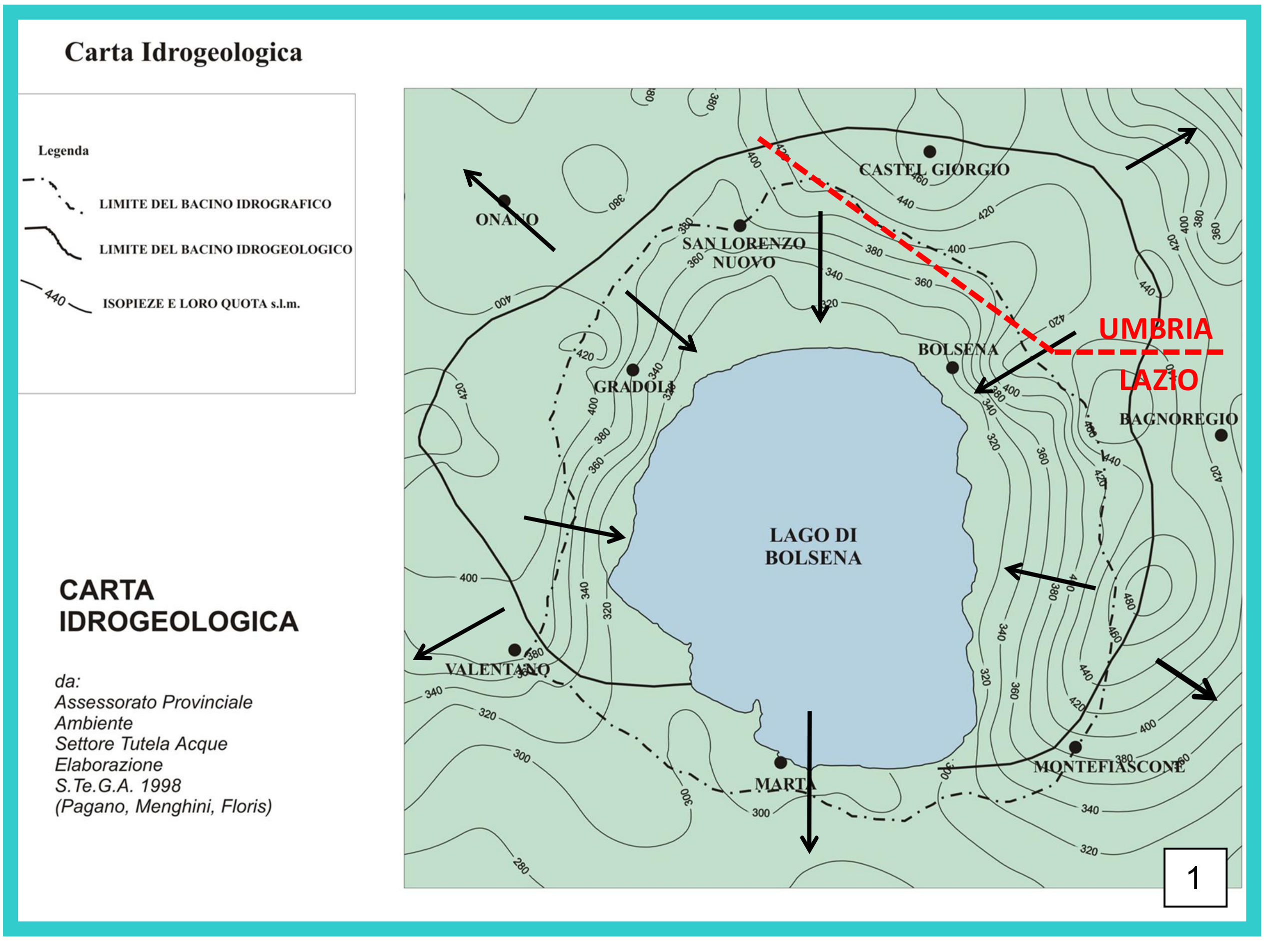
STATE OF LAKE BOLSENA - 2017

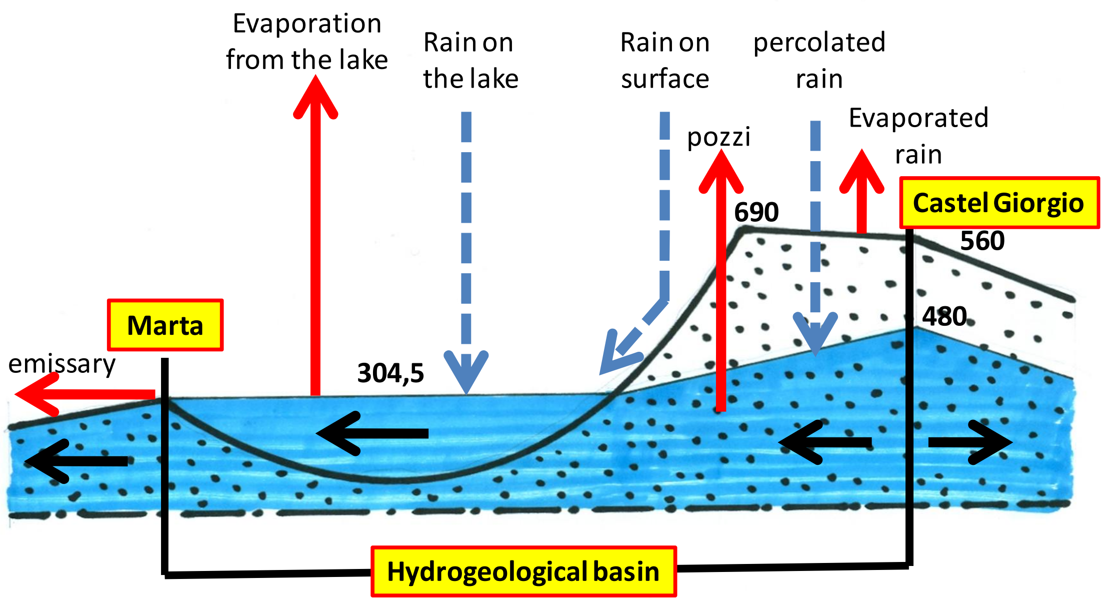
1. Eutrophication

Lake Bolsena, being of volcanic origin, differs from most lakes, in particular from those of the Alpine valleys. In these latter, the walls of the lake basin, being of impermeable rock, clearly delimit the space occupied by the water. The basin of Lake Bolsena, being porous and permeable, does not limit the space occupied by the water. In fact Bolsena lake is the outcropping part of a large aquifer.



