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HYDROLOGICAL CHARACTERISTICS AND RELATED ECOSYSTEM SERVICES OF SREBARNA AND CERKNICA LAKES

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INTRODUCTION

Wetlands are among the most endangered systems in spite of the fact that they have a great influence on human wellbeing, providing the majority of important ecosystem services. Karst wetlands are marked by changes in water level during the year. Water level fluctuations create a variety of habitats with diverse communities (G a b e r š č i k, U r b a n c – B e r č i č, 2002). A range of changes in water regime, soil properties and some other factors delineates habitats. Water level during the vegetation period as well as the intensity, timing and the extent of floods influence primary production and other processes, e.g. mineralization, decomposition, colonisation with plants, as revealed by different studies (M a r t i n č i č, L e s k o v a r, 2002; D i n k a et al., 2008). The intermittent Cerknica Lake appears at the bottom of the karstic depression Cerkniško Polje. The amount of water in the lake depends on precipitation and potential evapotranspiration on the polje and its surroundings (K r a n j c, 2002). During the rainy period, water is collected from the upstream-lying karst poljes, from the surrounding karstic plateaus and directly from the rainfall. The studies of processes in intermittent wetlands revealed that the water level during the vegetation period as well as the intensity, timing and the extent of floods and droughts, affect primary production, life cycles of animals, i.e. spawning of fish and nesting of birds, as well as mineralization and decomposition (B o u l t o n, B r o c k, 1999; G a b e r š č i k, et al., 2003, D i n k a et al., 2008). Clear zoning of different vegetation types could be observed on the area (M a r t i n č i č, L e s k o v a r, 2002) as was also the case in other wetlands (C r o n k, F e n n e s s y, 2001). The lake provides habitat or temporary shelter for numerous species many of which are on the Red List. Besides, the lake presents an important reservoir for water accumulation.

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Srebarna Lake is the largest natural wetland system along the Bulgarian sector of the Danube River. The first sources of information about the lake are connected with the travels and works of H o d e k (1882), K a n i z (1882) and L o r e n z – L i b u r n a u (1892). Biodiversity, especially diversity of birds, is the main topic of these early descriptions and investigations in the region of the lake. Felix Kaniz claims, that the lake is "Eldorado of waterfowl". The research of B o n c h e v (1929; 1942) defines the ecosystem as a karst lake, influenced by fluctuating water of the Danube River. The most variable hydrology occurs in spring (April-June), during the Danubian high water levels (Cherries waters). In certain years the Danube River floods the western part of Ajdemir lowland and transforms the lake into a river bay. This process had occurred regularly before the building of the artificial dike to protect the lowland from floods. The dike interrupted the natural connection between the Danube River and the Sreburna Lake. As a consequence of this interruption accelerated eutrophication processes occured in the lake, resulting in reduction of the water body size and the expansion of reeds and hydrophytes (Z h e l e z o v, 2007; 2008). Changes in abiotic conditions affected biodiversity and distribution of bird populations and ecosystem services. The lake is an important food provision area and presents precious habitats for nesting and reproduction of numerous species.

In this article two different wetlands - the intermittent Cerknica Lake and karst Srebarna Lake – are compared with respect to water quality and dynamics and the importance of related ecosystem services are pointed out.

SITES DESCRIPTION

The Cerknica Lake is a unique karstic ecosystem, being neither a lake nor a terrestrial system. It is located in the heart of Notranjska region and is *locus typicus* for intermittent lakes. The closed depression of Cerkniško Polje extends on 38 m^2 and the surface between 20 and 27 km^2 can be flooded when the polje changes into a lake (K r a n j c, 2002). H u t c h i n s o n (1975) classified the lake of Cerknica as a solution lake – a lake on soluble rocks, as well as a temporary lake. The basic rock of the area is carbonate. During dry periods the water sinks into the extended underground drainage system which has been formed over the millennia as a result of karstification, i.e. corrosion (K r a n j c, 2002). The sink caves, sinkholes, gorges, gullets and estavelles have been formed on the areas where rock consists of two components of different solubility, less soluble magnesium carbonate (dolomite) and more soluble calcium carbonate (chalk). Local inhabitants named the drainage area Rešeto, which means "sieve". In rainy periods karst watershed supplies enormous amounts of water to the area, which flood the polje in a very short time. The succession of wet and dry periods is the most outstanding characteristic feature of the lake and that is why it is called an intermittent lake. The basic processes are similar to those in the natural systems, classified as water level fluctuating ecosystems (O d u m, 1971), temporary waters and wetlands (B o u l t o n in B r o c k, 1999) or the river Stržen flood plain. A factor that also determines extreme water level fluctuations is the specific climatic condition - the influence of both Mediterranean and temperate continental climates with a high annual precipitation rate (table 1). Due to its unique structure and function the lake was included in the Natura 2000 network and in 2006 it was declared a Ramsar site.

