

Hydrogeology of the southern Middle Tiber Valley (Central Italy)

Idrogeologia del settore meridionale della media valle del Fiume Tevere (Italia Centrale)

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Riassunto: Scopo del presente lavoro è di dare un contributo alla conoscenza dell'idrogeologia della parte meridionale della Media Valle del Tevere, focalizzando l'attenzione sulle unità continentali emarine che colmano il graben del Paglia-Tevere al confine settentrionale della Regione Lazio (Italia Centrale). Un'importante campagna di rilevamento idrogeologico è stata condotta nell'estate del 2008, durante la quale è stata raccolta una cospicua quantità di dati piezometrici, chimico-fisici e di flusso idrico. Sono state realizzate quattro sezioni geologiche ed è stata elaborata una cartografia idrogeologica e di qualità delle acque sotterranee al fine di ottenere un modello concettuale del flusso idrico sotterraneo.

Abstract: *The aim of this work is to contribute to the hydrogeological knowledge regarding the southern Middle Tiber Valley focusing on the continental and marine units that fill the Paglia-Tiber graben in the northern Latium Region (central Italy). An important hydrogeological survey was performed in the summer of 2008, and a considerable quantity of piezometric, physio-chemical and flow data were collected. Four geological cross sections were realized, and a hydrogeological map and a groundwater quality map of the area were produced to obtain a conceptual groundwater flow model.*

Keywords: *Regional hydrogeology, conceptual groundwater models, Sabina.*

Parole chiave: idrogeologia regionale, modelli idrogeologici concettuali, Sabina.

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Introduction

Hydrogeological characterization of regional sedimentary basins is a common activity in the search for groundwater resources (Oullon et al. 2008; Westjohn and Weaver 1998). Moreover, it has become apparent that understanding relationships between Quaternary deposits and groundwater is a necessity in areas where most of the water supply comes from bedrock aquifers. Indeed, these deposits are frequently a major factor controlling confining conditions and the recharge of bedrock aquifers. However, delineating confining layers and sub-surface aquifers and aquitards in these complex settings is by no means a trivial task, and achieving precise integration of stratigraphic reconstructions and hydrogeologic applications still represents a significant challenge (Ross et al. 2005).

Many schemes and studies addressing hydrogeological units connected to the Tiber River have been proposed during the last several decades (Di Domenicoantonio et al. 2009; Reichenbach et al. 1998; Vivona et al. 2007); however, a hydrogeological characterization of the whole southern region of the Middle Tiber Valley is still lacking. In fact, as the area is characterized by debris-alluvial formations that are highly non-homogeneous, with frequent and important lateral facies variations, the hydrogeological interest in this region has never been fully developed. The only works focusing on hydrogeological features, even at a regional scale, are the Hydrogeological Map of the Latium Region (scale 1:250,000; Boni et al. 1988), the Hydrogeological Scheme of Central Italy (scale 1:500,000; Boni et al. 1986)¹.

The study area corresponds to the southern part of the Middle Tiber Valley (hereafter MTV) in the northern Latium Region. The axis of the valley runs NW-SE, beginning at the lower limit of the Umbria Region and extending to the northern suburbs of Rome; from that point until it reaches the mouth of the river, the direction of the Tiber valley is NE-SW (Fig. 1). This region is conventionally known as Sabina and is bounded by the Sabini Mountains to the northeast, the Lucretili Mountains on the east side, the Sabatini Volcanic Complex to the southwest and the Soratte Mount on the west side. In addition to the main river, there are several tributaries, which include the Farfa River, the Corese and Aia streams along the left river bank, and the Treja River and the S. Martino stream along the right bank

¹ *and the most recent Hydrogeological Map of Latium Region 1:100.000 scale (Capelli et al. 2013) and Hydrogeological Map of Rome (La Vigna et al. 2016b)*

The hydrogeological conceptual model presented in this work derives from an important hydrogeological survey in which data from approximately 230 wells/piezometers/springs were collected. At these survey points, the in situ temperature and electric conductivity of groundwater were measured as well. Analysis of more than 100 stratigraphies also substantially contributed to the defined model

Geological and hydrogeological setting

From a geological point of view, the MTV corresponds to the Paglia-Tiber graben (Funicello and Parotto 1978; Funicello et al. 1981), a tectonic depression filled by notably thick marine and continental units (Fig. 1). This region initially underwent a synorogenic compressive phase (during the middle to upper

Miocene) and a subsequent compressive phase (starting in the late Pliocene). This led to the development of the Paglia-Tiber graben (Cavinato and De Celles 1999) and to the formation of NW-SE normal fault systems.

These fault systems led to the formation of several subsiding graben and half-graben tectonic sedimentary basins aligned in the same direction (Faccenna and Funicello 1993; Cosentino et al. 1993; Cosentino and Parotto 1988; 1992). The structures of Mt. Soratte and Cornicolani Mountain horsts as well as indirect data on Bouguer gravimetric anomalies and residual anomalies (Di Filippo et al. 1992) (Fig. 2) provide clear evidence of this tectonic setting in the MTV.

