In: Lake Pollution Research Progress
Editors: F. R. Miranda, L. M. Bernard, pp. -
ISBN: 978-1-60692-106-7

Short Communication

AN UPDATED REPORT ON THE WATER CHEMISTRY OF THE LAKES OF CENTRAL ITALY

Franco Medici and Gilberto Rinaldi
Department of Chemical Engineering Materials and Environment, "La Sapienza" University of Roma, Via Eudossiana – 00184 Roma (Italy)

ABSTRACT

Albano, Bolsena and Bracciano are the most important lakes in Central Italy; the relevance and the potential vulnerability of these lakes is enhanced by their location in a populous area, with a high water demand for agriculture and other public uses. The waters of Lake Bracciano are already utilized for drinking supply to the city of Rome.

The aim of this paper is to update the information on the water chemistry of these lakes, on the basis of samplings carried out by the authors; moreover experimental data are compared with similar analyses available from the literature.

Besides the mass hydraulic balance of the lake system, the whole volcanic basin was considered and data related to the period 2000-2005 were also highlighted.

INTRODUCTION

The lake system of Central Italy, composed of five medium-sized lakes (Trasimeno, Bolsena, Bracciano, Vico and Albano) with a total water volume of 15.6 km^3, is the second in importance in Italy after the Alpine Lake district in the region of Lombardia (Mosello, 2004). Moreover, in terms of water volume, it collects approximately 11% of the Italian hydro lake resource, (the total volume of collected water being 150 km^3). The larger lakes of Central Italy are reported in table 1 with their main characteristics; a number of smaller lakes (area < 4 km^2), also located in the same area, are reported in table 2.

Table 1. Morphological characteristics of the main lakes (tw = theoretical water renewal time)

	Level (m)	Watershed area (km^2)	Lake area (km^2)	Volume (10^6 m^3)	Mean depth (m)	Max depth (m)	tw (y)
Trasimeno	259	383	128.7	590	4	6	24.4
Bolsena	305	159	113.6	9200	81	151	121
Bracciano	164	90	57	5050	89	165	137
Vico	510	28	12.1	261	21.6	48.5	17
Albano	293	16	5.9	464	77	175	48

Table 2. Morphological characteristics of the smaller lakes

	Level (m)	Watershed area (km^2)	Lake area (km^2)	Volume (10^6 m^3)	Max depth (m)
Chiusi	251	146	3.87	12.9	6
Martignano	207	6.2	2.49	71	60
Montepulciano	249	119	1.88	2.2	3
Nemi	318	11	1.67	32.5	33
Ripasottile	372	46	1.05	4	8
Canterno	538	67	0.65	13.6	30
Monterosi	237	0.8	0.32	2.2	8

The most important lakes are: Bolsena, Bracciano and Albano, which represent 59%, 32% and 3% (9.2, 5.1 and 0.46 km^3) of the area's collected water, respectively. Lake Trasimeno and Lake Vico, although significant, can be nevertheless considered less important.

According to an approved national classification (Tonolli, 2001), these lakes are classified as "regional", having been created by natural events which shaped the region and gave it a distinctive and prominent character. Of the Lazio lakes, those of volcanic origin are of particular interest, especially Bracciano, Vico and Albano. These are crater lakes, in that their water lies inside a primordial volcanic crater; whereas Lake Bolsena, similar in origin to Crater Lake in Oregon (USA), is located in a volcanic depression caused by the sinking of the centre of the volcanic cone, and is thus classified as a caldera volcanic lake. Lake Trasimeno, in the region of Umbria, differs from the Lazio lakes, being of tectonic origin.

The main lakes, (Bolsena, Bracciano and Albano), apart from being a fundamental source of drinking water and of irrigation, are also considered important for nature and tourism. The Lakes of Albano and Bracciano are public sites of natural and historic interest, and together with Lake Vico, they are part of three regional natural parks.

From the geographical and hydrografic point of view, Lake Albano and Lake Bracciano (see figures 1 and 2), are part of the district of Rome, and their water constitutes the main reservoir basin for the city; whereas Lake Bolsena and Lake Vico (see figure 1), are separated from the hydrographic basin of the Tiber river. The area is of strategic importance and interest for the region of Lazio and for the city of Rome, hence the management of these water systems becomes a very complex matter; what is more, the problems are worsened by the fact that the Mediterranean area is undergoing a phase of climate aridity, with a subsequent negative influence on the hydraulic equilibrium of all lake systems. (Medici, 2005 and 2007).

