

# Critical review of adaptation strategies for the restoration of Lake Koronia

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**Abstract:** Lake Koronia water basin, located in Northern Greece, depicts a characteristic example of non-sustainable water management case in Greece. The irrational pumping for irrigation in the catchment resulted in the overexploitation of groundwater resources and a serious decrease in the runoff to lake Koronia. Furthermore, the reduction of the mean annual precipitation and the increase of the mean annual temperature, and, therefore, the evaporation that were being observed in the area, due to climate change, are expected to further deteriorate the already distributed water balance of the lake. UTHBAL model along with MIKE SHE and MIKE HYDRO BASIN models are utilized in the present study for the calculation of the historical (1970-1999) and future (2020-2049, 2070-2099) water balances of lake Koronia. The water balance of the lake for the long-term time period was found to be negative even after the implementation of the adaptation measures that have been proposed in the most recent revised Master Plan for the restoration of the lake. An assessment of the efficiency of the most important measures that have already been implemented, in terms of decreasing the future water deficit of the lake, is carried out. The paper concludes that even after the implementation of the measures the water balance of lake Koronia still remains negative for the long-term future period and so complementary adaptation measures should be implemented in order to restore the negative water balance of the lake.

**Key words:** Lake Koronia, water balance, adaptation measures, climate change, Master plan

## 1. INTRODUCTION

Lake Koronia case study is a complex problem that needs an integrated approach taking into consideration social, technical, environmental, political and economic aspects in order to be efficiently resolved. In terms of water quality, many studies have been carried out (e.g. Perivolioti et al., 2016; Moustaka-Gouni et al., 2012) about ecological changes that have been occurred in lake Koronia during the last decades threatening its ecosystem.

In terms of water quantity, the number of studies regarding the water balance problem of the lake are limited. In their studies, Manakou et. al. (2013) developed a mathematical programming approach to restore the water balance of the hydrological basin of lake Koronia and they concluded that investment options including the water transfer from larger water sources, the creation of irrigation networks and canals and provision of subsidies to promote alternative land use for agriculture need to be taken. Kolokytha (2010) examined the contribution of Water Framework Directive and EU Common Agricultural Policy application in Lake Koronia towards the rehabilitation of its water balance in the future and she concluded that both European Policies can help to reduce the water problem of the lake but cannot solve it themselves. Mylopoulos et al. (2007) developed a groundwater model to simulate the lake Koronia-aquifer interaction and they suggested that a combination of a project recharging the lake with groundwater and water saving measures in the agricultural sector must be implemented to confront the water depletion of the lake.

## 2. STUDY AREA

Mygdonia water basin is located in Northern Greece and it belongs to the Water District of

Central Macedonia. The water basin covers an area of 2.061,48 km<sup>2</sup> and the mean elevation is 338 m. Lakes Koronia and Volvi are located at the lowest part of the basin at about 10 km and 35 km eastern of the city of Thessaloniki. Both lakes compose a wetland that affects and, also is being affected by the current economic activities in the whole catchment. The wetland is protected by several international and national laws. In particular, it constitutes a “Wetland of International Importance” (Ramsar site), a “Special Protection Area” (Directive 79/409/EEC), a “Site of Community Importance” (Directive 92/43/EEC) and a “National Wetland Park of Lakes Koronia – Volvi and Macedonian Tempi”.

Mygdonia catchment (Figure 1) was divided into the Koronia subcatchment (768.11 km<sup>2</sup>) and the Volvi subcatchment (1.293,37 km<sup>2</sup>). Afterwards, each one of them was further divided into six and thirteen subcatchments respectively in order for the surface water bodies to be more efficiently studied.

