, sono stati verificati anche sulla scorta di un accurato bilancio idrogeologico. Particolare attenzione è stata rivolta alla valutazione dell'evapotraspirazione reale per la quale si è fatto riferimento a due metodi diversi (Turc, 1954 e Hargreaves & Samani, 1982). Il volume di infiltrazione efficace è risultato assai simile nei diversi metodi applicati ed il suo valore confrontabile con il totale delle uscite dal bacino, con uno scarto inferiore al 5% per tutti i metodi. Tale percentuale, che rientra nei limiti di approssimazione dei bilanci idrogeologici, conforta la delimitazione del bacino idrogeologico proposta, così come è significativo che la quota media di tale bacino (circa 1000 m s.l.m.) sia risultata coerente con la quota valutata a partire dai dati isotopici delle acque sotterranee del substrato dolomitico.

ABSTRACT

The Conca di Acerno is an intra-Apennine graben located in the south-western sector of the carbonatic Mts. Picentini (Campania, province of Salerno). In the past, the graben hosted a lake basin, filled lat a later stage by fluvial-lacustrine deposits, cut in turn by the Tusciano River and by the Isca della Serra Creek. The town of Acerno lies on one of the terraced surfaces. Along the banks of the Tusciano River and the Isca della Serra Creek, on the outskirts of the town of Acerno, two important groups of springs (with a total discharge of about 1000 L/s) are located and tapped by the Ausino Consortium public water supply.

All previous data concerning the various groundwater catchment plants, implemented by new measurements (piezometric, hydrochemical and isotopic - ^{18}O and ^{2}H), have led to improve the knowledge on the various hydrogeological aspects related to the origin of the springs and their recharge areas. In detail, the main achieved results are the following:

- all the springs are, in different ways, exits of the same groundwater body hosted within the dolomitic bedrock, buried by the detritic-alluvial deposits of the graben;
- a significant groundwater flow to the Tusciano River comes from the right bank of the river, in contrast to the present hydrogeological interpretation;
- the limits of the groundwater basin feeding the Acerno spring groups have been established more accurately, especially on the basis of the groundwater balance.

Keywords: *groundwater balance, hydrochemistry, groundwater isotope analysis, Conca di Acerno, Campania*

INTRODUCTION

The Conca di Acerno (Fig. 1) hosted in the past a large lake that has been filled with fluvial-lacustrine deposits cut in turn by fluvial erosion. The main erosive action was generated by the Tusciano River and by its main tributary from the right, the Isca della Serra Creek, whose valleys, in the southern sector of the basin, are often very deep or, somewhere, real gorges.

Along their riverbeds, there are two spring groups close to the town of Acerno, tapped by the Ausino Consortium public water supply (total discharge: about 1000 L/s).

In the past, several hydrogeological studies have been carried out in this area (Budetta & De Riso, 1982; Celico, 1983; Piscopo *et alii*, 1993; Piscopo *et alii*, 2001). Nevertheless, the possibility for the authors to access to the data collected by the Consortium (1996-98) for tapping the groundwater resources on the right of the Tusciano River, as well as to many data from previous studies (Cassa per il Mezzogiorno, 1980), has renewed the interest on the hydrogeology of the area.

This information, implemented by new data (i.e.: piezometric, hydrochemical, isotopic etc.) collected for this study, has led to provide a better definition and interpretation of the various aspects connected to the springs of the area and their groundwater basin.

GEOLOGICAL SETTING

The study area is characterised by a 5 km long and 2 km wide graben extending NW-SE (700 - 750 m a.s.l.). Along the NW border, the graben terminates at the foothills of the Mt. Accellica (1660 m a.s.l.).

The ridge of the Mts. Picentini pertains to the Apennine carbonatic platform (*sensu* Mostardini & Merlini, 1986). The carbonate succession, with a thickness of several thousand metres, includes, at the base, Triassic dolomites followed by Jurassic dolomitic limestones and Jurassic-Cretaceous limestones. This succession tectonically overlies the deposits of the Lagonegro basin (mainly siliceous, clayey, marly and calcareous sediments), which outcrop in the southern part of the area of Fig. 2 (ISPRA, 2009 and ISPRA, in press).

In the study area, Triassic dolomites mainly outcrop, while Jurassic dolomitic limestones and Jurassic-Cretaceous limestones outcrop in the upper part of Mt. Accellica (Figs. 2 and 3). Limestones are stratified and fractured, and dolomites are often heavily fractured (e.g. Toppa della Faragna).

Along the northern and western slopes of the Mt. Accellica (between 850 and 975 m a. s.l.), some small sub-horizontal caves in limestone extend for a few metres. The largest karst cave, called Grotta dello Scalandrone (Nr. 5 in Fig. 2; Tab. 3), is