The black line of the map [1] shows the limit of the aquifer that affects the lake: it is called hydrogeological basin or catchment area. The rains that fall inside it converge towards the lake, and from the lake the water flows to the Tyrrhenian sea, through the emissary Marta. The rain that falls outside the catchment area reaches the sea through other basins such as those of the rivers Tiber and Fiora. The dotted line indicates the watershed of the surrounding hills. The map shows the isopiezes, that is the elevation with respect to the sea of the aquifer. While the lake is at 304.5 meters above sea level, the aquifer, near Castel Giorgio reaches a level of 480 meters above sea level.

The North/South section [2] shows the hypogeum flow within the aquifer and the surface runoff along the ditches within the watershed. In the catchment basin part of the rain percolates in the underlying aquifer. The hydrogeological balance [3] is difficult to assess because the rain that falls on the ground partly evaporates on the surface, without reaching the aquifer. An approximate balance is hereby proposed comparing the past situation with the present one.



PROPOSED HYDROLOGICAL BALANCE	
Percolated rain + rain from diches	+ 70 Mmc/y
Water extracted by wells	- 30 Mmc/y
Difference evaporation - rain on the lake	-10 Mmc/y
Rate of the missary flow =	**+ 30 Mmc/y**
Corresponding to 0,9 m3/second	

ELEVATION meter slm	
Castel Giorgio	560
Poggio Torrione	690
Aquifer (max)	480
Lake	304,5

2

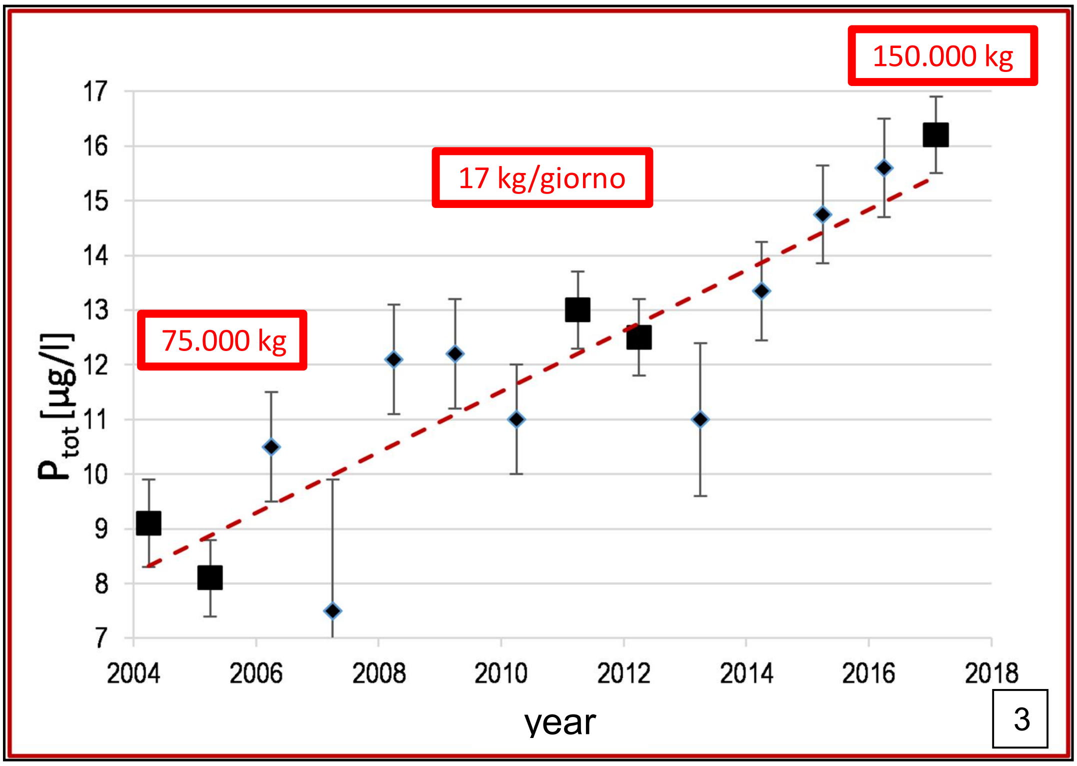
From the literature it is known that at the beginning of the last century the lake water's residence time was 120 years. It is also known that the evaporation from the lake' surface equaled the amount of rain. From these two considerations we may deduce that the annual water recharge from the emerged part of the basin, corresponded to 1/120 the volume of the lake (9.2 km^3), ie 77 Mm^3 .Currently, as the rainfall has decreased by about 10%, we may assume that the recharge from the basin is actually reduced to 70 Mm^3.

During the post-war period, more than 1000 wells for irrigation and drinking water were drilled in the basin, which subtract from the lake's recharge at least 30 Mm^3. The residual recharge therefore amounts to 70-30 = 40 Mm^3. On the lake surface a further reduction of 10 Mm^3 occurs on the lake due to difference between rain and evaporation. Therefore outflow through the emissary is 30 Mm^3, corresponding to a flow rate of 0.9 m^3/sec. At the beginning of the century the flow rate was 2.4 m^3/sec, which explains why the residence time has increased from 120 to 300 years.

The disposal of pollutants through the emissary when the replacement time was 120 years was clearly ineffective, today, having increased to 300 years, the disposal through the outlet has become practically non-existent: everything that enters the lake will remain there forever, eventually deposited as sediment on the bottom.

In the hydrogeological basin there are no industries, the pollutants that reach the lake from the hydrogeological basin are of urban and agricultural origin. They contain plant nutrients, including phosphorus which is the main cause of the eutrophication process. Phosphorus increases the phytoplankton biomass, which in turn causes the increase in animal biomass. At the end of their lives, their mortal remains, vegetables and animals, descend and settle on the bottom of the lake together with the phosphorus they have metabolized during their life time. To a greater quantity of phosphorus coming from the basin corresponds a greater accumulation of remains at the bottom of the lake. Here starts the process of decomposition that fixes at the bottom part of the phosphorus.

The ecosystem, despite the increasing the organic biomass, fails to break down all the amount of phosphorus that continuously arrives from the basin: a part of it remains in solution adding to the quantity not eliminated in the previous seasons. The amount of phosphorus that reaches the lake is not known, nor is it known how much the ecosystem breaks down. However, the concentration of phosphorus in the water's body is known by chemical analysis. Over the last 12 years, the total phosphorus concentration, expressed in µg /l, has doubled, as shown in the graph [3].