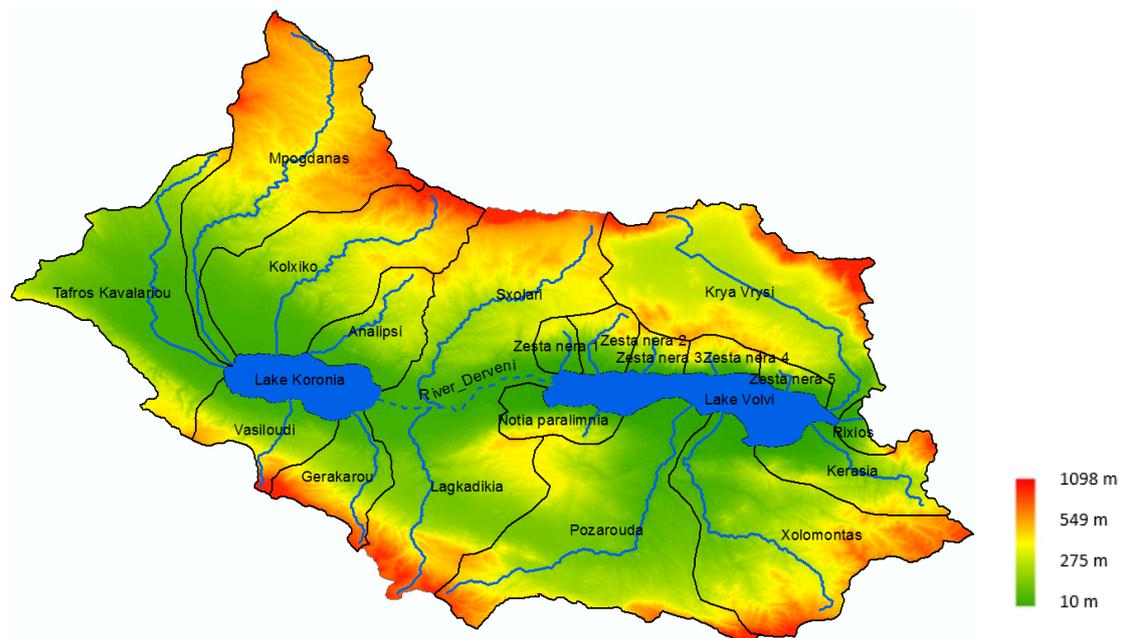


Figure 1. The nineteen subcatchments of the Mygdonia catchment

### 3. CALCULATION OF THE WATER BALANCE OF LAKE KORONIA

An integrated hydrological study has been carried out for the simulation of water inflows and outflows to lake Koronia. In particular, three different models have been applied: the UTHBAL hydrological model for the simulation of the surface hydrological processes, the MIKE SHE model for the simulation of the hydraulic interaction between lake Koronia and groundwater, and finally, the MIKE HYDRO BASIN model for the simulation of the water balance of the lake.

#### 3.1 Simulation of surface hydrological processes

The conceptual hydrological model UTHBAL (University of Thessaly water BALance model) (Loukas et al., 2007) has been used for the calculation of the hydrological parameters for the historical period 1970-1999.

UTHBAL model has six parameters to be optimised in order to estimate the hydrological cycle parameters. The model uses monthly time-series of areal precipitation, mean areal temperature, mean areal potential evapotranspiration and observed monthly discharge values as inputs. Mean areal surface precipitation and temperature for the whole Mygdonia catchment were calculated

equal to 518.69 mm/year and 13.27 °C using the Thiessen method along with the precipitation gradient method, and the temperature gradient method respectively. Mean areal potential evapotranspiration was calculated using the Thornthwaite method, and, finally observed monthly discharges of Mpogdanas, Analipsi, Lagkadikia, Sxolari, Gerakarou and Vasiloudi streams as measured at the outfall points for the period 1995-1999 (Veranis and Katirtzoglou, 2001) were also imported to the model.

The model was calibrated and validated with the observed monthly discharges of the six streams and the monthly hydrological cycle components for each one of the six subcatchments were calculated. The six hydrological parameters of the UTHBAL model were then transferred to the other thirteen subcatchments based on land use, slope and geological criteria in order to estimate the hydrological parameters of these subcatchments too.

The main outputs of the model are monthly time series of actual evapotranspiration, surface runoff and groundwater recharge. Mean annual runoff to lake Koronia was calculated equal to 7.49 hm<sup>3</sup>/year. It must be noted that only limited water amounts (about 6 hm<sup>3</sup>/year) flow into lake Koronia after the year 1985 due to the extensive pumping in the surrounding area that has resulted in the increase of recharge to groundwater and decrease of the surface runoff (Veranis and Katirtzoglou, 2001).

### ***3.2 Simulation of groundwater resources***

Mygdonia catchment is an endorheic basin in hydrogeological terms (Mpallas, 2007). The groundwater flow follows the longitudinal axis of the catchment; in normal conditions groundwater flows from Koronia subcatchment to Volvi subcatchment, and then a part of this discharge outflows to a neighbouring subcatchment at the eastern part of the Mygdonia catchment.

