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DUGOROČNE PROMENE U TROFIČKOM STATUSU I EKOLOŠKIM PARAMETRIMA AKUMULACIJE GRLIŠTE, SRBIJA

LONG TERM CHANGES IN TROPHIC STATUS AND ENVIRONMENTAL PARAMETERS OF GRLIŠTE RESERVOIR, SERBIA

ABSTRAKT

U cilju praćenja promene trofičkog statusa i kvaliteta vode u akumulaciji Grlište, u periodu od 20 godina, jednom mesečno je vršeno uzorkovanje vode i to na dva mesta. Dobijeni rezultati su korišćeni u svrhu pronalaženja uzroka cijanobakterijskog cvetanja, koje se javljalo u sušnim godinama u vreme kritično niskog nivoa vode u akumulaciji. Sadržaj azota u pritokama akumulacije je bio u trendu porasta u ispitivanom periodu, ali rezultati istraživanja su ukazali da je limitirajući faktor algalne produkcije bila svetlost a ne azot i fosfor. Na osnovu dobijenih rezultata analiziranih parametara, izračunati su Carlson-ovi indeksi trofičnosti (TSIChl$_{-a}$,TSITP i TSISD$_{-a}$) a razlika TSIChl$_{-a}$ i TSITP je ukazala da fosfor nije bio ograničavajući faktor algalne produkcije.Na osnovu koncentracija rastvorenog kiseonika, ukupnog fosfora i hlorofila *a* na površini i na dnu, zapaženo je da je akumulacija tokom ispitivanog perioda prošla kroz četiri razvojne faze. Uočeno je da je u prvim godinama nakon formiranja akumulacije trofičnost bila najizraženija (hipereutrofan status), da bi u daljem periodu zadržala uglavnom eutrofan status.

Ključne reči: monitoring, akumulacija, indeks trofičnosti, cijanobakterije, eutrofikacija

ABSTRACT

In the purpose of monitoring the change of trophic status and water quality in the reservoir Grlište, in the period of 20 years, once a month sampling of water was conducted at two places. The obtained results were used in the purpose of finding a cause of cyanobacteria bloom which appeared in the dry years in the time of critically low water level in the reservoir. On the basis of the obtained results of analyzed parameters, the trophic state indexes of Carlson (TSIChl$_{-a}$,TSITP and TSISD) were calculated and difference between TSIChl$_{-a}$ and TSITP showed that phosphorus was not a limiting factor of algal production. Content of nitrogen in tributaries of the reservoir was increased in the examined period, but research results indicated that limiting factor of algal production was light, not nitrogen and phosphorus. On the basis of the concentrations of dissolved oxygen, total phosphorus and chlorophyll a in the surface and in the bottom, it was concluded that the reservoir went through four development phases during the examined period. In the first years after the formation of the reservoir the highest trophicity was detected (hypereutrophic status), but later the reservoir maintained eutrophic status.

Key words: monitoring, reservoir, trophic state index, cyanobacteria, eutrophication

1. UVOD

Povećani zahtevi za vodom u zonama gde su teže dostupni drugi izvori vode za piće, uslovili su izgradnju velikog broja akumulacija. Nastanak akumulacija, pored brojnih pozitivnih ima i negativne efekte, koji se ispoljavaju kroz promenu prirodne hidrologije reka (Graf 2006) i nestajanje ugroženih vrsta (Losos et al.

1. INTRODUCTION

Increased demands for water in zones where are less accessible other sources of drinking water, caused the building of a large number of reservoirs. Creating reservoirs, beside numerous positive sides has also negative effects, which manifest through change of natural hydrogeology of the rivers (Graf 2006) and

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1995). Negativni antropogeni uticaji, potpomognuti povećanjem temperature, usled globalnih klimatskih promena utiču na porast ukupne organske produkcije i stepena saprobnosti, što se direktno odražava na pojavu i dinamiku njihove trofičnosti. U većini slučajeva, akumulacija se posmatra kao fizički objekat sa hidrograđevinskog i hidrogeološkog aspekta, a zanemaruje se njen geografski položaj i ekološko-biološki aspekt.

Programom dugoročnog vodosnabdevanja Republike Srbije predviđena je izgradnja većeg broja hidroakumulacija, kako za potrebe vodosnabdevanja tako i za potrebe energetike. Do danas je u Republici Srbiji izgrađeno više od 150 hidroakumulacija. U većem broju akumulacija zapažen je ubrzan proces eutrofikacije, ali je objavljen mali broj studija sa tematikom dugoročne dinamike trofičnosti akumulacije. Grliško jezero spada među značajnije akumulacije na teritoriji Republike Srbije i ono je ispitivano u nekoliko navrata (Bogdanović 2006).

Akumulacija „Grlište" je izgrađena 1989. godine, podizanjem brane na Grliškoj reci za potrebe vodosnabdevanja grada Zaječara i okolnih naselja (istočna Srbija). Prirodni i antropogeni uticaji sve više joj daju karakteristike nestabilnog akvatičnog sistema, u kome dominiraju procesi eutrofikacije. Proces eutrofikacije akumulacionog jezera „Grlište" postaje sve aktuelniji, nakon učestalih cvetanja vode, značajnih količina cijanotoksina i pritužbi potrošača na miris vode za piće. Problemi ove vrste su zahtevali identifikovanje uzroka koji dovode do degradacije kvaliteta vode u akumulaciji kao i faktora koji imaju dugoročan efekat na njenu trofičnost. Pored uobičajenih parametara koji karakterišu kvalitet vode, određivani su fosfor, hlorofil *a*, prozirnost i Carlson-ov indeks trofičnosti (TSI), s obzirom da se ovi parametri koriste za procenu dugogodišnje dinamike trofičnosti u akumulacijama (Havens 1995; Goldyn et al. 2003; Janjua et al. 2009; Li et al. 2009).

2. MATERIJAL I METODE

Akumulacija se nalazi na 187 m nadmorske visine, između planine Tupižnice na jugozapadu i Zaječarske kotline na severoistoku, uzvodno od ušća Grliške reke u Beli Timok (istočna Srbija). Pruža se u obimu od 28,5 km i zauzima površinu od 250 ha. Prosečna dubina vode u akumulaciji iznosi 6 m, a maksimalna dubina je 22 m na mestu neposredno pre brane (mesto vodozahvata). Maksimalna zapremina vode u akumulaciji iznosi 12 000 000 m^3, a prosečno vreme zadržavanja vode u akumulaciji je oko 82 dana. Akumulacija prima vodu sa brdovitog sliva površine oko 178 km^2, a dve vodom najbogatije pritoke kojima se akumulacija snabdeva su Lenovačka i Lasovačka reka. Sliv se nalazi u području sa izraženom kontinentalnom klimom, sa srednjom godišnjom količinom padavina za sliv u iznosu od 666,4 mm. Područje sliva akumulacije se može smatrati poljoprivrednim regionom i ugroženo

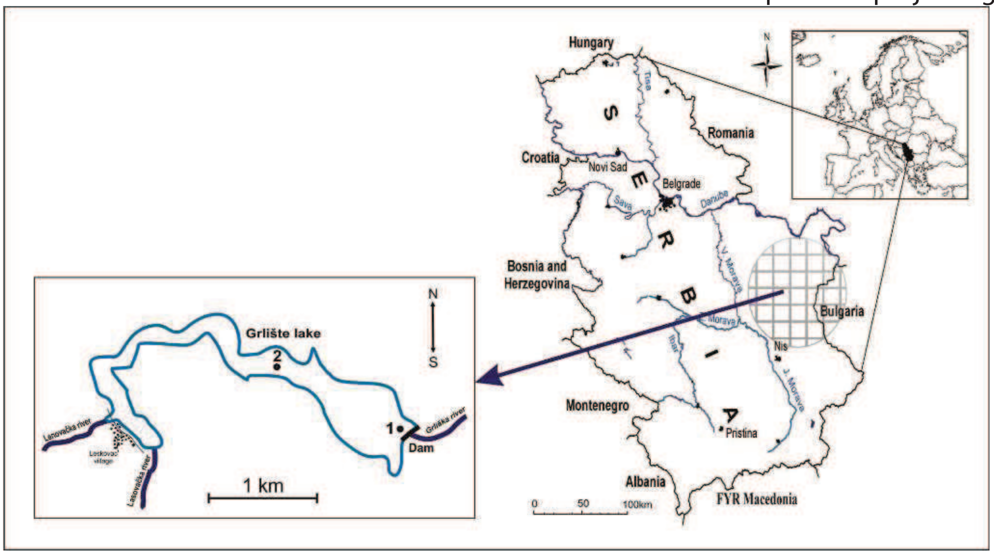
extinction of endangered species (Losos et al. 1995). Negative anthropogenic influences, supported by an increase in temperature, due to global climate changes affect the increase in total organic production and the level of saprobity, which directly reflects on the occurrence and dynamics of their trophicity. In most cases, reservoir is considered as a physical object from hydroconstructional and hydrogeological aspect, and its geographical position and ecological-biological aspect are being neglected.

By program of long term water supply of the Republic of Serbia, building of a larger number of reservoirs is planned for the needs of water supply and energetics as well. So far in the Republic of Serbia more than 150 reservoirs have been built. In larger number of reservoirs an accelerated process of eutrophication was detected, but small number of studies dealing with long term dynamics of reservoir trophicity was published. Grliško lake is among more significant reservoirs in the territory of the Republic of Serbia and it was examined on several occasions (Bogdanović 2006).

Reservoir „Grlište" was built in 1989 by constructing a dam on the Grliška River for water supplying the town Zaječar and surrounding settlements (eastern Serbia). Natural and anthropogenic influences give it the characteristics of an unstable aquatic system, in which eutrophication processes dominate. Process of eutrophication of reservoir Grlište is becoming more actual, after frequent water blooms, significant amounts of cyanotoxins and consumers complaints about the smell of drinking water. This kind of problems required the identification of the cause which leads to degradation of water quality in the reservoir and factors which have long term effect on its trophicity. Beside the usual parameters which define water quality, phosphorus, and chlorophyll a (Chl-a) were determined as well as transparency and the trophic state index of Carlson (TSI), given that these parameters are used for the assessment of long term dynamics of trophicity in the reservoirs and other water bodies (Havens 1995; Goldyn et al. 2003; Janjua et al. 2009; Li et al. 2012)

2. MATERIALS AND METHODS

Reservoir is located at 187 m above sea level, between mountain Tupižnica in the southwest and Zaječarska ravine in the northeast, upstream from the mouth of the Grliška river in Beli Timok (eastern Serbia). It stretches in the range of 28.5 km covering the area of 250 ha. Average water depth in the reservoir is 6 m, and maximum depth is 22 m at a point just before the dam (place of water intake). Maximum volume of water in the reservoir is 12000000 m^3, and average time of water retention in the reservoir is about 82 days. Reservoir receives water from a hilly basin, area of about 178 km^2, and two tributaries which supply the reservoir are the Lenovačka and Lasovačka river. Basin is located in the area with distinctive continental climate, with average annual amount of precipitation je erozionim procesima. Akumulacija je vremenom postala polifunkcionalna, iako je u fazi projektovanja, izgradnje i punjenja njena osnovna namena bilo vodosnabdevanje.