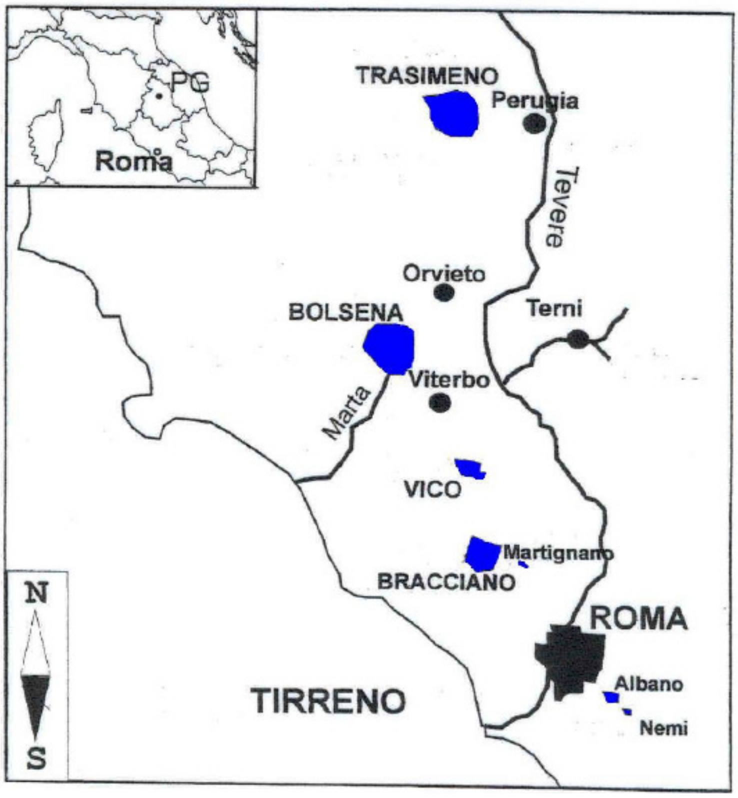

Figure 1. Main lakes of Central Italy.

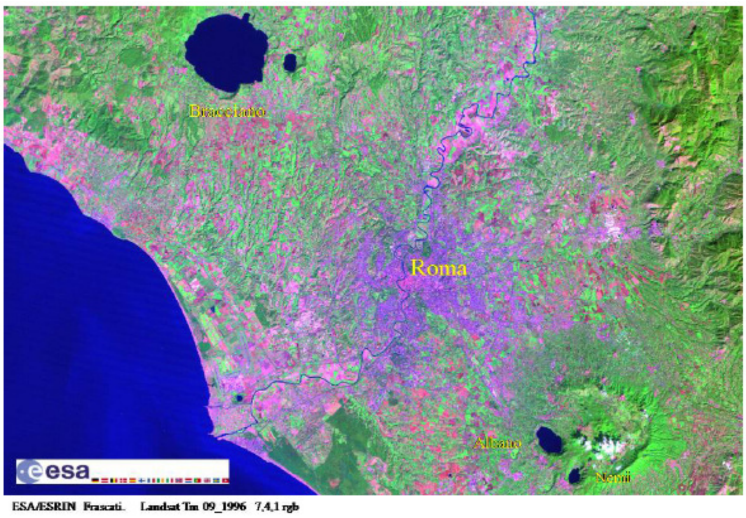

Figure 2. Lakes of the district of Rome.

HISTORY

Lake Albano is fed by underwater pollen and has an artificial outlet, excavated by the Romans in 398-397 b.C. However, since 1992 no surplus water flows from the lake.

Lake Bracciano, on the other hand, has various underground springs, for example the hot-springs of Vicarello, and it has two outlet distributaries: the Arrone River, which once carried the lake's drainage into the Tirrenian Sea, but no longer does so today, and the Paul Aqueduct (built by Pope Paul V in 1611), which still supplies some areas of Rome and the Vatican City gardens. It is important to note that of the thirteen aqueducts which supplied Ancient Rome only two collected lake water, supplying the Alsietina aqueduct (Augustus 2 b. C. with water taken from Lake Martignano), nevertheless already in that period considered undrinkable, and the Traiano aqueduct (Traiano 109. a. C.) which collected water from the foothills of the Sabatini Mountains in the area of Vicarello (Lake Bracciano), also regarded as low quality drinking water. In practice, both aqueducts supplied only water mills in the Gianicolo area of Rome, as well as the naumachia basin of Trastevere; any surplus water was used for irrigation purposes. The same waterspring sources of the Traiano aqueduct supplied the Paul aqueduct, which in fact used part of the Traiano arches to carry its low quality "Paola" water, the same which is still used today in some districts of Rome and the Vatican gardens, flowing along the same 16th century aqueduct structures. More recently, in order to ensure the supply of safe drinking water for the city of Rome, ACEA, Rome's Waterboard Authority, built an "emergency" pipeline which has a maximum carrying capacity of 8 m^3/s, with direct water withdrawal from the lake, at a depth of 50 m. An off take of this water pipeline also supplies the city of Civitavecchia. The total average removal is about 0.8 m^3/s = 25 (Mm^3/y).