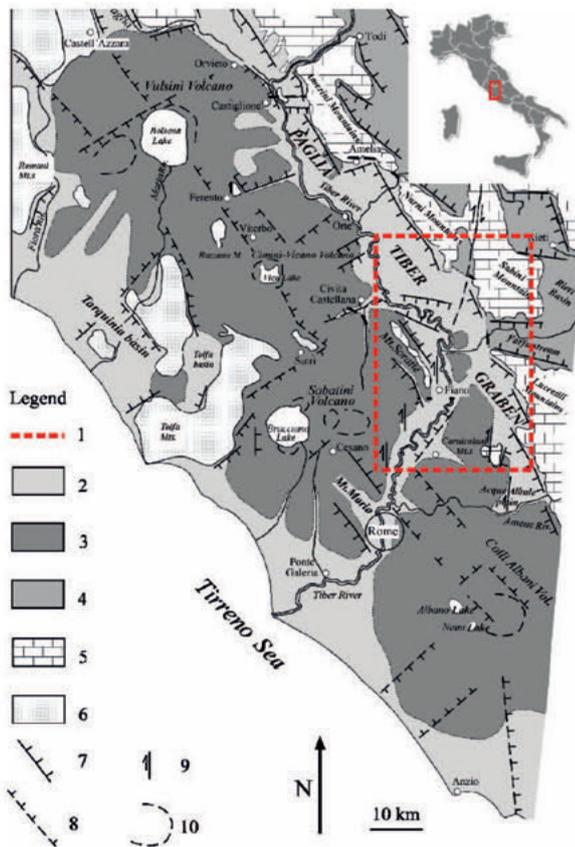


Fig. 1 - Tectonic sketch map of Latium (modified from Mancini et al. 2003-2004)
Legend: 1) Boundary of the study area.; 2) "Neotectonic" sedimentary successions, of the marine, transitional and non-marine environments (Early Pliocene- Quaternary); 3) Volcanic and volcano-sedimentary successions (Late Pliocene-Late Pleistocene); 4) Sedimentary successions of the intermontane basins (Middle Pliocene-Quaternary); 5) Carbonate and siliciclastic successions of the Umbro-Sabina domain (Trias-Miocene); 6) Siliciclastic and carbonate successions of the Tuscan and Ligurian domains (Trias-Miocene); 7) Normal fault; 8) Buried normal fault; 9) Strike-slip fault; 10) Caldera rim.

Fig. 1 - Schema tettonico del Lazio (modificato da Mancini et al. 2003-2004)
Legenda: 1) Limite dell'area di studio; 2) Neotettono (auct.), successione sedimentaria di ambiente marino, di transizione e continentale (Pliocene inferiore-Quaternario); 3) Successioni vulcaniche e vulcano-sedimentarie (tardo Pliocene - tardo Pleistocene); 4) Successioni sedimentarie di bacino intramontano (Pliocene medio - Quaternario); 5) Successioni carbonatiche e silicoclastiche del dominio Umbro-Sabino (Trias-Miocene); 6) Successioni silicoclastiche e carbonatiche dei domini Toscani e Liguri (Trias-Miocene); 7) Faglia diretta; 8) Faglia diretta sepolta; 9) Faglia trascorrente; 10) Bordo di caldera.

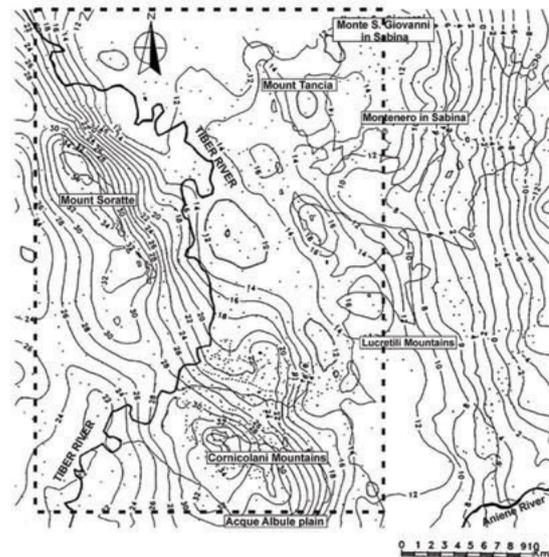


Fig. 2 - Bouguer anomalies map (anomalies contour interval 2 mGal) of the southern MTV (modified from Di Filippo et al. 1992). The rectangle highlights the study area.

Fig. 2 - Carta delle anomalie di Bouguer (intervallo delle isolinee 2 mGal) della media Valle del Tevere (modificato da Di Filippo et al. 1992). Il rettangolo identifica l'area di studio.

The Acque Albule area, just south of the Cornicolani Mountains, is an example of another subsiding tectonic sedimentary basin developed during the same period (Faccenna et al. 1994, 2008; La Vigna 2009)². All of these extensional basins are filled with siliciclastic, marine, transitional and continental successions with a maximum thickness of 3 km defined by the authors as Neotectonic (Cavinato et al. 1994; Mancini and Cavinato 2004); these basins were subsequently buried by a succession of volcanic and volcanic-clastic sequences (Barberi et al. 1994). The sedimentary units filling these extensional basins have been divided into two stratigraphic domains by the authors:

- The first domain, related to the main extensional and subsiding phase, is characterized by marine, transitional and continental deposition and locally by deltaic systems (Mancini et al. 2003-2004; Cavinato et al. 1994; Cavinato and De Celles 1999). This domain is represented by two depositional identified cycles; the first corresponds to the Chiani-Tevere and the Poggio Mirteto Formations, which

² La Vigna et al. 2012a, 2012b

are eteropic between themselves (Girotti and Mancini 2003). The Chiani-Tevere formation is characterized by marine transitional and continental deposits, while the Poggio Mirteto formation is characterized only by continental deposits. The latter formation corresponds to an ancient deltaic system of Gelasian-Santernian age from a paleo-Farfa river flowing from east to west when the coast line corresponded to the current Tiber Valley (Fig. 3).

- The second domain, related to the regional uplift still in effect in the west Apennine (started during the late Pleistocene), is characterized by continental and volcanic deposits.

On the Hydrogeological Map of the Latium Region by Boni et al. (1988), in the studied area, only a 10 m potentiometric line is displayed, and two hydrogeological complexes are defined based on the recharge rate of the outcropping lithologies.