Slika 1. Akumulacija „Grlište“ sa tačkama uzorkovanja
Figure 1. Reservoir Grlište with sampling points

Planom i programom upravljanja kvalitetom vode u periodu od 1991. do 2010. godine, jednom mesečno je vršeno uzorkovanje vode iz akumulacije „Grlište“ i njenih pritoka, Lenovačke i Lasovačke reke. U akumulaciji je vršeno uzorkovanje po uzdužnom profilu na sredini akumulacije u tački 2 i u tački 1 na mestu vodozahvata (Sliku 1). Na oba mesta vršeno je i uzorkovanje po visini vodenog stuba i to na površini (0 m), 3 m, 5 m i 10 m dubine i na dnu. Istovremeno je vršeno i uzorkovanje Lenovačke i Lasovačke reke, na udaljenosti oko 100 m pre uliva u jezero. Na mestu uzorkovanja vršeno je merenje temperature, pH vrednosti vode i prozirnosti pomoću Secchi diska (APHA 1999a). Uzorci za hemijsku analizu vode su prikupljani u plastične boce zapremine 1L, a u laboratoriji su spektrofotometrijski određivani ukupan fosfor (TP) (ASTM 1981a), nitriti (NO_2^-/L) (APHA 1999b) i nakon filtriranja i acetonske ekstrakcije hlorofil *a* (Chl *a*) (ISO 1992), na spektrofotometru firme Perkin Elmer (λ25/35/45 UV Vis), a jonskom hromatografijom određivani su amonijačni azot (NH_4-N/L) (ASTM 1981b) i nitrati (NO_3^-/L) (ISO 1995). Sadržaj rastvorenog kiseonika (DO) je određivan jodometrijskom metodom (SRPS ISO 1994).

Carlson-ov indeks trofičnosti (Carlson 1977) je računat na osnovu vrednosti providnosti vode merene Secchi diskom (TSISD), površinskih vrednosti hlorofila *a* ($TSIChl_{-a}$) i ukupnog fosfora (TSITP) prema jednačinama 1- 3. Vrednosti Carlson-ovog indeksa trofičnosti razmatrane su u opsegu od 0 (ultra-oligotrofni status) do 100 (hipertrofni status).

$$TSITP = 14.42 \times \ln(TPaverage) + 4.15 \qquad (1)$$

for the basin of 666.4 mm. Area of basin reservoir can be considered as an agricultural region and it is threatened by erosive processes. Over time reservoir has become polyfunctional, even though its main purpose in the phase of projecting, building and filling was water supplying.

According to plan and program of water quality management in the period of 1991 to 2010, once a month, sampling of water was conducted from the reservoir Grlište and its tributaries, Lenovačka and Lasovačka river. In the reservoir sampling was conducted by a vertical profile at the middle of the reservoir at point 2 and at point 1 at the place of water intake (Figure 1). At both places sampling was conducted by the height of a water column at the surface (0 m), 3 m, 5 m and 10 m depth and at the bottom. At the same time sampling of Lenovačka and Lasovačka river was performed, at a distance of 100 m before the inflow in the lake. At a sampling location temperature measurement was conducted, as well as pH value of water and transparency using Secchi disc (APHA 1999a). Samples for chemical analysis of water were collected in plastic bottles volume of 1 L. Total phosphorus (TP) (ASTM 1981a), nitrites (NO_2-N L-1) (APHA 1999b) and Chl-a after filtering and acetone extraction (ISO 1992) were determined spectrophotometricaly on the spectrophotometer (Perkin Elmer, λ25/35/45 UV Vis). Ammonia nitrogen (NH_4-N L-1) (ASTM 1981b) and nitrates (NO_3–N L-1) (ISO 1995) were determined using ion chromatography. Content of dissolved oxygen (DO) was determined by iodinemetric method (SRPS ISO 1994).

The trophic state index of Carlson (Carlson 1977) was calculated on the basis of the values of water transparency measured by Secchi disc (TSISD), surface values of Chl-a ($TSIChl_{-a}$) and total phosphorus (TSITP), according to Eqns (1-3). Values of Carlson index of trophicity were considered in the range from 0 (ultra-oligotrophic status) to 100 (hypereutrophic status).

$$TSITP = 14.42 \times \ln(TPaverage) + 4.15$$
Eqn (1)

$$TSIChl_{-a} = 9.81 \times \ln(Chl\text{-}a_{average}) + 30.6$$
Eqn (2)

$$TSISD = 60 - 14.41 \times \ln(SDaverage)$$
Eqn (3)

where:

$TSIChl_{-a} = 9.81 \times \ln(\text{Chl-aaverage}) + 30.6$ (2)

$TSISD = 60 - 14.41 \times \ln(\text{SDaverage})$ (3)

gde su:

TPaverage - prosečna vrednost ukupnog fosfora u vodenom stubu (μg/L);

Chl-aaverage - prosečna vrednost hlorofila a u vodenom stubu (μg/L);

SDaverage - providnost vode merena pomoću Secchi Disk-a, (m).

U periodu od aprila do oktobra (koliko traje vegetaciona sezona) tokom ispitivanog perioda u trajanju od 20 godina, dobijene vrednosti ispitivanih parametara statistički su obrađene pomoću osnovnih pokazatelja deskriptivne statistike (aritmetička sredina, medijana, minimum i maksimum) korišćenjem statističkog paketa STATISTICA 6.0.

3. REZULTATI

Nivo vode u akumulaciji tokom perioda ispitivanja varirao je i do nekoliko metara, a najniže vrednosti su zabeležene u 2002. godini (dubina: 18,8 m) i u 1993. godini (dubina: 19,7 m), što je grafički predstavljeno na Slici 2 u tački 1.

Rezultati ispitivanja su pokazali da su prosečne vrednosti temperature vode opadale po dubini na oba mesta uzorkovanja. Niže temperature na dnu zabeležene su u tački 1 (Slika 3a). Najveća prosečna temperatura vode na dnu u tački 2 (Slika 3b) zabeležena je u 2001. godini (12,6 °C), a u tački 1 u 2002. god. (Slika 3a) i 2008. godini, kada je njena vrednost iznosila više od 10 °C. Prosečne vrednosti za providnost vode su bile najniže u prvoj godini nakon punjenja akumulacije i iznosile su oko 1,1 m. Trend porasta prozirnosti može se uočiti u obe tačke, tokom celokupnog perioda ispitivanja, što je prikazano na Slici 4a za tačku 1 i na Slici 4b za tačku 2.

Prosečne godišnje vrednosti koncentracije rastvorenog kiseonika do dubine od 3 m pokazuju sličnu dinamiku kretanja na mestima uzorkovanja u tački 1 (Slika 5a) i u tački 2 (Slika 5b). Nakon formiranja akumulacije, koncentracije rastvorenog kiseonika na površini su najpre opadale, a potom rasle, da bi do kraja analiziranog perioda ostale na približno istom nivou. Izuzetak u ovom periodu je 2006. godina u kojoj su prosečne vrednosti na površini bile nešto više. U oblasti hipolimniona, naročito na dnu, razlike između ove dve tačke na longitudinalnom profilu akumulacije su bile daleko izraženije. U tački 1, gde dubina vode dostiže 20 m, vrednost koncentracije kiseonika (sa izuzetkom za 1991. i 1994. godinu kada je iznosila 4 mg/L), bila je ispod 2 mg/L, a 2002. godine je čak zabeleženo totalno odsustvo kiseonika u periodu od jula do oktobra meseca. U tački 2 koncentracija kiseonika na dnu je u prve tri godine od formiranja akumulacije bila neznat-

TPaverage - is the average value of TP in the water column (μg/L);

Chl-a average - is the average value of Chl-a in the water column (μg/L);

SDaverage - is the water transparency measured by Secchi Disc (m).

In the period from April to October (during the vegetation season) throughout the examined period in the duration of 20 years, the obtained values of the examined parameters were statistically processed using basic indicators of descriptive statistics (arithmetic mean, median, minimum and maximum) using statistical program (STATISTICS 6.0).

3. RESULTS

The level of water in the reservoir during the period of examining varied up to few meters, and the lowest values were registered in 2002 (depth: 18.8 m) and in 1993 (depth: 19.7 m), which is graphically presented in Figure 2 at point 1.

Research results showed that the average temperature values of water had been decreasing by depth at both sampling places. Lower temperatures at the bottom were registered at point 1 (Figure 3a). The highest average temperature of water at the bottom at point 2 (Figure 3b) was registered in 2001 (12.6 °C), and at point 1 in 2002 (Figure 3a) and in 2008 when its value was more than 10 °C. Average values for water transparency were the lowest in the first year after filling the reservoir and they were about 1.1 m. The increase of transparency can be seen at both points, during the entire period of examination, which is showed in Figure 4a for point 1 and in Figure 4b for point 2.

Average annual values of the concentration of dissolved oxygen up to 3 m depth show similar movement dynamics at sampling places at point 1 (Figure 5a) and at point 2 (Figure 5b). After formation of the reservoir, concentrations of DO at the surface initially declined, then increased and by the end of the analysed period remained at approximately the same level. The exception in this period is the year 2006 in which average values at the surface were slightly higher. In the area of hypolimnion, especially at the bottom, differences between these two points at a longitudinal profile of the reservoir were far more distinct. At point 1, where water depth reaches 20 m, value of oxygen concentration (with the exception for the year 1991 and 1994 when it was 4 mg L-1), was below 2 mg L-1, and in 2002 total absence of oxygen was registered in the period from July to October. At point 2 oxygen concentrations at the bottom in the first three years since the formation of the reservoir were slightly below 6 mg L-1, and then until 2006 it was in the range from 6 to 10 mg L-1. Until the end of no ispod 6 mg/L, a potom je sve do 2006. godine bila u opsegu od 6 do 10 mg/L. Do kraja ispitivanog perioda, u ovoj tački su zabeležene prosečne koncentracije kiseonika ispod 2 mg/L, sa izuzetkom u 2009. godini.

U tački 1 (Slika 6a) konstatovane su veće oscilacije i do tri puta veće prosečne vrednosti ukupnog fosfora na dnu u odnosu na tačku 2 (Slika 6b). Najveće vrednosti ukupnog fosfora, kako na dnu, tako i na površini, zabeležene su u prvim godinama nakon punjenja akumulacije, dok su kasnije samo u pojedinim godinama dostizale visoke vrednosti, u toku 2001. godine na dnu u tački 2 i u 2002., 2003. i 2008. godini na dnu u tački 1.

Srednje godišnje koncentracije amonijačnog azota su rasle od površine ka dnu na oba analizirana mesta u akumulaciji (Slike 7a i 7b). Koncentracije amonijačnog azota u blizini sedimenta pokazivale su dvostruko veće vrednosti u tački 1 (Slika 7 a) u odnosu na tačku 2 (Slika 7b).

