Investing in your future
Operation part financed by the European Union
Instrument for Pre-Accession Assistance

REPUBLIC OF SLOVENIA
GOVERNMENT OFFICE FOR LOCAL SELF-GOVERNMENT AND REGIONAL POLICY

ZNANSTVENORAZISKOVALNI CENTER

Pressures and Protection of the Underground Karst – Cases from Slovenia and Croatia

SI HR
INSTRUMENT FOR PRE-ACCESSION ASSISTANCE

Pressures and Protection of the Underground Karst

Cases from Slovenia and Croatia

ZNANSTVENORAZISKOVALNI CENTER

PRESSURES AND PROTECTION OF THE UNDERGORUND KARST – CASES FROM SLOVENIA AND CROATIA

PRITISKI IN VAROVANJE PODZEMNEGA KRASA – PRIMERI IZ SLOVENIJE IN HRVAŠKE

PRITISCI I ZAŠTITA PODZEMNOG KRŠA – PRIMJERI IZ SLOVENIJE I HRVATSKE

Editors / Urednika: Mitja Prelovšek, Nadja Zupan Hajna

Language review / Jezikovni pregled: Hugh Brown (Amidas d.o.o.), Wayne Tuttle and David C. Culver

Graphic design and page layout / Oblikovanje in postavitev strani: Mitja Prelovšek

Published by / Izdal in založil: Inštitut za raziskovanje krasa ZRC SAZU, Postojna / Karst Research Institute ZRC SAZU, Postojna

Represented by / Zanj: Tadej Slabe

Printed by / Tisk: Collegium Graphicum d.o.o., Ljubljana

Printrun / Naklada: 300 copies / izvodov

Postojna, junij 2011

The publication was published within the Karst Underground Protection project which is financially supported by the Slovenia-Croatia Operational Programme 2007-2013.

Knjiga je bila izdana v okviru projekta Karst Undergorund Protection financiranega iz Operativnega programa IPA Slovenija-Hrvaška 2007-2013.

CIP - Kataložni zapis o publikaciji
Narodna in univerzitetna knjižnica, Ljubljana

551.44(082)
551.44(497.4/.5)(082)

PRESSURES and protection of the underground karst : cases from Slovenia and Croatia = Pritiski in varovanje podzemnega krasa : primeri iz Slovenije in Hrvaške = Pritisci i zaštita podzemnog krša : primjeri iz Slovenije i Hrvatske / [editors, urednika Mitja Prelovšek, Nadja Zupan Hajna]. - Postojna : Inštitut za raziskovanje krasa ZRC SAZU = Karst Research Institute ZRC SAZU, 2011

ISBN 978-961-254-285-6
1. Vzp. stv. nasl. 2. Prelovšek, Mitja, 1980-

256340480

Pressures and Protection of the Underground Karst –
Cases from Slovenia and Croatia

Pritiski in varovanje podzemnega krasa –
Primeri iz Slovenije in Hrvaške

Pritisci i zaštita podzemnog krša –
Primjeri iz Slovenije i Hrvatske

Postojna, junij 2011

Contents

Foreword

In this publication we have attempted to collect together part of the work carried out over the last few decades by Slovene and Croatian researchers in the field of karst underground protection. The range of topics is by no means all-encompassing, but it does represent a varied selection of subjects from the field of karst underground protection in Slovenia and Croatia. Our aim has been to bring together a representative selection of existing knowledge, to evaluate it and compare it with the findings of other research, and to present the contents in an accessible manner to the broad circle of people who are indirectly involved in karst underground protection. By combing findings from the fields of speleology, hydrology and biospeleology in a single publication, we have endeavoured to go beyond the increasingly rigid division into individual fields of expertise and present the different aspects using a common denominator – that of karst underground protection. The karst underground is both the habitat of animals that live underground and an important source of drinking water. Caves contain important information on the palaeogeographic development of the underground and the surface, and also on climate change, and are an important economic category in the sense that some are used as show caves. At the same time they are usually extremely vulnerable, which greatly increases the need for strict protection, something that is frequently a secondary or even principal objective of the researchers who are directly involved with caves.

This publication is also the result of work on a cross-border project involving Slovenia and Croatia entitled Karst Underground Protection. Within the scope of this project, researchers from the Karst Research Institute at the Scientific Research Centre of the Slovenian Academy of Sciences and Arts, in conjunction with our Croatian partners (the Istrian Region and Natura Histrica), have combined educational activity (the “Classical Karst” International Karstological School in 2010 and 2011) and research (cross-border speleobiological research in Istria), upgraded and computerised the register of caves in the Istrian Region of Croatia, published our findings in local media and specialist circles, and planned the establishment of a network of institutions involved in karst protection in the project area. One direct result of the project in the karst underground has been the cleanup of 12 caves in Croatia and Slovenia by Slovene and Croatian cavers and refurbishment of once elementary school Lanišće (Municipality of Lanišće, Croatia) into “Speleo center”. A significant part of the funding has been provided by the IPA Operational Programme Slovenia-Croatia 2007–2013 and a contribution has also been made by the Republic of Slovenia and the Scientific Research Centre of the Slovenian Academy of Sciences and Arts.

We hope that the more general, introductory chapters in the first part of the publication will encourage you to go on to read the individual, in-depth case studies in the second part.

KUP project collaborators from the Istrian Region, the Karst Research Institute ZRC SAZU and Natura Histrica

Predgovor

V pričujoči publikaciji smo poskušali v grobem zbrati del več desetletnega dela slovenskih in hrvaških raziskovalcev na področju varovanja podzemnega krasa. Nabor tematik nikakor ni vseobsegajoč, vsekakor pa predstavlja pester nabor tematik s področja varovanja podzemnega krasa v Sloveniji in na Hrvaškem. Z izdajo smo želeli zbrati dosedanje znanje, ga ovrednotiti, primerjati z izsledki drugih raziskav ter vsebino na poljudno-znanstven način ponuditi v branje širšemu krogu ljudi, ki se z varovanjem podzemnega krasa ukvarjajo posredno. Z mešano izdajo speleoloških, hidroloških in biospeleoloških spoznanj smo hoteli presekati vse bolj uveljavljeno delitev na posamezna strokovna področja ter različne vidike postaviti na skupen imenovalec – varovanje podzemnega krasa. Le-ta je namreč tako življenjski prostor podzemnemu živalstvu, kakor tudi pomemben vir pitne vode. Jame nosijo pomembne informacije o paleogeografskem razvoju podzemlja in površja, spremembah podnebja ter so pomembna ekonomska kategorija v smislu turistične izrabe jam. Hkrati so praviloma izjemno ranljive, s čemer se močno poveča potreba po njihovem strogem varovanju, le-to pa je pogosto stranski ali pa poglavitni cilj raziskovalcem, ki se z jamami neposredno ukvarjajo.

Publikacija je tudi rezultat dela na čezmejnem projektu med Slovenija in Hrvaško z naslovom Karst Underground Protection. V sklopu projekta smo sodelavci Inštituta za raziskovanje krasa ZRC SAZU s hrvaškimi partnerji (Istrska županija ter Natura Histrica) povezali izobraževalno dejavnost (Mednarodni krasoslovni šoli »Klasični kras« 2010 in 2011), raziskovalno dejavnost (čezmejne speleobiološke raziskave Istre), nadgradili in informatizirali kataster jam v Istrski županiji, objavljali izsledke spoznanj v lokalnih medijih in strokovnih krogih, v planu pa imamo tudi vzpostavitev mreže institucij, ki se ukvarjajo z varovanjem krasa na projektnem območju. Neposreden rezultat projekta v podzemnem krasu je tudi 12 očiščenih jam na Hrvaškem in v Sloveniji, ki so jih očistili slovenski in hrvaški jamarji, ter vzpostavitev »speleo centra« v stari obnovljeni šoli v Vodicah (občina Lanišće, Hrvaška). Znatni del finančnih sredstev je prišel iz Operativnega programa IPA Slovenija-Hrvaška 2007-2013, del pa je prispevala tudi Republika Slovenija in Znanstvenoraziskovalni center SAZU.

Upamo, da vas bo branje uvodnih preglednih poglavij v prvem delu pritegnilo tudi k branju posameznih bolj poglobljenih primerov v drugem delu publikacije.

Sodelavci na projektu KUP iz Istrske županije, Inštituta za raziskovanje krasa ZRC SAZU in Nature Histrice

Predgovor

U ovoj smo publikaciji, pokušali u grubo sabrati rezultate desetgodišnjeg rada slovenskih i hrvatskih znanstvenika na području podzemnog krša. Raspon tema nipošto nije sveobuhvatan, ali predstavlja širok spektar tema iz područja zaštite podzemnog krša Slovenije i Hrvatske. Izdavanjem publikacije željeli smo prikupiti dosadašnja saznanja, vrednovati ih, usporediti s rezultatima drugih istraživanja, te sadržaj na popularno-znanstveni način ponuditi širem krugu ljudi, koji se neizravno bave zaštitom podzemnog krša. S izdavanjem speleoloških, hidroloških i biospeleoloških spoznaja o kršu smo željeli prekinuti sve više izraženo dijeljenje na pojedinačna stručna područja te različita viđenja svesti na zajednički nazivnik - zaštita podzemnog krša. Ovo potonje je naime životni prostor podzemnih životinja, kao i važan izvor pitke vode. Špilje nose važne informacije o paleogeografskom razvoju podzemnih, površinskih i klimatskih promjena te su značajna ekonomska kategorija u smislu turističkog iskorištavanja. Istodobno, špilje su vrlo ranjive, čime se uvelike povećava potreba za njihovom strogom zaštitom, što je često sporedni ili primarni cilj istraživača koji se njima izravno bave.

Publikacija je ujedno rezultat rada na prekograničnom projektu između Slovenije i Hrvatske, pod nazivom Karst Underground Protection. U sklopu projekta smo, suradnici Instituta za istraživanje krša ZRC SAZU i hrvatski partneri (Istarska županija i Javna ustanova Natura Histrica) povezali obrazovne aktivnosti (Internacionalna krasoslovna škola "Klasični krš" 2010 i 2011) i istraživačke aktivnosti (prekogranična biospeleološka istraživanja Istre), nadogradili i bazu speleoloških objekata u Istarskoj županiji, objavili rezultate spoznaja u lokalnim medijima i stručnim krugovima, a u planu je i uspostava mreže institucija koje se bave zaštitom krša na projektnom području. Također, izravan rezultat projekta o podzemnom kršu je 12 očišćenih špilja u Hrvatskoj i Sloveniji, koje su očišćene od strane slovenskih i hrvatskih speleologa, te uspostava "Speleo centra" u staroj renoviranoj školi u Vodicama (Općina Lanišće, Hrvatska). Značajan dio financijskih sredstava dobiven je iz operativnog programa IPA Slovenija-Hrvatska 2007-2013, a dio je osiguran od strane Republike Slovenije, Znanstveno razvojnog centra SAZU i Istarske županije.

Nadamo se da će vas čitanje uvodnih poglavlja prvoga dijela publikacije privući da pročitate i detaljnije pojedinačne slučajeve koji se opisuju u drugom dijelu publikacije.

Partneri na projektu KUP - Istarska županija, Institut za istraživanje krša ZRC SAZU i Javna ustanova Natura Histrica.

PROTECTION OF THE UNDERGROUND KARST FROM THE VIEWPOINT OF SPELEOLOGY, HYDROGEOLOGY AND BIOSPELEOLOGY

VULNERABILITY, PRESSURES AND PROTECTION OF KARST CAVES

Mitja Prelovšek [1]

Karst caves are, along with karst hydrology and surface morphology, the most recognisable element of karst as a natural phenomenon. Although the highly perforated karst underground is formed by fissures as well as by caves, it is caves – because of their size (in our anthropocentric way we tend to define them on the basis of their accessibility to human beings) – that give us a visual insight into the structure and characteristics of the karst underground and, consequently, provide us with knowledge about it.

Human attitudes towards karst caves have changed frequently over the course of history (Prelovšek 2011 – see page 101). In recent decades the emphasis has been on their functions in the fields of tourism, leisure and scientific research. Because human interventions in the karst underground are increasingly frequent and are more intensive – and frequently undesirable because of the vulnerability of the underground – the question of the protection of caves has begun to be raised. Although the protection of caves also represents a cost, we are committed to it because of our awareness of the long-term impact of anthropogenic changes in caves and our awareness of the importance of protecting them. We recognise the intrinsic value of karst caves, respect them because of their age, regard them as database of the changing palaeogeographic environments of the past, use them for tourism, recreation and scientific research, and understand them as an important part of our own survival because of the reserves of drinking water they contain. This is the origin of the need to protect karst caves: both for the purpose of conservation and to eliminate negative conditions that are a legacy of the past.

The vulnerability of caves

The vulnerability of caves is the logical consequence of the highly stable and slowly changing cave environment. Fluctuations of temperature and humidity are usually very low in caves. As a result, weathering processes are slow and the cave environment is remarkably stable. In principle, then, the cave environment changes extremely slowly, which means that any kind of major morphological alteration has long-term consequences which will only be remedied slowly by natural means – if at all. Analysis of caves sediments (Zupan Hajna et al. 2008) has established that approximately 63 % of analysed sediments in the larger horizontal caves in Slovenia are over 780,000 years old. Since cave sediments are merely the “filler” of caves, the caves themselves may be considerably older still. Damage to relict cave walls, in the absence of condensation corrosion, is practically permanent. Cave entrances and ponor caves, where the environment is more dynamic and natural renewal is much faster, are less vulnerable. There are also rare examples of weakly vulnerable flowstone-covered areas, where flowstone is deposited at the rate of sometimes more than 0.3 millimetres per year.

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, mitja.prelovsek@zrc-sazu.si*

The most vulnerable caves are those that no longer perform their primary function, i.e. the drainage of the waters that created the cave in the phreatic, epiphreatic or vadose zone. Since caves in the vadose zone are vertical and less visited, it is predominantly relict horizontal caves that are most endangered. These caves formed in the (epi)phreatic zone but remained in the predominantly dry vadose zone following the retreat of the water into deeper parts of the aquifer. In the vadose zone they are only transformed by mechanical processes, which are weak, and under the influence of percolation water, which has a point-source effect. These caves are the most suitable as show caves but at the same time are the most vulnerable, and therefore face the biggest threats. Vulnerability or threat can be reduced by cave infrastructure which, although it destroys part of the cave, at least in terms of the building of footpaths, nevertheless reduces impacts on those sections that tourists do not walk through. This is a good compromise between the need to use caves for tourism and their protection.

Pressures on caves

Although human beings were visiting caves even in Palaeolithic times, their impact on them was relatively small because only small adaptations were made. The first more noticeable impact appeared when livestock farming and agriculture began in the karst. The clearing of grassland resulted in unwanted rocks and stones being thrown into caves, while the remainder were used to build dry stone walls. It is believed that some caves were entirely filled up with such material, while others with smaller entrances were sealed up for safety reasons.

The first significant deliberate impact appears relatively late – in the 19th century, when caves began their transformation into show caves. It was in the 19th century that the first major infrastructure impacts appeared, for example the building of paths or cave railways (Škocjanske jame, Postojnska jama, Vilenica). Indirect impacts on caves were caused by the widening of cave entrances, which affected the natural climate in caves. The demand for souvenirs (in particular stalagmites and stalactites but also specimens of *Proteus anguinus*; Shaw 1999) resulted in some caves in the area being thoroughly plundered (Simić 2000), among them parts of Postojnska jama that at that time were not open to tourists (Mihevc 2011 – see page 34). In the late 19th century, and even more so in the 20th century, the electrification of caves led to the problem of lampenflora (Mulec 2011 – see page 64), while the increase in visitor numbers, with the building of new paths and the use of new caves for tourism, meant a further increase in the impact on existing show caves. A special form of tourism known as alternative cave tourism or cave trekking developed in the second half of the 20th century under the auspices of caving clubs. As a result of caves not being adapted to this form of "soft" tourism, considerable direct damage was caused to individual caves. Since karst caves are an extremely slowly developing environment, every period of the use of caves for tourism has brought new infrastructure, modern at the time, and the irreversible impacts that go with it, with the result that we can talk about a cumulative impact of all interventions (Mihevc 2011 – see page 64).

The widening of ponor cave entrances in the 19th century and the first half of the 20th century particularly affected caves on the edge of karst poljes. The aim of the interventions was to increase the drainage capacity of ponor caves and in this way reduce floods in karst poljes. This resulted in morphologically altered caves in the Notranjska region in the ponor area of Loško polje, Cerkniško polje, Planinsko polje and the Postojna basin, and in the Dolenjska region in Radensko polje, Lučki dol and Krška jama. By the early 20th century, in particular in the late 1960s, ideas about completely eliminating floods gave way to ideas about the creation of lakes and the blocking up of ponor caves (Kranjc 1987), but with the exception of dams in the entrance sections of the Velika Karlovica and Mala Karlovica caves, this was not put into effect and therefore the hydrological regime is significantly less altered than elsewhere in the poljes of the Dinaric karst (Zupan Hajna et al. 2010).

The development of caving in Slovenia in the late 19th century (1890: the founding of the Anthron caving society) and early 20th century (1910: the Cave Exploration Society of Ljubljana), and above all with the founding of a large number of caving clubs after the Second World War, greatly increased the number of caves where there was direct human impact. Nevertheless, because of the very great number of caves (more than 10,200), the impact is very dispersed and major impacts are only noted in frequently visited caves. Growing environmental awareness among cavers in the second half of the 20th century further reduced the impact on caves on the part of cavers. Even so, a lack of awareness means that damage is still caused by visitors to caves, particularly in flowstone- and clay-covered sections, which as well as having aesthetic value contain information on the past development of caves (sediment forms) and visitors to caves (human dwellings, dens of wild animals).

Military activity during and after the two world wars had a major impact on some caves and saw them converted into shelters and depots. It is estimated that more than 100 caves on the Soča/Isonzo Front alone were converted to military use for the needs of the army during the First World War (Simić 2000). Some caves (e.g. Križna jama) only just escaped undergoing major morphological changes when preparations were overtaken by the outbreak of the Second World War. Others underwent major morphological changes between the wars – for example the total levelling of Račiška pečina, which destroyed palaeontological evidence (of the use of the cave by cave bears, for example) and archaeological remains. During the Second World War the partisan style of warfare hardly caused any morphological changes to caves, although 1944 the entrance section of Postojnska jama was badly damaged when a German fuel dump inside the cave was blown up. Caves were also converted into depots and bunkers after the Second World War, but on a smaller scale.

The development of the roads network has had a direct and significant impact on caves lying near roads. To begin with efforts were made to avoid caves as far as possible. Later, however, mechanisation and the need for road sections to be as straight as possible led to some caves being completely filled in. During the construction of Slovenia's motorway network, attempts were made to avoid this wherever feasible (Knez and Slabe 2011 – see page 83) by assessing the importance of caves from the natural history and scientific research points of view. It may be said that the more important caves have remained accessible and that the impact on them is small.

A special form of destruction of caves occurs with the extraction of limestone and dolomite in quarries, during which it is common to come across karst caves. Despite the fact that numerous caves in quarries have been completely filled in or removed in past years, some have survived (Zupan Hajna 2011 – see page 93).

The visually most disturbing and environmentally most dangerous intervention in karst caves is caused by the dumping of waste in them. This problem appeared in particular with the development of modern society after the Second World War, with a major increase in material flow caused by human beings, responsible for the production of waste gases, solid waste and liquid waste. The last two of these groups in particular have an impact on caves, since until recent decades municipal wastewater was as a rule not treated and the removal of waste was not organised in the context of municipal waste management services, particularly in more remote

Fig. 1: Broken flowstone formations in the Polina Peč cave in the Matarsko Podolje area – caused by illegal collectors of cave fauna searching for specimens. In a similar way, some tens of square metres of cave floor have been dug up in the cave (photo: M. Prelovšek).

settlements. Despite the fact that this form of impact on the karst underground has lessened considerably, the problems of pollution of the karst underground still remain, particularly in the sphere of the semi-legal discharge of insufficiently treated municipal wastewater with high concentrations of soluble pollutants. With the removal of municipal solid waste, the impact on karst caves of solid waste has been greatly reduced, but it still remains in some areas (the Kočevje area and the Notranjska and Dolenjska regions).

Even cave experts have an impact on karst caves, through the excavation of archaeological-palaeontological profiles, particularly in the entrance sections of caves, which are not then restorated. Geological-geomorphological studies also have a minor impact. The mania for collecting cave fauna in some caves has led to genuine devastation, for example the breaking of flowstone in the Polina peč cave near Podgrad in the Matarsko Podolje area (Fig. 1).

Caves are not only affected by direct activities that take place inside them, but also activities in the surrounding area. Most frequently this involves indirect impacts via the water flowing into caves. The best-known case in Slovenia is the pollution of the Škocjanske jame and the cave system downstream of them, into which the river Reka carried pollution from the catchment area for decades. The Željnske jame near Kočevje are a special case. Here, some sections are entirely filled up with material from the screening process in the nearby coal mine. A notable case of pollution in recent years has involved the river Pivka in Postojnska jama. In terms of the impact of percolation water on caves lying underneath, the most obvious example is that of the discharge into the karst underground of inadequately treated water from (legal) treatment plants. The limited access to other seepage waters underground gives rise to doubts about the adequacy of treatment at other treatment plants discharging directly into the karst underground (Prelovšek 2011 – see page 54).

Protection of caves

The need for cave protection derives from awareness of the damage caused by human beings in caves and the negative attitude towards it. The first attempt at protecting caves can be noted in the area of the prohibition of the collection and sale of speleothems and cave fauna in the early 20th century, although a law passed in 1922 only prohibited the collection of rare species of animals and plants, but not the collection of speleothems (Simić 2000), and therefore the devastation of caves continued, particularly in the area around Postojna. Interestingly, the use of flambeaux in Postojnska jama was prohibited very early (1925; Mihevc 2011 – see page 34) because they produced too much soot. A formal prohibition of the breaking-off of speleothems was, however, not introduced for the majority of caves until the adoption of the Cave Protection Act in 2004.

The legal protection of karst caves represents the formal and, at least in essence, unambiguous protection of caves at the national level. The first attempts at the legal protection of caves in Slovenia date from the period between the wars. From the end of the Second World War until 1966, only some of the more important individual caves were specially protected, while the others were not covered by any protection regime (Simić 2000). Later, attempts were made to protect caves under the umbrella of nature conservation laws and within protected areas, but the first regional park (Škocjanske jame) was not proclaimed until 1996. Definitive legal protection for caves finally arrived in Slovenia in 2004 with the adoption of the Cave Protection Act, which protects all registered karst caves as natural heritage of national importance and defines them as state property. All Sloven caves are now legally protected by the Cave Protection Act, while at the same time protection regimes for them can be also prescribed within parks (Kepa 2001) and nature reserves. The highest level of protection is guaranteed for caves inside the Triglav National Park, while protection at

Fig. 2: Cleaning up karst caves can make a significant contribution to reducing existing environmental impact, reducing the danger of pollution of a wider area, and raising the awareness of the local population with regard to the harmfulness of this form of pollution of the karst underground (photo: M. Prelovšek).

Fig. 3: One of the rare examples of restoration in a karst cave in Slovenia – the successful restoration of rimstone dam from Križna jama (photo: A. Troha).

a lower level is provided for caves within the Škocjanske jame Regional Park (Cerkvenik 2011 – see page 43), where the Škocjanske jame themselves are protected by a number of regulations and international agreements as well as by national legislation, and caves within the Notranjska Regional Park. Somewhat milder forms of protection of caves also exist in protected landscape park areas. We may state that the legislation protecting caves is essentially good, although in the case of critical impacts there is a problem of implementation.

The Cave Protection Act also defines the status of closed caves and caves with controlled access. For both these types, entry to the caves is restricted by gates because of the vulnerability of the cave environment. Although the closure of caves may appear to be a step towards the greater protection of caves, the installation of gates raises many questions about the justifiability of such interventions from the point of view of visual impact, partial morphological changes to, in particular, the entrance sections of caves, and the accessibility of caves to animals. The closure of caves is, however, an extreme intervention at a point where other protective measures no longer suffice and the closure of a cave has a significantly smaller impact than allowing the cave to remain open.

An important step in the direction of sustainable management, in particular of show caves that are under more pressure, is represented by monitoring. The monitoring of individual parameters, particularly in caves that are subject to greater pressures (show caves), aims to provide a deeper understanding of natural processes and allow the quantitative evaluation of human impacts (Hamilton-Smith 2002) from the point of view of heat input, humidity, CO_2 concentration, movement of air and dust, which in the next phase leads to proposals for improvement of the existing situation in accordance with the carrying capacity of the caves in question. In Slovenia, regular monitoring is only carried out at Postojnska jama, under the terms of the concession agreement (Šebela 2011 – see page 74), while occasional monitoring takes place in other show caves and non-show caves. In the future it will undoubtedly be necessary to set up permanent monitoring of key parameters in all caves that are subject to greater pressures.

The largest number of visitors to open (non-show) caves are cavers, who have different nature protection standards depending on the caving club to which they belong. Environmental awareness is high in the biggest caving clubs and as a result there is constant pressure to increase the protection of caves and cave-friendly forms of visiting. In recent decades, the mission of cavers has started to incorporate the intensive protection of caves through monitoring of the status of caves, the reporting of illegal activities, the reduction to a minimum of the damage caused by visits and research, and in the field of cave cleaning, where cavers are practically the only group capable of carrying out this work in a safe and satisfactory manner. Despite the fact that at least 100 caves in Slovenia have already been cleaned up, it is estimated that 90 % of caves in the country are still polluted by solid waste (Prelovšek 2011 – see page 101).

If cave infrastructure is already being renovated, cave restoration, in other words returning caves to a state that is as close as possible to the state before development, is still to a large extent an unexploited potential for the remediation of undesirable impacts in caves. Although it is frequently impossible to restore a cave to its original state, cave restoration allows us to make an important contribution to improving its appearance or speeding up the natural process of renewal. Restoration is important above all because of the fact that caves are extremely slowly developing environments, where natural renewal can take tens of thousands of years or is no longer even possible. Despite the fact that some caves in Slovenia need restoration, activities of this kind have only been carried out successfully in a few locations in the past (e.g. Križna jama; Troha 2010; Fig. 3), and without expert supervision, which is essential in such interventions. A far more typical situation is that parts of caves that are no longer used for the purposes of tourism remain in the state that they were in at the time they were last used and are still waiting for at least an approximate restoration to their past state.

References

Hamilton-Smith E., 2002. Management assessment in karst areas. Acta Carsologica, 31/1: 13–20.

Kepa T., 2001. Karst conservation in Slovenia. Acta Carsologica, 30/1: 143–164.

Kranjc A., 1987. Cerkniško jezero – An example of man's impact on karst hydrology. In: Habič P. (ed.). Man's impact in Dinaric karst (Guide book). Department of Geography, Faculty of Letters, E. Kardelj University in Ljubljana & Institute for Karst Research ZRC SAZU in Postojna, Ljubljana: 65–79.

Zupan Hajna N., Mihevc A., Prelovšek M., 2010. Land Use. In: Mihevc A., Prelovšek M., Zupan Hajna N. (eds). Introduction to the Dinaric Karst. Karst Research Institute at ZRC SAZU, Postojna: 44–48.

Shaw T.R., 1999. Proteus for sale and for science in the 19th Century.

Acta Carsologica, 28/1: 229–304.

Simić M., 2000. Zgodovina varstva jam na slovenskem [History of cave protection in Slovenia]. Naše jame, 42: 49–77.

Troha A., 2010. Kako smo čistili jamo [Cleanup of Križna Jama]. In: Kržič M. (ed.). Križna jama. Ljubljana, Društvo ljubiteljev Križne jame: 10–15.

Zupan Hajna N., Mihevc A., Pruner P., Bosák P., 2008. Palaeomagnetism and magnetostratigraphy of karst sediments in Slovenia. ZRC Publishing, Ljubljana: pp. 266.

THE IMPORTANCE AND PROTECTION OF KARST WATERS

Metka Petrič [1]

The principal hydrogeological characteristics of karst areas are the absence of permanent surface streams, a heterogeneous structure with a combination of underground karst conduits and impermeable zones of bedrock, and the existence of large karst springs. We treat such areas as karst aquifers because for the most part they contain significant quantities of groundwater – which, according to Ford and Williams (2007), is used by almost a quarter of the world's population as a source of drinking water.

Karst aquifers usually extend over an area measuring from several tens to several hundreds of square kilometres. For the most part they consist of karstified carbonate rock, above all limestone and dolomite. The surface is frequently bare or has scant soil cover and the rock is fractured and karstified. As a result, rainwater percolates rapidly underground. In addition to diffuse recharge of this type, karst areas typically have point-source, concentrated recharge through ponors, where surface streams sink underground from areas of lower permeability and enter the karst aquifer (Fig. 1).

Underground, the infiltrated water from the surface flows through the unsaturated or vadose zone (pores not permanently filled with water) in a mainly vertical direction towards the saturated or phreatic zone (pores permanently filled with water). The transitional area between them is called the flood zone or epiphreatic zone and is defined by fluctuation of the water table. The karst water table is very often unconnected and it is very hard to determine its level, since it is constantly changing and very dependent on current hydrological conditions.

In the vadose zone rapid flow through primary drainage conduits is combined with slower percolation through fractured bedrock with low permeability. An important role is played in this type of recharge distribution by the epikarst zone in the upper part of the vadose zone (Mangin 1975, Király et al. 1995, Klimchouk 2000, Petrič 2002, Trček 2003). In the phreatic zone water flows through conduits, fractures and porous bedrock towards karst springs, through which groundwater returns to the surface. The structure and functioning of karst aquifers therefore differ greatly from those of non-karst aquifers (e.g. intergranular aquifers), since they are defined above all by extremely high permeability and high speeds of underground water flow, a variety of modes of flow and usually unknown directions of drainage of water underground, which can even reach areas several tens of kilometres away. The hydrogeological characteristics of karst aquifers are presented in more detail in karstological literature (Krešić & Stevanović 2010, Ford & Williams 2007, Bakalowicz 2005, White 1988, Bonacci 1987, Milanović 1979, etc.).

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, petric@zrc-sazu.si*

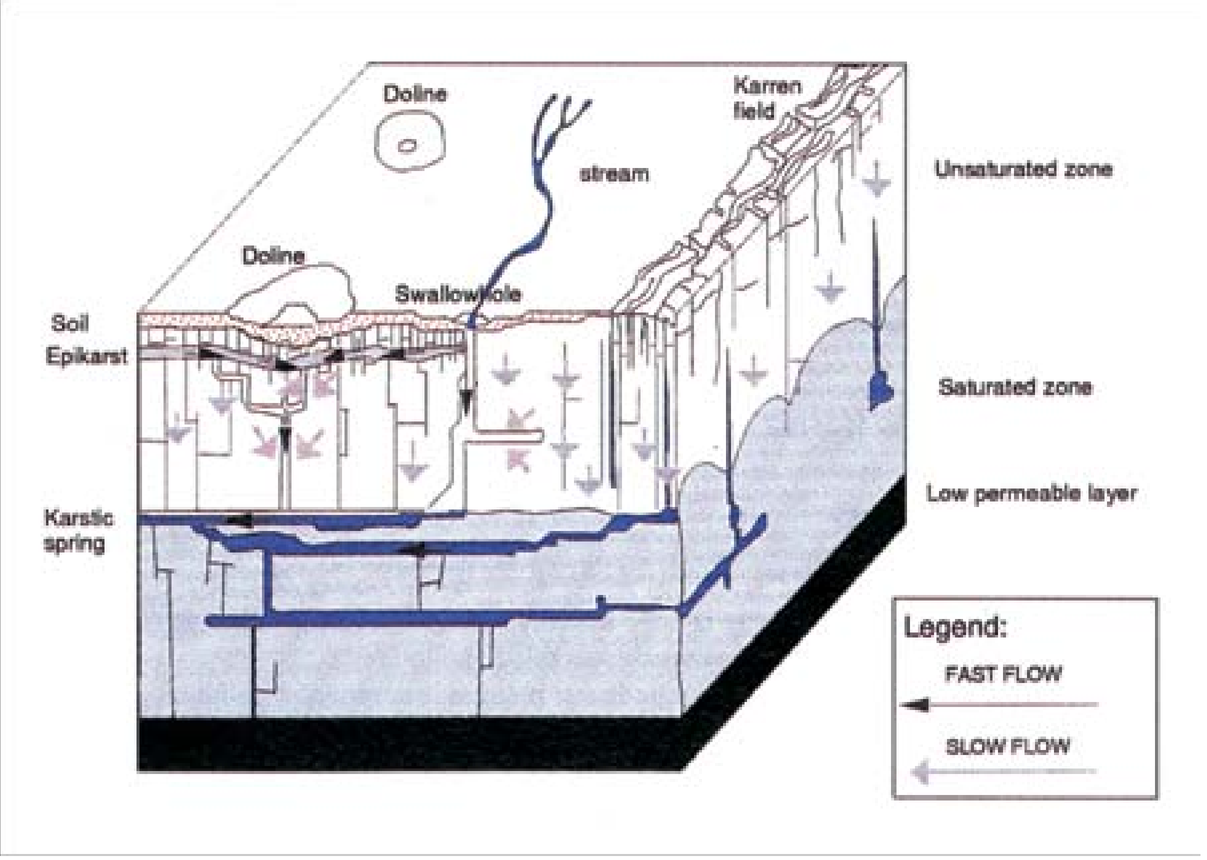

Fig. 1: Diagram of part of a karst aquifer (COST 65).

Vulnerability of karst aquifers

As a result of the characteristics described above, karst aquifers are extremely vulnerable to the consequences of various sources of pollution. The extent to which the effects of pollution on the karst surface are reflected in karst springs depends on the characteristics of the transfer of substances with water through karst rock (Kuhta 2011 – see page 128). The internal vulnerability of karst is a natural property of groundwater systems and is dependent on the geological, hydrological and hydrogeological characteristics of the karst and independent of the characteristics of the polluter (Zwahlen 2004). It describes the probability of pollution and we use it in order to assess the sensitivity of an aquifer to the consequences of various anthropogenic impacts. Various mapping methods are used to determine different levels of vulnerability. Some have been adapted to the particular characteristics of karst aquifers (Doerfliger et al. 1999, Zwahlen 2004, Vias et al. 2006, Ravbar 2007, Ravbar 2011 – see page 154).

In the assessment of karst vulnerability, unfavourable characteristics include the thinness of the weathering cover that covers the carbonate rock, resulting in negligible filtration and retention of harmful substances in this top layer. The high karstification of rock across the entire cast surface and the large number of connected fractures mean that along with rainwater any pollution can enter the karst aquifer system from the surface very quickly and practically anywhere. It can enter the aquifer even more directly via a sinking stream into a system of highly permeable karst conduits. Conduits and expanded fractures in the karst aquifer enable very rapid flow over large distances. This results in very brief retention times for the water underground and therefore a low self-cleaning capacity and a major threat to the karst springs towards which groundwater flows (Kogovšek 2011 – see page 119). Part of the infiltrated water can also be stored for a longer period in less permeable zones of the aquifer. The consequence of this is the cumulative collection of potential pollution which, given suitable hydrological conditions, can then be flushed out of the system after a considerable period and lead to a worsening of the quality of the water source.

Protection of karst water sources

Karst aquifers are an extremely important source of water – in some places practically the only source of water. Owing to their particular characteristics, however, they are extremely vulnerable to the consequences of various sources of pollution (Drew & Hötzl 1999). In order to ensure their suitable protection, good knowledge of the characteristics of the functioning of karst aquifers is essential. Through the use of a variety of research methods we are able to determine the main directions of groundwater flow and define zones of greater vulnerability (Ravbar 2011 – see page 147). Where and how quickly pollution from the karst surface spreads in the karst interior and in what springs we can expect to see it can only be successfully predicted if we have sufficient knowledge of the characteristics of the geological structure and hydrogeological conditions in this area. In various cases involving pollution it has been shown in practice that only in areas where comprehensive hydrogeological research has already been carried out are we able to predict when pollution will appear and in what springs (Petrič & Kogovšek 2011– see page 138, Kogovšek & Petrič 2011 – see page 112). As a result, immediate action is possible with constant parallel monitoring of water quality, and when harmful substances are detected the spring can be excluded from the water supply system in good time. Where we do not have such data, action is also less effective. For this reason it will be necessary to continue with the relevant research and at the same time develop a database of the characteristics of karst aquifers and the quantities and qualities of karst water.

The assessment of the vulnerability of karst aquifers is supplemented by description of impact on the environment, in which we define existing and potential sources of pollution. The result is an estimate of the threat to water sources which is the basis for the elaboration of a water management plan. Educating the public is another extremely important factor in the protection process and one that can make a fundamental contribution to successful protection.

Fig. 2: The Malenščica karst spring is used for the water supply of approximately 21,000 inhabitants of the municipalities of Postojna and Pivka.

References

Bakalowicz M., 2005. Karst groundwater: a challenge for a new resource. Hydrogeology Journal, 13: 148-160.

Bonacci O., 1987. Karst Hydrology. With special reference to the Dinaric karst. Springer-Verlag, Berlin, Heidelberg: 184.

COST 65. 1995. Hydrogeological aspects of groundwater protection in karst aquifers – Guidelines. European Commission, Directorate-General XII, Science, Research and Development, EUR 16526, Brussels, Luxembourg: 15.

Doerfliger N., Yeannin P.-Y., Zwahlen F., 1999. Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). Environmental Geology, 39/2: 165-176.

Drew D., Hötzl H. (eds.), 1999. Karst Hydrogeology and Human Activities. A.A. Balkema, Rotterdam, Brookfield: 322.

Ford D. C., Williams P. W., 2007. Karst Hydrogeology and Geomorphology. John Wiley & Sons, Chichester: 562.

Király L., Perrochet P., Rossier Y. 1995. Effect of epikarst on the hydrograph of karst springs: a numerical approach. Bulletin d'Hydrogéologie, 14: 199–220.

Klimchouk A. B. 2000. The formation of epikarst and its role in vadose speleogenesis. In: Klimchouk A. B., Ford D. C., Palmer A. N., Dreybrodt W. (eds.). Speleogenesis: Evolution of karst aquifers, Huntsville, Alabama: 91–99.

