Study of the Prespa-Ohrid lake system using tracer experiments and the lake's water balance

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Abstract

The Prespa-Ohrid lake system is shared between Greece, Republic of Macedonia (FYRO) and Albania. In recent years a water decrease in the Prespa Lake has been recorded. Though it has been established that the water from the Prespa Lake flows into the Ohrid Lake through the Galichica mountain, it is not clear whether this is the main reason for the lake's water loss in recent years. The three main reasons behind the lake's water loss investigated are: (i) underground flow from Prespa to Ohrid Lake, change in weather pattern, anthropogenic factors. Though there were several studies investigating the water level decrease in the lake, so far no conclusion on the reasons behind this phenomenon has been reached. As part of an ongoing research project supported by the NATO Science for Peace (SfP) programme the problem of water loss in the lake has been investigated. Some of the results of this study are presented.

Keywords: Prespa-Ohrid lake system, lake's water balance, tracer experiments.

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1 Introduction

Three lakes: Ohrid, Big Prespa and Small Prespa are on the borders between Albania, Republic of Macedonia (FYRO) and Greece, see Figure 1. Galichica and Dry mountains separate the lakes. It has been hypothesized at the beginning of the 20th century [1] that the water from the Prespa Lake drains through the Galichica and Dry mountains into Ohrid Lake. Investigations involving the use of natural isotopes ($\delta^{18}O$, ^{2}H) conducted by Anovski *et al.* [2] and later by other scientists confirmed this hypothesis.

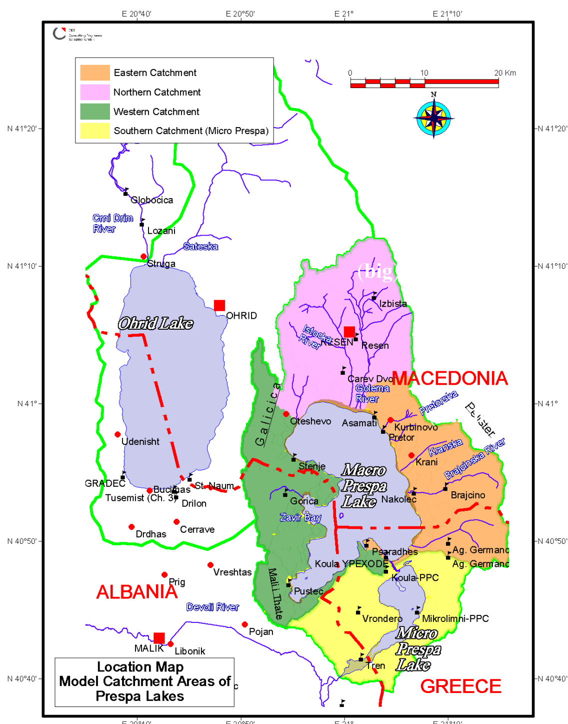

Figure 1: Ohrid, Big Prespa and Small Prespa lakes with catchments for rainfall-runoff [3].

The lakes Big Prespa (253.6 km^2) and Small Prespa (47.4 km^2) are at 850 m asl. and are linked by a small channel with a sluice that separates the two lakes. In the past, periodical oscillations of the lakes' level were in the range of one to three metres, depending on the amount of rain in the season. After the mid 80's, a steady decrease of the water level has been recorded, see Figure 2, that disturbs the ecological balance of the lake and the watershed area resulting in serious consequences for the fishing and tourist industry in the trans-boundary Prespa region. In addition to this, the industrial activities as well as the overuse of the herbicides in agriculture activities raised the problem of pollution of the water in the Prespa Lake.

The importance of Prespa Lake has been recognised worldwide because of its high biodiversity, including populations of rare water birds, like for example the Dalmatian pelican.

State authorities of the three countries have enforced the protection status of Prespa through the use of national and international legislative means. A large part of the lakes and catchment basin has been characterized as a National Park (Albania and Greece) or/and a Wetland of International Importance under the Ramsar Convention (Greece, R. Macedonia).