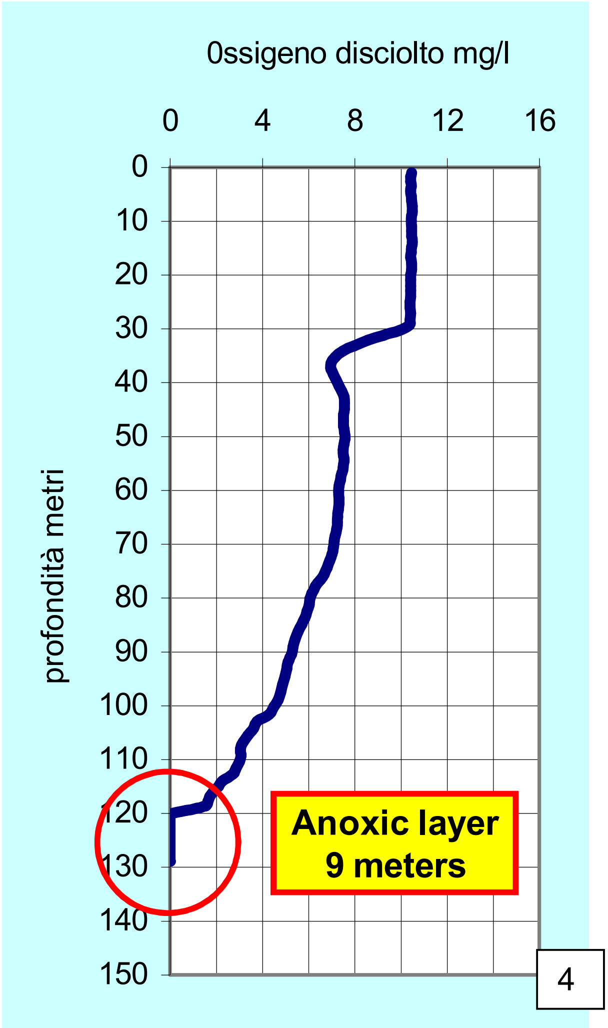
The measurement in µg/l does not make the problem clear enough, for which it is useful to convert this quantity in kg of phosphorus contained in the volume of the lake. It turns out therefore that the total phosphorus in the year 2005 was 75.000 kg while in 2017 it has increased to 150.000 kg. The daily increase in the considered period was 17 kg per day. In conclusion, the ecosystem naturally reduces an unknown quantity of phosphorus, but does not break down the excess of 17 kg/day that causes degradation. The only remedy is to identify the origins of excess and provide for its containment.

In the above situation, the dissolved oxygen in the body of water becomes important, particularly in the water layer at the bottom, which is in contact with the decomposing remains. The decomposition and the subsequent mineralization is a process that involves oxygen consumption. If the oxygen is insufficient and depletes, the decomposition by oxidation ends. The decomposition and mineralization slowly continue with a putrefactive anoxic process. This is a bad indicator of the lake status.

The oxygen dissolved in the water comes from the contact of the lake surface with the atmosphere. The oxygenated surface layer reaches the bottom when the lake is stirred by the strong northern winter winds, but the meteorological situation is not always favorable. In the graph [3] the years in which the complete remixing took place are indicated with a larger symbol, the absence of complete remixing may last up to 5-6 years. Lake of Bolsena is therefore a vulnerable environment not only because of the lake's long residence time, but also because of the unfavorable meteorological situation.

Sediments at the bottom

LAKE IN GOOD HEALTH
Demolition of the organic substance by means of aerobic bacteria. (oxidation)
DEGRADED LAKE
Demolition of the organic substance by means of anaerobic bacteria (putrefaction)



As shown in the graph [3], after the year 2012 there have been four years without remixing. In December 2016, a severe anoxia occurred, as shown in the registration carried out with a multiparametric probe [4]. Anoxia involves an additional degradation factor: the previously mineralized sediments can release soluble phosphorus that is added to the phosphorus coming from the basin. This is a supplementary "internal burden" that greatly accelerates the process of eutrophication.

Unusually at the beginning of 2017, a very strong and persistent northern wind oxygenated the whole column of water but, at the end of 2017, signs of anoxia at the bottom appeared again. It is therefore extremely urgent to reduce the arrival of phosphorus from the basin.

ARPA has issued an official table [5] on the state of the lakes of Lazio for the year 2015 from which we see that the ecological status of Lake Bolsena is "sufficient". According to the current legislation all the lakes that in 2008 were in "sufficient" status had to reach the "good" status by 2015; for the lake of Bolsena the reverse occurred, it was in "good" state in 2008 and became "sufficient" in 2015.

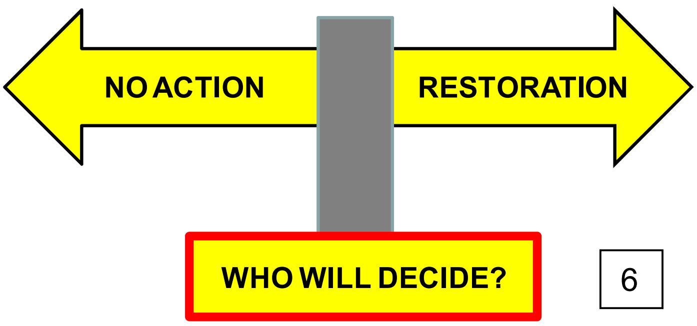
ARPA LAZIO – Stato ecologico dei corpi lacustri – 2014 – 2015
determinato secondo cinque classi di qualità:
ELEVATO – BUONO – SUFFICIENTE – SCARSO - CATTIVO

Stazione	Corpo idrico	Fitoplancton*	LTLeco	Tab 1/b	Parametri critici	STATO ECOLOGICO
L1.30	LAGO DI CANTERNO	Cattivo	Sufficiente	Buono		CATTIVO
L1.32	LAGO DI POSTA FIBRENO	Buono	Elevato	Buono		BUONO
L3.39	LAGO DI VENTINA	Sufficiente	Buono	Buono		SUFFICIENTE
L3.40	LAGO DI RIPASOTTILE	Cattivo	Sufficiente	Buono		CATTIVO
L3.41	LAGO LUNGO	Cattivo	Buono	Buono		CATTIVO
L3.42	LAGO DI SCANDARELLO	Buono	Buono	Buono		BUONO
L3.44	LAGO DEL TURANO	Buono	Sufficiente	Buono		SUFFICIENTE
L3.45	LAGO DEL SALTO	Sufficiente	Sufficiente	Buono		SUFFICIENTE
L3.57	LAGO DI PATERNO	Sufficiente	Sufficiente	Buono		SUFFICIENTE
L4.26	LAGO DI BRACCIANO	Elevato	Sufficiente	Buono		SUFFICIENTE
L4.27	LAGO DI MARTIGNANO	Elevato	Buono	Buono		BUONO
L4.28	LAGO DI NEMI	Sufficiente	Sufficiente	Buono		SUFFICIENTE
L4.29	LAGO ALBANO	Buono	Sufficiente	Buono		SUFFICIENTE
L5.30	LAGO DI BOLSENA	Elevato	Sufficiente	Buono		SUFFICIENTE
L5.34	LAGO DI VICO	Buono	Sufficiente	Sufficiente	Arsenico	SUFFICIENTE
L5.70	LAGO DI MEZZANO	Buono	Sufficiente	Buono		SUFFICIENTE

Tab. 1 – Stato ecologico dei corpi lacustri. Il calcolo del parametro "fitoplancton" si è basato sulla sola metrica "clorofilla" in quanto i metodi di calcolo del biovolume sono variati in corso d'opera rendendo i risultati difficilmente confrontabili.