Krešić N., Stevanović Z. (eds.), 2010. Groundwater hydrology of springs: engineering, theory, management, and sustainability. Butterworth-Heinemann, Burlington: 573.

Kuhta M., 2011.

Mangin A. 1975. Contribution a l'étude hydrodynamique des aquifers karstiques. Annales de Spéléologie, 29/4: 495–601.

Milanović P.T., 1979. Hidrogeologija karsta. HE Trebišnjica, Trebinje: 302.

Petrič M., 2002. Characteristics of recharge-discharge relations in karst aquifers. Založba ZRC, Postojna, Ljubljana: 150.

Ravbar N. 2007. Vulnerability and risk mapping for the protection of karst waters in Slovenia. Application to the catchment of the Podstenjšek springs. PhD Thesis. Univerza v Novi Gorici. Nova Gorica: 243.

Trček B. 2003. The epikarst zone and karst aquifer behaviour: a case study of the Hubelj catchment, Slovenia. Geološki zavod Slovenije, Ljubljana.
Vias J.M., Andreo B., Perles J.M., Carrasco F, Vadillo I, 2006. Proposed method for groundwater vulnerability mapping in carbonate (karst) aquifers: the COP method. Application in two pilot sites in Southern Spain. Hydrogeology Journal, 14/6: 912-925.
White W. B., 1988. Geomorphology and Hydrology of Karst Terrains. Oxford Univ. Press, New York, Oxford: pp. 464.
Zwahlen F. 2004. COST Action 620. Vulnerability and Risk Mapping for the Protection of Carbonate (Karst) Aquifers. Final report COST Action 620. European Commission, Directorate-General for Research, Luxembourg.

SUBTERRANEAN HABITATS AND FAUNA, THEIR THREATS AND CONSERVATION

Slavko Polak [1] & Tanja Pipan [2]

Subterranean fauna and their habitats represent an important component of the World and European natural heritage. Caves were not seriously considered as a habitat for the animals until 1831 when the first cave beetle *Leptodirus hochenwartii* and consequently others first representatives of cave fauna were discovered in the Postojnska jama (Polak 2005). A rich subterranean fauna was later discovered in the other parts of Europe and other continents. Despite being mostly small, colorless and usually eyeless, cave creatures have a great scientific importance due to their peculiar adaptations to specific subterranean conditions and especially due to the high degree of endemism compared to other habitats. Adaptations make cave fauna an excellent subject for scientific research, but at the same time an extremely vulnerable to any human impact.

Not just caves…

Beneath the surface there are many underground large and small spaces and cavities that can be air-filled or water-filled. All subterranean habitats share one very important physical property – the complete absence of sunlight (Culver & Pipan 2009). In addition to the permanent absence of light, subterranean habitats typically have no autotrophic production, and reduced environmental variability. The cavities large enough and usually accessible to man are called caves. In some karstic areas the number of caves can be surprisingly high, and rich in subterranean biodiversity as well (Culver & Sket 2000, Culver et al. 2006b). Caves large enough to admit a human being are the most investigated with regard to fauna. Subterranean fauna can be found also in lava tubes that fit the definition of caves. But this anthropocentric definition is not an especially useful biological definition of a cave habitat. A more useful definition is a natural opening in a solid rock with the areas of complete darkness, and larger than a few millimeters in diameter (Culver & Pipan 2009). But caves are not the only component!

There are plenty old and new classifications and definitions of the subterranean environments and their associated fauna, documented by Camacho (1992). The debates among speleobiologists about the ecological classification of subterranean animals are still open (Sket 2008). In general, subterranean ecosystems include *Terrestrial Subterranean Environments* and *Aquatic Subterranean Environments*. Each of them is further divided but boundaries among them are never sharp and easy to classify. Besides fauna deep in the cave underground, the subterranean terrestrial and aquatic fauna is well represented in *shallow subterranean habitats* (Culver & Pipan 2008). Terrestrial fauna can be found in the superficial zone of rock fissures and debris slopes. Such a

[1] *Notranjska Museum Postojna, Ljubljanska 10, SI-6230 Postojna, Slovenia, slavko.polak@guest.arnes.si*
[2] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, pipan@zrc-sazu.si*

habitat is MSS (Milieu Souterrain Superficiel) as originally described by Juberthie et al. (1980). It can be found after the last soil or edaphic horizon and differs from the endogenous environment because of its structure with greater empty spaces, porosity due fissures and interconnected spaces between rocks. The fauna in MSS is significantly different from those of soil, but similar to the cave fauna (Juberthie et al. 1980, Giachino & Vailati 2006).
Similarly the aquatic subterranean fauna can be found in the epikarst – the uppermost layer of the vadose (unsaturated) zone (Fig. 1), the stratum that is closest to the surface in the hydrological division of the karst underground (Culver & Pipan 2009, Pipan 2005). Additionally, there are some other subterranean habitats as interstitial habitats (Karaman 1935), anchialine habitats (Sket 2004), hypothelminorheic habitats (Culver et al. 2006a), chemoautotrophically based groundwater ecosystems (Sarbu & Popa 1992, Sarbu 2000), springs, etc.

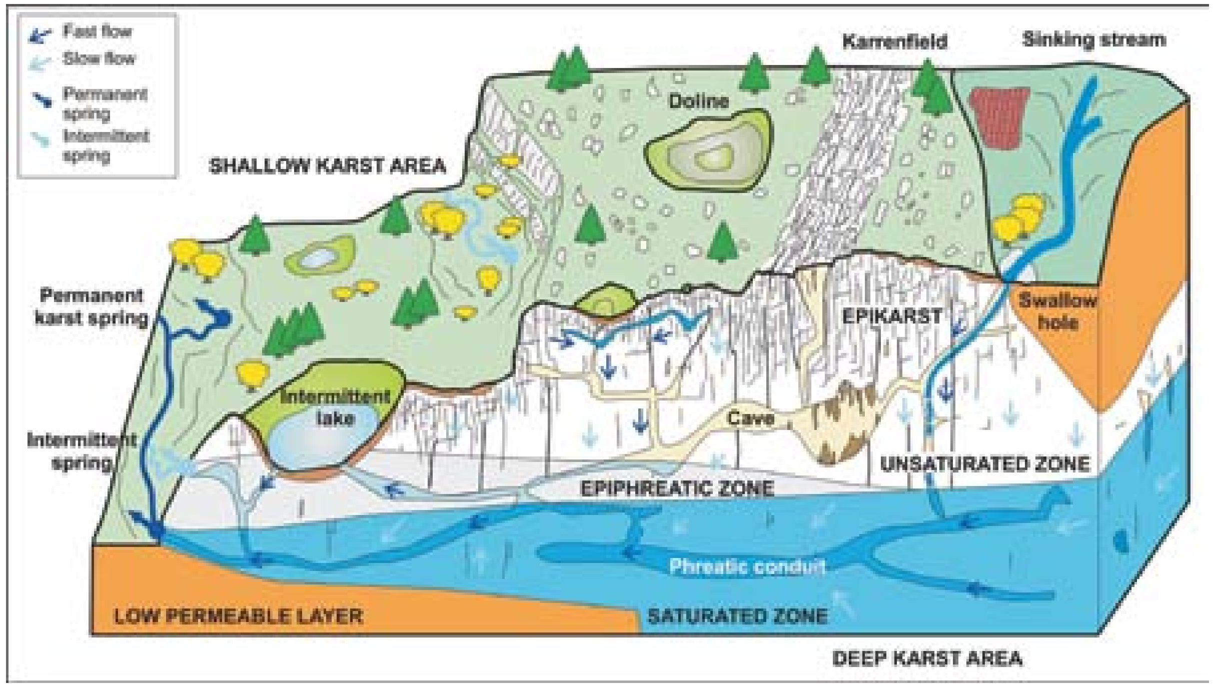

Fig. 1: Conceptual model of water flow in a karst aquifer system, showing direction of water flow, some karst features and subterranean habitats. From Ravbar (2007).

Threats to the subterranean habitats and fauna

Nowadays subterranean habitats and animals living there are attracting to and have an increased interest and concern of speleobiologists, cavers and conservationists. Most troglobionts (terrestrial obligate subterranean dwellers) and stygobionts (aquatic obligate subterranean dwellers) are highly geographically restricted and often rare, making them vulnerable even to relatively minor specimen loss (Ozimec 2011). Since scarce nutrient sources and stable environmental conditions characterize most subterranean habitats, the fauna develops a K-selected reproductive strategy with lower metabolic rate, resistance to starvation, reduction of circadian rhythm, reduced egg number but increased egg volume, lower reproductive rate and increased lifespan (Camacho et al. 1992). For example, individuals of the troglophilic beetle *Laemostenus screibersi* live up to 7 years longer than its epigean relatives that live only one or two seasons (Rusdea 1994).

Obligate subterranean fauna but especially bats that utilize caves are under threat, due to the low reproductive rates, high susceptibility to environment changes, and inability to respond on environmental stress.
Threats to subterranean habitats are about as diverse as threats to surface environments especially since most environmental disasters on surface sooner or later reflect in the subterranean realm.
There are three main overcastting categories of threats to the subterranean world: physical alternation of a habitat (quarrying, mining, tourist alternation); water quality and quantity changes (due to organic, pesticide, heavy metal and petroleum products, river damming and water extraction); and direct changes to the subterranean fauna (Jones et al. 2003).

Quarrying, mining and infrastructure building

One of the most serious direct threats to caves are quarrying (Zupan Hajna 2011 – see page 93), mining, road building as well as urbanization spreading. Quarries of limestone minerals (industrial gravel, marble, travertine and even sinter formations) are case of a direct intervention into the subterranean karst habitats because it completely removes the habitat. Sometimes not only the whole limestone hill but even entire caves within it are totally obliterated. In such cases, the local subterranean fauna is destroyed. Industrialization and urbanization as well as road and railway constructions occasionally hit the subterranean caves. Such incidental findings of caves are usually physically completely or partly destroyed by filling with waste construction materials (Knez & Slabe 2007, Knez & Slabe 2011 – see page 83). In Croatia, such a threat of physical devastation is particular pronounced in the karstic coastal region of Adriatic, mostly due to the rapid development of infrastructure for tourism (Ozimec & Katušić 2009).

Caves or sites which are designated as a type locality for taxa are from the scientific and conservation point of view extremely important and vulnerable, and in many cases may be the only place where a species is found. Therefore the precise type locality inventories as it was recently published in Croatia (Bedek et al. 2006) have to be performed (Ozimec et al. 2001 – see page 160).
In Slovenia and Croatia where karst areas cover a great part of the national territory such threats are limited but present. In Belgium, for instance, three caves which are of great biological interests as a habitat of an endemic cave beetle *Tychobythinus belgicus* are threatened since about ten other caves have already been destroyed (Hubart 1982).

Alteration due to tourism use

It is a special type of alternation of natural caves due to mass tourism use. Commercial caves, such Postojnska jama (Slovenia), Coves del Drac (Spain) or Mammoth cave (USA) have (or had) nearly 1 million visitors per year. Commercialization of a cave for tourism requires physical changes of natural passages and installation of lights, which more or less lead to a disappearance of troglobiotic fauna. Regular lighting of tourist passages results in "lampenflora" which is not native in the subterranean world (Mulec 2011 – see page 64). Tourist use of caves is in general limited since relatively small percentage of the total underground known passages and tunnels are changed for this purpose.
Not only tourism, but visiting of caves by sport cavers in some countries can represent a threat to the subterranean habitats (Tercafs 1992). To limit or control regular cave visits, the gates at the entrances are often placed. Physical alteration of cave entrances, either by filling or enlarging them can have impact on the fauna, especially terrestrial cave dwelling organisms. Filling or gating the cave entrances can

influence the movement of animals in and out of the cave like bats and crickets that represent significant food source for troglobionts. There are also possible changes in the air flow that affects the cave climate conditions. Nowadays, the significant progress has been achieved in putting the "bat friendly" gates at the cave entrances which have no effects or minor on the cave fauna and climate (Fig. 2).

Changes in water quality and quantity

In urban areas world wide the organic pollution due to improper agricultural practices as well as industry waste products can seriously affect the aquatic fauna. In the karst areas such organic pollution are the main threats to the subterranean stygobiotic fauna. Classical example is extinction or near extinction of once strong populations of cave salamander (*Proteus anguinus*) in some caves due to coal mining at the edge of Kočevsko polje in Slovenia (Sket 1972, Hudoklin 2011 – see page 169). A similar situation happened with river Reka in Slovenia that was practically a biologically dead river in 70's due to the chemical pollution. After collapse of heavy industry in Ilirska Bistrica, the river, which sinks in a famous Škocjanske jame (UNESCO site), recovered significantly (Kogovšek 2002). The Pivka river, which flows through the Postojna – Planina cave system, recognized as biologically the most diverse cave in the world, never faced such a heavy pollution. But the moderate organic pollution of the subterranean Pivka previously negatively impacted the stygobiotic fauna as the surface aquatic fauna outcompeted the subterranean fauna in the upper part of the underground river course (Sket 1972, 1977). Overuse of

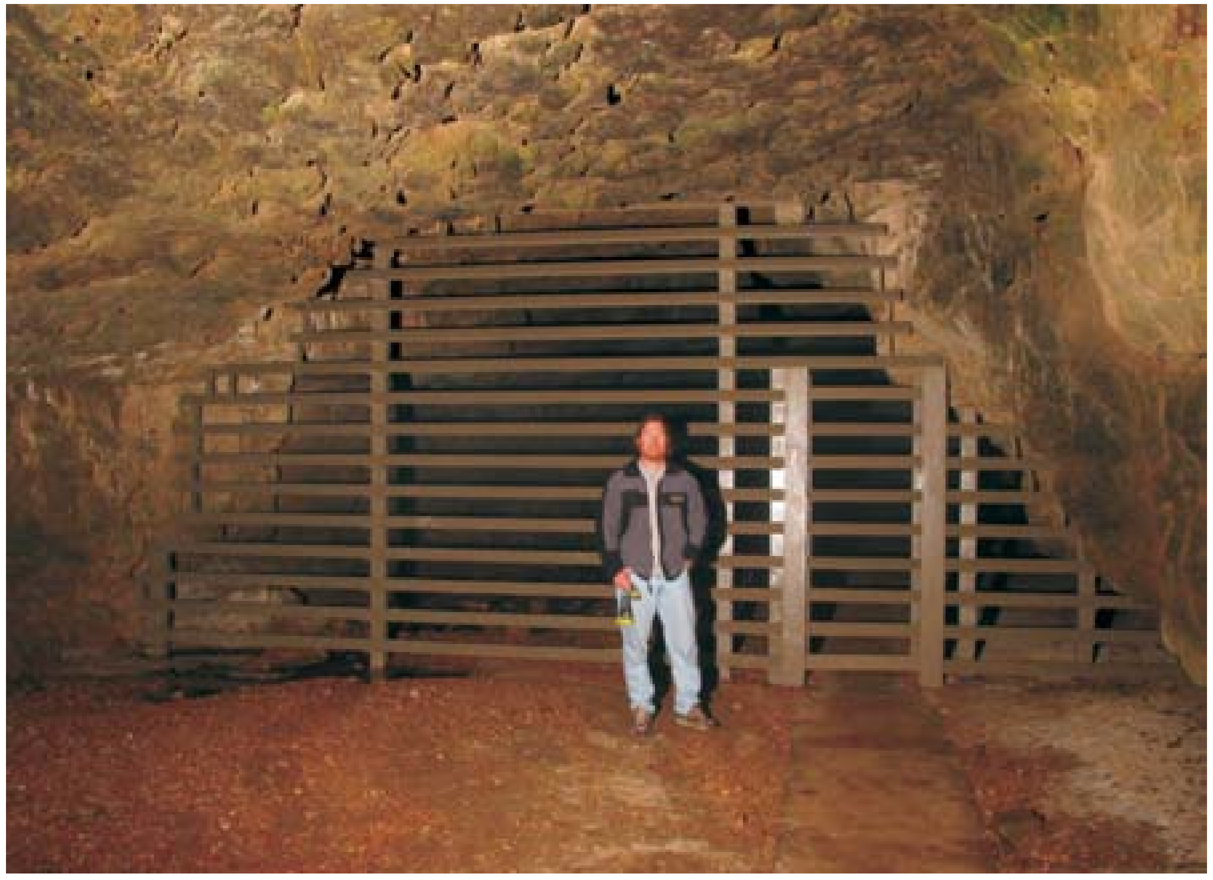

Fig. 2: Gate at the entrance to a cave in the USA designed to allow unimpeded access for bats (Photo: H. Hobbs III).

fertilizers and pesticides in agriculture leads to pollution of drinking water supplies and groundwater and has a negative impact on the subterranean fauna.

Another important driver is water extraction for industry, urban activities, irrigation, and hydroelectric power production. Such a water extraction is especially problematic in the arid zones. Groundwater levels have fallen in many areas, even more than 30 m in some cases (Danielopol et al. 2003). The case of Trebišnjica in Popovo polje in Hercegovina is an illustrative case of damage. At the edge of Popovo polje there are many caves including Vjetrenica, one of the most diverse cave in the world where river Trebišnjica used to sink (Lučić 2007). To provide hydroelectric power and to control flooding in 60's the state government constructed a dam and canalized the river to avoid flooding. Trebišnjica was no longer a flooding river and surrounding caves were starved for water and nutrients. Some endemic cave animals such a cave salamander *Proteus anguinus* and fish *Paraphoxinus ghetaldi* seriously declined. Huge populations of endemic cave clam *Kongeria kusceri* and cave polychete worm *Marifugia cavatica* also died out.

On the other hand damming of river for agriculture and especially for electric hydropower plants can affect the subterranean fauna by incising the water level.

In all of the cases of organic pollution, declines in water quality was accompanied by invasion of organisms typical for polluted waters. Competition and predation of invading species may actually be a bigger threat to the stygobionts than the water quality itself (Sket 1977).

Pollution by petroleum products are not common but can have serious consequences not only to subterranean fauna but to the

Fig. 3: A potentially specially damaging collecting technique is pitfall trapping. In the case that such traps are left for a longer period and in big number, the local cave population can be decimated (Photo: S. Polak).

drinking water supplies. There are some well documented incidents in Slovenia (Kogovšek 2011 – see page 119) and in Croatia, where leakage of 123 tons of oil from oil deposit to the river Pazinčica by its sink to Pazinska jama in Istria happend (Kuhta & Stroj 2010, Kuhta 2011 – see page 128).

Direct human impacts

The most direct human impact on cave fauna is caused by human visitation of caves. The most classical example is destruction of bats. In the past, bats were for the most people nothing more than vermin, carriers of diseases and even bloodsuckers. There are some documented destructions of the whole colonies of bats hibernating or breeding in caves. Recently our view and perception of bats significantly changed. Bats ware recognized as generally declining mammal group that plays an important role in the nature as an insect controller and with urgent need of protection. Bats are officially protected by law in the most European countries, bigger colonies are protected and monitored as well and cavers generally put efforts not to disturb hibernating bats. The main cause for bat population declines is use of insecticides but general loss of biodiversity is hardly to be monitored. On the other hand, the biggest losses in the U.S. are due to White Nose Syndrome and mortality associated with wind power generators.
Cave visitation may also have some negative impact on stygobiotic and troglobiotic species primary by disruption of cave streams and cave pool habitats. Over collecting for scientific purpose is unlikely to be serious threat to the populations. In Slovenia, which is biologically well investigated, only approximately 10 percent of caves have been sampled. Sampling

Fig. 4: Dog cadaver dropped in the cave. With plenty of organic material, the caves are invaded by surface decomposers and secondary predators and therefore the local subterranean fauna is not able to compete (Photo: S. Polak).

Fig. 5: It is already noticed that ice blocks in some ice caves start to melt. It seems that the first on the list and most critically endangered is fauna in the ice caves (Photo: S. Polak).

of epikarst, MSS habitats and other shallow subterranean habitats are virtually at the beginning (Pipan 2005, Pipan et al. 2011). But especially in Europe there is a traditionally developed cave beetle collecting by amateurs. A potentially damaging collecting technique is pitfall trapping (Fig. 3). Pitfall traps baited with cheese or rotting meat can attract hundreds of troglobionts, not only beetles in one day or two. In the case that such traps are left for longer period and in greater numbers, the local cave population can be decimated. Such a prolonged trapping can be serious particularly on single site endemics or type localities, since additional specimens are needed for additional investigations (e.g. molecular analysis).
Much more serious direct human impact is common dumping of organic and inorganic waste and garbage into the caves. Especially shafts are traditionally favored dumping places for locals. In regions where communal collecting of wastes is properly organized such an illegal dumping is significantly decreased. Nevertheless, some caves and shafts are still full of garbage. Some cave cleanup actions have been performed by groups of cavers. They are usually well supported by media as an attempt to raise general public awareness about the cave pollution problem (Prelovšek 2011 – see page 101). Among garbage sometimes dangerous products as chemicals, colors, unused drugs, accumulators, etc. can be found. Such a dangerous chemicals can, and probable make, serious influence on the particular cave fauna and water. Decomposing organic material such dead livestock and slaughterhouse waste products seem to be less destructive to the local subterranean fauna (Fig. 4). It is known that every deposited organic material in the food scarce resource caves can represent snack for cave animals, but this assumption turns wrong. With plenty of organic material caves are invaded by surface

decompositors and secondary consumers and therefore the local subterranean fauna is not able to compete with them. Long time is needed that low reproducing subterranean animals can return, if ever, in a such cave.

Climatic changes

A final human activity may, in the coming years, dwarfs all the other impacts. This is a global warming (Culver & Pipan 2009). Since subterranean habitats in general are less variable than surface habitats, organisms in subterranean habitats will experience less in the way of temperature extremes. However, the rise in average surface temperature will increase average temperatures of subterranean habitats since their temperature approximates the mean annual temperature on the surface. Since any organisms, surface or subterranean, is rarely adapted to temperatures in never encounters, rising temperatures my result in lethal conditions for some of them.

Sygobionts and troglobionts have very limited dispersal capability, and if temperatures rise relatively rapidly, species may go to extinct. It seems that the first on the list and the most criticaly endangered is fauna in the ice caves. It is already noticed that ice blocks in some ice caves presents in 80's (Drame 1986) start to melt (Fig. 5). Some inner parts of before inaccessible caves were opened and therefore some new ice cave adapted beetle species have been recently discovered in Slovenia. Ice cave fauna is adapted to temperatures of about 3 or 4 °C. Such species are ice age relicts. They live in extremely isolated patches all over the world and probably cannot disperse in other sites with suitable low temperatures as the other cave fauna can. Will they be the first?

Acknowledgement

We thank prof. dr. David C. Culver for his constructive review of the manuscript and helpful comments.

References

Bedek J., Gottstein Matočec S., Jalžić B., Ozimec R., Štamol V., 2006. Katalog tipskih špiljskih lokaliteta faune Hrvatske (Catalogue of Cave Type Localities of Croatinan Funa). Natura Croatica 15 (suppl.): 1–154.

Camacho A.I., 1992. A classification of the aquatic and terrestrial subterranean environment and their associated fauna. In: Camacho A.I. (ed.). The natural history of biospeleology. Monografias, Museo Nacional de Ciencias Naturales, Madrid: 60–103.

Camacho A.I, Bello E., Becerra J., Vaticon N., 1992. A natural history of the subterranean environment and its associated fauna. In: Camacho A.I. (ed.). The natural history of biospeleology. Monografias, Museo Nacional de Ciencias Naturales, Madrid: 174–197.

Culver D.C., Sket B., 2000. Hotspots of subterranean biodiversity in caves and wells. Journal of Cave and Karst Studies, 62: 11–17.

Culver D.C., Pipan T.,Gottstein S., 2006a: Hypotelminorheic – a unique freshwater habitats. Subterranean Biology, 4: 1–8.

Culver D.C., Deharveng L., Bedos A., Lewis J.J., Madden M., Reddell J.R., Sket B., Trontelj P., White D., 2006b. The mid-latitude biodiversity ridge in terrestrial cave fauna. Ecography, 29: 120–128.

Culver D.C., Pipan T., 2008. Superficial subterranean habitats – gateway to the subterranean realm?. Cave and Karst Science, 35: 5–12.

Culver D.C., Pipan T., 2009. The Biology of Caves and Other Subterranean Habitats. Oxford University press, New York: pp. 254.

Danielopol D.L, Griebler C., Gunatlika A., Notenboom J., 2003. Present state and future prospects for groundwater ecosystems. Environmental Conservation, 30: 104–130.

Drame L., 1986. Snow caves and glaciers in Notranjski Snežnik and eastern Javorniki and their use. Naš Krš, 12/20: 9–21.

Giachino P.M., Vailati D., 2010. The Subterranean Environment. Hypogean life, concepts and collecting techniques. WBA Handbooks, 3, Verona: pp. 132.

Hubart J.M., 1982. Tychobythinus belgicus (jeannel, 1948) (Coleoptera Pselaphidae). Etude et protection du biotope; nouvelles données écologiques. Natur. Belges. 63: 185–199.

Jones W.K., Hobbs H.H. III, Wicks C.M., Currie R.R., Hose L.D., Kerbo R.C., Goodbar J.R, Trout J., 2003. Recommendations and guidelines for managing caves on protected lands. Karst Waters Institute Special Publication, Charles Town, West Virginia.

Juberthie C., Delay B., Bouillon M., 1980. Extension du milieu souterraiunn en zone non-calcarie: description d'une nouveau milieu et de son peuplement parles coleopteres troglobites. Memoires de Biospeologie, 7: 19–52.

Karaman S., 1935. Die fauna der unterirdischen Gewässer Jugoslawiens. Verh. Int. Ver. Limnol., 7: 46–73.

Knez M., Slabe T. (eds.), 2007. Kraški pojavi, razkriti med gradnjo slovenskih avtocest. Založba ZRC, Ljubljana: pp. 250.

Kogovšek J., 2002. Multiparameter observations of the Reka flood pulse in March 2000. Acta carsologica, 31: 61–73.

Kuhta M., Stroj A., 2010. Primjeri incidentnih onečišćenja speleoloških objekata tekućim ugljikovodicima i njihove posledice. Stručni seminar o zaštiti špilja I podzemne faune, Ogulin 2010. Zbornik sažetaka, 9, Zagreb-Samobor-Ogulin.

Lučić I., 2007. Shafts of life and shafts of death in Dinaric karst, Popovo polje case (Bosnia & Hercegovina). Acta carsologica, 36: 321–330.

Ozimec R., Katušić L. (eds.), 2009. Crvena knjiga špiljske faune Hrvatske. Državni zavod za zaštitu prirode, Minstarstvo culture Republika Hrvatska. Zagreb.

Pipan T., 2005. Epikarst – a promising habitat. Copepod fauna, its diversity and ecology: A case study from Slovenia (Europe). Carsologica, Založba ZRC, Inštitut za raziskovanje krasa ZRC SAZU, Postojna – Ljubljana: pp. 101.

Pipan T., López H., Oromí P., Polak S., Culver D.C., 2011: Temperature variation and the presence of troglobionts in terrestrial shallow subterranean habitats. Journal of Natural History, 45/3–4: 253–273.

Polak S., 2005. Importance of discovery of the first cave beetle Leptodirus hochenwartii Schmidt, 1832. ENDINS, Mallorca, 28: 71–80.

Ravbar N., 2007. The protection of karst waters. Carsologica, Založba ZRC, Inštitut za raziskovanje krasa ZRC SAZU, Postojna – Ljubljana: pp. 254.

Rusdea E., 1994. Population dynamics of Laemostenus schreibersi (Carabidae) in cave in Carinthia (Austria). In: Desender K. et al. (eds.). Carabid Beetles. Ecology and Evolution. Kluwer Academic Publication, Dordrecht: 207–212.

Sarbu S.M., Popa R., 1992. A Unique chemoautotrophical based cave ecosystem. In: Camacho A.I. (ed.). The natural history of biospeleology. Monografias, Museo Nacional de Ciencias Naturales, Madrid: 640–666.

Sarbu S.M., 2000. Movile Cave: a chemoautotrophically based groundwater ecosystem. In Wilkens

H., Culver D.C., Humphreys W.F. (eds). Subterranean ecosystems. Elsevier Academic Press, Amsterdam: 319–343.
Sket B., 1972. Zaščita podzemeljske favne se ujema z življenjskimi interesi prebivalstva. Zelena knjiga. Prirodoslovno društvo Slovenije, Ljubljana: 137–140, 164–165.
Sket B., 1977. Gegenseitige Beeinflussung der Wasserpollution und des Hohlenmilieus. Proceedings of the 6th International Congress of Speleology, Olomouc, ČSSR, 4, 253–262.
Sket B., 2004. Anchialine habitats. In: Gunn J. (ed.). Encyclopedia of caves and karstic science. Elsevier Academic Press, Amsterdam: 46–66.
Sket B., 2008. Can we agree on an ecological classification of subterranean animals?. Journal of Natural History, 42: 1549–1563.
tercafs R., 1992. The protection of the subterranean environment – conservation principles and management tools. In: Camacho A.I. (ed.).The natural history of biospeleology. Monografias, Museo Nacional de Ciencias Naturales, Madrid: 482–522.

STUDY CASES FROM SLOVENIA AND CROATIA

POSTOJNSKA JAMA – USE AND PROTECTION OF THE CAVE

Andrej Mihevc [1]

Postojnska jama (Postojna cave) is the longest and most important show cave in Slovenia and one of the most famous karst caves in the world. The cave is a complex system of passages with large entrances, a river that disappears underground, subterranean chambers and a wealth of speleothems, and has been attracting large numbers of tourists for centuries. Its popularity and impressive visitor numbers are also helped by its geographical location in the so-called Postojna pass, the easiest route over the Dinaric mountains between the Pannonian plain and northern Italy.

To begin with local people only knew about the entrance sections of Postojnska jama, Črna jama, Pivka jama and Magdalena jama. Later they also discovered Otoška jama and the connections between the caves and confirmed that they all belong to the same cave system. The total length of the explored passages of Postojnska jama is 19,570 metres. Approximately 5,000 metres are open to tourists (Kranjc 2007).

The large entrances to the cave have long been attracting visitors. Signatures dating from the Middle Ages can still be seen on the walls of the cave, which was visited by the famous 17th-century polymath J. W. Valvasor and later by many other travellers and naturalists. By the beginning of the 19th century the caves were famous enough to be visited by the Emperor of Austria, Francis I. During preparations for his visit, in 1818, a higher passage into new sections of the cave was discovered. These new sections proved to be the most beautiful parts of the cave, and the sections most suitable for tourism. The local municipality, which was the owner of the entrance and the land above the cave, quickly realised the significance of this discovery. It set up a Cave Commission which from then on was responsible for managing the cave and cave tourism in Postojna. For this reason, tourism in the cave is considered to have begun in 1818. The cave entrance was closed by a gate and the work of laying paths through the cave began. The Cave Commission introduced lighting, a guide service and a visitors' book. A cave statute was drawn up and several guidebooks printed. Today the cave is managed by a public limited company under a concession agreement.

Following the discovery of the new sections, visitor numbers grew rapidly. In 1824 the cave was visited by 470 people; by the turn of the century this number had reached 9,527. In 1924 the cave received 61,116 visitors. The growth in the number of visitors continued after the Second World War and reached its peak in 1985, when the cave recorded 942,256 visitors. The record for the highest number of visitors in a day was set on 8 August 1978, when 12,025 people visited the cave. Visitor numbers fell dramatically when Slovenia gained independence: from 898,071 in 1990 to just 153,419 the following year (Šajn 1998). Numbers grew gradually in the years that followed and by 2010 had reached 492,266. The cave will shortly welcome its 34 millionth visitor (Paternost 2011).

The purpose of this article is to draw attention to the complex relationship between the use of the cave and the conservation of its valuable characteristics – in other words the protection of the cave and its surrounding area. Specialist literature and archive materials contain descriptions of the exploration of the cave, first or significant visits to the cave and notable developments such as the creation of paths, illumination of the cave, the construction of the railway, the electrification of the cave and the construction of buildings outside the cave entrance. All these developments and the use of the cave have been constantly accompanied by concern for its protection. But care for and protection of the cave have, of course, always depended on the knowledge, criteria and economic plans that were current at any given moment.

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, mihevc@zrc-sazu.si*

Formal protection of the cave

A law to protect the cave from vandalism, in particular the breaking-off and selling of stalactites and stalagmites, was first mooted in the late 19th century. Full legal protection of the cave did not arrive until 1948 (Simić 2000), while since 1999 caves in Slovenia have been protected by the general Nature Conservation Act and, since 2004, by the Cave Protection Act. Under the Act, Postojnska jama is the property of the state, which leases it to a concessionaire. The concession agreement contains a definition of ordinary show cave use, in other words ordinary visits to the cave. Special visits and events, on the other hand, must be approved by the Institute for Nature Conservation or the competent ministry. Investment in the cave is permitted on the basis of an approved annual and long-term programme of use of the cave. All tourism infrastructure in the cave is the property of the state. Money invested in infrastructure is taken into account in the payment of the concession fee to the state. Part of the concession fee goes to local communities.

The first criteria for the protection of Postojnska jama were established by the management, i.e. the Cave Commission, immediately after the discovery of the inner sections of the cave in 1818. In order to avoid damaging the cave,

Fig. 1: Broken speleothems in Matevžev rov. Here speleothems were broken off in order to be sold in the mid-19th century.

illumination with flaming torches or flambeaux was prohibited (because they produced too much soot), as were vandalism and the breaking-off of stalactites and stalagmites in the main sections of the cave. The commission in fact defined the side passages and even other caves where it was permitted to collect stalactites and stalagmites, which were then sold on stalls outside the cave. The money raised from their sale was counted towards the revenue of the cave. Private trading in speleothems by cave staff was prohibited and was considered theft (Kranjc 1998). An important source of speleothems for sale was the building of paths in the cave, since this involved the removal of hundreds of stalagmites. The speleothems were bought by collectors, while large and beautiful examples were given as gifts to important visitors to the cave such as kings and prime ministers, or to museums for their collections.

Illuminating the cave

The cave explorers and the first visitors used torches, candles and oil lamps. Torches were, however, relatively uncommon and evidence of their use is only found in the Črna jama. In as early as 1825 it was decided to prohibit the use of torches because of the excessive quantities of soot they produced. Visitors to the cave were accompanied by guides carrying lamps and the cost of admission also depended on the illumination provided. Later on, small oil lanterns fixed to the walls represented an important source of light. Holes were drilled in the cave walls (or in speleothems) and wooden plugs inserted. Metal brackets for oil lanterns were then affixed to these. Even today, hundreds of holes plugged with wood, the remains of brackets and oil lanterns are still visible in the cave. The lanterns were lit before visitors arrived and extinguished once they had passed. During important visits and on special occasions the cave was also illuminated by candles.

In 1891 the whole of the tourist path through the cave was light by electricity. Small brick structures were built at various points in the cave to house transformers or distribution stations. Some of these were later demolished and the bricks dumped in side passages. Today these housings are being replaced by small junction boxes. Electric wires were originally suspended

Fig. 2: *Electric cable protected and masked by concrete at Kalvarija.*

overhead and porcelain insulators were fixed to walls and stalactites. Later this system was replaced by cables hidden from the view of visitors. The cables were buried in the path or in sediment, or laid in ducts cut into the rock or flowstone floor and then cemented over. In some places cables were laid directly over flowstone and then cemented over. The reason for the cementing was to mask and protect the cables. The route of the wiring changed several times and as a result old cables and insulators, plastic, tar and other materials have remained at numerous points in the cave. The electrical wiring was later joined by other wiring systems, for example for communication systems and video surveillance, and fibre optic cables for computer systems.

Electricity was used to power various bulbs or arc lights. Fluorescent lights were later introduced, while more recently a transition to LED lighting has begun. The lights were shaded so as not to dazzle visitors. Shades were frequently constructed from rock or flowstone and other cave formations.

With the introduction of electric lighting, the problem of lampenflora appeared. At some points the surface of speleothems is already covered with green algae, while in places mosses can be seen growing near the lights. In the section known as the Lepe jame and the other greenest parts of the cave, the speleothems and rock are cleaned with hyperchloride and hydrogen peroxide. Cleaning is carried out just once a year or even less frequently.

Cave infrastructure

Construction of paths, steps and bridges commenced immediately following the discovery of the new sections of the cave. Evidence of the major earthmoving works undertaken in the cave at that time is provided by finds of hippopotamus, cave bear and cave lion bones. In 1819 the scientist H. Freyer, while looking for bones for the museum in Ljubljana, had to dig down through two metres of filling material in order to come to the original cave floor (Rakovec 1951).