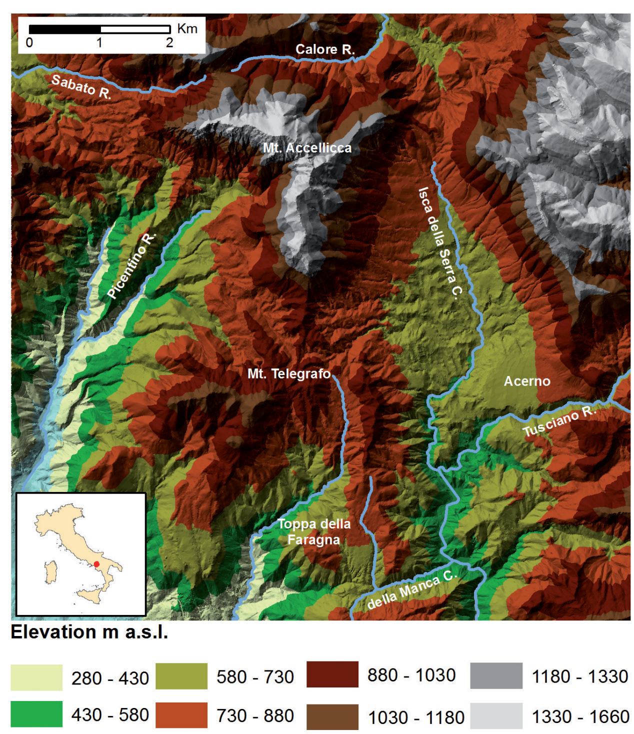


Fig. 1 - Location of the study area

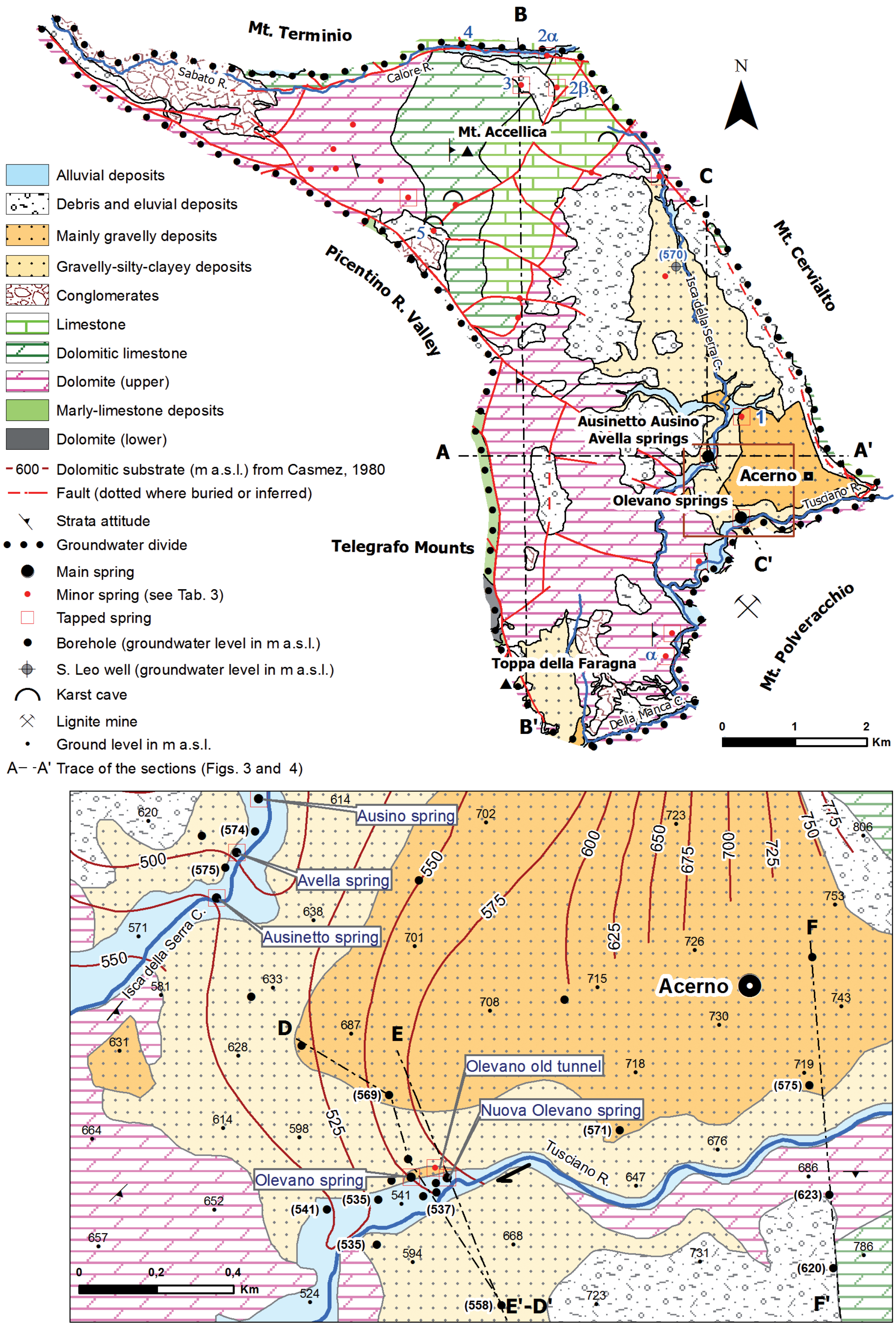


Fig. 2 - Hydrogeological maps of the Conca di Acerno; the sections are in Figs. 3 and 4; below is a detail of the area delimited in red

also the only one with a significant groundwater flow discharge (Qmed of about 30 L/s; Ferranti, 1993; Piscopo *et alii*, 2001; Sciumanò & Gengo, 2007).

At the Conca di Acerno, dolomites are covered by fluvio-lacustrine sediments in which two facies have been identified: a strictly lacustrine facies and a lacustrine fan delta facies (ISPRA, in press; Fig. 4). The first facies is made by an alternance of silty-sands, silt with clay and lignite beds, and thin pyroclastic layers. About 10 metres of conglomerates with sandy pelitic beds are present at its base (Budetta & De Riso, 1982). Above this succession, the lacustrine fan delta facies is formed by coarse gravels and sands which, in the westernmost areas, change to inter-bedded silts and clays (Cinque, 1986; Capaldi *et alii*, 1988). Close to the town of Acerno all these deposits reach a thickness of about 120 metres that progressively decreases northward.

In the past, the lignite beds constituted an important mineral resource. Indeed, about 1000 m SW of the town of Acerno a historical lignite mine is located (Fig. 2): the mine was active for several years in the 20th century with a production of about 10 tons/day. The mine stretches over an area of about 5 hectares which is crossed by more than 2600 m of galleries (Petrosino *et alii*, 2008).

Tephrochronological analysis of the pyroclastic levels in the lacustrine sediments, combined with a palynological study, determined the lake's age in Middle Pleistocene (Russo Ermolli, 2000; Munno *et alii*, 2001).

Southeast of the Tusciano River, the tectonic structure of Mts. Picentini is particularly complex due to the presence of tectonic doubling, which involved the successions of mesozoic platform and basin (Ferranti & Pappone, 1995; Ferranti & Oldow, 1999; Brozzetti, 2011; ISPRA, in press); these phenomena are particularly evident in the tectonic window of Campagna (*auct.*). Information of particular interest also derives from the borehole made by AGIP in 1996 (4625 m deep), about 3 km S of Acerno, which found in the first 1000 metres (from the top): 300 m of dolomites (of the Apennine platform; Upper Trias), 170 m of limestones and marls with flint (most likely "scaglia" of the Lagonegro basin), about 470 m of Miocene

