2.3 Groundwater

Member States are requested to carry out the first groundwater bodies characterisation in accordance with Article 5 of the WFD in order to identify water bodies at risk of failing to reach the WFD objectives. Water bodies at risk will be subject to a further, more detailed analysis.
This chapter describes groundwater bodies in the Tevere river basin and examples of further characterisation.

2.3. Initial characterisation

Hydrogeological structures and aquifers

The WFD provides indications on the analyses to carry out on groundwater, such as: location, perimeter, geological characteristics, pressures, and interdependence with surface aquatic and terrestrial ecosystems.
First of all, the necessity of identifying a reference hydrogeological context emerged from the analyses carried out in the Tevere river basin. Geological and hydrostructural conditions influence aquifer typology and the interrelation between surface water and groundwater.
Therefore, the Tevere river basin, which is characterized by abundant groundwater resources, was schematically subdivided into four main sectors with different hydrostructural characteristics (Figure 17):

The karstic sector, located in the eastern part of the river basin, is constituted mainly by carbonate rocks and contains complex hydrostructures;
The volcanic sector, located in the western part of the river basin, is composed of pery-thyrrenian volcanic structures and it contains important aquifers;
The alluvial sector, located in the central part of the river basin, near the main watercourses and in the intra-montane depressions, contains alluvial aquifers and marine and continental clastic deposits;

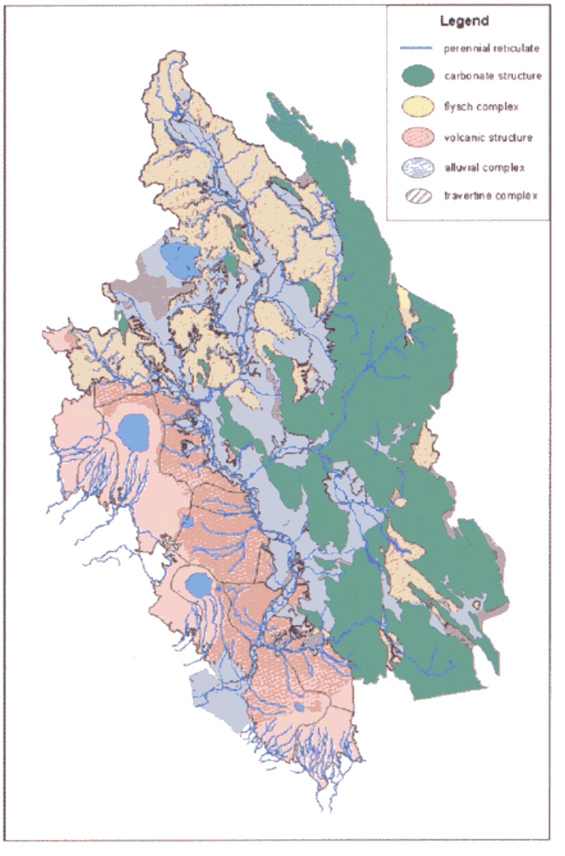

Fig. 17 – Main hydrogeological sectors in the Tevere river basin

The flysch sector, located in the upper part of the basin, is characterized by turbidites sequences consisting of marls, shales, clays and sandstones with evaporites. Only in the more permeable arenaceous sediments, water circulation sustains an appreciable perennial base flow.
During the initial characterisation, the aquifers contained in the flysch sector were neglected, because they are of local interest.

Karstic hydrostructures

Fifteen hydrostructures, mainly composed of carbonate rocks have been identified (Figure 18). These hydrostructures cover a surface area of about 7000 km^2, of which about 5220 km^2 fall within the Tevere river basin and contain the main groundwater resources that feed most of the springs and of the Tevere river basin's perennial hydrographic network. These groundwater resources are considered strategic for their abundance (4 billion m^3/year) and their excellent quality.
These "hydrostructures" are composed of rocks with sufficiently homogeneous characteristics, enclosed within generally well-defined hydraulic boundaries. The rocks that form these hydrostructures tend to absorb, store and discharge rainfall water into the surface through the springs. The hydrostructures that were identified generally do not contain only one significant aquifer, but rather overlapping aquifers that have not yet been identified and characterized individually.
The minor hydrostructures (C2 – Monti di Gubbio; C3 – Monte Malbe and Monte Tezio; C4 – Monte Subasio; C6 – Monte Cetona; C 10 – Monte Soratte) cover a surface area inferior to 60 km^2 and have a flow of several hundreds of liters per second. The big hydrostructures (C1 – north-eastern Umbria; C5b – Valnerina; C5a – Monte Terminillo; C7 – Stifone – Montoro; C8 – Capore – north-eastern Monti Sabini ; C11 – Monti Lucretili and Monti Cornicolani; C12 – southern Monti Sabini and Monti Predestini) are constituted mainly by carbonate successions (known as the Umbro-Marchigiana and Umbro-Sabina successions) deposited in a pelagic domain and influenced by intense translational tectonics that produced folding structures with north-south vergence. Within these large hydrostructures, recent studies identified the existence of various overlapping aquifers and well-defined

