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PREOBRAZBA UGREZNINSKEGA VELENJSKEGA JEZERA

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Izvleček
Velenjsko jezero je nastalo kot posledica podzemnega odkopavanja lignita v velenjskem premogovniku. V prispevku so obravnavane nekatere posebnosti, izoblikovane v procesu spremembe pokrajine iz rečne v jezersko zaradi rudarjenja in energetike. Na podlagi raziskovanja in monitoringa lastnosti ter kroženja jezerske vode so pojasnjene anomalije v jezerskem sistemu. Velenjsko jezero, ki je nastalo na kmetijskih površinah, je zaradi intenzivnega onesnaževanja v šestdesetih in sedemdesetih letih dvajsetega stoletja predstavljalo okoljsko poškodbo, ki se po večdesetletni obsežni okoljski sanaciji postopno preobraža v rekreacijsko območje.

Ključne besede: premogovniško ugrezanje, preobrazba jezer, zasoljevanje jezer, območje kopalnih voda, Velenje, Šaleška dolina, Slovenija

1 UVOD

Velenjsko jezero je največje izmed treh Šaleških ugrezninskih jezer, ki so nastala kot posledica podzemnega odkopavanja lignita v velenjskem premogovniku. Prvi, z vodo zaliti kotanji Velenjskega jezera, sta se pojavili že po drugi svetovni vojni, nato se je jezero povečevalo in do leta 2016 doseglo velikost 145 ha. Do osemdesetih let dvajsetega stoletja so ga onesnaževali s pepelom iz Termoelektrarne Šoštanj (TEŠ), kar je povzročilo visoko alkalnost, jezerska voda je bila praktično sterilna – brez živih organizmov (Šterbenk, Ramšak, 1999, str. 217). V devetdesetih letih je stekla okoljska sanacija termoelektrarne in po letu 1995 se je jezerska voda korenito izboljšala. Dolgoletno onesnaževanje je pustilo določene sledi, zaradi katerih je to jezero edinstveno in tudi izjemno zanimivo za preučevanje. Prva značilnost je povečana vsebnost sulfata, ki je v jezero prišel zaradi bližine območja sanacije ugreznin – tj. nasipa med Velenjskim in niže ležečim Družmirskim jezerom. Nasip se ugreza in s sprotnim vgrajevanjem pepela iz TEŠ-a ga vzdržujejo kot kopno površino. Iz istega razloga je povečana tudi vsebnost molibdena. Obe sestavini ne vplivata negativno na zdravstveno stanje ljudi, s koncentriranjem v spodnji plasti vode pa vplivata na kroženje vode v jezeru in razvoj organizmov.

Po več kot dveh desetletjih je Velenjsko jezero skupaj s svojim neposrednim in širšim zaledjem postalo zanimivo za rekreacijske in športne ter druge prostočasne aktivnosti. Na jezerskem bregu so že v osemdesetih letih 20. stoletja zgradili sprehajalne poti, ki so jih Velenjčani takoj pričeli uporabljati. Čeprav je voda primerna za kopanje že od leta 1996 (Šterbenk, 1999, str. 140), več kot desetletje ni prišlo do intenzivnejše rekreacijsko-športne rabe vodnih površin, saj je javnost jezero še vedno prepoznavala kot onesnaženo in nevarno. Ključni mejnik je bilo odprtje Velenjske plaže leta 2013. V poletnih mesecih leta 2016 so na njej našteli 65.000 obiskovalcev (Piano, 2017), poleg tega so se razvile še druge prostočasne aktivnosti (veslanje, kajtanje, jadranje – na deski in z manjšimi jadrnicami). Ob plaži že od leta 1995 deluje avtokamp (Lukaček, 2017, str. 248), ki zaradi dobrega obiska širi ponudbo. Skozi vse leto so dobro obiskane sprehajalne poti in tudi ostala obsežna rekreacijska infrastruktura.

V prispevku želimo pojasniti posebnosti antropogenega Velenjskega jezera in spremembe rečne v znatno občutljivejšo jezersko pokrajino. Na podlagi raziskovanja in monitoringa lastnosti ter kroženja jezerske vode pojasnjujemo anomalije v jezerskem sistemu. Opredelili smo vzroke za spremembe kakovosti vode, ocenili stopnjo evtrofikacije ter specifične kemijske spremembe, kot sta zasoljevanje jezera v hipolimniju in povišana vsebnost molibdena ter posledična meromiktičnost. V sklepnem delu podajamo analizo dosedanje preobrazbe ugrezninskega jezera v rekreacijsko-turistično območje in izpostavljamo omejitve glede nosilnosti območja za tovrsten razvoj z ozirom na občutljivost jezerske pokrajine.

2 METODE

Na inštitutu ERICo že od leta 1987 spremljamo Velenjsko jezero. Izvajamo monitoring osnovnih fizikalno-kemijskih parametrov, biološki monitoring ter celovito geografsko raziskovanje jezera in njegovega zaledja z vidika naravnih- in družbenogeografskih elementov pokrajine. V prispevku zato povzemamo nekatere rezultate večdesetletnih raziskav in izpostavljamo posebnosti jezera.

Raziskovalni poudarki so na analizi pojezerja, spremljanju kakovosti vode ter evidentiranju prevladujočih vplivov na jezera. Fizikalno-kemijske in biološke analize opravljamo štirikrat letno nad najglobljim delom jezera po globinskem profilu od 0 do 40 m. Vzorce zajemamo z vzorčevalnikom (*Van Dorn Water Sampler*) s prostornino 2,2 l. Ob vsakem vzorčenju izdelamo temperaturni profil jezera ter določimo bistvene kemijske in biološke parametre, in sicer s poudarkom na vsebnosti kisika in nasičenosti vode z njim ter posebnih onesnaževalih. Ob tem s Secchijevo ploščo merimo prosojnost in določimo še vrsto kemijskih parametrov (anioni, kationi ter različne kovine). Od leta 2012 spremljamo parametre, ki opredeljujejo kakovost kopalne vode (Uredba o upravljanju …, 2008). Na podlagi normativov za kakovost jezer (vsebnost hranil, stopnja trofičnosti ipd.) in ugotovljenega stanja so postavljene smernice za trajnostni model upravljanja jezer, ki vsebujejo predloge preventivnih in sanacijskih oziroma restavracijskih ukrepov.

Na podlagi poznavanja bioloških lastnosti jezera so ob smernicah za njegovo bodočo rabo predvsem navedene omejitve, ki jih je treba upoštevati pri razvijajočih se rekreacijsko-turističnih dejavnostih. Nekatere poteze Velenjskega jezera smo primerjali s podobnimi jezeri v svetu (stratifikacija zaradi vsebnosti soli), z vidika kakovosti kopalne vode pa smo ga primerjali z nekaterimi slovenskimi naravnimi kopališči.

Raziskovanje in usmerjanje razvoja Šaleških jezer je osredinjeno na izdelavo trajnostnega modela upravljanja jezer. Tovrstni model mora vsebovati predloge preventivnih in sanacijskih oziroma restavracijskih ukrepov ter določiti smernice za trajnostno sonaravno rabo vodnih in obvodnih površin. Opisani pristop naj bi vodil vsaj k zmerni evtrofni kakovosti jezer, s tem tudi k ustrezni tehnološki vodi in pogojem za razvoj prostočasnih ter drugih dejavnosti na jezerih in njihovih bregovih.

3 NASTANEK, ONESNAŽENJE IN SANACIJA VELENJSKEGA JEZERA

Območje lignitnega sloja (premogišče) Premogovnika Velenje se razprostira po skoraj celotni Šaleški dolini. Dolgo je okrog 8,3 km, široko od 1,5 km do 2,5 km, največja debelina sloja presega 160 m. Njegova vzdolžna os je razpotegnjena v smeri severozahod-jugovzhod. Gre le za eno, vendar izredno debelo in ekonomsko pomembno premogovo plast. V več kot 140-letnem izkoriščanju je bila glavna naloga rudarjev poiskati najučinkovitejšo odkopno metodo. Uporabljali so jih več; šele v drugi polovici dvajsetega stoletja se je uveljavila metoda s širokimi čeli, ki je bila kasneje nadgrajena v t. i. velenjsko odkopno metodo. Z njeno uporabo lahko pod zemljo naenkrat odkopljejo tudi več kot 10 m debelo plast premoga (Mavec, 2004).

Tovrstni način na površini povzroča velike reliefne spremembe, površje Šaleške doline pa se posledično ugreza. Nastajajo kotanje, katerih najgloblje dele zalije voda. Ta zaradi neprepustnih plasti ilovice in gline, ki se nahajajo med površino in lignitnim slojem, ne odteka na območje odkopov. Osrednji del Šaleške doline je bil pred začetkom premogovništva v veliki meri v kmetijski rabi, poseljen z gručastimi naselji. Agrarna naselja na območju pridobivalnega prostora Premogovnika Velenje so delno ali v celoti izginila (Družmirje, Preloge, Škale, Pesje). Podoba doline se zaradi delujočega premogovnika še vedno spreminja, enako tudi jezera. Ob podatkih o velikosti, globini in kakovosti jezer obvezno navajamo letnico, na katero se nanašajo (preglednica 1, slika 2). Prostornina ugrezninske kotanje je leta 2016 presegala 150 milijonov m^3, tri jezera so zavzemala dobrih 7 km^2 površine ter predstavljala približno tretjino prostornine (skoraj 58 mio m^3) in prav tako približno tretjino površine ugreznine (2,5 km^2).

Slika 1: Šaleška jezera spomladi 2017 – v ospredju je Družmirsko, ki se je leta 2006 zlilo z Gaberškim (zaliv levo zgoraj), v ozadju Velenjsko jezero. Med njima je območje sanacije ugreznin z manjšo vodno površino (foto: E. Šterbenk).

Preglednica 1: Osnovne izmere Šaleških jezer v letih 1980, 2000 in 2016.

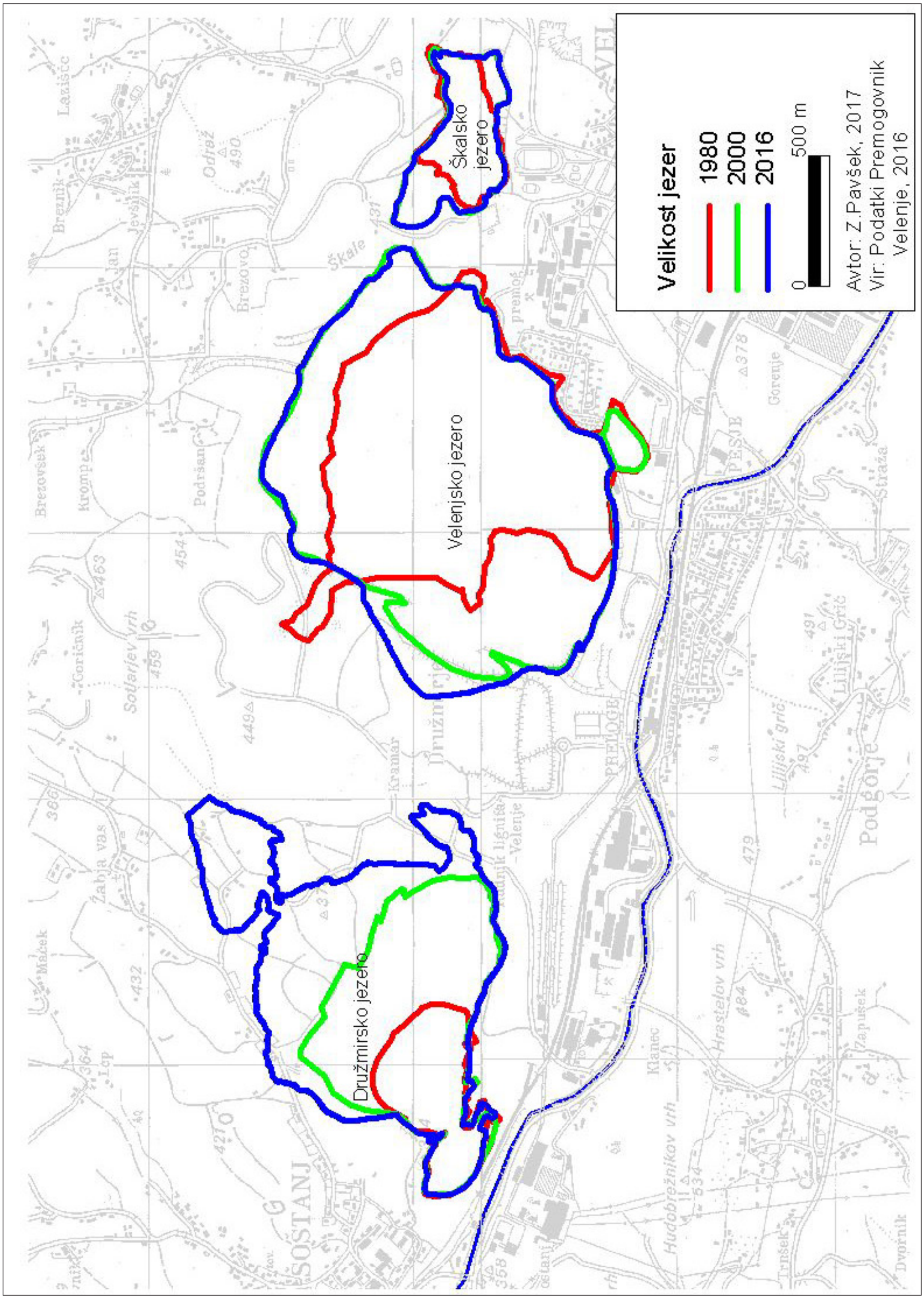
Značilnost / Jezero	**Velenjsko**			**Družmirsko**			**Škalsko**		
Leto	1980	2000	2016	1980	2000	2016	1980	2000	2016
Površina (ha)	93	139	145	19,7	52,0	93,9	11,9	16,8	16,5
Prostornina (mio m^3)	13,5	26,0	34,7	2,0	10,8	22,1	0,7	0,9	0,9
Največja globina (m)	34,0	54,1	63,4	30,0	69,1	85,3	16,0	19,4	18,2
Povprečna globina (m)	14,8	18,5	23,5	10,4	21,7	23,5	6,2	5,7	5,6

Vir: Premogovnik Velenje, 2016.

