Aquatic balance of Vegoritis Lake, West Macedonia, Greece, related to mining activity

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Abstact

Vegoritis Lake is located in the homonymous closed hydrologic basin in West Macedonia, Greece. It is the final receiving body of the surface run-off of the hydrological basin. Moreover, it is the surficial appearance of an enormous and not well-known karstic aquifer. Therefore interference in surface or groundwater conditions in every part of its area affects the level of the lake.

Water of the lake and of the karstic aquifer has been used for agricultural, industrial and domestic purposes, for the cooling system of power plants and for hydropower generation.

The basin and the lake appear to have had a negative water balance during recent decades.

In this paper we investigate the relationship between the water level decline, observed over the last 40 years, and the mining activity of P.P.C. (Public Power Corporation) in the area.

1 Introduction

Vegoritis basin is a closed hydrological basin, without any surface outflow to the sea. The final receiving body of the surface runoff of the basin, with a total area of 2000 km^2, is Vegoritis Lake (Figure 1), which is also the surficial appearance of an enormous and not well-known karstic aquifer (R.E 1988, Stamos 1996). Being a closed hydrological basin any interference in surface or groundwater conditions in any part of its area, affects the level of the lake.

Since 1896, when the first measurements of the water level were recorded, intensive fluctuation of the water levels has occurred. The level of the lake in 1900 was 525 masl, in 1942 was 542 masl, and in 1956 it reached 543 masl. The increase in the level of the lake is possibly related to the drainage of Ptolemais (Sarigiol) swamp through Soulou river, which discharges water to the lake. Since then, a continuous drawdown of the lake has taken place, interrupted by small periods of water level rise. During recent years the level of the lake has declined at a slower rate, fluctuating around 510 masl. Similar behavior had also appeared at earlier periods (1962-1964, 1968-1972, 1979-1984), so it is not clear if it is a permanent condition or a periodic phenomenon.

The reduction of the water level of the lake began in 1956, which coincided with the commencement of outflow of water through Arnissa tunnel in order to supply water to Agra Hydropower Plant. During the first few years of its operation the connection between the decrease of the level of the lake and the outflow from Vegoritis Lake, through the tunnel, was obvious. During subsequent years irregular fluctuations of the water level of the lake took place, which could not be directly connected to the quantities of water extracted from Vegoritis Lake through Arnissa tunnel. The outflow through Arnissa tunnel during the period 1975-1992 was extremely low (between 0 and 25×10^6 m^3/year) and in 1992 the outflow stopped completely. However, the decrease of the water level of the lake continued.

The research has been undertaken because the decrease of the water level of the lake is of major importance. All of the activities in the area (industrial, agricultural, fishery, ecological, tourism etc.), which in turn affect the financial, social, ecological and aesthetic role of the area, are dependent on the lake.

2 Current condition

The boundaries of the basin are defined to the east by Vermio mountain, to the south by Skopos mountain, to the west by Askio Mountain, to the northwest by the hills of Nymfeo and Klidi, and to the north by Vorras Mountain.

Water from the lake has been, and still is, used for the following purposes:

- Irrigation and water supply for the towns and villages of the area. The water is pumped directly from the lake or through water wells drilled in the karstic aquifer.

- For hydropower generation from P.P.C. (1956-1992). The water was discharged from the lake through Arnissa tunnel to the hydropower station of Agra.

