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HYDROLOGY OF LAKE PRESPA

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ABSTRACT

During the last century the Macro Lake Prespa experienced a significant water level fluctuation. After its last peak (1963) and after the separation of the Micro Lake Prespa (1975), the level generally dropped by approximately 8 m (2002). This resulted to a loss in water volume and even more significant a loss of water surface. The effects and causes of the changes in the Lake have been investigated in various studies carried out by interested parties from shareholding countries. Most of these studies had to rely on the hydrometeorological data that were not up-to-date or not complete. In this study, effort was made to collect long-term time series climatic and hydrological data and to assess the vulnerability of Lake Prespa to climate change and human actions in the watershed. Monitoring network and data quality and quantity is also discussed in the context of hydrological modelling and transboundary collaboration in integrated water resources management. Hydrological analysis is obtained using measured data for the period (1951-2010) at Pretor meteorological station and Stenje hydrological station.

Kay words: Prespa Lake, hydrology, precipitation, water balance

1. WATERSHED CHARACTERISTICS

The physical geographical characteristics of the Lakes Prespa watershed and sub-watersheds were defined on the basis of digital topographic maps in scale 1:25.000 and satellite images with high resolution. The Macro Lake Prespa catchment area is defined to be 1.110 km^2 (including 278 km^2 lake surface) and that one of Micro Lake Prespa is 253 km^2 (including 48,5 km^2 Lake surface) at Lake water level of 844 m asl. The Macedonian part of the catchment area is 52,1% and that of Lake surface is 65,7%. Northern and eastern parts of the watershed are well hydrographically developed, while the west part is rather poor. Around the Lake high mountains rise: in the West Galichitsa Mountain (2.262 m asl.), Dry Mountain (1.863 m asl.), and Petrinska Mountain (1.660 m asl.), in the east is Baba Mountain (2.601 m asl.), while in the north is Bigla Mountain (1.990 m asl.).

The cumulative distribution of elevations in the catchment has been defined on the basis of a 30x30 m Digital Elevation Model (DEM) and reflects the steep character of the watershed with moderately flat bottom. The elevation range is presented in Table 1. Mean altitude of the watershed is 1.118,37 m asl, while the mean slope is 21,37%. Main rivers in the Macedonian part of the watershed are: Golema (A=174 km^2) and Istochka (A=90 km^2) on the North, and Kranska (A=74 km^2), Kurbinska/Pretorska (A=8,6 km^2) and Brajchinska (A=74 km^2) on the East.

Land use and land cover of the watershed is defined by CORINE Land Cover (CLC) EU database which provides comparable digital maps on land cover, biotopes, soil, and acid rain for over 22 countries in Europe. The map was created in GIS ARC/INFO format based on the interpretation of satellite images with land cover types in 44 standard classes. The forests and semi natural areas cover 437,82 km^2 (75,38%), agricultural land participate with 120,53 km^2 (20,81%), artificial areas (urban, industrial and commercial units, mines, damps and construction sites) participate with 4,56 km^2 (0,785%), and water bodies cover only 6,4 km^2 (1,1%).

Table1. Watershed characteristics of Lakes Prespa

	Area (km^2)	Hmin (m asl)	Hmax (m asl)	Hav (m asl)	Slope (%)
Macedonia	761,00	844	2420	1118,37	21,37
Albania	261,19	844	2275	1207,41	26,23
Greece	341,52	844	2161	1132,60	24,41
Total:	1363,71				