These complexes consist of clastic heterogeneous deposits and the alluvial deposits. The first are defined as relatively cemented sandstones containing silt and clay interbedded with gravels and conglomerates (thickness of between 10 and 100 m). The hydrogeological features of this complex are extremely variable because of the large heterogeneity of its deposits; the complex contains non-continuous and modest aquifers in its gravel and sand levels. The second complex is defined as consisting of recent and ancient alluvial deposits (thickness of approximately 10–20 m for the tributaries and more than 100 m for the main Tiber valley)³. The groundwater resources can be considered to be notably limited for the alluvia of the tributaries, while in the main Tiber valley, they are especially significant and strictly related to the river.

The boundaries of the study area correspond to outcrops of limestone hydrogeological units in the left Tiber bank (Capelli et al. 1987) and to the Sabatini volcanic hydrogeological unit in the right Tiber bank (Capelli et al. 2005). On the right bank, the border of the valley is defined by the Mt. Soratte horst. The hydrogeological analysis presented in this work focused on the groundwater resources in continental alluvial filling units of the sedimentary basin and locally on carbonate aquifers (in the outcropping areas).

Available data and methods

Hydrogeological characterization of the southern MTV has been carried out through geological analysis and in-field hydrogeological prospecting. Starting from the most recent and detailed published geological map of the MTV (Mancini et al. 2004) and official geological maps (Carta geologica d'Italia, 1:100,000 scale), the research activity in this study initially focused on defining the geological relationships between the outcropping carbonate bedrock and the filling series of the tectonic basin and subsequently on the identification of the thickness and typology of these

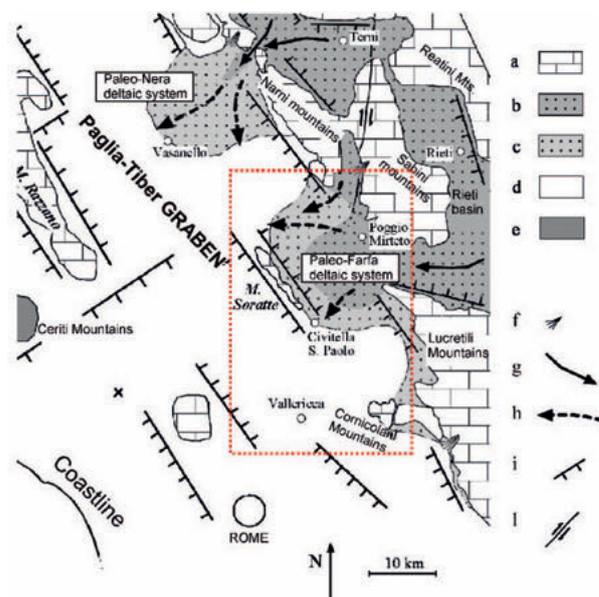


Fig. 3 - Palaeogeography of Latium in the progradational phase of the Late Gelasian-Santernian (modified from Mancini et al. 2003-2004). The red rectangle highlights the study area. Legend: a) Mesozoic-Cenozoic substratum; b) Alluvial and lacustrine, intermontane deposits; c) Deltaic and coastal, siliciclastic deposits; d) Travertines; e) Volcanites; f) Fan delta; g) Fluvial paleo current direction; h) Direction of delta progradation; i) Normal fault; l) Strike-slip fault.

Fig. 3 - Paleogeografia del Lazio nella fase di progradazione del tardo Gelasiano-Santerniano (modificato da Mancini et al. 2003-2004). Il rettangolo rosso identifica l'area di studio. Legenda: a) Substrato meso-cenozoico; b) Depositi alluvionali e lacustri intramontani; c) Depositi silico-clastici deltizi e costieri; d) Travertini; e) Vulcaniti; f) Conoide deltizia; g) Paleo-direzione dei principali assi fluviali; h) Direzione della progradazione deltizia; i) Faglia diretta; l) Faglia trascorrente.

sedimentary series. The hydrogeological interpretation carried out in this study was actually based on the definition of the geological setting to identify the thickness and extent of the aquifers. This was performed through four hydrogeological cross sections that were created as part of an analysis of more than 100 borehole stratigraphies. The carbonate bedrock was intercepted in several deep drillings and in certain vertical electrical soundings performed during the 1970s in the southeast section of the study area by a prospecting company (CMP – Compagnia Mediterranea di Prospezioni). These data were used in the development of the cross sections. While in the center of the main valley there are no boreholes intercepting the bedrock due to its depth, which can be deduced from the existing gravimetric maps (Fig. 2). The only available data about pumping tests derive from a technical report (unpublished data 1950) for the construction of the Nazzano dam on the Tiber River.

An important hydrogeological survey was performed during the summer of 2008 to examine the non-homogeneous hydrogeological setting of this system. The discharge of the main springs and streams, the piezometric levels in wells and piezometers, and the electric conductivity and temperature of groundwater were measured during this survey. Flow measurements were performed using a magnetic current meter and by analyzing the flow velocity along every section

³ In the new Hydrogeological Map of Latium Region 1:100.000 scale (Capelli et al. 2013), which was developed also using data presented here, the piezometric pattern shows the general groundwater flow direction towards the Tiber river course, the main springs and main riverbed springs.

(velocity area distribution of International Standards 2007)⁴. The discharge in many captured springs was measured by means of the traditional volumetric method at the sink.

At approximately 230 points, the water table was detected, and its elevation was defined in meters above sea level (m a.s.l.). The survey points for measurement of groundwater were piezometers and private wells drilled into the clastic-alluvial deposits; the depth was variable from about 20 meters to more than 100 meters, and all measurements were performed under static conditions. The location of every survey point was obtained using a GPS with an error of approximately 3 meters, while the elevation of every point was determined

from the most detailed existing geographic cartography resource (CTR – Carta Tecnica Regionale 1:10.000).