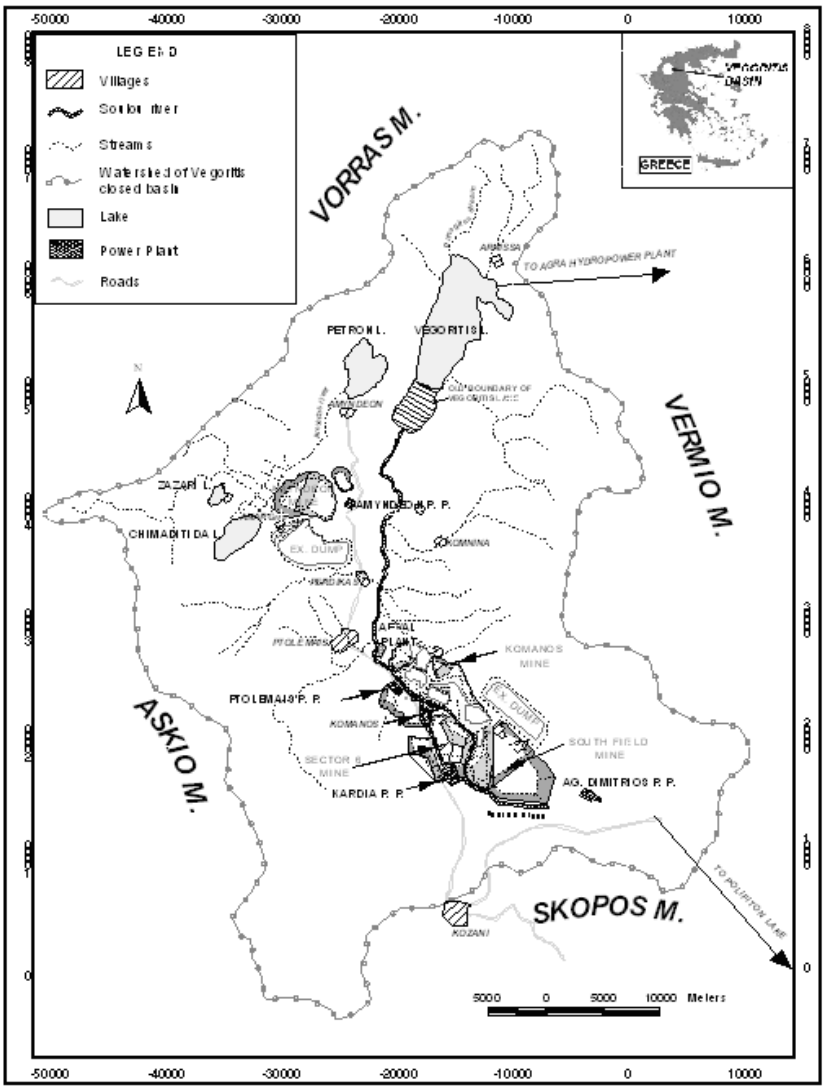

Fig. 1. The closed hydrological Vegoritis Basin

- For the cooling process at Amynteon and Ptolemais power plants (1976-1988). Water was pumped directly from the lake.

- For the industrial needs of a fertilizer plant (AEVAL, the operation of which stopped in 1983). Water was pumped from water wells in the karstic aquifer.

Other significant uses of the lake are as a fishery, and as a tourist attraction.

Vegoritis Lake, together with the nearby lakes of Zazari, Chimaditis and Petron, comprise a unique aquatic system. Together and individually these lakes are important biotopes, and have a significant influence on the climatic conditions of the area.

3 Quantity of water pumped out by P.P.C.

P.P.C. has developed significant mining activities in the area of Vegoritis Basin. 75% of the total electrical power of Greece is produced in this area, and almost $60x10^6$ tonnes of lignite is extracted per year. The environmental impacts of this activity on the area are significant.

At Vegoritis basin the following lignite open pit mines are under exploitation: a) South Field mine, b) Sector 6 mine, c) Komanos mine, d) North Field mine, e) Amynteon mine and f) Mavropigi mine (from 2003)

Extended pumping, for the protection of the mines, takes place through water wells located inside the pit and at the periphery of the mines.

Water supply for the Power Plants of the area is principally directly from the lake, but also from other sources inside the basin, such as the small dam at Soulou river, and groundwater wells.

3.1 Pumping for the protection of the mines

For the safe and economical exploitation of the lignite, dewatering of the layers above it, and in some cases depressurizing of the strata below it, is required.

According to P.P.C., the quantities pumped, for the protection of the mines operating within the boundaries of Vegoritis basin, are as shown in Table 1.

Table 1. Pumping volumes for the protection of mines (P.P.C. data).