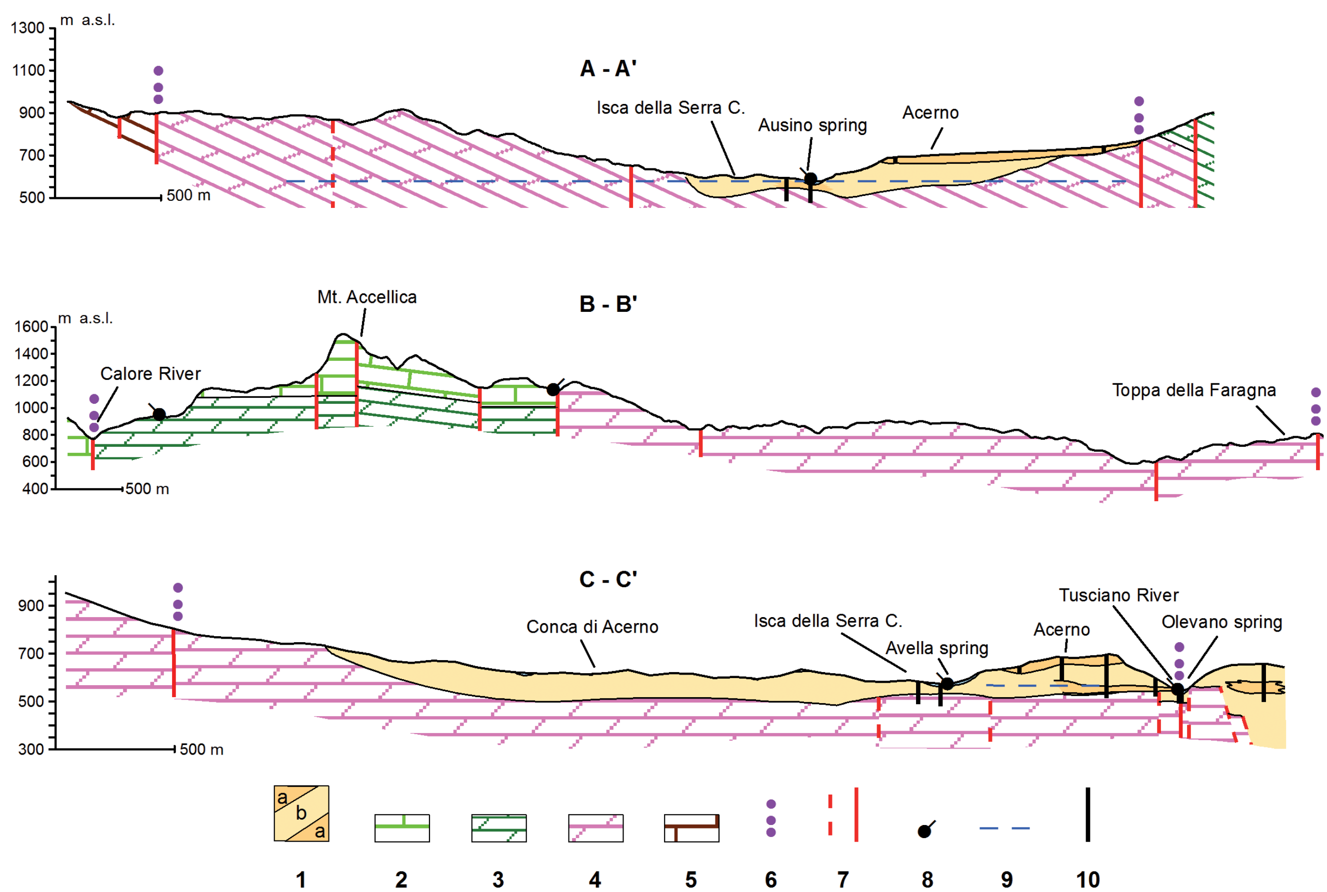


Fig. 3 - Hydrogeological sections of the Acerno groundwater basin (location in Fig. 2); 1) Mainly gravelly deposits (a) and gravelly-silty deposits (b); 2) Limestone; 3) Dolomitic limestone; 4) Dolomite bedrock; 5) Marly-limestone deposits; 6) Groundwater divide; 7) Main faults; 8) Spring; 9) Groundwater level; 10) Borehole

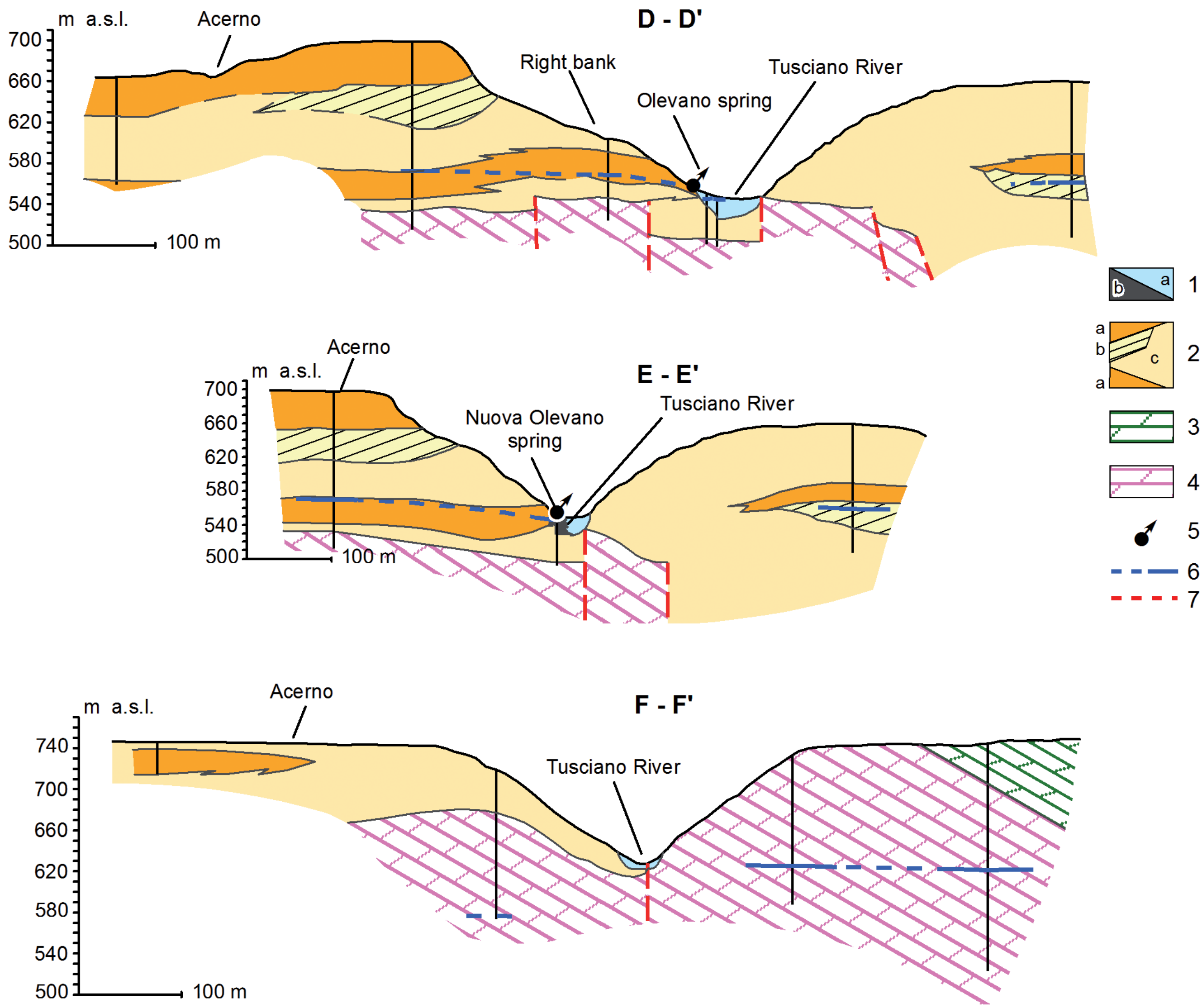


Fig. 4 - Hydrogeological sections in the area of the Olevano and Nuova Olevano springs (location in Fig. 2); 1) Recent alluvial deposit (a), travertine (b); 2) Mainly gravelly deposits (a), sandy (b) silty (c); 3) Dolomitic calcareous deposits; 4) Dolomites; 5) Spring; 6) Groundwater level; 7) Main faults; 8) Borehole