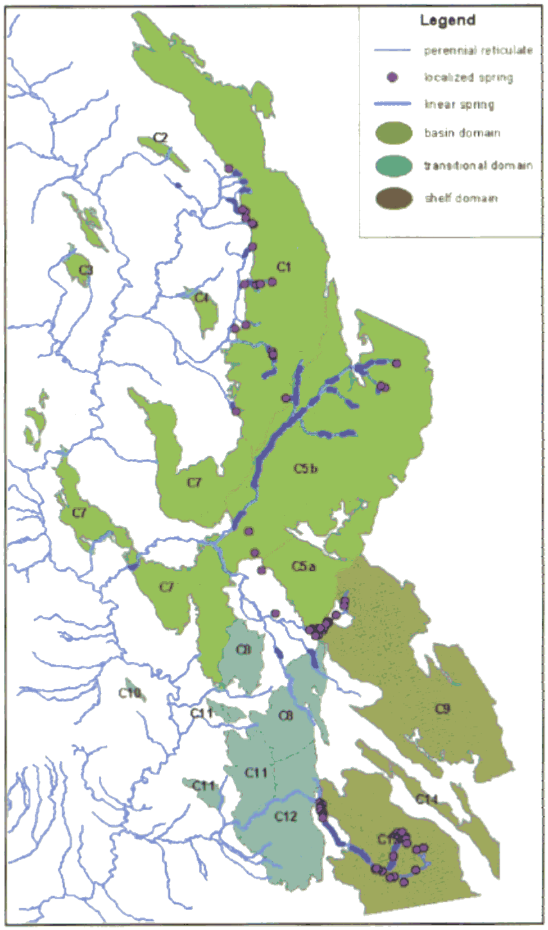

Fig. 18 - *Karstic hydrostructures in the Tevere river basin*

hydrostructural limits, mainly in meridian direction. There are numerous perched and basal aquifers, that supply small and large springs, located in circumscribed areas (localized springs) or distributed along perennial watercourses (linear springs).
There are other two important karstic hydrostructures (C9 – Monte Nuria – Monte Velino; C13 – north-western Monti Simbruini) composed of carbonate rocks of the typical Latium-Abruzzo succession, deposited in a carbonate shelf domain. These hydrostructures have more homogeneous lithological characteristics compared to the Umbro-Sabina succession and contain extended basal aquifers that feed large localized and linear springs.

Average yearly effective infiltration ranges from about 500 mm for hydrostructures in transition areas to about 900 mm for hydrostuctures in a carbonate shelf complex.
The base flow of these hydrostructures in the Tevere river basin is superior to 100 m³/s.
Table 5 shows the hydrostructures' values of the surface area and of the mean and minimum discharge in the dry season.

Aquifers in the volcanic structures

The Mount Amiata, Mount Vulsini, Mount Cimini, and Mount Sabatini volcanic structures are located on the right side of the Tevere valley. The Albano volcanic structure is located on the left side of the Tevere valley, downstream of the confluence with the Aniene River (Figure 19). The surface area covered by the volcanic structures accounts for 5,400 km², of which 2,640 km² fall within the Tevere river basin.