Figure 1. Prespa Lake is recognised by the natural beauty and rare biodiversity

2. MONITORING NETWORK

The monitoring in Macro Lake Prespa watershed has been established in accordance with the national legislative in Macedonia: Law on Waters, Law on hydrometeorological affairs and Programme for protection of Ohrid, Prespa and Dojran Lakes. The map of the existing hydrological and meteorological stations is presented in Figure 2. Hydrological stations for measuring the water level in the Lake are established at the villages: Stenje (1935), Asamati (1948) and Nakolec (1954). All stations are equipped with water level recorders and water level gauges. Besides these there are three stations on the main rivers in the watershed: on Golema River in Resen (1947), Leva River (1986) and Brajchinska in Brajchino (1964). Recently (2012) in Resen has been established an automatic hydrological station. Systematic groundwater monitoring doesn't exist. For agricultural purposes there are have been constructed 7 shallow wells at Krani, Asamati, Resen, Krushje, Carev Dvor, Preljublje and Stenje. At these points there are sporadic groundwater and water quality measurements. Within the UNDP project "Hydrogeological Study for the Lake Prespa Watershed" (2014/2015), 15 deep piezometers have been constructed with regular monthly water level fluctuation and water quality monitoring.

Meteorological monitoring is very important especially in hydrological modeling of surface runoff and erosion in the watershed. Climatologically station in Resen (881 m asl) is established in 1947 but stopped operation in 1993. Meteorological station in Pretor (993 m asl) is established in 1991. Since 2007 six automatic agro-meteorological stations have been established at Jankovec, Resen, Dolna Bela Crkva, Krani, Lavci and Gorno Dupeni with hourly data on precipitation, air temperature, humidity, wind speed, and solar radiation. Rainfalls are measured at rain gauges at Asamati (860 m asl), Brajchino (1020 m asl), Carev Dvor (864 m asl), Izbishta (980 m asl), Nakolec (850 m asl), Stenje (855 m asl). Unfortunately, there is no precipitation data for higher region of the watershed. Also, data on snow are not available on higher altitudes.

2.1 Data availability and evaluation

In vulnerability assessment of the Lakes and their ecosystem most important are historical data quantity and quality. Hydrological and meteorological data are basis in water balance modeling as one of the objectives in vulnerability assessment and adaptation measures. In Table 2 are presented all kind of data that have been collected and tools used within this study. The input and output components in the approximate water balance model are obtained as it follows.

2.1.1 Precipitation

The precipitations in the watershed have been analyzed by collected monthly data for the period (1951-2010) from 7 rain gauge stations in the watershed: Asamati, Stenje, Izbishta, Carev Dvor, Nakolec, Brajchino and Pretor. The total amount of precipitation in the watershed is computed by the following expression:

$$V_p = \sum P_{\Delta t} \cdot A \tag{1}$$

Where ($\Sigma P_{\Delta t}$) is the average precipitation sum in the watershed for the time period (Δt), and (A) is the watershed area. The average annual precipitation in Macedonian part of Lake Prespa watershed is 900 mm obtained by the method of isohyets.