The original paths have survived in fragmentary form in just a few places. They were narrow and winding and had many steps. The present wide paths were later built on top of them. These are cut into the rock or flowstone or run along embankments. Material for levelling the floor was

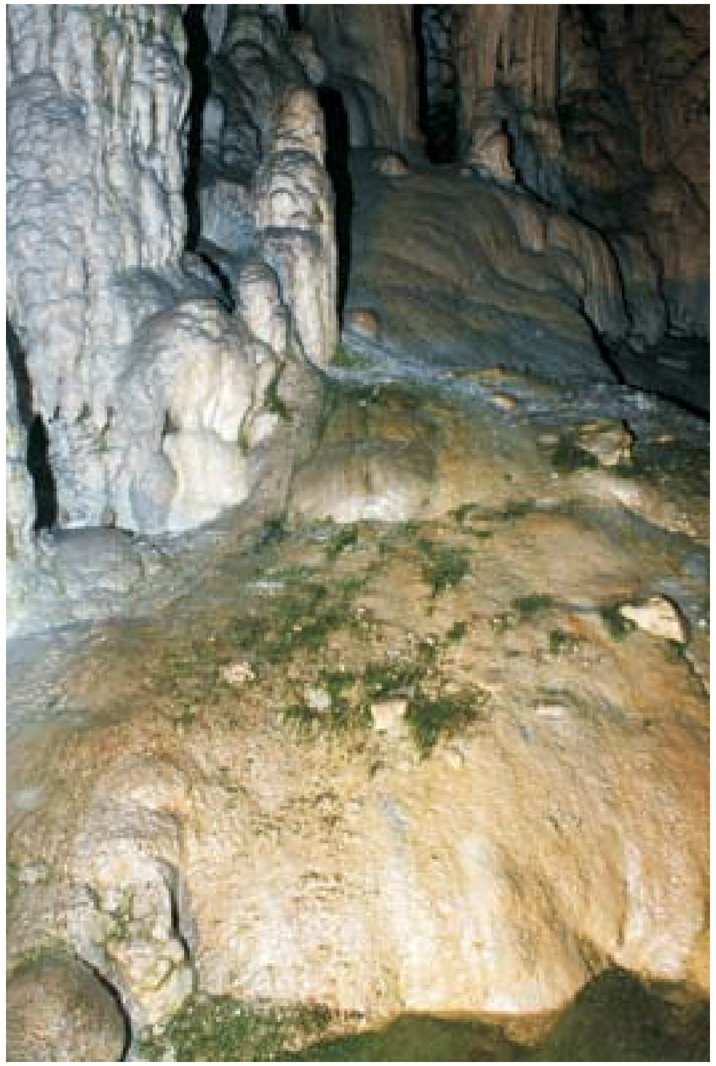

Fig. 3: *Growth of algae by a light below Kalvarija. Light and moisture are necessary for growth.*

excavated right next to the path in the passages. The quarries and sandpits at the top of Kalvarija and the claypits in the Stara jama section along the railway line are particularly unsightly. The paths through the cave are for the most part around two metres wide. Only in the Lepe jame are they narrower: at three points the path is less than a metre wide. In some passages the paths have been widened into broad platforms extending from wall to wall. The floor has also been levelled in the Kongresna dvorana and the Koncertna dvorana. The floor surfaces were originally covered with sand. In places this raised the floor level in the passages by several tens of centimetres and the sand got into the neighbouring flowstone or sediment surfaces. Later the floors were covered with cement. The cement paths are regularly washed with water so a drainage system is built into the path. In places the runoff from the paths is channelled into sedimentation ditches, while elsewhere it drains directly onto the floor of the passages.

A number of tunnels were built to ease access: for example in the section known as the Male jame, in the Tartarus section, and between the Pivka jama, the Črna jama and Postojnska jama. For the most part the excavated material was dumped in the cave, despite the fact that it amounted to hundreds of cubic metres of rock. The tunnels altered the natural circulation of air in the cave and were therefore sealed in places by solid doors.

Fig. 4: The old path from the first half of the 19th century. A visit to the cave along this path lasted several hours.

The most important development in the cave was without a doubt the railway. In 1872 a 1,500-metre railway track was laid on the levelled floor of the cave. Cave guides propelled little four-seater carriages down the track to a terminus below Kalvarija, after which the visit continued along the footpaths. Later the introduction of locomotives and larger trains began to be considered. The track was completed in 1924. At first visitors could choose between visiting the cave on foot or by train, but after construction of the 3.7-kilometre two-track loop in 1964, there was no longer room for a path in the passage. Construction of the railway line involved levelling practically the entire floor of the passage for a length of 1,500 metres

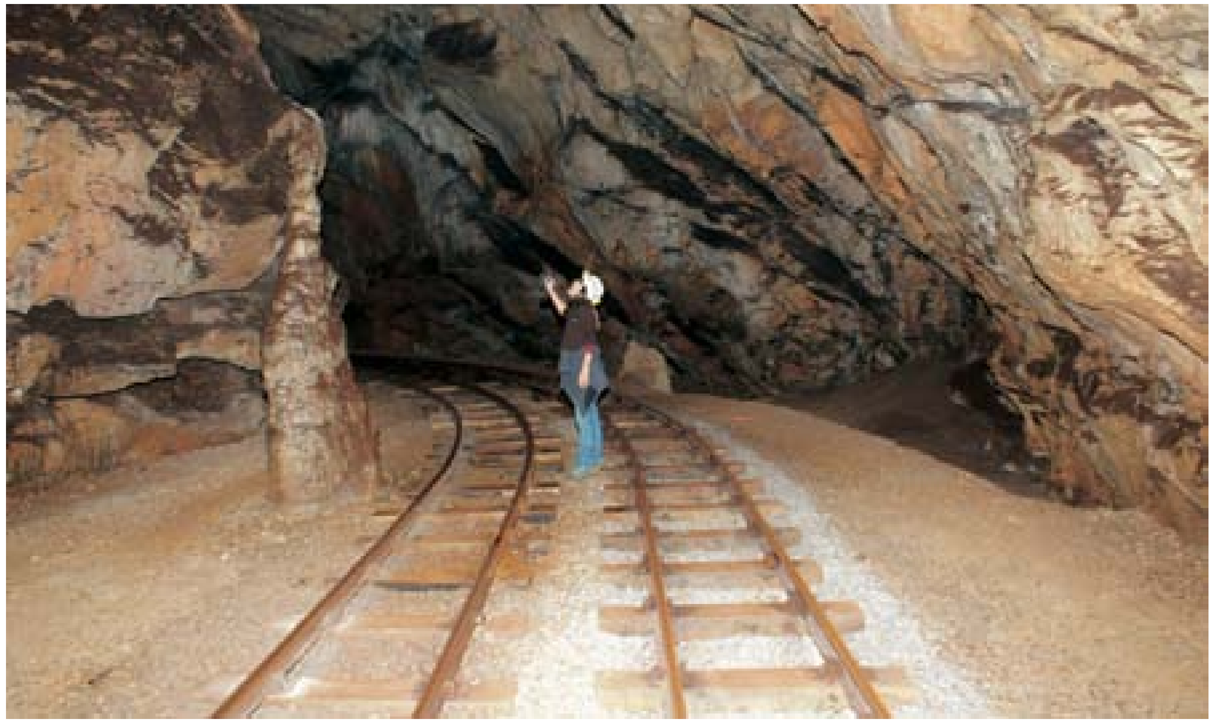

Fig. 5: The cave railway in Postojnska jama: the embankment covers the whole of the passage. The rust particles are raised into the air by the draught and settle on speleothems and rock. Part of the embankment where the gravel has been replaced is still white.

and, where necessary, covering it with sections of embankment. In places the line was even cut into the walls of the passage or into flowstone formations and tunnels.

While making it easier for tourists to visit the cave, operation of the cave railway also has a constant impact on the cave environment. The railway lines are laid on wooden sleepers. These sleepers rot and fungi grow on them, and as a result the part of the cave by the railway line has a characteristic rotten smell. The rails themselves and other parts of the line are subject to rust. Rust is washed onto the cave floor or, in winter, is carried through the cave when the railway passage dries out. It is then lifted by the wind of the passing train and deposited, together with mould spores, on the walls of the passage. A lot of dust is also raised by regular annual maintenance work, particularly welding, polishing and cutting rails. The walls of the passages along the railway line – both rock and speleothems – are therefore badly discoloured by brown rust. As soon as we move away from the line, the covering of rust disappears or is thinner and less visible.

Various structures were built in the cave in the past and subsequently removed. Some of them were necessary for the organisation of visits to the cave and may be considered cave infrastructure. Others served merely to increase revenue from the cave. Some of them today have historical value.

Several toilets with septic tanks were built in the cave for visitors. These toilets were later abandoned, although one still survives. The toilet in the Koncertna dvorana, with an outflow directly into a fissure in a side passage, has been in use for decades. The toilets are currently being renovated. A small treatment plant has been added that will have an outflow underground (Dvorščak 2011).

Other structures in the cave included a cave post office, a restaurant and a souvenir shop. There was also a diesel generator for electricity and a charging station for the batteries of the cave trains. Palaeolithic stone tools were found in the sediment-filled continuation of one of the passages which was cut through during

construction of the station and train workshop. The cave also contains several pools or aquariums to enable visitors to view specimens of the *Proteus anguinus*, "human fish" or cave olm.
In 1932 a biological research station containing numerous aquariums and terrariums was set up in the Rov novih podpisov. Today the station has become part of the show cave. A 10-metre tunnel was dug in Tartarus to enable the setting-up of a seismological station. This suffered from frequent flooding and is today abandoned. Various researchers have set up instruments in the cave, set traps for animals or taken samples of sediments. This is not so evident in the case of deposits in cuttings or lateral sections but is worse in the case of the removal of flowstone, despite the fact that every removal of samples for analysis is done in accordance with a permit from the competent institution.
Three free-standing monuments were erected in the cave to commemorate important Imperial visits – and later removed for political reasons. A number of different commemorative plaques were also erected. The majority of these have been removed.
The cave entrances have changed considerably (Mihevc 2004). The original entrance was small. A second entrance choked with sediments was later significantly deepened and a metal door fitted. The present large entrance to the cave was choked with sediments until 1866. Today it is blocked by a grille gate. When building the railway line or train shed, a continuation of the Rov novih podpisov was also connected with the surface. The ponor of the Pivka was widened. All these interventions had a considerable effect on air circulation in the cave and caused the entrance sections to dry out in winter (Gams 1968). Important parts of the cave were also destroyed, including entrances and archaeologically and palaeontologically interesting sediments.

Fig. 6: The old entrance to the cave with the original gate and the original stone gateway, today lost.

The impact of visitors on the cave

The cave is also affected by the large numbers of visitors. In the winter season, visits take place four times a day; in the summer there are up to 10 visits a day. Visitors remain in the cave for approximately one and a half hours. They travel a total of 3.2 kilometres by train and cover 1,800 metres on foot. Transporting visitors into the cave, lighting, and the visitors themselves release a considerable amount of thermal energy in the cave. Owing to the cave's large dimensions and the strong draughts, however, this does not significantly influence the temperature in the cave. Draughts occur in the cave because of the numerous entrances with a height difference of 112 metres, and because of the heat brought into the cave by the river Pivka (rate of flow 4.6 m^3/s). The draught is also effective in lowering the concentration of CO_2 in the cave.
The large number of visitors results in the release of a large quantity of dust particles and, in particular, fabric fibres, which accumulate in some parts of the cave. In most of the cave, however, this dust is washed away naturally because of the large quantity of annual rainfall and the consequent dripping in the cave, and is therefore not noticeable or unsightly. It is probable, however, that it will become a problem over time.
Traces of vandalism, in the form of deliberate damage to the cave, are visible everywhere, although for the most part they date from an earlier period. Many visitors have removed speleothems from the cave as a souvenir or for their own collection. Today's visitors remain behind a railing and are supervised at all times. Individual cases of visitors breaking off cave formations and climbing over the railings are rare.
Leaving one's signature in the cave was originally a privilege limited to just a few researchers and important guests. The signatures today have considerable historical value. Signatures of visitors from the first half of the 19th century are also common. These occupy prominent positions in the Rov novih podpisov and along the section known as the Stara jama. It appears that particularly eminent visitors were allowed to sign their names here, along with others who probably paid for this privilege. What is certain is that permission to sign the cave wall was granted by the guides who accompanied visitors through the cave. More recent signatures, particularly those from the 20th century, may be considered vandalism, since signing the wall of the cave is now prohibited.
Something else that may be considered a form of vandalism is the negligent maintenance of cave infrastructure: discarded light bulbs and pieces of wire in the vicinity of lights, building material that has not been removed from the cave, pieces of wood and so on. Some years ago rat extermination was carried out in the cave. Bags of rat poison, which no one later removed, were dumped throughout the sections of the cave open to visitors. It would be interesting to know who permitted the use of poisons in the cave.

Conclusion

After almost 200 years of intensive use as a show cave, Postojnska jama is still a unique, beautiful, interesting and relatively well preserved cave. In it, we can still sense the original essence of the underground world. At first glance, the tourism infrastructure and the traces of other developments in the cave do not alter this impression. A closer look, however, reveals that numerous interventions in the cave were carried out too hastily, since they have disfigured the cave and lessened its value as a tourist attraction without a thought for future development.
Numerous traces of its use as a show cave have remained in the cave. The cave contains a considerable infrastructure that enables large crowds of visitors to visit it easily. It also contains traces of interventions deriving from

the period of its exploration and development as a show cave, and from the maintenance of installations that were inappropriate, excessive or questionable and reduced the value of the cave both as a natural phenomenon and as a tourist attraction. The consequences of the daily use of the cave are also evident – and in some places continue to accumulate.

Postojnska jama was the first cave in Slovenia to have rules for its management or use. These rules have protected above all its value as a tourist attraction, its beauty and its wealth of speleothems.

The building of infrastructure in the cave has above all been conditioned by economic interests or the growth in visitor numbers. The railway, for example, was built as an attraction to advertise the cave. In a similar way, the construction of a chairlift was later considered in the Škocjanske jame. The majority of events organised in the cave could be placed in the same category, since they merely use the cave as a backdrop and it would therefore be better to organise them elsewhere.

Protecting the cave and ensuring its conservation has always depended on knowledge and a system of values. Great attention has been devoted to the protection of speleothems in the part of the cave open to visitors. In other parts of the cave, however, they have been broken off and sold. Rock walls and sediments had no value and were therefore destroyed, unnecessarily – for example the entrance to the Biospeleološka postaja and the sediments in the main entrance. The loss of palaeontological and archaeological material is a loss for science, and is also bad tourism because archaeological finds presented in a museum can also be profitable.

References

Dvorščak K., 2011. Biološka čistilna naprava-inovacija v koncertni dvorani Postojnske jame. Proteus anguinus, 7/1, 3, Postojna.

Gams I., 1968: Rast in oblika kapnikov v Postojnski jami. In: Bohinec V. (ed.). 150 let Postojnske jame : 1818-1968. Postojna, Zavod Postojnske jame: 89–104.

Kranjc A., 1998. O "rabi" kapnikov iz Postojnske jame. In: Kranjc A., Paternost S., Šajn S., (eds.). Postojnska jama : nova spoznanja : new discoveries. Postojna: 21–23.

Kranjc A., 2007. Uvod. In: Kranjc A., Kariž S., Paternost S., Polak S. (eds.). Postojnska jama : vodnik. Postojnska jama, turizem d.d., Postojna: 12–19.

Mihevc A., 2004. Show cave entrance: the case of Postojna cave. In: Zupan Hajna N. (ed.). Use of modern technologies in the development of caves for tourism. Postojnska jama, turizem d.d., Postojna: 107–110.

Paternost S., 2011. Struktura obiskovalcev v letu 2010. Proteus anguinus, 7/1, 2, Postojna.

Rakovec I., 1951. Jamski lev (Felis spelea Goldf.) iz Postojnske jame. Razprave 1: 127–164.

Shaw R. T., 1992. History of Cave Science. The Exploration and Study of Limestone Caves, to 1900. 2nd Edition. Broadway, New South Wales, Sydney Speleological Society: pp. 338.

Shaw T., 2008. Foreign travellers in the Slovene Karst 1486–1900. Ljubljana, ZRC Publishing: pp. 338.

Simić M., 2000. Prispevek k poznavanju zgodovine varstva jam na Slovenskem ob pripravi Zakona o varstvu podzemnih jam. Naše jame, 42: 49–77

Šajn S., 1998. Obiskovalci Postojnske jame. In: Kranjc A., Paternost S., Šajn S., (eds.). Postojnska jama : nova spoznanja : new discoveries. Postojna: 39–45.

TWO CENTURIES OF EXPLORATION, TOURIST USE, MANAGEMENT AND PROTECTION OF ŠKOCJANSKE JAME

Rosana Cerkvenik [1]

The Škocjanske jame cave system is located in the Škocjan karst, on the eastern edge of the Kras plateau, close to the Brkini flysch hills. The cave system is almost 6 km long, and comprises eleven karst cavities with four independent entrances. These active and fossil speleological objects are connected by two collapse dolines – Mala and Velika dolina (Rojšek 1993). The cave is a permanent ponor of the Reka – the greatest sinking river in Slovenia – which flows through the main channel to the sump roughly 2 km inside the cave. Approximately 3 km of the cave system is open to visitors. The caves have been protected as a natural monument since 1980 and as a Regional Park since 1996. At an international level, the caves were included in the UNESCO World Heritage List in 1986 and in the Ramsar List of Wetlands of International Importance in 1999. Since 2004, the park has also been a member of the UNESCO's MAB (Man and Biosphere) Programme as the Karst Biosphere Reserve.

Cave use

In order to understand the importance of the caves and the reasons for their protection, it is necessary to become familiar with the history of cave use. Throughout history, the caves have been used for different functions, from being used for hiding purposes and as a mythological location, to cave exploration, tourism and scientific research.

Caves in prehistoric times

In the Palaeolithic Era, the Roška (Ozka) špilja cave was settled in the part where it was possible to access the water in the river in Velika dolina (Gams 2003). Animal bones, several fireplaces and stone tools from the late Palaeolithic Era have been found in the cave (Puc 1999). The Tominčeva jama (Tominc's cave) was visited and settled in the Neolithic, Bronze, Iron and Roman ages (Gams 2003). The cave is acknowledged as being the most extensive archaeological cave site in the karstic terrain of the South Eastern Alps. Several culture layers were found, separated by sand and clay flood sediments. Stone tools, animal bones, ceramics and copper tools have been found in the lower layer. Ceramics date back to the Early Bronze Age and the beginning of the Middle Bronze Age. Ceramic and cooper tools from the Bronze Age have been found in the middle layer. The upper layer was rich with archaeological finds dating back to between the 3rd and 5th centuries BCE, and consisted mainly of fragments of amphora, ceramics, glass vessels and metal finds. Some of the finds indicate that Christian rites may have taken place in the cave. In the very top layer, finds from the Early Middle Ages have been discovered. The cave is also recognised as the largest burial place in

[1] *Škocjan Caves Park Public Service Agency, Škocjan 2, SI-6215 Divača, Slovenia, rosana.cerkvenik@psj.gov.si*

the Kras. In the passage, several skeletons from the Iron Age (5th to 4th century B.C.) have been discovered and the skeletons of ten young persons were found in a vault which dates back to the Neolithic Period. Important and varied archaeological findings were also found in other caves close to the main cave (Puc 1999). The finds in the cave indicate that Tominčeva jama was probably mainly used as a religious and mythological place, rather than for living or hiding purposes (Turk 2002). In the main part of the cave–the part containing the Reka river–there have been no archaeological finds. Any archaeological discoveries that might have been found in this part of the cave have been washed away by the river.

History of cave exploration, cave management and tourist development

The first written sources on Škocjanske jame originate from the Late Antiquity. Poseidonius of Apamea (135 BCE – 50 BCE) wrote, "the Timava river flows from the mountains, falls into an abyss, (i.e. Škocjanske jame) and then, after flowing about 130 stadia underground, springs beside the sea". Škocjanske jame features in the oldest published maps of this part of the world, such as the Lazius-Ortelius map of 1561 and Mercator's Novus Atlas of 1637. Valvasor was also impressed with this important phenomenon. He illustrated the basin of the Reka and described its underground flow in detail in his work entitled "The Glory of the Duchy of Carniola" (1689). The fact that the French painter Louis-François Cassas (1782) was commissioned to paint some landscape pieces also proves that, in the 18th century, the caves were considered one of the most important natural features in the Trieste hinterland. His paintings bear witness to the fact that people visited the bottom of Velika dolina at that time.

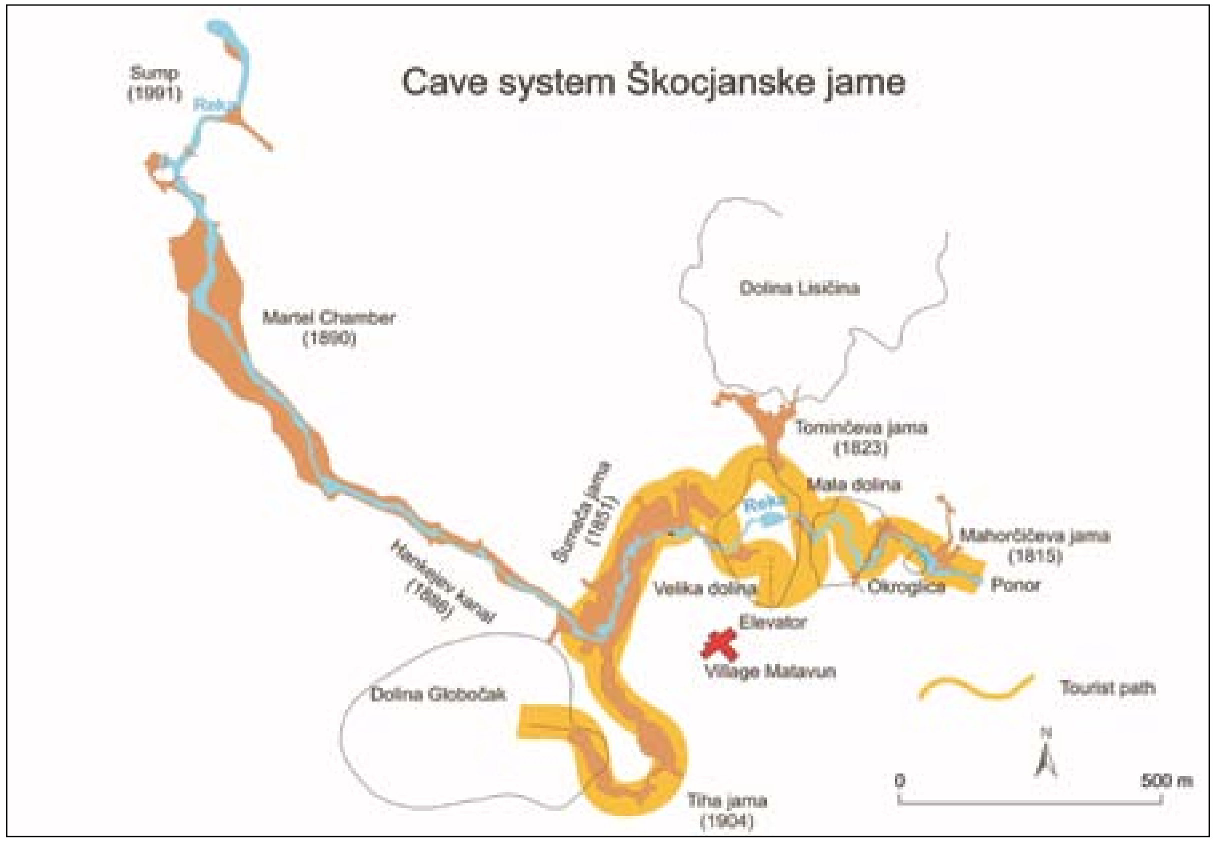

Fig. 1: Ground plan of the Škocjanske jame cave system with the present-day tourist path marked.

The local inhabitants have been visiting Mala and Velika dolina ever since. The first cave explorer to investigate the main water channel was, in all likelihood, Joseph Eggendorfer of Trieste who swam in the river in the Mahorčičeva jam (Mahorčič's cave) and Mariničeva jama (Marinič's caves)in 1815. The first visitor's book was opened in 1819 and the first tourist path to the Velika dolina was laid in 1823 and financed by Matej Tominc (Puc 1998). Upon completion of the path to Velika dolina, the community of Naklo kept the key and evidence of those who had visited (Savnik 1968).

Explorations of the main part of the cave (Šumeča jama) began in 1839 when Jakob Svetina (together with a local) followed the underground river by boat, but turned back after 110 m. He continued his research in 1840 and managed to get as far as the third waterfall (Shaw 2008 and Puc 1998). In 1851, Adolf Schmidl scrambled up the rocky slope from the bottom of the doline, very near to the water sink, up to the large dry cave now known as Schmidlova dvorana (Shaw 2008: 52).

A great step was taken in the history of Škocjanske jame in the years following 1884 when the Sektion Küstenland of the D.Ö.A.V. (Littoral Section of the German-Austrian Mountaineering Society) commenced with the systematic research of the cave. As well as the successful exploration of the cave, tourist paths and bridges were constructed, experienced guides made available, and standard fees were introduced, all more or less simultaneously (Shaw 2008). There were 27 members of Sektion Küstenland, comprising mainly Slovenians and immigrants from other parts of the Austro-Hungarian Empire (Žiberna 1981). The first visits made by members of Sektion Küstenland were in 1883; in 1884, a contract was signed between the Naklo community and Sektion Küstenland (Puc 1998). As systematic exploration began in 1884, a 5-year contract was signed in 1885 between Sektion Küstenland and the owners of the land at the entrance to the cave. The contract stated that the cave workers were permitted to lay paths in the cave, and to explore and enlarge (new) entrances and caves without being obliged to make any payment to the owners of the land. In 1884, an Act was declared on the issue of cave guiding for the Sektion. Following the book of rules, the local inhabitants were not only to be made available as guides, but were also to work as cave workers in laying paths and furthering cave exploration. In 1885, a public proclamation was prepared by Sektion Küstenland, stating that Sektion Küstenland had rented the caves for the purpose of opening them to the public and in order to explore the underground flow of the Reka. In order to achieve these goals, finances were required and a detailed price list was drawn up as a result (Puc 1999).

In the years that followed, the "company" of members of the Sektion Küstenland and local cave workers were particularly successful in their cave exploration and laying paths. On several occasions, water levels were high and prevented works and exploration from continuing. The underground canyon was explored to the sump in lake Marchesetti in 1893 (*Finish Erforschung*). After 1893, efforts focused on increasing the number of visitors, laying new paths and renovating those that had been destroyed by floods. The wooden constructions were decaying rapidly and the paths were cut into solid rock as a consequence. The cave workers cut the paths, hammered the pins and hauled steel. The last great success of this period was in 1904 when the local inhabitants explored the Tiha jama (Silent cave) passage. World War I brought almost all the activities carried out in the cave to an end and a total of 20 out of the 27 members of Sektion Küstenland died in battle. After World War I, the Primorska region became part of Italy and the intention of the fascist organisations in Italy at that time was to abolish all "foreign" societies, among which also D.Ö.A.V. Società Alpina delle Giulie Sezione di Trieste del Club Alpino Italiano took control of the management of the cave in 1922, as well as the D.Ö.A.V. archives in Trieste and Matavun and, in all probability, were responsible for destroying much of the archive in Matavun, including the visitor's book which dated back to 1819. In the same year, the General Civil Commissariat declared the Rules for mountain and cave guides, by virtue of which the guides were able to register only through Club Alpino Italiano. The Italians renovated the paths in the upper part of the cave, close to the entrance, but not in the Hankejev kanal downstream passage (Puc 1999). During World War II, all the works in the cave came to a halt, including the annual works carried out due to high waters (Habe 1974). Just after World War II (in 1945), management of the cave was assumed by a special institution – Kraške jame Slovenije (Karst Caves of Slovenia), based in Postojna. The cave was no longer to be managed by SAG, and the movable and fixed property contained therein were nationalised. As the cave infrastructure had not been maintained for several years, it was in a ruined and decayed state. Cave works focused on the renovation of the paths, enlarging certain paths and levelling some slopes. In 1951, cave management was taken over by the independent institution, Zavod Škocjanske jame, within the Community of Sežana. The main work of the institution was undertaken in 1958 and 1959 when the cave was electrically illuminated. Due to high overhead expenses, the management of the cave was then taken up by the institution, Zavod Postojnska jama (Puc 1999).

An important milestone was in 1965 when flooding damaged the infrastructure, mostly in the Mahorčičeva jama and Mariničeva jama. After the flood, the direction of the visits changed and remained as is the case at present. The visitors enter the cave through the tunnel in Globočak (1933) and exit from the cave in Velika dolina. In 1986, an elevator from Velika dolina was installed to facilitate an easier exit. Another change in the management was effected in 1969 when the company, Hoteli in gostinstvo, from Sežana assumed management of the cave. The company joined to the company TOP Portorož in 1984 and managed the cave until 1999; since then, the public agency, Javni zavod Park Škocjanske jame, has managed the cave and park (Puc 1999).

After the Tiha jama passage was explored in 1904, tourism became the main focus of the cave's use as all the dry passages now known to exist had been discovered. As at 1991, there were no further important cave explorations. According to Morel (Morel 1992) the cave diving explorations commenced only in 1991 as the Reka had been polluted before this time. In 1991, cave divers swam across the siphon in Lake Marchesetti and explored 680 m of cave passages. In September 1992, exploration continued and another 600 m of cave passages were explored (Sancin 1992).

In addition to cave exploration and the development of tourism, important scientific research has also been carried out in the caves. The studies carried out on Škocjanske jame were of interest to several researchers in the past and today. The most frequently cave hydrology was studied and its connection with the springs of Timava. In 1913, Guido Timeus performed a tracer test in order to prove the existence of a connection between the Reka, the Labodnica cave (Abisso di Trebiciano) and the springs of the Timava river (Galli 2000). The most important studies undertaken after World War II commenced after the year in which Gospodarič studied the speleogenesis of the cave, the age of flowstone and cave sediments. In 1990, several researchers, mainly from IZRK ZRC SAZU, studied several characteristics of the cave such as its speleogenesis, hydrology, cave rocky relief, tectonics, biology, etc. Several other studies were performed which did not relate to the cave directly, but covered the recent surface of the park. The employees of the park are also involved in the research; for example, the underground river is monitored in collaboration with cave societies and scientists from Slovenia and Italy.

As the cave is an important archaeological site, it is worth mentioning that the archaeological

excavations were led in 1888 by Marinič and the local inhabitants. Scientific excavations also continued in 1889, carried out by Marchesetti (Puc 1999).

Challenges in laying infrastructure

One of the greatest challenges in Škocjanske jame was to pass the channel of the Reka. In 1885, the Tommasini Bridge in Velika dolina was built; the Concordia bridge in Mala dolina was built in 1891. The bridge had been in a state of decay since 1920 and was replaced in 1931; the Italian Administration named it Ponte Luigi Vittorio Bertarelli (Puc 1999). Before 1904, all the works focused on equipping the path from Müller to Martelova dvorana (Martel's chamber) for tourist use. However, as the Tiha jama passage was explored, the whole concept of tourist paths changed. It became necessary to build a bridge across the river in the Müller Chamber as soon as possible (Habe 1974). In 1906, the Swida Bridge was constructed in the Müller Chamber to allow access to the Tiha jama passage. In 1909, another bridge (Novakov most) was built above the Hankejev kanal passage for the purpose of providing access to Tiha jama, even at high waters. In 1933, the Ponte della Vittoria bridge (Victory Bridge) was finally built by the Italians over the Hankejev kanal passage and remained in use until 2003 when it was replaced. The bridge is now named Cerkvenik Bridge, after the Cerkvenik family, the members of which were cave explorers and responsible for constructing the bridge in 1933. In 1933, a bridge over the river in Mahorčičeva jama was built, along with three smaller bridges. In the same year (1933), an artificial tunnel was dug between the Globočak collapse doline and the Tiha jama passage. Upon the renovation of the bridges and paths and the completion of the digging of the tunnel, the path through the whole cave was inaugurated in 1933. The path was called Strada del Littorio and led from the first ponor in Mahorčičeva jama, through Mala and Velika dolina, into the underground canyon to the Tiha jama, and finished in Globočak (Puc 1999). This route was made available to visitors until 1965 when flooding destroyed the Mahorčičeva jama infrastructure.

Since the establishment of the Regional Park, there have been many works undertaken. In 2003 the electrification system was renovated and the bridge over the Reka was replaced. In 2009 and 2010, the Mahorčičeva and Mariničeva jama caves' and Mala dolina's tourist infrastructure have been renovated. Through the renovation of the infrastructure in the Mahorčičeva and Mariničeva jama caves and in Mala dolina, a further 1 km of path became available for visitors (Fig. 2). The renovation of the infrastructure in Mahorčičeva and Mariničeva jama was cofinanced by the European Regional Development Fund 2007–2013 and the Ministry of the Economy of the Republic of Slovenia. The costs incurred amounted to € 1,160,000. During the project, the paths and retaining walls were renovated. For the first time in its history, the path was electrically illuminated. The greatest investment made was the construction of a new bridge over the Reka in Mala dolina. The old bridge was first built in 1891 and replaced in 1933.

Annual investments are also made in the infrastructure in the cave, such as the renovation of the path in the Hankejev kanal (Hanke's passage), the repair of tourist paths in the Tiha jama and Šumeča jama passages, the refurbishment of handrails, and the maintenance of the protecting nets on the walls in the underground canyon.

Visitors to the cave

Despite visits to Velika dolina and the cave already taking place in the 19th century, the systematic record of visitor statistics began in 1901. The statistics are incomplete for some years; the period during both World Wars is one example. Nevertheless, as mentioned earlier, all the works in the cave and any tourist activity came to a halt during this time. According to known data, there were approximately 2,600,000 visitors to the Škocjanske jame during the period 1901–2010.

During the period in which D.Ö.A.V. managed the cave (1901–1922), there were almost 40,000 visitors. In the next 20-year period, when the cave was managed by the Italians (1922–1940), the number of visitors rose to 113,000. Visitor numbers peaked in 1933 with more than 15,000 visitors per year. The Italians were well aware of the importance of the cave for tourist development, but they also wanted to present the cave as being an Italian cave. They established the Committee for Cave Settlement, the members of which were elected in 1932. They invited a special tender to finance and prepare a programme to encourage more visitors to attend (Habe 1974). Most of the visitors came from Trieste and North Italy (Puc 1999).

In the cave's history, the most important event to have taken place for its visitors was "Grottenfest", which was organised for the first time in 1885, but not in an official capacity. At least 100 members of Sektion Küstenland and local residents participated in the event. The aim of the event was to present the explorations and the works performed that year. The first official "Grottenfest" was held in 1886, the year in which the cave was officially inaugurated and the first anniversary of renting the cave. Since 1885, the "Grottenfest" has been organised every year until 1911 with up to 1,000 visitors annually. Thereafter, adverse weather conditions resulted in fewer visitors; this caused Sektion Küstenland to lose money and they decided not to organise it anymore. Sektion Küstenland organised another "Grottenfest" in 1912 (Puc 1999). The Italian Administration organised the event during the 1923–1933 period. After World War II, the event was held again in 1946. The name of the event has also been known by the local residents as "Belajtnga", which derives from the German word "Beleuchtung" which means "illumination". After many years, the Regional Park decided to organise the event in 2007 for the purpose of reviving such an important historical event. The festival is organised by the Regional Park and the Škocjan Tourist society. The number of visitors is around 1,500. During the festival, the cave is lit by carbide lamps and candles and its visitors proceed unaccompanied through the cave and the festival in the village, which includes the sale of local products and music until nightfall.

Fig. 2: Through the renovation of the infrastructure in 2010, a further 1 km of path in the Mahorčičeva and Mariničeva jama caves and in Mala dolina became available for visitors. in the Mahorčičeva and Mariničeva jama caves and in Mala dolina (Photo: B. Lozej, Archive of PŠJ).

Cavers from Sektion Küstenland made efforts to develop close ties with the local residents. As such, in December 1886, they gave presents to local scholars for the first time (at that time there were 160 scholars in Škocjan) and this custom was practised for several years. The popularity of the members of Sektion Küstenland rose rapidly. During the Italian period, the Administration gave presents to scholars from Škocjan in 1926 (Puc 1999).

Just after World War II, the number of visitors rose to 6,000 per year. But after 1959 the number of visitors increased, although there were some years when the number was lower. During the period 1960–1990, there were a total of just under 1,200,000 visitors, ranging from 20,000 to 70,000 per year and peaking in 1987. After the Slovenian Independence War in 1991, the number of visitors dropped from 56,000 to 24,000 visitors per year. Since 1992, visitor numbers have been generally increasing, and peaked at over 100,000 visitors in 2008. In light of the recent general economic situation, the number of visitors has dropped slightly since 2008, with just over 90,000 per year. Nowadays, promotion programmes are oriented towards sustainable tourism. The aim is to disperse visitor numbers throughout the whole year, to put an end to the high peak in the summer, and to enable visitors to spend more time in the park and the surroundings by providing suitable information about the options available.

In order to present the cave to its visitors, several guidebooks have been published. The first were published by Sektion Küstenland in 1887, 1896 and 1907 and were devoted entirely to Škocjanske jame (Shaw 2008). Several further publications were also published thereafter.

Cave management today and throughout history

In the last 200 years, cave management has changed considerably. When the Regional Park was established in 1999, it inherited the cave's immense historical value, its technical heritage since the 19th century, its infrastructure and the damage accumulated therein. Despite the many changes made to cave management, cave exploration, techniques and materials, there has been one constant factor – the local inhabitants' long-standing association with the cave. One of the main missions of the Regional Park is to respect the rich history of the local inhabitants and their attitudes towards the cave; in addition, close cooperation with the local inhabitants and ensuring they are included in cave presentations and cave-related events, as well as being kept up to speed with all the works carried out in the caves, are of particular importance.

During the period in which the caves were managed by the D.Ö.A.V., a distinction was made between cave explorers, usually educated members of the Sektion Küstenland, and local workers, known as "Grottenarbeiter", who were paid weekly for their work. However, the explorers soon realised that they were not capable of exploring the caves without the assistance of the local inhabitants and, as a result, the residents also became known as cave explorers. As the cave was equipped for the visitors, the locals became also cave guides and retained this role during the time when the cave was managed by the Italians. After World War II, the situation changed and cave guides became employees of the institutions responsible for managing the caves. As society and science has developed, the method of guiding has also changed, not least in the way in which guiding is construed. An increase in the number of visitors also requires more guides. In the Regional Park, there are full time employees (park rangers) who also guide visitors through the cave and the park. In the high season, there are also cave guides who work on a seasonal basis. Special attention is devoted to the education of the rangers and seasonal cave guides, all of whom regularly participate in lectures covering various aspects of karstology, speleology, geology, hydrology, speleobiology, archaeology, nature protection, cultural heritage, the interpretation of nature, rhetoric, foreign languages, etc. in order to present the caves and the protected area and their importance in the best way possible. One of the main missions of the Park is also to cooperate with other protected areas in Slovenia and Europe and to promote the importance of World Heritage.

An important distinction throughout history was also how the works carried out in the caves were financed.