All of these volcanic structures contain aquifers that feed a vast network of mainly linear springs.
The volcanic structures are composed of irregularly distributed pyroclastic rock and lava flows. These rocks were formed on a clayey-sandy substratum from the Plio-Pleistocene epoch and, locally, on

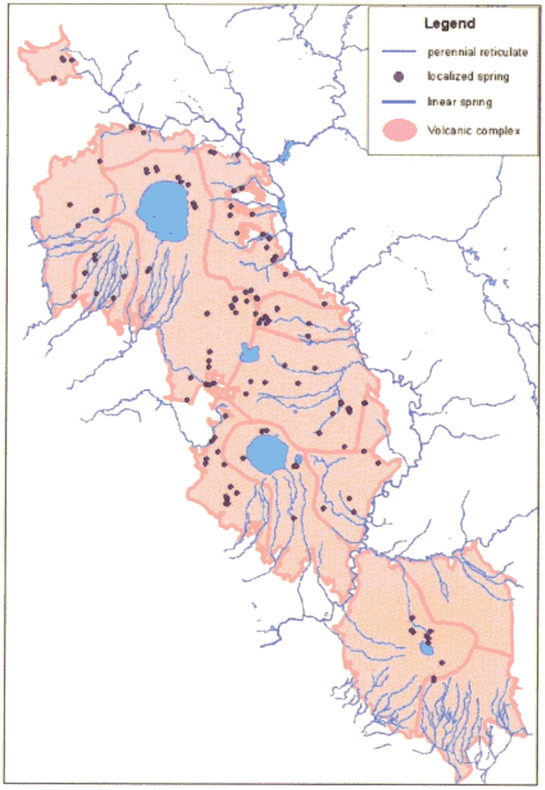

Fig. 19 - Volcanic structures in the Tevere river basin

Table 5 - Values of the surface area and of the mean and minimum discharge in the hydrostructures during the dry season

Structure	Surface area km2	Mean discharge m³/s	Minimum discharge m³/s
C1	1382	6,5	3,5
C2	24	0,2	
C3	60	0,8	
C4	41	0,7	
C5a	224	6	4,6
C5b	1610	19	15
C6	24	0,4	
C7	858	13,5	10
C8	371	5,5	4,5
C9	1032	32	22
C10	5	0,1	
C11	210	6	4
C12	378	2-apr	
C13	666	14	7,5
C14	124	out of the basin	
TOTAL	**7009**	**> 100**	**> 70**

alluvial deposits of the Paleotiber, that drain the overlying pyroclasts.
These aquifers composed of siliceous rocks are characterized by very low salinity water.
The mean effective infiltration of the Mount Vulsini, Cimini and Sabatini volcanic structures is of about 226 mm/year, with maximum values of about 280 mm/year and minimum values around 174 mm/year. *The base flow measured in the riverbed is about 5.2* m^3/s.
The mean effective infiltration calculated in the Colli Albani volcanic structure is about 244 mm/year, with maximum values of 293 mm/year and minimum values of 206 mm/year.

Significant aquifers in the fluvio-lacustrine alluvial and coastal deposits

The Tevere river basin's fluvio-lacustrine alluvial deposits can be divided into three large groups according to their characteristics and origin (Figure 20).
The first group comprises the fluvial alluvial deposits that border the Tevere river's course, from the source to the mouth (A1, A2 and A6), and analogous deposits along the Paglia river's course.
The second group includes the thick Pleistocene fluvio-lacustrine deposits of the intermontane Gubbio valleys (A3), Valle Umbra (A4), Conca Ternana (A7), Piana di Leonessa (A8) and Conca Reatina (A9), that were interested by important reclamation works.
The third group includes coastal aquifers near the mouth of the Tevere river (M1).
In total, nine main alluvial aquifers were identified, covering a total surface area of about 1260 km^2, with an overall flow of about 9 m^3/s.

Table 6 – Withdrawals in the Mount Cimini, Mount Vulsini and Mount Sabatini volcanic structures

	l/s	Mm^3/y
withdrawals for agriculture	7454,8	235,1
withdrawals for industry	1741,9	54,9
withdrawals for drinking water	2594,0	81,8

Table 7 – Colli Albani volcanic structure

	l/s	Mm^3/y
withdrawals for agriculture	1533	48,3
withdrawals for industry	1501	47,3
withdrawals for drinking water	2748	86,7

Groundwater abstraction

Karstic sector

Groundwater resources stored in the karstic aquifers are abundant and of excellent quality. Most of the groundwater is abstracted for drinking water supply directly from the springs or from wells. The abstracted water is then distributed through a vast pipeline network.
Water abstraction for drinking water supply is estimated to about 25 m^3/s, equal to about 790 Mm^3/y.