Basic physio-chemical parameters (temperature in °C and electric conductivity in $\mu\text{S}/\text{cm}$) of the groundwater were measured using portable probes. Hydrogeological survey data were used to realize a surficial aquifer potentiometric surface by the triangulation method. The groundwater level of the carbonate system was deduced from the literature.

A physio-chemical map was created following a descriptive statistical analysis using a bubble visualization. In fact, the interpolation of these values in such a large and heterogeneous aquifer system might not produce correct results.

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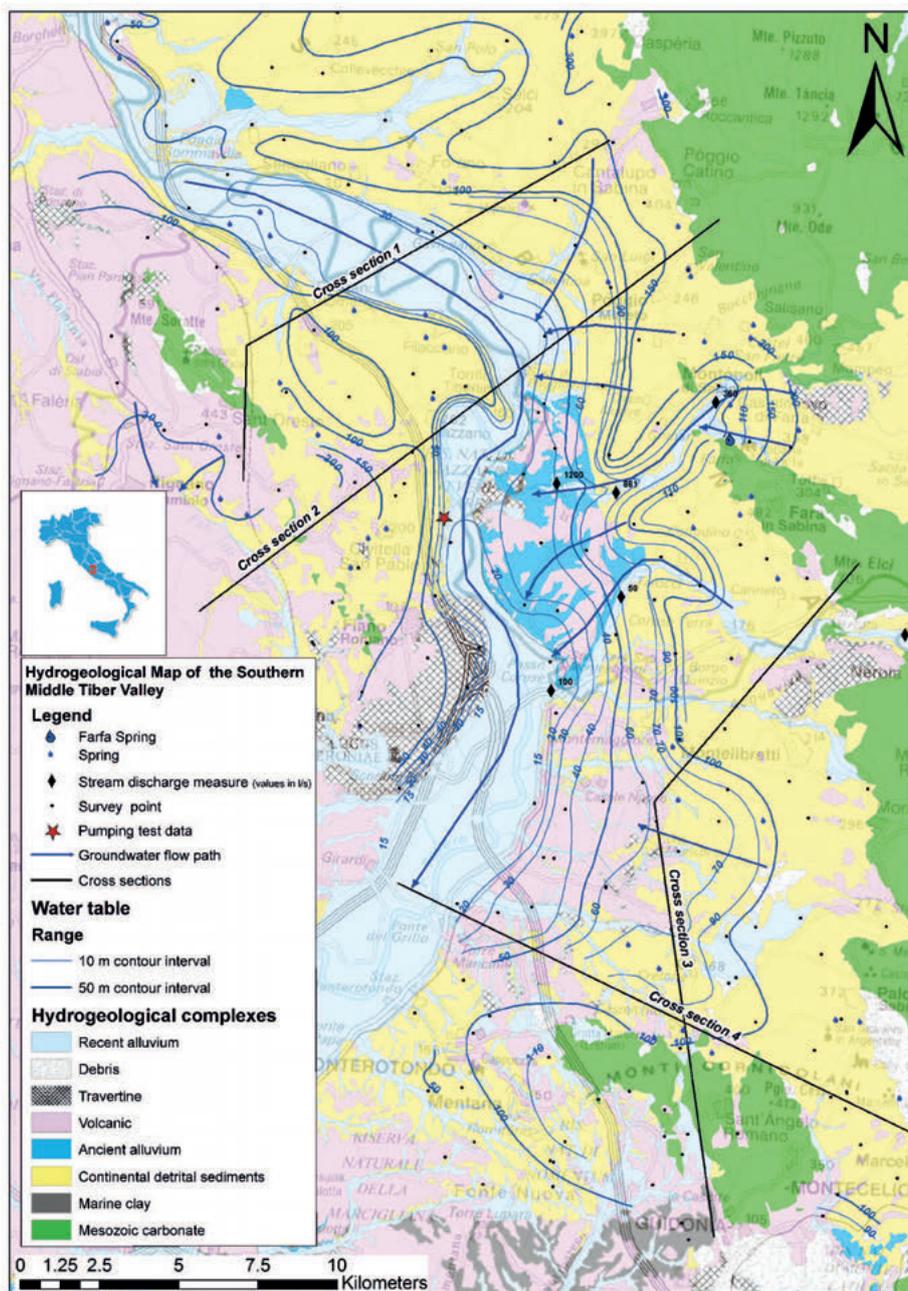


Fig. 4 - Hydrogeological map of the southern MTV.

Fig. 4 - Carta idrogeologica del settore meridionale della media valle del Fiume Tevere.