The Srebarna Lake is situated in the southwestern part of Ajdemirska Lowland. The whole protected area, which was determined on the basis of a normative act (1992), included the lake, the territory between the lake and Danube River and the Danubian island Devnya. Nowadays the lake is subject to a high level of nature protection. It is a breeding place for waterfowl (1942), Nature reserve (1948), wetland of international importance protected as Ramsar site (1971), Biosphere reserve protected by UNESCO (1975), Monument of World Culture and Nature Heritage (1985), CORINE site (1992), Ornithological place of international importance (1997) and part of the Natura 2000 network (2007). At present "Srebarna" biosphere reserve comprises an area of 902 ha. The Ramsar convention (1971) classifies the lake under "O" category – permanent fresh water lake or open water body. Z h e l e z o v (2010) defined Srebarna Lake as a marsh-type-wetland lake.

Several considerable anthropogenic measures have been undertaken on the territory of the reserve in the last sixty years, such as:

– building an artificial dike along the Danube bank of Ajdemirska Lowland, which interrupted the natural connection and interaction between the lake and the river in 1948;

– opening of the dike in the western part of the Ajdemirska Lowland at the 13-metre elevation of the river bank and building of a second protection dike in 1978;

– constructing an artificial canal between the lake and the Danube River in 1994.

Development of different activities for regulation and control of the processes in the wetland transformed the lake into a managed landscape system. The lake is maintained by karst springs originating in the region. An important factor, affecting the conditions and function of the wetland, are the rivers with irregular water regime Sreburska (Sitovska) and Kulnezha, which flow into the lake in its southwestern and southeastern part. The outflow "Dragajka" is situated in the northeastern part. The artificially built canal is its continuation. It regulates the water transfer between the lake and the Danube River. It is important for the lake water conditions and for the transfer of sediments from the bottom of the lake.

The building of the artificial canal between the Danube and the lake stabilized the wetland system just for a short period. Later on, control activities, referring to plant productivity, were introduced (regulated fires in September and October). The Danube water flowing through the opened dike sector is also an important measure for stabilizing the wetland system. In spite of all management activities, the open water area of the lake is still permanently decreasing.

WATER REGIME CHANGES IN CERKNICA LAKE

The hydrological characteristics of the lake are complex. They are presented in table 1. Differences between inflow and outflow show, that the evapotranspiration rate on the area is very high. During the rainy period the lake basin fills within one week, while the lack of precipitation usually in late spring results in shrinking of the lake volume. Over a longer dry period the water usually disappears in 3 to 4 weeks (Kranjc, 1986). The normal water level reaches 550 m a.s.l., covering about 53 % of the polje (Kranjc, 2002). When the water exceeds this level, extreme floods occur, the last one being in November 2000 (552.2 m a.s.l.).

T a b l e 1

Hydrological characteristics of the Lake Cerknica (Z u p a n č i č, 2002; K r a n j c, 2002)

I n d i c a t o r	V a l u e
Average precipitation rate (mm/year)	1700–1800
Potential evapotranspiration rate (mm)	750
Catchments area (km^2)	475
Average yearly duration of floods (days)	260
Maximum inflow (m^3/s)	210–240
Maximum outflow (m^3/s)	40–90

Monthly water level fluctuations in the last five decades were highly variable (fig. 1). The measurements of water level also indicated big differences within the vegetation periods when the availability of water is essential for plant activity. Monthly averages in the last seven years revealed, that the water level from November to February remained more or less the same, in May and June a trend towards a decrease was observed, while in October a slight increase occurred. An early dry season might be a problem for primary producers, due to more frequent heavy rains which can occasionally flood the area and newly grown vegetation. Such events, even for a very short time, affect plant success and the survival of other species. The year with the biggest extremes was 1985. The maximum water level at the measuring location (at Stržen Dolenje jezero) was measured in 2000 (654 cm).