Mygdonia groundwater simulation was performed using the MIKE SHE model. At first, the catchment was divided into six groundwater subcatchments (Koronia, Volvi, Mavrouda, Kroussion-Kerdyllion, Nteve Koran and Xolomonta-Oraiokastrou) for the analytical study of groundwater resources. Geometrical and hydraulic parameters, namely upper level, lower level, horizontal hydraulic conductivity, vertical hydraulic conductivity, specific yield and storage coefficient were imported to the groundwater model for each layer of each one of the above six groundwater subcatchments. Also, daily time-series of recharge to groundwater and pumping for agricultural, livestock, tourist and household water needs were also imported to the model.

The whole catchment of Mygdonia was divided into 8,244 grid cells (500x500 m the area of each grid cell) and the simulation was carried out from 01 October 1970 until 30 September 2000 with a daily time step. It was found that there is no hydraulic interaction between groundwater and lake Koronia.

### ***3.3 Simulation of lake Koronia***

Lake Koronia covers a maximum area of 46.03 km<sup>2</sup>, its bed elevation is 66.50 m above the sea level and it has a maximum depth of 6.50 m. Lake Volvi is located at 11 km eastern of lake Koronia and its bed elevation is 52.50 m lower than the one of lake Koronia. The overflow of lake Koronia flows by gravity through an artificial drainage ditch called River Derveni and it outflows to lake Volvi (Figure 1). Nowadays, the physical interaction between the two lakes has been interrupted because of the tremendous decline of the water depth of lake Koronia.

Mean annual precipitation and evaporation for the lake Koronia were calculated equal to 20.61 hm<sup>3</sup>/year and 29.51 hm<sup>3</sup>/year respectively from 1970 until 1999. As for the pumped water from the lake, according to the article 4, paragraph 2 of the Joint Ministerial Decision 6919/2004, pumping from lake Koronia is prohibited.

Simulation of inflows and outflows to lake Koronia was performed using the MIKE HYDRO BASIN model at a daily time step for the historical period 1970-1999. It was found that lake

Koronia had an average negative water balance of  $-1.41 \text{ hm}^3/\text{year}$ . The water level variation of lake Koronia for the period 1970-1999 is presented in Figure 2. The continuously decreasing trend of the water level of the lake is a result of the decreasing trends of precipitation and runoff to lake, and the increasing trend of evaporation from the lake.