5

Regardless of legislation, the 2016 anoxic layer [4] demonstrates that the lake has reached an alarming eutrophic state. Continuing to pour into the lake 7 Kg/day of phosphorus [3] the "internal load" will worsen further and the degradation will become irreversible. We are at a crossroads [6] and a prompt and conscious decision is needed.



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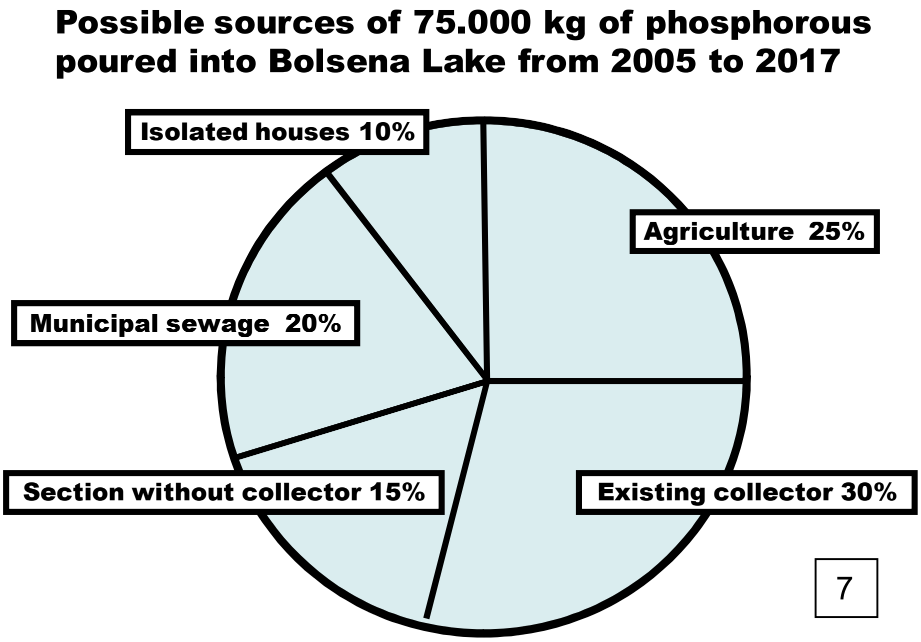
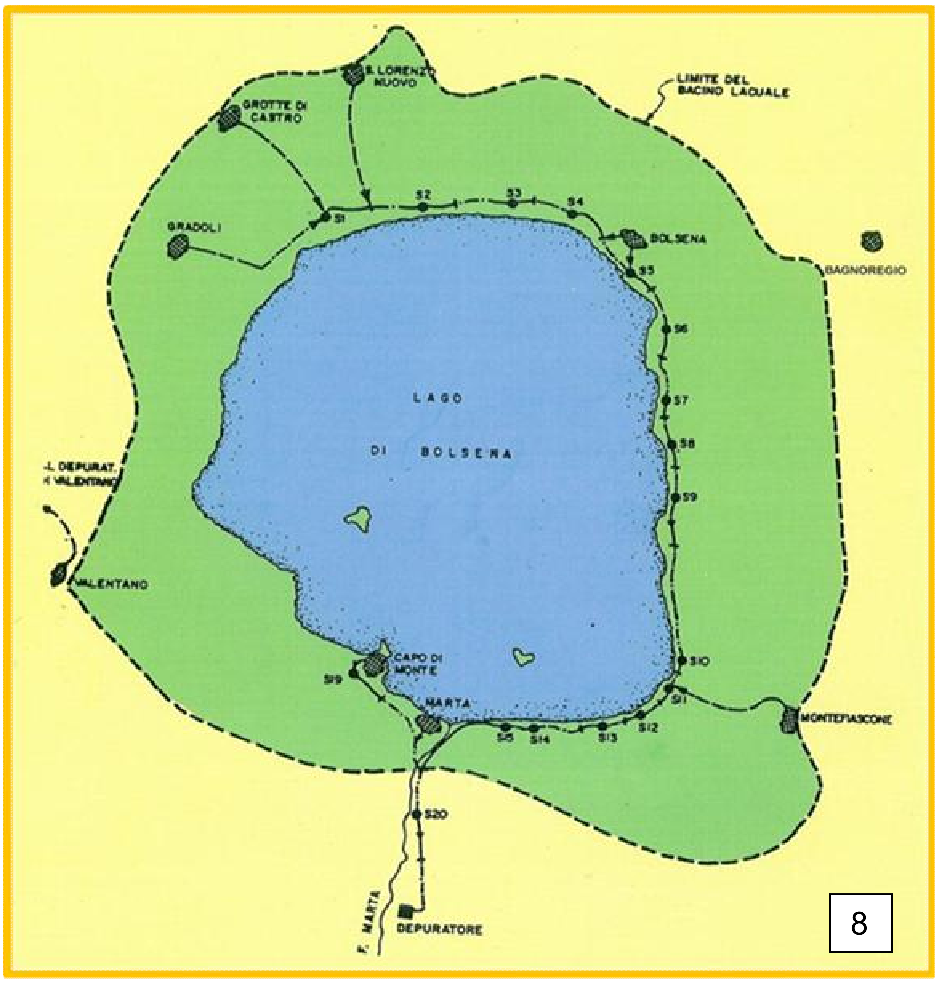
In order to attempt the path of restoration, it is first of all necessary to identify the origin of the exceeding 7500 kg of phosphorus that reached the lake from 2008 to 2017. The origin of the phosphorus, as previously anticipated, is of agricultural and urban origin. There are no studies to quantify the percentage of each cause, but the overall situation can be summarized by the following graph [7].



Agriculture 25% - In agriculture fertilizers, herbicides and pesticides are used. In the same activity, cattle and pig farms should be included. Phosphorus reaches the lake for percolation and runoff, in particular as a result of heavy rains. In order to reduce the contribution of phosphorus and chemical substances in the hydrogeological basin, the voluntary conversion into eco-compatible agriculture must be encouraged. Administratively, the situation is complicated by the fact that a significant part of the agricultural activity in the basin is carried out in the territory of the Umbria Region [1].