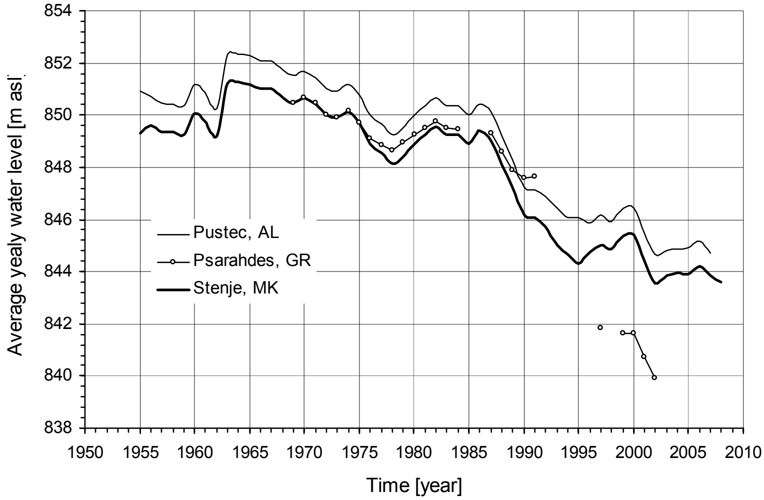

Figure 2: Variation of water level of Prespa Lake.

A joint project between five institutions from R. Macedonia, Albania, Greece and UK is currently funded through NATO Science for Peace and Security programme. The main objective of the project is to understand the mechanism behind the water loss in the Prespa Lake.

2 Description of the lakes' system

A great variety of rocks concerning their age, genesis, and lithology constitute this area. From the hydro-geological point of view, the rocks of Prespa-Ohrid area are classified as porous aquifers, karstic and fissured aquifers, fissured aquifers and practically non-aquiferous rocks.

During the years 2000 and 2002 charting and profiling of the bottom of the Big Prespa Lake was carried out. The results showed two characteristic trenches-like structures on the lake's bed. One of the trenches is 7 km long, 0.9 km wide and 35 m deep on average, while the other one is 12 km long, 1.5 km wide and

23 m deep on average. The south part of the Lake showed unexpected structure of the lake's bottom with sharp faults indicating strong tectonic movements. In the eastern part of the lake a large sedimentation area was identified, where several rivers inflow the lake.

There are a number of springs on the coast of Ohrid Lake, of which the largest ones are St. Naum and Tushemishti. Figure 3 shows the link between the Ohrid and Prespa lakes, where Prespa lake is on 155 metres higher elevation than Ohrid lake. The water in the Ohrid springs consists of mixture of water infiltration from the Prespa lake and precipitation on the mountain. The mixing of the water and contribution from these two sources is discussed in the next section.

One of the most important characteristics of the karstic formations are sinkholes. The swallow holes are considered as the most prominent karstic phenomena enabling the interconnection of surface and groundwater. The most important sink hole is at Zaveri situated in the western part of Prespa Lake, near the village Gollomboch in Albania.

Underground karstic morphology is represented with karstic forms like canals and caves. A lot of small and big caves can be observed at Prespa lake level, particularly near the Stenje village. So far there are known 12 caves in Galichica Mountain, with the length of the biggest one of 279 m (named Samoska Dupka).

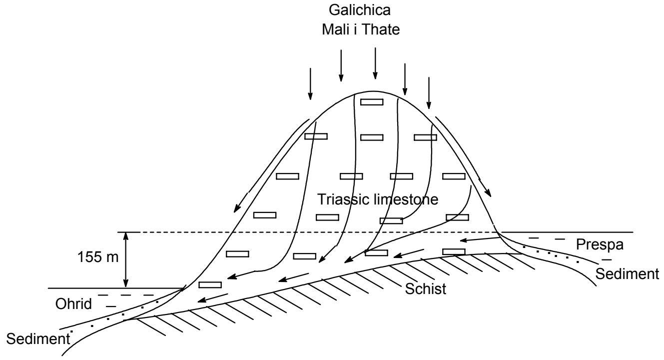

Figure 3: Simplified cross section of karstic massif of Galichica and Mali and Thate with connection between Big Prespa Lake and Ohrid Lake.

3 Use of natural isotopes

Previous studies [2, 4] suggest a yearly discharge in St. Naum springs of 220.75×10^6 m^3/y, or an average evaluated value of 7 m^3/s. Zagorcani and Tushemishti springs' contribute to the Ohrid Lake on a 3 km long shore. Their average discharge up to 1990 was evaluated to 2.5 m^3/s, or 78.84×10^6 m^3/y. By using the environmental isotopes data ($\delta^{18}O$ and ^2H) the contribution of the Prespa Lake to the springs St. Naum and Tushemisht have been estimated, see

Table 1. It is important to note that there are seasonal variations in the contribution of the Prespa Lake to the springs. When there is more precipitation then the contribution from the Prespa Lake is lower and vice versa.