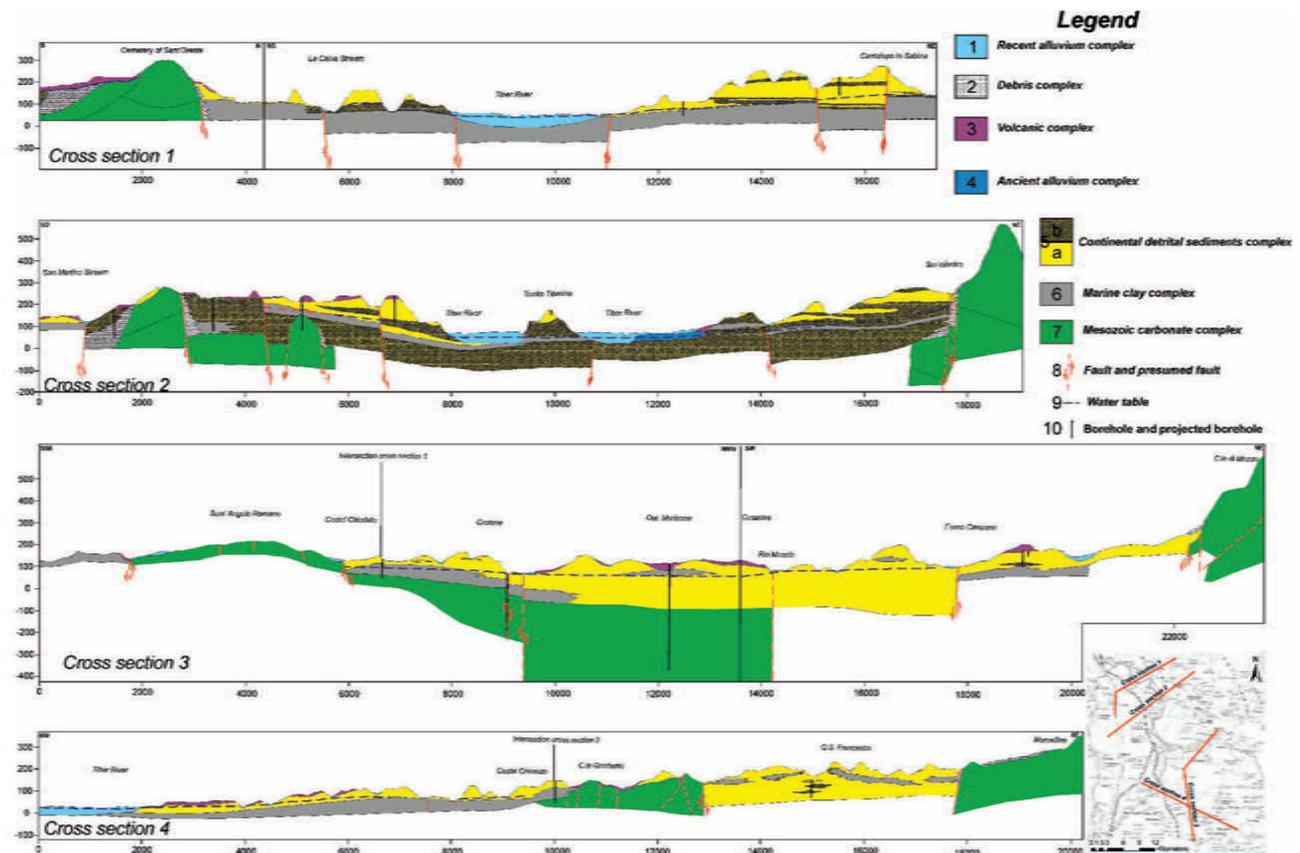


Fig. 5 - Hydrogeological cross sections.

Legend: 1) Recent alluvium complex – In the cross sections this complex comprises the current alluvial sediments together with recent travertines; 2) Debris complex – This complex is around the outcropping limestones and is characterized on average by high permeability; 3) Volcanic complex – This complex collects all volcanic unit covering the sedimentary successions and presents variable permeability ranging from medium and low; 4) Ancient alluvium complex – This complex corresponds to the ancient sedimentary cycles of the Tiber River and it exhibits high permeability; 5) Continental detrital sediments complex – This complex corresponds to the main filling of the tectonic basins. It is characterized by variable permeability ranging between medium (sandy-silty facies - a) and high (gravelly-conglomeratic facies - b); 6) Marine clay complex – This complex is characterized by very low permeability and constitutes generally the aquiclude confining the basal carbonate bedrock circulations and sustaining the upper surficial aquifers; 7) Mesozoic carbonate complex – Generally the permeability of these rocks is high and depending on their level of karst features and tectonic fracturing; 8) Fault and presumed fault; 9) Water table; 10) Borehole and projected borehole

Fig. 5 - Sezioni idrogeologiche.

Legenda: 1) Complesso delle alluvioni recenti - Nelle sezioni idrogeologiche questo complesso comprende le alluvioni recenti assieme ai travertini recenti; 2) Complesso detritico - Questo complesso circonda le rocce carbonatiche affioranti ed è mediamente caratterizzato da alta permeabilità; 3) Complesso vulcanico - Questo complesso comprende tutte le unità vulcaniche che ricoprono la successione sedimentaria che vanno dalla media alla bassa permeabilità; 4) Complesso delle alluvioni antiche - Questo complesso corrisponde agli antichi cicli sedimentari del Fiume Tevere e presenta alta permeabilità; 5) Complesso dei sedimenti detritici continentali - Questo complesso corrisponde al principale riempimento delle depressioni tettoniche. E' caratterizzato da un grado di permeabilità variabile che va da medio (facies "a" sabbioso-siltosa) a elevato (facies "b" ghiaioso-conglomeratica); 6) Complesso delle argille marine - Questo complesso è generalmente caratterizzato da permeabilità estremamente basse e costituisce di norma l'acquiclude che confina le circolazioni presenti nel substrato carbonatico e sostiene gli acquiferi più superficiali; 7) Complesso dei carbonati mesozoici - La permeabilità di queste rocce è generalmente alta e dipende dal livello di carsismo e fratturazione; 8) Faglia e faglia presunta; 9) Livello di falda; 10) Perforazione e perforazione proiettata.

Survey and hydrogeological analysis results

The main results of this study include a hydrogeological map, hydrogeological cross sections and a physio-chemical map. The units of the Geological Map of Italy (1:100,000 scale) and the Geological Map of MTV (1:40,000 scale; Mancini et al., 2004) were connected in hydrogeological complexes to complete the hydrogeological map (Fig. 4) and cross sections (Fig. 5). Every hydrogeological complex is characterized by units with similar hydrogeological properties that qualitatively define their capacities for infiltration and storage.

The defined hydrogeological complexes are as follows:

- Mesozoic carbonate complex – the aim of this work was to characterize Pliocene and Pleistocene continental and

marine sediments, and all Mesozoic carbonate rocks were considered as a unique, undifferentiated complex. This complex is usually notably permeable with good transmissivity and storage due to its fractures and karst features; moreover its aquifers are confined and often thermalized when are subsided by the tectonics and covered by very low permeability complexes (Capelli et al. 1987).