Water accumulation in the lake depends on the temperature regime and precipitation rate at a certain time of the year, as well as on human activity. In 1969–1971 the damming of the major sinkholes and sink-caves affected the drainage of water from the lake (S m r e k a r, 2002), but nevertheless the lake dried out. Anyhow it affected

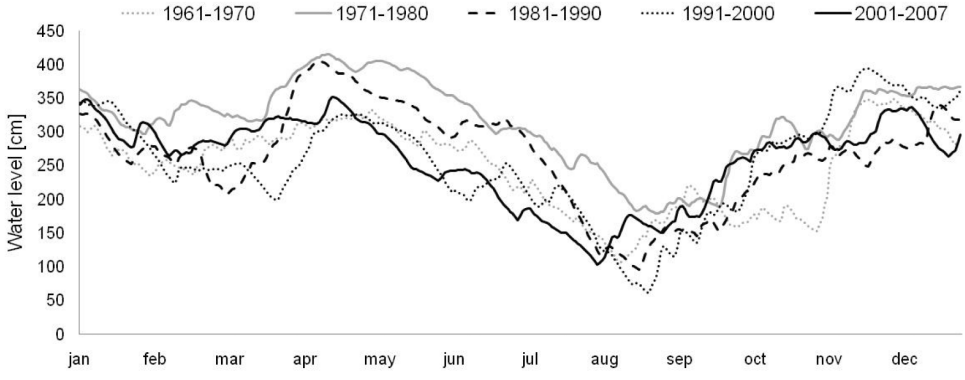

Fig. 1. Water level fluctuations in Lake Cerknica in the last 4 decades. Solid line indicates the average (Water level data source: Slovenian Agency for Environment)

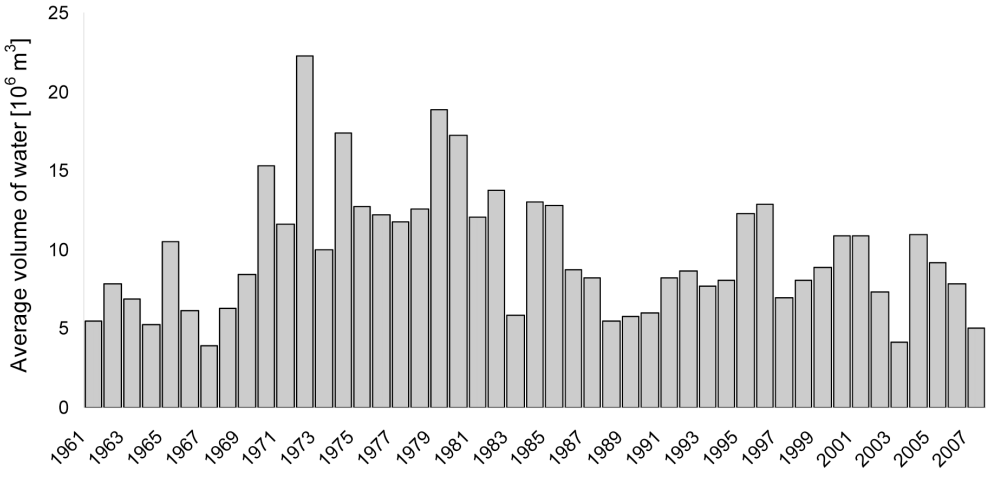

Fig. 2. Average annual water accumulation in the lake Cerknica
(Water level data source: Slovenian Agency for Environment)

the accumulation of water for some years (fig. 2). In 1992 the concrete plug was removed from Mala Karlovica.

