European Water 58: 197-202, 2017.

Assessment of the environmentally minimum lake level based on morphological features

C. Doulgeris[1*], P. Georgiou[2], A. Apostolakis[1], D. Papadimos[1], D. Zervas[1], O. Petriki[3], D. Bobori[3], D. Papamichail[2], V. Antonopoulos[2], C. Farcas[4] and P. Stålnacke[4]
[1] *The Goulandris Natural History Museum, Greek Biotope/Wetland Centre, 14th km Thessaloniki-Mihaniona, 57001 Thermi, Greece*
[2] *School of Agriculture, Faculty of Agriculture, Forestry and Natural Environment, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece*
[3] *Laboratory of Ichthyology, Department of Zoology, School of Biology, Aristotle University of Thessaloniki, 54006 Thessaloniki, Greece*
[4] *Norwegian Institute of Bioeconomy Research, Ås, NO-1431, Norway*
[*] *e-mail: haris@ekby.gr; chdoulgeris@gmail.com*

Abstract: The determination of environmentally minimum water level in lakes is essential for the protection of their ecosystems. The assessment of minimum water level depends on a number of biotic and abiotic factors of the lake ecosystem; however, in many cases these factors are not easy to collect and assess in their entirety. At the same time, the lakes in many cases consist an important water reserve to meet the requirements arising from economic activities, e.g. industry, agriculture. In this paper, the morphological features in four lakes – Vegoritida, Petron, Cheimaditida and Zazari – of Northern Greece are analysed in order to assess their environmentally minimum water level. The morphological analysis is based on the relationship of the lake surface area and volume with the water level. An optimization method is applied taking into account that the biodiversity is favoured as the surface area covered by the lake is increased and the human water requirements are satisfied to the greatest possible extent by the available water volume of the lake. The environmentally minimum water level determined by the morphological analysis in the four lakes is compared with the minimum water level based on the analysis of the requirements of fish fauna and macrophytes.

Key words: minimum ecological lake level, lake morphological analysis, Vegoritida-Petron-Cheimaditida-Zazari

1. INTRODUCTION

Hydromorphological pressures in aquatic ecosystems are usually associated to the need to control the water level in lakes and the flow in rives for the supply of water to economic sectors, such as industry, hydropower, domestic and agriculture. Also, the lake water volume, which depends on water level, is an easily available source of water to meet the human needs. Thus, the determination of the environmentally minimum water level in lakes is a key for the sustainable management of their ecosystems, as the minimum water level is the critical level below which there should be no further withdrawal to decrease the water level, and hence, ensuring the protection of lake ecosystems.

Many methods exist for the assessment of the environmentally minimum flow in rivers (Tharme, 2003; Jain, 2012); however, only few assessment methods exist to define a minimum water level in lakes and wetlands, probably due to partial understanding of the relationship between lake level and lake ecosystem. Furthermore, minimum water level assessment methods have not been used widely in lake management since they usually consider only part of the factors influencing the lake ecosystem. In general, minimum water level assessment methods include the historical lake level method (Xu et al., 2004; Leeper and Ellison, 2015), lake morphology analysis method (Li et al., 2007; Shang, 2013), habitat analysis method and species-environment models (Cui et al., 2005; Abbaspour and Nazaridoust, 2007; Mjelde et al., 2013). The historical lake level method integrates statistics in historical records, without including a direct connection between historical lake level and lake ecosystem. The lake morphology analysis method examines the existence of the inflection point in water level-area-volume curves of lakes to determine the minimum water level. On the other side, habitat analysis and species–environment models require intensive and detailed in situ survey.

In this paper, a lake morphological analysis based on the lake surface area-volume relationship is evaluated to assess the environmentally minimum water level of Lakes Vegoritida, Petron, Cheimaditida and Zazari in Greece. The minimum lake level determined by the morphological analysis method is compared with the seasonal minimum lake level based on the analysis of the requirements of fish fauna and macrophytes.

2. MATERIAL AND METHODS

2.1 Case study and data sets

Lakes Vegoritida, Petron, Cheimaditida and Zazari are located in the water district of Western Macedonia in Northern Greece (Fig. 1). The hydrological catchment of the lakes covers an area of 2,145 km^2 and is drained mainly by the streams Sklithro, Amyntas and Pentavryso (or Soulou). The four lakes are connected through the hydrographic network of the catchment and the excess of surface water is transferred from one lake to the other. Specifically, the water level in Lake Zazari is controlled by a weir and above the altitude of 599.7 m a.m.s.l., the excess of water overflows into Lake Cheimaditida via a canal. Similarly, the excess of water in Lake Cheimaditida overflows above 592.0 m into a drainage canal, which is joined downstream to the Amyntas stream, which ends up to Lake Petron. The latter overflows above 573.1 m and the water is driven through a tunnel into Lake Vegoritida.