Skozi zgodovino izkopavanja je nastalo več jezer, ki so se kasneje zlila v večje vodne površine. Takšen primer je Gaberško jezero, ki se je pojavilo leta 2012 in se je v štirih letih zlilo z Družmirskim (slika 1). Jezera napajajo pritoki Pake in so dobila imena po naseljih, ki so se morala umakniti ojezerjevanju (Škalsko, Družmirsko) oziroma po Velenju.

Od leta 1956, ko so zgradili prvi blok TEŠ, so pepel odlagali na območje ugreznin: sprva na breg Velenjskega jezera in kasneje v jezero, v katerega je tako tekla tudi transportna

Slika 2: Povečevanje Šaleških jezer med letoma 1980 in 2016.



voda. Samočistilno sposobnost Velenjskega jezera je močno presegel že 4. blok elektrarne, po izgradnji 5. bloka (leta 1977) pa so bile presežene še samočistilne zmogljivosti Pake. Elektrarna je za transport pepela letno porabila okoli 10 milijonov m^3 vode (Šterbenk, 1999, str. 139), kar je bila takrat skoraj polovica prostornine Velenjskega jezera. Od začetka sedemdesetih let dvajsetega stoletja do zaprtja transportnega sistema za pepel v jezeru ni bilo praktično nobenih živih organizmov, saj je pH vode znašal okoli 12.

Slika 3: V obdobju najvišje alkalnosti v Velenjskem jezeru ni bilo živih organizmov (foto: R. Ramšak, 1993).

V TEŠ-u so leta 1987 pričeli z izvajanjem Ekološkega sanacijskega programa. Z njim so načrtovali spremembo transporta in odlaganja pepela. Že v začetku osemdesetih let so pepel začeli vgrajevati v nasip. Kakovost Velenjskega jezera se ni izboljšala, saj je transportna voda še vedno tekla vanj (Šterbenk, 2009). Sanacije so se lotili sistematično in ustanovili skupino, iz katere je kasneje nastal inštitut za ekološke raziskave ERICo. Strokovnjaki so med drugim spremljali stanje jezer in iskali rešitve za izboljšanje. Postavili so pilotni sistem za transport pepela do ugrezninskega območja v obliki emulgata (gosta mešanica, praktično brez odpadnih vod; Stropnik, 1989). Dokončna rešitev je bil leta 1994 zgrajeni zaprti krogotok transportne vode za pepel.

Po znižanju alkalnosti vode si je Velenjsko jezero opomoglo in že istega leta so se vanj začeli vračati organizmi. V epilimniju so se takoj po zaprtju sistema pojavili planktonski organizmi in tudi ribe – v začetku le ob pritokih v jezero. Hipolimnij je bil v letu 1996 še obremenjen s hidroksidi. Kljub temu so ribe v zgornji plasti jezera (pre)živele vse leto in v poskusnem ribolovu novembra 1996 so ujeli naslednje primerke: krap, klen, rdečeperka, rdečeoka, zelenika ter ostriž (Šterbenk, Ramšak, 1999, str. 219). Leta 1997 so se življenjske razmere dodatno izboljšale, saj se je alkalnost znižala tudi v globljih plasteh. Ob živalskem in rastlinskem planktonu so se razbohotili obrežni makrofiti, katerih sestoji so poleg trstičja sestavljali prave podvodne gozdove (Ramšak, 1998, str. 59).

4 SPREMLJANJE KAKOVOSTI VELENJSKEGA JEZERA S POUDARKOM NA STANJU V LETU 2016

Sprva je kazalo, da se bo Velenjsko jezero hitro popolnoma izboljšalo, a dolgoletno onesnaževanje je pustilo posledice, ki so se po uresničenih ukrepih sanacijskega programa nepričakovano pojavljale. Zaradi evtrofikacije je občasno prihajalo do cvetenja alg, zaradi povečevanja slanosti pa do nepopolnega kroženja vode.

4.1 Hidrogeografske poteze jezera in pritiski na pojezerje

Kakovost jezera je odsev stanja v njegovem pojezerju. Pri Velenjskem jezeru je do leta 1994 prevladoval negativni vpliv proizvodnje električne energije, šele kasneje so postali vidnejši drugi vplivi. Njegovo padavinsko zaledje meri 20,5 km^2, več kot polovico tvori više ležeče Škalsko pojezerje z jezerom vred. Sega do nadmorske višine 900 m, vendar skoraj devet desetin površja leži niže od 700 m. Gozd prerašča skoraj polovico pojezerja, kar je za jezero ugodno, saj zmanjšuje negativne antropogene vplive, zlasti vplive premogovništva (povečana erozija in denudacija prsti) ter kmetijstva. Po ocenah v pojezerju živi okrog 2000 prebivalcev oziroma približno 100 prebivalcev/km^2. Kanalizacija je večinoma zgrajena v celotnem zaledju. Odpadnih voda ne čistijo na manjših čistilnih napravah, prečrpavajo jih v centralni kolektor, ki se zaključi na Centralni čistilni napravi Šaleške doline. Največje naselje v pojezerju, Škale, je v letu 2016 štelo 846 prebivalcev (Kotnik, Pavšek, Šterbenk, 2017).

Zaledje je bilo v preteklosti kmetijsko in redko poseljeno ter se urbanizira zadnja štiri desetletja. Naselja, kjer prevladujejo družinske hiše s parcelami okrog 1000 m^2, se čedalje bolj spreminjajo v spalne soseske. Prebivalstvo se v pojezerju zgošča zato, ker se osrednji del Šaleške doline (ugrezninsko območje) ugreza in ojezerjuje – posledično se ljudje od tam izseljujejo. Drugi razlog je bližina zaposlitve v Velenju in Šoštanju (Šaleška jezera – vodni vir …, 2011).

Preglednica 2: Raba zemljišč v pojezerju Velenjskega jezera leta 2017.

Kategorija dejanske rabe tal	Površina (ha)	Delež (%)
Njivske površine	745.498	3,6
Trajni nasadi	1.088.046	5,3
Travinje	4.494.014	21,9
Gozd	10.109.431	49,2
Pozidano in sorodno zemljišče	1.598.368	7,8
Vodne površine	1.714.896	8,4
Drugo	774.622	3,8
SKUPAJ	20.524.874	100,0

Vir: MKGP, 2017.

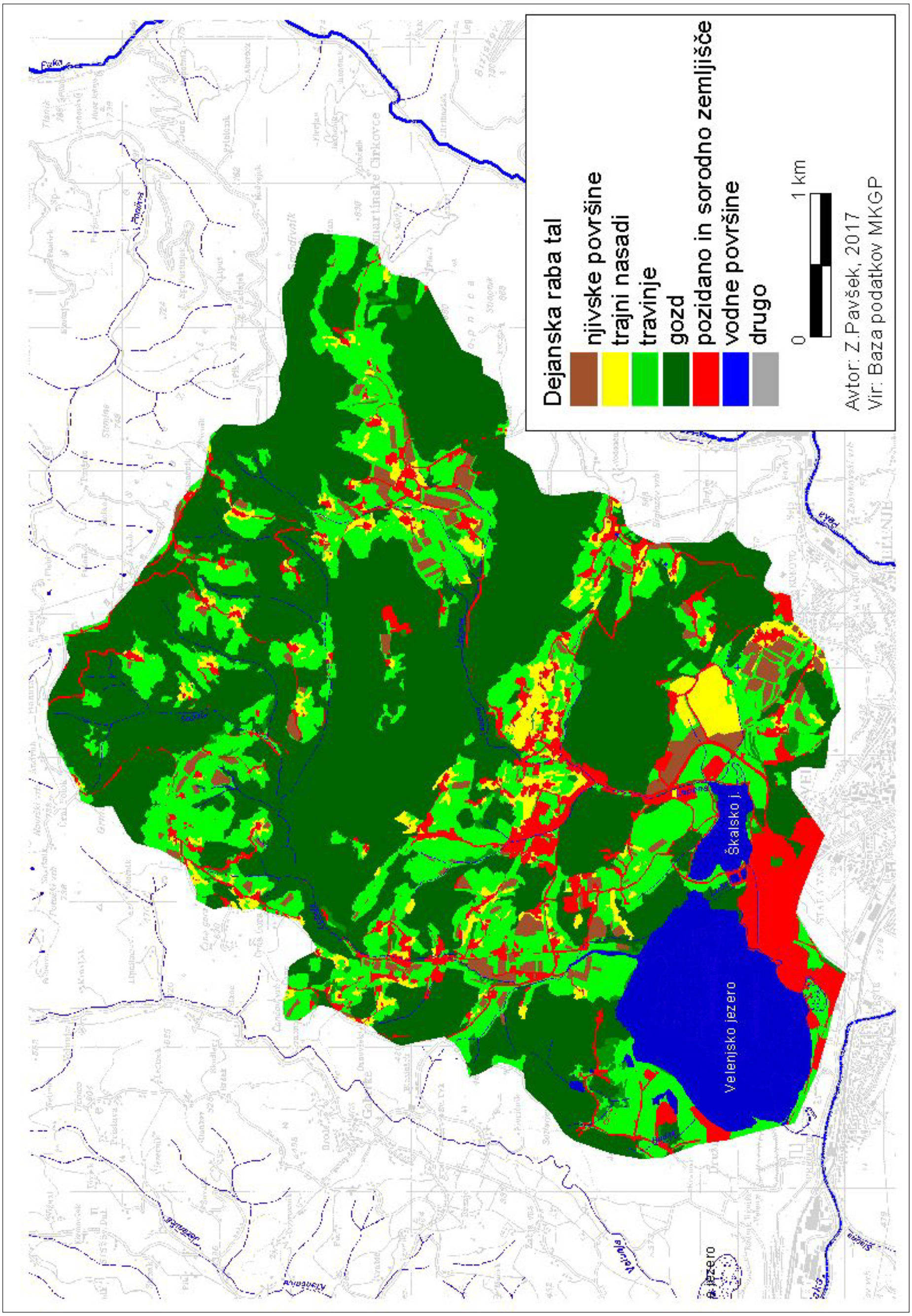
Kmetijstvo je večinoma usmerjeno v mlečno živinorejo. Prevladujejo manjša posestva, pridelava je najbolj intenzivna na manjšem številu visoko mehaniziranih kmetij. Kmetijstvo je na pojezerskih tleh tista gospodarska panoga, ki ima na jezera največji vpliv. Obdelovalne površine sicer predstavljajo manjši delež, so pa večinoma najbliže jezerom (preglednica 2, slika 4). Travnike in sadovnjake gnojijo pretežno z gnojevko, ki vode obremenjuje s hranili. Pri gnojenju nekateri ne spoštujejo niti 5-metrskega varstvenega pasu ob pritokih in jezerih. Kmetje uporabljajo zaščitna sredstva za koruzo, ki je poglavitni vir prehrane za govedo.

4.2 Temperatura vode in vsebnost kisika

Čista voda doseže največjo gostoto pri 4 °C, ta znaša pri normalnih pogojih 1 kg/dm^3. Z nižanjem ali višanjem temperature njena gostota pada, na primer pri 0 °C znaša 0,9998, pri 25 °C pa okoli 0,9970 kg/dm^3 (Boehrer, Schultze, 2008). Zaradi gostotne anomalije vode se pri jezerih v zmernih geografskih širinah poleti in pozimi voda razsloji (stratificira). Pri poletni plastovitosti je (v primeru, da je jezero dovolj globoko) temperatura spodnje plasti 4 °C, potem pa do površine narašča. Med zimsko plastovitostjo znaša temperatura na površini 0 °C, na dnu pa 4 °C. Poleti toplejša voda »plava« na hladnejši, pozimi pa je obratno. V času plastovitosti je kroženje vode omejeno le na zgornjo plast. Jezero se v celoti premeša spomladi in jeseni, v času homotermije. Takrat se hipolimnij obogati s kisikom, katerega vsebnost se skozi obdobje plastovitosti zmanjšuje.

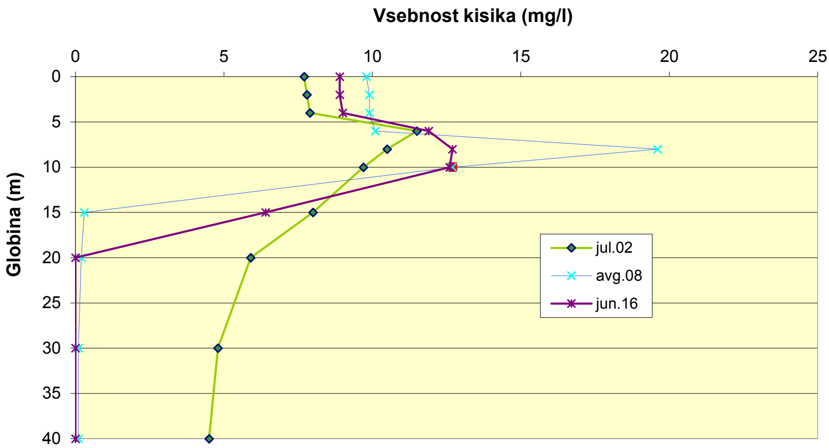
Takoj po sanaciji Velenjskega jezera (leta 1997) se je voda vsako leto dvakrat premešala, potem pa se je njeno kroženje začelo slabšati, kar je razvidno iz primerjave vsebnosti kisika v posameznih jezerskih plasteh med leti (slika 5). Vsebnost kisika se je v hipolimniju znižala. Kazalo je na evtrofikacijo, a dejanski vzrok je bilo poviševanje slanosti z globino. Iz podatkov je razvidno, da se je jezero v obdobju spomladanske homotermije leta 2002 še premešalo, v letu 2008 pa mešanja ni bilo več.

