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

I 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 become 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 became 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 conducive 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 m³, and the three lakes cover a surface area of more than 7 km², accounting for approximately a third of the volume (almost 58 million m³) and also a third of the surface of the subsidence area (2.5 km²).

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 m³ 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 become more visible. Its catchment area covers 20.54 km², 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/km², 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 m² 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/dm³ under normal conditions. By lowering or raising the temperature its density drops, e.g. at 0 °C it is 0.9998 kg/dm³, while at 25 °C it is about 0.9970 kg/dm³ (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	Date of sampling	Date of sampling	Date of sampling
	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			
Microbiological analysis¹																		
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 parameters²																		
Temperature (°C)	-		Binding value															
pH	6–9	-	-	13.3	21.0	22.6	23.8	25.6	22.6	25.3	25.3	24.1	24.0	23.3	23.5			
Transparency level	2m	-	-	8.3	8.5	8.4	8.4	8.4	8.5	8.4	8.3	8.5	8.4	8.3	8.3			
Dissolved oxygen (mg/l)	7–12	-	-	>2m	<2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m	>2m			
Oxygen saturation (%)	80–120	-	-	9.7	9.3	9.4	9.5	8.5	9.3	8.2	8.6	9.3	9.3	8.7	8.3			
Visible impurities	none	-	-	97	107	98	103	105	102	106	104	108	107	104	101			
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	-			
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 Sopot, 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 m³ 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 m³/s (interpolated values based on the water meter in Velenje). On this basis, we estimate that in Pesje 43.8 million m³ 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 m³ 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 m³/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 m³ 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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