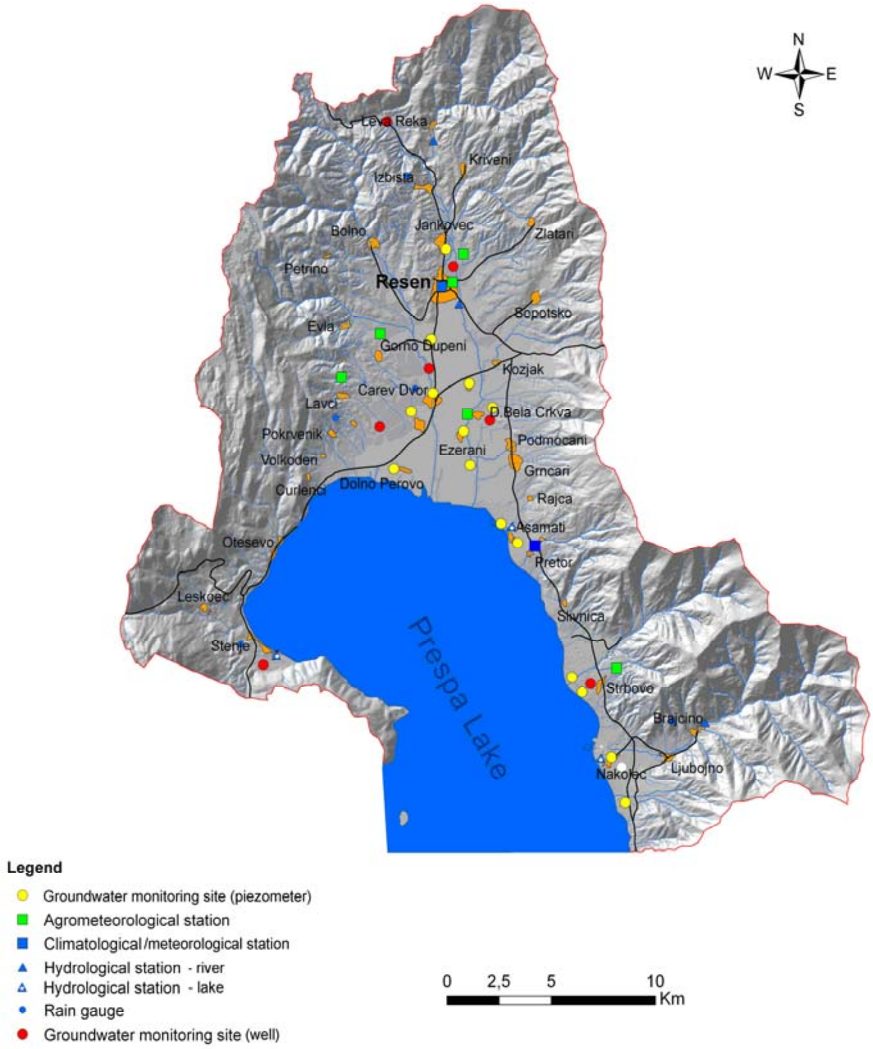

Figure 2. Monitoring sites in Macro Lake Prespa watershed

2.1.2 Water surface evaporation

Evaporation from free surface water in Lake Prespa watershed has been computed by empirical formulas using data on air temperature, saturated vapour pressure, radiation, sunshine duration, wind speed, and albedo effect. The total amount of evaporation from Lakes Prespa water surface is obtained by the expression:

$$I_E = \sum E_{\Delta t} \cdot \sum A \tag{2}$$

Where ($\Sigma E_{\Delta t}$) is the evaporated water from lakes' surfaces for the period (Δt), and (ΣA) is a free surface areas at normal water level (Macro Lake area A=278 km^2 and Micro Lake area A=48,5 km^2 at 844 m asl). Three recommended formulas have been use: Penman, Rohwer and Mayer. Penman results showed the most stable distribution and have been considered as the most reliable to be used in future analysis. The average annual evaporation sum is obtained to be 798.02 mm.

Comparing the annual amount of precipitation fall over the Lake and evaporation it is concluded that evaporated water is less than precipitation. Figure 3 presents precipitation at Stenje for the period (1951-2004) and computed evaporation using climatic data from Resen for the period (1952-1988). Monthly precipitation and evaporation distribution in an average year have shown that in April, May, June, July, August and September the evaporation is greater than the incoming water from precipitation.

Table 2. Available data and tools used in evaluation

Topographic			
Digital Elevation Model (DEM) (30×30 m)			
Land use			
CORINE Land Cover			
Climatic-meteorological			
Type of data	Station	Period	Missing
Precipitation	Asamati	1951-1991	
	Stenje	1951-2004	
	Izbishta	1951-2004	
	Carev Dvor	1951-2004	1991-1995
	Nakolec	1951-2004	1991-1993 1997-2002
	Brajchino	1951-2004	
	Resen	1952-1993	
	Pretor	1991-2010	
Temperature	Resen	1952-1993	
	Pretor	1991-2010	
Wind speed	Resen	1952-1990	
	Pretor	1991-2010	
Relative humidity	Resen	1952-1988	
	Pretor	1991-2010	
Sunshine duration	Resen	1952-1988	
	Pretor	1991-2010	
Hydrological			
Water levels	Stenje	1951-2010	