Year	Water wells $x10^6$ m^3	Surface ponds $x\ 10^6$ m^3	Total $x\ 10^6$ m^3
South Field Mine			
1996	4	4	8
2001	7.7	4	11.7

Year	Water wells $x10^6$ m^3	Surface ponds $x\ 10^6$ m^3	Total $x\ 10^6$ m^3
Sector 6-Kardia Mine			
1996	0.5	1	1.5
2001	1.7	1.5	3.2
Amynteon Mine			
1996	17.1	3.8	20.9
2001	17.8	6	23.8
North Field Mine			
1996	0.5	2	2.5
2001	0	1.7	1.7

The water pumped out from water wells for the protection of the mines is discharged to the Soulou or Amyntas rivers, and is then used for irrigation during summer, or flows to Vegoritis Lake during the winter. Recently an effort has been made to utilise this water for the domestic supply of the towns of Kozani, Komanos, Anargiri. Moreover, water pumped from Amynteo mine has partly been used at the Amynteo Power Plant (6-7 $x10^6$ m^3/year).

Figure 2 is a flow diagram of the aforementioned activities. It is apparent that the water pumped out for the protection of the mines is returned almost entirely to the basin, predominantly for agricultural usage.

3.2 Power Plants

A power plant needs water mainly for cooling purposes. A large percentage (60-70%) of this water is wasted through vaporization.

After its use, water from the cooling towers (clean water with higher hardness) flows to nearby rivers and lakes. On average, 30-35 % of the used water returns to the basin while the rest evaporates.

Within Vegoritis Basin 5 Power Plants are installed since 1959 having total capacity 4,108 Mw

P.P.C. has provided the following information on the water consumption of each of the power plants:

Liptol Power Plant (43 Mw): It is a small plant with a water consumption of 5,500 m^3/d.

Ptolemais Power Plant (620 Mw): The average water requirement of this plant is 30,000 m^3/day, with a maximum consumption of 42,000 m^3/day. The water is pumped from a small artificial lake at Soulou River.

Kardia Power Plant (1,200 Mw): At the beginning of its operation, the water needs of the plant were provided entirely by Vegoritis Lake. How-

ever, currently the plant uses water from Polifiton Lake which is located in another hydrological basin. The volumes pumped from Polifiton Lake for Kardia Power Plant are estimated at 18-20x10^6 m^3/year.

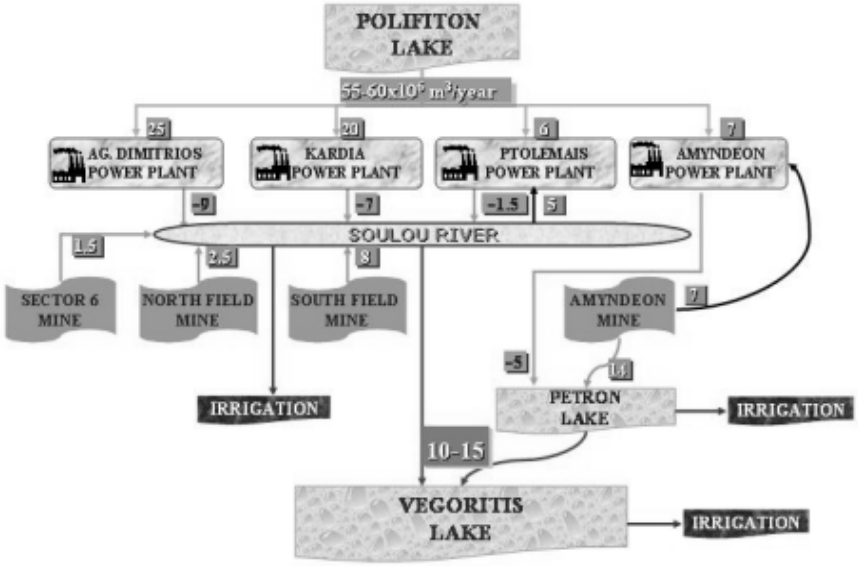

Fig. 2. Flow diagram of mining activity and water needs for the year 1996 (all volumes in 10^6 m^3/yr)

As previously mentioned, approximately 30-35% of the discharge water flows to the Soulou River, thus providing an additional 7-8x10^6 m^3/year to this hydrological basin (Figure 2).