The members of Sektion Küstenland realised that income generated by visitors was low, at least in the early stages, and so they invited wealthy members to become sponsors. For several years, this proved to be an excellent practice. The sponsors were also wealthy visitors. However, in 1897 the income generated by the visitors and sponsor donations were already insufficient to cover costs. Therefore, the Ministry for Agriculture granted funding for the purpose of laying down a section of the path (Puc 1999). After World War II, a socialist regime assumed power in Yugoslavia. Almost all the companies and institutions were nationalised. This situation changed in 1992 when Slovenia became an independent state. Cave investments were made by the managers (companies) from the income generated and, on occasion, also directly by the State, as the area was categorised as an underdeveloped region. The works were occasionally done by the soldiers or by volunteers as it was a common practice in socialism. Since the Park was established, its full-time employees are State employees and paid by the Ministry for the Environment of the Republic of Slovenia. The income generated by the Park's visitors is allocated for investment in its infrastructure, for the payment of the seasonal cave guides and for commercial expenses incurred (advertising, promotions at fairs, etc). European projects are also an important source of funds. The Park has participated in several projects, (e.g. PHARE, INTERREG, and the European Fund for Regional Development) through which its infrastructure has been renovated and educational programmes developed. Recently, the contribution of volunteers has been important – local residents participate in common actions and assist with the works carried out in the cave and in the Park on a voluntary basis.

The greatest advantage of cave management is that the caves enjoy the highest level of protection in holding the status of a Regional Park and as a World Heritage Site. With this kind of protection, all the activities carried out within the protected area are controlled.

One of the disadvantages (but this does not depend on cave administration) is that, despite the efforts made to disperse visitors throughout the whole year, most of the visitors arrive during the summer season and, as a result, the greatest pressures on the cave system are at this time.

Another disadvantage is that, with the increasing number of visitors, problems arise in relation to parking places and waste waters. Therefore, the carrying capacity has been in progress for the whole Park and not just for the cave.

The Park is making efforts to encourage its visitors to attend during the other seasons of the year through the use of various promotions, e.g. additional discounts and lower prices during the off-season.

Legal protection of caves in Slovenia

The legal protection of the caves dates back to 1980 when the Municipality of Sežana issued a decree whereby the caves and their surroundings were proclaimed a natural and cultural monument. The natural and cultural monuments, the surrounding of the monuments delineated listed and the limitations and prohibitions (Odlok o zavarovanju Škocjanskih jam 1980) were listed in the decree.

In 1996, the Parliament of the Republic of Slovenia passed a law on the Škocjanske jame Regional Park for the purpose of protecting and safeguarding the natural and cultural heritage of the caves and their environs. The government of the Republic of Slovenia subsequently established a public agency to manage the Park, monitor conditions in it, and look after the implementation of international conventions (Debevec et al. 2002). The public agency was established in 1997 and assumed the leadership of the caves from the previous company (Puc 1999: 3) in 1999. The law covers the entire protected area, the caves and the buffer zone.

The most recent estimate is that there are approximately 30 caves in the protected area. Owing to the particular importance in question (natural, cultural, historical or aesthetical value), some other sites are also protected as natural or cultural monuments. Caves are protected as natural monuments or archaeological monuments.

Among the activities which are prohibited, it is forbidden to: visit the caves without supervision; to dig, collect or remove any petrographic, mineralogical and palaeontological samples; to destroy or remove cave depositions and other cave inventory; to blast; to pollute the cave walls, ceilings or cave floor in any way; to throw rocks or other objects into the caves; to perform any interventions that could put the cave entrances and the cave surroundings at risk; or to film in caves.

Aside from these restrictions, the Minister for the Environment may permit the picking of biota or individual fauna to be sampled for scientific research; the Minister also has the power to permit filming in the caves.

One of the advantages of the law on the Škocjanske jame Regional Park is also the protection of the catchment areas of the Reka – the buffer zone. In this area, any interventions that could affect the recent water regime of the Reka and its quality are not permitted, except in protecting against flooding. Other interventions that could result in any risk or danger to the environment or have an impact on the Park are also prohibited. The quality of the Reka, according to the monitoring performed by the Environmental Agency of the Republic of Slovenia, has been in a good chemical and biological state since 1995. The quality of the water has considerably changed over time as the river was one of the most polluted rivers in Slovenia in the period 1969–1990. The main pollutants were wastewaters from the fibreboard factory and the production of organic acids in Ilirska Bistrica (Mejač et al. 1983). In 1990, the organic acid factory was closed and, as early as 1992, water quality noticeably improved (Kogovšek 1999).

The ranger service of the Park takes direct control; this control is also implemented by the Inspectorate of the Republic of Slovenia for the Environment and Spatial Planning and by the Inspectorate of the Republic of Slovenia for Culture.

In Slovenia, there are also other laws in place that cover the protection of the caves and are also valid for Škocjanske jame and park. In 1999, the Republic of Slovenia declared the Law of protecting the nature. The law was upgraded in 2000, 2002 and 2004. The law from 2004 has been recently valid. According to the Law of protecting nature, the surface and underground karst phenomena and underground caves have the status of natural value. The natural values can be of national or local importance. The difference is ascertained on the basis of expert values, comparing the whole country. In 2003, the Law protecting underground caves (published in 2004) was adopted in Slovenia. It was the first law in the territory of Slovenia that relates entirely to the caves themselves. The Law regulates the protection and use of underground caves, the protection regimes in place, protection provisions and other rules of treatment, including the restoration of underground caves that have been polluted or destroyed.

The Škocjanske jame have also been protected at an international level. In 1986, the caves were included in the UNESCO World Heritage List, according to several criteria: the largest known underground canyon in the world; an example of the contact karst; international karst terminology; numerous Karst phenomena; Velika and Mala dolina, the part of caves with sink holes and the underground canyon are examples of extraordinary natural beauty and have a great aesthetic value; due to particular microclimatic conditions an exceptional ecosystem has developed in Velika and Mala dolina; the region has a great cultural and historical significance as it has been inhabited since the Mesolithic period.

In 1999, the caves were included in the Ramsar List of Wetlands of International Importance.

Future of the cave system

It is clear that, after 200 years of use, the damage sustained to the cave by all cave users has been accumulating steadily. The most obvious damage has been sustained in the Tiha jama passage where fine sediment on the floor has been trampled; there are many off-trail footprints, damaged, soiled and broken flowstone formations, lampenflora and a great deal of debris, mainly a result of cave maintenance.

The rich history of cave exploration and the importance of the karst site must be presented properly. It is necessary to remove all decayed infrastructure without historical value and debris from the cave, as well as the objects and cemented plinths constructed which were used in the past for electric lightening, and pieces of dripstone which were cemented and placed in the cave. As most of the fine cave sediments have been trampled, these surfaces should be restored, as well as the prominent flowstone formations that have been damaged. It is also necessary to clean the cement and gravel leaking from the path on the sediments along the tourist paths.

The Programme for the Protection and Development of the Škocjan Caves Park for the 2011–2015 period is the main document where the relevant objectives to be met and the activities to be performed are defined. The infrastructure built in the cave should ensure that there are modern systems in place to guide and present the cave to visitors; electrical renovation is necessary in order to avoid the growth of lampenflora; the historic pathways should be restored in order to develop different cave guiding options and to present and preserve the technical heritage and historical value of the first cave explorers.

References

Galli M., 2000. La Ricerca del Timavo Sotterraneo. Trieste, Museo Civico di Sotria Naturale: pp. 174.

Gams I., 2003. Kras v Sloveniji v prostoru in času. Ljubljana, Založba ZRC, ZRC SAZU: pp. 516.

Habe F., 1974 (1973). Stopetdeset let turističnega razvoja Škocjanskih jam. 150 years of Touristic Development of the Škocjanske jame. Naše jame, 15: 23–40.

Kogovšek J., 1999. Onesnaženje vode na Krasu. In: Kranjc, A., (ed.): Kras: pokrajina, življenje, ljudje. Ljubljana, Založba ZRC; ZRC SAZU: pp. 311.

Mejač B., Roš M., Dular M., Rejic M., Ponikvar – Zorko P., 1983. Pollution of the river Notranjska Reka. In: Mednarodni simpozij "Zaščita Krasa ob 160-letnici turističnega razvoja Škocjanskih jam", Lipica, 1982. Sežana, SOZD TIMAV, DO TOP, TOZD Gostinstvo Sežana: 48–51.

Morel S., 1992. Za Mrtvim jezerom. Naše jame, 34: 152–153.

Puc M., 1998. Pomembnejši datumi v raziskovanju in turistični ureditvi Škocjanskih jam. Naše jame, 40: 75–80.

Puc M., 1999. Škocjanske jame pri Divači – kronika raziskovanj in turističnega obiska. Internal source: pp. 44.

Rojšek D., 1993. Škocjanski jamski splet. Naše jame, 35/2: 120–123.

Sancin S., 1992. Nova odkritja v Škocjanskih jamah. Naše jame, 34: 156–162.

Savnik R., 1968. Matej Tominc in Jakob Svetina. Prispevek k zgodovini raziskovanja Škocjanskih jam. Naše jame, 9/(1–2): 66–67.

Shaw T., 2008. Foreign travellers in the Slovene Karst 1486–1900. Ljubljana, Založba ZRC, ZRC SAZU: pp. 338.

Turk P., 2002. Archaeology. In: The Škocjan caves Regional Park. Škocjan, Park Škocjanske jame: pp. 101.

Žiberna J., 1981. Divaški prag. Divača, Svet krajevne skupnosti Divača: pp. 207.

KRIŽNA JAMA – A GOOD EXAMPLE OF THE SUSTAINABLE MANAGEMENT OF A SHOW CAVE

Mitja Prelovšek [1]

Križna jama is one of over 20 show caves in Slovenia. It lies at the centre of the triangle formed by Cerkniško polje, Loško polje and the Bloke plateau. With a length of 8,273 metres, it is one of Slovenia's longer caves, although only slightly over 10 % of its overall length is open to visitors. Owing to the cave's somewhat remote location, intensive development as a show cave did not begin until relatively late, in the mid-1950s. The cave's distance from main traffic and tourism routes is still today the main reason for the relatively low visitor numbers. In terms of the annual number of visitors (an average of 4,600 a year in the last five years), Križna jama is on the middle of the scale of show caves in Slovenia, where the two caves with by far the largest number of visitors are Postojnska jama (over 500,000 a year) and the Škocjanske jame (an average of 90,000 visitors a year in the last few years). These are followed by Vilenica (an average of 10,000 visitors) and the Jama pod Predjamskim gradom (8,810 visitors in 2006; Gabrovšek et al. 2008). The attractiveness of Križna jama is based on an underground watercourse that flows through several dozen underground lakes, which tourists can see during a visit to the cave. The cave is also notable as the site of a rich find of cave bear bones, which first attracted attention to the cave in the mid-19th century. An archaeological dig was led in 1878 by F. von Hochstetter (Puc 1986). The third notable feature is Križna jama's extraordinary subterranean biodiversity (fourth in the world in terms of the number of species), since the cave is home to as many as 44 (Sket 2000) or 45 (Culver & Sket 2000) different cave-dwelling species of animal. In view of the vulnerability of certain parts of the cave and, despite this, a very good state of conservation in relative terms, the management of Križna jama, particularly the current management, may be considered a model example of the management of a show cave with medium visitor numbers on the part of a local caving/tourism organisation.

Use of the cave through history and as a show cave

Evidence of periodic prehistoric visits to the cave is provided by fragments of charcoal in the Holocene calcite deposits in the entrance sections of the cave, where people made fireplaces in at least two separate locations. It is not known in what period fires were made in the cave, but on the basis of pottery finds it is clear that human beings used the cave during the Bronze Age (Bavdek et al. 2009). The first known signature on the cave wall dates from the year 1557 (Bavdek et al. 2009), while for the 17th century we have Valvasor's statement (1689) that it is highly likely that the inhabitants of the surrounding area went to Križna jama to fetch water. In the first half of the 19th century a few curious visitors had already gone beyond the first lake by boat, although they considered this point to be the end of the cave (Badjura 1909). In that period it was not only the local people who visited the cave, but also various travellers (Shaw 2008), although owing to the remoteness and "insignificance" of Križna jama their number was not great. In the middle of the 19th century, however, their scientific expertise contributed to the discovery of a rich find of cave bear bones in the Medvedji rov (Bear's passage). In the following century it was not only speleothems but also cave bear bones that were removed from the cave by visitors who wanted them as souvenirs (Badjura 1909, Puc 1986). As a result of archaeological excavations, this part of the cave has suffered the most damage. The excavations left behind excavated hollows, while their calcified covering of clayey sediments was shattered and completely destroyed.

The flooded section of the cave was explored in the 1920s, while between 1934 and 1937 the cave was systematically explored along a length of 5 kilometres (Puc 1986). In order to explore the cave, cavers used heavy wooden boats held together by nails, which were transported over the sensitive rimstone dams, causing serious damage. In dry periods, when the surface of the lakes can fall by several metres, people walked across the calcite-covered lake bottoms, in this way destroying the fragile calcite formations there. Nevertheless, because of the difficult access and, consequently, the relatively small number of visitors, relatively little damage was caused in the cave. Measurements made at that time resulted in detailed plans based on theodolite surveying. The cave's main passage was in fact measured by theodolite for the needs of the water supply system for the Loška dolina karst polje. As it turned out, the gradient was too slight to allow the collection of water, but in 1939 it was decided to transform the entrance section of the cave into a military facility (Archives of the Cave Exploration Society of Ljubljana). The outbreak of the World War II meant that the only work to be successfully completed was the widening of the path leading to the cave and the lowering of the entrance (Puc 1986) – which entirely destroyed any archaeological traces in the entrance section. Despite the plans, the interior of the cave remained unadapted to the needs of a military facility.

Following the World War II, in the 1950s, explorations of the cave revived, while at the same time the deliberate development of the cave as a show cave began – relatively late in comparison to other show caves in Slovenia. Despite the pre-war widening of the road leading to the cave, the post-war creation of a flat area in front of the cave, the setting up of a kiosk in front of it, the laying of a temporary path to the first lake and the organisation of a guide service from 1953 onwards (Planina 2010), the cave's out-of-the-way position slowed its development. Other reasons for the modest development of tourism were the fact that the entrance section of the cave was relatively free of cave formations, rendering it less interesting to the average tourist, and the difficulties involved in opening the water parts of the cave to tourists because of the need to drag heavy wooden boats over the rimstone dams. Despite these developments, the cave was also visited from time to time by unsupervised visitors, which resulted in damage. For this reason the entrance to the cave was protected by a gate in the early 1950s. Towards the end of the 1950s, the opening of an additional entrance was proposed in order to make it easier to visit the water section, but owing to the large financial investment required and the insufficient revenue from entrance fees, this idea was not realised (Archives of the Cave Exploration Society of Ljubljana). Despite plans in the 1950s, a lack of financial resources also meant that the cave was not electrified. Although visitor numbers were growing, until the 1970s revenue from entrance fees was not sufficient for investment in the

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, mitja.prelovsek@zrc-sazu.s*

tourism infrastructure of the cave. As a result, the Loška Dolina Tourism Association, which had managed the cave with the help of the Cave Exploration Society of Ljubljana from the mid-1950s to 1970, handed over custodianship of the cave to the Ljubljana Caving Club (today the Cave Exploration Society of Ljubljana; Archives of the Cave Exploration Society of Ljubljana). The 1980s saw an increase in tourism and caving activities in the water part of the cave, which despite its vulnerability was not supervised. As a result, irreparable damage was caused to the rimstone dams (Mihevc 1997). The caving club repaired the steps in the entrance section and made some extra wooden boats, but because of the distance of the caving club seat (Ljubljana) from the cave, management of the cave as a show cave would not have been possible without the support of the few local residents. For this reason, a gradual informal transfer of management of the cave took place in the 1990s. The Društvo ljubiteljev Križne jame (Society of Friends of Križna Jama) was established in 1997 and began informally providing a guide service and management of the cave. Since 2005, the Društvo ljubiteljev Križne jame has also been the formal custodian of the cave and the organiser of all tourism and infrastructure activities in it. In the space of a few years, members of the Društvo ljubiteljev Križne jame have also removed the bulk of the waste that has accumulated in the cave as the result of caving expeditions (for the most part carbide waste), restored some damaged cave formations and gour pools, removed newer writings on the cave walls (Troha 2010) and drawn up a cave management plan.

Current management of Križna jama and the problems of its protection

There are currently two types of visits to Križna jama (a visit to the "dry section" and a visit to the "water section"; Fig. 1). The difference between the two variants is based on the time that the tourist is prepared to spend in the cave (a visit to the dry section takes 1 hour, while a visit to the water section usually requires between 3 and 4 hours), the vulnerability and capacity of the cave, and the availability of guides. Problems with the provision of guides occur at the height of the tourist season in midsummer and when visitor numbers are low in winter, although visits to the cave are possible practically throughout the year.

The *"dry section"* consists of a visit to the entrance to the main cave passage up to the first lake, and a trip on the first lake in a large boat propelled by oars. Smaller groups are also occasionally given the opportunity to view the Medvedji rov containing the remains of cave bear bones. Bones are also exhibited along the ordinary tourist route. The path is reinforced by gravel and is not cemented. The more exposed parts are protected by a wooden railing. The path is marked by white tapes. Given present visitor levels and provided visitors are physically fit, these arrangements are entirely sufficient. Each visitor receives a battery torch and is issued with a pair of rubber boots, because there are puddles along the path and a slight increase in the water level makes wading necessary in part of the cave. The only major intervention along the route is the laying of a gravel path by the water course, making it possible to reach the first lake even without boots at medium water levels. The path is marked by tapes and continues as far as Kittlova brezna (Kittl's shafts), although this section is rarely used for tourist visits. Tourists are not guided into the side passages, since the absence of marked paths would lead to extensive damage to the natural cave floor and there is also a considerable possibility of physical injuries to tourists. There is no limit on numbers for visits to the "dry section" of the cave, since owing to ventilation and frost weathering and the consequently smaller number of cave formations, this section is less vulnerable to visitors. As they move along the path, tourists also have the opportunity to see a wall with the old signatures of former visitors.

During the winter it is necessary to keep noise to a minimum because of the presence of bats. This measure is sufficient to avoid any impact on the size of the bat population (Presetnik & Troha 2010). Revenue from tourism in the "dry section" of the cave, which on account of the larger number of visitors is, despite the lower cost of admission, slightly higher than revenue from guiding tourists through the "water section", is provisionally enough for the needs of guiding tourists through the cave and maintenance of the vital but modest infrastructure on the part of tourist guides, but insufficient for major investments in the cave on the part of subcontractors.

The *"water section"* includes a one-hour visit to the "dry section" of the cave and a continuation by boat over 13 lakes to Kalvarija (Calvary), where two underground streams meet in a stalactite-filled chamber. Visitors return by the same route. A visit to the continuation of the flooded passage as far as Kristalna gora (Crystal mountain) is possible by special arrangement. Every group of tourists visiting the cave is accompanied by at least one guide, who can take up to four tourists into the cave in one boat. Owing to the great vulnerability of the cave (rimstone dams), tourist capacity in the "water section" is limited to one boat per day, in other words four tourists per day, which at the height of the season represents a major loss of revenue but is necessary in order to protect this very vulnerable section of the cave. Revenue is also affected by summer droughts when the water level can fall by several metres, making visiting impossible because of the inevitable damage to uncovered rimstone dams. Each visitor to the cave is issued with a helmet complete with battery-powered headlamp, overalls and boots. The "water section" is directly at risk from tourist visits and indirectly at risk as a result of the unsatisfactory treatment of waters in the catchment area that periodically flow into the cave. The hydrological continuation of Križna jama – known as Križna jama 2 (one of the six closed caves in Slovenia with the strictest protection regime) – is indirectly threatened in the same way.

The vulnerability of Križna jama – pollution from the Bloke plateau

The turbidity of the water and the appearance of scum was first noted by Puc (1986), but even since then substantial pollution has never been

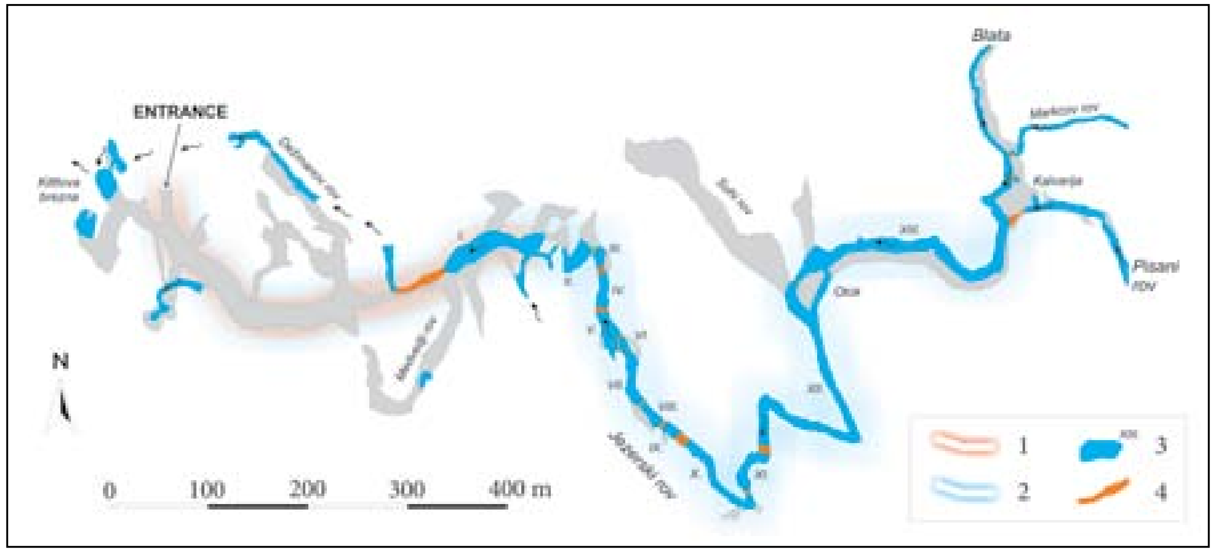

Fig. 1: Plan of Križna jama (1 – tourist route through the "dry section", 2 – tourist route through the "water section", 3 – lakes, 4 – rimstone dams).

demonstrated by chemical analysis of water samples. Periodic pollution is indicated above all by greasy stains in the form of lines that are deposited on the cave walls at the time of very high floods (Troha 2010), of which samples have never been taken, and a greasy film on the surface of high water which is trapped behind periodic siphons. The polluted water is believed to come from the inhabited Bloke plateau. Concern on the part of the custodian and show cave manager (Društvo ljubiteljev Križne jame) reached its peak in 2007 and 2008 with the construction of a small municipal water treatment plant (350 PE) at Fara on the Bloke plateau, which discharges partially treated water directly into a swallowhole, from where it is believed to flow into Križna jama. Because this is a small treatment plant, there is a legal requirement to ensure the suitability of the treated water from the point of view of COD and BOD_5, but not from the point of view of other pollutants (e.g. nitrogen, phosphorus). Doubts about the adequate treatment of the water, direct drainage into a swallowhole, the effect on subterranean fauna and the deposition of calcite from the cave stream, and doubts about the suitability of the Expert assessment of the impact of the small municipal treatment plant at Fara na Blokah (Geologija d.o.o. 2005) led the Karst Research Institute to carry out a tracer test on 4 December 2007 (Kogovšek et al. 2008). Before this a connection between the ponors of the Farovščica or another stream on the Bloke plateau and Križna jama had never been confirmed by a tracer test. Although Križna jama lies directly on the route between the traced ponor of the Farovščica and the Šteberk spring, where the majority of the tracer emerged, only 1.3 % of the tracer flowed through Križna jama. Interestingly, tracer appeared in the downstream Križna Jama 2 earlier and in a higher concentration than in the first lake in Križna jama, and even before that in all the sampled springs. This suggests a faster and more direct hydrological connection lying parallel to Križna jama (Kogovšek et al. 2008). Although the tracer test clearly indicated a weak connection of Križna jama with the ponor of the Farovščica on the Bloke plateau, the results need to be evaluated critically because they refer to a hydrogeological connection at a medium/low water level. At a higher water level, in view of Križna jama's properties as a good hydrogeological conductor, with an insignificant rise in the water level, which consequently lowers the piezometric level of the less perforated underground area directly by the cave and in this way attracts groundwater, the quantity of recovered tracer could be higher, although as a result of dilution the concentration of pollutants would nevertheless be lower. Consideration must also be given to the risk presented by the seepage into the ground of insoluble pollutants such as the various oils that have already been observed in Križna jama following flood events, that have different characteristics of transfer by groundwater flow and can have a significant effect on pollution of the underground, with the result that it differs from the pollution demonstrated by the tracer test. Two key questions remain unanswered: what effect does variously polluted water have on subterranean fauna, and how does it affect the deposition of calcium carbonate along the underground water course in Križna jama?

The vulnerability of Križna jama – erosion of rimstone dams

The main vulnerability of the "water section", in terms of the danger posed by tourists and cavers visiting the cave, is represented by the rimstone dams that retain water in dozens of lakes or pools. The creation of these dams is related to the precipitation of calcium carbonate from percolating water, which at low and medium water levels represents the bulk of the water flowing through the cave. The $CaCO_3$ crystals also contain clayey material and therefore the calcite in the pools is softer. Vulnerability increases from the first lake to Kalvarija

because the intensity of the deposition of calcite from the underground stream decreases from the confluences upwards (Prelovšek 2009, Prelovšek et al. 1008). For this reason the least sensitive sections are those around the first lake, where on average around 0.09 mm of calcite is deposited each year (Mihevc 1997), and at the lower end of the Pisani rov (Colourful passage) around Kalvarija, where the deposition of calcite is of a similar intensity (Prelovšek 2009). The most sensitive sections are those between Kalvarija and the second lake, where calcite deposition can be less than half that at the dam below the first lake. By far the largest amount of calcite is deposited at rimstone dams on a few very cold winter days, while in late summer slight dissolution occurs here (Prelovšek 2009). The top few centimetres of the rimstone dams is usually hard, while the calcite below is very soft. Removal of the top layer would inevitably lead to erosion, even by entirely natural processes as can already partially be seen in erosion holes in some parts of the rimstone dams.

Tourism activity in the water section is also necessarily accompanied by abrasion of the rimstone dams because of people walking and transporting boats over them. Since in principle we cannot influence the depositing of calcite and in this way reduce the vulnerability of the flooded section of the cave, the amount of abrasion in the water section is reduced by limiting the numbers of tourists to five people per day including a guide, and, since 1991, the compulsory use of rubber boats (Archives of the Cave Exploration Society of Ljubljana), by instructing visitors on how to walk over the rimstone dams before the visit starts, by close supervision of tourists during guided visits by the guide and by supervision of cavers' expeditions in the cave. At the same time, visiting the cave with neoprene clothing, which previously destroyed muddy calcite crystals on the lake bottoms, has been banned. In order to monitor the intensity of damage to the rimstone dams, in 2006 we set up micrometric points on two of the dams, both along the tourist route and away from it. This had already been proposed independently by Mihevc (1997). A comparison between the tourism-related and non-tourism-related measuring points would indicate the relationship between natural calcite deposition and the amount of abrasion and provide quantitatively justified guidelines for reducing damage to the rimstone dams. Mihevc (1997) has since 1994 been measuring the quantity of deposited calcite on the rimstone dam below the first lake. On the one hand this provides us with an average of over many years, while on the other it gives us an insight into the annual changeability of calcite precipitation. We began annual measurements at other dams and along the tourist route through the water section in 2006. An example of measuring points is shown in Fig. 2.

The figures are presented in Tab. 1 and show the average values of the nine measurements that are taken at each individual measuring point. They show temporal and spatial changes in calcite deposition by location of the measurement point (tourist route/away from tourist route). The annual quantity of deposited calcite below the first lake is on average around 0.08 mm/a. At the annual level between 0.04 mm (mild winters) and 0.11 mm (colder winters) is deposited (Prelovšek 2009). For the measuring points lying upstream, figures are available from 2006 onwards. Practically all the figures show smaller deposition of calcite in comparison to the measuring point below the first lake. This is related to the gradual aeration of the water downstream of the confluence at Calvary and the consequent increase in SI_{Ca} (Prelovšek 2009). In one case, away from the tourist route, we even recorded a prevalence of abrasion and corrosion over calcite deposition (2006–2007 between the ninth and tenth lakes). This is in all probability connected to the period of light corrosion at the end of the summer and the small amount of calcite deposited in winter (Prelovšek 2009). The periods of greater and lesser deposition correspond to the measuring point below the first lake. From the point of view

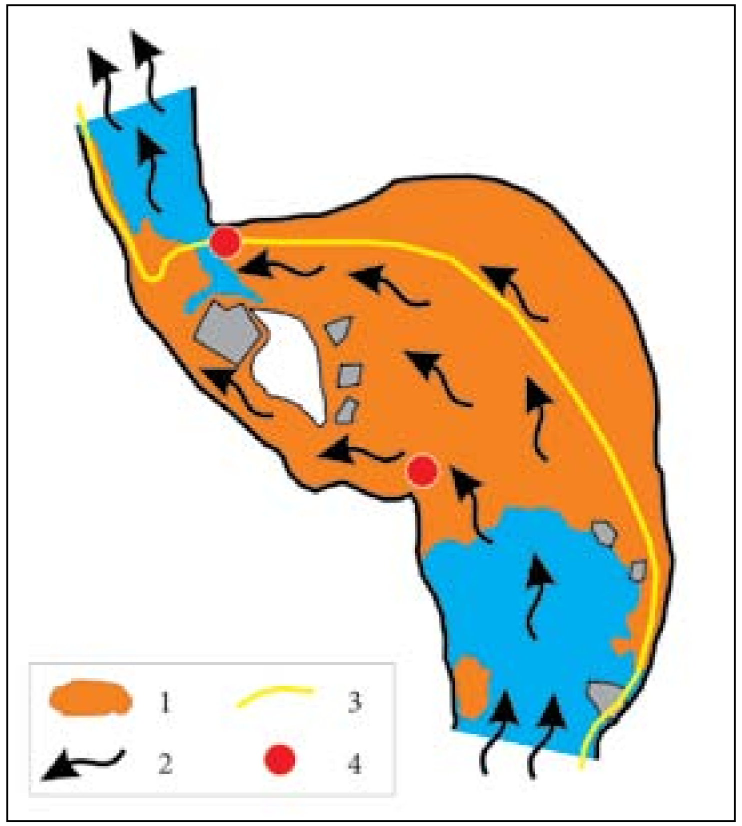

Fig. 2: Ground plan of the rimstone dam between the third and fourth lakes (1 – rimstone dam, 2 – watercourse, 3 – tourist path, 4 – micrometric points).

of the natural deposition of calcite, the highest-lying dams towards Kalvarija are therefore most at risk in periods of mild winters, when calcite deposition are smallest.

The phenomenon of abrasion is also clearly observable, since calcite deposition along the tourist route is as a rule smaller than in those points lying away from the tourist route, on average by 0.01 mm/a (between the ninth and tenth lakes) to 0.04 mm/a (between the third and fourth lakes). The difference between these two sets of measuring points is the consequence of the fact that when crossing the rimstone dam between the third and fourth lakes tourists still have some flinty sand and other sandy material from the "dry section" on their boots that effectively grinds down the rimstone dams. Despite greater wear, the lower-lying dams are less at risk because abrasion represents a good third of natural calcite deposition (34.2 %), while between the ninth and tenth lakes it is already less than a quarter (23.3 %). Although the abrasion values are extremely low, they frequently exceed the rate of renewal of the rimstone dams, particularly above the fourth lake, and therefore in the near future, despite drastic restrictions, we can expect problems at the rimstone dams closer to Kalvarija, where natural deposition of calcite is smaller.

Abrasion of the rimstone dams is higher than the abrasion of limestone, since because of its youth, structure and clay content, calc-sinter is softer than limestone. This is also shown by comparison between the measuring point between the third and fourth lakes on the tourist route and the "abrasion slab" of Upper Cretaceous limestone lying in a dry area by the first lake on the tourist route of the dry section. Tourists walk across both points in boots that retain flinty sand and sandy sediment. In four years 0.15 mm of calcite has been abraded on the rimstone dam, compared to just 0.08 mm on the "abrasion slab", i.e. just half, although almost 10 times fewer tourists walked over the rimstone dam than over the "abrasion slab". It should be pointed out that abrasion of the softer part of the rimstone dam that lies below the upper, more resistant layer is significantly faster.

Evaluation of existing management of Križna jama as a show cave and guidelines for future management

Križna jama belongs among the middle group of show caves in terms of visitor numbers and therefore there are no problems connected to mass tourism – tourist guiding is easier and there is less pressure on the cave. Fewer visitors, however, means smaller revenue from tourism, which can lead to problems with the maintenance of tourism infrastructure outside and inside the cave. Current conditions show that revenue from tourism activities combined with voluntary work is sufficient to maintain the existing modest tourism infrastructure. This falls to the existing Društvo ljubiteljev Križne jame (Society of Friends of Križna Jama) or the group of individual members of the Society that manages the cave today.

From the point of view of protection of the cave, the most important thing is that the cave's capacity is not exceeded, or in other words that the cave is managed sustainably. It is our finding that the management of Križna jama as a show cave has never been at such an enviable level as it is now. Owing to the low vulnerability, sustainable management is fully characteristic of the "dry section" of the tourist path. Construction of the tourist route did not require a major intervention, since it was merely necessary to remove some larger rocks from the route, while in places infilling was required to a height of some tens of centimetres. Individual lighting prevents problems with lampenflora. Small, easily supervised groups of tourists do not present a threat to the bats hibernating along the tourist route. Those parts of the cave where there are large numbers of bats are not open to tourists. Given current visitor levels, tourism infrastructure of this type is sufficient for current needs.

The "water section" of the tourist route is more difficult to manage, both from the point of view of vulnerability and in terms of financial investment. The rimstone dams are significantly more vulnerable. Because the manager/custodian is aware of the gravity of the problem, the best possible measures for their protection are ensured. Even so, figures from the micrometer measurements show that despite the use of practically all measures to ensure the protection of the rimstone dams and the surface of the lakes behind them, which also impede the freedom of movement of visitors to the cave, levels of wear, particularly of the higher-lying rimstone dams closer to Kalvarija, are at the limit of natural regeneration. We are nevertheless of the opinion that without additional infrastructure measures, which would mean a significant intervention in Križna jama, it is practically impossible to achieve better results. It is therefore necessary to attempt to preserve existing measures. With more investment, it would be possible to open an additional entrance to Križna jama through the Suhi rov (Dry Passage), by means of a tunnel

Table 1: Natural deposition of calcite away from the tourist route in comparison to the deposition of calcite along the tourist route in the "flooded section".

Measurement place/period	Calcite deposition (mm/a)					
	1994-1997	1997-2006	2006-2007	2007-2008	2008-2009	2009-2010
Downstream of the first lake	0.09	0.09	0.04	0.11	0.08	0.05
Between the third and fourth lake (tourist path)	/	/	0.01	0.03	0.02	0.03
Between the third and fourth lake (out of tourist path)	/	/	0.01	0.12	0.07	0.03
Between the seventh and eighth lake (out of tourist path)	/	/	0.00	0.04	0.02	0.02
Between the ninth and tenth lake (tourist path)	/	/	-0.03	0.06	-0.01	0.00
Between the ninth and tenth lake (out of tourist path)	/	/	-0.01	0.09	0.01	0.00
Abrasion slab	/	/	0.00	-0.04	0.01	-0.05

positive values indicate deposition and negative erosion measuring some tens of metres. This would reduce pressure on the majority of the rimstone dams but would also make it feasible to start using a part of the cave not previously used for tourism, bringing a danger of changes to the microclimate (although it would be possible to limit these), and, most importantly, a threat to the safety of the bats hibernating in the Suhi rov (Presetnik & Troha 2010). If as a result of increasingly mild winters the deposition of calcite on the rimstone dams continues to decrease, as indicated by figures from the last four years, in order to maintain the use of the cave for tourism it will be necessary either to reduce the number of visitors to the flooded section or to implement infrastructural changes to prevent the erosion of the rimstone dams. Preservation of the dams is of key importance for the natural appearance of the cave and for maintaining Križna jama's biggest attraction, i.e. the underground watercourse and lakes. Although tracer tests (Kogovšek et al. 2008) indicate that a relatively small percentage of wastewater or treated water from the Bloke plateau flows through Križna jama, the risk needs to be further reduced by means of more thorough treatment and better drainage of wastewater, in this way also ensuring more suitable water quality in the wider aquifer, i.e. in caves that have not yet been explored but are likewise a habitat for subterranean fauna.

Acknowledgement

Thanks are due to the Društvo ljubiteljev Križne jame for allowing experts to work in the cave over the course of many years and for providing figures on the number of visitors to the "dry" and "water" sections of Križna jama.

References

Badjura R., 1909. Križna jama. Dom in svet 22/1: 30–33.

Bavdek A., Mihevc A., Toškan B., Velušček A., 2009. Arheološke najdbe iz Križne jame/Archaeological finds from Križna Jama cave. Arheološki vestnik 60. Ljubljana, SAZU & ZRC SAZU: 17–31.

Culver D., Sket B., 2000. Hotspots of Subterranean Biodiversity in Caves and Wells. Journal of Cave and Karst Studies 62/1: 11–17.

Gabrovšek F., Kranjc A., Mulec J., 2008. Turistične jame (kartografsko gradivo) [Show Caves (maps)]. In: Kras: trajnostni razvoj kraške pokrajine. ZRC Publishing, Ljubljana: pp. 295.

Geologija d.o.o., 2005. Hidrogeološko poročilo in strokovna ocena o vplivu male komunalne čistilne naprave Fara na Blokah na podzemne vode [Hydrogeological report and expert assessment of the impact on groundwater of the small municipal water treatment plant at Fara na Blokah]. Detailed expert report. Geologija d.o.o., Idrija: pp. 16.

Kogovšek J., Prelovšek M., Petrič M., 2008. Underground water flow between the Bloke Plateau and Cerkniško Polje and the hydrological function of Križna Jama, Slovenia. Acta Carsologica 37/2-3: 213–225.

Mihevc A., 1997. Meritve hitrosti rasti sige na pregradah v Križni jami [Measurements of calcite deposition on rimstone dams in Križna jama]. Naše jame 39: 110–115.