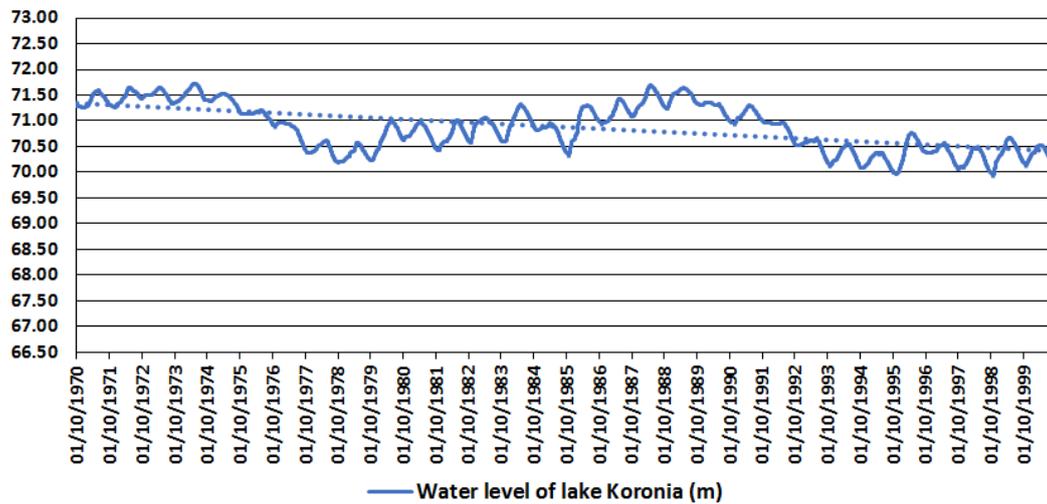


Figure 2. Water level of lake Koronia for the period 1970-1999

## 4. LAKE KORONIA WATER BALANCE REHABILITATION STRATEGIES

### 4.1 Revised Plan for the restoration of lake Koronia

In 1998, Knight Piesold Ltd. & Karavokyris and Partners conducted a “Master Plan” for the restoration of lake Koronia proposing a number of alternative measures to confront its water deficit. In 2004, a “Revised plan for the restoration of lake Koronia in the Prefecture of Thessaloniki” was carried out revising the Master Plan and proposing several scenarios to fulfil the Master Plan goals. Both the Master Plan and the Revised Plan have focused on lake Koronia considering it within the broader context of the Koronia subcatchment. In this study, a more integrated analysis considering the surface-groundwater interaction for the whole Mygdonia catchment has been carried out for the calculation of input and output water amounts to lake Koronia.

The Revised Plan proposes three scenarios for the quantitative and two others for the qualitative rehabilitation of lake Koronia. The three scenarios regarding the quantitative rehabilitation of lake Koronia are presented below: (a) *Ecosystem connectivity and exports from lake Koronia*: Under normal conditions water and nutrient exports from lake Koronia drain into lake Volvi and so they are considered as important driving factors for the structure and ecosystem operation of both lakes. Lake Koronia is in danger of becoming a permanently closed basin because of its significant water level decrease. Therefore, the maximum level of lake Koronia was proposed to be declined from 73 m to 72 m. Also, embankments were constructed at the Western part of the lake resulting to the decrease of the maximum surface area and volume of the lake at about  $2.59 \text{ km}^2$  and  $41.72 \text{ hm}^3$  respectively. (b) *Streams diversion*: Sxolari and Lagkadikia streams drain a wide area in the northern and southern part of the Mygdonia catchment respectively and they outflow to the artificial ditch. It was proposed two spillways to be constructed before their outflow to the ditch in order the 15% of the Sxolari stream discharge and the total discharge of Lagkadikia stream to outflow to lake Koronia. (c) *Rehabilitation of the groundwater aquifer*: The irrational pumping for irrigation has resulted in a very significant pressure on the water resources of the area and the continuously decline of the groundwater table. The wells surrounding the Mpogdanas stream are proposed to be removed and a public irrigation network to be established.

#### 4.2 Review of the lake Koronia water balance rehabilitation strategies

The proposed measures in the “Revised plan for the restoration of lake Koronia in the Prefecture of Thessaloniki” do not take into account climate change effects. In this paper, their suitability, in terms of confronting the water deficit of the lake for the future time periods, is tested.

At first, monthly precipitation and temperature data were calculated for a mid-term (2020-2049) and a long-term (2070-2099) time period. Raw monthly precipitation and temperature data of the KNMI-RACMO2 GCM-RCM (Global Climate Model – Regional Climate Model) under the SRES A1B (IPCC, 2007) were collected from the EU ENSEMBLES project database for the periods 1970-1999, 2020-2049 and 2070-2099 at a 25-km resolution. Because of the significant bias in the raw model projections, the Bias Correction Quantile Mapping (BCQM) method was selected to be performed in order to reduce the bias in the GCM-RCM projections for both precipitation and temperature. The BCQM method has been successfully used in many studies to correct RCM outputs over Europe (e.g. Sunyer et al., 2015; Gudmundsson et al., 2012). In this study, BCQM was implemented in R programming language using the *qmap* package. After the implementation of the BCQM, it was found that the mean annual surface precipitation and the mean monthly temperature for the whole Mygdonia catchment will be equal to 499.50 mm and 486.67 mm, and 13.65 °C and 14.57 °C for the mid-term (2020-2049) and the long-term (2070-2099) periods respectively.

The first two of the quantitative measures described in the previous section, namely the “Ecosystem connectivity and exports from lake Koronia” and the “Streams diversion” were taken into account in this study since they have already been implemented. The third measure has not been further described in the Revised Plan since the exact number and location of the agricultural wells were unknown until the end of the year 2016 when all the illegal wells have been recorded. However, these data have not been provided for public use yet.

The mean water balance of lake Koronia was calculated equal to 0.04 hm<sup>3</sup>/year and -3.42 hm<sup>3</sup>/year for the mid-term (2020-2049) and long-term (2070-2099) periods respectively. Hydrological inputs and outputs to lake Koronia for the historical and future periods are presented in Table 1. It was found that the already implemented infrastructure works in lake Koronia cannot confront its negative water balance which will be further deteriorated until 2100 due to climate change.