Slika 4: Dejanska raba tal v Velenjskem pojezerju leta 2017.



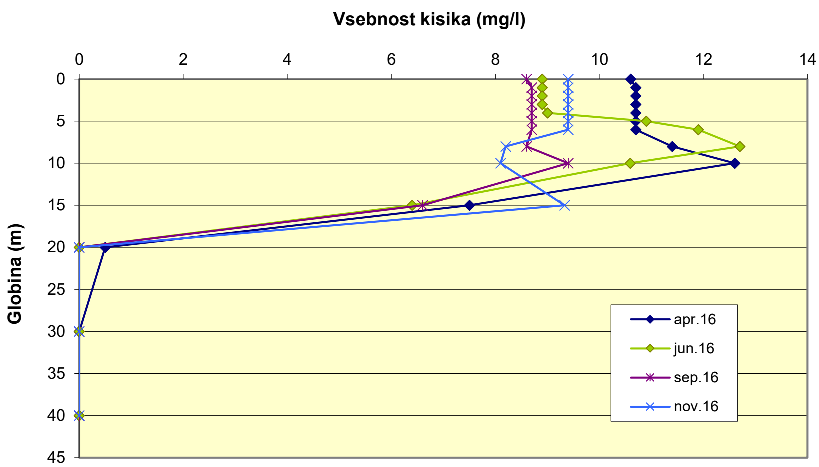
Podobno je bilo v letu 2016: jezero je bilo meromiktično, saj se vse leto ni premešalo. Premešalo se je do globine med 15 in 20 m, saj globlje od 20 m raztopljenega kisika praktično ni bilo.

Slika 5: Vsebnost kisika v Velenjskem jezeru poleti 2002, 2008 in 2016.



Vir: ERICo, 2017.

Slika 6: Vsebnost kisika v Velenjskem jezeru aprila, junija, septembra in novembra 2016.



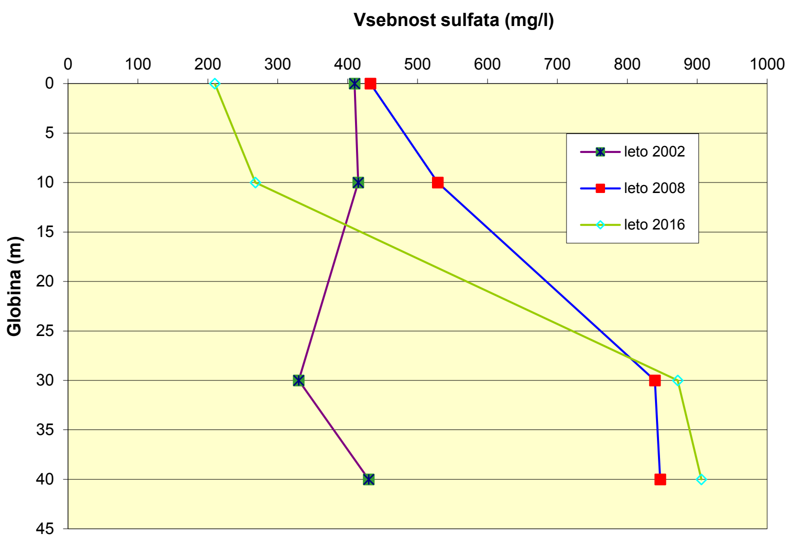
Vir: ERICo, 2017.

4.3 Kemijsko stanje in onesnaževali (sulfat, molibden)

Velenjsko jezero je po kemijskih parametrih uvrščeno v dobro kemijsko stanje, in sicer zlasti na površini ter v celotnem epilimniju. Temperaturne razmere so običajne za jezera zmernotoplega podnebnega pasu, le temperatura hipolimnija zaradi povečane gostote vode v zimskem času odstopa (morala bi biti okoli 4 °C). Jezero je tudi dovolj prosojno (med 5,5 in 10 m). V hipolimniju oziroma plasti brez raztopljenega kisika je povečana koncentracija amonija (Ramšak, 2017). V Poročilu o okolju v Republiki Sloveniji 2017 (str. 82) je izpostavljeno, da je leta 2013 vsebnost fosforja znašala 60 µg/l, kar je bilo več kot 5-letno povprečje (2007–2012), a nastajanje fitoplanktona motijo onesnaževala, zlasti sulfat. Osnovni vzrok, da se Velenjsko jezero ne uvršča med jezera z dobrim ekološkim stanjem, je previsoka vsebnost sulfata in molibdena. Sulfat ne vpliva samo na kakovost vode, ampak tudi na njeno mešanje.

Večje količine sulfata so v jezero prišle zaradi pepelne transportne vode. Njegova vsebnost se z globino povečuje. Na površini znaša okoli 250 mg/l, v spodnji plasti jezera pa se približa 1000 mg/l. Po Uredbi o stanju površinskih voda (2009, 2010, 2013, 2016) je največja dovoljena vsebnost sulfata za dobro ekološko stanje naravnega vodnega telesa 150 mg/l, kar obenem predstavlja tudi kriterij za uvrstitev med kopalna območja. Vsebnost sulfata se na površini zadnja leta giblje med 200 in 300 mg/l. Slovenska zakonodaja dovoljuje vsebnost 250 mg/l v pitni vodi. Torej voda v Velenjskem jezeru glede vsebnosti sulfata ni ustrezna za kopanje, a hkrati ustrezna za pitje. Donat, ena bolj znanih mineralnih vod v Sloveniji, vsebuje več kot 2000 mg/l sulfata.

Slika 7: Vsebnost sulfata v različnih globinah Velenjskega jezera (v letih 2002, 2008 in 2016).



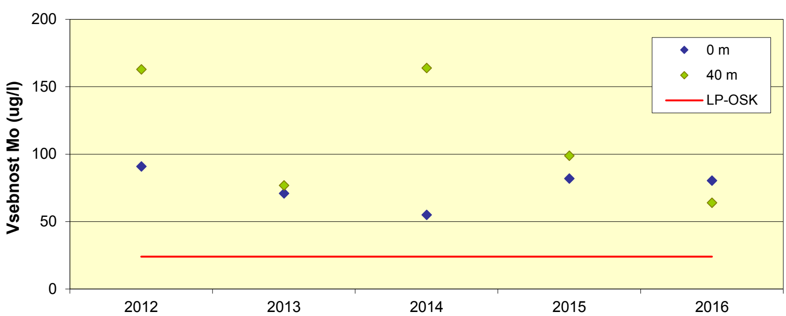
Vir: ERICo, 2017.

Zaradi povečane koncentracije sulfata v večjih globinah je Velenjsko jezero postalo meromiktično. Temperatura celotnega vodnega stolpca se izenači spomladi in jeseni (homotermija), a voda se ne premeša. Hipolimnijska voda zaradi večje gostote ostaja pri dnu. Med homotermijo je temperatura celotnega jezera okoli 8 °C. V poletnem času se epilimnijska voda segreje, pri čemer se njena gostota še zmanjša. Epilimnij sega poleti najgloblje do 11 m. Temperature vode na površini občasno presežejo 25 °C. V obdobju zimske plastovitosti bi morala biti temperatura hipolimnija 4 °C, a dejansko znaša okoli 8 °C. Slika 7 prikazuje, da je bila koncentracija sulfata v letu 2002 po celotni globini jezera dokaj enakomerna, v letih 2008 in 2016 se je njegova koncentracija na dnu pa močno zvišala.

V literaturi najdemo redke podobne primere, ki so posledica drugačnih vzrokov. Boehrer in Schultze (2008) navajata različne vrste jezer, kjer je kroženje vode bolj ali manj oteženo zaradi raztopljenih snovi naravnega ali umetnega izvora, globine, dotoka vode ali tipa podnebja, posledično je stratifikacija vode v jezeru bolj ali manj izrazita, včasih celo stalna. Kot pomemben vzrok navajata raztapljanje različnih snovi, na primer soli s cestišč ali raztapljanje snovi v jezerih, ki so nastala po rudarjenju v odprtih kopih (Boehrer, Schultze, 2008). V jezerih Tanners Lake in Parkers Lake (Minnesota, ZDA) je v letu 2006 zaradi prekomerne uporabe soli za posipanje cest in njenega spiranja v jezeri prišlo do tako močne kemijske stratifikacije, da je bilo spomladansko kroženje vode v jezeru onemogočeno, kar je podobno kot v Velenjskem jezeru. Avtorji so ugotovili, da koncentracija soli v jezerih narašča proporcionalno s količino soli, porabljene za posipanje cestišč (Novotny in sod., 2008). Obenem so avtorji tudi nakazali, da je za izboljšanje treba ponovno vzpostaviti kroženje vode oziroma odstraniti zasoljeno hipolimnijsko vodo.

Molibden je esencialni element za organizme. Kriterij za dobro ekološko stanje vodnega telesa po Uredbi o stanju površinskih voda (2009, 2010, 2013, 2016) je povprečna letna koncentracija pod 24 µg/l, posamezne meritve pa lahko dosegajo do 200 µg/l.

Slika 8: Molibden v Velenjskem jezeru na površini in globini 40 m (od 2012 do 2016).



Opomba: LP-OSK (Okoljski standard kakovosti, izražen kot letna povprečna vrednost parametra kemijskega stanja).
Vir: ERICo, 2017.

Na površini Velenjskega jezera vrednost 200 µg/l ni bila nikoli dosežena, dovoljeno povprečje pa je preseženo, saj so vrednosti dokaj konstantne. V kopalni sezoni je bila občasno merjena koncentracija molibdena na površini. Leta 2013 je znašala 74 µg/l, 65 µg/l v letu 2014, 82 µg/l v letu 2015 ter 80,5 µg/l v letu 2016 (slika 8). Vsebnost molibdena na globini 40 m pa za oceno kopalne vode ni pomembna.

Po smernicah Svetovne zdravstvene organizacije je za zdravje neškodljiva koncentracija molibdena v pitni vodi 70 µg/l, saj je po istem viru dnevna potreba po tem elementu med 100 in 300 µg (Guidelines for …, 2011, str. 394). Tudi v slovenskem pravilniku o zdravstveni ustreznosti pitne vode, ki je veljal do leta 2004, je bila dovoljena vrednost 70 µg/l. Veljavni Pravilnik o naravni mineralni vodi, izvirski vodi in namizni vodi (2005) navaja, da je molibden esencialni element in zanj ne predpisuje mejnih vrednosti.

4.4 Primernost vode za kopanje

Velenjsko jezero je zaradi povišanih vsebnosti sulfata in molibdena uvrščeno v zmerno ekološko stanje (Rekar, 2015). Po drugih parametrih, ki jih določa Uredba o stanju površinskih voda (2009, 2010, 2013, 2016), bi lahko bilo uvrščeno v dobro ekološko stanje. Ker je Velenjsko jezero umetna tvorba, ga ne moremo enačiti z naravnimi in zato govorimo o ekološkem potencialu in ne o ekološkem stanju. Mestna občina Velenje od leta 2012 zagotavlja spremljanje kakovosti vode v Velenjskem jezeru skladno z Uredbo o upravljanju kakovosti kopalnih voda (2008). Kakovost jezerske vode je bila za kopanje vsako leto ustrezna (Ramšak, 2016). V celotnem obdobju spremljanja kakovosti kopalne vode so bili vsi rezultati analiz znotraj predpisanih meja, torej je bila voda bakteriološko ves čas primerna za kopanje. Glede prisotnosti koliformnih bakterij je bila velika večina vzorcev uvrščenih v najboljši razred (odlično) in le trije v dobrega. Po prisotnosti streptokokov fekalnega izvora pa so bili vsi odvzeti vzorci uvrščeni v najvišji razred (odlični). V nadaljevanju je podana preglednica rezultatov kakovosti vode po merilih kopalnih vod za leto 2016 (Ramšak, 2016).

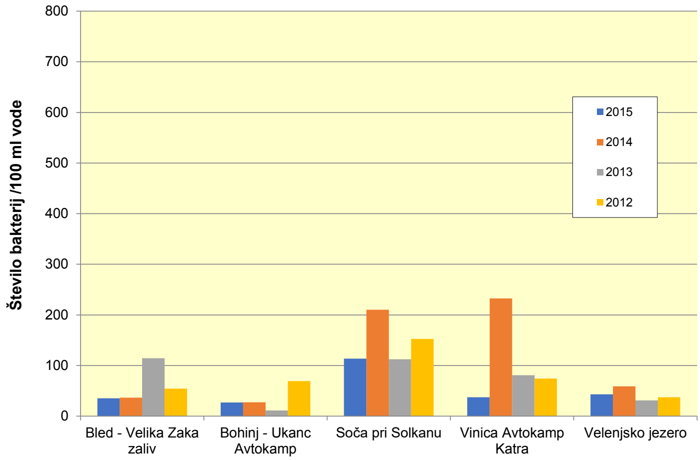
Bakteriološko sliko kopalne vode Velenjskega jezera smo primerjali z drugimi kopalnimi območji v Sloveniji in ugotavljamo, da velenjska spada med boljša. Za primerjavo smo vzeli naravni alpski jezeri, Bohinjsko in Blejsko, Sočo v Solkanu ter Kolpo v Vinici. Vsebnost *E. Coli* bakterij in kakovost vode na Velenjski plaži je primerljiva z vodo v Blejskem jezeru. Bohinjsko je od Velenjskega za odtenek boljše, kakovost vode v Soči in Kolpi pa je malce slabša (slika 9). Vse vrednosti, izmerjene na teh kopališčih, so bile v obdobju 2012–2015 v mejah, ki določajo odlično mikrobiološko stanje.

Preglednica 3: Rezultati analiz vode na Velenjski plaži leta 2016.