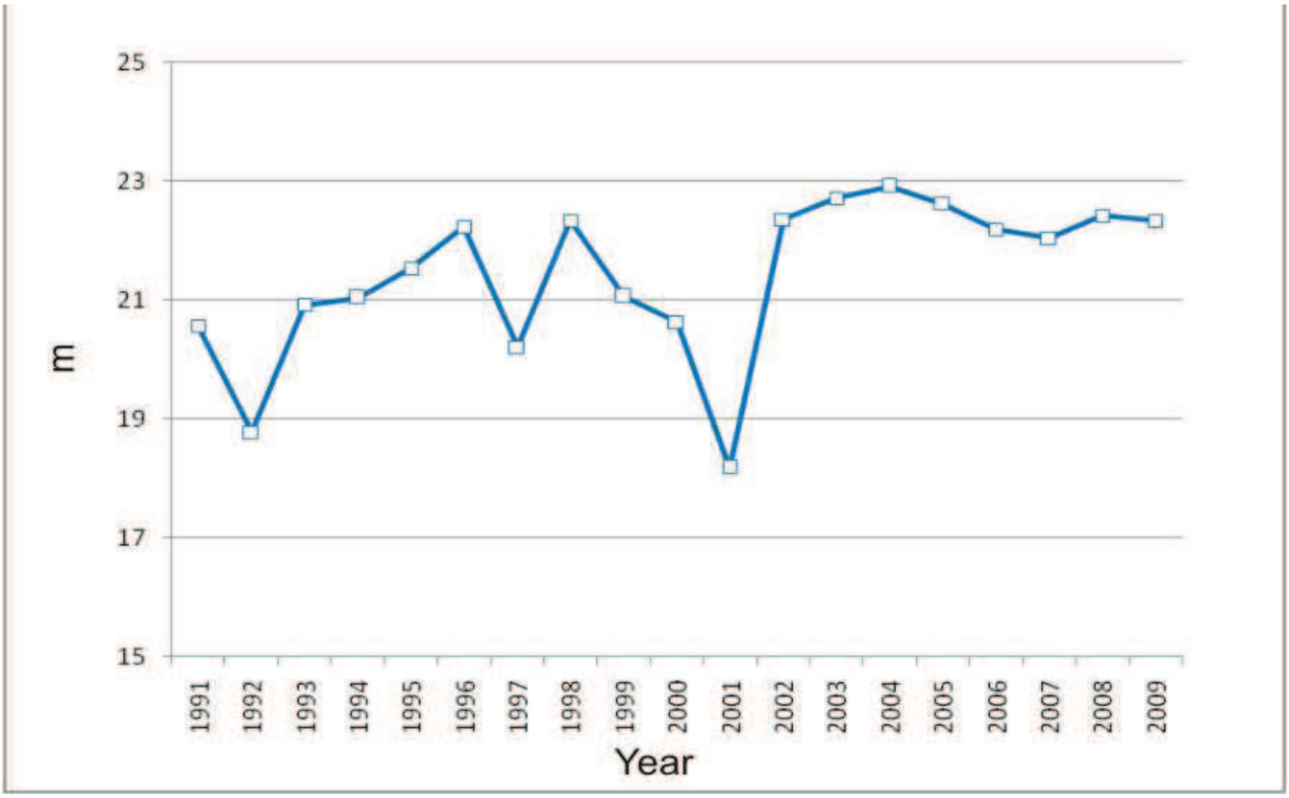
U prvim godinama postojanja akumulacije zabeležene su najveće prosečne vrednosti koncentracija hlorofila-*a* i to po vertikalnom profilu u obe tačke, do dubine od 5 m (Slike 8a i 8b). Od tada, pa sve do kraja ispitivanog perioda može se uočiti jasan trend opadanja sadržaja ovog pigmenta u vodi.

the examined period, at this point average concentrations of oxygen below 2 mg L-1 were registered with the exception of the year 2009.

At point 1 (Figure 6a) significant oscillations were detected, up to three times higher average values of TP at the bottom compared to point 2 (Figure 6b). The highest values of TP at the bottom and at the surface, were registered in the first years after filling the reservoir, while later on only in certain years they reached high values, during the year 2001 at the bottom at point 2 and in the years 2002, 2003 and 2008 at the bottom at point 1.

Average annual concentrations of ammonia nitrogen rose from surface to bottom at both analysed locations in the reservoir (Figures. 7a and 7b). Concentrations of ammonia nitrogen nearby sediments showed twice higher values at point 1 (Figure 7a) compared to point 2 (Figure 7b).

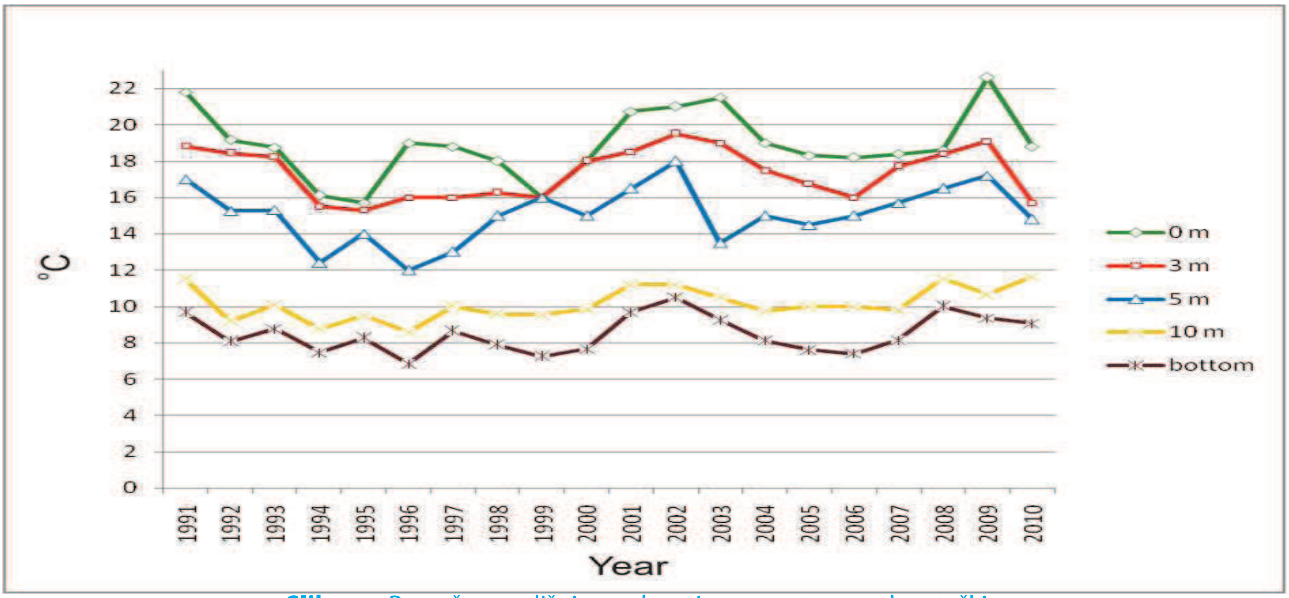
In the first years of accumulation recorded the highest average values of chlorophyll-a concentration per vertical profile of both points, to a depth of 5 m depth (Figures. 8a and 8b). Since then, until the end of the examined period a clear decline of content of this pigment in water can be seen.



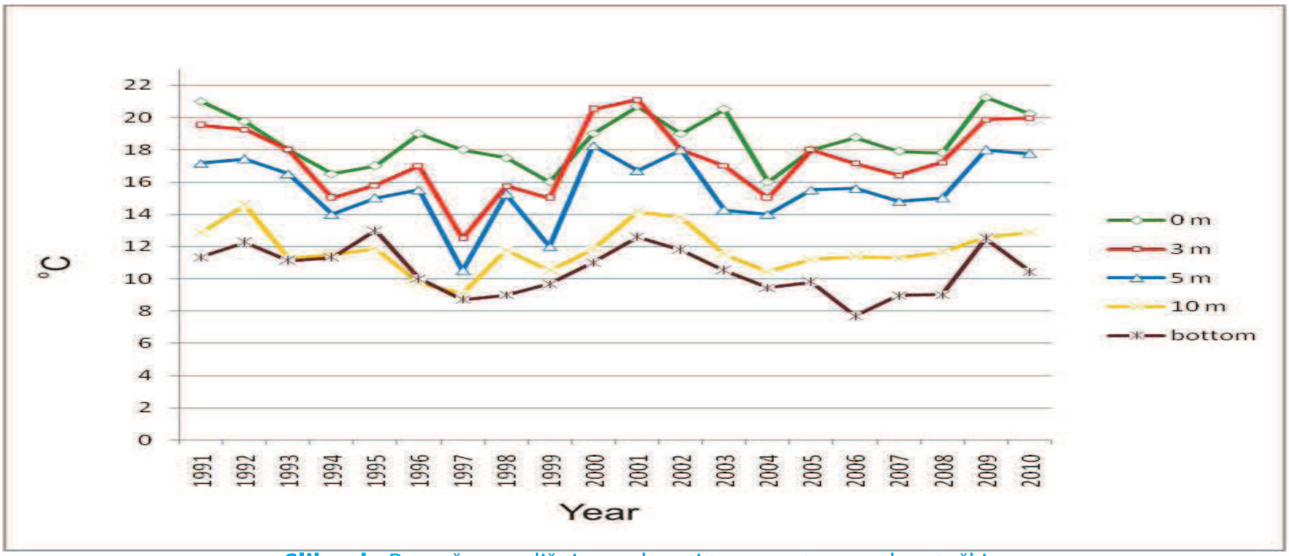
Slika 2. Srednje vrednosti dubine vode u akumulaciji u tački 1
Figure 2. Mean values of water depth in the reservoir at point 1

Carlson-ov indeks trofičnosti izračunat na osnovu ukupnog fosfora ima veće vrednosti u odnosu na indeks trofičnosti izračunat preko koncentracije hlo-

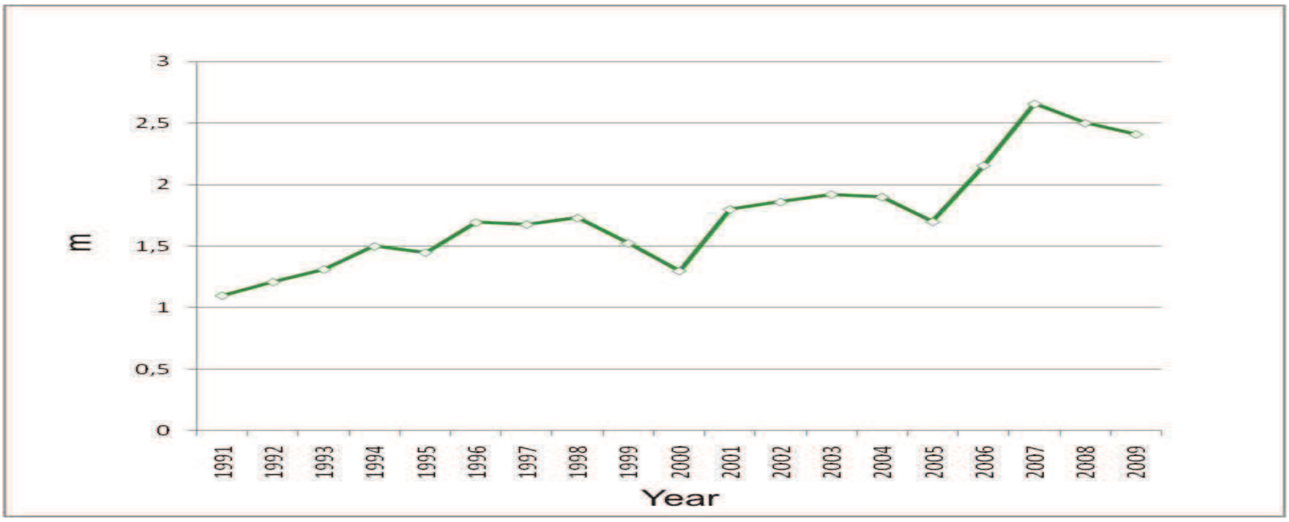
The trophic state index of Carlson calculated on the basis of TP has higher values compared to trophic indexes calculated using concentration of Chl-a and transparency (Figure 9). On the basis of the values of Carlson's trophic state index calculated using TP (TSITP) it can be concluded that the reservoir was hypereutrophic in the first two years since its formation (1991-1992), eutropho-hypereutrop-