Fig. 20 - Main alluvial and coastal aquifers in the Tevere river basin

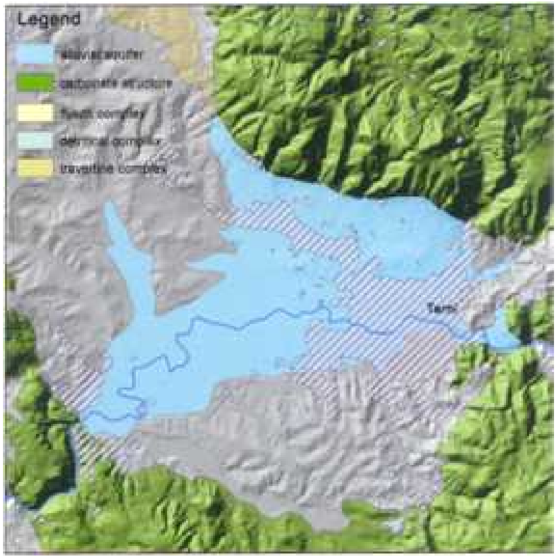

Fig. Terni Valley

Volcanic sector

The estimated total withdrawals in the whole area of the Vulsini, Cimini and Sabatini volcanic structures, comprising the areas within the Tevere river basin and the regional river basins, amounts to about 370 Mm^3/y. Total withdrawals in the Colli Albani volcanic structure amounts to about 180 Mm^3/y.
The following Tables 6 and 7 show the distribution of the abstracted water for different uses.

Alluvial sector

Alluvial aquifers are exploited for agricultural and industrial use and to a lesser extent for drinking water supply.

2.3.2 Examples of further characterisation

Alluvial aquifer (Terni Valley)

The Terni Valley has an extension of about 100 square kilometers. It is formed by a central alluvial plain surrounded by a slightly steep belt that joins the plain area to the calcareous mountains that bound the valley (Figure 21).

The entire area falls within the Nera river basin. The Nera river flows through the Terni Valley from East to South-West.
The area between the calcareous formations of the mountains and the alluvial deposits is represented by extended fluvial and lacustrine deposit outcrops, characterized by various granulometry. In the northern part an ample strip of clastic deposits divides the Martani mountains that delimit the Valley in the north from the plain area.
The main aquifer is located in the alluvial plain which extends for about 40 km^2. It is composed of gravel and sand and it has a thickness of about 20-30 m. It is located on fluvial and lacustrine deposits mostly made of conglomerates in the eastern part and of clayey deposits in the western part. The covering is made of limestone-sandy terrain with a thickness of about 10 meters in the eastern part and of a more reduced or null thickness in the central and western parts of the valley. The aquifer is in hydraulic contact with the Nera river that exerts its influence up to almost the margins of the deposits producing a significant groundwater base flow and recharging the aquifer.
The clastic deposits of the area lying at the base of the Martani mountains are thicker than 50 m in the north and their thickness decreases towards south. They lie on conglomerate and travertine fluvial and lacustrine deposits, where an aquifer of limited dimensions is situated.
In the area characterized by fluvial and lacustrine deposit outcrops, made up of sandy-conglomerate or sandy-clayey sediments, there are small and not very thick confined and unconfined aquifers.

Quantitative status

The regional monitoring network covers both the alluvial plain and the piedmont area of the Martani Mountains.
The plain area is fed by the Nera river that manages to maintain the aquifer in equilibrium, despite the fact that the base flow is strongly modified by withdrawals for hydropower use.
The piezometric trends of some stations of Rome's Hydrographic Services starting from the 50s' were reconstructed on the basis of precedent studies. Fluctuations have always been limited and there have never been repercussions even consequently to the increased civil and industrial withdrawals, that

amounted in certain periods to over 1800 l/s. Historical piezometric measurements and quantitative monitoring data carried out on a periodical basis confirmed these indications.
The sector of the aquifer located in the central part of the plain can be included in Class A (in accordance with the Italian national legislation).
Regarding the built-up area of Terni, the quantitative and chemical status cannot be defined at the present moment because monitoring stations are lacking and the hydrogeological situation is complex.
The area at the feet of the Martani Mountains is subject to intense exploitation for drinking water supply. Withdrawals for drinking water supply account for more than 50% of mean annual recharge. Monitoring data from 1998 to 2002 shows an elevated variability in the water levels in this sector of the aquifer, which is classified in Class C.