sandstones and limestones (AGIP S.p.A., 1996; Patacca, 2007; ISPRA, in press). Given the proximity of the borehole to the study area, it is possible to a) hypothesize that the Lagonegro sediments constitute the basement also of the dolomites in the Conca di Acerno; b) determine the approximate thickness of the dolomitic substratum of the graben (about 300 m).

The subsequent extensional tectonic events of the Quaternary are responsible for the current morphostructure of the Mts. Picentini, based upon uplifted and rotated carbonatic blocks. During this last tectonic phase (0.75 Ma) the Acerno Lake was emptied and captured by the Tusciano River (Cinque, 1986; Capaldi *et alii*, 1988; Munno *et alii*, 2001).

DATA AND METHODS

The hydrogeological balance calculation is based on climatic data of 10 gauge stations, managed by the Centre for weather forecasting and landslide monitoring - Regional Department of Civil Protection - Campania Region, of 2 stations of the Alto Calore Servizi S.p.A. and of the station of the Ausino S.p.A. - Serv. Idrici Integrati. Data are from 2000 to 2010 and the elevation of the stations ranges between 28 and 745 m a.s.l. (Tab. 5).

To estimate the actual evapotranspiration (*ETa*), two methods have been applied: Turc, 1954; Hargreaves & Samani, 1982 (Tab. 6).

The existing crops used in the formulas were obtained from the IV level Corine Land Cover (CLC) map drawn up by the Mts. Picentini Regional Park (http://www.parcoregionalemontipicentini.it/web/monti/home).

The stream flow measures have been performed by Cassa per il Mezzogiorno and by Ausino Consortium public water supply during the activities for tapping the main springs of the area.

About 20 stratigraphies of boreholes were collected and used for drafting the hydrogeological cross sections. Groundwater levels were measured by the authors in more than 10 wells and some pumping tests are carried out in dolomites, close to the Tusciano River.

The physico-chemical characteristics are partly from Piscopo *et alii* (2001) and partly from the analysis carried out for this study after groundwater sampling from wells and springs. Anion and cation content was determined by ion chromatography (Metrohm 761) at the Department of Chemical Sciences (University of Naples, Federico II). Electrical conductivity, pH, alkalinity and temperature were determined in situ. The isotopic analysis (D, ^{18}O) for the same groundwater points were performed for this study at the "Laboratorio degli Isotopi Stabili" of the Istituto di Geologia Ambientale e Geoingegneria - CNR - University of Roma La Sapienza.

RESULTS

The Acerno groundwater basin

In this tectonically complex setting, the presence of extensional faults, associated to broad cataclastic belts of low permeability, affects the groundwater flow and leads to more or less independent groundwater basins.

The main groundwater reservoir of the Conca di Acerno is hosted in the dolomitic rocks. In relation to the thickness and grain size of the overlying materials, dolomites form a confined or unconfined aquifer (Fig. 3, Sections A-A' and C-C'; Fig. 4).

The aquifer pumping tests carried out in dolomites close to the Tusciano River indicate a mean transmissivity of 2.20 x 10^{-4} m^2/s.

The hydrogeological limits of the Acerno groundwater basin proposed below can be essentially related to the tectonic setting (Budetta & De Riso, 1982; Celico, 1983; Celico *et alii*, 1987; Piscopo *et alii*, 1993; Budetta *et alii*, 1994; Piscopo *et alii*, 2001), but its reliability was verified by the authors through piezometric measures, an accurate hydro-stratigraphic reconstruction of the area near the Tusciano River (Fig. 4) and the groundwater balance.

Northward, the Acerno groundwater basin is separated from the carbonate basin of Mt. Terminio by major faults along which the rivers Calore and Sabato have their flow (Fig. 2); these faults and the groundwater level difference (about 100 m) between the adjacent basins (Piscopo *et alii*, 1993), make difficult groundwater exchanges.

Towards E and W the dolomitic aquifer is equally bordered by faults. In the first case, the faults are those limiting the Cervialto massif, as indicated by the following data. In the eastern zone of the Conca di Acerno the groundwater level in the dolomitic bedrock is about 545 m a.s.l.; groundwater in the Cervialto massif, instead, should have a level much lower, given that the main groundwater discharge is the Sanità spring (in Caposele town), flowing more than 15 km towards SE, at about 420 m a.s.l.

Towards W, the limit follows the fault along the valley which separates the Conca di Acerno from the valley of the Picentino River (Piscopo *et alii*, 1993; Fig. 2).

The southern limit of the groundwater basin coincides with the Montecorvino Rovella-Calabritto fault (Capaldi *et alii*, 1988; Piscopo *et alii*, 1993), along the Tusciano River. The sections in Fig. 4 are very illuminating in this respect: they indicate that the two slopes bordering the Tusciano River have clearly different geological and/or piezometric conditions.

The groundwater exits of the dolomitic acquifer are the big springs around the town of Acerno and the groundwater inflow (Tab. 1) to the Tusciano River (south of the town - Q about 200 L/s) and to the Isca della Serra Creek (about 100 L/s). The groundwater level in the dolomite aquifer, measured at the springs (Tab. 1) and in the boreholes of Fig. 2, is between 575 and 543 m a.s.l.; the lowest levels are near the riverbed of the Tusciano River.

The main spring groups

The springs Ausino, Ausinetto and Avella (total discharge about 500 L/s) lie NW of the Acerno town, along the Isca della Serra Creek and they have an elevation between 563 and 568 m a.s.l. (Fig. 2 and Tab. 1).