WATER CHEMISTRY IN CERKNICA LAKE

The densely vegetated Cerknica Lake (fig. 2) functions as a sink for nutrients discharging into the lake (J o e r g e n s e n, 1990; P i e c z y n s k a, 1990; W e t z e l, 1990; G a b e r š č i k & U r b a n c – B e r č i č, 2002). Monitoring indicated a relatively high content of nutrients in the surface tributary Cerkniščica (G a b e r š č i k & U r b a n c-B e r č i č, 2002; G a b e r š č i k et al., 2003). This is not the usual case in karst flows and nutrients from distant areas, where they originate, are brought to the locations of the lake (G a b e r š č i k et al., 1994). We presume that during floods nutrients quickly incorporate into the biomass of primary producers and that is why nutrient loads from polluted tributaries present an insignificant source of pollution for the lake. In a dry period Stržen, the permanent main stream, and the tributaries become the refuge for the remaining fish population and other organisms. At this time the self purification efficiency of the system is much lower and therefore water quality becomes of primary importance. The analyses revealed significant negative relation between the water level and nutrient content in the flows Cerkniščica River, which bring the majority of nutrients (G a b e r š č i k et al., 1994; D o l i n a r et al., 2010). At other locations water quality parameters seemed to be variable and no correlation to water level was found. Besides the water level, the water quality depends on several other factors, i.e. the success of colonisation by macrophytes, amount and distribution of precipitation, runoff, decomposition potential, temperature, etc. Therefore at low or at high water levels the contents of nutrients in water could be either high or low. Due to the annual variability, significant differences of water qual-

ity parameters among the locations were found only in the case of total phosphorus in Cerkniščica River, which revealed to be much higher than that at other locations ($p \geq 0.01$). The most outstanding location in the lake is Zadnji Kraj (Back place) where the lowest amounts of total phosphorus and nitrogen were found (G a b e r š č i k et. al., 2003). It holds true for other ions, too, such as ammonium, nitrite, nitrate, sulphate, ortho-phosphate, calcium, magnesium, sodium and potassium (G a b e r š č i k & U r b a n c – B e r č i č, 2002). Dense and extended reed stands at the location act as an efficient trap for matter and energy, reducing the influence of the main stream Stržen.

The conditions on the locations are also determined by water temperature. In both surface tributaries water temperature varies a lot (G a b e r š č i k et al., 1994). It is high in summer (up to 24 °C) and much lower in winter (near 0 °C). That affects the populations of macrophytes, which are rather poor. The situation is different in karst tributaries where water temperatures are revealed to be less extreme (from about 5 °C in winter up to 15 °C in summer) (G a b e r š č i k et al., 1994). Such conditions are more favourable for aquatic plants and some of them prolonged their vegetation period into the wintertime.

WATER REGIME CHANGES IN SREBARNA LAKE

The main characteristics of the Srebarna Lake are shown in table 2. The most important factor, affecting the water regime in the lake, is the presence of water of karst origin in the whole catchments area. The Danube waters affect mainly the water level fluctuations, dynamics and conditions of the lake. The input of the Danube water supports the growth of hydrophytic vegetation and slows down the decomposition processes in the lake. The natural connection between the two wetlands explains in general the changing landscapes and the habitat diversity in different parts of the year. The highest water level occurs in spring (April, May and June) and coincides with the nesting period of waterfowl. The time of the lowest water level is summer (July, August and September). There is a slight increase of the lake waters or secondary maximum in November and in the second half of October, respectively. The lake waters are usually frozen. At this time ducks and geese populations dominate.

T a b l e 2

*Hydrological characteristics of the Lake Srebarna (*M a n a g e m e n t p l a n, 2001*)*

Indicator	Value
Water level (m)	10,0–13,2
Catchments area (km^2)	402
Length of shore line (km)	18,5
Reserve area (ha)	902,1
Open water body (ha)	120
Capacity (km^3) – at low water levels	2,81
Capacity (km^3) – at high water levels	14,35
Maximum depth (m)	3,3
Time of stay (months)	2,67

The analysis of the Danube River water level changes for the period 1994–2008 was performed in order to find out if it is possible to condition the lake with riverine water. Most important are the maximum water levels at which, the water levels in the river and in the lake are inter-related. Data on water level of the Danube River in Silistra hydrometric station for the period 1994–2008 were published by the National Institute of Meteorology and Hydrology. The level at the base of the artificial canal is 11,5 m. Minimum, middle and maximum water levels of the Danube were taken into account for the analysis. The results showed that the minimum and middle Danubian water levels don't reach the elevation level of 11,5 m. For the conditioning of the lake water the most influential seemed to be the maximum (high) water levels.