Amynteo Power Plant (600 Mw): The water needs of the plant at the beginning of its operation were provided entirely by Vegoritis Lake. For the period 1976-1988 12.5x10^6 m^3/year were pumped from Vegoritis Lake for Amynteon and Ptolemais power plants. Since 1994 a portion of the volume pumped (6.8x10^6 m^3) for the protection of Amynteon mine has been used for the needs of the associated power plant. Moreover, from November 1997 Polifiton Lake has supplied the plant. Amynteon Plant uses 13.8x10^6 m^3 of water per year, 5-6x10^6 m^3 of which is returned to the basin.

Ag. Dimitrios Power Plant (1560 Mw): According to P.P.C., during the period 1990-1996 20x10^6 m^3/year of water were transferred from Polifiton Lake to Ag. Dimitrios plant. Today, these quantities have been increased to 25-26x10^6 m^3/year. The loss of water through vaporization is 15-16x10^6

m^3/year. Quantities of 9-10x10^6 m^3/year are returned to the Vegoritis basin.

Agra Hydropower Plant: Arnissa tunnel, at the northeastern end of Vegoritis Lake, was used to transfer water from Vegoritis Lake to Agra Hydropower plant. This water was removed from Vegoritis basin and entered another basin, where it was used for hydropower generation, and then for irrigation.

The fluctuation in volumes of water pumped for the Agra plant, together with fluctuations of the water level of Vegoritis Lake, is illustrated in Figure 3 (Dimitrakopoulos 2001).

The outflow through the tunnel stopped in 1992. However, since 1977 the outflow was very low (10-20x10^6 m^3/year) and the water was used almost entirely for irrigation.

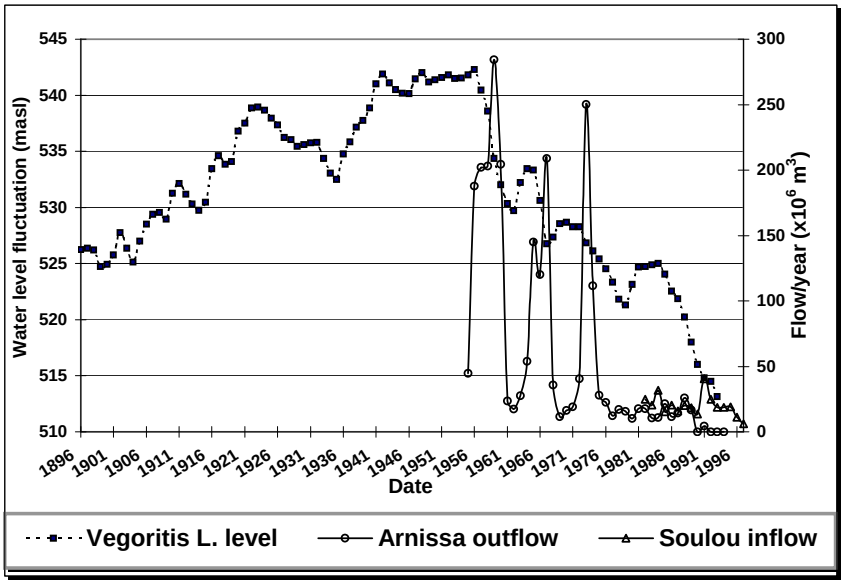

Fig. 3. Water level fluctuation of Vegoritis Lake and pumped out quantities from PPC directly from the lake.

A summary of the sources of supply for the various power plants, and their requirements, is given in Table 3.

Table 2. Water needs of Power Plants.