Finally, Lake Bolsena is supplied by underground springs reduced by a third over recent years (Pagano, 2000). The lake's outlet is the River Marta, also reduced to a minimum vital ebb flow of 0.5 (m^3/s) = 15.768 (Mm^3/y).

The following sections take into account the most important lakes of the Lazio region (Bolsena, Bracciano and Albano). Their hydraulic balance and water quality is analyzed and commented on, followed by a section on the problem of increasing water pollution over the last two decades.

WATER BALANCE

The analysis was carried out by applying the traditional methods of mass balance, using equations from the literature (Medici, 2007) and the meteorological data available for the region of Lazio in the period 2000 – 2005 (average monthly temperatures, humidity and precipitation). The aim is to evaluate the direct withdrawal of water in stationary conditions carried out to avoid a decrease in the hydrometric level, which makes it compatible with the mass balance. The frame of reference used is reported in figure 3

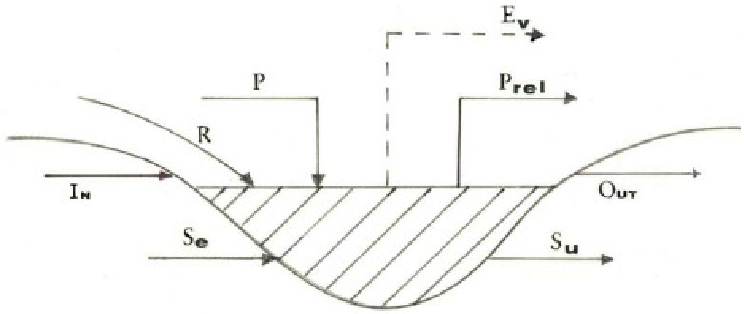

Figure 3. Conceptual scheme of a lake model.

The lake's recharge consists of direct rainfall water over the lake surface (P), of surface run off coming from the drainage basin (R), of underground inflow springs (Se), and of inflow capacity (I_N). The water outflows are made up of evaporation components (Ev), of direct withdrawals from the lake area (Prel), as well as the system of underground outflows (Su) and of the outlet flow capacity (Out). In stationary conditions, it is possible to write the following balance equation:

$$P + R + Se + I_N = Ev + Su + Prel + Out \quad (1)$$

In this case, the inflow capacity (I_N) is usually zero. In fact, the lakes of Lazio do not have inflows; hence, with the term $\Delta S = (Se - Su)$, referring to the water table recharge, the equation (1) can be written more simply as:

$$P + R + \Delta S = Ev + Prel + Out \quad (2)$$

All the parameters of the equation are deducible from annual meteorological data published by the region of Lazio or from the literature, in particular the ΔS values (water table recharge) have been taken from two specific studies (Gazzetti, 2005; Pagano, 2000). The evaporation component measurement (Ev) which is the total sum of the surface lake-water evaporation and the evapo-traspiration of the rain-collecting basin, is based on data from the literature (Medici, 2007, Dragoni, 2006). The global results of the processed data are reported in table 3.

Table 3. Hydraulic balance (data in Mm^3/y)

	Albano	Bracciano	Bolsena
P +R	7.044	86.013	128.620
ΔS	2.428	18.761	67.475
Ev	10.146	90.117	177.270
Out	-	-	15.768
Balance	- 0.674	+ 14.657	+ 3.057

The hydraulic balance results in the above table, report Lake Bracciano and Lake Bolsena as [(P +R) + ΔS > Ev]: that is, the surface evaporation is lower than the total sum of the rain-water recharge and the water table inflows; whereas the equation for Lake Albano is [(P+R) + ΔS) < Ev]: that is, the surface evaporation is higher than the total sum of the rain water recharge and the water table inflows.