Parameter	Ocena kakovosti kopalne vode			Datum vzorčenja											
Mikrobiološke analize[1]	**Odlično**	**Dobro**	**Zadostno**	**3.5.**	**6.6.**	**27.6.**	**4.7.**	**11.7.**	**18.7.**	**25.7.**	**1.8.**	**8.8.**	**16.8.**	**22.8.**	**29.8.**
Koliformne bakterije fekal. izvora (*E. Coli*), št./100ml	500*	1000*	900**	Ni	6	10	1	3	36	11	70	4	20	4	1
Streptokoki fekal. izvora (*intest. enterokoki*), št./100 ml	200*	400*	330**	Ni	2	17	N	<4	8	<4	20	4	33	<4	Ni
Fizikalno kemijski parametri[2]	**Priporočena vrednost**	**Obvezujoča vrednost**													
Temperatura (°C)	-	-		13,3	21,0	22,6	23,8	25,6	22,6	25,3	25,3	24,1	24,0	23,3	23,5
pH	6–9	-		8,3	8,5	8,4	8,4	8,4	8,5	8,4	8,3	8,5	8,4	8,3	8,3
Prosojnost	2 m	-		>2m	<2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m
Raztopljeni kisik (mg/l)	7–12	-		9,7	9,3	9,4	9,5	8,5	9,3	8,2	8,6	9,3	9,3	8,7	8,3
Nasičenost s kisikom (%)	80–120	-		97	107	98	103	105	102	106	104	108	107	104	101
Vidne nečistoče	brez	-		brez	brez	brez	brez	brez	brez	brez	brez	brez	Brez	Brez	Brez
Mineralna olja (mg/l)	<0,3	brez značil. vonja in vidne plasti na površini vode		0,14	<0,05	<0,05	-	<0,05	-	<0,05	-	<0,05	-	0,06	-
Amonij (mg/l)	-	-		<0,3	0,02	<1,3	-	<1,3	-	<1,3	-	<1,3	-	<1,3	-
Nitrat (mg/l)	-	-		2,26	2,18	2,14	-	0,44	-	2,04	-	1,82	-	1,74	-
Fenoli (fenolni indeks) (mg/l)	<0,005	brez značil. vonja <0,05		<0,05	<0,05	<0,05	-	<0,05	-	<0,05	-	<0,05	-	<0,05	-
Primernost vode za kopanje				DA	DA	DA	DA	DA	DA	DA	DA	DA	DA	DA	DA

Opombi: [1] Mikrobiološke analize so ocenjene na podlagi Uredbe o upravljanju kakovosti kopalnih voda (Ur. l. RS, št. 25/08):
** … na podlagi vrednotenja 95-ega percentila v skladu z Uredbo o upravljanju kakovosti kopalnih voda;*
*** … na podlagi vrednotenja 90-ega percentila v skladu z Uredbo o upravljanju kakovosti kopalnih voda.*
[2] Pri oceni so podane orientacijske vrednosti.
Vir: Ramšak, 2016.

Slika 9: Povprečno število E. Coli bakterij (število bakterij/100 ml) v Velenjskem jezeru in v nekaterih slovenskih naravnih kopališčih v obdobju 2012–2015.*



** Opomba: zgornja meja za odlično mikrobiološko stanje je 500 bakterij v 100 ml vode.*
Vir: ARSO, 2012–2015; ERICo, 2017.

5 PREOBRAZBA VELENJSKEGA JEZERA IN NJEGOVIH BREGOV V REKREACIJSKO OBMOČJE

5.1 Oris turistično-rekreacijske rabe Velenjskega jezera

Rekreacijsko območje so na bregu Škalskega jezera zgradili že v petdesetih letih 20. stoletja in je hitro postalo širše znana turistična lokacija. Velenjčani so zgradili kopališče, restavracijo, nogometno-atletski stadion, mini golf, letni kino in postavili počitniške hišice. Nove infrastrukture niso koristili le domačini, prav tako so bile dobro obiskane tamkajšnje prireditve. To obliko rekultivacije ugreznin so predstavljali tako jugoslovanskim gostom kot tujcem, saj so Velenje lokalni in republiški politiki predstavljali kot »socialistični čudež« (Mali Bled …, 2017). V sedemdesetih letih so odkopali nekaj etaž premoga pod tem območjem ter velik del športne in gostinske infrastrukture preselili ob Velenjsko jezero. Na južnem bregu so leta 1981 začeli graditi novo restavracijo, ob njej pa športna igrišča. Urejanje so zaključili v začetku devetdesetih let z izgradnjo (teniške) Bele dvorane.

Že v osemdesetih letih je bilo Velenjsko jezero kljub onesnaženosti med domačini priljubljeno za jadranje na deski. Do leta 1995 o rabi vode za kopanje praktično ne moremo govoriti. Po izgradnji restavracije Jezero so zajezili manjšo kotanjo v neposredni bližini in novo kopališče je privabljalo rekreativce, a ne množično (Pavšek, 2003). Pomembno spremembo na tem področju je prineslo šele odprtje Velenjske plaže (2013), potem ko se je po enoletnih analizah voda izkazala kot primerna za kopanje. V naslednjih letih se je število kopalcev močno povečalo in v letu 2016 smo med poletnimi konci tedna ocenili, da je na njegov breg po naših ocenah dnevno prišlo več kot 3000 ljudi (v večji meri prebivalcev Šaleške doline). V letu 2017 se je število kopalcev še povečalo (slika 10). Mestna občina Velenje je v času kopalne sezone organizirala službo reševanja iz vode in poskrbela za širšo ponudbo športne opreme in igral.

Slika 10: Velenjsko plažo vsako leto obiskuje več ljudi, ob koncih tedna v letu 2017 je bilo parkiranih tudi do tisoč vozil (foto: EXTREM d. o. o., 2017).

Velenjsko jezero že zaradi njegovega antropogenega nastanka težko uvrstimo med naravna kopališča. Glede na rezultate monitoringa kopalne vode pa ne po slovenski Uredbi o upravljanju kakovosti kopalnih voda (2008) ne po EU direktivi (2006/7/ES) ni dvoma, da je voda primerna za kopanje. Toda zaradi strogih zahtev slovenskega Pravilnika o podrobnejših kriterijih za ugotavljanje kopalnih voda (2008) območje (še) ni uvrščeno med kopalna.

Ker postaja jezero med kopalci vse bolj priljubljeno, bi bilo nejasnosti treba razrešiti. Direktiva 2006/7/ES v 5. členu določa: *»Če se kopalna voda pet zaporednih let razvrsti kot 'slaba', se kopanje trajno prepove ali trajno odsvetuje. Vendar lahko država članica kopanje trajno prepove ali trajno odsvetuje pred koncem petletnega obdobja, če meni, da bi bilo nemogoče ali nesorazmerno drago doseči 'zadostno' kakovost.«* Predstavniki

Mestne občine Velenje so leta 2012 vložili pobudo za razglasitev Velenjskega jezera kot kopalnega območja. Za uvrstitev dela brega Velenjskega jezera med kopalna območja bi Velenjsko jezero moralo biti v dobrem ekološkem stanju, kar pa je zaradi posebnih onesnaževal (sulfat, molibden) nemogoče. Na Inštitutu za varovanje zdravja so podali mnenje, da z vidika zdravja kopalcev niti povišana vsebnost sulfata niti molibdena nista nevarni (Gale, Petrovič, 2013).

Voda na plaži Velenjskega jezera po nobenem kriteriju ne more biti označena kot slaba. Poleg tega velja upoštevati, da gre za umetno vodno telo. Plažo je vsekakor treba opredeliti kot kopalno območje ali pa kopanje prepovedati. Velenjsko jezero je bilo po kriterijih za ekološko kakovost leta 2014 – enako kot Blejsko – ocenjeno za zmerno (Rekar, 2015).

5.2 Razvojne usmeritve ob upoštevanju okoljskih omejitev

Velenjsko jezero in njegov breg sta že v rekreacijsko-turistični rabi, čeprav posamezne dejavnosti, ki se odvijajo na jezerskem bregu, med sabo niso popolnoma usklajene. Prav tako niso dovolj natančno določene in opredeljene naravne omejitve. V Strategiji razvoja in trženja turizma Mestne občine Velenje so izpostavili cilj razvoja objezerskega turizma, da jezera postanejo osrednja in izhodiščna točka za vse aktivne programe na območju Mestne občine Velenje (2016, str. 70). Za te potrebe je nujno pripraviti in izdelati strateški-razvojni načrt za trajnostni razvoj turizma ob jezerih, ki bo obenem osnova za usmerjanje potencialnih vlagateljev. Prvi korak v to smer je nakazan v poročilu o Razvoju turistične destinacije jezera Velenja (Žerdin, Šeliga, 2015). Osnovne razvojne usmeritve so nadaljevanje dosedanjih aktivnosti v povezavi z globalnimi trendi ter s krovnimi usmeritvami slovenskega turizma. Ne smemo ostati le pri koordinaciji med različnimi vodnimi športi, ampak tudi med različnimi rabami jezerskih bregov in širšega zaledja, saj so jezerske površine in bregovi omejeni. V letu 2016 ustanovljeni Zavod za turizem Šaleške doline bo postopoma v celoti sprejel upravljanje te turistične destinacije. Na ta način bo ob intenzivnejši komunikaciji z javnostjo in širši promociji mogoče usmerjati in nadzorovati več dejavnosti; uresničevati strategije razvoja, povečevati učinkovitost trženja, dodajati nove turistične produkte in zasebne vlagatelje spodbujati k investiranju. Seveda je ob intenzivnejši rekreacijsko-športni rabi nujno redno spremljati kakovost Velenjskega jezera med kopalno sezono, določiti plovbni in kopalni režim, vzpostaviti sodelovanje med upravljavci in načrtovalci dejavnosti v jezerih in ob njih ter vsemi uporabniki, ob uvajanju novih dejavnosti pa skrbno preveriti mogoče negativne vplive in predvideti omilitvene ukrepe.

Že pri dosedanji stopnji rabe tega območja prihaja do neželenih vplivov zaradi obremenjevanja v preteklosti in zaradi dejavnosti, ki trenutno potekajo. Za turistično rabo mora biti jezero dobre kakovosti. Velik del varstvenih oziroma omilitvenih ukrepov je že opredeljen (Šaleška jezera – vodni vir …, 2011), niso pa oblikovani kot občinski odlok, ki bi jim dal bistveno večjo težo.

Na področju odvajanja komunalnih voda, razen izgradnje zadrževalnih bazenov za visoke vode, prostora za izboljšave ni, saj je zgrajena krožna kanalizacija. Na področju kmetijstva se izpiranje hranil v vodotoke lahko zmanjša s preventivnimi ukrepi, kot so: dosledno upoštevanje 5-metrskega varstvenega pasu, zasaditev živih mej med obdelovalnimi in vodnimi površinami, z ekoremediacijskimi ukrepi na jezerskih pritokih, ekoremediacijsko ureditvijo jezerskih bregov, z dovajanjem sveže vode na dno Velenjskega jezera in s trajnostnim gospodarjenjem z ribjo populacijo.

Ukrepi za zmanjšanje intenzivnosti evtrofikacije so usmerjeni v zmanjševanje vnosa hranil v Velenjsko jezero in v njihovo vgrajevanje v rastlinsko biomaso (odstranjevanje oziroma žetev večjih vodnih rastlin ob koncu vegetacijskega obdobja in plavajoči čistilni otoki na območju pritokov v jezera, prepovedano krmljenje rib v vseh jezerih zaradi ribolova, premestitev ribogojnih bazenov pod Velenjsko jezero, obstoječe ob Škalskem jezeru pa spremeniti v rastlinske čistilne naprave). Naslednja skupina ukrepov je namenjena zagotavljanju dovolj kakovostne tehnološke vode za elektroenergetiko, hidroenergetsko rabo in sploščanje poplavnega vala vodotokov ter zajema: program zadrževanja visokih voda v jezerih in zmanjševanje pretoka Pake pod njimi ter preučitev možnosti energetske rabe Velenjskega in Družmirskega jezera.

5.3 Možnosti za intenziviranje menjave vode, izboljšanje poplavne varnosti in energetsko rabo

Lepena in Sopota, pritoka Velenjskega jezera, skupaj z neposrednim odtokom z ožjega jezerskega brega in s padavinami, ki padejo na jezero, letno v jezero prispevata dobrih 11 milijonov m^3 vode. Čas teoretične menjave vode v Velenjskem jezeru presega 3 leta. V zadnjem desetletju se je evtrofikacija kljub pospešeni gradnji kanalizacije povečala. Kopičenje hranil v jezerih povzroča razvoj bakterij, fito- in zooplanktona. Ko plankton odmre, se organske snovi usedajo na dno in za razpadanje porabljajo kisik.

Ena izmed potencialnih možnosti za izboljšanje je hitrejša menjava jezerske vode, kar bi bilo mogoče doseči z uvajanjem dela vode iz Pake v jezero. Glede na poznavanje kakovosti vode Pake ugotavljamo, da bi to na jezero vplivalo ugodno le v obdobju majhnih pretokov, ko le-ta prenaša manj raztopljenih in suspendiranih snovi. Srednji mesečni pretoki Pake v Pesju znašajo od 1,1 do 1,8 m^3/s (interpolirane vrednosti glede na vodomer v Velenju v obdobju 1991/2010). Na tej podlagi ocenjujemo, da v Pesju razpolagamo s slabimi 44 milijoni m^3 vode letno. Če bi vso spustili v jezero, bi se voda v njem teoretično menjala hitreje kot v letu. V primeru zagotavljanja ekološko sprejemljivega pretoka Pake v Šoštanju (400 l/s) bi bilo letno na voljo 31,7 milijonov m^3 vode, tako da bi se teoretično zamenjala v dobrem letu. Z meritvami smo ugotovili, da Paka v obdobjih visokih vod prinaša bistveno več snovi kot ob srednjih malih pretokih, v času katerih v skladu z zakonodajo spremljamo njeno kakovost (Šaleška jezera – vodni vir …, 2011).