Existing collector 30% - This consists of a pipeline that collects the urban wastewater from 7 municipalities [8]. The sludge is driven by a succession of 20 pumping stations that take it out of the hydrogeological basin to a purifier located along the river Marta. The protection of the lake is entrusted to the collector and pumping stations. Any failure of the sewage treatment plant does not affect the lake, but only the river. The collector and the purifier are managed by a consortium among the municipalities (COBALB), while the sewers are managed by the individual municipalities.

The attribution to the collector of 30% of the phosphorus arrival is due to numerous spills of the collector due to: pumping station failures; heavy rainfall flowing into the collector; pipeline leaks, and so on. Photo [9] shows the final section of the pipeline at station 20. The pipe releases the sludge into the river, instead of sending it to the purifier, which anyway is out of service. This release of sludge into the river has lasted almost one year. The pollution reaches the shore of the Tyrrhenian Sea.

9

Presso Stazione 20
Data: 22/12/17
Coordinate foto
42°21'22'' N,
11°55'08'' E
Portata circa 5 l/sec

The release does not concern the lake but there is the suspicion of severe leaks also in the lake because the flow rate at station 20, being of the order of 5 liters/sec, appears too low as compared to the 32600 residents served by the collector. This suggests that there are many losses in the whole sewage collection system.

10

Presso stazione 9
Data 2/1/2018
Coordinate foto
42°35'11.7"N
11°59'43.7"E
Portata circa 7 l/sec

Along the lakeside there are visible losses coming from the collector and some municipal sewers. At station 9 there is a large flow of sewage towards the lake [10]. Perhaps it is the entire rate of flow collected upstream.

11

Proceeding along the lake there is a loss from a substation that discharges part of the sewage of S. Lorenzo into a ditch [11]. Part of the losses are not visible because they are submerged: we know they exist from olfactory manifestations.

Municipal sewage 20% - This is due to leaking pipes or missing connections to the main collector pipeline. Photo [12] was taken at the end of summer when the tourist load was high. We see the manhole that overflows with sewage. Photo [13] was taken in winter when the slurry load was lower or after the inconvenience was repaired.

12

13

Da Montefiascone
Data 1 Settembre 2017
e 2 gennaio 2018
Coordinate foto
42°36'09.7"N
11°59'53.1"E

Photo [14] is an example of permanent unloading in the ground during the winter season. The flow increases considerably during summer.

14

Quartiere S.
Antonio
Data 2/1/2018
Coordinate foto
42°36'09.7"
N 11°59'53.1"E)

Photo [15] shows the loss of a municipal sewer that took place years ago, which in the specific case was promptly repaired by the Municipality. After repair people forget about the failure, thinking the problem is over. The lake does not forget: it memorize each failure as reported in graph [3]. Nor will forgive the phosphorous influx while waiting for the repair of the main collector and other sewerage losses.

Furthermore, the sludge losses in the lake are the cause of a serious collateral health effect due to their content in fecal bacteria. The remote alarm system is a total disaster, consequently losses are not communicated to ARPA which is not therefore in the condition to impose mandatory bathing bans. COBALB has been reported to the Attorney for pollution of the lake and the shore of the Tyrrhenian beaches near the outlet of the emissary river.

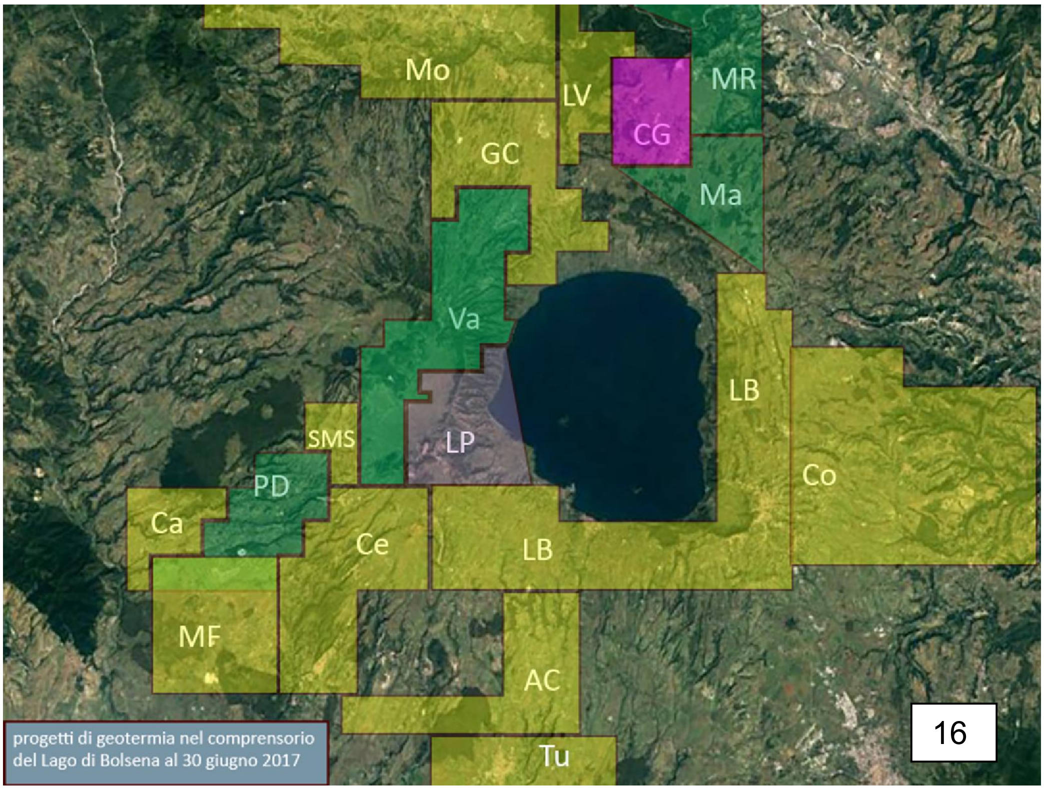
Isolated houses 10% - It is estimated that isolated houses are of the order of 300, often farms or tourist accommodations. They use biological pits which are loosing polluted liquid percolating in the aquifer then reaching the lake. Also for this type of pollution the contribution of phosphorus from the Umbria region is unknown. There is no independent body that certifies and checks the regularity of all discharges.