The balance analysis, performed in stationary conditions, clearly identifies the maximum volume of water which could be drawn from the lake surface, in order to avoid the decrease of the reference levels. Water should not be taken from Lake Albano, whereas 14.7 and 3 (Mm^3/y) can be drawn from Lake Bracciano and Lake Bolsena, respectively.

In actual fact, the lakes undergo heavy water drawings for various uses (agriculture, drinking water and ornamental purposes). From Lake Bracciano in particular, ACEA draws approximately 25 (Mm^3/y) for drinking water for the city's supply (Musmeci, 2002); Lake Bolsena supplies 10 (Mm^3/y) for agricultural use (personal communication to the authors from the Province of Viterbo), and finally Lake Albano supplies approximately (1 Mm^3/y) for ornamental purposes (for the gardens of Villa Barberini, the Vatican City gardens and other private parks).

In conclusion, taking into account direct water removal, the hydraulic balance is highly negative for all three lakes; the calculated decrease, according to reference levels, is about 30, 18, 11 (cm/y) for Lake Albano, Bracciano and Bolsena, respectively. To have an idea of the decrease of the reference levels of the Lakes of Albano and Bracciano, see figures 4, 5 ,6 and 7.

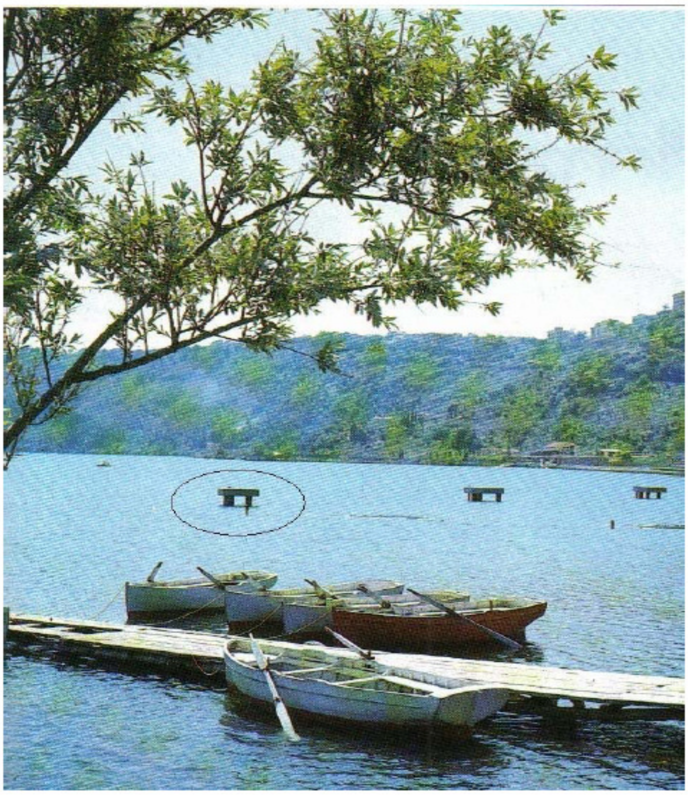

Figure 4. Lake Albano (1970), circled: a pier.

Figure 5. Lake Albano (2005), circled: the same particular of the figure 4.

Figure 6. Lake Bracciano (2006): the pier of Trevignano.

Figure 7. Lake Bracciano (2006): lowering of lake' s water.

WATER QUALITY

The surface water of all three lakes under analysis, is characterized by an average ion concentration of between 5 to 6 (meq/l), with a prevalence of bicarbonate ion among the anions. Table 4 reports the average analytical results recorded for some chemical parameters, related to the samples of surface water taken from different points and concerning recent studies (2004-2007), together with recent data obtained for Lake Nemi.

Table 4. Analytical results (surface samples)

	pH (-)	Conductivity (µS)	Total alkalinity (meq/l)	Total hardness (meq/l)	Number of samples
Albano (Medici, 2004)	7.8	380	4.7	2.9	16
Bracciano (Catalani, 2006)	7.7	390	3.8	2.1	24
Bolsena (Bruni, 2007)	8.5	480	4.1	2.3	8
Nemi (Medici, 2004)	7.6	277	3.27	2.1	8

An important study (Mosello, 2004) made it possible to identify the ion balance for the waters of the five lakes in the region of Lazio, the results of which are reported in figure 8.