Ob povečanem pretoku 17. 9. 2010 (6,3 m^3/s) bi Paka v jezero dnevno prinesla več kot 2 t celotnega dušika in 885 kg celotnega fosforja. Z vidika vodnih količin je bogatenje jezera pozitivno, ne pa tudi z vidika vnosa snovi – in to zlasti ob visokih vodah (Šaleška jezera – vodni vir …, 2011). Z vidika vnosa hranil je spuščanje visokih vod v jezero torej neustrezno. V jezero bi veljalo spuščati vodo iz Pake v obdobjih, ko s sabo prenaša najmanj snovi. Treba bi bilo zgraditi jez, najustrezneje pa vodo pred spuščanjem v jezero še dodatno čistiti. Še manj primerna se je Paka pokazala z vidika bakteriološke obremenitve, saj bi z njenim spuščanjem v jezero zmanjšali primernost njegove vode za kopanje. To dokazujejo rezultati meritev iz leta 2011. V Pesju je bilo število koliformnih bakterij in število koliformnih bakterij fekalnega izvora v Paki 2419,6 MPN/100 ml, kar kaže na organsko obremenitev. To je bistveno večja vsebnost kot v Lepeni in Sopoti. Po tej meritvi bakteriološke slike nismo več spremljali, a bi to veljalo storiti. Med leti 2012 in 2015 so v porečju Pake dogradili manjkajoče dele kanalizacije v Velenju, Podkraju in Pesju, tako da je pričakovati izboljšano stanje Pake.

Z dovoljenim nihanjem gladine (0,6 m) Velenjsko jezero predstavlja potencial za (delno) akumulacijo poplavnega vala. Razlika med zgornjo in spodnjo točko predstavlja milijon m^3 in z zadržano vodo bi lahko omilili ali celo preprečili poplave niže v porečju Pake. Ni nujno, da bi Pako zato speljali v jezero, že če bi nekaj ur v njem zadržali vode Lepene in Sopote, bi se pretoki Pake temu primerno zmanjšali.

Nenazadnje bi bilo mogoče zaradi razlike višin gladin (7 m) Velenjskega in niže ležečega Družmirskega jezera pridobivati električno energijo. Če bi med jezeroma zgradili elektrarno, bi lahko vodo iz Družmirskega jezera ponoči črpali v Velenjskega, v jutranji konici pa jo spuščali nazaj in poganjali generator (Vodušek, 2012). Pri tem je ob vprašanjih glede stabilnosti pregrade in razlik kakovosti vode v obeh jezerih še veliko neznank, ki bi jih bilo treba pred uresničitvijo te ideje opredeliti in rešiti.

6 SKLEP

Velenjsko jezero spada med večja v Sloveniji, s svojo ožjo ter širšo okolico postaja vedno bolj prepoznavno kot rekreacijsko-turistično območje. Po kakovosti je voda Velenjskega jezera primerna za kopanje, saj zlasti po bakteriološkem stanju spada med boljše v Sloveniji. V Velenju so zato na jezerskem bregu zgradili plažo, ki jo koristijo številni kopalci in poleti postaja središče dogajanja na širšem območju. Na Mestni občini Velenje so organizirali nadzor nad kakovostjo vode in reševanje iz vode ter poskrbeli za komunalno, prometno, rekreacijsko in turistično infrastrukturo. Jezero načrtujejo še intenzivneje koristiti v rekreacijsko-turistične namene, a je pri dodajanju nadaljnje infrastrukture treba skrbno pretehtati mogoče posledice zaradi njegove občutljivosti.

Zaradi prisotnosti človeku nenevarnih posebnih onesnažil jezero ne dosega dobrega ekološkega stanja (ampak dosega zmerno ekološko stanje), kar je pogoj za razglasitev kopalnega območja. Odlaganje pepela vanj in na njegov breg je povišalo vsebnost sulfata in molibdena. Gre za vrednosti, ki ustrezajo določilom za pitno vodo, predpisi pa za (naravna) vodna telesa določajo nižje vrednosti. Omenjeni sestavini ne vplivata negativno na zdravje ljudi in kopanje je varno, kar potrjuje mnenje Inštituta za varovanje zdravja Republike Slovenije. Povečana koncentracija sulfata v spodnji plasti ovira naravno kroženje jezerske vode, zato iščemo možnosti, kako to spremeniti. Za prestrezanje komunalnih odpadnih voda je zgrajena krožna kanalizacija, za zmanjšanje kmetijskih vplivov pa so načrtovani ekoremediacijski ukrepi. V naslednjih korakih se odpira širok nabor možnosti, tj. od dovajanja sveže vode na dno jezera do spuščanja vode iz Pake vanj. Vsaka od teh možnosti je zgolj teoretična in bi jo bilo treba dobro preučiti, preden bi se za katero odločili, saj bi z nepremišljenim posegom lahko povzročili nepopravljivo škodo. Velenjsko jezero je tako specifično, da smo v literaturi naleteli le na redke podobne prakse, ki so na stopnji raziskav in ne olajšajo iskanja ustreznih rešitev.

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TRANSFORMATION OF THE VELENJE SUBSIDENCE LAKE

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Abstract
Lake Velenje formed as a result of the underground extraction of lignite in the Velenje coal mine. The article deals with certain special issues that have arisen as part of the process to transform the landscape from a riverine to a lake system as a result of mining and energy production. Anomalies in the lake system are explained drawing on research and monitoring of the properties and circulation of the lake water. As it was established on agricultural land, and due to intense pollution in the 1960s and 1970s, the lake initially was considered an environmental disaster; later, extensive environmental rehabilitation initiatives turned it into a recreational area.

Keywords: coal mining subsidence, transformation of lakes, salinisation of lake, bathing areas, Velenje, Šalek Valley, Slovenia

1 INTRODUCTION

Lake Velenje is the largest of the three Šalek subsidence lakes, which were created as a result of underground excavation of lignite in the Velenje coal mine. Water first flowed into the basin of Lake Velenje after the Second World War, after which the lake grew and by 2016 had reached a size of 145 hectares. Up until the 1980s, it was being polluted with ash from the Šoštanj thermoelectric plant (hereinafter referred to by its Slovene acronym TEŠ), which caused high alkalinity and the lake water was virtually sterile - devoid of living organisms (Šterbenk, Ramšak, 1999, p. 217). In the 1990s, environmental rehabilitation initiatives were implemented at the thermoelectric plant, and since 1995, the lake water has radically improved. Long-term pollution has left traces – remains that make the lake unique and interesting as a research subject. The first feature is the elevated sulphate content, which made its way into the lake due to the proximity of a land subsidence rehabilitation area - the embankment between the Velenje and lower-lying Družmirje lakes. The embankment is subsiding and is continually being built-up with ash from TEŠ so as to maintain the integrity of the land surface. For the same reason, there are also elevated levels of molybdenum. Neither substance has a negative effect on human health, though by concentrating in the lower water layer, they impact water circulation in the lake and the development of organisms.

Over the past two decades or so Lake Velenje, along with its immediate surroundings as well as the wider hinterland, has became an area of interest for recreational, sports and other leisure activities. As early as the eighties walking paths were built along the lakeshore, which Velenje residents immediately began to take advantage of. Although the water has been suitable for swimming since 1996 (Šterbenk, 1999, p. 140), more than a decade passed without even an uptick in recreational and sports use of the water body, the lake still being considered contaminated and dangerous in the eyes of the public. The main turning point was the opening of Velenje Beach in 2013. In the summer months of 2016, the beach hosted 65,000 visitors (Piano, 2017), while it also become a venue for a range of other leisure activities (rowing, kiteboarding, sailing – in small sailing boats, and windsurfing). A campsite opened alongside the beach in 1995 (Lukaček, 2017), expanding the services on offer and increasing the number of visitors. Walking paths along with the rest of the extensive recreational facilities are well visited throughout the year.

The paper aims to clarify the special features of the artificial Lake Velenje, as well as discuss how the riverine landscape has changed to become a much more sensitive lake environment. Drawing on research and monitoring of the properties and circulation of lake water, we elaborate on anomalies in the lake system. We identified the causes of changes in water quality and assessed the degree of eutrophication and specific chemical changes such as salinisation of the lake's hypolimnion and increased molybdenum levels, and consequent meromicticity of the lake. In the concluding sections we present an analysis of hitherto transformation of the subsidence lake into a recreation and tourism area and we outline the limitations the area faces in terms of its capacity for such development, considering the sensitivity of the lake landscape.

2 METHODS

At the ERICo institute we have been monitoring Lake Velenje since 1987. This monitoring has covered both basic physicochemical parameters and biological monitoring, as well as comprehensive geographical examination of the lake and its hinterland from the perspective of the natural and social components that make up the landscape. Thus, the article brings together the findings of several decades of research and presents the specific features of the lake.

The research centred around analysis of the lake catchment, monitoring of water quality and cataloguing of the dominant impacts on the lakes. We perform physicochemical and biological analyses four times a year above the deepest part of the lake along a depth profile from 0 to 40 m. We collect samples using a 2.2 L (Van Dorn) water sampler. During each sampling, we measure the temperature profile of the lake and record essential chemical and biological parameters, particularly oxygen levels and saturation of the water with oxygen along with specific pollutants. Additionally, a Secchi disk is used to measure transparency and determine a number of chemical parameters (anions, cations and different metals). Since 2012, we have been monitoring the parameters that determine the quality of bathing water (Uredba o upravljanju …, 2008). Drawing on norms for the quality of lakes (nutrient content, level of trophicity, etc.) and taking account of observed conditions, guidelines laying out a sustainable model of lake management have been developed, containing proposals for preventive as well as rehabilitative and restorative measures.

Based on knowledge of the biological properties of the lake, alongside guidelines for its future use, particular attention is given to outlined restrictions, which are necessary to consider in the evolving recreational and tourism activities. Some of the phenomena exhibited at Lake Velenje were compared with similar lakes around the world (stratification due to salt content), and we also compared its quality of bathing water with some natural bathing areas in Slovenia.

Research and development guidelines for the Šalek Lakes focus on developing a sustainable model for managing the lakes. Such a model needs to incorporate proposals for protection and rehabilitation/restoration measures and specify guidelines for long-term sustainable use of water bodies and waterside areas. Such an approach should ensure at least moderate eutrophic lake conditions, and thus provide for appropriate technological water and conditions conducent to the development of leisure and other activities on the lakes and their banks.

3 FORMATION, CONTAMINATION AND REHABILITATION OF LAKE VELENJE

The area of the lignite layer (coal seam) of the Velenje coal mine extends over almost the entire Šalek Valley. It is about 8.3 km long and 1.5 km to 2.5 km wide, with a maximum layer thickness of over 160 m. Longitudinally it stretches along a northwest-southeast axis. There is just one coal seam, although it is extremely thick and economically important. Over the course of more than 140 years of exploitation, the main task was finding the most effective method of extraction. Many methods were used, though only in the second half of the twentieth century was the longwall extraction method introduced, which subsequently developed into the so-called Velenje mining method. Applying this method, a layer of coal more than 10 m thick can be excavated underground, at a time (Mavec, 2004).

Such a method causes huge changes to relief on the surface, and consequently the ground of the Šalek Valley is subsiding. Hollows form, the deepest sections of which are flooded with water. Due to the impermeable layers of clay minerals, which are located between the surface and the lignite layer, this water does not flow into extraction areas. Prior to the commencement of coal mining, the central part of the Šalek Valley was largely used for agriculture with the population based in clustered settlements. Agrarian settlements in the area acquired by the Velenje coal mine have partially or completely disappeared (Družmirje,

Figure 1: The Šalek Lakes in the spring of 2017 – in the foreground is Lake Družmirje, which merged with Lake Gaberke in 2006 (inlet in the upper left), in the background is Lake Velenje. Between them is a subsidence rehabilitation area with smaller water bodies (photo: E. Šterbenk).

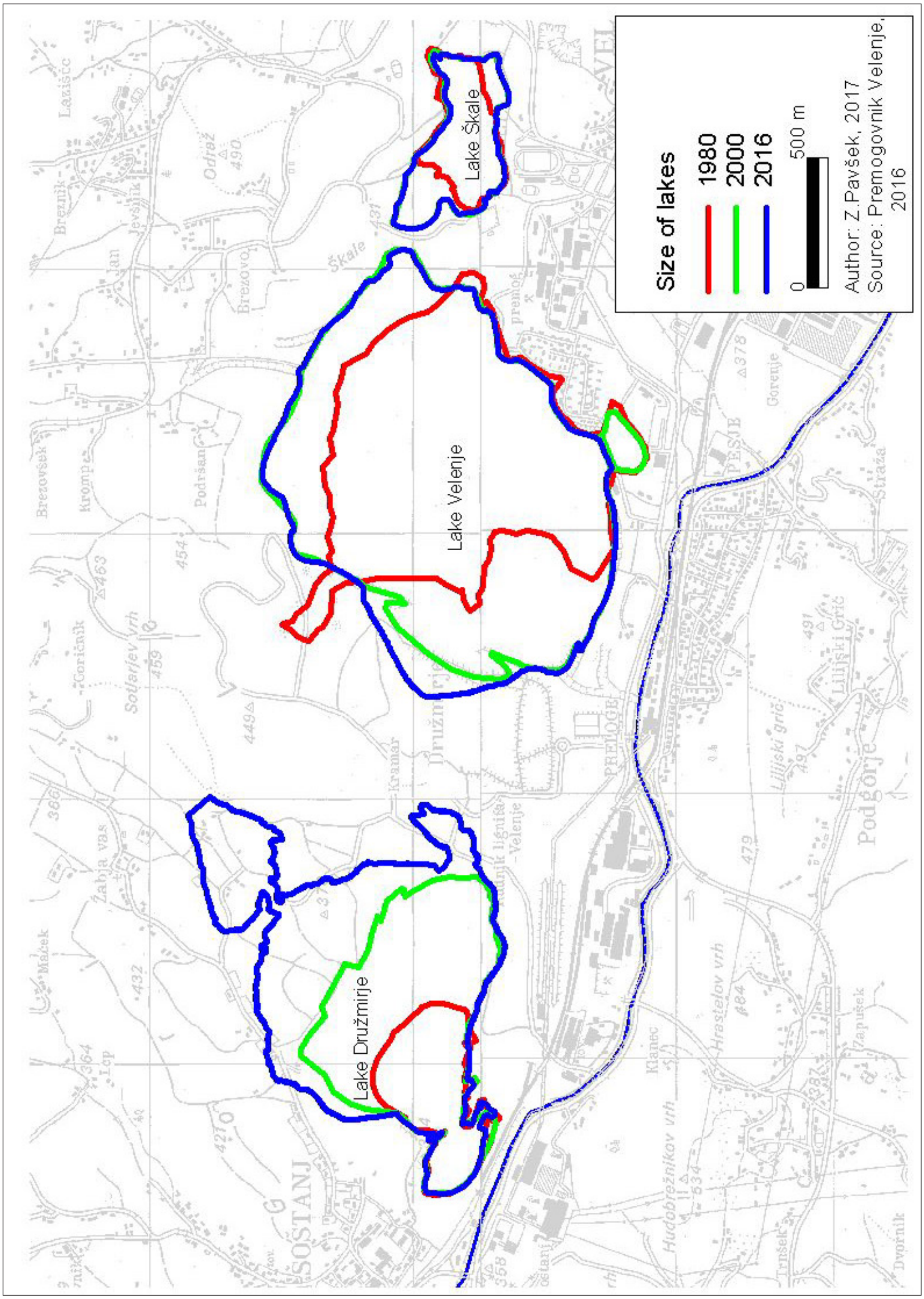
Preloge, Škale, Pesje). The appearance of the valley, so too of the lakes, is still changing as a result of the functioning coal mine. Alongside data on the size, depth and quality of the lakes, we are required to indicate the year to which they relate (Table 1, Figure 2). In 2016 the volume of subsidence hollows exceeded 150 million m^3, and the three lakes cover a surface area of more than 7 km^2, accounting for approximately a third of the volume (almost 58 million m^3) and also a third of the surface of the subsidence area (2.5 km^2).