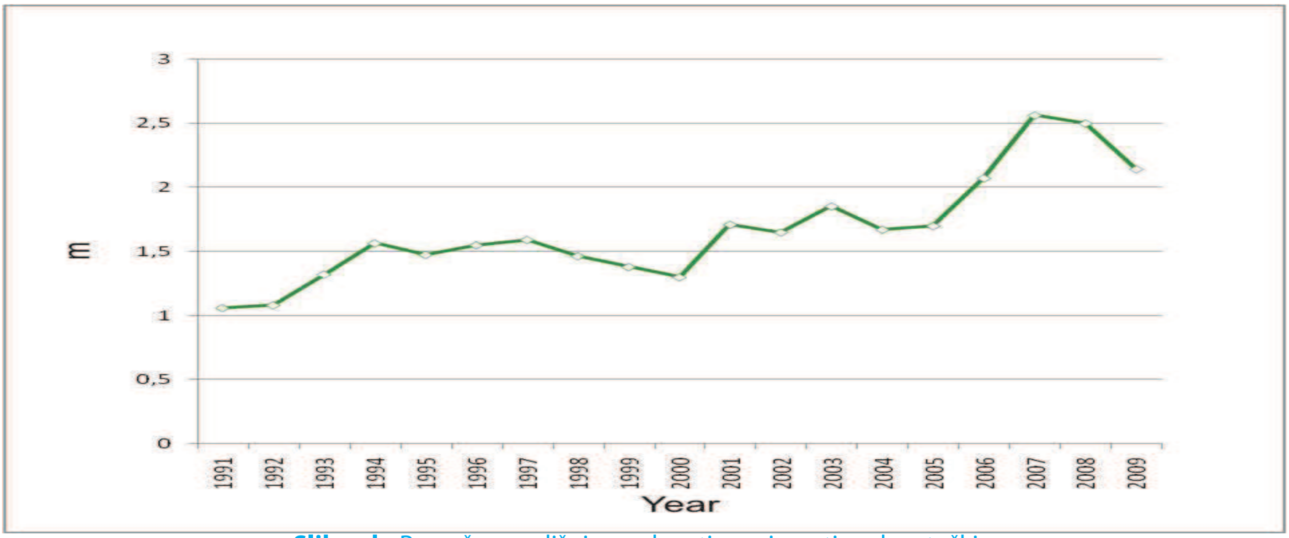
Slika 3a. Prosečne godišnje vrednosti temperature vode u tački 1
Figure 3a. Average annual values of water temperature at point 1



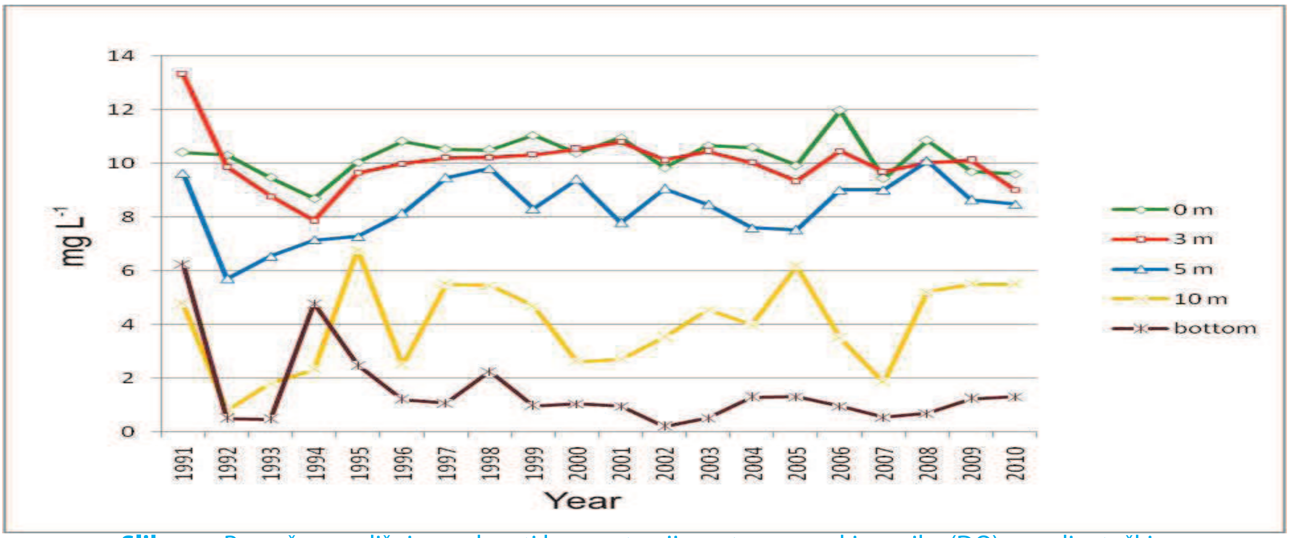
Slika 3b. Prosečne godišnje vrednosti temperature vode u tački 2
Figure 3b. Average annual values of water temperature at point 2



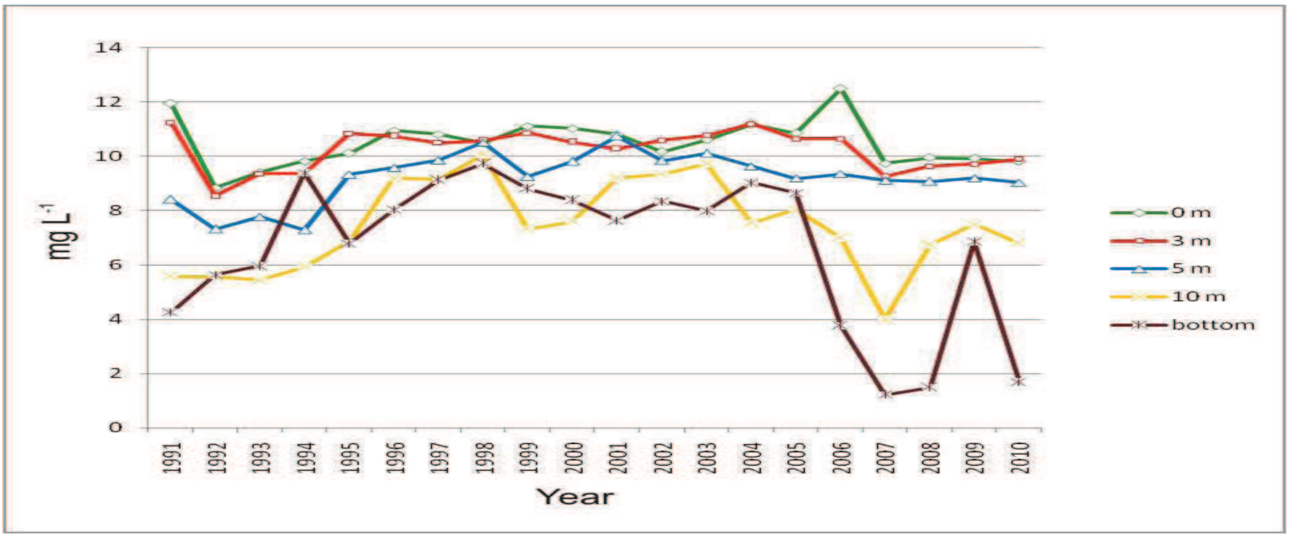
Slika 4a. Prosečne godišnje vrednosti prozirnosti vode u tački 1
Figure 4a. Average annual values of water transparency at point 1



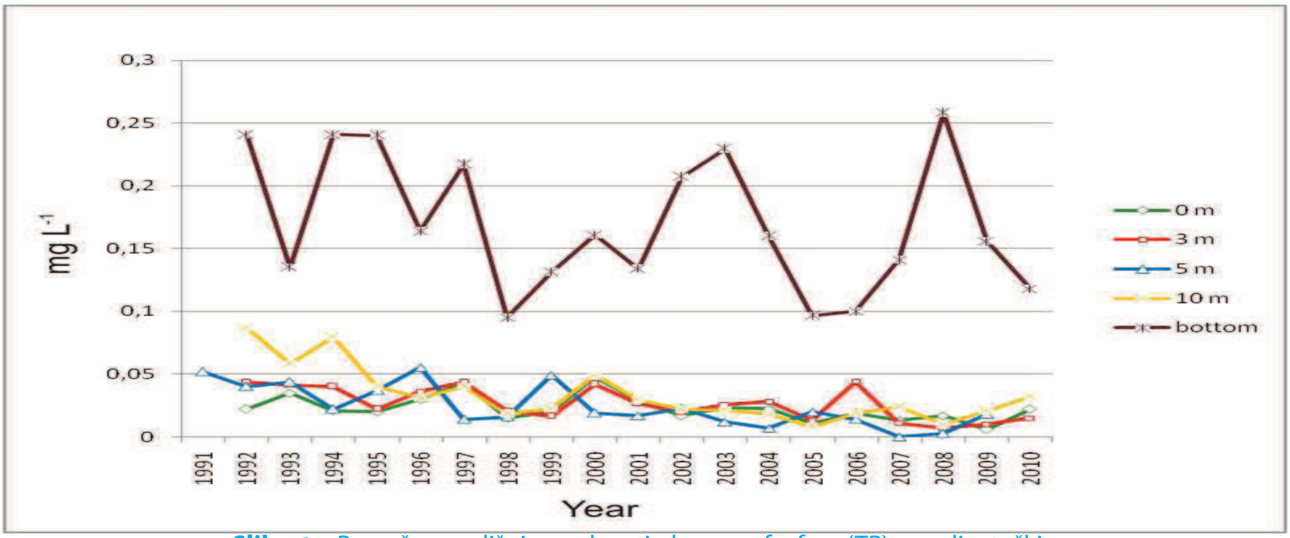
Slika 4b. Prosečne godišnje vrednosti prozirnosti vode u tački 2
Figure 4b. Average annual values of water transparency at point 2



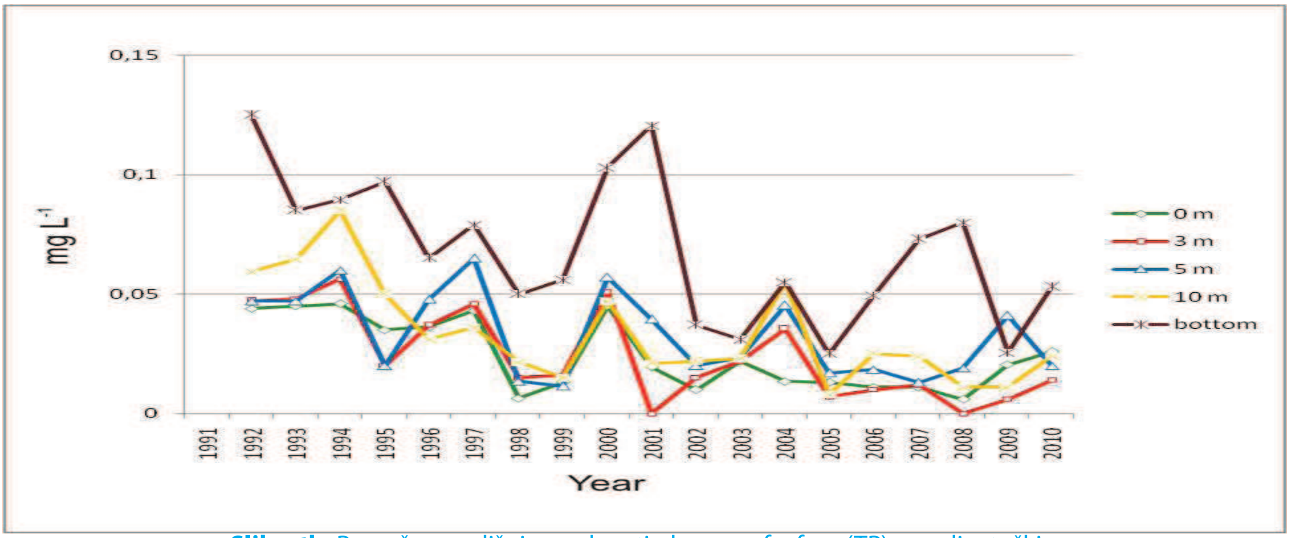
Slika 5a. Prosečne godišnje vrednosti koncentracije rastvorenog kiseonika (DO) u vodi u tački 1
Figure 5a. Average annual values of DO concentrations in water at point 1