- Marine clay complex – this complex is characterized by notably low permeability and constitutes the aquiclude that confines the deep carbonate aquifer in the tectonic depressions and sustains the surficial aquifers.

- Continental detrital sediment complex – this complex is the most interesting hydrogeologically. It outcrops widely in the study area, and its thickness is limited in the northern section (a few tens of meters), while in the center of the study area, it reaches more than 100 m on both the left and right ridges of the Tiber. Near the Cornicolani Mountains, close to the town of Monterotondo, this complex has a minor thickness of approximately 10 meters. Lithologically, the sediments present significant heterogeneity: the thickest section is predominantly characterized by gravels and conglomerates interbedded with a sand and clay lens, which is a type of alternation typical of deltaic environments (paleo-Farfa river delta - Mancini et al. 2003-2004); the thinner sections in the northern and southern regions of the study area are conversely characterized by sandysilty facies. In the cross sections presented in Fig. 5, this complex was divided into two sub-complexes based on the described differences using borehole data analysis and more detailed maps.
- Ancient alluvium complex – this complex contains the ancient alluvial sedimentary series of the Tiber, which are mainly characterized by gravels in a sandy matrix. The complex exhibits high permeability and, where it exists, determines the hydraulic connection between the continental sediments and the volcanic complex with the recent Tiber alluvium.
- Travertine complex – this complex combines travertine deposits from different facies, such as fitoclastic and waterfall facies characterized by primary porosity and massive and lithoid facies characterized by secondary porosity. The complex usually presents by medium-high permeability and variable thickness depending on the depositional basin.
- Volcanic complex – this hydrogeological complex exhibits a low thickness in the study area and often covers the continental sediment complex. The permeability in this complex is variable, ranging between medium and low due to its heterogeneity and pyroclastic and tufaceous nature.
- Debris complex – this complex is characterized by recent and ancient debris that bound the carbonate outcrops. The permeability is high on average, and the complex can contribute locally to the hydraulic connection between the carbonate aquifers and the continental sediment complex.
- Recent alluvium complex – this represents the current sedimentary cycle of the Tiber River and its tributaries. This complex is characterized by alternating gravel sands and clay that generate several superimposed aquifers strictly related to the water courses.

In Tab. 1 ranges of hydraulic conductivity of some of the hydrogeological complexes deduced by the available pumping tests of the Nazzano dam project are listed. These pumping tests, performed in 1950, interested the recent and ancient alluvial series and the continental detrital sediments in the gravelly and in the sandy facies. The shown values can vary by location depending on the local lithological differences, so their application to all the complexes' extension is only valid as order of magnitude.

The hydrogeological map of this section of the MTV (Fig. 4) depicts a rather complex piezometric pattern that drains into the Tiber River. The minimum measured groundwater level is approximately 15 m a.s.l. in the southern section, while the maximum level is approximately 300 m a.s.l. close to the village of Casperia to the north. The main groundwater flow is oriented from the north to the south in the valley, and the flow receives important contributions to the northeast, especially in the Farfa stream area. This stream is the only minor watercourse whose measured discharge considerably increases downstream passing from 360 l/s in

Tab. 1 - Hydraulic conductivity range about some of the defined hydrogeological complexes. The pumping tests location about the Nazzano dam project is shown in Fig. 4, while data about hydraulic conductivities of the Mesozoic carbonate bedrock and of Travertines are taken from the calibrated numerical model proposed by La Vigna (2009)^a for the Acque Albule plain, located just south to the study area. The shown values can vary by location depending on the local lithological differences.

Tab.1 - Range di conducibilità idraulica di alcuni dei complessi idrogeologici identificati. Lubicazione delle prove di emungimento del progetto della diga di Nazzano è mostrata in Fig.4, mentre i dati relativi alle conducibilità idrauliche del bedrock carbonatico mesozoico e dei travertini derivano dalla calibrazione del modello numerico idrogeologico proposto da La Vigna (2009)^a per la piana delle Acque Albule, collocata subito a sud dell'area di studio. I valori possono variare in base alla località e alle condizioni litologiche locali.

a La Vigna et al. (2016a)

Hydrogeological complex	Hydraulic conductivity range	Data from
Mesozoic carbonate complex	$K \approx 1 \cdot 10^{-4}$ m/s	La Vigna, 2009a
Marine clay complex	$K < 1 \cdot 10^{-10}$ m/s	La Vigna, 2009 ^a
Cont. detrital sed. complex (sandy facies)	$1 \cdot 10^{-5} > K > 1 \cdot 10^{-6}$ m/s	Nazzano Dam proj.
Cont. detrital sed. complex (gravelly facies)	$1 \cdot 10^{-3} > K > 1 \cdot 10^{-4}$ m/s	Nazzano Dam proj.
Ancient alluvium complex	$1 \cdot 10^{-3} > K > 1 \cdot 10^{-4}$ m/s	Nazzano Dam proj
Travertine complex	$1 \cdot 10^{-3} > K > 1 \cdot 10^{-4}$ m/s	La Vigna, 2009 ^a
Volcanic complex	No data available	
Debris complex	No data available	
Recent alluvium complex	$1 \cdot 10^{-5} > K > 1 \cdot 10^{-6}$ m/s	Nazzano Dam proj.