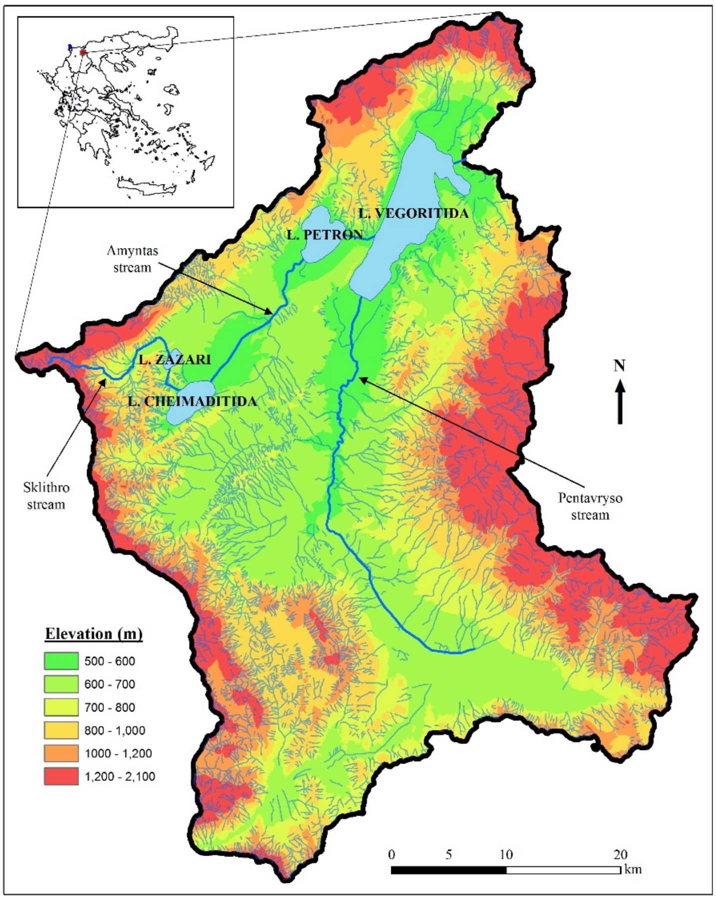

Figure 1. The hydrological catchment of Lakes Vegoritida, Petron, Cheimaditida and Zazari

The economic activities in the catchment that exert pressures in the lakes ecosystems are related mainly with industry and agriculture. Several steam-electric power plants exploit the lignite deposits in the region, consume water and augment the pollution load. Agricultural activity consume water for irrigation and produce non-point pollution; the main crops are wheat, corn, alfalfa and vineyard. Most populated urban areas in the catchment are Ptolemaida and Amyntaio, and the sewage treatment plant of the latter outflows into Lake Petron.

Lake Vegoritida has undergone great changes on its natural environment in the last decades as a result of its water level alteration. Based on water level recordings from the 1980s and afterwards, the water level dropped from 525 m to 510 m a.m.s.l. circa in the early 2000s, mainly due to water abstraction by the Public Power Corporation. During this period the lake has lost 45% of its volume and 29% of its surface area. Ever since the abstraction ceased, the water level is rising and nowadays varies around to 518.5 m.

The morphology of the shallow lakes Cheimaditida and Petron as well as the deeper lakes Zazari and Vegoritida has been studied recently by the Greek Biotope/Wetland Centre, in the context of the National Water Monitoring Network (http://nmwn.ypeka.gr/en). Specifically, the bottom elevation of the lakes Vegoritida, Zazari and Cheimaditida has been recorded by using a portable shallow water echo sounder equipped with GPS and dual frequency capabilities. Elevation data from in situ measurements were enriched by data available in maps from the Hellenic Military Geographical Service and processed by using GIS tools to create the bathymetric Digital Elevation Model (DEM) of each lake. The bathymetric DEMs were used to extract a high accuracy hypsographic curve and water level-volume curve for each lake. In Table 1 are given the hydromorphological features of the lakes at the maximum/overflow water level.