Chemical status
Terni Valley's alluvial aquifer benefits from two hydrogeological conditions that allow the aquifer to maintain the water's good qualitative condition: recharge from the Nera river and elevated permeability.
In the central area, at direct hydraulic contact with the river, the water quality results good. Getting farther away from the river the aquifer characteristics get worse due to an increase in the nitrates concentration, that however maintains average values under the threshold of 50 mg/l.
Bad water quality characteristics are evident in the detrital aquifer at the margins of the Martani mountains. This aquifer is characterized by medium to low permeability and it does not benefit from the karstic aquifer's recharge. The consequence is an accumulation of pollutant input in the aquifer.
The main problems are linked to the presence of pollutants from industrial activities. In particular, monitoring of organic volatile halogen compounds evidenced diffuse pollution from *tetrachloroethylene*. This compound was identified in almost all the monitoring points of the network, although in concentrations that were rarely superior to the limits imposed by law. Among these compounds rare positive cases of *trichloroethylene* and *trichloroethano* were identified.

Environmental status
Terni Valley's alluvial aquifer is characterized by a substantial hydrogeological equilibrium and the anthropogenic impact on the water resource quality is considerably mitigated by the Nera river's recharge. The central part of the aquifer, in direct hydraulic contact with the river, shows good ecological status. The more distant areas from the river are characterized by sufficient environmental status. The situation of the aquifer lying at the base of the Martani mountains is different. Its chemical and quantitative status are compromised, therefore its environmental status is poor (Figure 22).
On the basis of environmental status four groundwater bodies have been identified (Figure 23).

Volcanic aquifer (Colli Albani)
The Colli Albani hydrogeological structure is located in the lower part of the Tevere river basin, near the city of Rome (Figure 24).
In the last 50 years this area has been subject to growing pressures due to the expansion of urban settlements, industrial activity and agriculture (water-demanding crops). The water demand was mainly satisfied by groundwater abstraction from wells. Consequently, in the last years, also due to a decrease of rainfall, the base flow in surface watercourses dropped by 50% (Figure 25). In particular, the water level of Albano lake, which is in direct contact with the aquifer, dropped of about 2 m (Figure 26).
Considering that surface base flow is fundamental in sustaining aquatic ecosystems and that the flow of water bodies receiving wastewater discharge determines the quality status of water bodies, it is very important to maintain the base flow at a compatible level with the life of aquatic ecosystems and the achievement of good quality status.
Hydrogeological balance calculations were carried out analyzing the spatial and temporal variability of precipitations and climatic conditions on a monthly basis, analyzing the effects of morphological, lithological, pedological conditions, vegetation and land use on runoff and evapotranspiration with elevated spatial detail, estimating the withdrawals. This methodology allowed us to determine the ratio between withdrawals and effective infiltration.
On the basis of these calculations four balance units have been identified. The balance units have different

withdrawal/recharge ratios and can be considered as four water bodies (Figure 27).

Karstic aquifers (Mount Cucco)
Different aquifers were identified in the C1 structure. Detailed studies allowed for the identification and characterisation of the aquifers' hydro-structural limits, recharge areas, springs, and piezometric fields.
Figure 28 shows an example of more detailed studies carried out in the area of Mount Cucco, in the Umbria-Marche region.

Mount Cucco is situated in the western margin of the Umbria-Marche Apennines and it is constituted by calcareous sequences that go from the Jurassic to the Cretaceous epoch and by arenaceous flysch from the Miocene epoch.
The structure of Mount Cucco is an asymmetrical anticline overturned towards east on the most external anticlinal folds; the eastern and western slopes and the inner part of the structure are characterized by evident tectonic features (faults). In particular, two important faults delimit the central