Here, the dolomitic bedrock lies approximately 50 m below the ground level; it is covered by poorly permeable fine-grained lacustrine deposits and it forms a confined aquifer. The hydraulic head in this aquifer, detected in a well close to the springs, is almost 1 m above the ground level. Groundwater emerges at the springs and the exit is made possible both by the more permeable layers within the poorly permeable lacustrine sediments or by the erosion of the same sediments operated by the Isca della Serra Creek (Fig. 3, Sect. A-A'). For the same reasons, various

Spring	*Elevation (m a.s.l.)*	*Discharge (L/s)*	*Year*
Ausino	568	310*	2004/2007
Ausinetto	567		
Avella	563	190	
Olevano	550	270	
Nuova Olevano	543-548	260**	2010

*Tab. 1 - Data concerning the main springs in the Conca of Acerno; inflows: * to Isca della Serra Creek 100 L/s and to ** Tusciano River about 200 L/s* discharging points (about 100 L/s) are present along the creek.

The second group of springs (SW of the town of Acerno) includes Olevano spring (about 550 m a.s.l.; Qmed 270 L/s) and Nuova Olevano spring, formed by various discharging points located between 543 and 548 m a.s.l. and with a total mean discharge of about 460 L/s, including the subsurface flow to the Tusciano River (Tab. 1).

At the Olevano springs, data show the lower conglomeratic layer above the dolomitic substratum. The groundwater table of the dolomitic aquifer rests inside the conglomerates determining locally unconfined condition (Fig. 4; Sect. D-D'). In this case the spring is due to: a) changes in permeability within the conglomerates and b) the elevation of the contact between alluvial deposits of the Tusciano River and conglomerates. Indeed, the boreholes drilled close to the riverbed indicate that the incision in the lacustrine deposits made by the Tusciano River was subsequently partly re-filled by alluvial materials (Fig. 4). The Olevano spring was tapped by draining tunnels drilled into the conglomerates.

The Nuova Olevano springs group has similar conditions of exit (Fig. 4); the most significant difference lies in the mean elevations of the discharge points, lower than for the other spring. This is likely due to a) the lower elevation of the conglomerates and b) the occurrence of a very permeable layer of travertine, located close the conglomerates (Sect. E-E' of Fig. 4). The main discharge points of Nuova Olevano spring were tapped in 1999 by a spring box to avoid interference with the Olevano spring catchment system, located not far away, at a bit higher elevation. Eastward, there is no occurrence of other significant discharge points along the right bank of the Tusciano River, because the groundwater elevation in the dolomitic aquifer remains below the riverbed (Sect. F-F' of Fig. 4).

As stated above, the sector of the Tusciano River at south of the town of Acerno receives considerable groundwater inflow from the right river banks (about 200 L/s, Tab. 1). On the left bank, the situation is much less favourable: discharges to the riverbed are still possible along the Section F-F' of Fig. 4, due to local geological and piezometric boundary conditions. Moving westward, this possibility decreases since the left bank mainly consists of poorly permeable silts (Sect. D-D' and Sect. E-E' of Fig. 4), preventing a groundwater flow towards south.

In the Acerno zone there are two man-made draining tunnels (Tab. 2); the first (Olevano old tunnel) is located in the same zone of the Nuova Olevano spring group, though tree metres higher in elevation. Probably the waters of the tunnel come from a layer of conglomerates positioned at higher elevation, but still fed by the dolomitic aquifer. The second tunnel, nowdays abandoned, intercepted groundwater during the excavation in the dolomites of Mt. Toppa della Faragna (Fig. 2). Inside Mt. Toppa della Faragna the groundwater level is at about 565 m a.s.l., hence in accordance with the mean elevation of the main springs.

Spring	***Elevation (m a.s.l.)***	***Discharge (L/s)***	***Year***
Olevano old tunnel	555	50	2010
Toppa Faragna tunnel (**α**)	495	40	1995

Tab. 2 - Artificial springs in the Acerno area (location in Fig. 2)

ID	***Spring***	***Elevation (m a.s.l.)***	***Discharge (L/s)***	***Year***
1	Acqua Tremola (I - II)	607	3.0	2010
2α-2β	Raio della Ferriera (I - V)	744 - 880	70	2008
3	Madonna delle Neve (I - II)	895	4.0	2008
4	Alveo Calore	840	1.0	2008
5	Scalandrone	800	40	1997

Tab. 3 - Data concerning the minor springs; see Fig. 2

Other springs connected to shallower aquifers, hence not connected to the dolomitic aquifer, are found in various zones (Fig. 2 and Tab. 3). The springs along the northern and western slopes of Mt. Accellica (Nrs. 2-5 in Tab. 3 and Fig. 2) are due to the stratigraphic contact between limestones and dolomites (less permeable) or they are related to karst phenomena (Piscopo *et alii*, 2001). As a result, in correspondence with Mt. Accellica, only part of the recharge reaches the dolomitic aquifer.

Some small springs also occur in the plain of Acerno (Nr. 1 in Tab. 3 and Fig. 2) and are fed by the groundwater hosted in the conglomerates, lying above the poorly permeable deposits of the lacustrine facies; therefore, these springs are not connected with the dolomitic substratum of the plain.

Hydrochemistry and isotopic data

All the groundwater chemical data of the Acerno area are reported in Table 4. Their study leads to the following results:

- The waters of the two main spring groups (Tab. 1) show comparable chemical profiles (Fig. 5). That confirms that they originate from the same aquifer (dolomitic bedrock) and the different underground flowpaths do not affect their chemistry. The same chemical characteristics and the same pattern are found for the waters sampled in the S. Leo well, at a depth of 157 m (Fig. 2), several kilometres N of the Ausino/Ausinetto/Avella springs; this well reaches the dolomitic bedrock after 28 m of loams and calcareous debris.
- Groundwater chemistry does not changes over time, as indicated by the chemical profiles of Figs. 6, 7 and 8, drawn up on the basis of the analysis carried out at different times and by different laboratories (Tab. 4).
- Groundwater of the Olevano old tunnel (Tab. 2) has a chemical pattern (Fig. 8) fully comparable with those of Fig. 5 and therefore its origin should be the same of the Olevano and Nuova Olevano springs.
- Groundwater of the lignite mine (Tab. 4 and Fig. 2) indicates the presence of a reduced environment revealed by very low values of sulphates and nitrates.