Table 1. Hydromorphological features in Lakes Vegoritida, Petron, Cheimaditida and Zazari

	Vegoritida	Petron	Cheimaditida	Zazari
Surface area (km^2)	47.2	12.6	10.1	2.0
Stored volume (10^6 m^3)	1,206.2	40.8	14.7	9.7
Average depth (m)	26	3.5	1.5	5
Maximum depth (m)	52.6	5.5	4.8	7.6

2.2 Methodology

The morphological features of a lake ecosystem play an important role to the determination of the environmentally minimum water level. In most cases, the morphology of a lake is described adequately by a hypsographic curve, i.e. a relationship of lake's water level-surface area, and a water level-volume curve. Lake surface area is an appropriate index for the habitat protection of lake ecosystems, assuming that the biodiversity in lakes increases with the surface area (Browne, 1981). On the other hand, the water volume stored in a lake could be taken as an index for available water to meet the water requirements for industry, agriculture etc. Based on the above, the lake surface area method has been proposed by Shang (2013) to define the minimum ecological lake level by considering both to protect lake ecosystems and to meet water requirements of economic activities.

Lake surface area increases with the lake volume, but the rate of increase or the slope of surface area-volume (S-V) relationship may increase or decrease with the volume depending on lake morphology, and thus, a critical lake storage at which the lake surface area does not change significantly may exist. The critical storage corresponding to the breakpoint of the lake surface area-volume curve can be used to define the minimum water level in lakes, similarly to the wetted perimeter method for determining the minimum environmental flow in rivers (Gippel and Stewardson, 1998). Specifically, the minimum water level could be calculated from the multi-objective optimization model (Shang, 2008; 2013):

$$\max z_1 = s(v) = S(V)/V_{max} \quad (1)$$

$$\min z_2 = v = V/V_{max} \quad (2)$$

where z is the water level, and s and v are the dimensionless lake surface area and volume, respectively. The first objective (eq. 1) represents the maximization of lake surface area taking into account that the biodiversity of lake is favoured as the lake surface area increases. The second objective (eq. 2) represents the minimization of lake storage in order to meet the water requirements of economic activities to the greatest possible extent. The solution of the optimization problem results in:

$$\min \{w_1 v + w_2[1-s(v)]\} \quad (3)$$

where w_1, w_2 are non-negative weights. Weight w_1 expresses the minimization of lake volume to meet water requirements and w_2 expresses the maximization of lake surface area to protect as much as possible habitats in the lake ecosystem. If the weights have the same value, i.e. $w_1=w_2=50\%$, the two objectives of the optimization model are expressed equally.

3. RESULTS AND DISCUSSION

In Table 2 is given the minimum water level in Lakes Vegoritida, Petron, Cheimaditida and Zazari by applying the analysis of their morphological features. The assessed minimum water level is strongly depended by the values of the weighted factors w_1 and w_2. In Lake Vegoritida for the case of *envScenario* ($w_1=30\%$, $w_2=70\%$), the minimum water level is 1.8 m below the maximum level resulting to a decrease of lake surface area by 3% and to an exploitation of available water volume by 7%. In the cases of *eqScenario* ($w_1=w_2=50\%$) and *wuScenario* ($w_1=70\%$, $w_2=30\%$), the minimum water level is assessed around 27 m and 40 m below the maximum level, respectively; these non-realistic minimum water levels corresponds to a decrease of the lake surface area by 51% and 77%, respectively, compared to the maximum lake surface area. Furthermore, if the *eqScenario* is assumed for example, the lake water volume will be decreased by 933.4 million m^3 (i.e. 77% decrease compared to the maximum water volume) and, based on the lake catchment runoff, several years will be required to the rise of the water level up to its maximum level.

Table 2. Maximum water level and proposed minimum water level according to the morphological analysis in Lakes Vegoritida, Petron, Cheimaditida and Zazari

Water Level (WL), m a.m.s.l.	**Vegoritida**	**Petron**	**Cheimaditida**	**Zazari**
Maximum WL	518.0	573.1	592.0	599.7
Minimum WL, *envScenario*: ($w_1=30\%$, $w_2=70\%$)	516.2	571.1	591.3	596.0
Minimum WL, *eqScenario*: ($w_1=w_2=50\%$)	490.9	570.3	591.2	594.9
Minimum WL, *wuScenario*: ($w_1=70\%$, $w_2=30\%$)	477.9	569.1	589.2	594.0

In Lake Petron, the minimum water level is assessed 2.0 m below the maximum level for the *envScenario*. In this case, the lake surface area and water volume is decreased by 18% and 56%, respectively. According to the *eqScenario*, the minimum water level is 2.8 m below the maximum level resulting to a decrease of lake surface area and water volume by 31% and 75%, respectively.