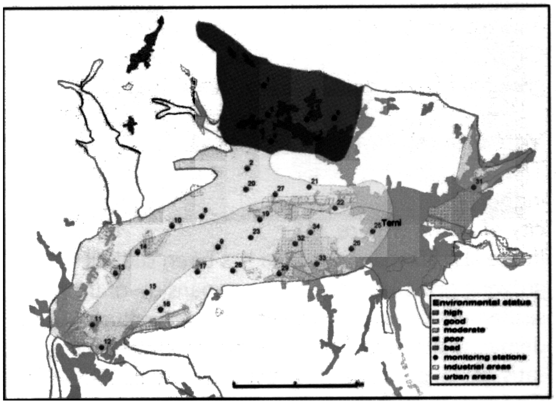

Fig. 22 - Environmental status of the Terni Valley's alluvial aquifer

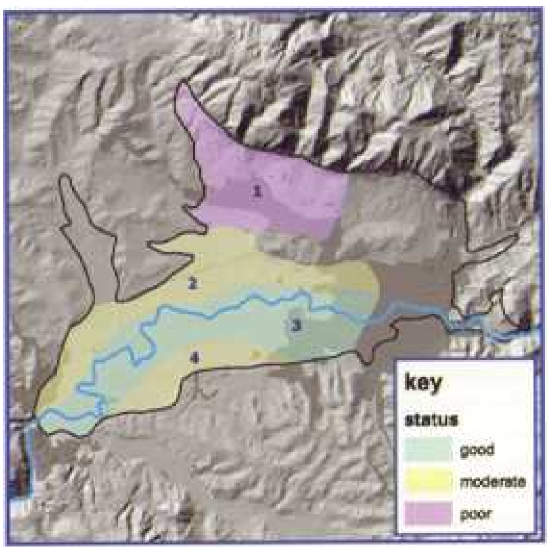

Fig. 23 - Groundwater bodies in the Terni Valley's alluvial aquifer

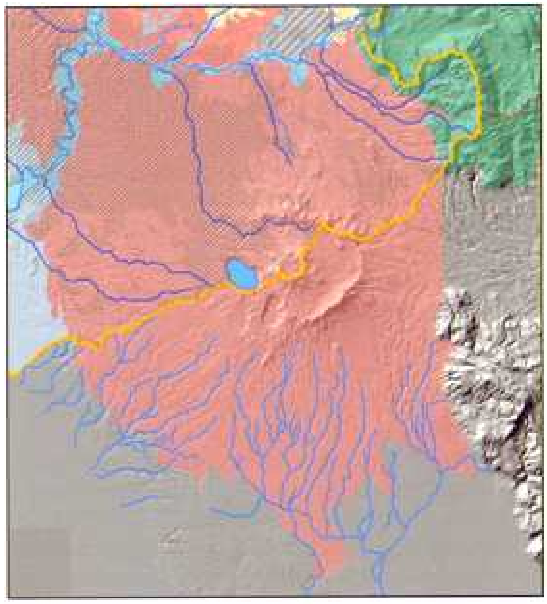

Fig. 24 - The Colli Albani hydrogeological structure

Fig. 25 - Flow measurements in a river of the volcanic sector

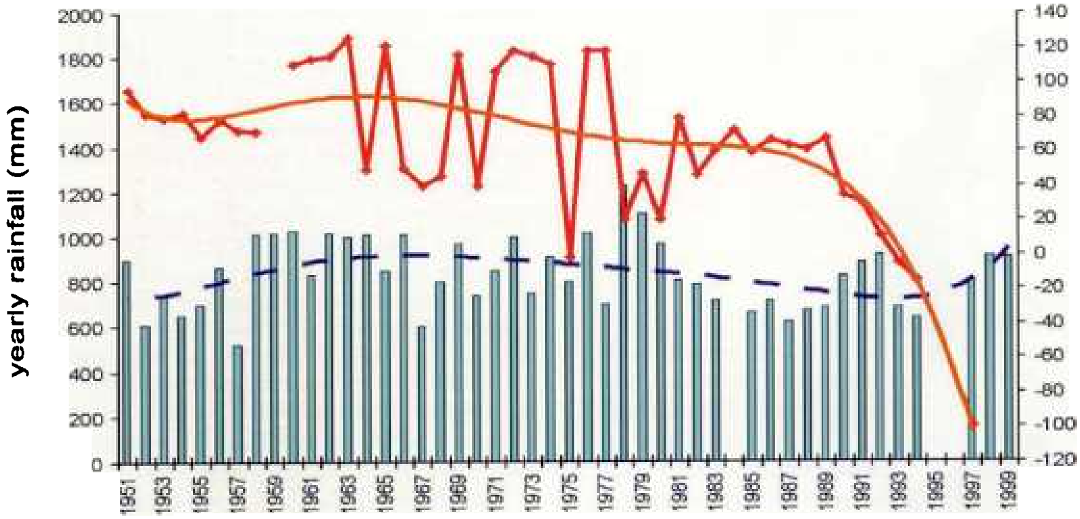

Fig. 26 - The red line shows the hydrometric measurements in the Albano lake between 1995-1999, compared to mean annual precipitations measured in the pluviometric stations of Frascati in the same period