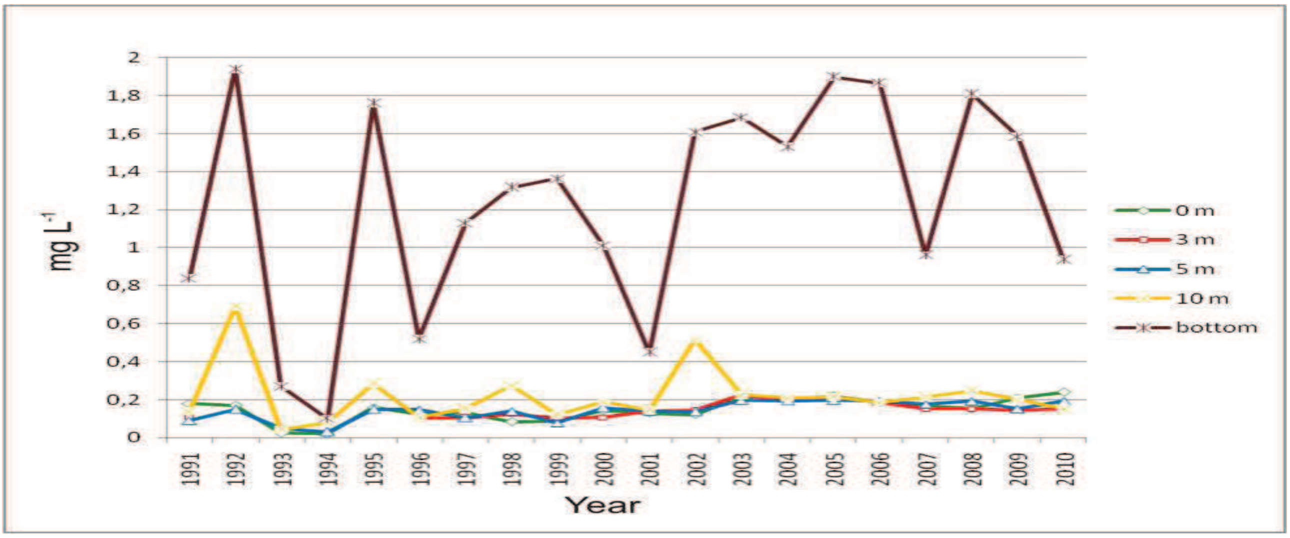
Slika 5b. Prosečne godišnje vrednosti koncentracije rastvorenog kiseonika (DO) u vodi u tački 2
Figure 5b. Average annual values of DO concentrations in water at point 2



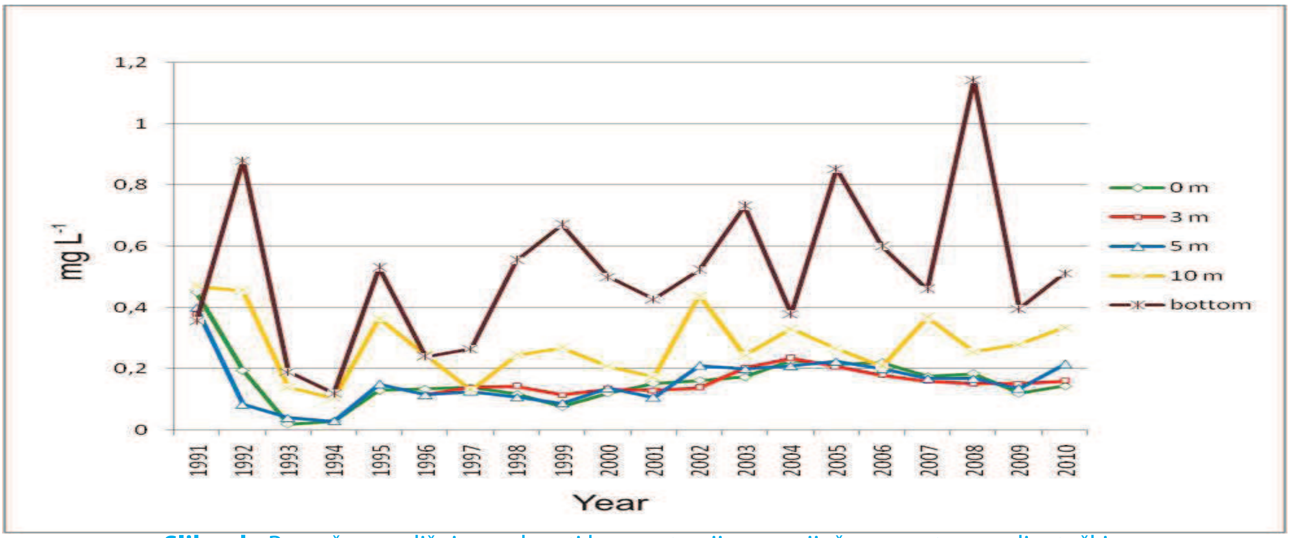
Slika 6a. Prosečne godišnje vrednosti ukupnog fosfora (TP) u vodi u tački 1
Figure 6a. Average annual values of TP concentrations in water at point 1



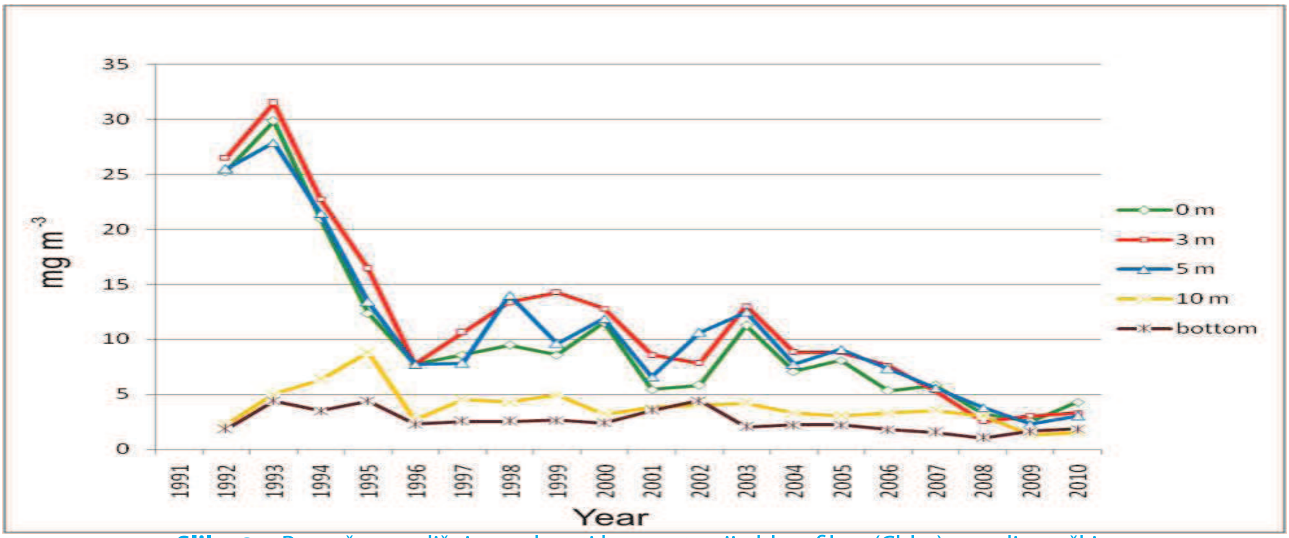
Slika 6b. Prosečne godišnje vrednosti ukupnog fosfora (TP) u vodi u tački 2
Figure 6b. Average annual values of TP concentrations in water at point 2



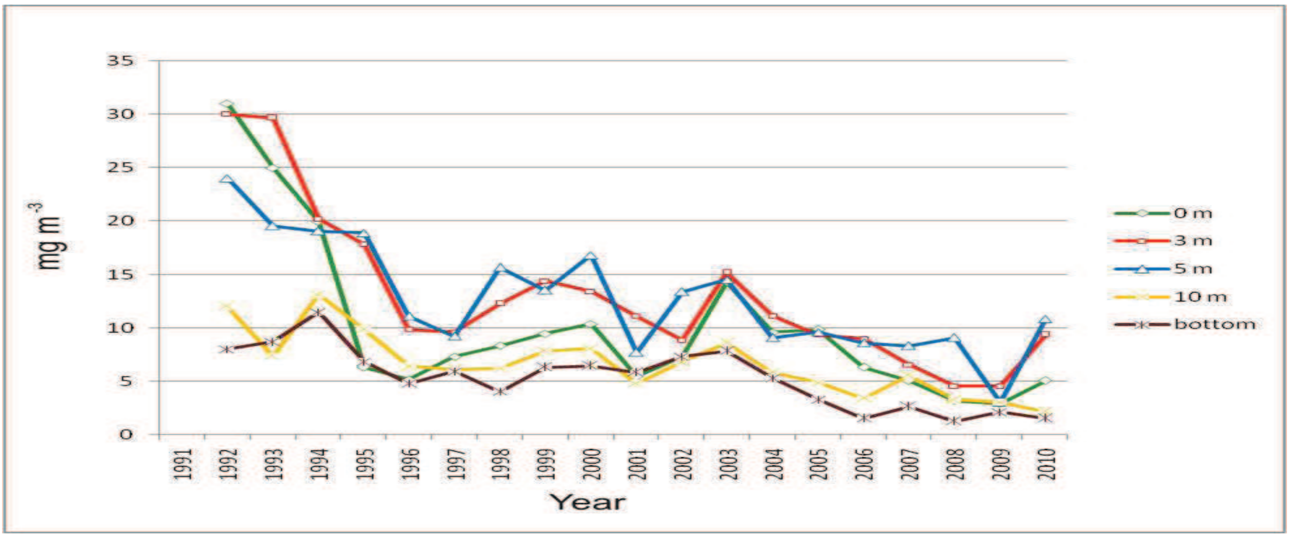
Slika 7a. Prosečne godišnje vrednosti koncentracije amonijačnog azota u vodi u tački 1
Figure 7a. Average annual values of ammonia nitrogen concentrations in water at point 1



Slika 7b. Prosečne godišnje vrednosti koncentracije amonijačnog azota u vodi u tački 2
Figure 7b. Average annual values of ammonia nitrogen concentrations in water at point 2



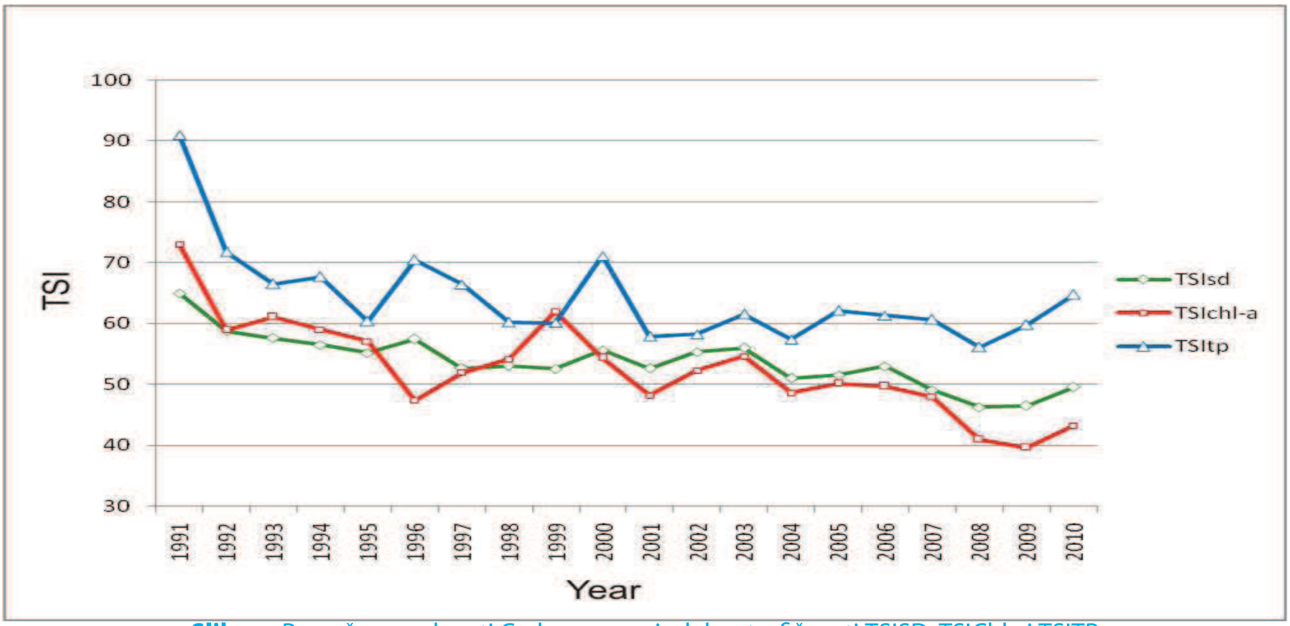
Slika 8a. Prosečne godišnje vrednosti koncentracije hlorofila *a* (Chl-a) u vodi u tački 1
Figure 8a. Average annual values of Chl-a concentrations in water at point 1