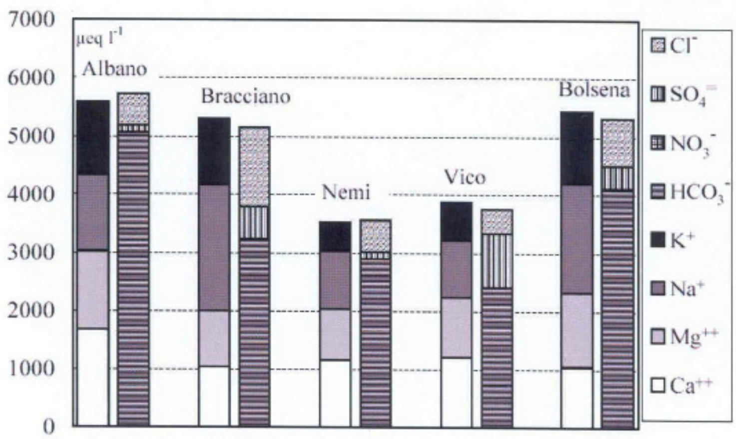

Figure 8. Ion balance of five lakes of Central Italy (Mosello, 2004).

As regards anions, the ion balance suggests that $HCO_3^{\ -}$ > ($SO_4^{\ 2-}$ + $Cl^{\ -}$); regarding cations, on the basis of total hardness the following occurs: (Ca^{+2} + $Mg^{\ +2}$) > $Na^{\ +}$ > $K^{\ +}$, for all the examined lakes.

Botrè and others (1975) in one of their studies, concluded that the water conditions at Lakes Albano and Bracciano were to be defined as discrete, in relation to the parameters set for nitrogen and phosphorus, and in relation to pollution levels from agricultural activities and urban waste. Further studies (1986-2007) analyzed Lakes Albano, Bracciano and Bolsena and a comparison of total nitrogen and phosphorus detected is reported in tables 5, 6 and 7.

Table 5. Lake Albano, total nitrogen (TN) and phosphorus (TP): a comparison

	TN (mg/l)	TP (μg/l)	Number of samples
Botrè, 1975	0.18	-	9
Pagnotta, 1986	0.21	68.4	not indicated
Pettine, 2001	0.31	24.5	4
Medici, 2004	0.87	31	32

Table 6. Lake Bracciano, total nitrogen (TN) and phosphorus (TP): a comparison

	TN (mg/l)	TP (μ/l)	Number of samples
Botrè, 1975	not detectable	not detectable	13
Pagnotta, 1986	0.08	11.5	not indicated
Ferrara, 2002	0.29	9	not indicated
Catalani, 2006	0.37	< 15	48

Table 7. Lake Bolsena, total nitrogen (TN) and phosphorus (TP): a comparison

	TN (mg/l)	TP (μ/l)	Number of samples
Pagnotta, 1986	0.11	11	not indicated
Mosello, 2004	0.21	8	2
Bruni, 2007	0.27	8	7

CONCLUSIONS

It is evident that the basins of Lakes Albano, Bracciano and Bolsena, which constitute a naturalistic and environmental heritage for Europe, are undergoing an intense exploitation of their waters.

Excluding direct removal from the lake surfaces, the state of natural hydrological equilibrium results negative for Lake Albano (- 0.674 Mm^3/y), but positive instead, for Lake Bolsena (+3.057 Mm^3/y) and Lake Bracciano (+14.657 Mm^3/y). However even if actual direct withdrawal of water is also taken into consideration, (Villa Barberini in the case of Lake Albano, ACEA at Lake Bracciano and private concerns at Lake Bolsena), it is easy to demonstrate, also theoretically, what has been amply seen in the last decade, that is, the constant lowering of the lakes' surface equal to 30-18-11 (cm/y) respectively for Lake Albano, Lake Bracciano and Lake Bolsena (see figures 4, 5, 6, and 7).

The concentration of nitrogen measured in different studies over the years demonstrates the alarming increase in the eutrophication of Lake Albano and Lake Bracciano, though less serious at Lake Bolsena. The concentration of nitrogen between 1986 and 2006 increased nearly four times at Lakes Albano and Bracciano, and about 2.5 times at Lake Bolsena.

The situation is particularly worrying at Lake Bracciano, whose water is used as drinking water in certain areas of Rome, and whose replacement time is in theory 137 years, which is longer compared to that of Lake Albano (48 years) and of Lake Bolsena (121 years).

Finally it must be remembered that the waters of Lake Bracciano, as has been noted since 1800, have always contained a certain amount of fluoride ion, recently measured at 1.41 mg/l (Catalani, 2006), very close to the limits of 1.50 mg/l set by the European Directive for Drinkable Water (98/83/EEC). In the event of "global warming", an increase in temperature could determine a growth in evaporative components which would exceed the above limits, with easily predictable consequences.