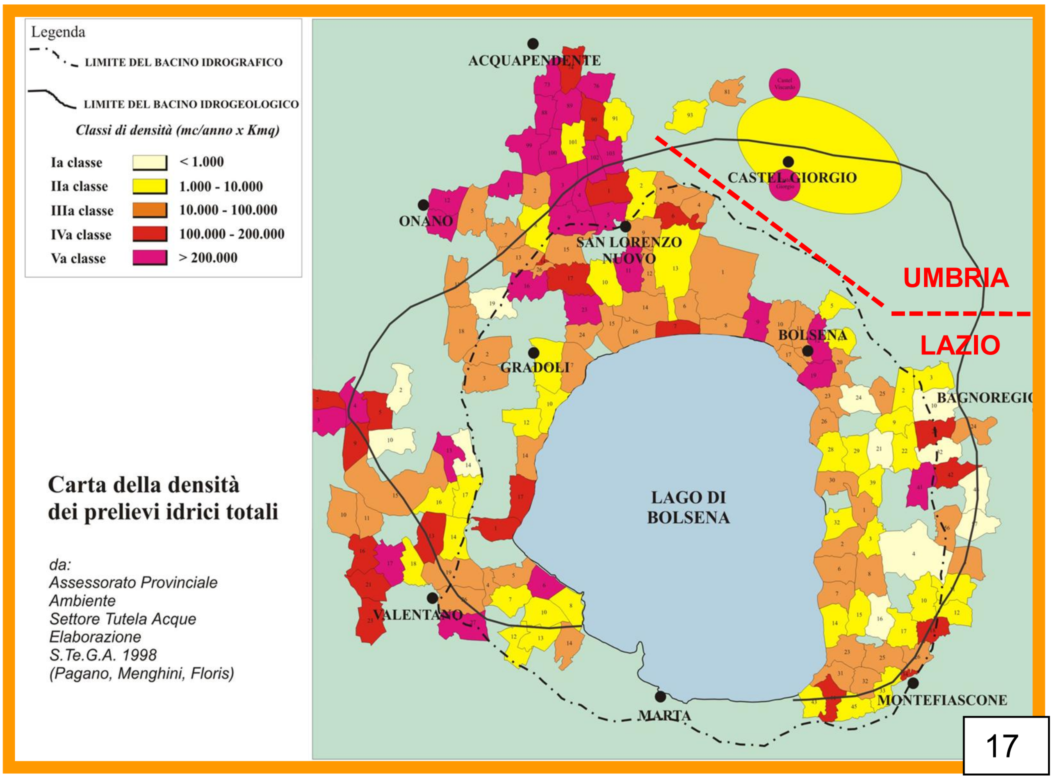
Section without collector 15% - in this area there are numerous tourist activities and restaurants. An eventual additional collector should link up with the pumping station near Capodimonte, but it should cross the area of Mount Bisenzo, on which there is an archaeological zone. As an alternative to the collector, local phyto depurators could be installed.

Citizens make a big confusion among the three different types of pollution: (a) pollution related to bathing, caused by bacteria contained in urban sewage; (b) eutrophication, due to phytoplankton fertilizers, such as phosphorus, which degrade the ecological state of the lake in a slow but lasting way; (c) chemical pollution, currently not present, but which could occur if geothermal plants would be authorized, which would cause the presence of arsenic and other carcinogenic substances in the aquifer and in the lake. COBALB ensures that the collector will be repaired by April 2018, for which sewage losses and pollution related to bathing will cease, al least for the part attributable to the collector. As far as eutrophication is concerned, it will take a very long time to restore the lake to the "good" status. There is no hope that the repair of the existing collector will solve all problems of eutrophication: it is necessary to intervene also on all the other causes [7].

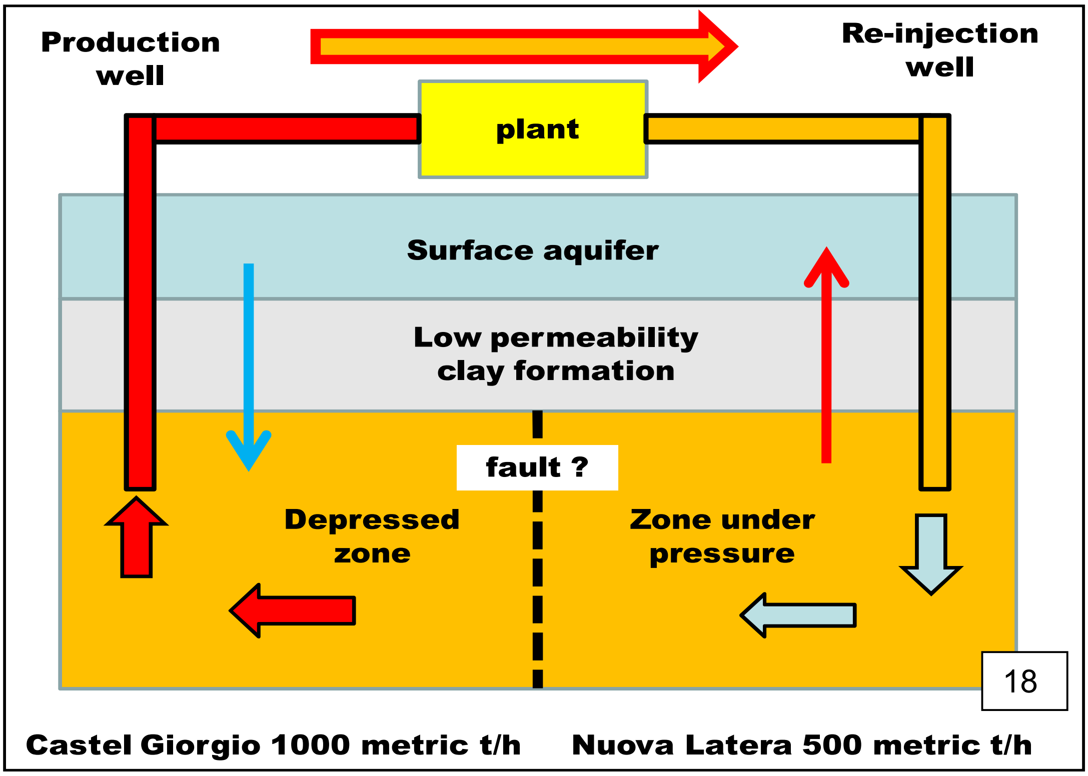
2 – Geothermal projects

Map [16] indicates the geothermal projects in the area surrounding Lake Bolsena. Most of them are located in the same areas from which water is drawn for drinking and irrigation purposes [17]. The map does not report the situation in Umbria, but there are also large withdrawals from it. It is a situation that deserves extreme attention due to the danger of pollution of the aquifer and the increase in risk, as well as the possible damage to nearby thermal activities.





The process of the various types of geothermal power plants, currently in use, have in common that they take in the reservoir rock high temperature fluid by mean of production wells and, after having extracted heat from the fluid, they return it cooled to the same rock, by mean of re-injection wells [18]. The extraction and re-injection are carried out at a distance of a few kilometers so that the fluid can re-heat itself in the hypogeum return path between the reinjection zone and the production area.