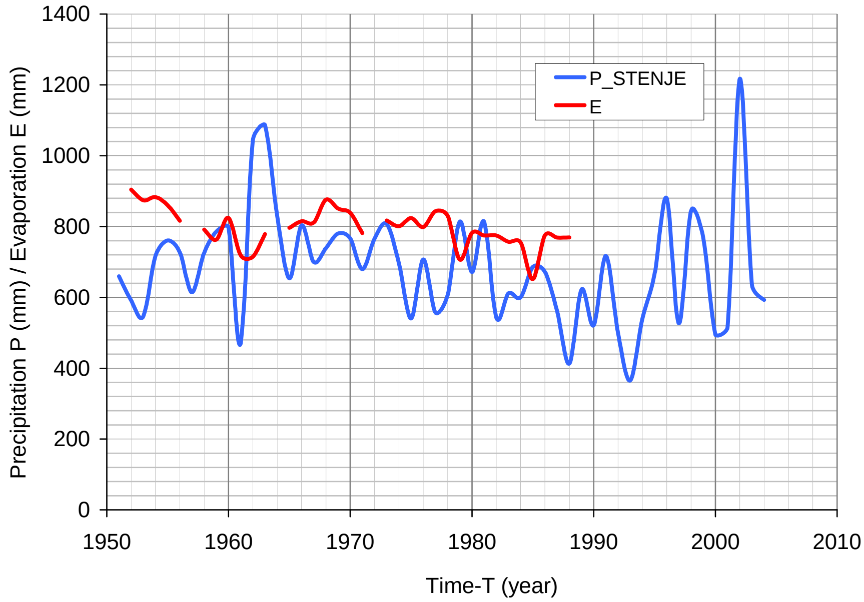

Figure 3. Annual precipitation and evaporation distribution over the Lake

2.1.3 Evapotranspiration

The quantity of evaporation from land in Lake Prespa watershed is computed by the following expression:

$$I_{ET} = \sum ET_{\Delta t} \cdot A_{ET} \quad (3)$$

Where ($\Sigma ET_{\Delta t}$) evapotranspiration from the watershed, (A_{ET}) is the area in (km^2). Evapotranspiration has been computed by Penman formula, Table 3. Climatic data have been taken from Resen for the period (1961-1988) and Pretor for the period (1991-2010). Maximum air temperatures (T_{max}) are recorded in July and minimum (T_{min}) in December. The average relative humidity (U) is 65%. The average evapotranspiration (ETo) is obtained to be 1,67 mm/day.

Table 3. Monthly evapotranspiration with data from Pretor station (1991-2010)

Month	T_{max} (^oC)	T_{min} (^oC)	U (%)	W (m/s)	n (hours)	Solar radiation ($MJ/m^2/d$)	ETo (mm/day)
January	19,0	-14,1	71,6	0,89	3,62	6,2	0,249
February	19,0	-16,0	66,6	1,03	4,65	8,3	0,661
March	23,7	-12,4	62,8	0,94	5,70	11,9	1,019
April	26,5	-10,3	62,9	0,97	5,78	16,1	1,913
May	30,6	1,0	64,2	0,73	10,63	19,9	2,699
June	34,8	1,4	61,5	0,66	9,17	22,9	3,196
July	37,4	6,0	56,8	0,6	10,37	25,2	3,418
August	36,2	7,8	56,4	0,62	9,98	22,3	3,151
September	32,5	1,0	62,7	0,56	7,40	17,0	1,899
October	28,4	-1,3	68,7	0,76	5,62	11,5	0,860
November	23,2	-10,0	70,1	0,819	3,94	7,5	0,380
December	17,6	-13,0	72,6	0,959	2,76	5,6	0,614
Average	27,41	-4,99	64,75	0,795	6,634	14,5	1,672