Planina T., 2010. Pregled raziskovanja [History of exploration]. In: Križna jama. Ljubljana, Društvo ljubiteljev Križne jame: 6–9.

Prelovšek M., 2009. Present-day speleogenetic processes, factors and features in the epiphreatic zone. PhD Thesis. Nova Gorica: 297.

Prelovšek M., Turk J., Gabrovšek F., 2008. Hydrodynamic aspect of caves. International Yournal of Speleology, 37/1: 11–26.

Presetnik P., Troha A., 2010. Prezimujoči netopirji [Hibernation of bats]. In: Križna jama. Ljubljana, Društvo ljubiteljev Križne jame: 24–31.

Puc M., 1986. Križna jama pri Ložu [Križna jama cave near Lož]. Notranjski listi III. Cerknica: 7–24.

Shaw T., 2008. Foreign Travellers in the Slovene Karst 1486-1900. ZRC Publishing, Ljubljana: pp. 338.

Sket B., 2000. Pregled in izbor jam v Republiki Sloveniji, ki so pomembne za ohranjanje podzemske favne [Overview and selection of caves in the Republic of Slovenia that are important from the view of the preservation of subterranean fauna]. Detailed expert report. www.natura2000.gov.si/uploads/tx_library/jame.pdf

Troha A., 2010. Kako smo čistili jamo [Cleanup of Križna jama]. In: Križna jama. Ljubljana, Društvo ljubiteljev Križne jame: 10–15.

LAMPENFLORA IN SHOW CAVES IN SLOVENIA

Janez Mulec [1]

The most obvious difference between wild and show caves is that tourist infrastructure has been introduced in the latter. Tourist infrastructure usually includes gates, fences, walking surfaces and, in many caves, lighting. A cave-friendly sustainable approach is achieved by introducing as few external materials as possible; the installation of lighting is the most drastic change to occur in a light-deprived cave environment. The available photons emitted by lights can be captured by oxygenic phototrophic organisms. In the case of underground alien flora named lampenflora, these organisms can be found on a variety of surfaces which are near to sources of light in caves, mines and other artificial and light-deprived environments such as cellars and stores (Fig. 1). “Lampenflora” is originally a German term, but has also been adopted into the vocabulary of the English language. Lampenflora grows at sites where phototrophic organisms do not appear under natural circumstances. Lampenflora is a complex – but not particularly diverse – community of cyanobacteria, algae, mosses and ferns. Vascular plants are sometimes found around lamps, but almost always only as germinating shoots (Mulec et al. 2008). Some viable propagules of phototrophs reach underground voids. There are three main modes by which the viable propagules of phototrophs and other small-sized organisms are transported underground – air currents, water flow and by being introduced by migratory animals and humans. In the lampenflora community, non-phototrophic organisms such as bacteria and fungi also thrive. Lampenflora is a result of underground light eutrophication and, as it biodeteriorates the various types of substrata onto which it is attached, it is of particular interest to cave management (Mulec, in press).

Light for photosynthesis in the underground

In phototrophic organisms, photons are absorbed by photosynthetic pigments, which have their own characteristic absorption spectra. Photosynthesis leads to the synthesis of glucose and starch. Chlorophyll absorbs all the wavelengths of visible light except green, which it reflects, producing the green colour of higher plants and the macroscopic appearance of thalli of microalgae. The main photosynthetic pigment for oxygenic phototrophs is chlorophyll *a*. In order to bridge the gap in the light absorption of chlorophyll *a*, plants synthesise accessory pigments such as chlorophyll *b, c1, c2, c3*, xanthophylls, and carotenes (van den Hoek et al. 2002). This ability is extremely important in poorly lit habitats where plants attempt to capture as much light as is available at a particular site. The energy absorbed by accessory pigments is funnelled into the reaction centre for conversion into chemical energy. Besides chlorophyll *a*, cyanobacteria contain phycobiliproteins (Fig. 2) in their cells, which do not just lend cyanobacterial colonies a slightly different macroscopic appearance, but also allow for the efficient absorption of light between peaks (440 and 680 nm) of chlorophyll *a* (Oliver and Ganf 2000). At cave temperatures (~9 °C) and a low photo¬synthetic photon flux density (PPFD<10 μmol photos/m^2/s) around lamps in show caves, the biosynthesis of accessory photosynthetic pigments for two frequently encountered organisms in lampenflora – the cyanobacterium *Chroococcus minutus* and the green alga *Chlorella* sp. – was found to be considerably elevated (Mulec et al. 2008). The unit of photon fluxes, expressed in μmol photos/m^2/s, defines the energy available for photosynthesis and is referred to as photosynthetically active radiation. It accounts for the output of a light source with a wavelength of between 400 and 700 nm. In every case, regardless of which pigment first captures the light, the energy absorbed always ends up in chlorophyll *a*; this is because the absorption peak of chlorophyll *a* is at a longer wavelength than any of the other pigments, i.e. 680 nm (Kirk 1983). During the evolutionary process, some phototrophs develop the ability to withstand various harsh conditions such as desiccation, and even growth, in the absence of light (Stal 2000, Stewart 1974, Wynn-Williams 2000). Knowledge of the absorption spectra of photosynthetic pigments, organisms in the lampenflora community, as well as their physiology and ecology, should direct cave managers as to how to deal with lampenflora.

The cave ecosystem is in a state of dynamic equilibrium, which is disturbed when high levels of light are introduced. Photosynthetic organisms, with their primary production occurring in caves, can sustain a complex community of other organisms. Newly-formed lampenflora biomasses are available for cave-adapted animals and other occasional cave dwellers. For example, troglobitic fauna have been observed grazing on lampenflora on many occasions. However, a significant source of new biomasses in caves means that competitive non-troglobitic fauna can oust troglobitic animals from some cave niches and a troglobitic animal population may therefore be affected as a result (Mulec, in press).

Fig. 1: *Lampenflora in Postojnska jama along the tourist train railroad, 2007.*

Recent studies of lampenflora in Slovenia

When a phototrophic propagule reaches an illuminated place in a cave it starts to proliferate. A survey of cyanobacteria and algae in lampenflora conducted in 2003 included eight caves and mines: Postojnska jama, Kostanjeviška jama, Pekel pri Zalogu, Pivka jama, Rudnik svinca in cinka Mežica (Mežica Lead and Zinc Mine), the Rudnik živega srebra Idrija (Idrija Mercury

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, janez.mulec@guest.arnes.si*

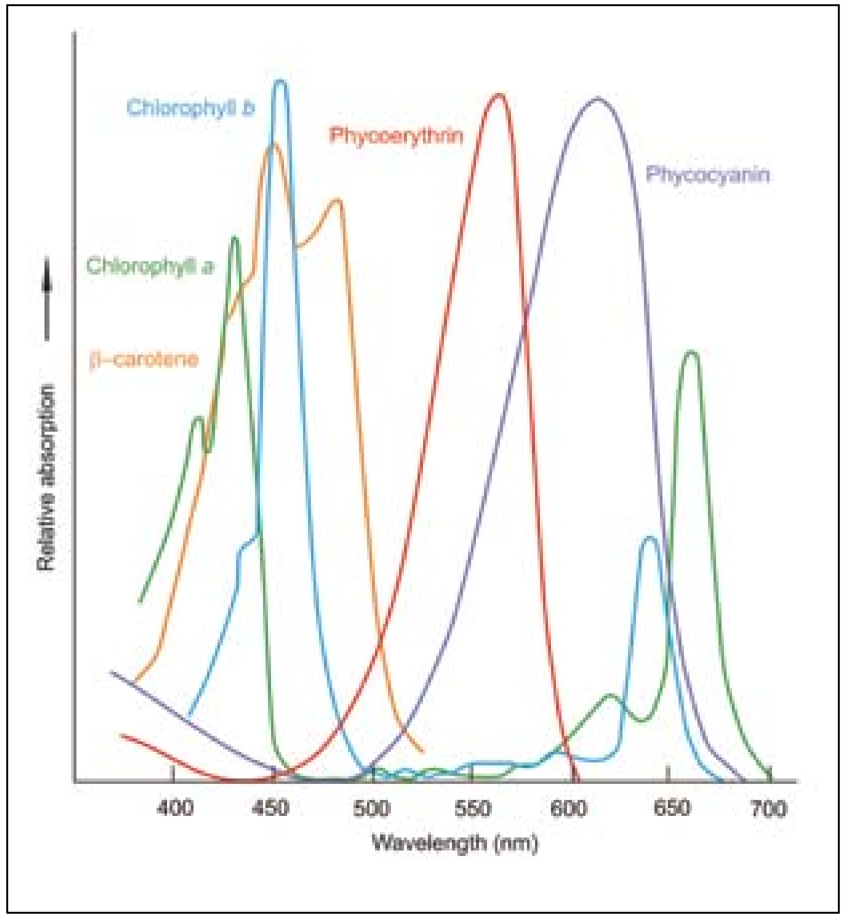

Fig. 2: Absorption spectra of some phototrophic pigments, compiled from various sources.

Mine), Škocjanske jame, and Županova jama (Fig. 3). During the year, these caves are generally exposed to lighting for a long period of time (Tab. 1). In comparison to the naturally occurring algal and cyanobacterial community in cave entrances, where the community is almost exclusively composed of cyanobacteria, green algae are more dominant in lampenflora. In the latter stages of species succession in the lampenflora community, cyanobacteria are more abundant and community structure becomes more similar to the community structure found at the cave entrance (Mulec et al. 2008). This is an important finding that even a notable change in light quality in the later stages may not have a significant influence on lampenflora, as cyanobacteria have accessory pigments which are very successful in capturing different wavelengths of light (Fig. 2). In all eight caves, a rather low number of taxa (60) were identified in the lampenflora community. Cyanobacteria were the most abundant group (47 %), followed by Chlorophyta (30 %) and Chrysophyta (23 %) (Fig. 4). The green alga, *Trentepohlia aurea*, appeared with the highest frequency in Slovenian show caves (Mulec et al. 2008). In general, the biodiversity of lampenflora is poor; the majority of lampenflora organisms are ubiquitous, fast reproducing and adaptable soil algae (Rajczy 1989). Krivograd Klemenčič and Vrhovšek studied Krška jama in 1998, 1999 and 2000 (Krivograd Klemenčič and Vrhovšek 2005) and also came to similar conclusions.

As referred to above, not only do microscopic algae and cyanobacteria thrive in the lampenflora community; mosses and–to a lesser extent–ferns are also usually encountered. Eight show caves: Črna jama, Postojnska jama, Kostanjeviška jama, Krška jama, Pekel pri Zalogu, Pivka jama, Škocjanske jame, Županova jama and two mines equipped for tourist visits (the Idrija Mercury Mine, and the Mežica Lead and Zinc Mine) were screened for the presence of Bryophyte lampenflora in 2008 (Fig. 3). Bryophytes were collected at a wide range of PPFDs, from 0.2 to 530.0 µmol photons/m^2/s. A total of 37 taxa of Bryophyta and Pteridophyta were identified in the caves. The most frequently found organisms were *Amblystegium serpens*, *Brachythecium* sp., *Eucladium verticillatum* and *Fissidens taxifolius*. *E. verticillatum* had the highest span of PPFDs, ranging from 1.4 to 530.0 µmol photons/m^2/s. The *Cratoneuron fil-*

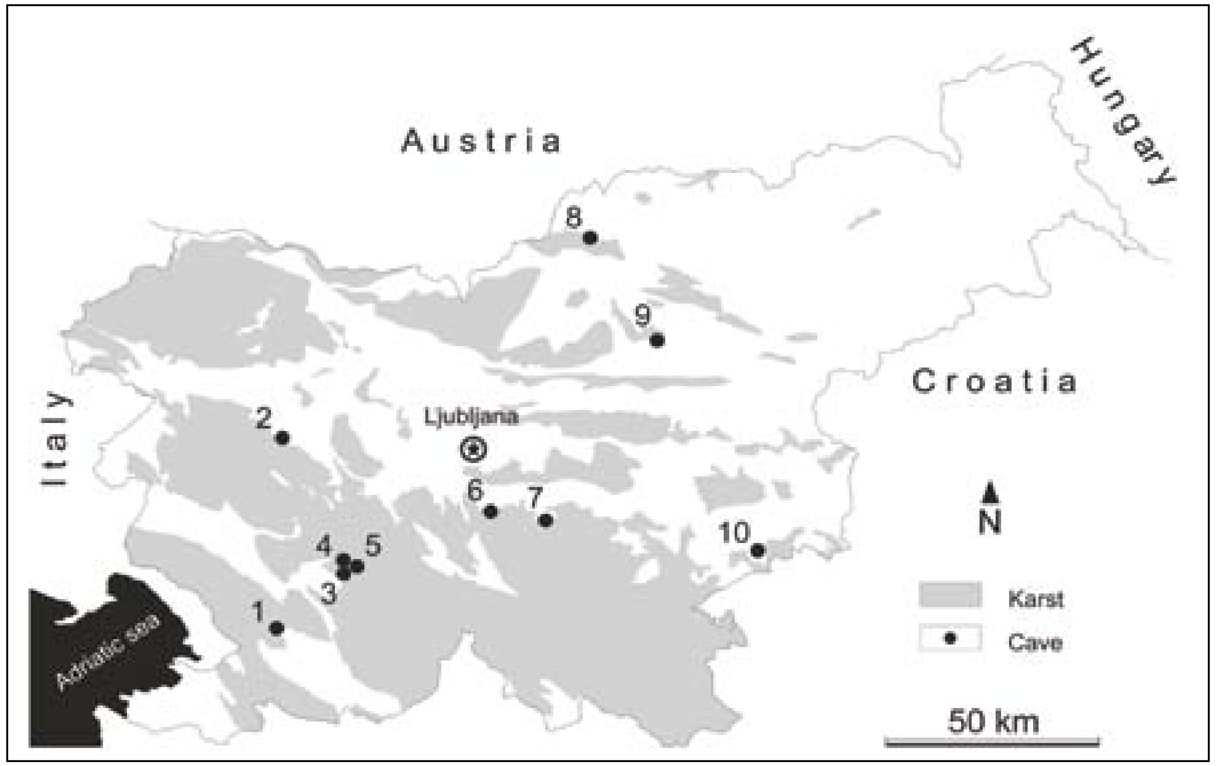

Fig. 3: Caves with lampenflora in Slovenia (1-Škocjanske jame, 2-Idrija mine, 3-Postojnska jama, 4-Pivka jama, 5-Črna jama, 6-Županova jama, 7-Krška jama, 8-Mežica mine, 9-Pekel pri Zalogu and 10-Kostanjeviška jama).

icinum identified in the part of the Mežica mine where lights are on 24 hours a day developed sporophytes at only 2.1 and 2.4 µmol photons/m^2/s; *Brachythecium salebrosum* developed sporophytes in Postojnska jama at 4.7 µmol photons/m^2/s (Mulec and Kubešová 2010).

In studies performed on lampenflora, the non-phototrophic part of the community is occasionally overlooked; however, these organisms also exhibit the significant deteriorative effects of illuminated natural and man-made surfaces (Canaveras et al. 2001, Cifferi 1999). Sterile limestone tablets and limestone tablets covered with Jaworski agar, which support the growth of microscopic phototrophs, were used in a colonisation-adhesion experiment (Mulec 2005). Tablets were placed around the lamps in the Idrija Mercury Mine and Škocjanske jame. Jaworski agar and light support growth of phototrophs; however, algae and cyanobacteria did not colonise these surfaces to a great extent, despite the available photons. Heterotrophic organisms such as bacteria, fungi, flagellates and other microscopic fauna were mostly observed on these tablets. On the other set of tablets, which did not have a layer of Jaworski agar, phototrophs were more prevalent in comparison to heterotrophic organisms. The phototrophs frequently encountered were: *Apatococcus* cf. *lobatus*, *Chlorella* sp., *Lyngbya* sp., *Navicula mutica* and *Trentepohlia aurea* (Fig. 5). The experiment again confirmed that some eukaryotic microalgae are particularly successful in colonising newly illuminated niches on stony surfaces (Mulec 2005). This is the reason why these organisms are quick to re-colonise former green patches around lamps in many show caves after the application of biocides to kill lampenflora.

Four Slovenian caves (Francetova jama, Jama pod Babjim zobom, Vilenica, Železna jama), which are also equipped with electric lighting, were not included in the studies because no visible lampenflora and no deteriorative effects on speleothems were observed. All the screened

Tab. 1: Caves and mines with lampenflora in Slovenia with data on tourist management.

Cave/Mine	Lithology	Altitude (m)	Annual number of visitors	Electric equipment	Use of biocides	Annual illumination (hrs/sector)	Maximum power of individual lamp (W)	Open for visitors
Črna jama	Cretaceous limestones	540	3,000	1929	+	>70	1000	1 Jun–30 Sep
Kostanjeviška jama	Cretaceous limestones, dolomites	170	10,000	1970	-	>60	500	15 Apr–31 Dec
Krška jama	Jurassic and Triassic limestones, dolomites	540	10,000	1995	-	>100	1000	1 Apr–30 Sep
Pekel pri Zalogu	Triassic limestones, dolomites	314	20,000	1972, 1976, 1997b	+	>100	300	1 Mar–31 Dec
Pivka jama	Cretaceous limestones	540	3,000	1929	+	>70	1000	1 Jun–30 Sep
Postojnska jama	Cretaceous limestones	529	500,000	1884	++	1000	2000	1 Jan–31 Dec
Škocjanske jame	Cretaceous and Paleogene limestones	425	100,000	1959	-	477	500	1 Jan–31 Dec
Županova jama	Jurassic limestones	468	10,000	1937	-	>80	500	1 Mar–30 Sep
Idrija, mercury mine	Permocarbonian shales, dolomites	330	25,000	1994	+	>214	100	1 Apr–31 Oct
Mežica, lead and zinc mine	Carnian limestones, Triassic dolomites, shales	500	17,000a	2000a	-	8.760	200	1 Jan–31 Dec

a no tourist visit in the area with lampenflora
b successive electrification

++ regular; + occasional; - never

caves were illuminated for less than 100 hours per year. Two other show caves (Ravenska jama, Rotovnikova jama) were also not included in the study because they have been closed to visitors since 1998. In order to ascertain the presence of lampenflora, the speleotherapy station for patients with pulmonary diseases at Sežana Hospital, located in an artificial underground gallery, was also screened. Despite the relatively high mean illumination per year (~610 hours), no green patches were observed. The reason for this is probably due to the different type of illumination utilised in comparison to other show caves and mines. Speleothems or other objects of historic importance are usually directly illuminated in caves; however, in this case, light is dispersed in the space due to the lighting setup installation, which does not illuminate solid

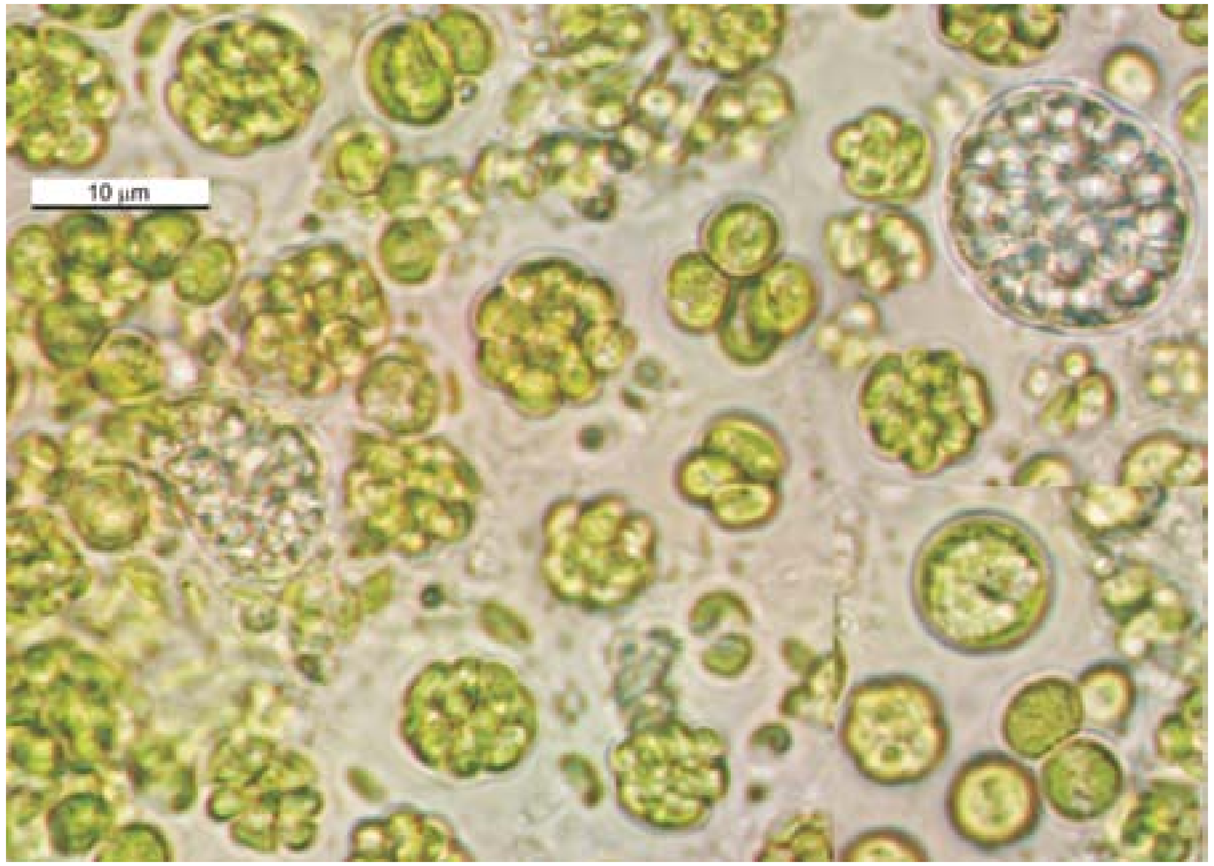

Fig. 4: Mix culture of lampenflora algae from the Mežica mine in Jaworski medium after eight days of incubation, as seen under a microscopic light magnification of 1,000.

surfaces, but serves only to ensure patient safety during their activities (Mulec 2005).

The spring cave, Pekel pri Zalogu, is heavily colonised in some parts by lampenflora, as was reported in 1981 (Martinčič et al. 1981). In this cave, sampling was performed in order to determine the concentration of chlorophyll *a* on a surface unit. The concentration of chlorophyll *a* is a reliable estimate for phototrophic biomass and, consequently, environmental pollution (Wetzel and Likens 1995). The sites selected to ascertain the chlorophyll *a* levels of epilithic cave algae were chosen carefully. Known flat rocky surfaces with minor substratum irregularities with confluent algae overgrowth were scraped off with an alcohol flame sterilized pocket knife and collected in a test tube. When phototrophs were firmly attached to the surface, a special sampling device was used (Fig. 6). Lampenflora algae from this cave showed higher values of chlorophyll *a*, ranging between 0.57 and 2.44 mg/cm^2, and lower than the algae from the cave entrance (max. 1.71 mg/cm^2). This difference can be explained due to the different lighting regime in both microhabitats, (i.e. the changing quality of light and levels of irradiance during the day in the cave entrance), different periods of illumination, different in situ moisture levels, and different species composition (Mulec 2005, Mulec et al. 2008).

Control of lampenflora growth

Actually growing lampenflora or lampenflora which is dead and encrusted with calcium carbonate is not only of particular concern

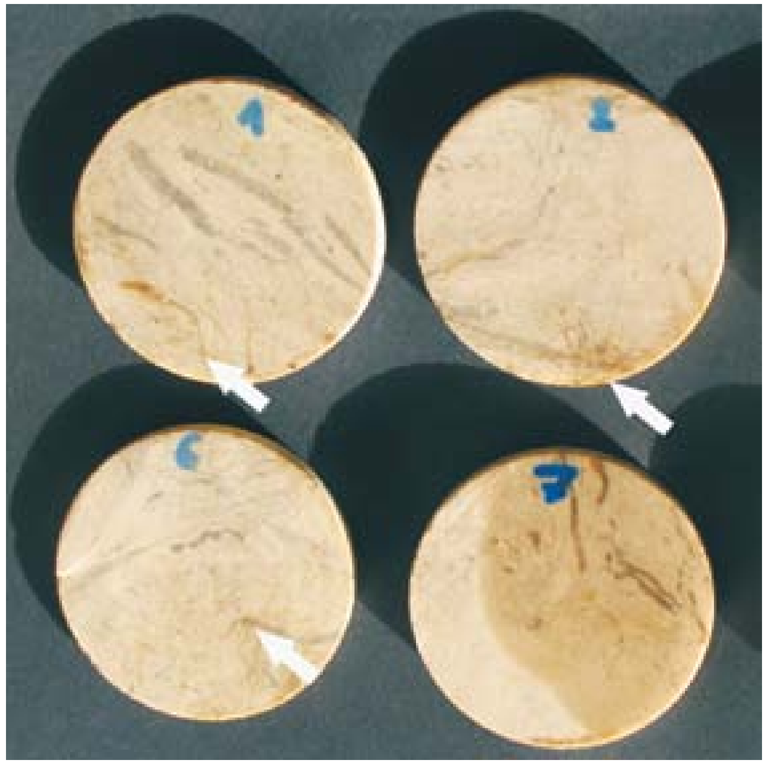

Fig. 5: *Colonised limestone tablets with the green alga,* Trentepohlia aurea.

when associated with speleothems and other karstological features, but also especially when it covers prehistoric paintings or historic inscriptions. Lampenflora lends a strange and unnatural greenish appearance to caves and other underground formations.

In those Slovenian show caves and mines where lampenflora has been studied recently, lamps are periodically switched on for tourist visits and in order to maintain tourist infrastructure (Krivograd Klemenčič & Vrhovšek 2005, Mulec et al. 2008, Mulec and Kubešová 2010). The times vary as to when caves are exposed to lighting; the longest period of illumination is in Postojnska jama and Škocjanske jame. In Mežica Lead and Zinc Mine – at the sampling location, which is not visited by tourists – lamps are switched on 24 hours a day due to the constant monitoring required of the underground water flow. Each cave is subject to different tourist visit frequencies; Postojnska jama has the longest tradition and the highest number of tourists (Tab. 1). Lampenflora is an urgent issue in some Slovenian caves, especially in the Postojnska jama cave system, which also includes two other show caves, Črna jama and Pivka jama, next in Škocjanske jame and also in the Pekel pri Zalogu cave. Only in Postojnska jama is lampenflora regularly removed (Tab. 1). Until 2010, the regular removal of lampenflora in Postojnska jama included the application of active chlorine with a working concentration of 100 mg/l (Mulec and Glažar, in press).

Over the last few decades, many approaches to control lampenflora have been tested, including the physical – reducing the intensity and duration of light – and also through the use of chemicals by applying various biocidal chemicals, such as formalin, bromine and cupric solutions, and solutions based on active chlorine (Mulec and Kosi 2009). Besides chlorine's unpleasant smell, chlorine compounds also react with many different substances in nature, which results in the formation of various toxic products. In addition, chlorine compounds in water lower its pH and this leads to the corrosion of carbonate speleothems (Faimon et al. 2003). Aggressive chemicals such as chlorine are not appropriate for a sensitive cave environment.

Based on literature (Faimon et al. 2003), laboratory tests and experiments conducted in test sites in Postojnska jama, a novel procedure has been developed for the purpose of removing lampenflora. Instead of using chlorine solution, an environmentally-friendly and odour-free 15% solution of hydrogen peroxide was prepared with a carbonate buffer (pH 7.0–7.5) and applied three times during a one-month period in 2010. In Postojnska jama, the hydrogen peroxide solution was effective in reducing lampenflora. In comparison to bleach, the hy-

Fig. 6: *A device for the chlorophyll a estimate per surface unit in cases where algae were strongly adhered to the surface. The device is composed of an inflow tube, into which distilled water is poured (1), a valve to prevent the formation of a vacuum (2), a brush fixed to a rotation axle and connected to a spring which enables a secure connection between the brush and the surface (3), and is rotated using a battery boring machine, packing (4), and an outflow tube to collect algae re-suspended in water (5).*

drogen peroxide solution is less effective and its application is more time consuming, but is less hazardous and creates less toxic products in oxidation reactions (Mulec and Glažar, in press).

Cave management should avoid the introduction of any chemical compounds in the cave environment. More attention should be devoted to a suitable lighting installation, focusing on the minimum lighting duration, the minimum intensity, and those sites which are appropriate for illumination. A very promising recent approach is the installation of light emitting diodes (LEDs) because they have low energy consumption, are long lasting and possess the potential to tune in to the desirable emission spectrum (Toomey et al. 2009). In several caves around the world, this new type of illumination is already in use (Fig. 7). With recent advances in technology, the use of fibre optics in cave lighting appears to be another alternative. Through optimisation and further studies conducted in cave lighting, such installations have the potential to enhance control over the reduction of lampenflora growth (Mulec, in press).

Conclusions

From a biological perspective, the introduction of energy and/or light in caves will always reflect in cave allochtonous and autochthonous biota. Light will always support the growth of phototrophic organisms – at least to a certain extent. Phototrophs are able to live at very low photon fluxes and, in some cases, even in the absence of light. The change in cave management's attitude towards the problem that lampenflora brings to caves, is in the last period positive and evident, e.g. the use of "environmentally-friendly" biocides and the weaker illumination of speleothems. Cave managers began to consult biology specialists and search for modern lighting systems which save energy, are long lasting, easy to maintain and provide minimal support for phototrophic growth. On the other hand, there is also significant pressure to open new show caves and prolong illumination periods during tourist visits. One must take into consideration that the nature of phototrophic organisms is not easy to overcome, even with the use of modern technologies. In Slovenia and throughout the world, many caves are still excessively illuminated. Tuning the light spectrum is sometimes sufficient to suppress lampenflora growth, but not to prevent its growth entirely. On the other hand, lampenflora offers researchers an appropriate experimental platform to study the physiology and ecology of these organisms under controlled conditions.

Acknowledgement

Useful comments on the manuscript were provided by Aleksandra Krivograd Klemenčič.

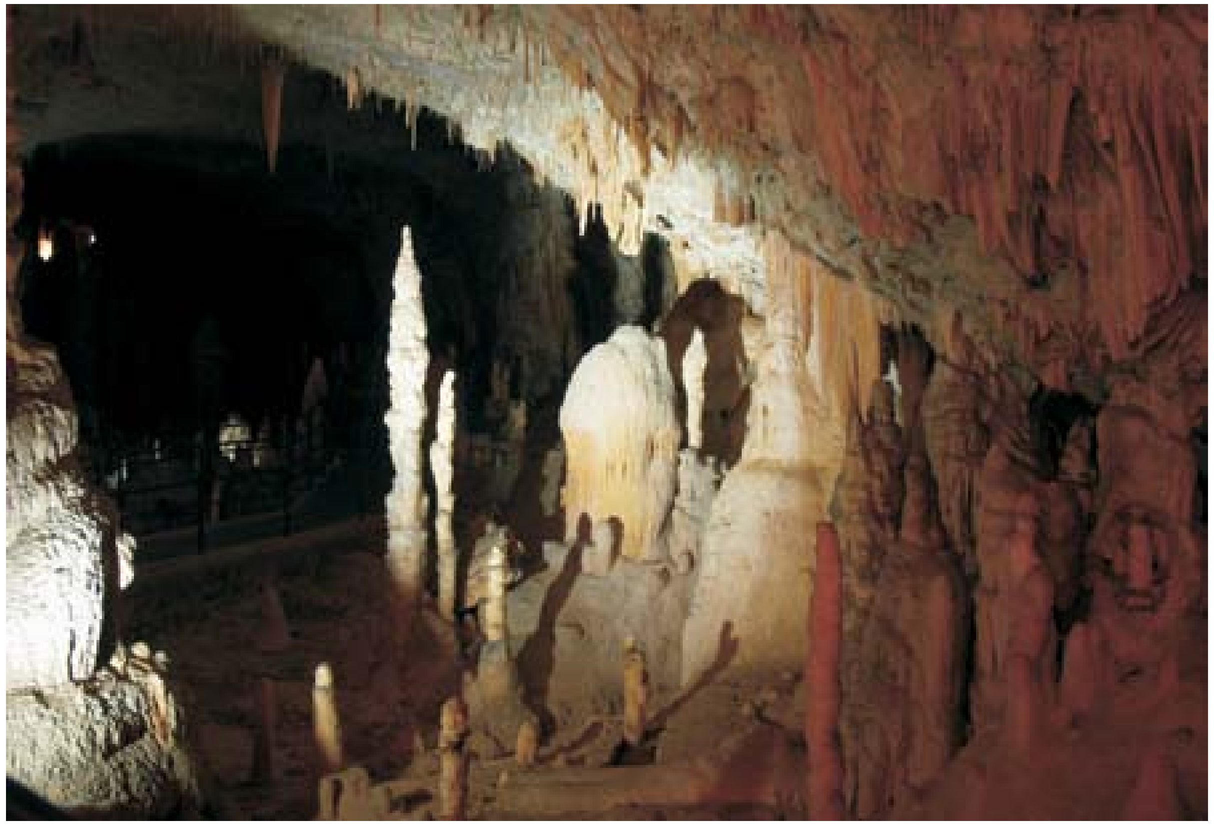

Fig. 7: Experimental lighting setup in Postojnska jama based on LED technology (Photo: Alexander Chrapko).

References

Canaveras J., Sanchez-Moral S., Soler V., Saiz-Jimenez C., 2001. Microorganisms and microbially induced fabrics in cave walls. Geomicrobiology Journal, 18/3: 223–240.

Ciferri O., 1999. Microbial degradation of paintings. Applied and Environmental Microbiology, 65/3: 879–885.

Faimon J., Stelcl J., Kubešova S., Zimák J., 2003. Environmentally acceptable effect of hydrogen peroxide on cave "lamp-flora", calcite speleothems and limestones. Environmental Pollution, 122: 417–422.

Kirk J., 1983. Light and photosynthesis in aquatic ecosystems. Cambridge University Press, Cambridge: pp. 401.

Krivograd Klemenčič A., Vrhovšek D., 2005. Algal flora of Krška jama cave, Slovenia. Sborník Národního Muzea v Praze, Řada B, Přírodní Vědy: Historia Naturalis, 61: 77–80.

Martinčič A., Vrhovšek D., Batič F., 1981. Flora v jamah z umetno osvetlitvijo. Biološki Vestnik, 29: 27–56.

Mulec J., 2005. Alge v kraških jamah Slovenije [Algae in the karst caves of Slovenia]. University of Ljubljana, Ljubljana: pp. 149.

Mulec J., in press: Lampenflora. In: White W., Culver D.C. (eds.). Encyclopedia of caves, 2nd edition. Elsevier, Amsterdam.

Mulec J. Glažar S., in press. First results on use of a hydrogen peroxide solution in Postojnska jama (Slovenia) to remove lampenflora. In: Bella P., Gažík P. (eds.). Proceedings of the 6th ISCA Congress, 18–23 October 2010, Demanovska Valley, Slovak Caves Administration, Liptovský Mikuláš.

Mulec J., Kosi G., 2009. Lampenflora algae and methods of growth control. Journal of Cave and Karst Studies, 71/2: 109–115.

Mulec J., Kosi G., Vrhovšek D., 2008. Characterization of cave aerophytic algal communities and effects of irradiance levels on production of pigments. Journal of Cave and Karst Studies, 70/1: 3–12.

Mulec J. Kubešová S., 2010. Diversity of bryophytes in show caves in Slovenia and relation to light intensities. Acta Carsologica, 39/3: 587–596.

Oliver R.L., Ganf G. G., 2000. Freshwater blooms. In: Whitton B.A., Potts M. (eds.). Ecology of cyanobacteria, Kluwer Academic Publishers, Dordrecht: 149–194.

Rajczy M., 1989. The flora of Hungarian caves. Karszt és Barlang, Special issue 1989: 69–72.

Stal L., 2000. Cyanobacterial mats and stromatolites. In: Whitton B.A., Potts M. (eds.). Ecology of cyanobacteria. Kluwer Academic Publishers, Dordrecht: 61–120.

Stewart W.D.P. (ed.), 1974. Algal physiology and biochemistry. Blackwell Scientific Publications, Oxford: pp. 989.

Toomey III R.S., Olson R.A., Kovar S., Adams M., Ward R.H., 2009. Relighting Mammoth Cave's new entrance: improving visitor experience, reducing exotic plant growth, and easing maintenance. In: White W.B. (ed.). ICS 2009 15th International congress of speleology, Proceedings, 19–26 July, Vol. 2. Greyhound Press, Kerrville: 1223–1228.

van den Hoek C., Mann D., Jahns H., 2002. Algae: an introduction to phycology. Cambridge University Press, Cambridge: pp. 623.

Wetzel R., Likens G., 1995. Limnological analyses. Springer, New York: 139–165.

Wynn-Williams D., 2000. Cyanobacteria in deserts – life at the limit? In: Whitton B.A., Potts M. (eds.). Ecology of cyanobacteria. Kluwer Academic Publishers, Dordrecht: 341–366.

EXPERT CONTROL AND RECOMMENDATIONS FOR MANAGEMENT OF POSTOJNSKA JAMA, CLIMATIC AND BIOLOGICAL MONITORING

Stanka Šebela [1]

The Postojnska jama cave system (20,570 m) is the most visited karst cave in Slovenia. There were almost 500,000 visitors to the Postojnska jama cave system in 2010. The Ministry of the Environment and Spatial Planning (MOP) awarded the concession contract for the management of the cave to the private company POSTOJNSKA JAMA, d.d. (previously known as TURIZEM KRAS Destinacijski management, d.d.) for a 20-year period (2009–2028). The cave is listed in the Register of Natural Assets as an asset of national importance.
The following protection status is in place for Postojnska jama:

- Ordinance on the Proclamation of Cultural and Historical Monuments and Natural Sites of Special Interest in the Area of the Municipality of Postojna (Ur. Obj. Primorske novice 29/84),
- Regulations on the Designation and Protection of Natural Assets – 40747-Jamski sistem Postojnska jama (Ur. l. RS 111/2004, 70/2006),
- Decree on Ecologically Important Areas – 31300 Notranjska triangle (Ur. l. RS 48/2004),
- Decree on Special Protected Areas of Natura 2000 – SI 3000232 Notranjska triangle (Ur. l. RS 49/2004, 110/2004, 59/2007),
- Cave Protection Act (Ur. l. RS 2/2004).