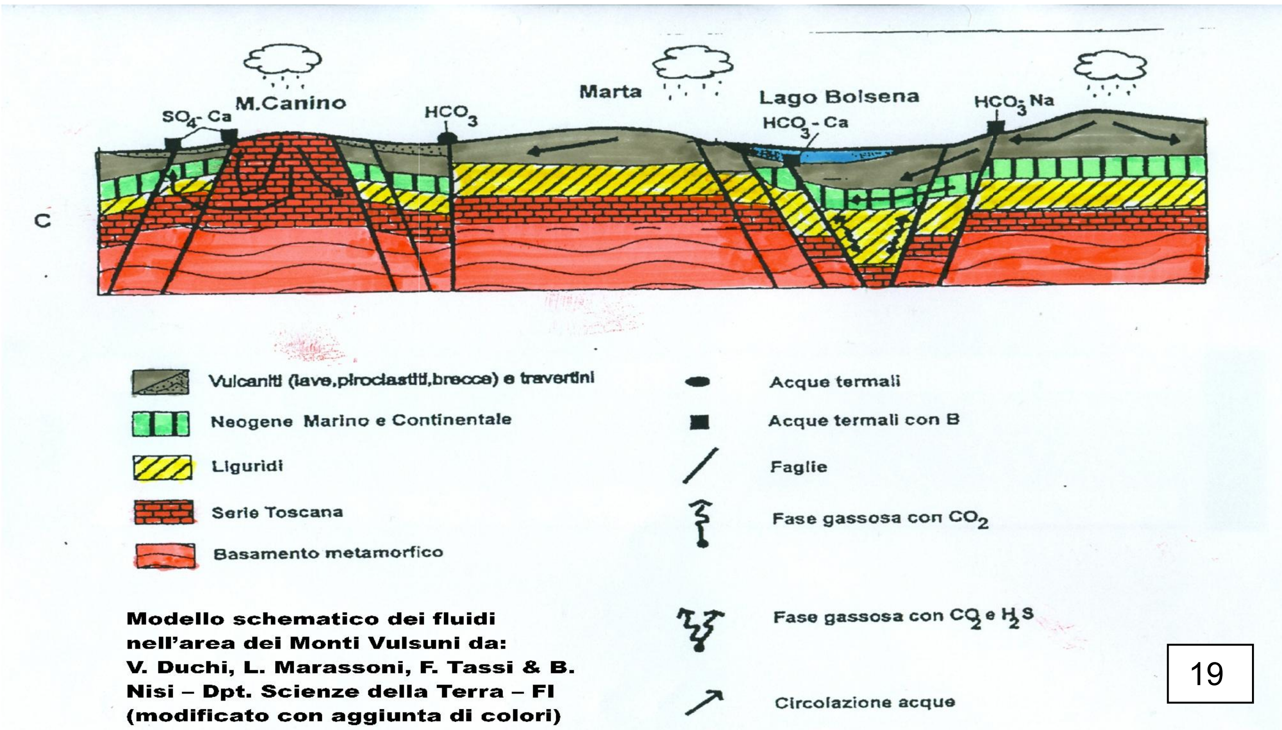


The process is based on two hypotheses: (a) the geothermal fluid can return freely from the reinjection zone to the production one: (b) the rock covering the geothermal reservoir has no permeability, thus preventing hydraulic communication between the geothermal reservoir and the surface aquifer. Both hypotheses are very questionable.

The volcanic zone under consideration, being a caldera. has plentiful faults which may obstruct horizontal flow. In such a case instead of a return from injection to production wells there would be a transfer of geothermal fluid from one section to another one. These are huge quantities: for example, the Castel Giorgio plant would extract and re-inject 1000 tons per hour of geothermal fluid for many years. It would create a thermal and pressure unbalance between two compartments separated by faults thus increasing the seismic risk. Concerning the fact that faults can create watertight compartments see the work of Vignaroli and others, published on Tectonophysics in 2013, related to the nearby Alfina area. Since it is not possible to predict the effectiveness of the recirculation, the application of the precautionary principle should be compulsory .

Furthermore the faults can facilitate vertical communication between the geothermal reservoir and the superficial aquifer. In fact the rock cover is not impermeable as demonstrated by the numerous thermal facilities in the area. As the geothermal fluid contains high percentages of arsenic, the risk of contamination of the drinking network and the lake is very high.

The geological section [19] is a schematic model showing lake Bolsena and the circulation of fluids in the Vulsini area. Note the presence of numerous faults in the area of the caldera and the ascent of gas along the faults.



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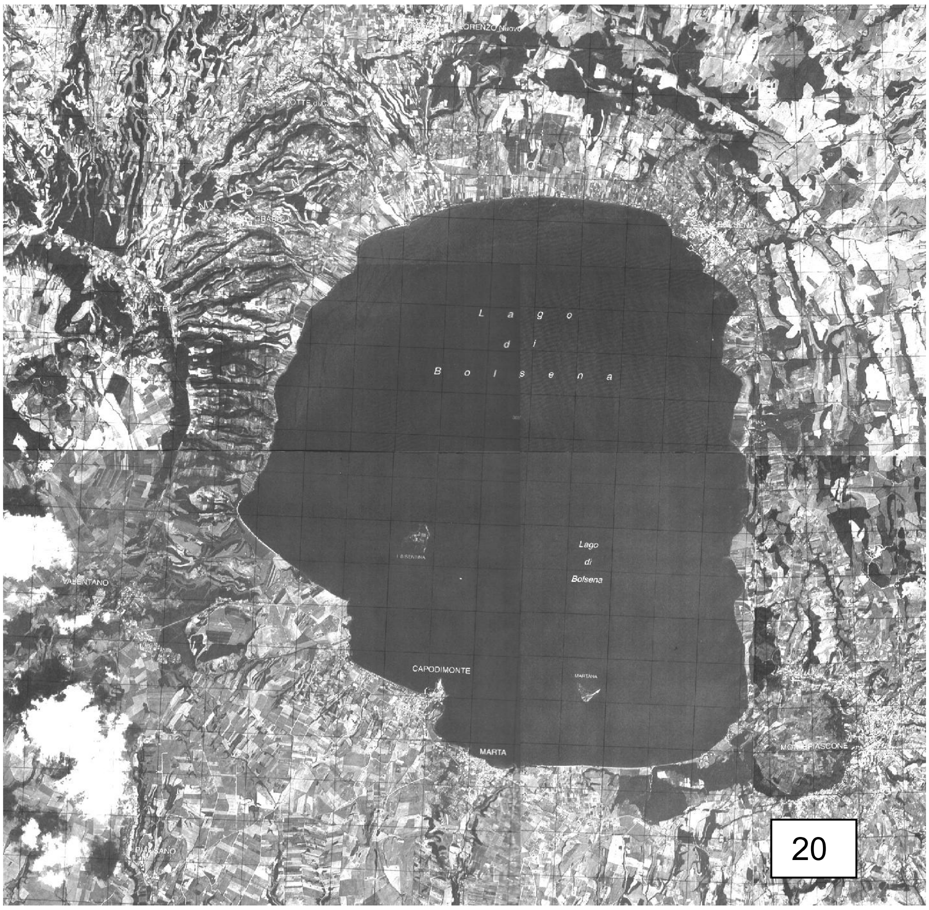