2.1.4 Outflow from the lake

There is no free surface outflow from Lake Prespa. In the article "Study of underground communication of Lakes Prespa and Ohrid using environmental isotopes of Hydrogen and Oxygen of water" Zoto *et al.*, (2013) some results out of the environmental isotope measurements are presented. The results indicate that 52% of the mean discharge of Tushemishti springs is recharged from Prespa Lake and 48% from precipitation infiltration in Dry (Mali i Thate) and Galichitsa Mountains. These results are comparable with those obtained by Anovski *et al.*, (1988) in Macedonian part of the watershed where it is estimated that about 42% of the Saint Naum spring is recharged by Lake Prespa. The average annual runoff at St Naum spring for the period (1991-2004) is obtained to be 6,86 m^3/s with maximum in December (7,65 m^3/s) and minimum in February (6,29 m^3/s). The average annual runoff at Tushemishti spring for the period (1971-2004) is obtained to be 0,37 m^3/s with maximum in April (0,46 m^3/s) and minimum in November (0,35 m^3/s). Total outflow from Prespa Lake is estimated to be 3,09 m^3/s.

2.1.5 Water supply and irrigation

Water resources in Prepa Lake watershed have been used for water supply of the population and industry. In KfW Feasibility Study (2005) it is estimated that annual water demand in Macedonian side is 1,5 million m^3, and 2,5 million m^3 together with Greece and Albania.

Data on crop water demand has been taken from the report "Irrigation Systems and Crop Water Demand" (Hydrogeological Study for the Lake Prespa Watershed, 2013) where the net irrigation water demand is estimated to be 24,76 million m^3. Considering 70% efficiency of the irrigation systems the gross water demand for irrigation is 24,76/0,70=35,37 million m^3 annually.

2.1.6 Water level fluctuations

One of the objectives of the performed study is to clarify the water level strong fluctuations and their relationship to precipitation, Figure 4. Analyzing the precipitation and the Lake water level change it is concluded that there is no significant relationship.

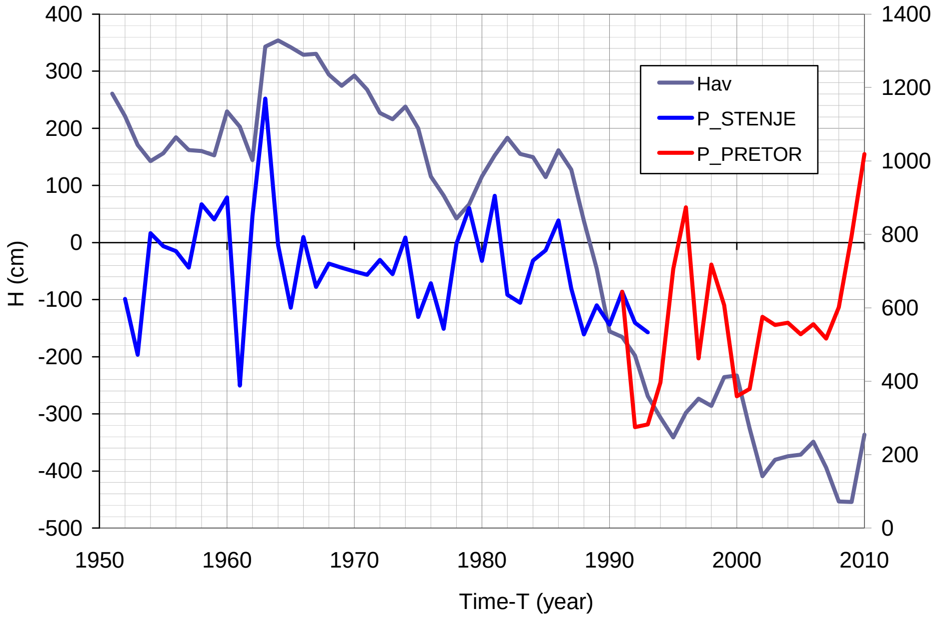

Figure 4. Comparative analysis of the annual water level fluctuation and precipitation

The precipitation trend line has a small decreasing gradient, while the water level trend line is extremely steep.