In Lake Cheimaditida, the minimum water level is assessed 0.7 m below the maximum level for the *envScenario* resulting to a decrease of lake surface area by 17% and water volume by 46%. In the *eqScenario* the assessed minimum water level is similar to the minimum level of the *envScenario*.

In Lake Zazari, the minimum water level is 3.7 m below the maximum level for the *envScenario* resulting to a decrease of lake surface area by 26% and water volume by 66%. In the case of *eqScenario*, the minimum level is 4.8 m below the maximum level resulting to a decrease of lake surface area and water volume by 37% and 82%, respectively.

It is mentioned that for the *wuScenario* (w_1=70%, w_2=30%), the assessed minimum water level in the four lakes corresponds to an exploitation of the available water volume above 90% and a decrease of the lake surface area among 50 to 90%, which practically leads to a severe disorder of the aquatic ecosystems if not in their disappearance.

Figure 2 shows the monthly minimum water level assessed by the analysis of fish fauna requirements (Petriki and Bobori, 2016) and the analysis of macrophytes requirements (Zervas, 2016) in comparison to the minimum water level assessed by the analysis of lakes' morphological features and according to the *envScenario* (w_1=30%, w_2=70%). In Lake Vegoritida, the minimum level assessed by the morphological analysis is 40 to 90 cm below the water level assessed by the macrophytes analysis and 1.6 m above the water level assessed by the fish fauna analysis. In Lake Cheimaditida, the morphological analysis suggests a minimum water level quite close to the minimum water level proposed by the analysis of fish fauna and macrophytes requirements. In Lake Petron and Lake Zazari, the minimum water level assessed by the morphological analysis is below the minimum level proposed by the species requirements, especially in Lake Zazari.