By using the data from Table 1 the contribution of Prespa Lake to the St. Naum springs can be estimated to an average of 40% or 2.8 m^3/s, which is equivalent to 88.3×10^6 m^3/y. In a similar way the contribution of the lake to the Tushemisht springs is estimated to 1.3 m^3/s, which is equivalent to 41×10^6 m^3/y. The total contribution of the lake to these two groups of springs is estimated to 4.1 m^3/s or 129.3×10^6 m^3/y. It is not an easy task to estimate the total contribution of the Prespa Lake to the springs in Ohrid Lake since the contribution to the sublacustric springs is not known.

Table 1: Contribution of the Prespa Lake to the recharge of springs at Ohrid Lake side (PL - Prespa Lake water, IP – infiltrated precipitation in the karstic massif).

Author	Anovski *et al.* [2]		Eftimi and Zoto [3]		IAEA Project RER 8/008 (2003)	
Spring	PL %	IP %	PL %	IP %	PL %	IP %
St. Naum	42	58			37	63
Tushemisht			52	48	54	46

4 The artificial tracer study 2007-2008

Studying ^2H and ^{18}O stable isotopic contents in Saint Naum-Tushemishte springs and Big Prespa has provided the first physical prove of an underground hydraulic connection between Big Prespa and Ohrid Lakes [2, 4]. The fact that the δD seasonal differences in Big Prespa and Saint Naum and Tushemishti springs at the coast of Ohrid Lake are practically equal means that the communication between Prespa and Saint Naum springs is very rapid. Other studies have shown this system's groundwater moves through well developed karstic channels. Therefore, no significant mixing or dispersion takes place in the Galichica mountain. An artificial tracer test would demonstrate in these conditions short transit times and relatively sharp tracer pulses. The study carried out on 2002 by using Sulphorhodamine G Extra has confirmed this [5]. On the other hand the predominant stability of water discharges through Saint Naum – Tushemishti springs suggests the communication between Prespa and Ohrid should be better described by longer transit times, due to the very high degree karstification of the Dry Mountain and Galichitsa, with numerous elements that could trap or delay groundwater movement through them. But this assumption could not be tested in the tracer study of 2002.

The tracer study of 2007-2008 was designed to verify part of these results and assumptions as well as to achieve some other, more specific objectives.

A recognition campaign on Albanian part of Ohrid - Prespa Lakes system (September–October 2006) was organized in order to have a relatively complete inventory of principal water objects that could be used as sampling points in any future artificial tracer study. A number of these locations were included in the sampling network, which was made up of 10 points (Fig. 4).

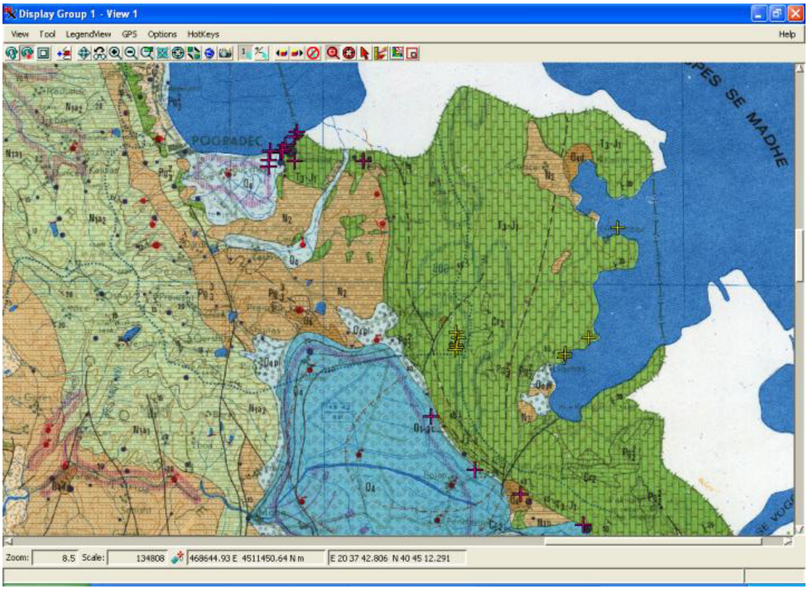

Figure 4: Sampling points (red crosses) and potential injection points (yellow crosses).