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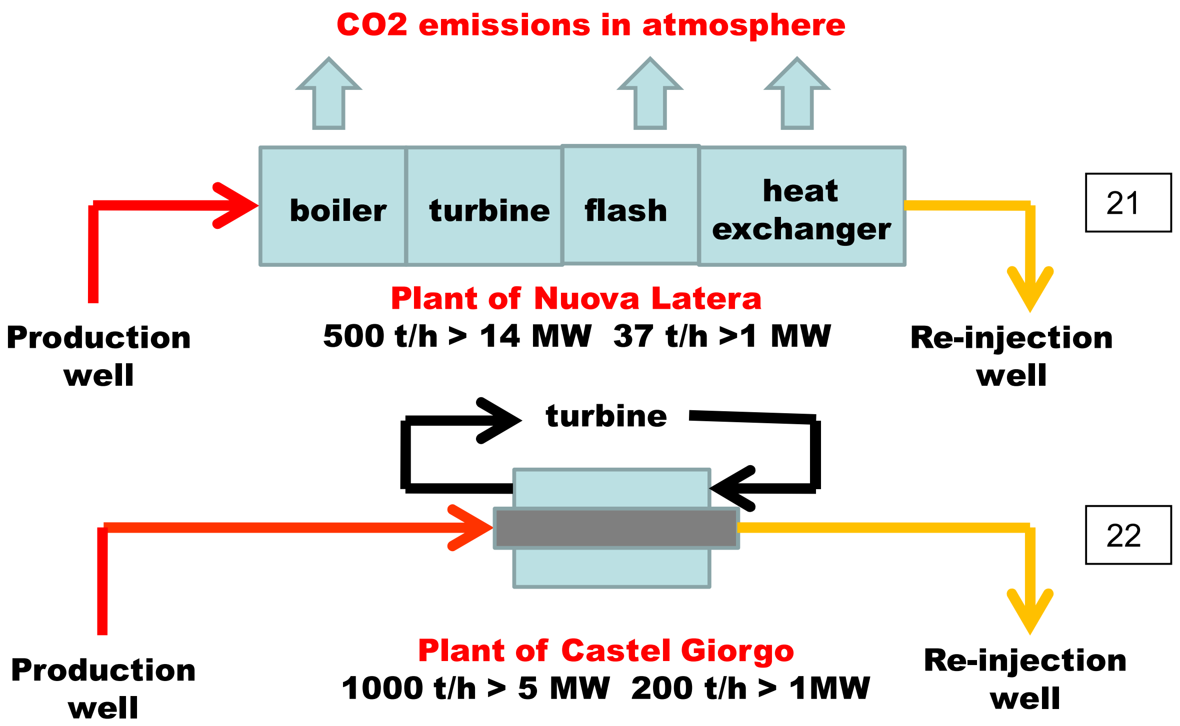
The satellite photo [20] shows at east the presence of concentric steps, parallel to the coast of the lake, which attest the numerous faults. To the west, the steps are not visible because they are covered by the ashes of the Latera volcano

Most of the geothermal plants are of the so-called "flash" type. They release incondensable gases into the atmosphere because they cannot be re-injected into the geothermal tank. Carbon dioxide is the most present gas that, in our areas, exceeds the amount that would be emitted by a modern gas plant. The objective of lucrative incentives is the reduction of damaging emissions. When this is not respected, there is no reason to incentivize this type of plant. Atmospheric emissions include other malodorous and carcinogenic gases that are only partly killed by filters. The plant layout [21] refers to the "Nuova Latera" plant which, by means of a boiler that burns 2 tons per hour of wood chips, overheats the incoming geothermal fluid.



The plants called “pilot” [22] receive higher incentives because they do not emit gas into the atmosphere. The heat is subtracted from the geothermal fluid by mean of an exchanger which transfers the heat to a service fluid which activates the turbine.

As compared to the flash plants they are apparently an improvement for not releasing gas into the atmosphere, under the condition that CO_2 in the geothermal fluid does not exceed 1%. The reservoir of Castel Giorgio contains about 5% of CO_2. According to the opinion of the ENEL experts reservoirs containing over 1% of CO_2 are not suitable for full reinjection. In the subsoil the situation of the “pilot” plants is pejorative because it requires a greater movement of geothermal fluid. In fact, to produce one MW the Castel Giorgio plant requires 200 tons of fluid per hour, while Nuova Latera requires 37.

The Castel Giorgio plant has five production wells and four reinjection wells. As clearly specified in the project, the production wells extract geothermal fluid from under the Tiber basin in Umbria and re-inject it under the hydrogeological basin of Lake Bolsena. The Lazio region, the Province of Viterbo and the Municipality of Bolsena would become therefore the site of the waste from the Umbria region with all the consequences related to the arsenic pollution.

Conclusions

The lake is the outcropping part of a large aquifer with which it forms a single body, as shown by the first two illustrations of this report. It is a non-separable whole, which from the environmental point of view cannot be treated separately because the pollution of the aquifer soon or later will reach the lake. Lake Bolsena is very vulnerable because of the extremely long water resident time.

The aquifer is exposed to the pollution of substances containing phosphorus that come from above, in the form of urban sewage and agricultural fertilizers. It would also be exposed from below by rising fluid containing arsenic and other carcinogens if geothermal exploitation with deep wells would be authorized.

Lake Bolsena is Site of Community Interest and Special Area of Conservation. The legislation prescribes that in those area must be applied "the conservation measures necessary for the maintenance or restoration, in a satisfactory state of conservation, of natural habitats". But this regulation is disregarded.

The protection is limited just to the lake. The law prescribes that any plan or project that may have significant effects on the site, is subjected to an appropriate Environmental Impact Evaluation on the site. However experience shows that the impact evaluations are very questionable.

To start an effective protection and restoration program, it would be proper to place the entire hydrogeological basin under environmental protection. In fact, the recent rejection of the Torre Alfina geothermal plant demonstrates the effectiveness of the environmental protection which had been applied. Compared to "Torre Alfina", the hydrogeological basin of Lake Bolsena appears more relevant and deserving equal protection.

An additional intervention could be requested by the Province of Viterbo and the Lazio Region to the Government in order to obtain the entire province included among the areas not suitable for geothermal energy. Whoever has the power and the duty to decide should take action as soon as possible.

Finally, the compact opposition of the Mayors, the Citizen and the Environmental Associations, that foresee a different destination of their territory, is of fundamental importance.

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