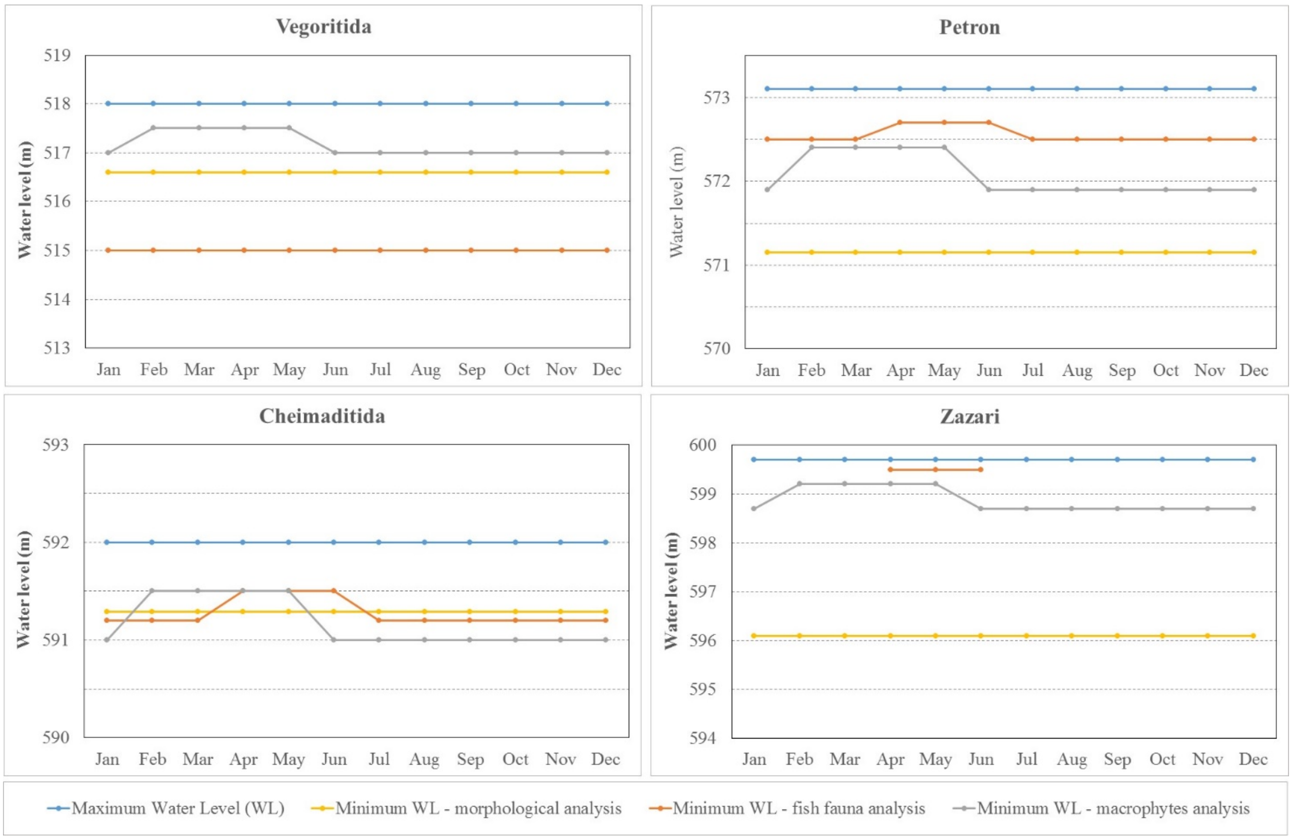

Figure 2. Environmentally minimum water level based on the analysis of species requirements and morphological features in Lakes Vegoritida, Petron, Cheimaditida and Zazari

4. CONCLUSIONS

A lake morphology analysis method based on the hypsographic curve and the water level-volume curve was proven useful to assist a quick decision for a reliable assessment of the environmentally minimum water level in four lakes of Northern Greece. The method propose a balance to protect biodiversity and to meet human water requirements. The application of the method showed clearly that among the three scenarios, only the *envScenario* (w_1=30%, w_2=70%) –

in which the protection of biodiversity is favoured against the fulfillment of human water requirements to the greatest possible extent – may lead to safe assessments of the environmentally minimum water level. Regarding the minimum water level based on the analysis of biological species requirements, the morphological analysis estimates comparable minimum water level in Lakes Vegoritida and Cheimaditida and lower minimum water level in Lake Perton and, especially, in Lake Zazari.

The morphological features of a lake are important data that should be taken into account to the determination of the environmentally minimum water level. The method applied in this paper reconciles the protection of lake ecosystems and the availability of water volume to meet the economic activities.

ACKNOWLEDGEMENTS

This work is part of the project «Improving the knowledge in determining the minimum water level and flow of water bodies» (http://eordaia-nestos.gr/en), which is financed by the European Economic Area Financial Mechanism 2009-2014 and the Public Investment Program.

REFERENCES

Abbaspour, M., Nazaridoust, A., 2007. Determination of environmental water requirements of Lake Urmia, Iran: an ecological approach. International Journal of Environmental Studies, 64(2): 161–169.

Browne, R. A., 1981. Lakes as islands: biogeographic distribution, turnover rates, and species composition in the lakes of central New York. Journal of Biogeography, 8(1): 75–83.

Cui, B. S., Zhao, X., Yang, Z. F., 2005. Eco-hydrology-based calculation of the minimum ecological water requirement for lakes. Acta Ecologica Sinica, 25(7): 1788–1795.

Gippel, C. J., Stewardson, M. J., 1998. Use of wetted perimeter in defining minimum environmental flows. Regulated Rivers: Research & Management; 14(1): 53–67.

Jain, S. K., 2012. Assessment of environmental flow requirements. Hydrological Processes, 26(22): 3472–3476.

Leeper, D. A., and Ellison, D.L., 2015. Proposed Minimum and Guidance Levels for Lake Hancock in Polk County, Florida. Southwest Florida Water Management District. Brooksville, Florida.

Li, X. H., Song, Y. D., Li, Y. T., et al. 2007. Calculation methods of lowest ecological water level of lake. Arid Land Geography, 30(4): 526–530.

Mjelde, M., Hellsten, S., Ecke, F., 2013. A water level drawdown index for aquatic macrophytes in Nordic lakes. Hydrobiologia; 704:141–151

Petriki, O., Bobori, D., 2016. Analysis of fish fauna requirements on minimum seasonal water level and water quality in Lakes Zazari, Cheimaditida, Petron and Vegoritida (D.A1.1). Fisheries Research Institute (INALE). N. Peramos, Greece. 67 p.

Shang, S. H., 2008. A multiple criteria decision-making approach to estimate minimum environmental flows based on wetted perimeter. River Research and Applications, 24(1): 54–67.

Shang, S. H., 2013. Lake surface area method to define minimum ecological lake level from level–area–storage curves. J Arid Land; 5(2): 133−142.

Tharme, R. E., 2003. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications, 19(5–6): 397–441.

Xu, Z. X., Chen, M. J., Dong, Z. C., 2004. Researches on the calculation methods of the lowest ecological water level of lake. Acta Ecologica Sinica, 24(10): 2324–2328.

Zervas, D., 2016. Analysis of aquatic macrophytes requirements on minimum seasonal water level and water quality in Lakes Zazari, Cheimaditida, Petron and Vegoritida (D.A1.2). Greek Biotope/Wetland Centre (EKBY). Thermi, Greece. 63 p.