The tracer injection was carried out at Zaveri on 25th October 2007. Four barrels with 60 litres of water solution of Uranin AP each were added to the water course on the injection point. Uranin AP is excited at 490 nm and emits almost instantly light at 512 nm. Two LS 55 Luminescence Spectrometers with movable monochromators have been used in the Tracer Labs of Tirana and Skopje in order to detect its presence and measure its content. All water and carbon samples bearing evidence of Uranine presence have then been sent to another, specialized lab (WasserResourcenManagement, in Graz, Austria), to check the results, by using an HPLC technique as well as another spectrofluorometer. Besides, a method was specially elaborated to chemically process carbon samples and analyze them for fluorescent tracers, and the system LS 55 was calibrated by using some standards. The calibration line was of the form:

$$\mathbf{IF = 155.586 * C + 3.07} \qquad \text{(with R = 0.9999)}$$

Only results having been verified by at least three different measuring instruments or analytic methods have been accepted and further interpreted. The most important ones are the following:

The fastest water communication component is observed at Zagorçani springs. The tracer took only 6 hours to appear there after having been injected at Zaveri, about 17 km away. There were other Uranine AP appearances at other sampling points within a time period of few days to few months. All these results repeat almost identically the ones of the 2002 tracer experiment, with some differences that should be interpreted in terms of various hydrometeorological and hydrogeological frames of respective studies.

The most interesting result of the actual tracer study was the detection in a number of sampling points of Sulphorhodamine G Extra, which is the tracer being injected almost 6 years ago into the same injection point, at Zaveri, during the 2002 tracer test (Figure 5).

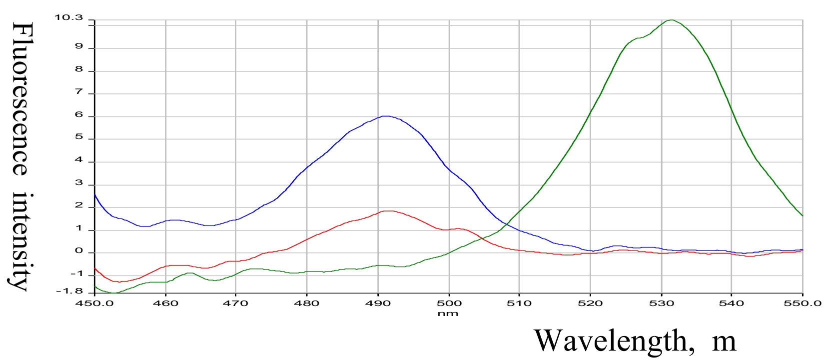

Figure 5: Uranin AP and Sulphorhodamine emergences on Zagorçani Spring.

This fact is in good agreement with mean residence time calculations made on the basis of natural Tritium contents in different water components of the system under the study. The Sulphorhodamine G Extra presence was observed over a relatively extended period of time, from January 2008 until the end of the sampling campaign. Its emergences coincide with wet months of the year, which proves that it is trapped within the massif of the Dry Mountain and enters groundwater circulation following larger precipitation events.

The artificial tracer experiment supplied valuable evidence about the system under the study and its complexity. Different parts of this system behave in different ways, which thing has been verified by using stable isotope contents of ^{2}H and ^{18}O, as well as the analysis of water discharges at springs situated on Albanian and Macedonian parts of the system.

5 Water balance for Prespa Lake

The cycle of water circulation for a lake includes water inflow into the lake, as well as water outflow from the lake.

The inflow waters in the lake Q_{IN} can be determined by the following equation:

$$Q_{IN} = R_L + K_L + (Q_{INR} + Q_{INUG} + Q_{INAR}) \qquad (1)$$

R_L – direct rainfall over the lake surface [m^3/month] or [m^3/year]
K_L – direct condensation over the lake surface [m^3/month] or [m^3/year]
Q_{INR} – surface waters inflow into the lake, run-off [m^3/month] or [m^3/year]
Q_{INUG} – underground waters inflow into the lake [m^3/month] or [m^3/year]
Q_{INAR} – artificial water inflow into the lake (if exist) [m^3/month] or [m^3/year]