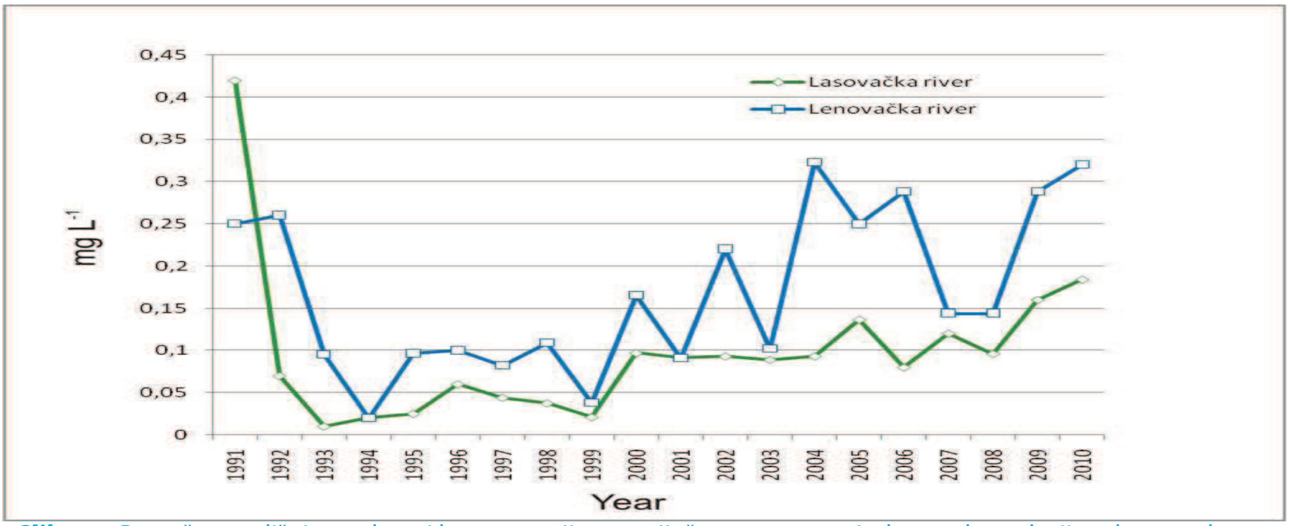
Slika 8b. Prosečne godišnje vrednosti koncentracije hlorofila *a* (Chl-a) u vodi u tački 2
Figure 8b. Average annual values of Chl-a concentrations in water at point 2

rofila *a* i prozirnosti (Slika 9). Na osnovu vrednosti Carlson-ovog indeksa trofičnosti izračunate preko ukupnog fosfora (TSITP) može se zaključiti da je akumulacija u prve dve godine od formiranja (1991.-1992. god.) bila hipereutrofna, u periodu 1993.god. do 2001. godine eutrofno-hipereutrofna, a od 2002. godine do 2010. godine izrazito eutrofna. Ako se kao kriterijum trofičnosti uzme koncentracija hlorofila *a* i prevede u $TSIChl_{-a}$ indeks, može se zaključiti da je akumulacija 1991. godine bila hipereutrofna, zatim sve do 2001. godine eutrofna, a u kasnijim godinama njena trofičnost je bila na granici između mezotrofnog i eutrofnog statusa. Značajno je istaći da je u novembru 2002.god. prosečna godišnja vrednost indeksa TSISD bila veća od TSITP i tada je zabeleženo intenzivno cvetanje cijanobakterije vrste *Aphanizomenon flos-aquae*, a i providnost vode je iznosila samo 0,2 m.

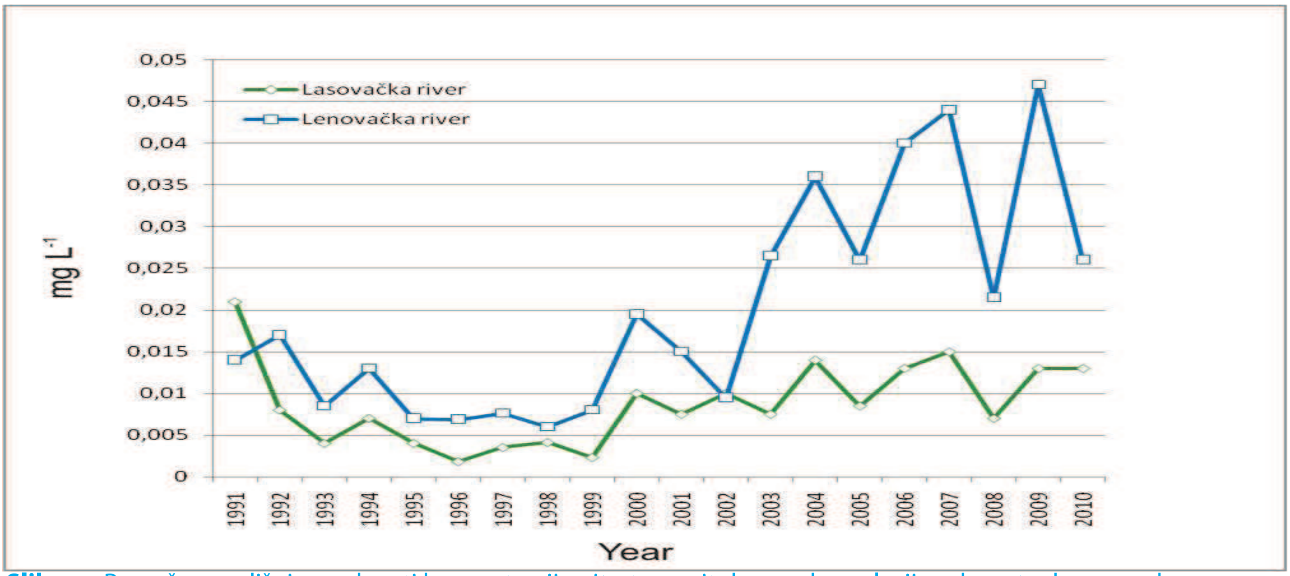
hic in the period from 1993 to 2001, and highly eutrophic from 2002 to 2010. If a criterium of trophicity concentration of Chl-a is taken and converted to $TSIChl_{-a}$ index, it can be concluded that the reservoir in the year 1991 was hypereutrophic, then until 2001 it was eutrophic, and in the following years its trophicity was on the limit between mesotrophic and eutrophic status. It is important to point out that in November 2002 average annual value of index TSISD was higher than TSITP and in that time intensive bloom of cyanobacteria species *Aphanizomenon flos-aquae* was registered and water transparency was only 0.2 m.



Slika 9. Prosečne vrednosti Carlson-ovog indeksa trofičnosti TSISD, $TSIChl_{-a}$ i TSITP
Figure 9. Average values of trophic state indexes TSISD, $TSIChl_{-a}$ and TSITP



Slika 10. Prosečne godišnje vrednosti koncentracije amonijačnog azota u pritokama akumulacije od marta do novembra za ispitivani period
Figure 10. Average annual values of ammonia nitrogen concentrations in tributaries of the reservoir from March till November for the examined period



Slika 11. Prosečne godišnje vrednosti koncentracije nitrata u pritokama akumulacije od marta do novembra meseca za ispitivani period

Figure 11. Average annual values of nitrates concentrations in tributaries of the reservoir from March till November for the examined period

U pritokama akumulacije Grlište analizirane su i prosečne vrednosti koncentracije azotovih jedinjenja (Slike 10-12) i ukupnog fosfora (Slika 13). Na osnovu dobijenih rezultata, može se uočiti njihov trend rasta u analiziranom periodu.

In tributaries of Grlište reservoir average values of concentrations of nitrogen compounds were also analysed (Figures 10-12) as well as TP (Figure 13). On the basis of the obtained results, their increase in the analysed period can be noticed.

Slika 12. Prosečne vrednosti koncentracije nitrita u pritokama akumulacije

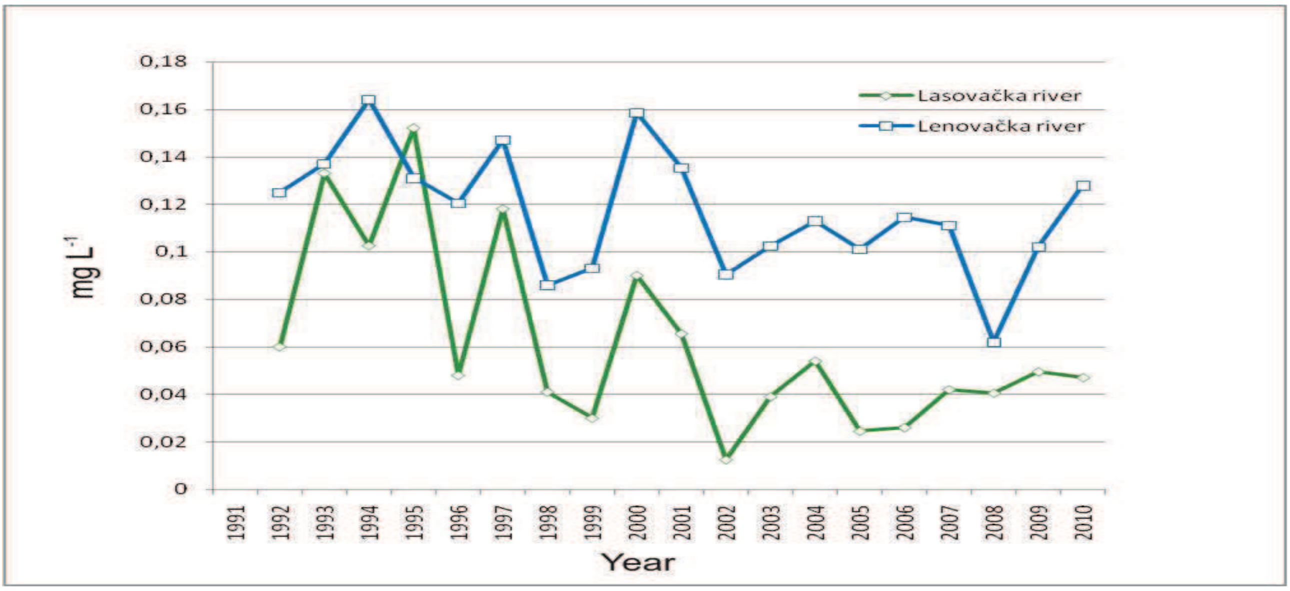
Figure 12. Average values of nitrites concentrations in reservoir's tributaries

4. DISKUSIJA

Kontinuirani dugoročni monitoring vodenih sistema je značajan za sagledavanje njihove kompletne evolucije, kao i za rešavanje eventualnih problema u vezi sa kvalitetom. Podaci dugoročnog monitoringa sadržaja nitrata mogu da ukažu na nepoželjne promene koje se mogu javiti u vodenim sistemima (Burt et al. 2010). Značaj studije je utoliko veći što su promene hemijskih parametara i hlorofila *a* praćene po vertikalnom i po horizontalnom profilu. Dugoročna dinamika trofičnosti akumulacije se može sagledati

4. DISCUSSION

Continuous long term monitoring of water systems is significant for perception of their complete evolution, as well as for solving eventual problems, in relation to water quality. The data of long term monitoring of nitrates contents can show the undesirable changes which may occur in water systems (Burt et al. 2010). Importance of the study is that much greater, because the changes of chemical parameters and Chl-a were monitored by vertical and horizontal profile. Long term dynamics of reservoir trophicity can be perceived in adequate way, given that the moni-



Slika 13. Prosečne vrednosti koncentracije ukupnog fosfora u pritokama akumulacije
Figure 13. Average values of TP concentrations in reservoir's tributaries

na adekvatan način, s obzirom da je monitoringom obuhvaćen dovoljno dug period (1991-2010. godina).