Water needs x10^6 m^3/year	Pumped from

Water needs $x10^6$ m^3/year	Pumped from
Ptolemais Power Plant	
11	1959-1988 from Vegoritis Lake. Since 1988 from an artificial dam at Soulou R.
Kardia Power Plant	
20	At the beginning of its operation from Vegoritis Lake. Today from Polifiton Lake
Amynteo Power Plant	
14	1986-1997 from Vegoritis Lake & dewatering of Amynteon Mine. Today from Polifiton Lake and dewatering wells.
Ag. Dimitrios Power Plant	
25	Polifiton Lake

4 Water balance of Vegoritis Basin

For the evaluation of the water balance of the basin many studies and surveys have been carried out, as discussed below

The complex aquatic system, the unknown extent of the karstic aquifer and leakage through the karstic sinkholes are some of the problems that make the estimation of the water balance very difficult. Many assumptions have been made and different results have been presented. Some of the most important estimates and assumptions that have been made are as follows:

- Xorafas (1957), gives a figure of $170x10^6$ m^3/year for the inflow to the lake. The outflow from Arnissa tunnel to another basin had been estimated at $150x10^6$ m^3/year, so there was estimated to be a positive balance to the lake of $20x10^6$ m^3/year. Despite this, the water level of the lake was decreasing during this period (see Figure 3).
- Sapounas (1998) suggested that there was a net loss of 32.43 x 10^6 m^3/yr from the lake over the period 1981-1993. Sapounas (1998) also calculated the balance for the entire basin, and concluded that there was a net loss of 20.59 x 10^6 m^3/yr.
- Stamos (1996) suggests that the exploitable water resources of the basin are approximately $200x10^6m^3$/year. He estimates the water balance of the lake for the period 1993-1994, concluding that losses equate to $60x10^6m^3$/year. This includes pumping $10x10^6m^3$/year directly from the lake for irrigation, and the use of $20x10^6m^3$/year by PPC.

However confusion remains over the water balance of the lake itself, as distinct from the entire basin, and over the hydrological interaction between the lake and the karstic aquifer.

It is our view that the problem of decreasing water levels must be addressed in the context of the entire basin, and therefore that the irrigation and domestic and industrial supply uses must be investigated together with uses by the mines and power plants.

According to 1991 data for Sarigiol basin, which covers 500 km^2, approximately 1/4 of the total basin (27,000 hectares) is irrigated. In 1996 there were 300 recorded water wells used for irrigation, with an estimated total abstraction of 20 x 10^6 m^3/year, and 32 for domestic use, with an estimated total abstraction of 3-4 x 10^6 m^3/year (Dimitrakopoulos et al 2000). 10 years earlier there were just 100 irrigation wells, and thus the usage has increased substantially (Louloudis 1990).

In 1996 546 irrigation water wells and 11 domestic wells were in use in the Chimaditis sub-basin (355 km^2). This compares to 260 and 116 wells in 1990 and 1985 respectively. In 1996 it was estimated that 38 x 10^6 m^3/year of water was used for irrigation (Dimitrakopoulos 2001).

These data reveal an increasing trend in the consumption of water, used mainly for irrigation, over the last decades. However, on the positive side, water pumped from the mines is at least returned to the basin for use in irrigation or flows into the lake.

5 Conclusions

The water balance of the area is as follows (and shown in Figure 2):

Outflows:

- The main outflow from Vegoritis Lake, through Arnissa tunnel for hydropower generation, stopped in 1977. Outflow of small quantities (10-20x10^6 m^3/year) continued since 1992 for agricultural use during the summer.
- Pumping of 6-7x10^6 m^3 from water wells of the basin, for the cooling towers of two of the power plants.
- Pumping of significant quantities for irrigation (estimated at 38 x 10^6 m^3/year in 1996).
- For dewatering and protection of the mines from surface and groundwater, 33-40 x10^6 m^3/year are pumped out. This volume of water returns, almost entirely, to the basin, where it is used for irrigation or flows into Vegoritis Lake.

Inflow:

· Pumping from Polifiton Lake equals 55-60x10^6 m^3/year for the cooling towers of the power plants of the basin. A portion of the amount used by the power plants is vaporized and the rest (~ 30%) flows into the basin as inflow (recharge).

The activity of P.P.C., in general, results in a positive water balance of the basin of up to 10x10^6 m^3/year.

According to the above, the mining activity results in a neutral water balance for the basin, since all of the water pumped returns to the same basin.

The reasons for the continuous decrease of the water level in Lake Vegoritis, which has been marked since 1985, therefore appears unlikely to be attributable to mining activities, but seems more likely to be due to the increase in irrigation uses.

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