The outflow waters from the lake can be determined from the following equation:

$$Q_{OUT} = E_L + (Q_{OUTR} + Q_{OUTUG}) + Q_{OUTAR} + Q_{IRR} \quad (2)$$

E_L – direct evaporation from the lake surface [m^3/month] or [m^3/year]
Q_{OUTR} – surface waters outflow [m^3/month) or [m^3/year]
Q_{OUTUG} – underground waters outflow through porous media and karst [m^3/month] or [m^3/year]
Q_{OUTAR} – artificial water outflow [m^3/month) or [m^3/year]
Q_{IRR} – Irreversibly consumed water (irrigation mainly) [m^3/month] or [m^3/year]

Equations (1) and (2) are utilized for global estimation of water potential, but sometimes are very difficult to determine all components, especially hydro-meteorological parameters concerning the condensation over the catchment area, direct condensation over the lake surface, underground water inflows and underground water outflows.

The main idea of the water balance calculations was to take the net balance of water outflow or inflow through the bottom of the lake as unknown and find calculate it from the above equations, where the other terms in the above equations are known. In this way it is possible to analyze the influence of the water outflow to Ohrid lake on the water loss in the lake.

The difference between underground waters inflow into Prespa Lake (Q_{INUG}) and underground outflow from Prespa Lake (Q_{OUTUG}) has been obtained using

$$Q_{INUG} - Q_{OUTUG} = \frac{\Delta V}{\Delta t} - Q_{TOTIN} + E_L - P_L + Q_{IRR} \quad (3)$$

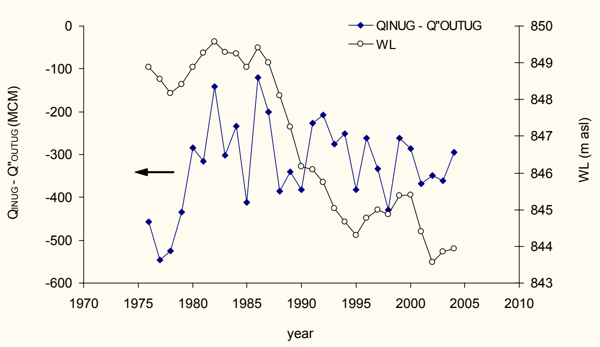

Figure 6: Comparison of the outflow from Prespa Lake to groundwater (Ohrid Lake) and the water level in the lake.

Figure 6 shows the comparison of the net balance of communication of Prespa Lake with the aquifer over time compared with the change of water level of the lake in the same period.

Table 2 shows the water balance for the Prespa Lake in the period from 1990 to 2008. The analysis shows an average loss of water equivalent to 0.129m drop in the water level of the lake, which over a period of 18 years totals 2.33m. It is evident that the irrigation and the water supply do not significantly influence the water loss in the lake.

Table 2: Water balance for Big Prespa Lake in the period from 1990 to 2008.

Elements	Inflow 10^6 m^3/y	Outflow 10^6 m^3/y	Difference 10^6 m^3/y	Change of water level (m)
Run-off from catchment area	266.1			1.046
Precipitation over the lake surface	159.4			0.627
Underground outflow		250		-0.983
Evaporation		195.3		-0.768
Irrigation and water supply		13		-0.051
Total	425.5	458.3		-0.129
Water shortage			-32.8	
Total for 18 years			590.4	-2.33

6 Conclusions

The lakes Ohrid and Prespa (big and small) represent unique and very complex water system, where the water from the Prespa Lake drains into the Ohrid Lake through underground pathways. The recent steady water level decrease in the Prespa Lake suggests that this beautiful lake, which is part of this unique water system, can be lost soon, unless the reason behind the water level drop is investigated and efficient measures are proposed for use of the water from the lake's watershed. One of the current efforts in saving the lake is the NATO SfP project, which has as main objectives to discover the mechanism behind the water level decrease.

It is speculated that the water level decrease could be due to: (i) changes in the hydrological link between the Ohrid and Prespa Lakes (increase in the hydraulic conductivity of the aquifer linking the two lakes); (ii) change in weather conditions in recent years; (iii) change in water use by the local population for agricultural and industrial purposes. It is also possible that the cause for the water level decrease is due to combination of the above three possible causes.

The results presented in this paper show that the most likely cause for the water loss in the lake are the water flow by underground pathways from Prespa Lake into the Ohrid Lake and possible changes in weather conditions. The use of the water for local water supply and for agriculture is just a fraction of the total loss of water in the lake and cannot be taken as the reason for the changes in the lake's water level.

Acknowledgement

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