^a La Vigna et al. (2016a)

the highest measuring station, to 1200 l/s near the confluence to the Tiber (Fig. 4). The hydraulic relationships between the Mesozoic carbonate complex and the continental sediment complex can be analyzed in three cases based on data in the literature: west of Mt. Soratte, the water table was observed to sustain an elevation of approximately 200 m a.s.l., while in the Mt. Soratte carbonate aquifer, the water table has been found to attain an elevation of approximately 80 m a.s.l. based on measurements performed during the drilling of the Rome-Florence high-speed train gallery (personal communication of Prof. Maurizio Parotto). The groundwater level of Pozzo del Merro, the karst lake in the Cornicolani Mountains, was also found to reach an elevation of approximately 80 m a.s.l. (Caramanna, 2001; Caramanna & Gary, 2004), and the water table around this carbonate outcrop has been reported to sustain an elevation of approximately 110 m a.s.l. There is still no data regarding the water table elevation in the Sabini and Lucretili Mountains, but Capelli et al. (1987) described the recharge basin and conditions about the Farfa spring (130 l/s) (Fig. 4). The hydrogeological relationships between the carbonate outcrops and the continental detrital complex

in this area suggest a certain discharge from the carbonate reservoir into the overlying sediments, which are supported by the measured discharge increase of the Farfa stream.

The previously described geological structural setting of the MTV as well as the horst and graben style characterizing the carbonate bedrock and outcrops on Mt. Soratte, Mt. Cornicolani, Mt. Sabini and the Lucretili Mountains can be seen in the hydrogeological cross sections (Fig. 5). Cross section 1 shows that in the northern section of the study area, the marine clay complex is predominant, and the low thickness of the overlapping sandy facies of the continental sediment complex does not allow considerable groundwater circulation. In contrast, in cross section 2, the gravelly and conglomeratic facies of the continental sediment complex is predominant and presents a considerable thickness throughout the central section of the study area, with frequent sandy-silty and clayey intercalations being observed.

Cross sections 3 and 4 show the hydrogeological setting of the southern portion of the study area extending northward to the Cornicolani Mountains, where the sandy-silty facies of the continental sediment complex is again predominant.

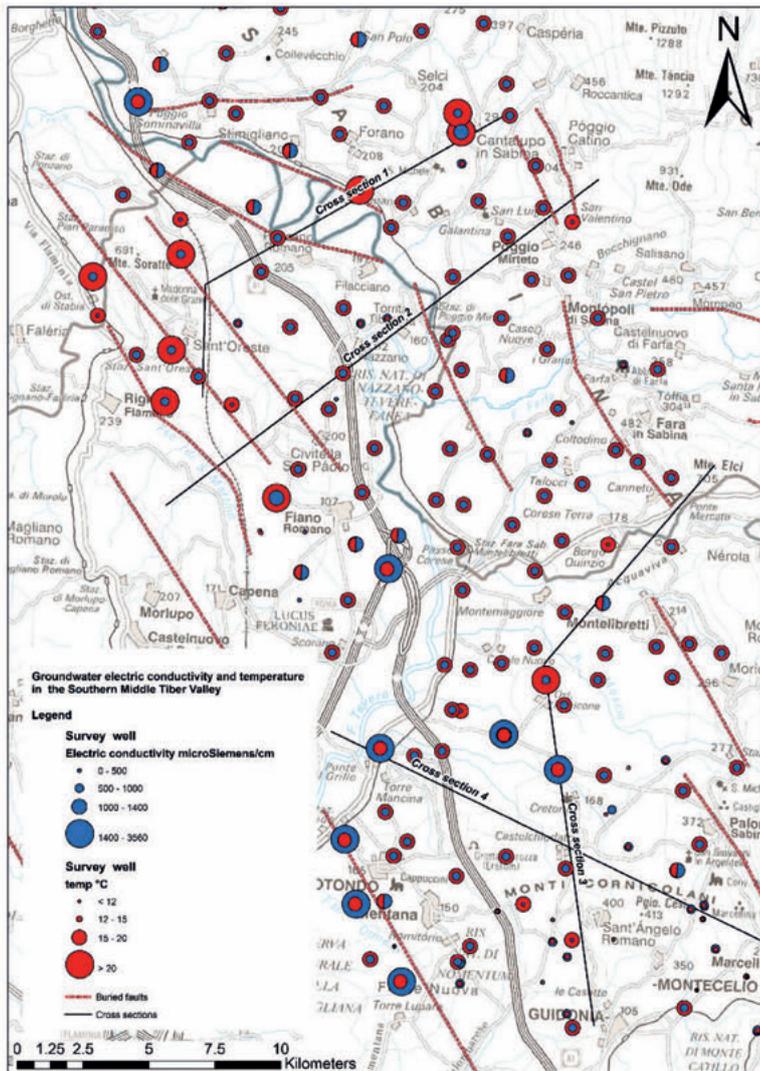


Fig. 6 - Groundwater physio-chemical bubble map of the southern MTV. The plotted buried faults, if compared with the groundwater quality parameters, suggest somewhere the possible upwelling of endogenous fluids.

Fig. 6 - Mappa a bolle dei parametri chimico-fisici di base del settore meridionale della media valle del Fiume Tevere. L'ubicazione delle faglie sepolte note in bibliografia, se confrontate con i parametri chimico-fisici, suggerisce in taluni casi una possibile risalita di fluidi endogeni.

The bubble map presented in Fig. 6 depicts the distribution of groundwater physio-chemical parameters and highlights the detected anomalous values. The established buried faults reported in this area (Mancini et al. 2003-2004) are plotted on this map. Several outlier values for temperature and electric conductivity are aligned according to the Appenninic direction (NW-SE), often overlapping these buried faults. This relationship between groundwater physio-chemical outliers and faults may be explained by gas and endogenous fluid upwelling along the faults.

Conceptual groundwater model

A conceptual model addressing groundwater in the southern MTV (Fig. 7) is proposed here according to the presented results. The paleo-Farfa delta sediments, which are comprised of the gravelly and conglomeratic facies of the continental sediment complex (in the central section of the study area), constitute the most hydrogeologically interesting portion of the southern MTV. According to the piezometric pattern, this aquifer is recharged in the Rieti plain area to the northeast and also by lateral discharge from the Sabini Mountains, and the groundwater flow is sustained by the low permeability marine clay complex. Also the stream flow measurements depicts a considerable increment of discharge

going downstream, especially in the Farfa River (Fig. 4).