In the absence of urgent intervention, which are currently unforeseen, Central Italy could very soon find itself facing an environmental disaster. Lake Albano could be reduced to a polluted, stagnant pond while Lake Bracciano could very well dry up and in any case its "last" waters would be so fluoride enriched as to be rendered undrinkable without costly purifying treatment.

It must be remembered an emblematic intervention at the beginning of the last century (1905-1913): the construction of an aqueduct for the growing city of Los Angeles to supply water from a distance of 400 km caused intense desertification of the surrounding area and the salinization of Lake Owens (Sierra Nevada, USA).

Such scenarios, the scientific community agrees, irregardless of opinions on the causes of climate change and reasons for the intense exploitation of the water table recharge of lakes, must be taken into serious consideration by those responsible for lake management. Urgent intervention by the State is needed, given the technical and economic dimensions involved, that cannot be delegated to local public or private entities.

ACKNOWLEDGEMENT

Authors thank Dr. Emanuele Loret (c/o Earth Observation Program Science Application Department of European Space Research Institute of Frascati – Italy) for the satellite image of figure 2.

REFERENCES

Bruni P. (2007). I laghi vulcanici della provincia di Viterbo. www.bolsenaforum.it

Botrè C., Ielmini M., Sanna M., Bielli G. (1975). Contributo alla conoscenza dello stato di inquinamento dei laghi in provincia di Roma: Albano, Bracciano e Nemi. *Rassegna Chimica*, 2, 76-92.

Catalani A., Medici F., Rinaldi G. (2006).Bracciano lake waters: an experimental survey on the surface layer pollution. *Annali di Chimica,* 96, 743-749.

Dragoni W., Piscopo V., Di Matteo L., Gnucci L., Leone A., Lotti F., Melillo M., Petitta M. (2006). Risultati del progetto di ricerca PRIN "laghi 2003-05". *Giornale di Geologia Applicata*, 3, 39-46.

Ferrara O., Vagaggini D., Margaritora F. G. (2002). Zooplankton abundance and diversity in lake Bracciano, Latium, Italy. *Journal of Limnology*, 61(2), 169-175.

Gazzetti C., Loy A., Mazza R., Rossi S., Sarandrea P. (2005) Fattori morfologici, lito – pedologici e territoriali. In *Strumenti e strategie per la tutela e l' uso compatibile della risorsa idrica Lazio,* Pitagora Ed. Bologna-Italy, 95 – 103.

Medici F., Rinaldi G. (2004) Problemi di qualità delle acque dei laghi Albano e di Nemi. *Acqua e Aria*, 35(7), 32-36.

Medici F. (2005). Laghi Albano e di Nemi: carenza idrica e alterazione della qualità delle acque. *Geologia dell' Ambiente*, 13 (1), 8 -11.

Medici F. (2007). Laghi Albano e di Bracciano: bilancio idrico e valutazione dei prelievi. *Geologia dell' Ambiente,* 15 (2), 2-5.

Mosello R., Arisci S., Bruni P. (2004). Lake Bolsena (Central Italy): an updating study on its water chemistry. *Journal of Limnology*, 63(1), 1-12.

Musmeci F., Correnti A. (2002). Elementi per il bilancio idrico del lago di Bracciano. E.N.E.A. Bracciano-Italy, LIFE 02 ENV/IT/000111 Project.

Pagano G., Meneghini A., Floris S. (2000). Ground water budget of the Vulsini basin. *Geologia Tecnica and Ambientale*, 3, 24 - 35.

Pagnotta R., La Noce T., Pettine M., Puddu A. (1986). I laghi dell' Italia Centrale: classificazione trofica ed analisi dei fattori che la influenzano. In *Proceedings of Seventh A.I.O.L. Congress*, Trieste-Italy, June 1986, 385-396.

Pettine M., Tartari G. (2001). Studio sulla caratterizzazione delle acque superficiali del parco dei Castelli Romani. *Proceedings workshop Ricerca sulla qualità delle acque superficiali del parco regionale dei Castelli Romani*, Castel Gandolfo, March 2001.

Tonolli V. (2001). Introduzione allo studio della limnologia. *Edition of Istituto Italiano di Idrobiologia*, C.N.R. Pallanza-Italy, 8 - 24. 13th May 2008