Najniže vrednosti za providnosti bile su odmah nakon punjenja akumulacije, zbog podizanja suspendovanih čestica usled potapanja zemljišta (Straškraba et al. 1993). Uobičajeno je da se providnost vode u akumulaciji smanjuje tokom vremena, što je i jedan od pokazatelja uznapredovale eutrofikacije (Portielje & Van der Molen 1999). Međutim, u ovom istraživanju to nije bio slučaj, jer vrednost za providnost vode u akumulaciji Grlište nije opadala, već je, nasuprot, bila sve veća. Ovakva pojava bi se mogla dovesti u vezu sa bujnim razvojem makrofita (Stanković et al. 2009), što je doprinelo većoj providnosti vode u akumulaciji. Naime, makrofite ''čiste vodu'' tako što smanjuju količinu suspendovanih čestica i ukupnog fosfora u vodenom stubu (Van Nes et al. 2007).

Temperatura vode na dnu je bila niža u tački 1 u odnosu na tačku 2, zbog veće dubine. Najveće prosečne temperature vode na dnu akumulacije (2001. godine u tački 2, a 2002. i 2008. godine u tački 1) kao posledica snižavanja nivoa vode u akumulaciji, uticale su i na povećanje temperature sedimenta. Tokom letnjeg perioda i početkom jeseni, dolazilo je do zagrevanja površinskih slojeva vode, a dno akumulacije je ostajalo izolovano od epilimniona. Stratifikacija je naročito izražena u godinama kada proticaj u pritokama drastično opada, a vreme zadržavanja vode u akumulaciji se produžava, što je i zabeleženo 2002. godine kada je Lenovačka reka presušila tokom letnjih meseci.

Niske koncentracije kiseonika u vodi u prvim mesecima nakon punjenja akumulacije mogle bi se objasniti potrošnjom kiseonika, usled oksidacije organskih materija koje su dospele u vodu nakon potapanja. Ova pojava je izraženija u tački 1 gde je i trajala duže, usled nedovoljnog mešanja površinske vode sa vodom sa dna, zbog veće dubine. U ovoj tački, koja se nalazi

toring included long enough period of time (from the year 1991 to 2010).

The lowest values of transparency were right after the filling of the reservoir, because of the rising of suspended particles due to the inundation of soil (Straškraba et al. 1993). It is common that the transparency of water in the reservoir reduces through time, which is one of the indicators of the improved eutrophication (Portielje & Van der Molen 1999). However, in this research that was not the case, because the value of water transparency in the reservoir Grlište was not decreasing, but on the contrary it was getting higher. This kind of occurrence can be linked to an exuberant development of macrophytes, (Stanković et al. 2009) which contributed to higher transparency of water in the reservoir. In fact, macrophytes ''clean the water'' by reducing the amount of suspended particles and TP in the water column (Van Nes et al. 2007).

Temperature of water at the bottom was lower at point 1 compared to point 2, due to a larger depth. The highest average temperatures of water at the bottom of the reservoir (in year 2001 at point 2, and in 2002 and 2008 at point 1) as a consequence of decreasing the water level in the reservoir, influenced on the increase in the temperature of the sediment. During summer period and in the beginning of autumn, there has been a warming of the surface layers of water, and the bottom of the reservoir remained isolated from the epilimnion. Stratification is especially distinct in the years when flow rate in tributaries intensively decreases, and time of water retention in the reservoir is prolonged, which was registered in 2002 when the Lenovačka river dried out during summer months.

Low concentrations of oxygen in water in the first months after filling the reservoir can be explained by oxygen consumption, due to oxidation of organic neposredno ispred brane, vrednosti za potrošnju kiseonika bile su mnogo veće, usled intenzivnijeg taloženja, pojave mulja i veće količine organske materije koja podleže oksidaciji. Nepovoljan kiseonični režim zabeležen je u toplim mesecima 2002. godine, kada je temperatura vode pri dnu bila najveća, a nivo vode u akumulaciji najniži. U periodu od 2006. godine, pa sve do kraja ispitivanog perioda, zabeležene su niske koncentracije kiseonika u tački 2 na dnu. U 2006. godini, zabeležena je i visoka vrednost koncentracije kiseonika na površini (pa i iznad 18 mg O_2/L), dok je na dnu došlo do pada vrednosti rastvorenog kiseonika. Ovo se može objasniti masovnim razvojem fitoplanktona, što za posledicu ima i hipersaturaciju površinskih slojeva kiseonikom, dok uginuće algi dovodi do oksidacije istaložene organske materije i smanjenja vrednosti koncentracije kiseonika pri dnu. Ovaj proces je nastavljen i u 2007. i u 2008. godini, kada je i nivo vode u akumulaciji opadao.

Dobijene maksimalne vrednosti ukupnog fosfora na dnu su posledica porasta temperature vode pri dnu, što je prouzrokovalo eluaciju fosfora u vodeni stub (Böstrom et al. 1988). Povećanje vrednosti ukupnog fosfora u tački 1 u odnosu na tačku 2 bilo je propraćeno niskim vrednostima koncentracija kiseonika. Tako su u 2001. godini u tački 2, u 2002. godini i u 2008. godini u tački 1, zabeleženi porasti koncentracija ukupnog fosfora na dnu bili propraćeni porastom temperature vode na dnu. Istovremeno, sa porastom sadržaja fosfora porastao je i sadržaj amonijaka, usled nastanka redukcionih uslova pri dnu (Beutel 2006), što je naročito bilo izraženo na većim dubinama (tačka 1). Ova pojava je potvrđena i odsustvom kiseonika pri dnu u periodu od nekoliko meseci u tački 1, što se može uočiti sa Slike 5a.

Vrednosti koncentracija hlorofila *a*, parametra koji ukazuje na biomasu fitoplanktona, bile su najveće nakon formiranja akumulacije, što je u saglasnosti sa teorijom o starenju akumulacije (Straškraba et al. 1993; Jørgensen et al. 2005). Nakon potapanja zemljišta, količina nutrijenata (P i N) u vodi je velika, što pored odsustva predacije od strane zooplanktona uslovljava bujan razvoj fitoplanktona. Starenjem akumulacije dolazi do razvoja zooplanktonske zajednice, pa se biomasa fitoplanktona smanjuje. Ovo ukazuje da je akumulacija u periodu od 1990. do 1992. godine prošla kroz prvu razvojnu fazu (faza punjenja) koju karakteriše povećana trofičnost (Slika 14) i visoka prosečna vrednost nutrijenata. U fazi punjenja dolazi do oslobađanja nutrijenata iz potopljenog zemljišta, što je i potvrđeno visokim sadržajem ukupnog fosfora u jesen 1991. godine (2 mg/L). U ovom periodu zabeleženo je i opadanje vrednosti koncentracije rastvorenog kiseonika i na površini (Slika 5a) i na dnu (Slika 5b).

Na osnovu dobijenih vrednosti za koncentracije rastvorenog kiseonika, ukupnog fosfora i hlorofila *a* na površini i na dnu, na vodozvatu (tačka 1) mogu se razgraničiti druge razvojne faze u životu akumulacije (Slika 14). Drugu razvojnu fazu u životu akumulacije,

matter which entered the water after the inundation. This occurrence is more distinct at point 1 where it lasted longer, because of insufficient mixing of surface water with the water from the bottom, due to larger depth. At this point, which is located just in front of the dam, values for oxygen consumption were significantly higher, due to more intensive deposition, appearance of sludge and larger amounts of organic matter which is subjected to oxidation. Unfavourable oxygen regime was registered in warm months in the year 2002 when the temperature of water at the bottom was the highest, and water level in the reservoir was the lowest. In the period from the year 2006 until the end of the examined period, low oxygen concentrations were registered at point 2 at the bottom. In the year 2006 high value of oxygen concentration at the surface was registered (even above 18 mg O_2 L-1), while at the bottom there has been a decrease in values of DO. This can be explained by a massive development of phytoplankton, which causes the hypersaturation of surface layers with oxygen, while the death of algae leads to oxidation of deposited organic matter and reduction of values of oxygen concentration at the bottom. This process was continuing during 2007 and in 2008, when the water level in the reservoir was dropping.

The obtained maximum values of TP at the bottom were the consequence of the increase in temperature of water at the bottom, which caused the eluation of phosphorus in the water column (Böstrom et al. 1988). Increase in values of TP at point 1 compared to point 2 was followed by low values of oxygen concentrations. So in the year 2001 at point 2, in the year 2002 and in 2008 at point 1, increases in TP concentrations at the bottom were detected and they were followed by an increase in temperature of water at the bottom. At the same time, with the increase in content of phosphorus, content of ammonia had also risen, due to the creation of reduction conditions at the bottom, (Beutel 2006) which was very distinctive at larger depths (point 1). This occurrence was confirmed by the absence of oxygen at the bottom in the period of several months at point 1, which can be seen from Figure 5a.

The values of Chl-a concentrations which indicates the biomass of phytoplankton, were the highest after formation of the reservoir, which is in compliance to the theory of the reservoir's aging (Straškraba et al. 1993; Jørgensen et al. 2005). After the inundation of soil, amount of nutrients (P and N) in water is high, which along with the absence of zooplankton predation causes the massive development of phytoplankton. The development of a zooplankton community occurs with the reservoir's aging, so the biomass of phytoplankton gets smaller. This shows that the reservoir in the period from 1990 to 1992 went through its first development phase (phase of filling) which is characterized by an increased trophicity (Figure 14) and high average value of nutrients. In the phase of filling it comes to a releasing of nutrients from flookoja je trajala od kraja 1992. do kraja 1996. godine, karakteriše maksimalna vrednost koncentracije hlorofila *a*, kao posledica bujnog razvoja fitoplanktona. Na početku ove faze na dnu u tački 1 zabeležene su niske koncentracije rastvorenog kiseonika, sa izuzetkom blagog rasta u 1994. godini, nakon čega je koncentracija opadala ispod 2 mg/L što je trajalo sve do kraja ispitivanog perioda. U trećoj razvojnoj fazi akumulacije koja je trajala od 1996. godine do polovine 1998. godine, došlo je do pada vrednosti ukupnog fosfora i blagog porasta vrednosti koncentracije rastvorenog kiseonika na dnu. Porast sadržaja ukupnog fosfora na dnu vodozahvata je okarakterisao početak poslednje razvojne faze (četvrte) koja je trajala sve do kraja ispitivanog perioda. Ova faza je okarakterisana problemima u vezi sa senzorskim svojstvima kvaliteta vode za piće usled primedbi potrošača. Povodom toga, javila se potreba za pronalaženjem rešenja za ove probleme i njihovu adekvatnu sanaciju. U ovom periodu zabeležen je nizak nivo vode u akumulaciji, kao posledica smanjenog dotoka vode iz pritoka, što je dovelo do razvoja stratifikacije u toplim mesecima. Pojava stratifikacije predstavlja jedan od najznačajnijih faktora koji uslovljavaju cvetanje cijanobakterija (Oliver & Ganf 2000; Mitrovic et al. 2011).