Recorded data on Lake Prespa water levels have been taken from hydrological station at Stenje (water gauge zero 847,68 m asl) for the period (1951-2010). Starting from 1987 the water level is decreasing reaching maximum drop down of 493 cm (842,75 m asl) bellow the water gauge zero in 2008. Between 1951 and 1963 the water level fluctuated around a comparatively high level (app. 850 m asl). Rapid jump of approximately 2,2 m occurred due to heavy rainfalls. During the next 12 years (1963-1975) the water level smoothly but steadily decreased reaching the previous average value of approximately 850 m asl. After 1975 the water level decreased for the first time rapidly. Thereafter the steady decline continued until 1978 when the water level fell bellow 849 m asl. In 1986 the water level start to decline sharply and continuously reaching the maximum drop in 1995 (app. 844 m asl). After the lake recovered by water level increase of about 1,2 m, in 2000 start sharply dropping that continuous until 2008. Thereafter due to the rainfall increase in the region the water level recovering with seasonal fluctuations appeared.

3. WATER BALANCE

Many environmental problems are caused by changes in aspects of the hydrological cycle, Figure 5. Water balance modeling combined with field experiments can give us a better understanding of the components of the hydrological cycle from which is develop appropriate management options. Water balance models can be developed at any level of complexity. In simple models only the most important processes are represented. Complex models are needed to understand complex feedbacks and interactions among different processes of the system. However, increasing the complexity of the model does not necessarily lead to a more accurate model and it is essential that model complexity matches the availability of data.

Within the project "Hydrogeological Study of Prespa Lake" (UNDP Project, 2013) a simple "bucket" model is applied. The water balance simple model is developed on annual basis with monthly data. The average annual water balance components are shown in Table 4 and the monthly water balance storage change in Figure 6. It is concluded that water shortages in the Lake's watershed occur usually from May to September.

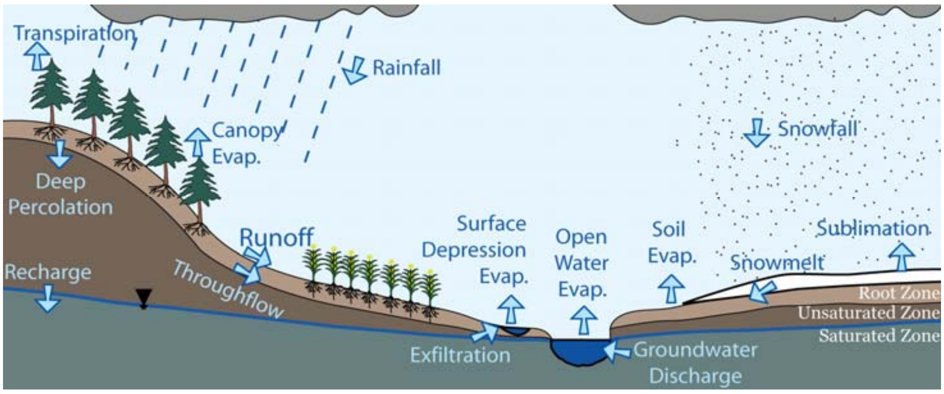

Figure 5. The hydrological cycle components

Table 4. Water balance summary results

WB Component	MCM
Inflow water from precipitation	1245,60
Outflow water due to evaporation from free water surface	247,38
Outflow water due to evapotranspiration in the watershed	612,87
Outflow water through karstic underground	97,41
Used water for water supply	2,5
Used water for irrigation	35,37
□Water storage change (inflow-outflow)	204,72