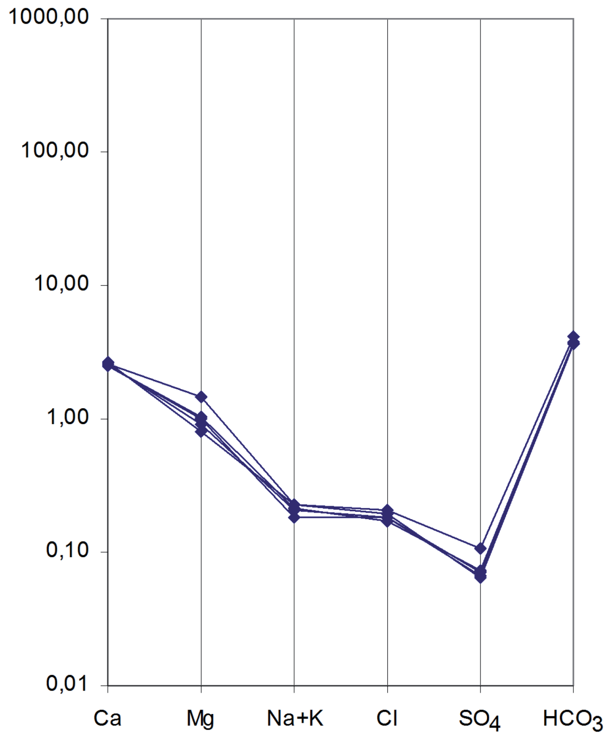


Fig. 5 - Schoeller-Berkaloff diagram of the Avella, Ausino, Ausinetto, Olevano and Nuova Olevano springs. Values in meq/L

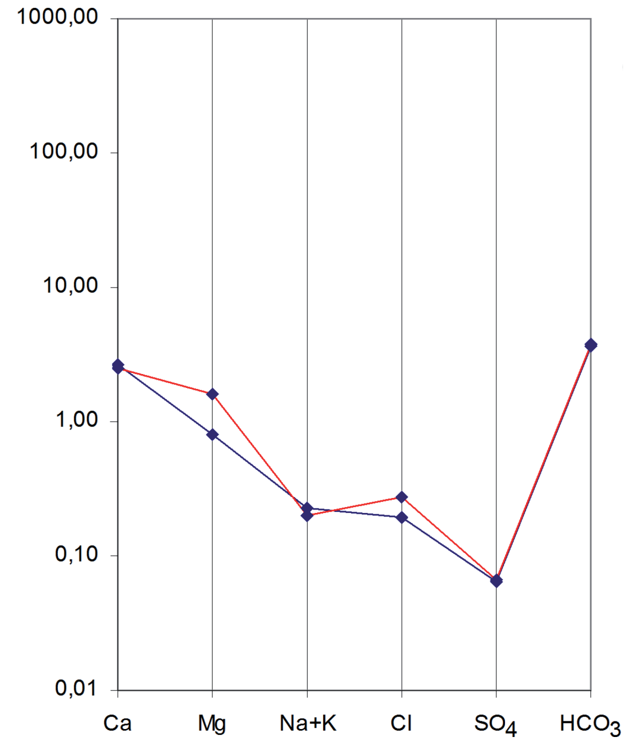


Fig. 6 - Schoeller-Berkaloff diagram of the Olevano spring in 1996 (red). Values in meq/L

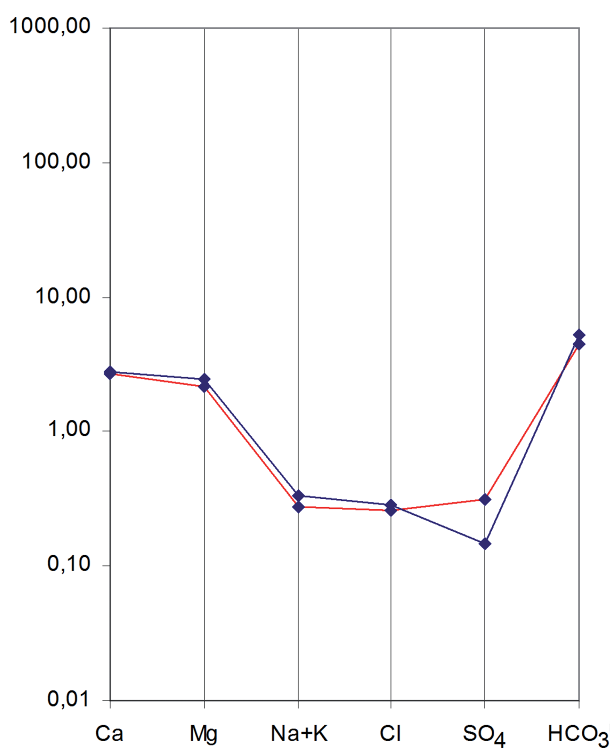


Fig. 7 - Schoeller-Berkaloff diagram of the groundwater from Toppa della Faragna tunnel, 1996 (red). Values in meq/L

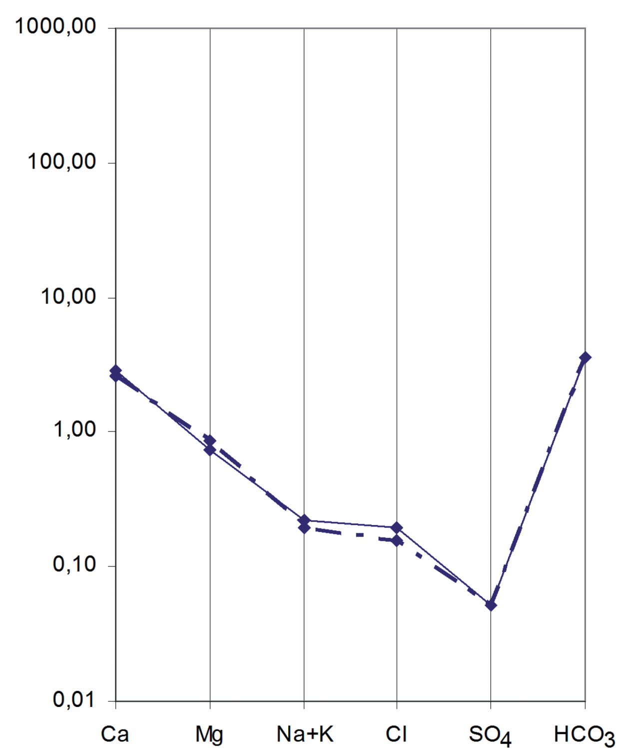


Fig. 8 - Schoeller-Berkaloff diagram of the groundwater of Olevano old tunnel 1996 (line). Values in meq/L

- The hydrochemistry of the Scalandrone spring (Tab. 3) is consistent with the calcareous aquifer of Mt. Accellica, as shown by a very low rMg/rCa ion ratio (0.093).

Fig. 9 shows the isotopic data (D, ^{18}O) for the same groundwater. Although the values are poorly differentiated, isotopic data follow a trend in accordance with the curves reported by LONGINELLI & SELMO (2003) for several stations in southern Italy and by LEONE & MUSSI (2004) for the area of Palinuro (at about 80 km as the crow flies). These curves are also very close to the Global Meteoric Water Line (GMWL; LEONE & MUSSI, 2004). The similarity of the isotope ratios confirms that all groundwaters are linked to the same aquifer and, moreover, it proves that there are no significant variations in the mean elevation of the recharge area. The values shown in Fig. 9 may be correlated with a mean elevation of the recharge area of about 1000 m a.s.l. based on: 1) the isotopic values at sea level (i.e.: -5.8 ^{18}O δ‰; MINISSALE & VASELLI, 2011) and 2) the average isotopic gradient (i.e.: 0.2‰ / 100 m for ^{18}O; LONGINELLI & SELMO, 2003).