Slika 14. Razvojne faze u životu akumulacije Grlište

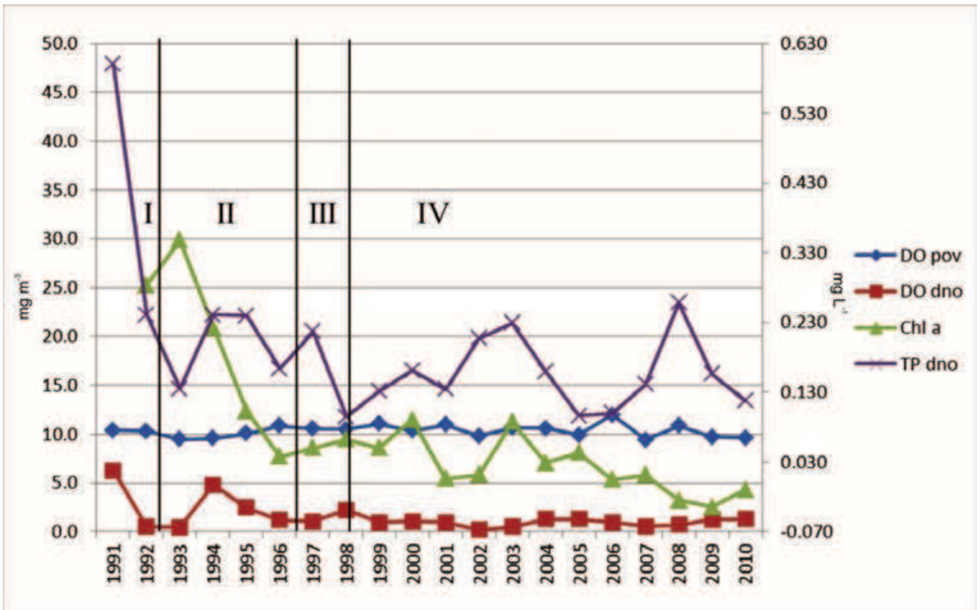


Figure 14. Development phases in the life of Grlište reservoir

Primedbe potrošača, zbog produkata razlaganja modrozelenih algi, potvrđene su direktno njihovom kvalitativnom analizom. U letnjim mesecima 2002. godine presušila je jedna od pritoka (Lenovačka reka) što je uslovilo manji dotok vode u akumulaciju, produžilo njeno retenciono vreme i stvorilo uslove za masovnu pojavu cvetanja cijanobakterija sa dominacijom vrste *Aphanizomenon flos-aquae* (Vučković & Mirjačić-Živko-

ded soil, which was confirmed by high content of TP in the autumn of 1991 (2 mg L-1). In this period decrease in values of DO concentrations was registered at the surface (Figure 5a) and at the bottom (Figure 5b).

On the basis of the obtained values of DO concentrations, TP and Chl-a at the surface and at the bottom at the water intake (point 1) other development phases in the life of the reservoir can be isolated (see Figure 14). Second development phase in the life of the reservoir, which lasted from the end of the year 1992 to the end of 1996 was characterized by maximum value of Chl-a concentration, as a consequence of a massive development of phytoplankton. At the beginning of this phase, at the bottom at point 1, low concentrations of DO were registered, with the exception of slight increase in the year 1994 after which the concentration decreased below 2 mg L-1 which lasted until the end of the examined period. In the third development phase of the reservoir which lasted from the 1996 until the half of 1998 there had been a decrease in TP and mild increase in the concentration of DO at the bottom. Increase in the content of TP at the bottom of the water intake, characterized the beginning of the last development phase (fourth) which lasted until the end of the examined period. This phase is characterized by problems regarding the sensor characteristics of quality of drinking water due to the consumer's complaints. Therefore, there is a need for finding the solution for these problems. In this period, low water level in the reservoir was detected, as a consequence of reduced water from tributaries, which led to stratification development in warm months. Appearance of stratification presents one of the most significant factors which cause the cyanobacteria bloom (Oliver & Ganf 2000; Mitrovic et al. 2011).

Consumer's complaints regarding the products of decomposition of blue-green algae were confirmed directly by their qualitative analysis. In summer months in 2002, one of the tributaries dried out (Lenovačka river), which caused lower inflow of water into the reservoir, extended its retention time and created the conditions for a massive occurrence of cyanobacteria with the domination of the species *Aphanizomenon flos-aquae* (Vučković & Mirjačić-Živković 2002). In 2006 consumers complained again, regarding the odour of drinking water which reminded on the smell of rot and mold. Given the fact that occurrence of bloom was not vić 2002). U 2006. godini opet su se pojavile primedbe potrošača, u vezi sa neprijatnim mirisom vode za piće koja je podsećala na miris truleži i buđi. S obzirom da ove godine nije zabeležena pojava cvetanja, to je najverovatnije posledica nedovoljnog poznavanja uzroka degradacije kvaliteta vode u akumulaciji i neodgovarajuće frekvence biološkog monitoringa.

U ispitivanom periodu od dvadeset godina zabeležena je veća vrednost trofičkog statusa akumulacije Grlište određenog na osnovu indeksa TSITP, u odnosu na klasifikaciju prema biološkom indeksu trofičnosti ($TSIChl_{-a}$). Carlson (Carlson 1991) i Havens (Havens 1995) su ustanovili da odstupanje između Carlson-ovih indeksa trofičnosti ukazuje na stepen ograničenosti nutrijentima. Pošto je razlika indeksa $TSIChl_{-a}$ - TSITP < 0 , što ukazuje da fosfor nije bio ograničavajući faktor algalne produkcije, što je potvrđeno i odsustvom korelacije između njih (r = 0,077, p = 0,350, n = 149). S druge strane, dobijena je značajna korelacija između indeksa TSISD i TSIChl (r = 0,50, p < 0,001, n = 117), što pokazuje da je providnost vode u akumulaciji Grlište u najvećoj meri uslovljena gustinom fitoplanktona.

Povećano opterećenje sedimenta i vode nutrijentima iz pritoka može u velikoj meri uticati na pojavu eutrofikacije i izazvati znatne nepovoljne ekološke efekte na recipijente u obliku cvetanja algi i smanjenja koncentracije rastvorenog kiseonika (Burt et al. 2010, Abell et al. 2013). Trend povećanja sadržaja neorganskih azotovih jedinjenja u vodi akumulacije u drugoj polovini ispitivanog perioda posledica je povećanog unosa ovih nutrijenata iz pritoka akumulacije. Sa Slika 10-12 se može videti porast vrednosti koncentracija amonijaka, nitrata i nitrita u Lenovačkoj i Lasovačkoj reci od 2000. godine, kao i da Lenovačka reka nosi veću količinu ovih nutrijenata. Zabeležen je neznatan porast ukupnog fosfora u pritokama akumulacije, ali je Lenovačka reka i u ovom slučaju unosila veću količinu ovog nutrijenta u akumulaciju (Slika 13).

Pošto količina azotovih jedinjenja koje pritoke unose u akumulaciju Grlište pokazuje trend porasta u toku dvadeset godina monitoringa (Slike 10-12), a pokazano je da fosfor nije bio limitirajući faktor algalne produkcije, onda je verovatno svetlost bila ograničavajući faktor za rast algi u akumulaciji. Potvrđeno je da biomasa fitoplanktona u slatkovodnim jezerima u određenim okolnostima može da bude ograničena svetlošću (May 2010; Xu et al. 2010).

5. ZAKLJUČCI

Na osnovu koncentracije nutrijenata, pre svega fosfora, rastvorenog kiseonika i hlorofila *a* u vodi, zaključeno je da akumulaciju „Grlište" od samog formiranja, pa do kraja ispitivanog perioda, karakterišu četiri razvojne faze. Istraživanja su pokazala da su promene kvaliteta vode, pre svega, posledica sinergetskog dejstva nepovoljnog klimatskog i hidrološkog režima akumulacije. Snižavanje nivoa vode u akumulaciji do-

registered in 2006, that is most probably the consequence of insufficient knowledge of the cause of degradation of water quality in the reservoir and inadequate frequency of biological monitoring.

In the investigated period of twenty years, the higher values of trophic status determined on the basis of TP in the water of the reservoir Grlište were registered compared to classification according to biological trophic state index ($TSIChl_{-a}$). Carlson (Carlson 1991) and Havens (Havens 1995) reported that the deviation between Carlson's trophic state indexes indicated the degree of limitness by nutrients. Since the difference of indexes $TSIChl_{-a}$ - TSITP < 0 that indicates that phosphorus was not a limiting factor of algal production, which is confirmed by the absence of correlation between them (r = 0.077, p = 0.350, n = 149). On the other hand, a significant correlation between indexes TSISD and $TSIChl_{-a}$ (r = 0.50, p < 0.001, n = 117) was obtained, which shows that water transparency of the reservoir Grlište was mostly caused by density of phytoplankton.

Increased load of sediments and water with nutrients from tributaries, can largely affect the appearance of eutrophication and cause negative ecological effects on the recipients in the form of algal bloom and reduction of DO (Burt et al. 2010; Abell et al. 2013). The trend of increase in the content of inorganic nitrogen compounds in water of the reservoir in second half of the examined period is the consequence of a higher intake of these nutrients from reservoir's tributaries. From the Figures 10-12, an increase in the values of ammonia, nitrates and nitrites concentrations can be seen in the Lenovačka and Lasovačka river from the 2000 and that the Lenovačka river carries a higher amount of these nutrients. The slight increase in TP was detected in the reservoir's tributaries, but the Lenovačka river also in this case brought higher amount of this nutrient into the reservoir (Figure 13).

Since the amount of nitrogen compounds which tributaries bring into the reservoir Grlište had been increasing in the past twenty years of monitoring (Figures 10-12), and it was showed that phosphorus was not a limiting factor of algal production, than the light was probably a limiting factor for the algal growth in the reservoir. It is confirmed that the biomass of phytoplankton in fresh water lakes on certain occasions can be limited by light (May 2010; Xu et al. 2010).

5. CONCLUSIONS

On the basis of the concentration of nutrients, primarily TP, DO and Chl-a in the water, it was concluded that the reservoir Grlište from its formation, to the end of the examined period, is characterized by four development phases. Researches have shown that changes of water quality, above all, are the consequence of synergy effect of negative climate and hydrological regime of the reservoir. Lowering the water level in the reservoir led to the occurrence of summer stratification vodilo je do pojave letnje stratifikacije i pogodnih uslova za razvoj cijanobakterija. Da bi se sprečilo pogoršanje kvaliteta vode za piće i sprečile primedbe potrošača, potrebno je češće i detaljnije sprovođenje biološkog monitoringa, sa posebnim akcentom na učešće cijanobakterija u fitoplanktonskoj zajednici. U cilju sprečavanja pojave cvetanja, predlaže se primena aeracije za razbijanje letnje stratifikacije.

and suitable conditions for development of cyanobacteria. In order to prevent the deterioration of drinking water quality and to avoid consumers complaints, it is necessary to conduct more frequent and more detailed biological monitoring, with special emphasis on the participation of cyanobacteria in phytoplankton community. In the purpose of preventing the occurrence of water blooms, it is suggested to apply aeration for breaking the summer stratification.

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