The Karst Research Institute ZRC SAZU has undertaken regular climatic and partial biological monitoring of Postojnska jama at selected locations since 2009, as well as performing the functions of karstology consultant or cave custodian in the implementation of the concession contract, meaning that we professionally monitor the state of the cave with an emphasis on the impact of the use of the cave as a natural asset (Šebela 2010).
The most important tasks of the cave custodian in the Short-Term Programme of the use of natural asset of the Postojnska jama (2009–2013) include climatic, biological and lampenflora monitoring, regular communication with the Nova Gorica Regional Unit of the Institute of the Republic of Slovenia for Nature Conservation (ZRSVN OE Nova Gorica) regarding the implementation of the concession and the state of the cave, the implementation of a rehabilitation programme to eliminate the impacts caused by the use of the natural asset, to draw attention to the external factors that put the cave at risk, the monitoring and supervision of major encroachments and events in the cave (Fig. 1), recording research, drawing up an inventory of encroachments, and maintaining a list of the cave system's cultural heritage.

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, stanka.sebela@zrc-sazu.si*

In the framework of the tasks of the cave custodian, the Long-Term Programme for the exploitation of natural assets (2009–2028) anticipates environmental protection measures relative to the results of the five-year monitoring of the cave's climate and fauna.
The task of the cave custodian is to carry out professional supervision and management consultancy services in order to ensure the sustainable development of the cave system, to develop guidelines for the use of the cave system as a natural asset, and to carry out the climatic and biological monitoring of the cave.

Monitoring of cave climate, biology and waters

Within the framework of the climatic monitoring of Postojnska jama, we measure air temperatures (Šebela & Turk 2011a, 2011b) at various locations, using a variety of measuring instruments, as well as measure atmospheric pressure, relative humidity, CO_2 concentrations, and air flow velocity (Figs. 2 and 3). Air temperature is usually measured on an hourly basis, and periodically at shorter intervals. In 2010, two meteorological stations were installed in the cave, the first of which was located in the main passage between Veliki dom and Kongresna dvorana, and the second of which was located in Lepe jame (Fig. 2). Both stations use a number of temperature sensors, a sensor for the pool's water temperature, an ultrasonic wind speed monitor, a sensor for measuring the concentration of CO_2 in the air, and a sensor for measuring relative humidity. Both stations are equipped with data recorders that take data every ten minutes from all the sensors and save

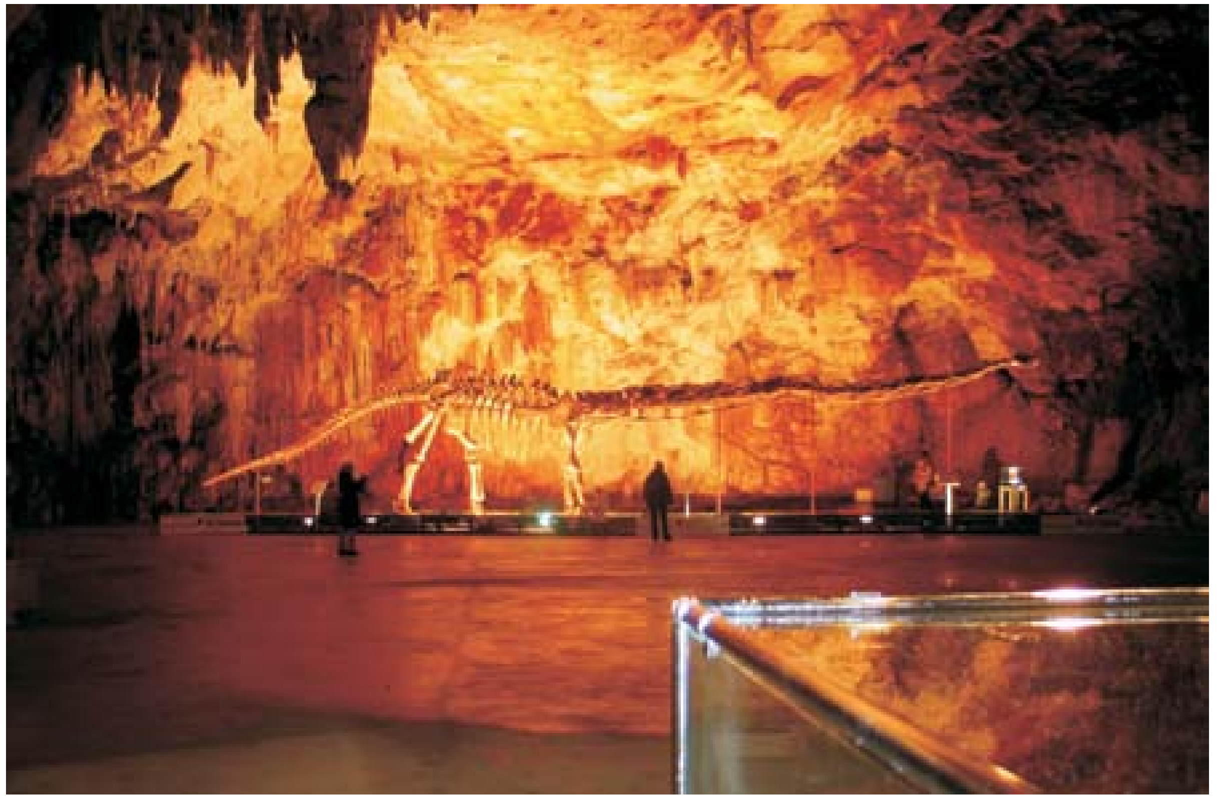

Fig. 1: Exhibited replica of a dinosaur skeleton in Koncertna dvorana during the Postojnska jama exhibition in 2009 (photo: Stanka Šebela).

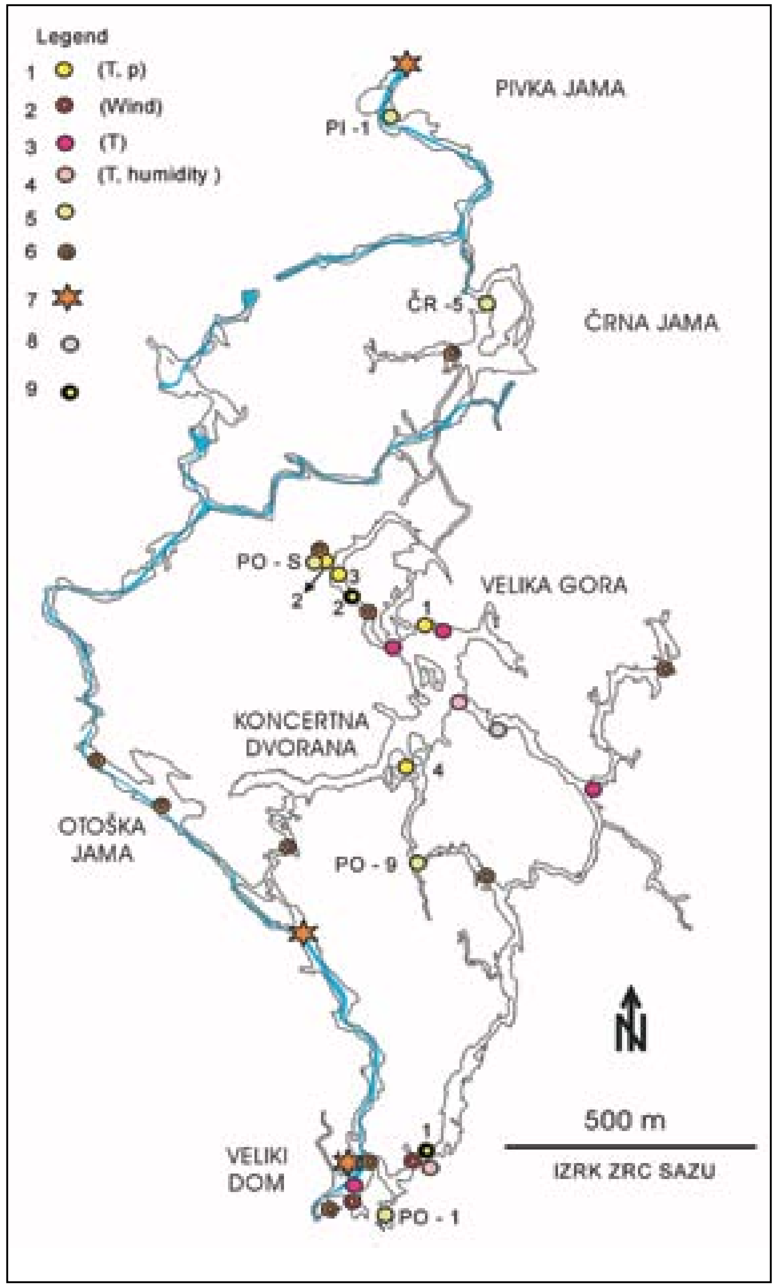

Fig. 2: Measuring sites for climatic and biological monitoring in the Postojnska jama.

1. *Climatic monitoring (hourly measurements of air temperature and atmospheric pressure) (1 = Postojna 1 – Velika gora, 2 = Postojna 2 – Lepe jame v stranskem rovčku, 3 = Postojna 3 – Lepe jame ob turistični poti, 4 = Koncertna dvorana).*
2. *Climatic monitoring (air temperature measurement station, wind velocity, wind flow).*
3. *Climatic monitoring (air temperature).*
4. *Climatic monitoring (air temperature and humidity) .*
5. *Biological monitoring (the monitoring of fauna in percolated water).*
6. *Biological monitoring (the seasonal sampling of bioaerosols and atmospheric data, including air temperature, relative humidity, CO2 concentration, wind velocity, atmospheric pressure).*
7. *Biological monitoring (the sampling of the underground section of the Pivka river for bacteriological analyses and water temperature measurements, pH, and conductivity at various water levels of the Pivka river).*
8. *Monitoring of the stability of overturned stalagmites.*
9. *Meteorological station (1 – Stara jama, 2 – Lepe jame).*

them to a memory card. It must be stated that the first meteorological studies of Postojnska jama cave system were carried out by Crestani and Anelli (1939). Gabrovšek and Mihevc (2009) were the editors of the field-trip guidebook of the 17th International Karstological School dedicated to "cave climate".

During those events and festivities held in the cave that attract a larger number of visitors, the normal values for CO_2 increase by up to four times (400–1,600 ppm) (Gabrovšek et al. 2010). We have also observed a simultaneous rise of air temperature by up to 0.3 °C (Postojna 3, Fig. 2) in December 2009 during the *Live Christmas crib in Postojnska jama* performance. According to the data of POSTOJNSKA JAMA d.d., the Postojnska jama received 15,198 visitors in December 2009, and 9,524 visitors in November 2009. The performance of *Live Christmas crib in Postojnska jama* was attended by 10,530 visitors over six days and represents almost 70% of all the visitors in December 2009. The increase in air temperature by up to 0.3 °C and the increase of CO_2 by up to four times (Postojna 3, Fig. 2) were due to the performance being well-attended. When the number of visitors returned to a normal level, the CO_2 concentrations and the temperature returned to their previous values.

In December 2010, the cave received 13,417 visitors. *Live Christmas crib in Postojnska jama* 2010/11 attracted 9,984 visitors. The CO_2 concentration increased by 2.5 times, from 600 ppm to 1,500 ppm (Gabrovšek et al. 2011). The air temperature at Postojna 1 (Velika gora) rose by less than 0.1 °C, by 0.2 °C at Postojna 2 (Lepe jame) and by almost 0.4 °C at Koncertna dvorana. The rise in the number of visitors by almost 75 % during the performance of *Live Christmas crib in Postojnska jama* at the end of December 2010 showed similar results to 2009 with regard to the increase in the air temperature and CO_2 levels. Most of the cave is well ventilated due to the large cave entrance, which has been artificially opened since 1866 (Kranjc et al. 2007). This is why the elevated values returned to normal when the number of visitors returned back to previous numbers before the performance.

Fig. 3: Climatic monitoring in the Lepe jame, meteorological station (photo: Stanka Šebela).

The air temperature range at Postojna 3 (Fig. 2) was between 10.34 °C and 11.04 °C in 2010; this means the maximum oscillation for 2010 was 0.7 °C. During 2010, the maximum air temperature oscillation at Velika gora (Postojna 1) was 0.56 °C and 1.03 °C at Postojna 2 (Lepe Jame). Raised temperatures during more frequent tourist visits in the cave are within the range of annual temperature oscillations in the cave.

In the cave system, biological monitoring demonstrates the importance of protecting its rich underground fauna and records the current status. A status inventory of the cave fauna is compiled by Slavko Polak (Notranjska Museum). The indicatory species are determined in various parts of the cave that are at risk. Biological monitoring also includes ecological studies of cave fauna from percolated waters (Fig. 4) and the sampling of bioaerosols on a seasonal basis. In accordance with existing legislation, the monitoring of the part of the Pivka river that sinks into Postojnska jama is undertaken by the Ministry of the Environment and Spatial Planning. Pivka river pollution is an important issue and relates to the proper operation of the Postojna communal water treatment plant, which must encompass all the waters that sink into the cave system. The underground section of the Pivka river must not be additionally polluted from other sources inside the cave system, (e.g. toilets in the cave).

The sampling of the underground section of the Pivka river for bacteriological analysis is undertaken within the scope of biological monitoring.

The idea is also to formulate and introduce the existing Postojnska jama monitoring protocol (climatic and biologic) to other show caves in Slovenia.

Expert control and recommendations for Postojnska jama management

The Short-Term (2009–2013) Programme of cave custodian duties are as follows:

- The coordination of activities regarding the monitoring of the impacts of the use of the cave as a natural asset.
- To performing and adjust part of monitoring, including: cave climate measurements, the monitoring of the quality of percolation waters that are connected with cave system, monitoring lampenflora (algae and moss), and biological monitoring.
- Supervision of the infrastructure management of those parts of the cave, which are included in the use of the cave.
- Regular reporting to ZRSVN OE Nova Gorica on the issue of concession contract activities and with regard to the state of the cave, with special emphasis devoted to the impacts of the use of cave as a natural asset, in accordance with a detailed monitoring programme.
- Suggestions for mitigation arrangements regarding the impacts of the use of the cave as a natural asset.
- Performing annual programmes for improvements to be made to the cave's natural conditions and to eliminate the consequences of impacts of the use of the cave as a natural asset.
- To draw up an inventory of interventions made in the cave in the past (on the basis of accessible information) and to re-establish the inventory evidence of all interventions made inside the cave since commencement of the concession contract.
- Drawing attention to external factors threatening the cave and proposing initiatives for the solution of problem (such as pollution of the Pivka river, etc.).
- Organising and harmonising the new geodetic measurements of the cave, which will form the bases for cave digital maps.
- To run the evidence of historical and current scientific research, which are carried out in the cave (through the use of the special registration book).
- To run the evidence of speleological visits in those parts of the cave, which are not open to visits.
- To monitor regular activities carried out in the cave, to control large scale interventions in the cave, to draw the attention of the cave management and governmental institutions to making possible improvements.

- To control performances in the cave and to find appropriate solutions in the event of a negative impact on the cave.
- To control the cleaning of pools (Fig. 5) and tourist paths in Lepe jame.
- To provide assistance in formulating an appropriate modernised method of underground transport for tourist visits.
- To monitor the stability of overturned stalagmite in Stara jama.
- To implement photo-monitoring of the cave during performances and times when there are elevated numbers of visits.

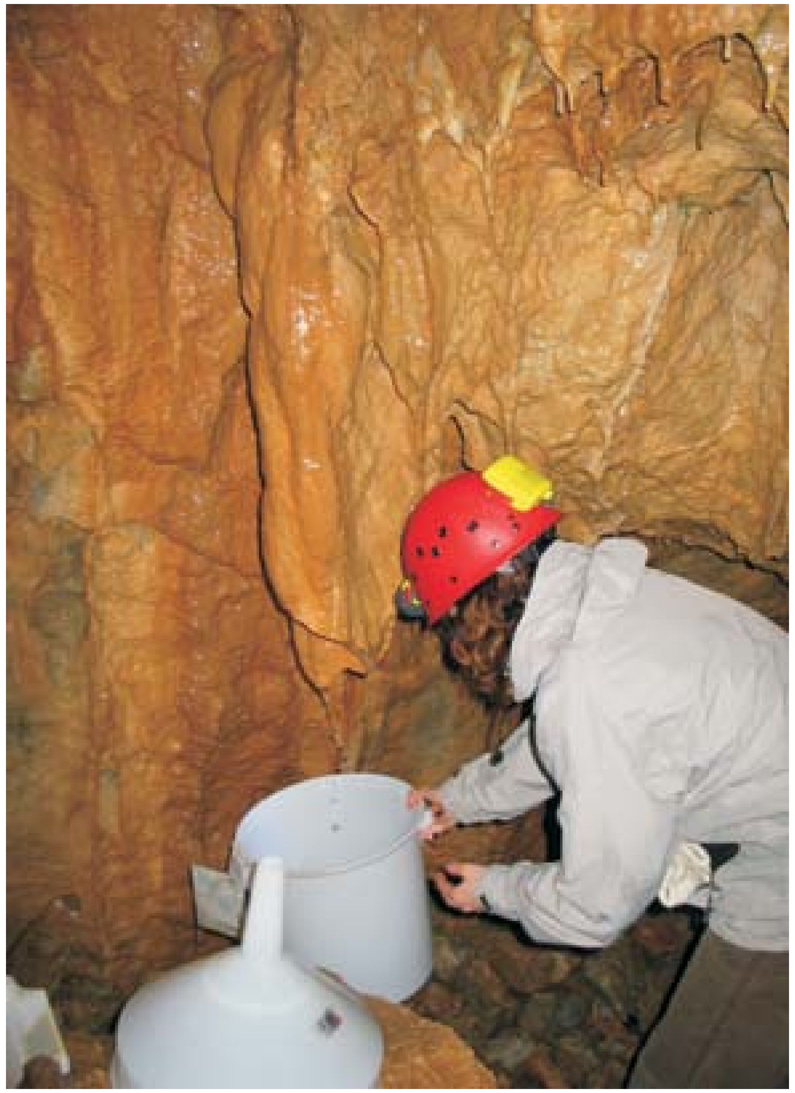

Fig. 4: Biological monitoring of fauna in percolated water (photo: Stanka Šebela).

There are some other problems that exist, which are related to the work of the cave custodian. Postojnska jama is an archaeological monument (Ur. l. RS 16/2008, Article 28 and 59).

An important task was accomplished at the beginning of 2011. The inventory of the material proves of the cave use (technical and cultural heritage) was fulfilled. The cave has been known since at least the 12th century. In 1818, the new, more extensive, part of the cave was discovered. Inside the cave, there remain numerous objects of historical significance relating to its use, such as candlesticks, water pools (Fig. 6), ancient inscriptions on walls, a variety of commemorative plates, parts of railway infrastructure, etc. The basic perspective taken by the ZRSVN OE Nova Gorica is that the material proves for the cave use and technical heritage that are not in use any more must be identified, documented and removed from the cave so that they do not burden the cave unnecessarily. Such material should be stored in suitable institutions such as museums. The cave custodian is supposed to introduce the guidelines to solve problems in the case of existing material proves of the cave use.

The Long-Term Program (2009–2028) is intended for the purpose of strengthening the role of the cave guardian, which is responsible for taking care of the cave system. The principal roles of cave guardian are:

- To regularly monitor the use of the cave programme activities and to make appropriate and swift decisions when resolving problems or possible complications.

- To regularly monitor the climate of the cave, water quality, fauna and to take all necessary precautions.
- To take all natural protection arrangements for the reconstruction or enlargement of cave infrastructure into account.
- To monitor the impact of the tourist use of the cave on the state of the cave.
- To monitor the quality of the river Pivka and to provide suggestions for improvements.
- To implement natural protection arrangements regarding the results of the 5-year monitoring of cave climate and fauna.
- To photo-monitor the state of the cave, including regular photo documentation of tourist paths, ancient inscriptions, interventions in the cave, etc.
- To form the on-line net for monitoring the water parameters in the cave, which are analysed and presented in real time, and the enlargement of the monitoring sites in those areas outside the tourist paths.
- To create a database, spreading of monitoring sites outside the tourist paths and to prepare a model that includes a forecast of cave climate parameters in the future, short-term as seasonal dynamics and long-term as climate change and the impact of climate change to the cave ecosystem.

Conclusions

We make regular written reports of cave custodian visits to the cave system supported by observations and findings on the management of the cave system and hold regular meetings with the concessionaire and representatives of the ZRSVN OE Nova Gorica on urgent and ongoing issues.

Fig. 5: Cleaning of pools in Lepe jame (photo: Stanka Šebela).

The suggested improvements of natural conditions within the cave are proposed by the cave custodian and must be designed to eliminate the consequences of the inappropriate use of the cave. The climatic and biological monitoring is organised in such a way so as to determine the impacts of the use of the cave on the natural cave environment.
Lampenflora represents one of the most significant problems in the show cave. The application of new LED lights in Postojnska jama remains subject to further experimentation.
The contract of the cave custodian is the first step to be taken regarding the sustainable preservation of the cave system. The results of several years of monitoring (climatic and biological) will provide the bases for the application of guidelines. In this way, the "natural protection conservator" can successfully hold an important role in cave management.

Fig. 6: Cultural inventory in the cave – water pool used for Proteus anguinus *in the past (photo: Stanka Šebela).*

Acknowledgement

The study was carried out within the scope of the projects entitled *Expert control and recommendations for the management of cave systems and Climatic and biologic monitoring of cave systems*, financed by POSTOJNSKA JAMA, d.d. It also forms part of the *Karst Research Programme* (P6-0119) and *Measurements and Analysis of Selected Climatic Parameters in Karst Caves: Example of the Postojna Cave System* (L6-2156), cofinanced by the Slovenian Research Agency, POSTOJNSKA JAMA d.d. and Meiss d.o.o.

References

Crestani G., Anelli F., 1939. Ricerche di meteorologia ipogea nelle grotte di Postumia. Publicazione N. 143, Ministero dei lavori pubblici, Magistrato alle Acque, Ufficio idrografico, XVII, Roma: 1–162.

Gabrovšek F., Mihevc A., 2009. Cave climate. 17th International Karstological school "Classical Karst", 15–20 June 2009, Guide book & Abstracts, Postojna: 15–17.

Gabrovšek F., Kogovšek J., Mihevc A., Mulec J., Petrič, M., Pipan T., Prelovšek M., Šebela S., Turk J. (authors), Šebela S. (editor), 2010. Poročilo skrbnika (IZRK ZRC SAZU) o opravljanju koncesije v Postojnskem in Predjamskem jamskem sistemu – v letu 2009 (unpublished report) [Report of the cave custodian on implementation of concession in the Postojnska jama and Predjama cave systems for 2009]. Postojna: pp. 51.

Gabrovšek F., Mihevc A., Mulec J., Pipan T., Prelovšek M., Šebela S., Turk J. (authors), Šebela S. (editor), 2011. Poročilo skrbnika (IZRK ZRC SAZU) o opravljanju koncesije v Postojnskem in Predjamskem jamskem sistemu – v letu 2010 (unpublished report) [Report of the cave custodian on implementation of concession in the Postojnska jama and Predjama cave systems for 2010]. Postojna: pp. 54.

Kranjc A., Kariž S., Paternost S., Polak S., 2007: Postojnska jama, vodnik [Postojnska jama, guide book.]. Postojnska jama, turizem d.d., Postojna: pp. 94.

Šebela S., 2010. Strokovni nadzor in svetovanje pri upravljanju s Postojnsko jamo in Predjamo [Expert supervision and consulting on management of Postojnska jama and Predjama]. Kras 105/106: 24–25.

Šebela S., Turk J., 2011a. Local characteristics of Postojna Cave climate, air temperature, and pressure monitoring. Theor. Appl. Climatol., Springer, DOI 10.1007/s00704-011-0397-9 (published online on 19 January 2011).

Šebela S., Turk J., 2011b. Klimatske značilnosti Postojnskega jamskega sistema [Climatic conditions in cave system Postojnska jama]. In: Kuhar M. (editor), 2011. Raziskave s področja geodezije in geofizike 2010, zbornik predavanj, 16. Strokovno srečanje Slovenskega združenja za geodezijo in geofiziko (Ljubljana, 27 January 2011): 7–11.

Ur. l. RS [Official Journal of the Republic of Slovenia]:

2/2004. Zakon o varstvu podzemnih jam [Cave Protection Act].

48/2004. Uredba o ekološko pomembnih območjih [Decree on Ecologically Important Areas].

49/2004, 110/2004, 59/2007. Uredba o posebnih varstvenih območjih Nature 2000 [Decree on Special Protected Areas of Nutura 2000].

111/2004, 70/2006. Pravilnik o določitvi in varstvu naravnih vrednot [Regulations on Designation and Protection of the Natural Assets].

16/2008. Zakon o varstvu kulturne dediščine [Cultural Heritage Protection Act].

Ur. Obj. Primorske novice [Official Announcements of the Primorska news]:

29/1984. Odlok o razglasitvi kulturnih in zgodovinskih spomenikov ter naravnih znamenitosti na območju občine Postojna [Ordinance on Proclamation of Cultural and Historical Monuments and Natural Sites of Special Interest in the Area of the Municipality of Postojna].

CAVE PRESERVATION DURING MOTORWAY CONSTRUCTION IN SLOVENIA

Martin Knez [1] & Tadej Slabe [2]

Over the last fifteen years, the construction of modern expressways in Slovenia has been one of the country's major construction projects, and is aimed at connecting important parts of the country and opening them up to the rest of Europe. Almost half of Slovenia is karstic and more than half of the population's water supply comes from karstic aquifers. Slovenia is home to Kras, the classical karst region that gave its name for this unique carbonate rock landscape to numerous world languages, and is also the cradle of karstology. We need to better understand this fragile karst landscape and do everything in our power to preserve it, since it is an important part of our natural and cultural heritage.

In this contribution, we focused on examples from the Classical karst, the low karst of the Dolenjska region, and the karst on breccia in the Vipava Valley.

For a number of years, karstologists have cooperated in the planning and construction of expressways in the Kras region (Kogovšek 1993, 1995, Knez et al. 1994, Knez & Šebela 1994, Šebela & Mihevc 1995, Slabe 1996, 1997a, 1997b, 1998, Mihevc & Zupan Hajna 1996, Mihevc 1996, 1999, Kogovšek et al. 1997, Mihevc et al. 1998, Šebela et al. 1999, Knez et al. 2003, 2004a, 2004b, 2008, Bosák et al. 2000, Knez & Slabe 1999, 2000, 2001, 2002, 2004a, 2004b, 2005, 2006a, 2006b, 2007). In the selection of expressway and railway routes, the main consideration taken into account is the integrity of the karst landscape and, therefore, the routes chosen avoid the more important surface karstic features (dolines, poljes, collapse dolines, karst walls) and those caves that are already known. Special attention is devoted to the impact of the construction and use of expressways on karst waters. Expressways should be impermeable so that runoff water from the road is first gathered in oil collectors and then released cleaned onto the karst surface.

Road construction planning

Before construction commences, the accuracy of known data regarding the caves in the field is verified, and possible new measurements of and explanations for their development added. In order to shed light on the situation, we present existing data on perforation of the aquifer and elaborate prognosis subsurface maps, with particular emphasis on the anticipated lithological and tectonic changes in the rock composition and structure. Before starting construction work, the perforation of the karst is presented as accurately as possible. The position of underground caves can be determined by drilling, and, along with measurement indicators, the type of potential fill material (flowstone, fluvial deposits) is

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, knez@zrc-sazu.si*

[2] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, slabe@zrc-sazu.si*

also identified. To a certain extent, the shape, type, and incidence of caves in the vicinity can be predicted using existing knowledge of the known surface and underground features.

The degree of underground karstification puts its own unique stamp on the construction of expressways in the Kras region. In addition to its varied development, Slovenia's karst is characterised by tectonic and lithostratigraphic diversity and it is therefore difficult to determine in advance where caves are located. As a rule, caves occur more frequently along those areas where flysch comes into contact with limestone. The perforation of the karstic aquifer is therefore primarily determined on the basis of a thorough and comprehensive understanding of the karst, and continuous rigorous work undertaken in the planning and construction of the expressways and railways.

When planning expressways, the link between the surface and underground karst features requires the karstological evaluation of the karst surface as well as the karst underground, the hydrological situation, and the presented variables. On all the expressway construction sites in Kras, we encountered a variety of karst phenomena, including dolines, caves with or without sediments, and sections of old and current drainage systems throughout the karst. The lowering of the karst surface, which occurred through denudation, exposed many of the karst caves which are now visible in the Kras region. In recent years, there has been a focus on unroofed caves "discovered" during the construction of expressways. We are of the view that a thorough karstological study of the area where a road is planned results in improved route selection and represents a fundamental starting point when planning expressway construction in this unique and vulnerable landscape.

We begin by assembling published literature, archives, and various unpublished studies to learn about the surface karst features, thereby identifying any dolines, collapse dolines, and other morphological features. Through carrying out a field survey, we establish the starting points for mapping the areas of the selected route. In the field, we evaluate the different types of rock from a karstological perspective. On theme maps we present the known entrances to underground caves and supplement them with potential new entrances. We anticipate the branching of underground cave systems on the basis of surface mapping and explanations of the development of morphologically identified unroofed caves visible in the relief. On the basis of surface mapping performed, we also consider the options for dumping waste material if necessary.

Experience tells us that every route that crosses Kras will encounter underground caves or parts of cave systems during the construction process. To a certain degree, the shape and type of caves can be estimated using existing knowledge of surface and underground phenomena. We trace the caves in the wider area of the traffic route, determine their type, position, and role in the aquifer, their shape, rock relief, the fluvial material and flowstone found therein, and present this in suitable maps. In order to make the maps easier to read, we present the previous data on the degree of underground karstification of the aquifer and elaborate predictions, placing special emphasis on the anticipated lithological and tectonic changes in the rock.

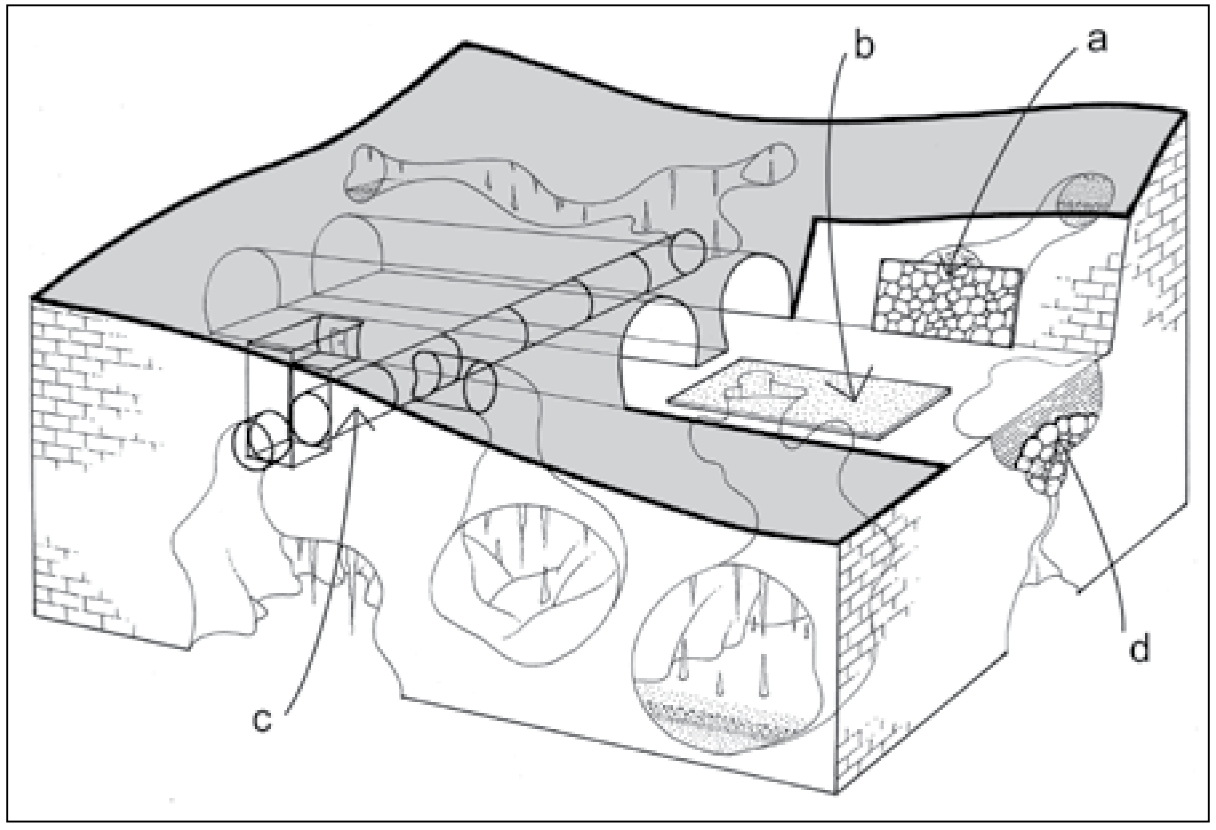

Fig. 1: Cave preservation, a – in road cuts, the caves are hidden behind rocky scarps, b – the caves lying below the road with narrow mouths and, if their rim is not damaged too much by blasting, are covered by concrete lids, c – in the side of the tunnel pipe there is a special door which leads to the caves. Below, road caves are connected with large concrete pipes, d – karst openings (bottom of dolines, tops of shafts) are often reinforced by arches of large rocks which concrete poured on top.

Fig. 2: Preservation of the cave in the road cut near Sežana.

Fig. 3: Old dry cave through which once stream flowed.

Monitoring of motorway construction on the Kras plateau

Special attention is devoted to Kras, a karst plateau rising above the northwesternmost part of the Adriatic Sea that is bordered on the southwest by a vast flysch area with elevations exceeding 600 metres. Located at up to 500 metres above sea level, the plateau covers 440 km^2 and, in a broad sense, belongs to the Outer Dinarides. At present, all rivers that lie close to Kras sink at the point where they cross the boundary between flysch and limestone bedrock and flow underground toward the springs of the river Timava in Italy. The largest stream is the Reka, which sinks in the Škocjanske jame caves, whereas 65% of the aquifer's water is contributed by autogenic recharge. From an ecological perspective, Kras is one of the most vulnerable natural systems in Slovenia.

The removal of soil and vegetation from the karst surface and, of course, major earthworks such as the excavation of cuts and tunnels, reveal surface, epikarst, and subsoil karst features. Our task is to study these features as part of the natural heritage, advise as to how to preserve them (Figs. 1 and 2), and, of course, share our new findings with the constructors. These findings are used to overcome obstacles in the construction process.

During the past few years, 350 caves have been opened on the 70-kilometre section of expressway built in Kras. With regard to the development of the aquifer, we distinguish between old caves through which watercourses flowed when the karstic aquifer was surrounded and covered by flysch and shafts through which water vertically percolates from the permeable karst surface to the underground water. The deepest shaft found measured 110 metres in depth. Some old caves are almost without sediment; almost two thirds of the caves are completely filled with sediment, and one third are unroofed caves.

Caves are opened when vegetation and soil is removed from the surface, and a large number of caves were opened during the excavation. Blasting caused their roofs to collapse, and cross sections of passages were preserved in embankments. The most shafts were opened at the bottoms of dolines when the soil and fluvial sediments were removed.

We studied all the caves, drew plans of them, determined their shape, examined the rock relief, collected samples of fluvial sediments for paleomagnetic and pollen analyses, and sampled flowstone for mineralogical analyses and age determination. We extrapolated the extent of the caves on the basis of their shapes and the geological conditions, which is especially useful for road builders.

Beside the other usual guidelines, the basic karst guidelines for planning traffic routes include:

1. The selection of a route, based on a comprehensive assessment of the karst with an emphasis on local features;
2. The selected traffic route shall avoid specific exceptional karst features;
3. The conservation of karstic aquifers shall be one of the planning priority goals.

Karst features discovered during motorway construction in the shallow karst of Dolenjska (Bič-Korenitka section)

It is a fact that limestone along the Bic-Korenitka motorway route is, from a tectonic perspective, strongly deformed and splintered into broad broken and crushed fault zones where limestone is often broken to the degree of tectonic breccia. Unlike the karst in south-western Slovenia, where Cretaceous limestone prevails, this karst developed in Triassic and Jurassic limestone and dolomites which are covered with thicker sediment than that in south-western Slovenia. The most conspicuous karst formations are swallow holes and estavelles at the bottom of closed depressions or "uvalas". During the work carried out, underground karren and caves (Fig. 3) were uncovered. Those that developed at the bottom of valleys and are often flooded by underground streams are of exquisite shapes and have specific rock relief which, as far as we are aware, is now being described for the first time (Fig. 4). Old dry caves (Fig. 3), through which streams once flowed, testify to the reduction in the level of groundwater, which reaches the surface only in the lowest-lying valleys, and to the probable tectonic dissection of the karst surface. A good part of the caves are filled with fine-grained sediment and have been transformed underneath the sediment. The shaping of fissure caves (Fig. 5), located predominantly along vertical cracks, can be defined as having occurred subterraneously. Water widened cracks into fissure caves and, at the same time, filled them with small-grained sediment. With regard to Classical karst, the number and size of newly discovered caves was smaller, as the majority were filled with gravel and covered by concrete lids. The characteristics of a shallow (underground water is close to the surface), sediment-covered, specific type of Slovenian karst are brought to light. These characteristics should be fully taken into consideration in future encroachments on karstic areas. They are not visible at first glance, but each encroachment on the karst reveals them, many of which (caves, underground karren or stone forests) are worth protecting and preserving.