The maximum water level of the Danube River ranges between 12,0–15,7 m, which usually occurs in the period March–May. The lowest water level is ussualy observed in the period July–October as the hydrogram (fig. 3) reveals. Significant part of the registered maximum monthly water level ranges between 11,5–12,5 m.

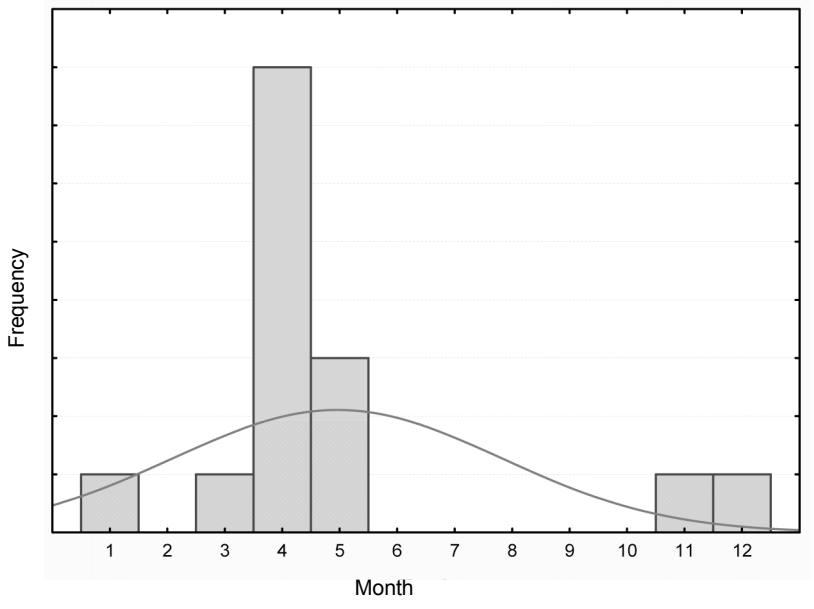

Fig. 3. Frequency of recorded absolute monthly maximum water level of the river Danube in Silistra hydrometric station for the period 1994–2008

The probability of occurrence of certain water level is shown in table 3.

Similar approach was used to determine the probability of monthly maximum water levels (table 4).

Table 3

Probability of occurrence of maximum water levels of the river Daube in the sector of the Lake Srebarna

H_{av} = 13,373 м; C_v = 0,074; C_s = 0,877					
Probability	5 %	25 %	50 %	75 %	95 %
Water level (m)	15,7	14,1	13,2	12,7	12,1

Table 4

Probability of occurrence of monthly maximum water in the Lake Srebarna

P %	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
25,0	12,6	11,6	13,0	13,7	13,8	12,4	12,3	11,7	11,5	11,5	11,8	12,0
50,0	11,2	11,4	12,1	12,9	12,8	11,3	10,7	10,0	10,6	9,8	10,1	11,1
75,0	10,4	10,9	11,3	12,0	11,4	10,8	9,5	8,9	8,8	9,3	9,4	9,3

Besides water from the Danube River, the Srebarna Lake is conditioned also by other underground and surface water sources. Their contribution can be analysed by using a flow map module (for the surface flow) and by drawing an analogy with the regime of the nearest wells (for the underground flow). The rain water is the least important in the lake water balance.

The catchment area of the lake is 400 km^2. It comprises three river catchments – Sreburska, Babushka and Kulnezha Rivers, the tributaries to the lake in the southern part.

The Sreburska River has an irregular water regime. The maximum flow occurs in early spring as a result of snow melting and heavy rains. The average annual flow is 2,419 million m^3 based on the Atlas of Bulgaria (1973).

The Kulnezha River has a higher flow capacity as a result of karst waters present in the region. The water flow to the lake is approximately 0,504 million m^3 .

The Babushka River catchment is situated between the Sreburska and Kulnezha Rivers. The southern part of the basin is karst area. The average annual water volume of Babushka River is 1,260 million m^3.

The average annual amount of surface flow to the lake is 4,185 million m^3 as a whole while the underground flow is estimated at around 0,305 million m^3.