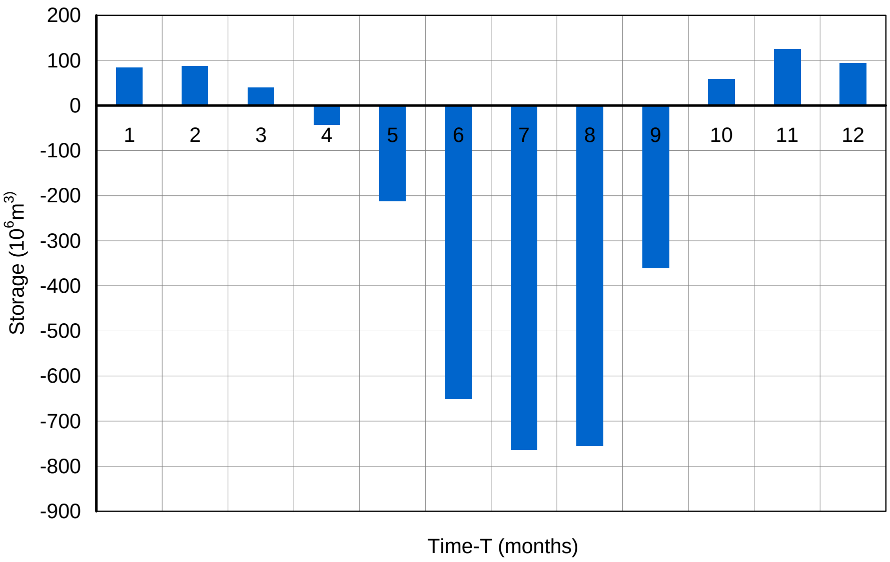

Figure 6. Monthly water balance

4. CONCLUSIONS AND RECOMMENDATIONS

The analysis of the available hydrological data necessary in hydrological modelling and integrated watershed management plans development has shown the need of data quality and quantity improvement. This is essential in clarification of the causes of rapid lake water level decrease that started in early nineties and did not recover completely yet. The last decade it is observed small water level increase that can be referred mainly to the rather wet hydrological regime. Precipitation increase is observed as well as precipitation redistribution in the region. This statement can be supported by the fact that water use scenarios and water resources management in all three countries that share the Lake and its watershed have not been changed. Those changes are expected after the "Prespa Lake Management Plan" (UNDP Project, 2010) according to EU Water Framework Directive will be implemented. After that it will be possible to assess how much the human activity impacted the water level drop and how much it is due to the natural causes.

The water balance summary results show that for a long term average year the inflowing water is greater than the outflows. More reliable estimation of groundwater components should change the obtained summary results. And yet, a critical overview of the uncertainties of estimating the water balance of lakes is done by Thomas Winter (1981) that can be summarized as it follows:

"Evaluation of hydrologic methodology used in a number of water balance studies of lakes shows that most of these studies calculate one or more terms of the budget as the residual. A literature review was made of studies in which the primary purpose was error analysis of hydrologic measurement and interpretation. Estimates of precipitation can have a wide range of error, depending on the gage placement, gage spacing, and areal averaging technique. Errors in measurement of individual storms can be as high as 75%. Errors in short term averages are commonly in the 15-30% range, but decrease to about 5% or less for annual estimates. Errors in estimates of evaporation can also vary widely depending on instrumentation and methodology. The energy budget is the most accurate method of calculating evaporation; errors are in the 10–15% range. If pans are used that are located a distance from the lake of interest, errors can be considerable. Annual pan-to-lake coefficients should not be used for monthly estimates of evaporation because they differ from the commonly used coefficient of 0.7 by more than 100%. Errors in estimates of stream discharge are often considered to be within 5%. Comparison of several lake water balances in which the residual consists solely of errors in measurement, shows that such a residual, if interpreted as ground water, can differ from an independent estimate of ground water by more than 100%."

The developed approximate water balance model has shown insufficient hydrological, meteorological and water use data. Monitoring and data collection in Lake Prespa watershed can be assessed as not sufficient regarding the vulnerability of the Lake and its ecosystem on climate and human actions. Monitoring in the watershed should be organized according to the EU Water Framework Directive (2000/60/EC) where three basic monitoring types have been proposed: a) surveillance; b) operational; c) investigative. The differences among these three types are in number of parameters to be monitored, number and distribution of the monitoring points/stations, frequency and etc.