Calcareous massif nucleus, that culminates in correspondence with Mount Cucco, uplifting it in respect to the south-eastern and north-eastern sectors. Furthermore, the nucleus is characterised by a vast network of fractures and by highly developed hypogeous karst phenomena, with more than 50

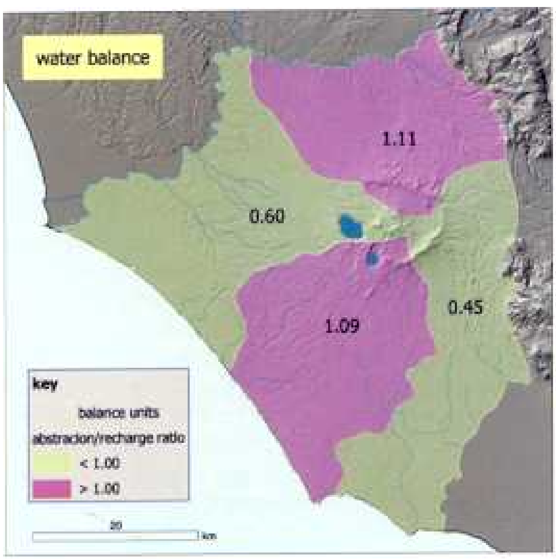

Fig. 27 - Colli Albani hydrogeological balance unit

cavities, for 30 km and a maximum depth of 922 m. A vast recharge area was identified in the nucleus of the hydrogeological structure. The recharge area is hydraulically delimited by overthrust folds towards NE and by the fucoid Marl complex. The calcareous Scaglia belt, externally delimited by prevalently marl complexes, was identified in the north-western, western, and south-western slopes. It is possible to identify two distinct aquifers: a basal aquifer in the calcareous massif of the structure and a peripheral aquifer in the Scaglia. The aquifers' perennial springs are located along the impermeable boundaries and are represented by linear springs distributed along watercourses and to a lesser extent by localized springs. The Scirca spring, the largest localized spring, with a flow of 230 l/s, is exploited for drinking water supply.

Provisional establishment of objectives

The characterisation activity led to the conclusion that it is necessary to carry out a typology analysis also on groundwater resources.
In the Tevere river basin we identified two main typologies for which different objectives must be set:
- Aquifers that represent strategic water resources, that must be safeguarded and for which no

chemico-physical alterations are allowed (this aspect is hardly dealt with in the WFD and it is completely missing in the Daughter Directive on groundwater);
Aquifers at risk, impacted by significant pressures, for which the objective is recovery of chemico-physical status and quantitative status, in accordance with the indications contained in the Daughter Directive, although the Daughter Directive is lacking in regard to quantitative aspects and to the combined effect of quantitative and qualitative aspects.

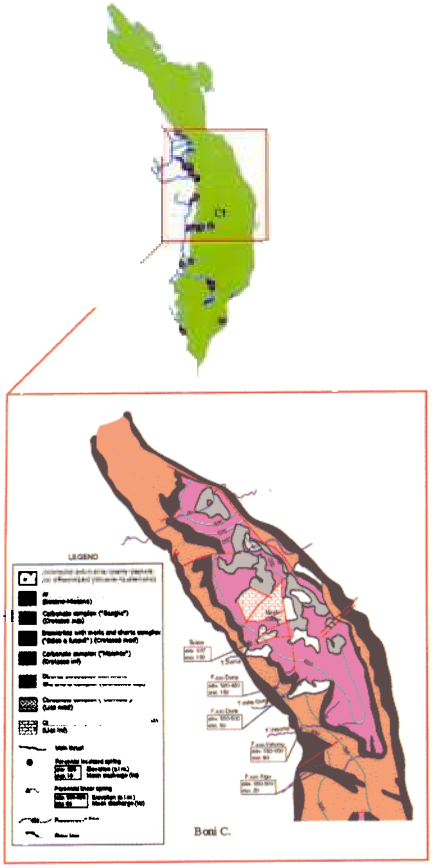

Fig. 28 - Hydrogeological map of Mount Cucco

Authors
Manuela Ruisi

Contributions
Carlo Boni, Giuseppe Capelli, Angiolo Martinelli, Roberto Mazza, Alessandra Santucci