Groundwater balance

The groundwater balance was elaborated to verify the boundary of the Acerno groundwater basin. The reference period (2000-2010) was selected on the basis of the availability, only for this interval, of significant "output" data (spring discharge etc.); the data for rainfall and temperature were obtained from various sources (§ Data and Methods and Tab. 5).

The parameters considered for the balance are the classic ones for an area with low human impact, like the study area:

$$P = ETa + Ru + Re$$

where: *P* is precipitation; *ETa* is actual evapotranspiration; *Ru* is surface runoff and *Re* is recharge.

Given to the steep morphology of the area (mean elevation > 1000 m a.s.l.) and the lack of weather stations at high elevation, first of all the relationships temperature (T) – elevation (H), and rainfall (P) – elevation (H) were verified. Being the linear correlations both significant (correlation coefficients of 0.86 and 0.68 respectively), using a GIS, the found relationships (inverse for T-H and direct for P-H) were applied to the digital terrain model (DTM) to obtain thematic maps of rainfall and temperature throughout the study area (37.82 km^2).

Mean precipitation (P), for the period 2000-2010, was 2612 mm/yr, corresponding to 86.6 x 10^6 m^3/yr (Tab. 6).

The actual evapotranspiration (ETa) has been estimate using two methods (TURC, 1954 and HARGREAVES & SAMANI, 1982;

Station	Elevation (m a.s.l.)	P (mm)	T (°C)	Authority
Salerno (Genio Civile)	28	1058.78	-	*Centre for weather forecasting and landslide monitoring* *REGIONAL DEPARTMENT OF CIVIL PROTECTION* *REGIONE CAMPANIA*
Persano Sele	35	- - -	16.23	
S. Mauro	37	999.72	17.35	
Battipaglia	50	1010.99	17.51	
Montecorvino R.	154	1156.71	15.87	
Contursi	164	- - -	14.83	
Mercato S.Severino	177	1259.95	15.49	
Montella	501	1490.72	12.73	
Senerchia	582	- - -	13.95	
Bagnoli Irpino	745	- - -	12.97	
Mercogliano	450	- - -	14.26	Alto Calore Servizi S.p.A.
Montella - Cerasa	720	2122.47	- - -	
Acerno	564	1983.22	- - -	Ausino S.p.A. - Servizi Idrici Integrati

Tab. 5 - Rainfall and temperature gauge stations

Spring / well	*pH*	*Cond. µS/cm*	*TDS mg/L*	*Hardn. °F*	*NO_3^- mg/L*	*F^- mg/L*	*Na^+ meq/L*	*K^+ meq/L*	*Ca^{+2} meq/L*	*Mg^{+2} meq/L*	*Cl^- meq/L*	*HCO_3^- meq/L*	*SO_4^{-2} meq/L*
Ausinetto spring	7.40	320	214	17.6	1.3	0.15	0.15	0.04	2.52	1.00	0.18	3.61	0.071
Ausino spring	7.50	352	236	20.5	2.7	0.17	0.18	0.05	2.62	1.47	0.21	4.10	0.106
Avella spring	7.77	290	194	17.8	1.5	0.08	0.18	0.03	2.53	1.03	0.17	3.79	0.073
Nuova Olevano spring	7.66	312	209	17.5	1.8	0.10	0.17	0.04	2.59	0.90	0.18	3.64	0.067
Olevano spring	7.53	315	211	17.6	1.7	0.22	0.18	0.04	2.73	0.80	0.19	3.67	0.065
Olevano spring (year 1996)°	7.50	316	- - -	- - -	2.1	0.10	0.17	0.03	2.57	1.63	0.28	3.77	0.067
Olevano old tunnel (1996)°	7.07	255	211	18.8	1.0	0.20	0.18	0.04	2.89	0.73	0.20	3.58	0.050
Olevano old tunnel (2011)	7.20	316	221	- - -	2.1	0.05	0,16	0,04	2.69	0.86	0.16	3.62	0.05
Acqua Tremola*	7.52	455	305	26.1	11.4	0.13	0.23	0.05	3.88	1.34	0.27	5.06	0.192
Toppa Faragna tunnel	7.62	455	305	26.4	3.3	0.34	0.26	0.08	2.79	2.48	0.28	5.33	0.148
Toppa Faragna tunnel (1996)	7.40	400	- - -	- - -	- - -	2.00	0.24	0.03	2.73	2.14	0.26	4.54	0.314
Lignite mine**	7.40	316	- - -	- - -	1.1	0.10	0.16	0.03	3.02	0.97	0.20	3.87	0.002
Scalandrone***	--	--	154.5	- - -	- - -	- - -	0.20	0.10	3.43	0.32	0.16	3.75	0.070
S.Leo well**	7.83	403	270	16.5	0.2	0.04	0.14	0.04	2.38	0.53	0.16	2.95	0.070

*Tab. 4 - Main physical and chemical data of groundwater in the Acerno area. Analysis, unless otherwise shown, are from 2010 / 2011 and were carried out for the present study c/o Department of Chemical Sciences of the University Federico II (Naples, Italy); *Tab. 3 and Nr. 1 in Fig. 2; ** in Fig. 2; *** analysis in PISCOPO et alii, 2001; ° data from Ausino Consortium*

Tab. 6). The latter estimates potential evapotranspiration ET_0 by directly measuring the daily maximum and minimum temperature and calculating extraterrestrial radiation as follows:

$$ET_0 = 0.0022 \cdot R_{extra} \cdot (T_{mean} + 17.8) \cdot (T_{max} - T_{min})^{0,5}$$

where: ET_0 is the reference evapotranspiration [mm d^{-1}], R_{extra} is extraterrestrial radiation [mm d^{-1}], T_{max}, T_{min} [°C] daily maximum and minimum temperature at 2 m of height.

This formula, accredited by the FAO (Allen *et alii*, 1998), provides good results (Fagnano *et alii*, 2001), although some climatic factors are not considered in the method (such as wind speed and relative humidity) and radiation is estimated with a simplified approach, starting from the temperature excursion (Donatelli & Bellocchi, 2000). There is also a good correlation between the monthly means of ET_0 and elevation (Pulina, 1986). Actual ET is thus obtained from the equation $ETa = ET_0 Kc$ (where *Kc* stands for experimentally obtained coefficients for various types of crops). The *Kc* used in this research for each existing crop (IV level CLC map) and for every month was chosen on the basis of the large number of crop coefficients reported in the FAO publication (Allen *et alii*, 1998; Corniello *et alii*, 2010).