Motorway construction on the breccia in Vipava valley

The geological, geomorphological, speleological, and hydrological diversity of Slovenia's karst has been also demonstrated by the study carried out on the underground karstification of the breccia that formed beneath the western slopes of Nanos mountain (Fig. 3a). Water, in most cases percolating diffusely through the permeable surface of scree material or breccia to the more or less impermeable

Fig. 4: *Subsoil karren.*

Fig. 5: *Subsoil shaft along fault.*

flysch bedrock, creates relatively young karst phenomena.
Rainwater covers large rocks on the karst surface with flutes and solution pans. Fissures crossing the rock in the direction of the slope indicate tensions in the rock mass and its exposure to sliding (Fig. 7). Breccia and scree material lie on slanting flysch, and the majority of water flows along the points at which they make contact, causing their instability.
The percolating water is collected on the surface where the breccia is mostly consolidated. Earthworks carried out have revealed the early stages in the formation of unique dolines.
Caves which have developed in the young and very porous breccia, which is consolidated only in places, lying on the more or less slanting flysch, an impermeable layer of bedrock, are characteristic of this area. The true karst caves are small and their development was influenced by the sediment that, as a rule, fills them. They formed in a locally and periodically flooded zone and are often paragenetically enlarged.

The largest caves formed above the point at which contact is made with the impermeable flysch bedrock where the largest streams join. Their shape reflects the varying degrees of consolidation of the breccia. In areas where the breccia is less consolidated, and along fissures, they rise into domes. Along the fissures that are the consequence of the sliding of breccia and scree material down the slanting bedrock of frequently saturated flysch, fissure caves formed across the slope (Fig. 7); some of them are very long and wide enough in places to make them accessible. As a rule, their walls are covered with flowstone.
To a negligible extent, karstification also takes place inside the flysch where the marlstone or sandstone contains at least calcite cement. Karstification at the points of contact between marlstone and calcarenite, where caves which are several metres in size form, is more significant. In places with almost vertical layers, water quickly percolates into the underground, but the heavily fractured layers hinder the formation of larger caves.
Although the karst described is relatively young and has been discovered in its early development stages, it still reveals all the characteristics of the karstification of breccia in characteristic geological, geomorphological, and hydrological conditions. Learning about this expands our knowledge of Slovenia's diverse natural karst heritage and forms the basis for the future planning of interventions in the environment.

Preserving as many karst caves as possible

We make every effort to preserve as many caves as possible. The shafts were easiest to preserve and concrete plates were used to close the smaller entrances (Fig. 1). It was similarly possible to preserve old caves with solid circumferences, but caves located in fractured rock or opened during blasting needed to be filled with gravel. Rock walls (Figs. 1 and 2) were used to close caves crossed by road cuts with entrances on embankments. Their circumferences were fractured to such an extent that they were unsuitable for visiting purposes, and water could wash clay from caves filled with sediments and flowstone deposits on the roads. One well-preserved cave was left open for travellers driving on the expressway (Fig. 2). The

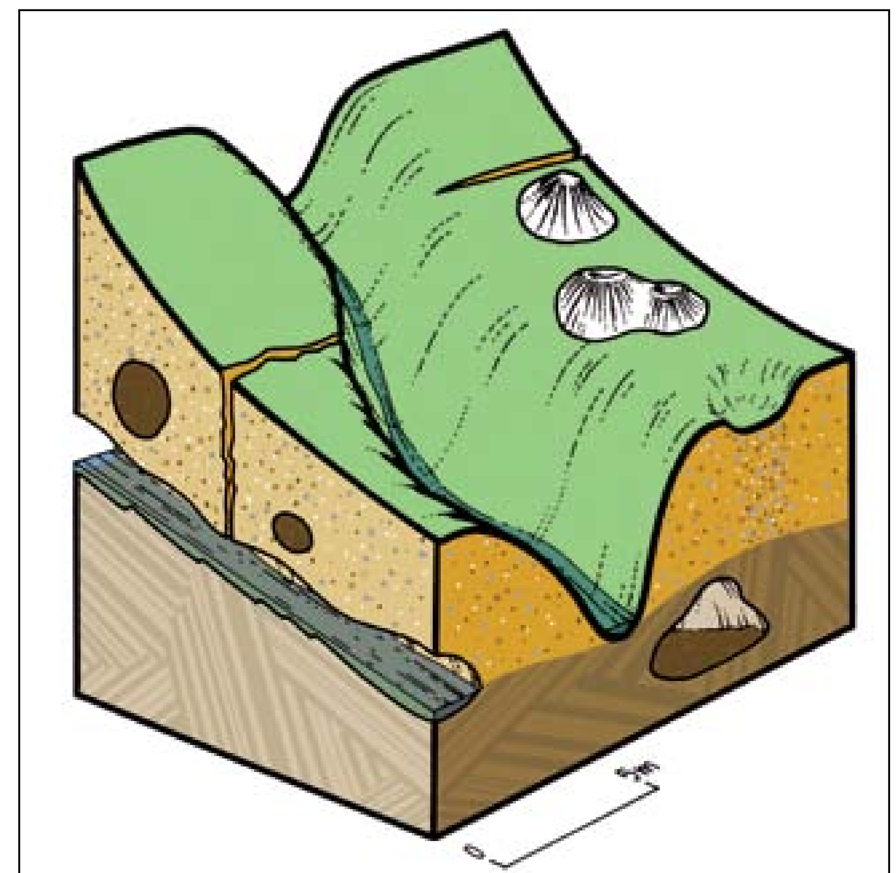

Fig. 6: *Karst in breccia in contact with flysch.*

most interesting and best preserved caves have been completely secured and made accessible for visiting purposes despite being located under the expressway or even wound around a tunnel, as is the case with the Kastelec tunnel (Fig. 1). They are accessible via concrete culverts closed at the roadside and in the tunnel through a doorway.

We also studied the consequences of blasting in caves, which will help us in road construction and the preservation of karstic features in the future.

Fig. 7: Cave formed along fissure in breccia.

Conclusion

It is clear that cooperation between karstologists in the construction of expressways in the karst regions has brought positive results. It is important that karstologists participate in the planning and construction of expressways and that they continue to monitor the impact of the expressways on the environment, that is, throughout the entire process of encroachment on the vulnerable karst landscape. This cooperation helps preserve the natural heritage (in this case, also the caves themselves) and increase our basic knowledge of the creation and development of the karst and the construction of expressways in this unique environment. There are many types of karst and each requires a unique approach which calls for permanent and constant cooperation between road builders and karstologists. Over the last fifteen years, cooperation between the planners and builders of expressways and karstologists has resulted in the knowledge put to use in the planning and implementation of other encroachments in karst areas.

References

Bosak P., Knez M., Otrubova D., Pruner P., Slabe T., Venhodova D., 2000. Paleomagnetic Research of Fossil Cave in the Highway Construction at Kozina (SW Slovenia). Acta Carsologica, 29/2: 15–33.

Knez M., Kranjc A. Otoničar B., Slabe T., Svetličič S., 1994. Posledice izlitja nafte pri Kozini [The consequences of oil spill near Kozina]. Ujma, 9: 74–80.

Knez M., Otoničar B., Slabe T., 2003. Subcutaneous stone forest (Trebnje, Central Slovenia). Acta Carsologica, 32/1: 29–38.

Knez M., Slabe T., 1999. Unroofed caves and recognising them in karst relief (discoveries during motorway construction at Kozina, South Slovenia). Acta Carsologica, 28/2: 103–112.

Knez M., Slabe T., 2000. Jame brez stropa so pomembna oblika na kraškem površju: s krasoslovnega nadzora gradnje avtocest na krasu [Denuded caves as important feature on karst surface: recognition from supervision of motorway construction on karst]. In: Gostinčar A. (ed.), 2000. 5. slovenski kongres o cestah in prometu. Zbornik povzetkov referatov. Družba za raziskave v cestni in prometni stroki Slovenije, Ljubljana: 29.

Knez M., Slabe T., 2001. Karstology and expressway construction. Proceedings of 14th IRF Road World Congress, Paris.

Knez M., Slabe T., 2002. Unroofed caves are an important feature of karst surfaces: examples from the classical karst. Zeitschrift für Geomorphologie, 46/2: 181–191.

Knez M., Slabe T., 2004a. Karstology and the opening of caves during motorway construction in the karst region of Slovenia. International Journal of Speleology, 31/(1/4): 159–168.

Knez M., Slabe T., 2004b. Highways on karst. In: Gunn J. (ed.), 2004. Encyclopaedia of caves and karst science. Fitzroy Dearborn, New York, London: 419–420.

Knez M., Slab, T., 2005. Caves and sinkholes in motorway construction, Slovenia. In: Waltham T., Bell F., Culshaw M. (eds.), 2005. Sinkholes and Subsidence. Karst and Cavernous Rocks in Engineering and Construction. Springer, Praxis, Chichester: 283–288.

Knez M., Slabe T., 2006a. Dolenjska subsoil stone forests and other karst phenomena discovered during the construction of the Hrastje-Lešnica motorway section (Slovenia). Acta Carsologica, 35/2: 103–109.

Knez M., Slabe T., 2006b. Krasoslovne raziskave pri gradnji avtocest preko slovenskega krasa. Annales, 16/2: 259–266.

Knez M., Slabe T., (eds.), 2007. Kraški pojavi razkriti med gradnjo slovenskih avtocest [Karst phenomena discovered during Slovene highway construction]. Crasologica 7, Založba ZRC, Ljubljana: pp. 250.

Knez M., Slabe T., Šebela S., 2004a. Karstification of the aquifer discovered during the construction of the expressway between Klanec and Črni Kal, Classical Karst. Acta Carsologica 33/1: 205–217.

Knez M., Slabe T., Šebela S., 2004b. Karst uncovered during Bič-Korenitka motorway construction (Dolenjska, Slovenija). Acta Carsologica 33/2: 75–89.

Knez M., Slabe T., Šebela S., Gabrovšek F., 2008. The largest karst caves discovered in a tunnel during motorway construction in Slovenia's Classical Karst (Kras). Environmental geology, 54/4: 711–718.

Knez M., Šebela S., 1994. Novo odkriti kraški pojavi na trasi avtomobilske ceste pri Divači [Recently discovered karst phenomena in the motorway section near Divača]. Naše jame, 36: 102.

Kogovšek J., 1993. Kakšna je sestava voda, ki odtekajo z naših cest? [What is the composition of waters from Slovene roads?] Ujma, 7: 67–69.

Kogovšek J., 1995. The surface above Postojnska jama and its relation with the cave. The case of Kristalni rov. Proc. of Symposium International Show Caves and Environmental Monitoring: 29–39.

Kogovšek J., Slabe T., Šebela S., 1997. Motorways in Karst (Slovenia). Proceedings & Fieldtrip excursion guide, 48th highway geology symposium: 49–55.
Mihevc A., 1996. Brezstropa jama pri Povirju [Denuded cave near Povir]. Naše jame, 38: 65–75.
Mihevc A., 1999. The caves and the karst surface – case study from Kras, Slovenia. Etudes de géographie physique, suppl. XXVIII, Colloque européen – Karst 99: 141–144.
Mihevc A., Slabe T., Šebela S., 1998. Denuded caves. Acta Carsologica 27/1: 165–174.
Mihevc A., Zupan Hajna N., 1996. Clastic sediments from dolines and caves found during the construction of the motorway near Divača, on the Classical Karst. Acta Carsologica, 25: 169–191.
Slabe T., 1996. Karst features in the motorway section between Čebulovica and Dane. Acta Carsologica, 25: 221–240.
Slabe T., 1997a. Karst features discovered during motorway construction in Slovenia. Environmental Geology, 32/3: 186–190.
Slabe T., 1997b. The caves in the motorway Dane-Fernetiči. Acta Carsologica, 26/2: 361–372.
Slabe T., 1998. Karst features discovered during motorway construction between Divača and Kozina. Acta Carsologica, 27/2: 105–113.
Šebela S., Mihevc A., 1995. The problems of construction on karst – the examples from Slovenia. In: Beck B. F., Pearson F. M. (eds.), 1995. Karst geohazards, engineering and environmental problems in karst terrain. Proceedings of the Fifth Multidisciplinary Conference on Dolines and Engineering and Environmental Impacts on Karst: 475–479.
Šebela S., Mihevc A., Slabe T., 1999. The vulnerability map of karst along highways in Slovenia. In: Beck B. F, Pettit A. J., Herring J. G. (eds.), 1999. Hydrogeology and engineering geology of dolines and karst. Proceedings of the Seventh Multidisciplinary Conference on Dolines and the Engineering and Environmental Impacts on Karst: 419–422.

HUMAN INTERVENTION IN THE KARST UNDERGROUND THROUGH QUARRIES; EXAMPLES FROM SLOVENIA

Nadja Zupan Hajna [1]

When extracting stone in quarries, quarry operators frequently encounter caves of different types including open shafts, horizontal caves or old passages entirely filled with various sediments. Such cases can be found in all quarries where limestone is exploited. All caves in Slovenia, even those in privately owned quarries, are state property and are protected by the Cave Protection Act (Ur. l. RS 2/2004). Under the Act, quarry operators are obliged to notify the competent services when they find a cave. In practice, however, this does not always happen and it depends on the operators' goodwill or awareness whether or not they inform someone about the find of a cave (for example a regional department of the Institute of the Republic of Slovenia for Nature Conservation, a local caving club, the Karst Research Institute, etc.), after which the cave can be explored, its contents recorded and evaluated, and other measures taken in accordance with the Act. In some cases, a found cave is explored and measured and its contents registered, and after work continues in the quarry. If, however, in the opinion of experts the cave is of outstanding importance because of its form or content, the cave is protected and the exploitation of stone ceases in that part of the quarry (the ledge or area) where the cave is located.

Limestone quarries in Slovenia

Human beings have always used stone. Various stones are useful for building and decoration because of their characteristics and attractive appearance. The majority of quarries in Slovenia are in carbonate rock, i.e. limestone and dolomite. One of the most interesting regions with natural stone is without a doubt the Kras (Karst), where various types of limestone have been and still are widely used in construction and stonemasonry.
In the past the quarries were the property of the families on whose land the rock was located. Today most quarries belong to the state and stone can be exploited on the basis of a concession which the state grants to a mining company or private individual. The exploitation of stone for construction and engineering purposes is regulated by the Mining Act (Ur. l. RS 56/1999, 46/2004).
Generally speaking, natural stone in Slovenia is exploited in three basic ways (Vesel & Senegačnik 2007): a) by the traditional method on high ledges, b) with progressive rehabilitation and c) underground. The majority of quarries in Slovenia operate on the surface in the form of open-cast workings. Reasons of environmental acceptability, better yields and the introduction of new technologies, however, mean that the

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, zupan@zrc-sazu.si*

potential of the other two methods is becoming increasingly apparent. The underground exploitation of blocks of natural stone was introduced in the Hotavlje I limestone quarry in 1993 and in the Lipica II limestone quarry in 2002.
The location of a limestone quarry is conditioned by geological factors and regulatory factors – in the latter case this means above all the need to conform within laws and planning documents that take into account built-up and water-protection areas, parks of different sizes and types, Natura 2000 areas, environmental acceptability, etc. (Vesel & Senegačnik 2007).
A quarry can represent a wound on the surface of the landscape and be unacceptable from the aesthetic point of view. The expansion of a quarry can be problematic for various reasons, and the operation of quarries has a direct impact on the underground. Quarrying limestone uncovers the vulnerable karst underground, a world of living organisms, water connections and caves and their frequently extremely important contents (speleothems, fossils, sediments, archaeological remains, etc.).

Caves in limestone quarries in Slovenia

Most limestone quarries are situated on the Kras (Lipica I and II, Debela Griža, Bezovščina and Lesična), the Podgorski kras (Podgorje karst: Črni Kal and Črnotiče) and the area around Ljubljana (Podpeč, Verd, Lesno Brdo (Fig. 1), Drenov Grič and Hotavlje). Quarries of different sizes may also be found in different types of limestone elsewhere in Slovenia.
The extraction of stone on the Kras has a millennial tradition dating from antiquity. Small quarries called java may be found outside the majority of Kras villages. Landowners opened these on their own land for their own use or for tenants. In these small quarries, for the most part monolithic blocks of limestone were extracted although in places blocks of flowstone from roofless caves or caves near the surface were also extracted.
The two active quarries in Lipica extract thickly bedded Upper Cretaceous limestone of the Lipica Formation, specifically two types of architectural/building stone linked to rudist biostromes and bioherms (Pleničar & Jukovšek 1997). The first type is "Lipica Unito", a light olive-grey fine- to thick-grained limestone with rudist fragments. The second type is "Lipica Fiorito", a light-grey limestone with high rudist content. The limestone in both quarries is highly fractured and karstified in the upper sections below the surface, although no natural caves are known of in these two quarries.
The Črni Kal and Črnotiče quarries are situated in alveolinid-nummulitic limestone of Lower Tertiary age on the edge of the Podgorski kras. The limestones are overthrusted on an Eocene flysch base and they are considerable tectonically crushed. In both quarries several vertical shafts filled with cave sediments have been opened during quarrying, some of them containing traces of Pleistocene fauna. Scientific descriptions have been made of finds of mammals (cave bear, cave lion, red deer, roe deer, cattle) dating from the Late Pleistocene, particularly from vertical shafts in the Črni Kal quarry (Pohar 1992, Pavlovec & Pohar 1997). The Caves Register (IZRK ZRC SAZU and JZS) contains data on a cave located directly in the lower part of the quarry.
Three caves from the area of the Črnotiče quarry (Fig. 2) appear in the Caves Register but have now been completely destroyed. During work

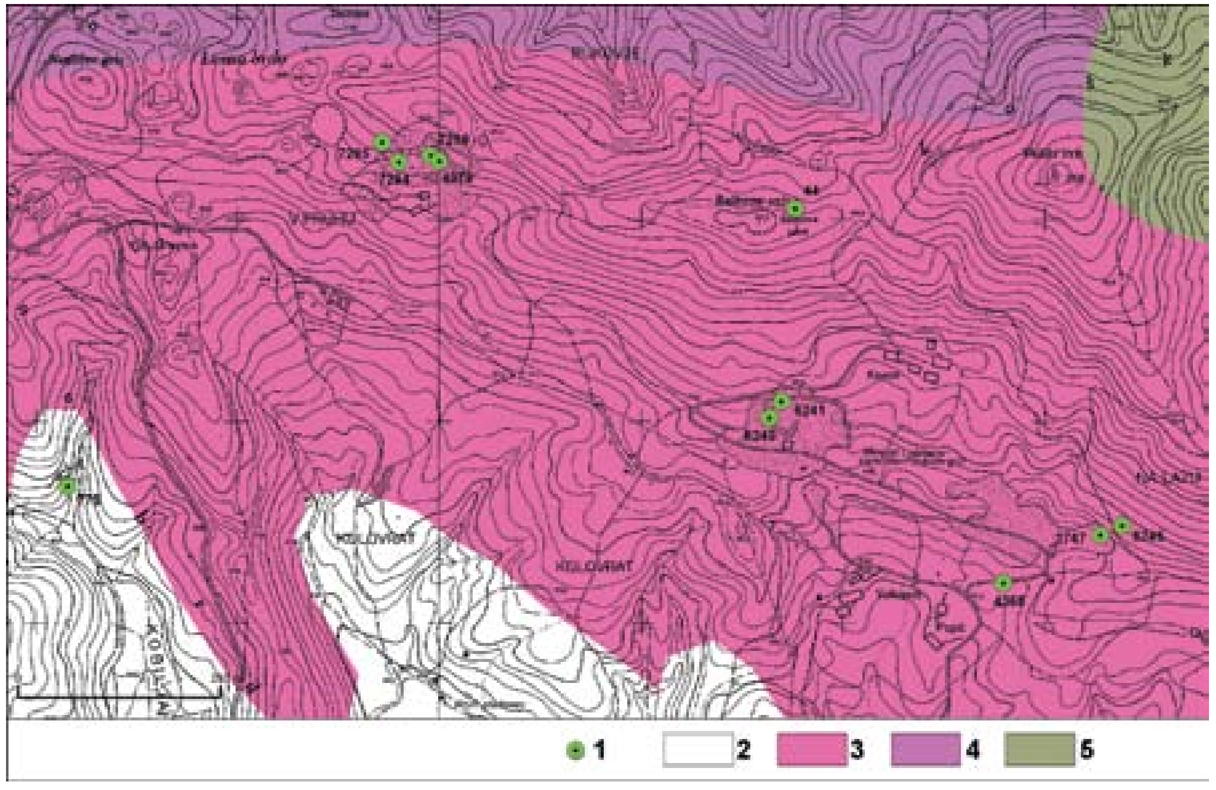

Fig. 1: Location of cave entrances in the area of Lesno Brdo quarries. Legend: 1- Caves with Register No., 2 – Quaternary sediments , 3 - Upper Triassic limestone, 4 – Ladinian limestone with chert and sandstones, 5 – Permo-Carboniferous clastic rocks (source: Basic Geological Map 1 : 100 000 (Sheet Kranj), Geological Survey of Slovenia; Cave Register of Karst Research Institute ZRC SAZU and Speleological Association of Slovenia).

Fig. 2: During exploitations in the Črnotiče quarry many small caves have opened more or less filled with flowstone or clastic sediments (photo: Nadja Zupan Hajna).

in the quarry, small caves more or less filled with flowstone, calcite crystals and various clastic sediments have opened in the face of the quarry. By virtue of their contents and information they can provide, these are of inestimable value to the specialist and scientific public. At the southern edge of the quarry, work has exposed a roofless cave on the upper ledge, the so-called Črnotiče II Profile (Bosak et al. 1999, Zupan Hajna et al. 2008), filled with fluvial sediments and flowstone in its upper section. It is famous above all as the site in which fossil tubes of the freshwater cave-dwelling tube worm Marifugia cavatica, believed to be more than 5 million years old, were found (Horaček et al. 2007). Samples containing *Marifugia cavatica*, which is at the same time the oldest fossilised cave animal (Mihevc 2000), are kept at the Natural History Museum of Slovenia.

In the wider surrounding area of Ljubljana there are several large limestone quarries such as Hotavlje, Verd, Podutik, Podpeč, Drenov Grič and Lesno Brdo. The types of stone quarried in the Drenov Grič and Lesno Brdo area are Upper Triassic dolomite, Upper Triassic black limestone (Lower Quarry and Kucler's Quarry) and white and mottled limestone (Upper Quarry); Hotavlje limestone is of the same age as the mottled limestone from Lesno Brdo. The black limestone beds in Kucler's Quarry are strongly folded. In between beds there are remains of a vertical shaft partly filled with flowstone. Cavers from caving club JK Železničar found approximately 20 caves in a belt of the described limestones; belt is around three kilometres long and a couple of hundred metres wide on average, in an area measuring not more than 1.5 km² (Lajovic 2003). The cavers explored, measured and documented all the larger caves and photographed the smaller ones. The fossilised remains of a cave lion were found in one of the vertical shafts in the Lesno Brdo quarry (Pavlovec 1965). The total length of all known passages is over one kilometre. As a result of the extraction of stone in quarries, known caves gradually lose their walls and it often happens that they are completely destroyed. Cavers have managed to save two caves in Kalce, which have been registered as Jama ("Cave") 1 and Jama 2 in the Drenov Grič quarry. Opening them up makes caves more easily accessible and thus the breaking-off of stalactites and stalagmites becomes a major problem.

Osovniška jama – the case of a cave discovered during work in a quarry

Osovniška jama was discovered in the spring of 2001 during work in the Pijovci quarry near Lemberg, to the north of Šmarje pri Jelšah (eastrn Slovenia). It was named Osovniška jama ("Osovnica Cave") after a nearby hill. The owner of the quarry is Viktor Strašek of Sotensko pri Šmarju. At his request, researchers from the Karst Research Institute ZRC SAZU measured the cave and carried out a karstological inspection (Zupan Hajna 2002), because the owner was interested in developing the cave as a show cave. The cave was also explored by members of the Črni Galeb caving club from Prebold. The total length of the measured passages at that time was 290 metres and the depth reached was 18 metres, making the cave the longest cave in the eastern part of Slovenia (Fig. 3). After completing our research we forwarded a report on the cave to the Celje regional department of the Institute of the Republic of Slovenia for Nature Conservation, who then attempted to protect the cave in accordance with the Cave Protection Act and laid down guidelines for the development of the quarry.

The entrance to the cave opened in the Pijovci quarry during extraction of lithothamnian limestone at a height of 320 metres above sea level. A belt of lithothamnian limestone of Miocene age extends between Ponikve and Mestinje in an east–west direction (Aničić & Juriša 1984, Buser 1977). Lithothamnian limestone is a reef formation deposited

in the Pannonian Sea between limestone conglomerate and sandstone. The main fracture zones of this area run in an NW–SE direction (Aničić & Juriša 1985). The limestone in the quarry area shows intense tectonic crushing but the strata are not visible (reef limestone). The surface inclines from the west towards the east and the limestone belt narrows strongly near the Osovnica hill. The surface is well karstified and numerous dolines appear, although to date caves are not known of in this limestone belt. Work in the quarry opened up two large passages between which at that time there was no open connection. The entrances to three smaller passages filled with sandy and clayey sediments were also visible. In general terms the cave extended in a NW–SE direction.

In April 2001 a shorter passage running in a NW–SE direction ("Entrance 1") was opened in the face of the quarry, dividing after 30 metres into two short passages ending in a collapse. The collapse of the passage walls in both sections was the consequence of quarrying. The main passage was up to seven metres high and three metres wide. Next to "Entrance 1" on the south side was a passage blocked by flowstone, one of the continuations of the same passage. The continuation of the passage towards the West was blocked by a flowstone. The ceiling of the passage was seven metres below the surface. The passage had a keyhole-shaped cross section. At the top were the remains of the original phreatic conduit into which a narrow meander later incised by gravitational process. Corrosion

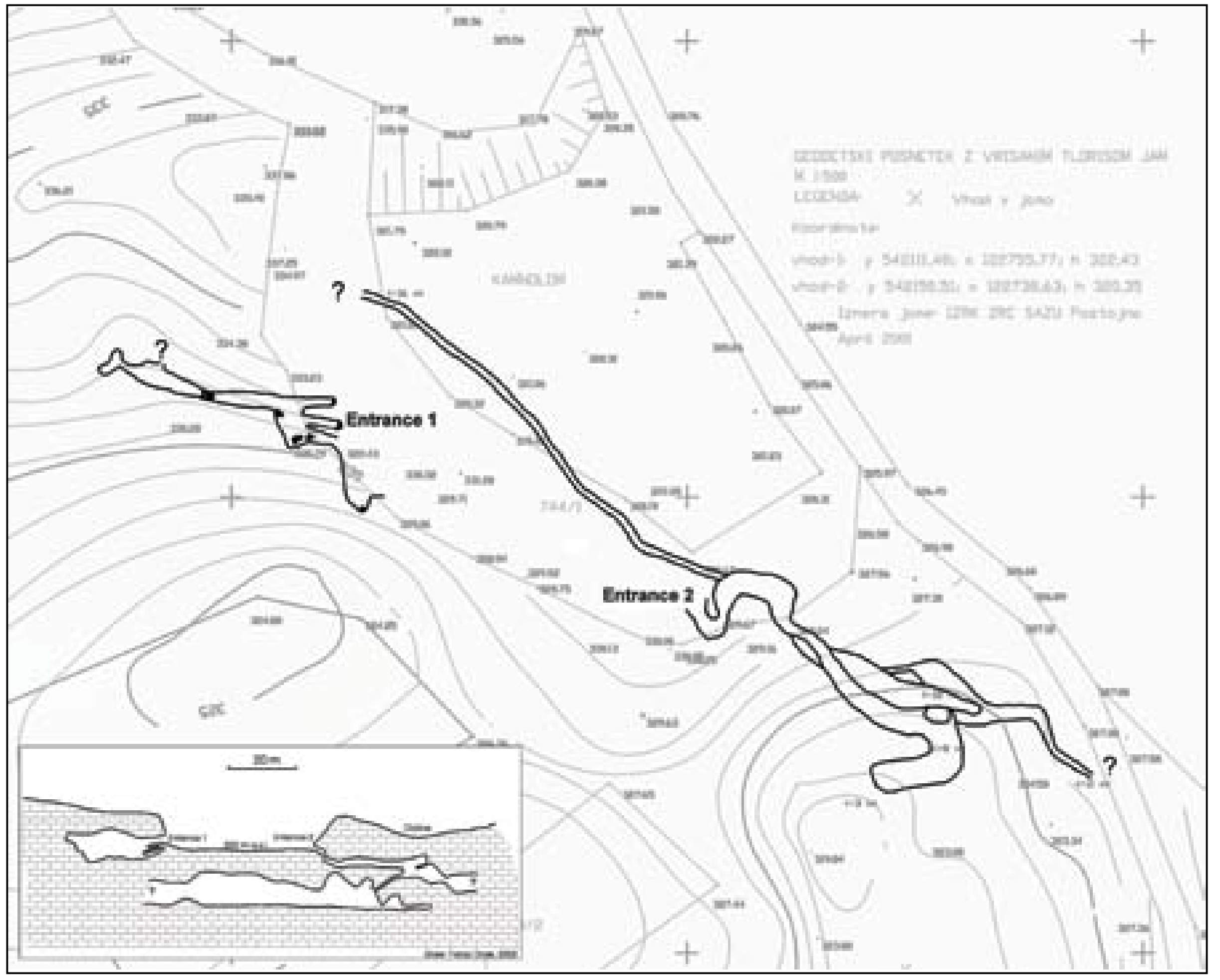

Fig. 3: Basic plan of Osovniška jama in Pijevci quarry with schematic cross-section; situation in 2001 (from Zupan Hajna 2002).

notches were clearly visible on the passage walls at several different levels. These were formed by the gradual changes in the level of the water flow. The conduits formed in the phreatic zone but the meander is probably of vadose origin. At some stage the meander was completely filled with clastic sediments of allochthonous origin (sand and gravel). In places the gravel was already bound into conglomerate. The entire passage was covered by flowstone of a wide variety of forms. At the time of our visit the passage was already largely demolished and crumbling and the speleothems damaged. There was a very great danger of collapse, particularly in the first section, where the passage is also traversed by a major N–S fissure. The fracture was new and probably opened as a result of work in the quarry.

The entrance to the main part of the cave was through "Entrance 2", where the passages were positioned on three levels. The entrance was opened along a fault zone running in a 300–120 direction and winding vertically in an S shape. The first level of the cave, with 38 metres of passage, was up to 13 metres below the surface. The meander-shaped channel was at the beginning up to 2.5 metres high and up to 3 metres wide, before widening into a small chamber. From chamber was a drop of three metres into the lower parts of the cave on two further levels. A short flowstone-covered passage continued towards the south and then towards the west, gradually rising towards the surface (the distance to the bottom of the doline above was about 3 metres). The meander of the second level, full of spaghetti-like tubular stalactites and flowstone curtains, continued towards the SE and ended after 19 metres. The third and lowest level ran in a NW–SE direction and at that time had a known length of 87 metres. The meander-shaped passage was very narrow, up to 1.5 metres wide and up to 11 metres high. Infiltrating water was retained on the bottom of the passage and had combined with sediments to form viscous mud. In places the passage was covered with stalagmites and small flowstone piles. The SE section of this passage ends with a collapse in the area of the small chamber on the second level. The entrance level was thus up to 5 metres below the bottom of the quarry at that time (320 metres above sea level), with the second level up to 10 metres and the third level up to 18 metres below the base level of the quarry. Taking into account the 11-metre height of the third level, also this passage was very close to the bottom of the quarry (up to 7 metres). As a result, the effects of any deepening of the quarry would also be apparent in the lowest sections of the cave.

We agreed with the Celje regional department of the Institute of the Republic of Slovenia for Nature Conservation that because of the special characteristics of the cave in the context of Slovenia and the wider region (the fact that the cave formed in young lithothamnian limestones, the fact that there are few caves in this part of Slovenia, the shape of the cave passage, the state of conservation of the speleothems), it was important to protect the main part of the cave behind "Entrance 2" from being destroyed, and that it was therefore necessary to halt work in the quarry above the cave, since with a continuation of quarrying and a deepening of the quarry bottom, the consequences of undermining would sooner or later be apparent in the main part of the cave.

We envisaged that because of the small number of caves in this region, the size of the cave and the beauty of the speleothems contained in it, the cave would very probably cause a lot of interest among people from the immediate area and further afield, and that it would be therefore necessary to close the entrance to the cave, supervise visits to the cave, and cease operation of the quarry above the cave. It would also be necessary to ask cavers visiting the lower, muddy sections of the cave to change their clothes immediately on passing into the upper section of the cave. Otherwise the upper section of the cave would very quickly become covered with clay. It would also be necessary to protect the speleothems, since the ceiling in the first part of the cave is very low and there would be a risk of careless visitors breaking off stalactites. In the case of guided visits to the upper part of the cave (small groups, e.g. school groups of up to 10 or 12 people) we would recommend marked paths and the protection of cave formations and the creation of a platform in the small chamber where visitors could stop safely and turn round. The shorter section of the cave, behind "Entrance 1" was already so badly damaged during our visit in 2001 and, at the same time, dangerous, that it is not recommendable for visits, while because of its damaged state it is not worth conserving. In the case of a continuation of work in the quarry, we requested the owner to inform us about the discovery of any new cave passages. The owner, however, later decided to block up the entrances to the cave, with the result that the cave is not currently accessible.

According to the oral report of Ms Ljudmila Strahovnik of the Institute for the Conservation of Nature in Celje, the state of Osovniška jama in October 2010 was as follows:

- The owner of the quarry has sealed the entrance to the cave by filling it with earth because remediation of the scarp has been carried out in this section in accordance with the plan.
- The Decree on Mining Rights (Ur. l. RS 97/2006) provides the possibility of exploiting mineral raw materials in the Pijovci quarry for a period of five years (above all for the needs of final remediation of the quarry). The original initiative included a larger area but in its guidelines for the development of the quarry the Institute for Nature Conservation indicated restrictions in connection with protection of the cave, with the result that their proposal for a reduced area of operation was accepted.
- On the basis of the present state in the quarry, it was considered that the owner has removed a fairly thick layer of material in the central portion of the site above the cave passages, with the result that there is a question mark over the thickness of the cave ceiling and re-inspection of the state of the cave is recommended.

Conclusion

Many caves are opened up during working quarries because the upper layer of karst (epikarst) is crisscrossed by open and sediment-filled fractures, vertical shafts and the remains of former caves.

Opening a cave to the surface, however, destroys the natural environment in the cave, affects living conditions in the cave and has a negative impact on subterranean biodiversity, destroys various cave forms and sediments and information about geological and speleological history. Every cave that is opened up during the working of the quarry should be measured and mapped, its contents should be registered and its importance should be evaluated from the point of view of conservation, after which its protection or destruction should be incorporated into the development guidelines of the individual quarry.

References

Aničić B. & Juriša M., 1984. Osnovna geološka karta 1 : 100000, list Rogatec. Zvezni geološki zavod, Beograd.

Aničić B. & Juriša M., 1985. Tolmač lista Rogatec, Osnovna geološka karta 1 : 100000, Zvezni geološki zavod, Beograd: pp. 76.

Bosák P., Mihevc A., Pruner P., Melka K., Venhodová D., Langrová A., 1999. Cave fill in the Črnotiče

Quarry, SW Slovenia: palaeomagnetic, mineralogical and geochemical study. In: Kranjc A. (ed.) Papers presented at 7th International Karstological School "Roofless Caves", Postojna 1999. Acta Carsologica, 28/2: 15–39.
Buser S., 1977. Osnovna geološka karta 1 : 100000, list Celje. Zvezni geološki zavod, Beograd.
Grad K., Ferjančič L., 1974. Osnovna geološka karta SFRJ, list Kranj, 1: 100 000. Zvezni geološki zavod, Beograd.
Horáček I., Mihevc A., Zupan Hajna N., Pruner P., Bosák P., 2008. Fossil vertebrates and paleomagnetism update of one of the earlier stages of cave evolution in the Classical karst, Slovenia : Pliocene of Črnotiče II site and Račiška pečina Cave. Acta Carsologica, 36/3: 453–468.
Lajovic A., 2003. Kras Lesnega Brda. Bilten JKŽ, 23: 42–53.
Mihevc A., 2000. The reconstruction of the Pliocene paleoenvironment of the unroofed caves with fossil remains of *Marifugia cavatica* from the Črnotiče quarry, Podgorski kras, W Slovenia. Acta Carsologica, 29/2: 261–270.
Pavlovec R., 1965. Ostanki ledenodobnih živali v Lesnem brdu pri Vrhniki. Proteus, 28/6: 155–156.
Pavlovec R., Pohar V., 1997. The Črni Kal quarry - an example of destroying geotopes. Geologia Croatica, 50/2: 181–184.
Pleničar M., Jurkovšek B., 1997. Rudisti iz lipiške formacije v kamnolomu Lipica I. Annales: Anali za istrske in mediteranske študije, 11/97: 115–140.
Pohar V., 1992. Poseljenost Kraškega roba v kvartarju. Proteus, 54/(6-7): 266–268.
Ur. l. RS [Official Journal of the Republic of Slovenia]:
56/1999. Zakon o rudarstvu [Mining Act].
2/2004. Zakon o varstvu podzemnih jam [Cave Protection Act].
46/2004. Zakon o spremembah in dopolnitvah zakona o rudarstvu [Act amending the Mining Act].
97/2006. Uredba o rudarskih pravicah [Decree on Mineral Rights].
Vesel J., Senegačnik A., 2007. Geološke raziskave kot osnova za opredelitev najprimernejšega načina pridobivanja blokov naravnega kamna. In: Kortnik J., Likar J., Hafner G., Jelen B. (eds.). Zbornik Strokovnega posvetovanja rudarjev in geotehnologov ob 40. Skoku čez kožo, Ljubljana, 30th March 2007. Ljubljana, Slovensko rudarsko društvo inženirjev in tehnikov - SRDIT: 55–64.
Zupan Hajna N., 2002. Osovniška jama, the cave in isolated karst in the east of Slovenia. Acta Carsologica, 31/3: 75–87.
Zupan Hajna, N., Mihevc A., Pruner P., Bosák P., 2008. Paleomagnetism and Magnetostratigraphy of Karst Sediments in Slovenia. Carsologica 8, Ljubljana, Založba ZRC: pp. 266.