In the Cornicolani Mountain and Mt. Soratte sections, the carbonate aquifer does not appear to be directly hydraulically related to the continental sediment complex. The northern and southern portions of the study area are not notably hydrogeologically productive because of the limited thickness of the continental sediment complex and/ or because of the increased presence of the sandy-silty facies of this complex. This setting reduces the contribution of important aquifers.

This general hydrogeological setting of the southern MTV is not expected to be notably dissimilar from the northern section of the MTV, where there are other buried deltaic systems (paleo-Nera) composed of thick series of coarse detrital material (Fig. 3). Regionally, the aquifer system of the continental deposits complex is not as interesting, while at the scale of the study area, the same aquifer system is important and productive, especially in its gravelly conglomeratic facies.

Finally, a regional deep thermalized circulation should be considered to exist in the Mesozoic carbonate complex, which discharges to the surficial system through upwelling flows, concentrated locally along regional faults; this discharge is highlighted by the temperature and electric conductivity anomalies (Fig. 6). However, the depicted outliers could be a result of the upwelling of gases (without water),

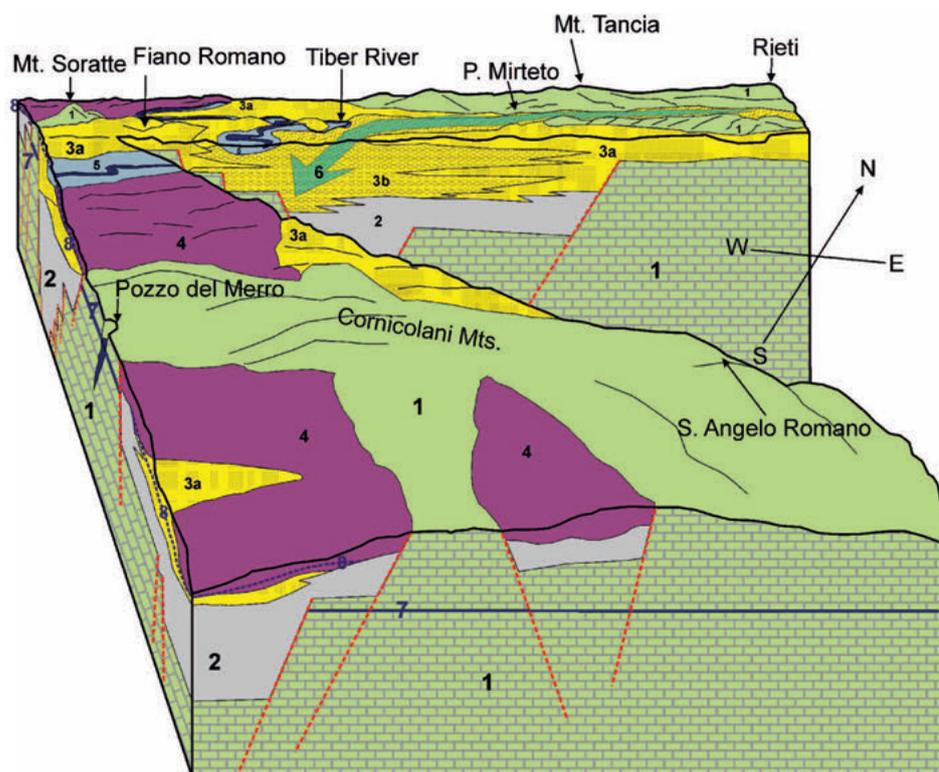


Fig. 7 - Groundwater conceptual model of the southern MTV. Legend: 1) Mesozoic carbonate complex; 2) Marine clay complex; 3) Continental detrital deposits complex - a) sandy-silty facies - b) gravelly and conglomeratic facies; 4) Volcanic complex; 5) Recent alluvia complex; 6) Main groundwater flow path; 7) Water table of the carbonate complex; 8) Surficial water table.

Fig. 7 - Modello idrogeologico concettuale del settore meridionale della media valle del Fiume Tevere. Legenda: 1) Complesso carbonatico mesozoico; 2) Complesso delle argille marine; 3) Complesso detritico continentale - a) facies sabbioso-siltosa - b) facies ghiaioso-conglomeratica; 4) Complesso vulcanico; 5) Complesso delle alluvioni recenti; 6) Principali linee di deflusso sotterraneo; 7) Livello potenziale di falda del complesso carbonatico basale; 8) Livello della falda acquifera superficiale.

which would not reflect an increase in the recharge of the surficial aquifer. The deep thermalized circulation on the Mesozoic carbonate complex is manifest in the hydrothermal springs of Cretone (Carucci et al., 2011), in the south-eastern side of the study area (Fig. 4), and of the Acque Albule basin (Petitta et al., 2011; La Vigna, 2009)⁵.

This work contributes to filling the hydrogeological information gap related to the southern MTV, which is still not completely defined with respect to all of its local characteristics due to the high heterogeneity of the aquifers. The absence of numerous deep borehole data and pumping test results does not allow more detailed and quantitative evaluations of these aquifers to be presented at the present time.

Final remarks

The main outcomes of this study can be summarized as follows: A detailed hydrogeological survey of approximately 230 survey points distributed in the southern MTV over a 400 km² area was performed.

A hydrogeological map with 4 cross sections was constructed using more than 100 stratigraphies from borehole data and existing geological maps. The map and cross sections highlight the hydrogeological complexes and the potentiometric surface of the surficial aquifer.

A physio-chemical map of temperature and electric conductivity values for groundwater was produced using the data collected during this survey.

A groundwater conceptual model of the southern MTV depicting the main groundwater flow was proposed.

5 La Vigna et al. 2012a, 2012b; La Vigna and Gnoni 2014.

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