Surveillance monitoring defined points/stations that are representative for large water bodies. This monitoring should collect data necessary to assess the long-term changes of the water bodies as results of human activities. The monitoring parameters are grouped into physical-chemical, biological and hydromorphological parameters. Hydromorphological parameters are defined within two subgroups: a) hydrological; and b) morphological. Hydrological monitoring includes surface water level record, runoff record, ground water level record, residence time, and sediment transport river capacity. Morphological monitoring includes data on river/lake geometry changes, river/lake bottom structure, riparian cover, and etc.

Operational monitoring is established for those water bodies that were assessed in surveillance monitoring with risk not to fulfill the environmental aims. Such monitoring program is necessary especially for the water bodies that are recipients of polluted waters with substances in the priority list of WFD. This monitoring is focused on the pressures as result of point or nonpoint/diffusive pollution.

Investigative monitoring is established when with the other monitoring types could not be defined the causes why the water body could not achieve good status of classification. Very often this monitoring is focused on only one parameter and/or a few parameters.

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HIDROLOGIJA PRESPANSKOG JEZERA

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Rezime

Prespansko jezero je najbolji primer vrlo nepovoljnih tendencija u oblasti voda u svetu u posledinjih nekoliko decenija. Zbog sve većeg nesklada između skromnih raspoloživih resursa obnovljivih voda, sa jedne strane, i brzo rastućih potreba za vodom brojnih korisnika, posebno navodnjavanja, sa druge strane, dolazi do veoma nepovoljnih tendencija u brojnim jezerima sveta – do velikih obaranja nivoa. To je posebno izraženo u slučaju Prespanskog jezera, čije vode koriste Makedonija, Grčka i Albanija. Zbog nadeksploatacije osobito u sušnim periodima, dramatično se snižavaju nivoi u jezeru, čime se ozbiljno narušavaju ekološki uslovi u tom jezeru koji je sa pravom tretiran kao ekološki dragulj Evrope. Sličnu sudbinu doživljava i Dojransko jezero, nekada ekološki svetski poznato jezero po bogatstvu biodiverziteta. Zbog toga je članak uvažene profesorke Cvetanke Popovski veoma dragocena i upozoravajuća analiza. (*Komentar Glavnog urednika*).

U drugoj polovini prošlog veka u Prespanskom jezeru je došlo do značajnih oscilacija nivoa vode. Nakon poslednjeg visokog nivoa (1963), a nakon odvajanja Micro Prespanskog jezera (1975), zbog nadekspoatacije jezera za navodnjavanje došlo je do narušavanja ravnoteže vodnog bilansa i postepenog snižavanja nivoa, tako da su nivoi smanjeni čak za oko 8 m (2002). Smanjena je zapremina jezera, ali je sa ekološkog, urbanog i socijalnog stanovišta još nepovoljiji efekat – smanjenje površine jezera i povlačenje ureza vode daleko od ranijih linija obala koje su uticale na formiranje naselja i prateće infrastrukture. Ti nepovoljni efekti su analizirani u više studija u sve tri zaninteresovane zemlje, ali im je manjkavost bila nedovoljna baza hidrometeoroloških podataka. Za potrebe ovog rada učinjen je napor da se sakupe dugoročne vremenske serije klimatoloških i hidroloških podataka, kako bi se dala što relevantnija procena ugroženosti Prespanskog jezera od klimatskih promena i ljudskih aktivnosti u slivu. Hidrološke analize i procene su obavljene na osnovu izmerenih podataka za period 1951-2010 na meteorološkoj stanici Pretor i hidrološkoj stanici Stenje hidrološke. Razmatra se i neophodna mreža za monitoring i osmatranja u kontekstu hidroloških modela i prekogranične saradnje u integrisanom upravljanju vodnim resursima sliva Prespanskog jezera.

Ključne reči: Prespansko jezero, hidrologija, padavine, vodni bilans

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