Table 1: Basic measurements of the Šalek Lakes in 1980, 2000 and 2016.

Data / Lake	**Velenje**			**Družmirje**			**Škale**		
Year	1980	2000	2016	1980	2000	2016	1980	2000	2016
Area (ha)	93	139	145	19.7	52	93.9	11.9	16.8	16.5
Volume (million m^3)	13.5	26	34.7	2	10.8	22.1	0.7	0.9	0.9
Maximum depth (m)	34	54.1	63.4	30	69.1	85.3	16	19.4	18.2
Average depth (m)	14.8	18.5	23.5	10.4	21.7	23.5	6.2	5.7	5.6

Source: Premogovnik Velenje, 2016.

Figure 2: Enlargement of the Šalek Lakes between 1980 and 2016.



Throughout the history of the mine several lakes formed, which subsequently merged into larger bodies of water. Such an example is Lake Gaberke, which appeared in 2012, and within four years, merged with Lake Družmirje (Figure 1). The lakes are fed by tributaries of the Paka River and were named after the settlements (Škale, Družmirje) that had to make way as the lakes formed and after the town of Velenje.

Since 1956, when the first section of the TEŠ was built, ash has been deposited in the area of the subsiding land – initially on the shore of Lake Velenje and later on in the lake – while transport water also flowed into the lake. The fourth section of the plant already significantly exceeded the self-cleaning capacity of Lake Velenje, while following the construction of the fifth section in 1977, the self-cleaning capacity of the Paka River was also exceeded. Annually the plant used about 10 million m^3 of water to transport the ash (Šterbenk, 1999, p. 139), which at the time was almost half the volume of Lake Velenje. From the beginning of the 1970s until the system for transporting ash was shut down there were practically no living organisms in the lake as the pH of the water was around 12.

Figure 3: During the period when alkaline levels were at their highest there were no living organisms in Lake Velenje (photo: R. Ramšak, 1993).

In 1987 TEŠ introduced the Ecological Rehabilitation Program, the implementation of which began immediately. It laid out plans to change how ash was transported and disposed of. From the early eighties ash began to be embedded in the embankment. The quality of Lake Velenje did not improve, since water used for transportation still flowed into it (Šterbenk, 2009). Rehabilitation was approached in a systematic manner and a group was established to oversee the initiative, out of which the ERICo Environmental Research Institute was subsequently created. Experts, *inter alia*, monitored the conditions of the lakes and sought solutions to improve them. They set up a pilot system for transporting ash to subsiding areas in the form of an emulsifier (dense mixture, virtually without wastewater – Stropnik, 1989). A definitive solution was reached in 1994 with the construction of a closed-circuit ash transport water system.

After the alkalinity of the water decreased, Lake Velenje recovered and in the same year organisms returned. In the epilimnion, immediately after the closure of the system, planktonic organisms and also fish appeared – initially only at inlets to the lake. In 1996, the hypolimnion was still overloaded with hydroxides. Nevertheless, fish lived (survived) in the upper layers of the lake throughout the year and during a fish capture survey in November 1996 the following specimens were caught: carp, chub, common rudd, common roach, common bleak and perch (Šterbenk, Ramšak, 1999, p. 219). In 1997, as alkaline levels decreased also in deeper layers, living conditions further improved. Alongside planktonic animals and plants, macrophytes flourished, joining with reeds to form a genuine underwater forests (Ramšak, 1998, p. 59).

4 MONITORING THE QUALITY OF LAKE VELENJE WITH AN EMPHASIS ON CONDITIONS IN 2016

Initially it seemed as though Lake Velenje would quickly and fundamentally improve, but long-term pollution has left consequences that, even after the implementation of initiatives as part of the rehabilitation program, are unexpectedly still present. Due to eutrophication algal blooms occasionally occur, while elevated salinity levels cause incomplete circulation of the water.

4.1 Hydrogeographic features of the lake and impacts on the catchment

The quality of the lake is a reflection of conditions in its landscape. The negative impacts of electricity production prevailed in Velenje until 1994, only after which did other influences became more visible. Its catchment area covers 20.54 km^2, with more than half made up of the higher lying Škale lake catchment and its series of lakes. Velenje Lake's catchment extends to an elevation of 900 m above sea level, although almost nine-tenths of its surface lies below 700 m. Forests cover practically half of the catchment, which is beneficial for the lake, as it reduces negative anthropogenic effects, especially the impacts of the coal industry (increased erosion and soil denudation) and agriculture. It is estimated that over 2,000 residents, or about 100 inhabitants/km^2, live in the catchment of the lake. The sewerage system covers practically the entire catchment. Wastewater is not treated in smaller treatment plants, rather it is pumped into centralised collection facilities that feed into the Šalek Valley central wastewater treatment plant. The largest settlement in the district is Škale; in 2016 it had a population of 846 (Kotnik, Pavšek, Šterbenk, 2017).

In the past the catchment was a rural and sparsely populated area; it has urbanised only in the past four decades. Settlements typically consisting of family houses on plots around 1000 m^2 are increasingly transforming into commuter neighbourhoods. Population density is increasing in the catchment since the central parts of the Šalek Valley (subsidence area) are subsiding and forming lakes – consequently residents have had to move from these areas. While the density is also increasing due to proximity to employment considerations around Velenje and Šoštanj (Šaleška jezera – vodni vir ..., 2011).

Table 2: Land use in the catchment of Lake Velenje in 2017.

Category of land use	Area (ha)	Percentage (%)
Arable land	745,498	3.6
Permanent crops and orchards	1,088,046	5.3
Meadows	4,494,014	21.9
Forests	10,109,431	49.2
Urban and built up areas	1,598,368	7.8
Water surfaces	1,714,896	8.4
Other	774,622	3.8
Total	20,524,874	100

Source: MKGP [Ministry for Agriculture, Forestry and Food], 2017.

Agriculture is mainly geared towards dairy farming. Small holdings dominate the sector, while a limited number of highly mechanised farms account for the bulk of production. At ground level, agriculture is the economic sector in the district that has the greatest impact on the lake as well as the population. Arable land makes up a small proportion of the district, although is generally found closest to the lake (Table 2 and Figure 4). Pastures and orchards are generally fertilised with compost, which overload the water with nutrients. Some individuals who fertilise do not even leave a five-metre protective zone along waterways and lakes. Farmers use pesticides on maize crops, the main feed source for cattle.

4.2 Water temperature and oxygen content

Pure water reaches a maximum density of 4 °C, equal to 1 kg/dm^3 under normal conditions. By lowering or raising the temperature its density drops, e.g. at 0 °C it is 0.9998 kg/dm^3, while at 25 °C it is about 0.9970 kg/dm^3 (Boehrer, Schultze, 2008). Due to anomalous density of water, lakes in temperate geographical latitudes see their water stratify in summer and winter. During summer stratification (in cases where a lake is deep enough), the temperature of the lower layer is 4 °C, and increases moving towards the surface. During winter stratification, the temperature at the surface is 0 °C, and at the bottom is 4 °C. In summer warmer water "floats" on colder water, while in winter it is the

Figure 4: Actual land use in the catchment of Lake Velenje in 2017.

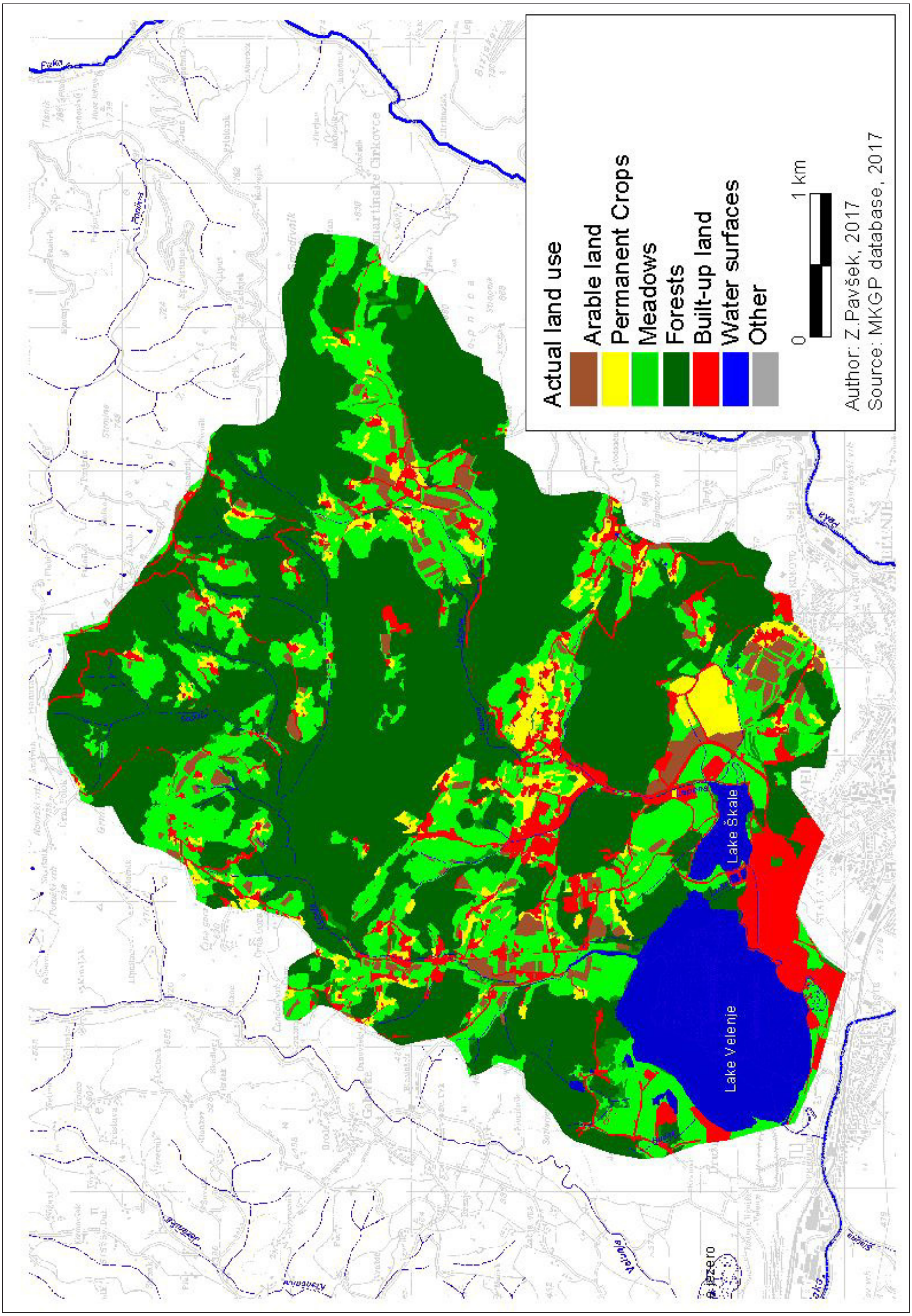
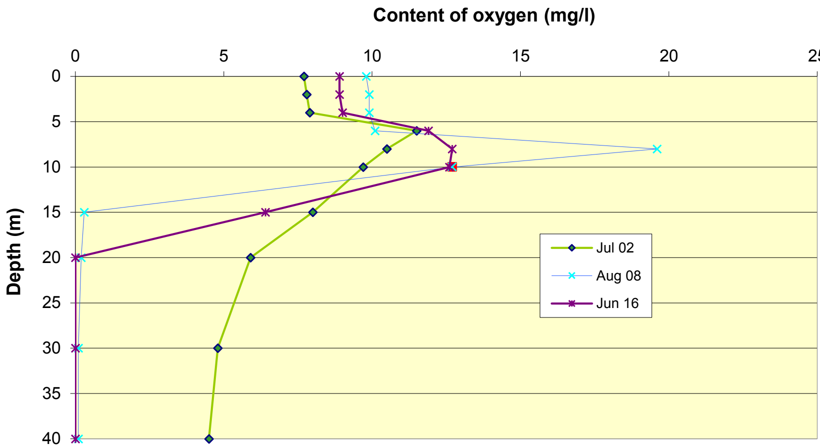
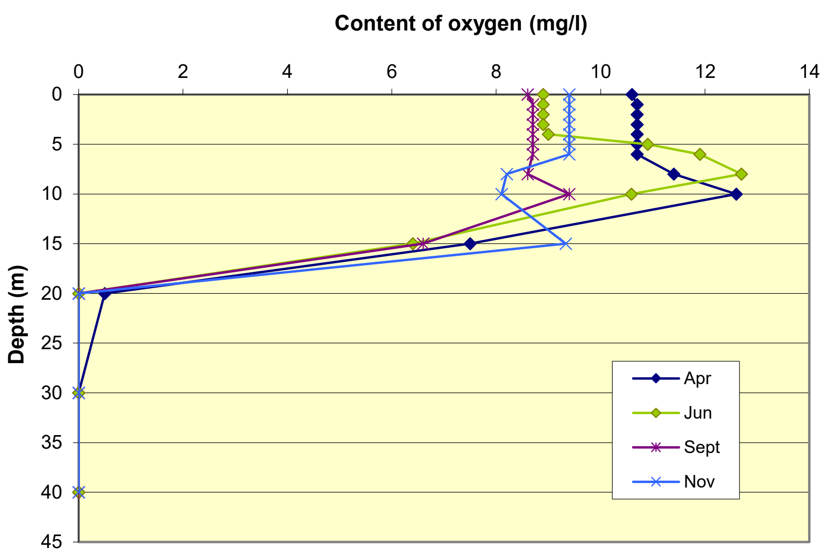


Figure 5: The content of oxygen in Lake Velenje in the summer of 2002, 2008 and 2016.