Table 1. Historical and future water balance of lake Koronia

	1970-1999	2020-2049	2070-2099
<b>Inflows to lake (hm<sup>3</sup>/year)</b>			
Precipitation	20.61	19.76	19.10
Runoff	7.49	11.24	10.48
Outflow from groundwater to lake	0.00	0.00	0.00
<b>Outflows from lake (hm<sup>3</sup>/year)</b>			
Evaporation	29.51	30.14	32.39
Recharge to groundwater	0.00	0.00	0.00
Outflow from lake to River Derveni	0.00	0.82	0.61
<b>Water balance (hm<sup>3</sup>/year)</b>	<b>-1.41</b>	<b>0.04</b>	<b>-3.42</b>

## 5. CONCLUSIONS AND DISCUSSION

The negative water balance of lake Koronia for the long-term future period reveals the deficiency of the proposed technical measures of the Revised Plan to confront the problem of the negative water balance on their own. Additional measures need to be taken for the restoration of the water balance of the lake. Those measures should be both structural and non-structural. A possible option is the development of a structural model providing farmers and policymakers with an understanding of how to improve adaptation in order to reduce climate-driven compensations to agriculture, since agriculture is the main water consumer in the area. Reforms in the agricultural sector, may require a change towards more heat-tolerant and less water intensive crops. Technical interventions, in terms of irrigation technique improvements would also provide valuable water

conservation.

As the development model in the area is mainly based on agricultural activities, the restoration of the lake would need a brave shift towards new development activities that are based on the carrying capacity of the whole ecosystem. Solutions should be built taking advantage of the main strengths of the area such as the natural landscape, human resources and crops compatible with the climate and the soil.

This work is part of a PhD thesis which is currently investigating potential land use changes and other structural and non-structural measures in providing a new sustainable development model for the area.

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## REFERENCES

- Gudmundsson, L., Bremnes, J. B., Haugen, J. E., and Engen-Skaugen, T., 2012. Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations – a comparison of methods. *Hydrol. Earth Syst. Sci.*, 16, 3383–3390.
- IPCC, 2007. Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Kolokytha, E., 2010. European policies for confronting the challenges of climate change in water resources. *Current Science*, 98(8).
- Loukas, A., N. Mylopoulos, and L. Vasiliades, 2007. A modeling system for the evaluation of water resources management strategies in Thessaly, Greece. *Water Resources Management*, 21(10), 1673-1702.
- Manakou, V., Tsiakis, P., & Kungolos, A., 2013. A mathematical programming approach to restore the water balance of the hydrological basin of Lake Koronia. *Desalination and Water Treatment*, 51(13-15), 2955-2976.
- Moustaka-Gouni, M., Michaloudi, E., Kormas, K.A., Katsipai, M., Vardaka, E., and Genitsaris, S., 2012. Plankton changes as critical processes for restoration plans of lakes Kastoria and Koronia. *European Water*, 40, 43-51.
- Mpallas, L., 2007. Implementation of fuzzy rules in the water resources management – Case study of the Volvi catchment. PhD thesis submitted in School of Rural and Surveying Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece.
- Mylopoulos, N., Mylopoulos, I., Kolokytha, E., and Tolikas, D., 2007. Integrated water management plans for the restoration of Lake Koronia, Greece. *Water International*, 32(S1), 720-738.
- Perivolioti, T.M., Mouratidis, A., Doxani, G., and Bobori, D., 2016. Monitoring the Water Quality of Lake Koronia Using Long Time-Series of Multispectral Satellite Images. In *Lining Planet Symposium*, 740, 249.
- Sunyer, M. A., Hundedcha, Y., Lawrence, D., Madsen, H., Willems, P., Martinkova, M., Vormoor, K., Burger, G., Hanel, M., Kriauciunien, J., Loukas, A., Osuch, M. and Yucel, I., 2015. Inter-comparison of statistical downscaling methods for projection of extreme precipitation in Europe. *Hydrology and Earth System Sciences*, 19(4), 1827-1847.
- Veranis, N. And Katirtzoglou, K., 2001. Study of the potential of the deep aquifer of the lake Koronia subcatchment. Calculation of the water balance of the Koronia subcatchment. Greek Institute of Geology and Mineral Exploration.