HYDROCHEMICAL CHARACTERICS OF LAKE WATER

The lake water chemical composition demostrates considerable dynamics and is related to the changes in aquatic environment. There are significant interactions between water regime dynamics and changes in chemical composition of the water. Most influential was the interruption of the natural connection between the lake and the Danube River. This also promoted the growth of aquatic plants.

The lake was in mesotrophic ecological state at the begining of the 20th century (E c o l o g i c a l m o n i t o r i n g, 2002). Later on the state of lake water changed into euthrophic as a result of accumulation of organic and nonorganic material in the lake and the catchment area (R o z h d e s t v e n s k i, 1964). There is evidence of phosphate, sulphate and nitrate concentration increase. H_2S release grew as a result of anaerobic processes in the closed water body. The lake water was of sulphate type until 1994, but after the construction of an artificial canal it was transformed into the bicarbonate type. Water quality in the lake is similar to that in the Danube River. For example, electrical conductivity, which is an indicator of soluble substances, ranges from 420–520 μS/m in the lake and 300–540 μS/m for the Danube water, respectively. There is a trend towards an increase in the amount of soluble substances during the last years, which is confirmed by our research (table 5).

T a b l e 5

Results of the field investigations of the selected physical and chemical properties of the waters in Lake Srebarna (30.09.2009)

Parameter	SW part	S part	East part	N part	Central part	W part	Pelican's bay	Water body "Chervenka"	Boat wharf
T (°C)	18,9	19,3	18,6	18,7	20,4	23,2	18,9	20,6	20,7
PH	8,91	8,93	9,02	8,93	9,03	8,82	8,92	8,15	8,94
Mv (mg/1)	111,1	–113	–117	–112	–118	–106	–110,9	–66,7	–112.7
Electrical conductivity (μS/m)	536	582	577,5	586	567,4	598	590	637,3	579,3
TDS (mg/l)	262	310	308,1	313	286	319	315,2	338,4	309,2
Salinity (ppm)	285	281	281	286	268,7	288	290,2	310,3	285,9
Resistance (Ω)	1,7–1,8	1,71	1,728	1,73	1,847	1,71	1,693	1,578	1,718

Similar tendency is observed for the pH: pH ranged from 7,3 to 8,5 for the period 1998–2001, but it was permanently over 8,5 in the last few years (except for the water body of "Chervenka"). This might be a conseqence of the intensive processes of primary production and mineralization of the organic material (E c o l o g i c a l ..., 2002). The most serious ecological problems of the lake are the reduction of the water body size and accumulation of sediments (organic and nonorganic).

Present water transfer between the Srebarna Lake and Danube River around the canal area is not sufficient for revitalising of the lake waters. In the past there was a

direct connection beetween the Danube and the northwest part of the lake. In this case beneficial influence of the Danube River maintained ecological conditions, which were near to the natural.

ECOSYSTEM SERVICES

Goods and services, which support our lives, are based on ecosystem processes. Besides tourism and food provision, both lakes provide important supporting services. The most important processes in the Cerknica and Srebarna Lakes, as well as in many other wetlands, are accumulation of water, production of biomass, decomposition and mineralization. The complexity of the processes depends on organism diversity and performance, which in the Cerknica Lake is mainly regulated by water level fluctuations (G a b e r š č i k and U r b a n c-B e r č i č, 2002b; D o l i n a r et al., 2010; C o s t a n z a et al., 2007) and in the Srebarna Lake by the availability of Danube water.

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ХИДРОЛОЖКА ХАРАКТЕРИСТИКА И СВЪРЗАНИТЕ ЕКОСИСТЕМНИ УСЛУГИ НА ЕЗЕРАТА СРЕБЪРНА И ЦЪРКНИЦА

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(Р е з ю м е)

Представената разработка разглежда хидроложките особености на езерата Сребърна (България) и Църкница (Словения). Поставя се акцент върху динамиката и химичните показатели на водните маси. Те са определящи за параметрите на екосистемните услуги в двете системи от влажни зони. Езерата Сребърна и Църкница се отличават с уникално ландшафтно разнообразие и предоставят различни хабитати. Спецификата на хабитатите е обвързана с динамиката на водите и главно с измененията на водните количества в рамките на хидроложката година. Развитието на мониторингова и контролна система по отношение на водите е ключов елемент в цялостния защитен, регулационен и консервационен процес в двете езера.