Source: ERICo, 2017.

Figure 6: The content of oxygen in Lake Velenje in April, June, September and November 2016.



Source: ERICo, 2017.

other way round. During periods of stratification water circulation is restricted to the upper layer. In spring and autumn, during periods of homeothermy, a lake mixes completely. At that time, the hypolimnion is enriched with oxygen, the levels of which decline during periods of stratification.

Immediately after rehabilitation efforts at Lake Velenje began (1997), the water mixed twice a year, and then its circulation began to deteriorate, as can be seen from the comparison of oxygen content in individual lake layers for different years (Figure 5). Oxygen content decreased in the hypolimnion. This pointed towards eutrophication, but the actual cause was the increase in salinity with depth. From the data it is clear that during the spring homeothermy in 2002 the lake was still mixing, while in 2008 no mixing occurred. It was a similar situation in 2016: Figure 6 shows the lake was meromictic, since throughout the year it did not completely turnover. It mixed to a depth of between 15 and 20 m, indeed at depths below 20 m there was practically no dissolved oxygen.

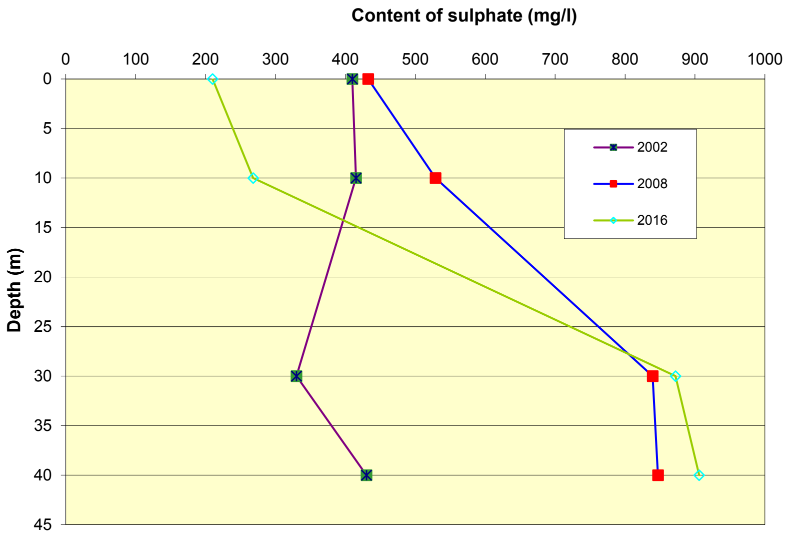
4.3 Chemical status and contamination (sulphate, molybdenum)

Based on chemical parameters, Lake Velenje is classed as having good chemical status - especially on the surface and in the entire epilimnion. The temperature conditions are normal for a lake in this climatic zone, only the temperature of the hypolimnion stands out (it should be about 4 °C) during the wintertime given the increased water density. The lake is also sufficiently transparent (between 5.5 and 10 m). However, in the hypolimnion, or else in the layer without dissolved oxygen, there is an elevated concentration of ammonium (Ramšak, 2017). The State of the Environment Report for the Republic of Slovenia 2017 (Poročilo o okolju v Republiki Sloveniji 2017, p. 82) notes that in 2013 the phosphorus content was 60 µg /l, which was more than the five-year average (2007–2012). The emergence of phytoplankton is disrupted by pollutants, especially sulphate. The main reason that Lake Velenje is not assessed as having good ecological status is the excessive level of sulphate and molybdenum. Sulphate affects not only water quality, but also how it mixes.

Larger quantities of sulphate are found in the lake due to the impact of ash transport water. Concentration of sulphate increases with depth. On the surface there is about 250 mg/l, while in the lower layer of the lake it approaches 1,000 mg/l. According to the Decree on the state of surface water (Uredba o stanju površinskih voda, 2009, 2010, 2013, 2016) the maximum permitted sulphate content for good ecological status of a natural body of water is 150 mg/l, which is also the criteria for being assessed as a bathing area. In recent years sulphate concentration at the surface has varied between 200 and 300 mg/l. Slovenian legislation permits a concentration of 250 mg/l in drinking water. Thus, the water in the Lake Velenje is not suitable for bathing, but at the same time it is considered potable. For example, Donat, one of the more well-known mineral waters in Slovenia, contains more than 2,000 mg/l of sulphate.

Concentrations of sulphate increase with depth, which has resulted in Lake Velenje becoming meromictic. The temperature of the entire water column stabilises in spring and autumn (homeothermy), but the water does not turnover. Due to its higher density, hypolimnetic water remains at the bottom. During homeothermy the temperature of the

Figure 7: Concentration of sulphate by depth in Lake Velenje in 2002, 2008 and 2016.



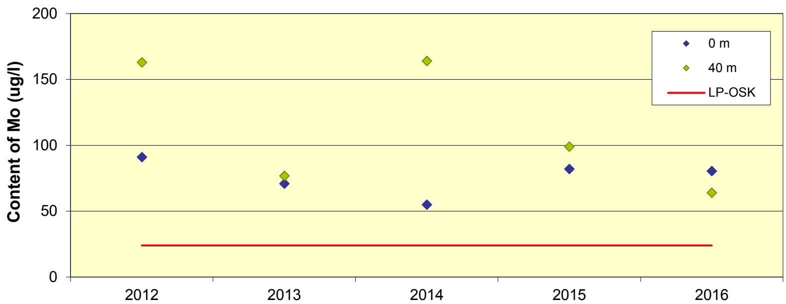
Source: ERICo, 2017.

entire lake is about 8 °C. In the summer epilimnetic water warms up - consequently its density is further reduced. The epilimnion extends to its deepest level, to 11 m, in summer. The water temperature at the surface occasionally exceeds 25 °C. During the winter stratification period, the temperature of the hypolimnion should be 4 °C, but in fact is around 8 °C. Figure 7 shows that the concentration of sulphate in 2002 was fairly uniform across the entire depth of the lake, while in 2008 and 2016 its concentration significantly increased at the bottom.

In the literature we have found limited similar cases and these are caused by different factors. Boehrer lists different types of lakes where water circulation is more or less restricted because of dissolved substances of natural or artificial origin, depth, water inflow, or type of climate, resulting in lake water stratification to a greater or lesser extent, while it is sometimes even a permanent condition. He suggests an important cause of this is the dissolution of various substances: for example, salt from roads or materials in lakes formed by open pit mining (Boehrer, Schultze, 2008). At Tanners Lake and Parkers Lake (Minnesota, USA) in 2016, excessive use of salt for road-sanding and subsequent runoff into the lakes resulted in such a strong chemical stratification that springtime water circulation in the lake was prevented, which is similar to the phenomena in Lake Velenje. The authors found that the concentration of salt in the lakes increased proportionally to the amount of salt used for road-sanding (Novotny et al., 2008). In doing so the authors also demonstrated that in order to improve conditions, it is necessary to restore water circulation and desalinate hypolimnetic water.

Molybdenum is an essential element. The criteria for good ecological status of a water body under the Decree concerning the management of bathing water quality (Uredba o stanju površinskih voda, 2009, 2010, 2013, 2016) specifies an average annual concentration of molybdenum below 24 µg/l, while individual measurements cannot exceed 200 µg/l.

Figure 8: Molybdenum in Lake Velenje on the surface and at a depth of 40 m from 2012 until 2016.



Note: LP-OSK (Environmental Quality Standard: expressed as annually average value of the parameter of a chemical state).
Source: ERICo, 2017.

On the surface of Lake Velenje, a value of 200 µg/l has never been reached, while the permitted average is exceeded: indeed, the values are fairly constant. The concentration of molybdenum on the surface during the bathing season has been intermittently measured. It measured 74 µg/l in 2013, 65 µg/l in 2014, 82 µg/l in 2015 and 80.5 µg/l in 2016 (Figure 8). The concentration of molybdenum at a depth of 40 m is not important for the assessment of bathing water.

According to the World Health Organization's guidelines, a molybdenum concentration of 70 µg/l in drinking-water has no adverse health effects; indeed, the same guidelines list a daily requirement for this element of between 100 and 300 µg (Guidelines for ... 2011, p. 394). Likewise, in Slovenia 70 µg/l was allowed under the rules on drinking water quality, which were in effect until 2004. Current regulations, Rules on natural mineral water, spring water and table water (Pravilnik o naravni mineralni vodi, izvirski vodi in namizni vodi, 2005), state that molybdenum is an essential element and do not set a limit value for it.

4.4 Suitability of water for bathing

Due to the elevated levels of sulphate and molybdenum, the lake is classed as having moderate ecological status (Rekar, 2015). In terms of other parameters, it is judged to have good ecological status. Given that it is an artificial formation, it cannot be equated to a natural lake and we refer to it in terms of its ecological potential rather than its ecological state. Since 2012 the Municipality of Velenje has been monitoring the water quality of

Table 3: Results of water analysis at Velenje Beach in 2016.

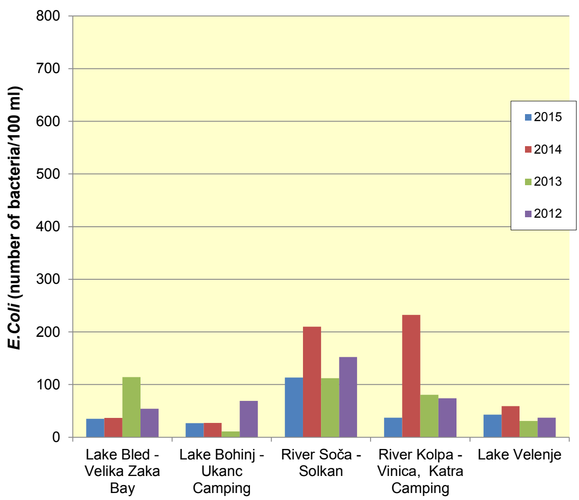
Parameters	Assessment of bathing water quality			Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling	Date of sampling
Microbiological analysis[1]	**Excellent**	**Good**	**Sufficient**	**03.05. 2016**	**06.06. 2016**	**27.06. 2016**	**04.07. 2016**	**11.07. 2016**	**18.07. 2016**	**25.07. 2016**	**01.08. 2016**	**08.08. 2016**	**16.08. 2016**	**22.08. 2016**	**29.08. 2016**
Coliform faecal bacteria (E. Coli), no./100ml	500*	1000*	900**	Not detected	6	10	1	3	36	11	70	4	20	4	1
Faecal streptococci (intestinal enterococci), no./100ml	200*	400*	330**	Not detected	2	17	Not detected	<4	8	<4	20	4	33	<4	Not detected
Physicochemical parameters[2]	**Guide value**	**Binding value**													
Temperature (°C)	-	-		13.3	21.0	22.6	23.8	25.6	22.6	25.3	25.3	24.1	24.0	23.3	23.5
pH	6–9	-		8.3	8.5	8.4	8.4	8.4	8.5	8.4	8.3	8.5	8.4	8.3	8.3
Transparency level	2m	-		>2m	<2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m
Dissolved oxygen (mg/l)	7–12	-		9.7	9.3	9.4	9.5	8.5	9.3	8.2	8.6	9.3	9.3	8.7	8.3
Oxygen saturation (%)	80–120	-		97	107	98	103	105	102	106	104	108	107	104	101
Visible impurities	none	-		none	none	none	none	none	none	none	none	none	none	none	none
Mineral oils (mg/l)	<0.3	no characteristic odour and no visible layer on the surface of the water		0.14	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	-	0.06	-
Ammonium (mg/l)	-	-		<0.3	0.02	<1.3	-	<1.3	-	<1.3	-	<1.3	-	<1.3	-
Nitrates (mg/l)	-	-		2.26	2.18	2.14	-	0.44	-	2.04	-	1.82	-	1.74	-
Phenols (Phenol index) (mg/l)	<0.005	no characteristic odour <0.05		<0.05	<0.05	<0.05	-	<0.05	-	<0.05	-	<0.05	-	<0.05	-
Suitability of water for bathing				**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**

[1] Microbiological analyses are assessed on the basis of the Decree concerning the management of bathing water quality (Official Gazette of the Republic of Slovenia, no. 25/08):
** ... based on valuation of the 95th percentile in accordance with the Decree concerning the management of bathing water quality;*
*** ... based on the valuation of the 90th percentile in accordance with the Decree concerning the management of bathing water quality.*
[2] Approximate values are given in the assessment.
Source: Ramšak, 2016.