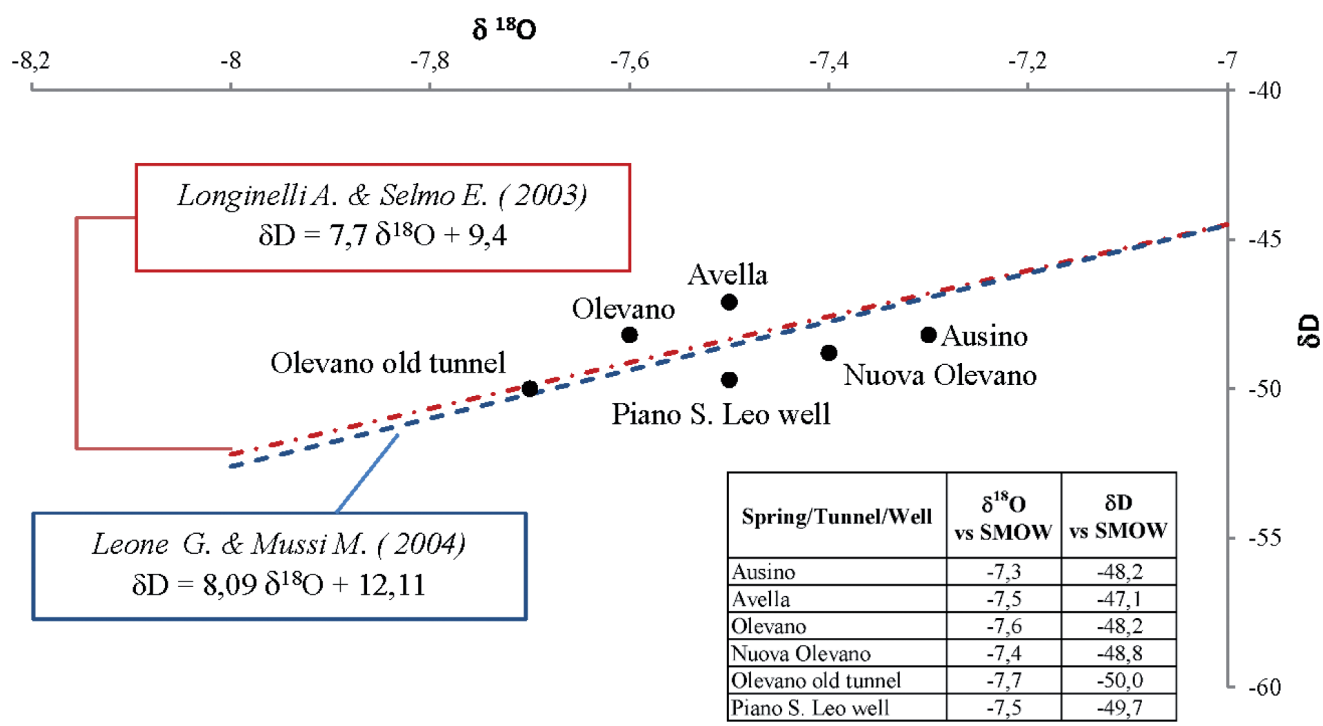
Recharge was thus obtained by multiplying the effettive rainfall by the potential infiltration coefficients (PIC) of the various outcropping lithologies (Civita, 2005). Finally, the recharge volume (resulting quite similar by the various methods - Tab. 6) was compared with the groundwater outflows from the basin (48.6 x 10^6 m^3/year) in the form of spring discharges (39.0 m^3/year x 10^6) and inflows to the Tusciano River (6.4 m^3/year x 10^6) and Isca della Serra Creek (3.2 m^3/year x 10^6). The discrepancy between inflows and outflows (Tab. 6) is, for all methods, less than 5 %. This percentage, falling within the limits of approximation for groundwater balances, offers further proof of the previously proposed boundary of the groundwater basin.

Terms of the GW balance	Unit	Turc	Hargreaves & Samani
Rainfall (*P*)	mm/year	2612	2612
Potential Evapotranspiration	mm/year	- - -	602
Actual Evapotranspiration (*Eta*)	mm/year	518	421
Surface runoff (*Ru*)	mm/year	719	922
Recharge (*Re*)	mm/year	1375	1269
Inflow (*Re*)	m^3/year x 10^6	52.0	48.0
Outflow (*Q*)	m^3/year x 10^6	48.6	48.6
Re-Q	m^3/year x 10^6	3.4	-0.6
Re-Q	%	6.5	1.3

Tab. 6 - Outline of the groundwater balance evaluated for the period 2000-2010 (assuming negligible change in groundwater storage); the study area is about 38 km^2

CONCLUSIONS

The set of available and/or acquired data contributed to better define the groundwater flow in the Acerno groundwater



Spring/Tunnel/Well	$\delta^{18}O$ vs SMOW	δD vs SMOW
Ausino	-7,3	-48,2
Avella	-7,5	-47,1
Olevano	-7,6	-48,2
Nuova Olevano	-7,4	-48,8
Olevano old tunnel	-7,7	-50,0
Piano S. Leo well	-7,5	-49,7

Fig. 9 - Relationship between $\delta^{18}O$ and δD. The dotted lines in red and blue are the relationship of mean monthly samples of atmospheric precipitation collected in southern Italy (Longinelli & Selmo, 2003) and in Palinuro area (Leone & Mussi, 2004). The location of the S. Leo well is in Fig. 2

basin. In detail:

- along the Tusciano River and eastward, the major faults block the groundwater flow towards south;
- the hydrogeological setting along the banks of the Tusciano River indicates the occurrence of significant groundwater flows toward the Tusciano River; these flows give rise to a group of springs (Nuova Olevano spring) and to the direct discharge to the riverbed (about 200 L/s); these groundwater flows originate chiefly from the right river bank and this suggests that the groundwater flow in the opposite side should be deeper studied;
- in the stream beds of the Tusciano River and of the Isca Serra Creek significant contributions from aquifers are present, which could usefully be considered for further exploitation;
- all the main springs come from the same groundwater body, hosted in the dolomitic bedrock of the Conca di Acerno, with different underground flowpaths;
- the groundwater balance verified the limits of the groundwater basin of Acerno; the average elevation of this basin (> 1000 m a.s.l.) is also consistent with the elevation calculated through isotopic data;
- in the spring groups located NW and S of Acerno the quality of groundwater is constant, due to the confinement/protection operated by a considerable layers of poorly permeable sediments.

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