Lake Velenje in accordance with the Decree concerning the management of bathing water quality (Uredba o upravljanju kakovosti kopalnih voda, 2008): each year water-quality of the lake has been assessed as being suitable for bathing (Ramšak, 2016). Throughout the entire period of monitoring the quality of bathing water, all analysed results have been within prescribed limits – that is, at all times the water has been bacteriologically suitable for bathing. In terms of the presence of coliform bacteria, the vast majority of samples received the best ranking (excellent), while just three were ranked good. While in terms of the presence of streptococci of faecal origin, all samples taken were classified in the highest grade (excellent). Table 3 provides a summary of the results of water-quality based on bathing water measurements for 2016 (Ramšak, 2016).

We compared the bacteriological condition of Lake Velenje's bathing water to that of other bathing areas in Slovenia, and found that it ranked among the better areas. We used the natural alpine lakes of Bohinj and Bled, along with bathing areas on the Soča River at Solkan and on the Kolpa River at Vinica. *E. coli* bacteria content and quality of water at Velenje Beach is comparable with the water in Lake Bled. Lake Bohinj is a fraction better than Lake Velenje, while the quality of water in the Soča and Kolpa rivers is slightly worse (Figure 9). All values measured at these bathing sites in the period 2012 to 2015 were within the limits defined for bathing areas with excellent microbiological status.

Figure 9: Average number of E. coli bacteria (number of bacteria/100 ml) in Lake Velenje (Velenjsko jezero) and in certain Slovenian natural bathing areas in the period 2012 to 2015.*



** NB: The upper limit for excellent microbiological status is 500 bacteria in 100 ml of water.*
Source: ARSO, 2012–2015. ERICo,2017.

5 TRANSFORMATION OF LAKE VELENJE AND ITS BANKS INTO A RECREATIONAL AREA

5.1 An overview of recreational and tourism activities at Lake Velenje

A recreational area was developed on the shoreline of Lake Škale as early as the 1950s and quickly became a more widely renowned tourist destination. Velenje residents built a swimming pool, restaurant, football-athletic stadium, mini-golf course and an outdoor cinema, while holiday cabins were also erected. The new infrastructure was not only used by locals, with events being hosted there being well-attended. This form of revitalisation of a subsidence area was shown off to both Yugoslav guests and foreigners, indeed in the eyes of local and republican politicians Velenje was a "socialist miracle" (Mali Bled ..., 2017). In the 1970s, a few storeys were excavated in the coal mine under this area and most of the sports and visitor amenities were shifted to the shore of Lake Velenje. On the southern shores, in 1981, they proceeded to build a new restaurant, along with a sports ground. The development was completed in the early nineties, with the construction of the Bela dvorana tennis stadium.

Despite the pollution, even in the 1980s Lake Velenje was popular among local wind-surfers. Up until 1995 there was really no use of the lake for bathing. After the construction of Restavracija Jezero (i.e. The Lake Restaurant), very close-by a small swimming hole was formed; the new bathing area attracted recreational visitors, though was not a mass tourism destination (Pavšek, 2003). Significant development from a tourism perspective only came about later with the opening of the Velenje Beach in 2013 and following water testing that took place a year later and found the lake to be suitable for bathing. In the following years the number of bathers increased significantly. Indeed, on weekends during the summer months of 2016 we estimated that more than 3,000 people visited its shores daily – most visitors were Šalek Valley residents. In 2017 the number of bathers was even higher (Figure 10). During the bathing season, the Municipality of Velenje organised lifeguards for the lake and provided a wider range of sports facilities and play equipment.

Because of its anthropogenic origins it is difficult to classify Lake Velenje as a natural bathing area. Based on the results of bathing water quality testing, and with reference to the Slovenian Decree concerning the management of bathing water quality (Uredba o upravljanju kakovosti kopalnih voda, 2008) and the EU Directive 2006/7/EC (Directive…, 2006), there is no doubt that the water is suitable for bathing. However, due to the strict requirements of Slovenia's Rules on detailed criteria for identification of bathing water (Pravilnik o podrobnejših kriterijih za ugotavljanje kopalnih voda, 2008) the area (so far) has not been classified as a bathing area.

Given that the lake is becoming an increasingly popular destination for swimmers, there is a clear need to clarify this ambiguity. Directive 2006/7/EC states in Article 5 that: *"If a bathing water is classified as 'poor' for five consecutive years, a permanent bathing prohibition or permanent advice against bathing shall be introduced. However, a Member State may introduce a permanent bathing prohibition or permanent advice*

Figure 10: More people visit Velenje Beach every year; on weekends in 2017 there were even up to a thousand cars parked at the lake (photo: EXTREM d.o.o., 2017).

against bathing before the end of the five-year period if it considers that the achievement of 'sufficient' quality would be infeasible or disproportionately expensive." In 2012, representatives of the Municipality of Velenje filed an initiative to have it declared a bathing area. In order for part of Lake Velenje's shore to be declared a bathing area, Lake Velenje would need to have a good ecological status, while the presence of specific pollutants means this is impossible. The Institute of Public Health gave advice that from the point of view of bathers' health, neither the elevated sulphate content, nor molybdenum pose any dangers (Gale, Petrovič, 2013).

Water at the beach of Lake Velenje cannot, by any criteria, be labelled as poor. Furthermore, it should be noted that the lake is an artificial body of water. In any case it is necessary to declare the beach as a bathing area – or alternatively prohibit swimming there. Based on the criteria for ecological quality, in 2014 Lake Velenje was assessed the same as Lake Bled, as having moderate status (Rekar, 2015).

5.2 Development guidelines taking in consideration environmental limitations

Lake Velenje and its bank are already used for recreational and tourism purposes, although certain activities that take place on its banks are not sufficiently coordinated. Namely, environmental limitations have not been thoroughly enough defined. The Strategy for tourism development and marketing in the Municipality of Velenje (Strategija razvoja in trženja…, 2016) sets out that development of tourism supplementary to the lake should be a goal, it also states that the lakes remain a central element and starting point for all active programmes in the region of the Municipality of Velenje (Strategija razvoja in trženja…, 2016, p. 70). To these ends it is essential that a strategic development plan for sustainable development of tourism alongside the lakes be put together and implemented; this will also serve as basis for attracting potential investors. A start has been made in the form of the report: Development of Velenje Lakes as a tourist destination (Žerdin, Šeliga, 2015). The basic guidelines are a continuation of previous activities, drawing on global trends and with reference to the overarching guidelines of Slovenian tourism. It is necessary to coordinate between different water sports, since lake surfaces and shores are limited. In 2016, the Šalek Valley Tourism Office was established and it will gradually take on the responsibility for managing this tourist destination. Thus, the office will be more active in public relations as well as promoting the area, while directing and overseeing further activities, including: implementing the development strategy; increasing the effectiveness of marketing, identifying further tourism products; and, encouraging private investments. Of course, as recreation and sports activities intensify it is essential that the quality of the lake is regularly tested – particularly, during the bathing season, navigation and swimming regimes be put in place, and also that avenues for collaboration among operators, planners and all other stakeholders who use the lakes and the surrounding areas are established, while the roll out of new activities should occur with careful consideration to possible negative impacts and mitigation measures should be outlined.

Even the degree of human activity in the area to date has led to adverse effects, both because of overburdening the environment in the past as well as because of activities that are still taking place. In order to be used for tourism purposes, a lake must be in good condition. Protection and mitigation initiatives are defined and catalogued in several groupings (Šaleška jezera – vodni vir..., 2011).

In the field of municipal wastewater disposal, with the exception of the construction of containment reservoirs to handle high water, there is no room for improvement, given that a circular sewage system has been built. In the field of agriculture, nutrient runoff into waterways can be reduced through preventive measures, such as: strictly applying five-metre protection zones; installing hedges between cultivated areas and water bodies; implementing eco-remediation initiatives on inlets to the lake; enacting eco-remediation and management of lake banks; pumping fresh water to the bottom of Lake Velenje; and sustainably managing of the fish population.

Measures to reduce the intensity of eutrophication focus on reducing the amount of nutrients in Lake Velenje by incorporating them into plant biomass (removing or harvesting larger aquatic plants at the end of the vegetation period; installing floating cleaning islands, particularly where tributaries enter the lakes; prohibiting fishers feeding fish in all lakes; moving aquaculture pools to areas beneath Lake Velenje; and, transforming existing ones at Lake Škale into a plant water treatment facility). The next group of measures is aimed at ensuring there is technological water for electricity, hydro-electric use and to dampen flood waves in watercourses; features a programme for containing high waters in the Šalek Lakes and reducing the flow of the Paka River below the lakes, as well as exploration of the possible use of Velenje and Družmirje lakes for electricity production.

5.3 Possibilities for intensifying water transfer, improving flood protection and energy production

Lepena and Sopota, tributaries of Lake Velenje, along with the direct drainage from the narrow lakeshore and precipitation that falls on the lake, annually contribute an estimated 11 million m^3 of water to the lake. Theoretically the time it takes for water turnover in Lake Velenje exceeds three years. In the last decade, eutrophication has increased despite the accelerated construction of the sewage system. Accumulation of nutrients in the lakes causes the growth of bacteria, phyto- and zoo- plankton. When the plankton dies, organic substances are deposited at the bottom and oxygen is consumed during decomposition.

If more water discharged into the lake from the Paka River, turnover in the lake would accelerate. By analysing nutrient content and individual substances, together with bacteriological analyses, we found that this would be beneficial for the lake only during periods when the Paka River is experiencing low flows, when it transports less dissolved and suspended substances. Monthly midstream flow of the Paka River at Pesje ranges from 1.1 to 1.8 m^3/s (interpolated values based on the water meter in Velenje). On this basis, we estimate that in Pesje 43.8 million m^3 of water are available per year. If all this water was released into the lake, the water in it would theoretically turnover in less than a year. Maintaining ecologically acceptable flow of the Paka River in Šoštanj (400 l/s), 31.7 million m^3 of water would be available annually, such that, theoretically, lake water would turnover in a little over a year. We analysed the Paka River at various water levels in 2010. The measurements of high water enabled us to determine that the Paka carries significantly more material compared to average small watercourses, during times when we monitored its quality, in accordance with legislated monitoring (Šaleška jezera – vodni vir ..., 2011).

During increased flow on 17 September 2010 (6.3 m^3/s) we calculated that the Paka River would transport on a daily basis more than 2 t of total nitrogen and 885 kg of total phosphorus into the lake. From the point of view of water quantities, diverting the Paka River into the lake is a positive thing, however it is not when considering the introduction of substances, especially when water levels are high (Šaleška jezera – vodni vir ..., 2011). Considering the health of the lake, the release of high waters into the lake is not appropriate, since substantially more nutrients than ever before would flow into it. It would be most appropriate to release water from the Paka River into the lake at times when the river carries the least substance into it. A dam would need to be built, and ideally the water would be additionally treated before being released into the lake. Diversion of the Paka River was shown to be even less suitable from the point of view of bacteriological loads. In the river at Pesje there were a number of coliform bacteria and coliform bacteria of faecal origin 2419.6 MPN/100ml (measurements from 4 May 2011). Compared to the Lepena and Sopota tributaries, there were significantly more bacteria in the Paka River, which points to it being overburdened with organic material, including of faecal origin. Following these measurements, bacteriological conditions were no longer monitored, although such testing should take place. Between 2012 and 2015 missing parts of the sewerage system in the Paka catchment were upgraded in Velenje, Podkraj and Pesje, thus improvement in the condition of the Paka River is expected.

Lake Velenje can accommodate a surface level fluctuation of 0.6 m and thus has the potential to (partially) contain a flood wave. The difference between the upper and lower points represent one million m^3 and the accumulation of water in it could dampen or even prevent floods in lower-lying areas of the Paka catchment. In this regard, the Paka River may not necessarily need to be diverted into the lake, even if the waters of Lepena and Sopot were retained for just a few hours, the flow of Paka would be reduced accordingly.

There is a 7 m height difference between the surfaces of the Velenje and Družmirje lakes. If a power plant were built between them, water from Lake Družmirje could be pumped overnight into Lake Velenje, then in the morning could be released back, powering a generator (Vodušek, 2012). In this regard, there are many outstanding questions concerning the stability of the barrier and differences in water quality of both lakes. These issues would need to be further examined and resolved before such a development could occur.

6 CONCLUSION

Lake Velenje is one of the largest lakes in Slovenia, while the immediate and broader surroundings of the lake are becoming more and more recognised as a recreational and tourism area. In terms of water quality, the lake is suitable for bathing; indeed, its bacteriological status ranks it among the better bathing areas in Slovenia. As such, a beach was constructed on the lakeshore in Velenje, which is used by thousands of swimmers and in summer becomes a focal point for activities. The municipality has organised monitoring of water quality and lifeguards, while also taking care of additional infrastructure. They plan to use the lake even more intensively for recreational purposes but, due to its sensitivity, decisions to put in place additional infrastructure need to be carefully balanced against possible consequences.

Due to the presence of specific non-hazardous pollutants, the lake does not reach a good ecological status (Lake Velenje has moderate ecological status), which is a condition for declaring it a bathing area. Deposition of ash into the lake and on its banks increased the content of sulphate and molybdenum. Concentrations of these substances are low enough that the water is considered drinkable, although the rules for (natural) water bodies stipulate lower concentrations. These substances do not have a negative impact on human health and bathing is safe, which is backed up by the advice of the Institute of Public Health of the Republic of Slovenia. The increased concentration of sulphate in the lower layer hinders the natural circulation of lake water: we are looking for solutions to solve this issue. A circular sewage system has been constructed to intercept municipal wastewater, while eco-remediation measures are planned to reduce agricultural impacts. Moving forward, a wide range of options are on the table from pumping fresh water to the bottom of the lake to releasing water from the Paka River into it. Each of these options is purely theoretical and should be carefully examined before a decision is made as to which way to go. An ill-considered decision could cause irreparable damage. Lake Velenje is so specific that in reviewing the literature we came across only a limited number of similar cases for which there was high-quality research. Nor were we able to satisfy our search for suitable solutions.

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