POLLUTION AND CLEANUP OF KARST CAVES IN SLOVENIA

Mitja Prelovšek [1]

The creation and elimination of waste is a constant of every form of existence, since waste is defined as matter that a user no longer needs for the performance of his life or activities. When it comes to meeting basic biological needs, human beings are no exception in this natural cycle: animals also produce waste matter (e.g. droppings, hair/fur/feathers, remains of food), as do plants (e.g. falling leaves). Since, however, most of this waste matter is part of the natural circulation of matter, quantities are small and usually rapidly degradable, accumulation in the environment only occurs in exceptional circumstances and major environmental impacts are rare.

A significant shift occurs with increased material flow – a consequently greater quantity of waste and less easily degradable waste caused by human beings. Increasing population densities and an increase in per capita material flow led to a constantly increasing quantity of concentrated waste. The development of waste-related diseases soon began to pose a threat to human beings. A form of waste management was developed, the primary function of which was to remove waste from areas of habitation and transport it to sites where it would no longer be harmful. The carcasses of dead animals were frequently buried in the ground, burnt or dumped in inaccessible locations, in this way limiting the biological transmission of contagious diseases that were once significantly more widespread than today. People in fact have to "get rid" of waste somehow, since otherwise it can be a cause of diseases and epidemics in society, which is something to be avoided. Inaccessible, "useless" sites that are therefore useful for the dumping of waste include – alongside other depressions, rivers and precipices – karst caves. These, however, have the unfortunate characteristic of being a link between the karst surface and springs that are frequently used for drinking water. Not only that, but owing to the absence of light and less drastic meteorological fluctuations, degradation processes take place considerably more slowly than on the surface.

The use of karst caves for the dumping of waste is closely connected to their usability or otherwise: caves that once offered people protection from external factors were not used as waste dumps, at least not while human beings lived in them. This also applies to caves where people buried their dead (Koblarska jama (Jamnik et al. 2002), Ajdovska jama near Nemška vas (Horvat 1989), Tominčeva jama (Leben 1978), Lukenjska jama near Prečna (Osole 1983), Skeletna jama/Jama na Prevali I (Frelih 1998), or which they used as temples (Sveta jama pri Socerbskem gradu, Landarska jama). People have long had a completely different attitude towards caves that are not suitable for activities of this type, do not belong to anyone and are unproductive for them, later above all from the agricultural point of view. As a result, people soon began to dump unwanted things in them: in rocky karst areas, this mainly meant rocks collected during the clearance of fields, meadows and pastures (Marnošnova jama, Pokčeva jama, Bestažovca, Jama na Prevali II, Špirnica, etc.), and later continued with less degradable waste (iron, plastics). Prosperity led to a steady decline in the

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, mitja.prelovsek@zrc-sazu.si*

reuse of materials (recycling) and, consequently, to increasing quantities of waste – particularly since the World War II, as far as Slovenia is concerned. Just like earlier forms of waste disposal, the dumping of waste in the karst also represents a health risk. As a result of the quantity, toxicity and poor degradability of waste materials (this last is, of course, a positive characteristic while materials are in use), practically none of the water sources in inhabited karst areas is any longer drinkable without preliminary physical/chemical treatment of the water (in part because of the impact of other sources of pollution of the underground karst).

This has also been joined by the phenomena of caving and cave tourism, which use caves for their own activities. In this context the appearance of waste in caves is seen as an undesirable phenomenon, particularly in the visual sense. The first record of pollution of a cave appears in the Slovene Caves Register in as early as 1912 (Simić 2000), while other accounts and appeals in daily newspapers against the pollution of caves date from 1913 (Habe 1982). These appeals fell on deaf ears – at least in Slovenia – right up until the second half of the 1980s, when the removal of municipal solid waste was organised on a larger scale. People "had to" get rid of waste, and dumping waste in caves was still considered to be harmless – it did not spoil the appearance of the landscape and was therefore "appropriate". From this point of view, the ineffectiveness of the inspection services is also easy to understand: quite apart from the difficulties involved in discovering who was responsible for pollution in a cave, they were also faced with people's "instinctive" and utterly reasonable desire to remove waste from their dwellings to a location that was as invisible as possible – and in the karst this means caves.

Organized removal of waste – a key condition for the start of the cleanup of caves

The first and most fundamental condition for the cleanup of caves is the organised removal of waste and its disposal in landfills. Once this condition is met, the cleanup of caves becomes a reasonable proposition and is able to keep pace with the continuous reduction in the dumping of waste in caves. The organised removal and disposal of waste satisfies the human need for a healthy and comfortable living environment, while in principle the need to dump waste in caves – if we ignore the financial impact – disappears. Although in the context of towns the removal of waste and its dumping in a safer area began very early in human history, in areas of scattered settlement, which include the majority of karst areas, this practice was not established in Slovenia until the 1990s. Before this (e.g. in 1969) fewer than 20 % of the inhabitants of the Dolenjska region were included in organised waste removal. In the karst areas of the Notranjska and Primorska regions this figure was under 40 % (Klemenčič 1991). Since significantly higher percentages are characteristic of cities and larger towns, the proportion of the population included in the organised removal of waste in the countryside is considerably lower – according to some figures just 10–20 % (Fajgelj 1994). A system for the collection and removal of waste was not introduced on a larger scale until the mid-1990s. In 1995 76 % of households in Slovenia were included in the system of organised waste collection and removal. By 2001 this figure had risen to 94 %. As expected, the quantity of municipal solid waste in caves stopped growing. There were also improvements in the veterinary service and the removal of sick and dead domestic animals, which further reduced pressure on karst caves. The end of waste dumping in flood areas and the creation of controlled landfills caused an improvement in the situation as regards the washing of waste into karst ponor caves.

The reduction of pollution pressure on caves has also been affected by warnings of the danger of dumping waste in caves and the consequent increase in environmental awareness, both among people who have begun to recognise the importance and beauty of caves and among cavers, who were practically the only organised group able to tackle the cleanup of caves. Awareness was raised in particular by pollution censuses indicating significant pollution of karst caves particularly in Dolenjska (11.3 % of caves (Habe 1982), 25 % of caves or all caves in the vicinity of villages and paths and none in the heart of karst massifs (Hudoklin 1995, 2002) 15–60 % in Bela Krajina (Klepec 1989)) and in Notranjska (20 % of caves in the municipality of Cerknica (Drame 1989)). Data was collected either by inspection of Slovene Caves Registers or cataloguing in the field, and from 1986 in part by means of a census promoted by the Institute for the Protection of Natural and Cultural Heritage and the Republic Inspectorate, although because of the need to fill in time-consuming forms, the response from cavers was poor (Puc 1987). Since 2003 data on polluted caves has also been systematically collected in the Slovene Caves Registers, where the basic records are contained in a section entitled "Pollution of caves and other human impacts". At the same time, the Cave Protection Act (Ur. l. RS 2/04) was adopted in 2003. Article 12 of the Act defines the monitoring of cave pollution from the side of some caving clubs and reporting it to the organisations responsible for nature conservation. Parallel with this, campaigns were run to inform the public about the harmfulness of cave pollution, including documentary recordings of cavers from karst caves showing the beauties of the underground and polluted parts of caves. In 1995 the cavers of the Jamarski klub Novo mesto (Novo Mesto Caving Club), in conjunction with local broadcaster Televizija Novo Mesto, made the film Kotarjeva prepadna ali žalosten vsakdan dolenjskih jam [Kotarjeva prepadna cave or the Sad Reality of the Caves of the Dolenjska Region] and made it possible for interested non-cavers to enter the cave. A year later they also carried out a cleanup of the cave (Hudoklin 1996). Between 1998 and 2002, a well-publicised cave cleanup operation took place, organised by the environmental fund of paint company Helios (Simić 2000). Articles on cave cleanups appeared in the national and local press and the subject was featured in radio and television programmes, in many places raising awareness of the undesirability of dumping rubbish in caves.

The third extremely important condition is motivation and willingness on the part of cavers, who are practically the only group capable of tackling the cleaning up of caves, because of the difficulties involved. Before the 1990s, the active dumping of rubbish in caves, poor environmental awareness and the costs that caving clubs would have had to sustain on their own meant that motivation was low. Occasionally local institutions would provide financial assistance to enable the cleanup of ponor caves because of problems with floods caused by sinkholes becoming blocked (also by rubbish). But such cleanups, however, cannot be considered as the result of environmental awareness. Environmental awareness is weak even in the case of the cleanup of caves in the immediate catchment area of water sources used to supply drinking water, since here the only motivation is the need to ensure drinking water of suitable quality only for human beeings. An exception were the individuals who were prompted by their own nature protection impulses to tackle the cleanup of the Brimšca cave in 1972. In 1971 excessive pollution and a high concentration of CO_2 prevented them from cleaning up another cave, Kozinska jama (V. Bernetič, personal correspondence). It was not until the 1990s that a strong environmental awareness began to awaken among cavers, leading to voluntary cave cleanups. It took another 10 years or so for annual cave cleanups to become a habitual part of the activities of some caving clubs. Cave cleanups involve socialisation, establishing caving's place in society, discovering sections of caves blocked by wastes and, in part, maintaining the financial position of caving clubs; local communities, meanwhile, pay for the costs of removing and disposing of waste and in this way avoid the extremely high labour costs that could otherwise fall on their shoulders. In the majority of cases cave cleanups are a voluntary activity on the part of caving clubs and one that is practically without profit, where there is a clear non-economic interest. Awareness, however, varies greatly among individual caving clubs. This was made evident by the census of polluted caves in 1986, when the majority of information on polluted caves was collected in the Dolenjska and Bela Krajina regions and the Domžale area, while practically no information was collected for the Notranjska and Primorska regions and the area around Kočevje (Puc, 1987). The spatial distribution of caves in Slovenia that have been cleaned to date shows a similar picture (Fig. 1).

Cleaning up caves

Cave pollution censuses in the 1990s pointed to an extremely poor situation in caves in lowland areas that required rapid and effective action – to remedy the existing pollution of caves and prevent further pollution. The cleanup of caves was of course also facilitated by the organised removal of waste to landfills, which guaranteed the prevention of further pollution, and the motivation of some of the larger nature-protection-oriented caving clubs.

If we exclude the cleanup of sinkholes in 1980s, which "incidentally" included the removal of waste from ponors, although its main purpose was protection against floods rather than nature protection (Požirak cave in Loški Potok in 1983 – DZRJ Ribnica, ponors of Rašica brook near Dobrepolje area in 1979 – DZRJ Ljubljana), some sanitary interventions in caves in the catchment area of springs used to supply drinking water, carried out for preventive

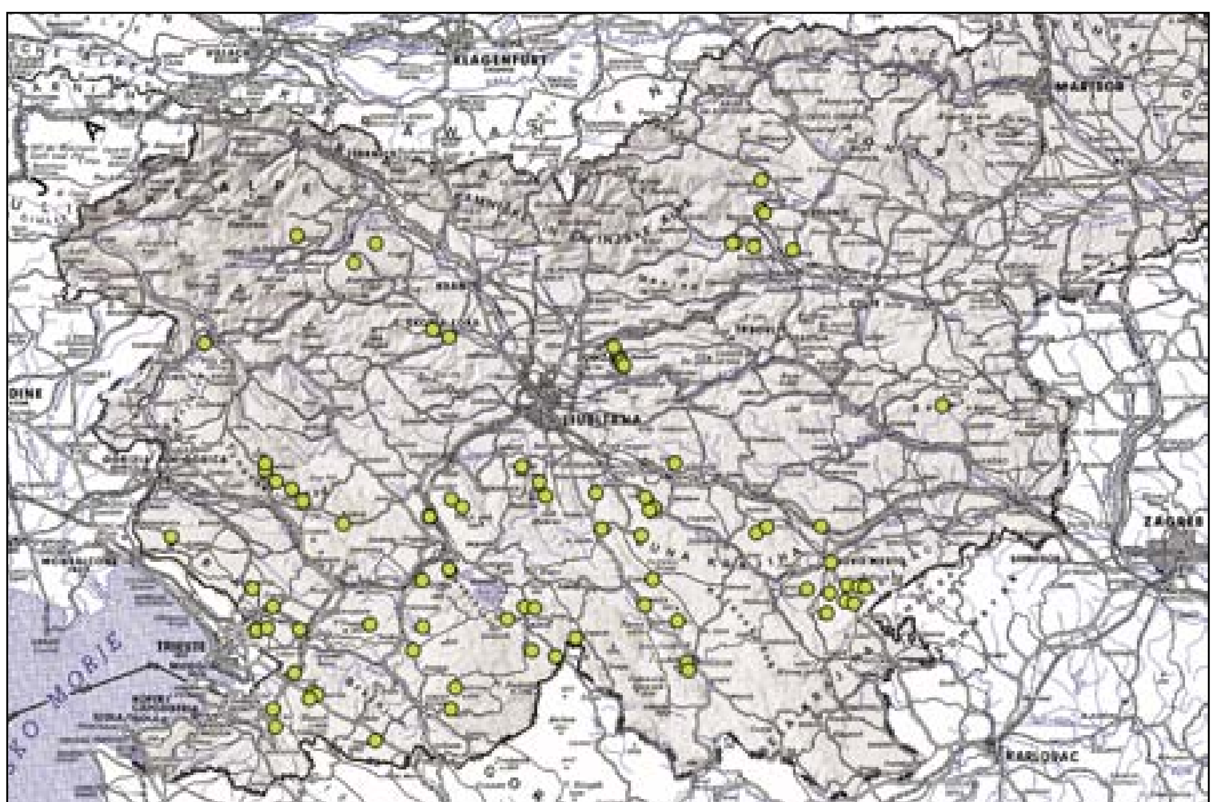

Fig. 1: *Distribution of cleaned caves in Slovenia.*

reasons (Badovinčeva jama in Lavrtce (cat. no 5568) in 1993 – JK Novo Mesto, Gašperčeva jama (cat. no 8127) in 1994 – DZRJ Ribnica) and the excavation of human bones (Mihovska jama (cat. no 6484) in 1994 – JK Novo Mesto), during which cavers simultaneously cleaned up the shaft, and a few other exceptions (Brimšca cave in 1972 – JD Dimnice Koper), the cleanup of karst caves in Slovenia can be said to have begun in the second half of the 1990s. The first very widely reported cave cleanup with a primarily nature protection background took place in Kotarjeva prepadna cave (cat. no 187) in 1996 under the aegis of JK Novo Mesto and included a parallel information campaign. The following year, in 1997, the Mišnica cave (cat. no 185) – a high-water sinkhole on Dobriniško polje – was cleaned, although here too the primary purpose was something else: the cavers of JK Železničar wanted to get past the waste and debris in order to reach a previously inaccessible siphon that would open a route for them into the flooded underground.

In 1995 members of DZRJ Ljubljana (Cave Exploration Society of Ljubljana) attempted to obtain funds to clean up the Brimšca cave (cat. no 1132) purely for reasons of nature protection, but their application was refused because of an administrative error. Despite this setback, it was actually this unsuccessful application that led to a four-year cave cleanup campaign organised by the environmental fund set up by paint company Helios (Simić 2000). The company in fact committed itself to paying 50 tolars (€ 0.21) into an environmental fund for every litre of water-based paint it sold. So much money had been collected by 2002 that in the four years of the campaign 225 m^3 of waste was removed from 17 karst caves. Ten caving clubs from around Slovenia took part in the project, while others failed to make the cleanup list because of their limited financial resources. Clubs tackled the cleanup in different ways, ranging from the manual removal of waste from caves to the use of technically more complex cableways, the use of electric winches and tractor winches and the use of mobile cranes to lift heavy loads. The cave cleanup operation enjoyed a considerable response in the media, thanks in part to the interesting tie-up between the world of business (Helios), a government ministry (the Ministry of the Environment and Spatial Planning) and NGOs (the cavers; Simić 2000). Taken together, these cave cleanup campaigns can be considered a turning point in views on the social mission of cavers and their role in nature protection activities, a role that can only be maintained by bigger, more environmentally aware caving clubs.

Since there are more than 50 different caving clubs in Slovenia, and since the primary mission of caving clubs is the exploration of caves, internal motivation is relatively scarce and dependent on external stimuli. This can be shown by a quantitative look at the last decade of cave cleanups, where in most years just two caves were cleaned per year. The exceptions are 2003, 2004, 2007 in 2010 (Fig. 2). The increase in 2003 and 2004 is the result of the cleanups of eight caves in Dolenjska by JK Novo Mesto, which as well as having good environmental awareness enjoys strong support from municipalities in the region. Despite the large number of caves, the quantity of waste removed from the eight caves is not very large, with an average just over 2 m^3 of waste removed per cave. That same year individual caving clubs removed up to 29 m^3 from caves. The year 2007 is notable because of the Nationwide Cave Cleanup organised by the Caving Association of Slovenia and the Nature Protection Institute, to which it is also necessary to add other cave cleanups that happened to coincide with it.

The biggest cleanup of caves and of the environment in general took place in Slovenia on 17 April 2010 as part of an event called Let's Clean Up Slovenia in One Day! This event saw 78,000 m^3 of waste collected around Slovenia and taken to landfills (Očistimo... 2011), including at least 85 m^3 of wastes in caves, which is actually a very low percentage and evidence of the extraordinary difficulty

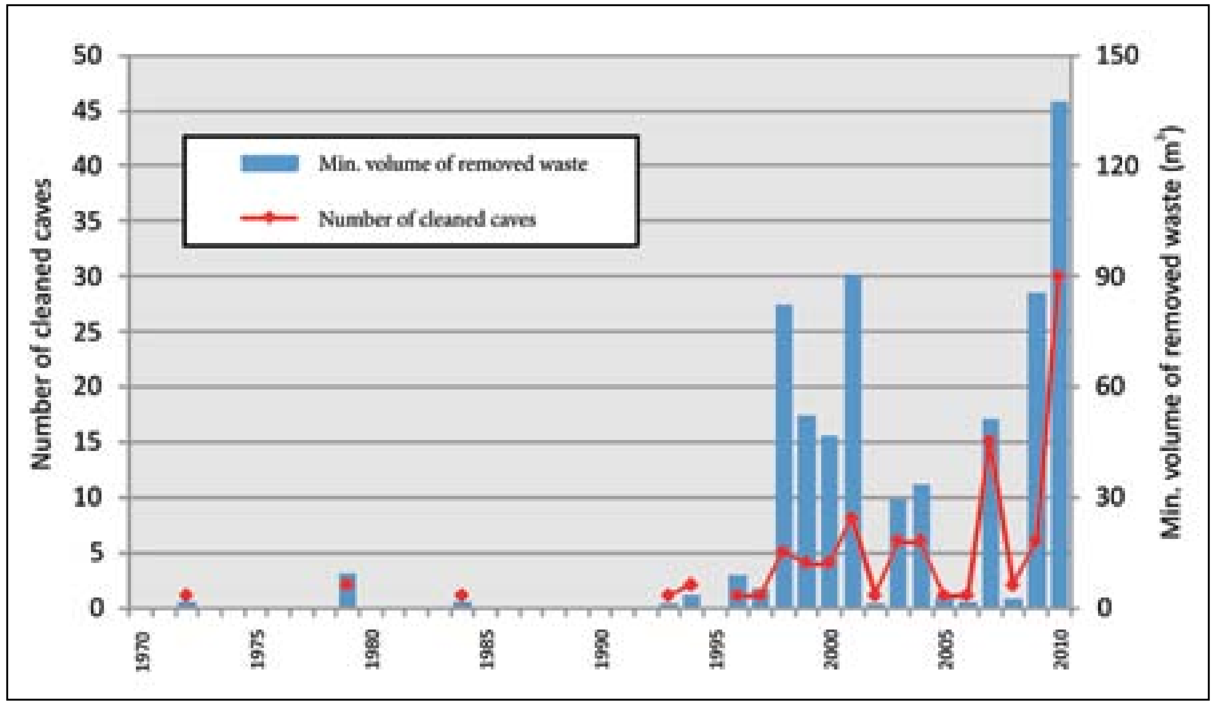

Fig. 2: Number of cleaned caves and minimal volume of waste removed from them. In 2009, information about min. volume of waste includes also 40 m³ of fluvial deposits from sinkhole Požiralnik 1 v Lučah.

involved in cleaning up polluted caves. The problem was not the response from cavers, since 24 caves were cleaned up during the event, with at least 17 caving clubs getting involved. These included clubs that had not in the past been particularly active in this field, and of course clubs that clean caves as part of their regular caving activities. The total number of caves and waste removed in 2010 were joined by four caves that were cleaned up as part of the Karst Underground Protection project.

Cave cleanups as part of the Karst Underground Protection (KUP) project

In the autumn of 2009 the Karst Research Institute ZRC SAZU, together with two partners in Croatia (the Istrian Region and Natura Histrica), succeeded in obtaining € 52,393 of funding to purchase equipment for the cleanup of caves and to cover the costs of labour and the removal and disposal of waste. The success of the application for funding was partly due to the good response to the cleanup of six caves in Croatia as part of the Underground Istria project run in past years by the Istrian Region, and to the connection between education (the "Classical Karst" International Karstological Schools, speleobiological research) and raising the awareness of the local population about the importance of the karst environment and its vulnerability. Funds were provided for the cleanup of six caves in the border area between Slovenia and Croatia, the caves themselves to be identified following approval of the project.

The caves cleanup project within the KUP project is also interesting from the point of view of the integrated approach to the problem of cleaning up caves – from obtaining European funds from the Operational Programme IPA Slovenia-Croatia 2007–2013, identifying potential caves for cleanup, field inspections of potential locations, tendering procedures for the purchase of equipment and the selection of contractors, the cleanup itself and cooperation with municipal services for the removal and disposal of waste.

The catchment area of the Rižana spring, which supplies water to the whole of Slovenia's coastal region, was selected as the primary cleanup area, although we were also open to suggestions from caving clubs all along the border between Slovenia and Croatia. We obtained data on cave pollution from the polluted caves layer on the Geopedia website (http://www.geopedia.si/), which combines various sources on cave pollution. We obtain more detailed information from the Slovene Caves Register of the Karst Research Institute, where, however, in practically every case there was a lack of fundamental information on pollution such as the quantity or type of waste, the location of waste or the difficulty of cleanup, on the basis of which it is possible to make a decision on a specific cave cleanup action. Cleaning up a horizontal cave polluted by a bag of rubbish in fact requires a completely different approach from the cleaning of a narrow semivertical shaft dozen of metres deep that is polluted by several cubic metres of hazardous waste. The use of the Sloven Caves Register on its own turned out to be insufficient, but it did enable us to identify a range of caves that were potentially suitable for cleanup and the exclusion of a number of caves where cleanup would be too dangerous (fresh remains of domestic animals, unexploded munitions), beyond the reach (quantity of waste too big, too far from an access route) or off limits (caves used as execution sites after or during World War II). A field trip to 15 potentially polluted caves showed an extremely wide range of waste in terms of both type and quantity (from 0.25 m³ to over 50 m³). We eventually chose six medium-polluted caves to which access was in principle possible with a waste container lorry. In estimating the time necessary for the cleanup and the consequent allocation of financial resources to a specific cave, we took into account the quantity of waste, the depth at which the waste was located and the technical difficulties of the cleanup. The norms for the work done were determined on the basis of past cave cleanup campaigns, where the quantity and depth of waste was known, as was the number of hours spent cleaning up the cave and the number of people involved in the cleanup operation (=1.34 m³ of waste from a depth of 1 metre per person per hour). We obtained the value in hours by estimating the quantity of waste, the depth and the technical difficulty, which ranged from 1 (simple cleanup) to 1.5 (demanding cleanup). The hourly rate per caver was determined taking into account the skills necessary for the work, the risk involved in the cleanup operation, and amounted to € 19 per hour.

The contractor for the cleanup (a caving club) was chosen on the basis of a call for tenders, which enabled the transparent use of funds, equal treatment of all interested caving clubs and the establishing of ability to clean up caves safely. On the basis of the call for tenders, three caving clubs were selected for the cleanup operation, where JD Rakek took on the cleanup of four caves and DZRJ Luka Čeč of Postojna and JK Železničar of Ljubljana took on one cave each. The removal of waste to landfills was carried out by the companies that provide waste removal services in the municipality in which the individual cave was located.

The cleanup of the five cleaned caves to date took place in autumn/winter, where the low temperatures and the consequent ventilation of the caves meant that excessive smell was avoided, while the low altitude meant that there were no problems with snow. Different techniques were used to lift the waste out of the caves, ranging from the technically advanced (a steel cableway with an electric winch) to the very simple (a double pulley system). In the technically more demanding caves, the system for lifting waste was set up on the day before the cleanup, while in the simple caves it was set up on the day itself. No accidents occurred during the cleanup. The biggest danger was represented by falling rocks below the entrance shafts. In the case of Pokčeva jama there was a risk of anthrax infection, which we reduced by using masks and gloves to protect the respiratory organs and preventing contact of the waste with the skin. Since there was an equal or greater danger of anthrax infection in the Golobnica cave, we decided not to take the risk and substituted the cave with a safer one. Four items of unexploded ordnance were found during the cleanup but since they were lying on the surface they were not a surprise and therefore not a risk for an accident.

Following the cleanup of the caves, we established that despite the quantitative approach to determining the difficulty and costs, the number of hours envisaged for the cleanup was overestimated in the case of the deeper caves because of the rapid mechanical lifting apparatus, while in the case of the smaller caves it was underestimated because of the relatively time-consuming process of loading and unloading. The estimate of the quantity of waste corresponded relatively well to the actual situation with a tolerance of ±25 %. The only exception was Pokčeva jama near Praproče (cat. no 5251), where the difference was significant because of an underestimation of the thickness of the waste layer (estimated quantity 16 m^3, actual quantity 29 m^3). Because we overestimated the quantity of waste in some caves and underestimated it elsewhere, the total quantity of waste was in the region of the ±25 % tolerance. A total of 59.5 m^3 of waste was removed. Where possible, ferrous waste was separated from other mixed waste. As a result, 24 m^3 of metal waste was separated from the total quantity to follow principles of mixed waste reduction and meterials recovery. Municipal solid waste was the single biggest component of mixed waste. Environmentally hazardous waste included electronic components, the remains of dead animals, batteries, car engines with the remains of oil derivatives, and containers with residues of fuels, lubricants, detergents and paints. A rough estimate put hazardous waste at 2 m^3 or over 500 kg. Although this is a small proportion of the total quantity of waste removed, it is necessary to take into account the reduction in danger to the environment, which is significantly greater with the removal of hazardous waste than in the case of the removal of relatively inert waste.

Results of cave cleanup campaigns

Cave cleanup campaigns produce results at a number of different levels which do not only include the quantity of waste removed from caves and the reduction of existing environmental impacts. The following results may be highlighted:

- preventive activity or raising public awareness of why it is wrong to dump waste in caves,
- removal of waste from caves:
    - elimination of negative visual impact,
    - elimination of existing negative impacts (on living things, i.e. subterranean fauna, and on the inanimate world, i.e. water and the caves themselves),
    - elimination of risks deriving from currently low-impact waste (i.e. hazardous packaged waste).

In this context, prevention or raising public awareness is extremely important. Clear presentation of the harmfulness of dumping waste in caves, the underground beauty that is spoiled by waste in caves, and the effort needed to clean up caves prevents further dumping of waste in caves and raises awareness of valuable underground features in the local area. This makes cleaning up caves worthwhile.

The majority of waste has little impact on the environment because it is relatively inert (building materials, stone, wood, glass, plastic, iron). Even so, such waste is not a desirable phenomenon in underground caves because it spoils the appearance of the underground and mutilates its nature, and in some places blocks access to the interior of caves. This reduces the number of access points – already few in number – to the deeper/longer passages that are interesting from several specialist points of view (hydrological, geomorphological, speleobiological). As well as restoring caves to their original appearance, the removal of inert waste thus opens up the possibility of exploring deeper sections of caves.

Although the impact of pollution of the underground with environmentally hazardous waste overlaps, particularly in water sources, with other sources of pollution and is difficult to define in quantitative terms, we can say that the removal of waste reduces negative impact on the environment. During cleanup operations in caves, small but highly toxic quantities of waste are frequently discovered. These include waste electronic components (heavy metals, PCBs from condensers are extremely long-lived, are highly toxic and carcinogenic and accumulate in organisms), large quantities of slaughterhouse waste (biological pollution, transmissible diseases/zoonoses, an organic basis for the replacement of subterranean animal species with surface-dwelling species), unexploded ordnance (heavy metals), oils and other petroleum products, pesticides, medicines, washing powders and detergents, batteries (heavy metals, acids) and a mass of compounds that form as the consequence of the interaction of waste. All the above types of waste are not a hypothetical source of pollution but an actual source of pollution, since they have already been removed from karst caves in at least 100 past cave cleanup campaigns in Slovenia up to April 2011.

The large quantity of waste in caves covering deeper layers of waste, the sometimes very poor records of polluted caves, the lack of clarity from the point of view of potential environmental hazards, and the considerable number of caves that can no longer be identified at all on the surface because they are entirely filled up with waste of unknown type – all these represent a potential danger if substances that are currently still kept separate from the natural environment by packaging begin to escape into the environment. This type of risk is the hardest to define, because its "potentiality" means that little data is available. The most recent example is in the extremely complex catchment area of the source of the river Krka, where abnormally high concentrations of pesticides have been appearing in the spring since 2009 (Kakovost podzemnih voda… 2009). Given the periodically high concentrations, the pollution is most likely to be point source pollution, where a likely cause would appear to be the leaching of pesticide residues dumped in one of the caves in the catchment area. Despite inspection of the caves by cavers, the source of pollution has not yet been identified. Extremely limited access to groundwater makes more accurate identification of the point of pollution difficult. For the reasons stated at the beginning of the paragraph, which apply in particular in the catchment area of the Krka, it is highly probable that owing to the karstic nature of the catchment area the source of the pollution will never be discovered.

Conclusion

It is estimated that around 10 % of caves in Slovenia are polluted, in other words around 1,000 underground caves. The largest number of them are located in the vicinity of areas of habitation and the pollution is the consequence of the lack of organised removal of municipal solid waste. Although the introduction in the 1990s of the organised removal of waste in even the most remote karst settlements reduced pressure on karst caves, there is still a danger to the environment as a result of the dumping of waste in the past. We find that in a period of just over 10 years about 100 caves have been cleaned. Thus, in the absence of further pollution and with the same intensity of cleanup operations, just under a century will be required to clean all of them. It should of course be added that under current circumstances caving clubs are only capable of dealing with moderately polluted caves, while for highly polluted caves – either because of the quantity of waste or its toxicity – a more professional and technologically advanced method of cleaning up caves will be necessary. The cave cleanup activities of caving clubs nevertheless need to be supported, while also taking into account the dangers that exist. At the same time the cataloguing of cave pollution in areas where such data do not exist or are of insufficient quality (the area around Kočevje, NW Dolenjska, Gorenjska, Notranjska) needs to continue. Although it is extremely difficult to quantify the positive environmental impact of cave cleanup operations in comparison to the remedying of other types of pollution, the cleanup of caves that includes the removal of already polluting waste and the discovery of potentially harmful pollution that already has occurred in the past, represents an important contribution to a cleaner and safer underground karst and karst (drinking) waters.

Acknowledgement

Thanks are due to all the caving clubs and individuals who have contributed to the topics and substance of this article by cleaning up caves. Thanks are also due to the representatives of caving clubs or representatives of other environmental institutions (Anton Della Schiava, Vlado Bernetič, Slavko Hostnik, Jasmina Rijavec, Marko Pavlin, Tina Kotnik, Franjo Drole, Franci Malečkar) who have helped in the collection of data on all up to now cleaned caves in Slovenia.

References

Bučar Z., 2002. Čiščenje Shornice [Cleanup of Shornica]. Dolenjski kras 4. Jamarski klub Novo Mesto, Novo Mesto: 80.

Drame L., 1989. Onesnažene in uničene jame v občini Cerknica [Polluted and Destroyed Caves in the Municipality of Cerknica]. Naše jame 31. Jamarska zveza Slovenije, Ljubljana: 49–52.

Fajgelj A., 1994. Odpadek [Waste]. In: Enciklopedija Slovenije 8. Mladinska knjiga, Ljubljana: 88–90.

Frelih M., 1998. Škocjanske jame in mitični vhod v Hadovo Kraljestvo [The Škocjan Caves and the Mythical Entrance to the Kingdom of Hades]. Naše jame 40, Jamarska zveza Slovenije, Ljubljana: 81–108.

Gašperič A., 2002. Čiščenje Pristavske jame [Cleanup of Pristavska Jama]. Dolenjski kras 4. Jamarski klub Novo Mesto, Novo Mesto: 77–79.

Habe F., 1975. Naloge jamarjev pri zaščiti kraškega podzemlja [Role of Cavers in Karst Underground Protection]. Naše jame 17, Jamarska zveza Slovenije, Ljubljana: 173–178.

Habe F., 1982. Onesnaževanje jam dolenjskega krasa [Pollution of of Caves in the Dolenjska Karst]. Dolenjski kras. JK Vinko Paderšič-Batreja Novo Mesto, Novo Mesto: 38–41.

Horvat M., 1989. Ajdovska jama pri Nemški vasi [Ajdovska Jama near Nemška Vas]. Ljubljana.

Hudoklin A., 1995. Onesnaženost kraških jam na Dolenjskem [Pollution of Caves in the Dolenjska Region]. Naše jame 37, Jamarska zveza Slovenije, Ljubljana: 223–231.

Hudoklin A., 1996. Kotarjeva prepadna ali reševanje onesnaženih jam na Dolenjskem [Kotarjeva Prepadna – Saving Polluted Caves in Dolenjska]. Naše jame 38, Jamarska zveza Slovenije, Ljubljana: 189–192.

Hudoklin A., 2002. Onesnaženost jam v Mestni občini Novo Mesto [Pollution of Caves in the Municipality of Novo Mesto]. Dolenjski kras 4. Jamarski klub Novo Mesto, Novo Mesto: 69–76.

Jamnik P., Leben-Seljak P., Bizjak J., Horvat B., 2002. Koblarska jama na Kočevskem – prazgodovinsko grobišče in kultni prostor. Antropološka analiza skeletnih ostankov z opisom pridatkov [Koblarska Jama in the Kočevje Region – Prehistoric Burial Site and Place of Worship. Anthropological Analysis of Skeletal Remains with Description of Burial Objects]. Arheološki vestnik 53: 31–49.

Kakovost podzemne vode v Sloveniji v letu 2009 [Groundwater Quality in Slovenia in 2009]. ARSO.

Klemenčič T., 1991. Komunalna dejavnost [Municipal Services]. In: Enciklopedija Slovenije 5. Mladinska knjiga, Ljubljana: 216–225.

Leben F., 1978. Osteološke in kultne najdbe prazgodovinskega človeka iz kraških jam Slovenije in mejnega ozemlja [Prehistoric Bone Finds and Religious Artefacts from the Karst Caves of Slovenia and the Border Area]. Arheološki vestnik 29: 13–35.

Malečkar F., 2010. Speleoškovacini ali jamarski prispevek čistejši Sloveniji [Cleanup of Caves As a Speleological Activity for a Cleaner Slovenia]. Jamar 3/1. Jamarska zveza Slovenije, Ljubljana: p. 7.

Očistimo Slovenijo v enem dnevu! [Let's Clean up Slovenia in One Day!] Poročilo. 28 April 2011. URL: http://ocistimo.si/O-projektu.aspx.

Osole F., 1983. Epigravitien iz Lukenjske jame pri Prečni [The Epigravettien in Lukenjska Jama near Prečna]. Por. razisk. pal. neol. eneol. Slov. 11: 7–25.

Puc M., 1987. Onesnažene jame v SR Sloveniji [Polluted Caves in the Socialist Republic of Slovenia]. Naše jame 29, Jamarska zveza Slovenije, Ljubljana: 50–52.

Rijavec J., 2008. Vseslovenska čistilna akcija čiščenja jam 2007 [Slovenia's Nationwide Cave Cleanup in 2007]. Jamar 1/1. Jamarska zveza Slovenije, Ljubljana: p. 8.

Simić M., 2000. Prispevek k poznavanju zgodovine varstva jam na Slovenskem ob pripravi Zakona o varstvu podzemnih jam [The History of the Protection of Caves in Slovenia during Preparation of the Cave Protection Act]. Naše jame 42, Jamarska zveza Slovenije, Ljubljana: 49–77.

Simić M., 2000. Čiščenje jam s pomočjo Heliosovega sklada za ohranjanje slovenskih voda [Cleanup of Caves with the Help of the Helios Fund for the Preservation of Waters in Slovenia]. Naše jame 42, Jamarska zveza Slovenije, Ljubljana: 156–161.

Ur. l. RS 2/04 [Official Journal of the Republic of Slovenia 2/04]. Zakon o varstvu podzemnih jam [Cave Protection Act].

LANDFILLS ON KARST AND THEIR IMPACT ON KARST WATERS

Janja Kogovšek [1] & Metka Petrič [2]

In today's world the quantity of waste is constantly growing and finding a solution for the processing and dumping of waste that will have the least possible harmful consequences for the environment is becoming increasingly important. Despite the introduction of new technologies, a large percentage of waste still has to be dumped in landfills. These represent a danger to the environment because of the concentration of harmful substances in one place. This applies in particular to karst areas which, because of their special characteristics, are particularly vulnerable to the consequences of various sources of pollution. Owing to the extremely high permeability of karst rock, rainfall and the harmful substances dissolved in it can rapidly percolate underground from the surface and quickly flow off towards karst springs in various directions and even over large distances. Natural filtration capacity is low in the karst and the extent of the potential negative impact is very great, since landfills represent a more or less constant input of contaminants over a longer period.

Older landfills are particularly problematic because the risk of pollution of underground waters was not taken sufficiently into account in the choice of location or in their construction. Adequate measures were not taken to reduce the permeability of the ground to a sufficient extent and, in this way, at least limit the discharge of harmful substances from the main body of the landfill into the underground. Owing to the differing content of waste, leakages are complex compounds with a high content of salts, metals and organic substances, while their quantity and chemical make-up are typically dependent on the quantity and distribution of rainfall and the structure of waste (Hötzl 1999).

There are, however, relatively few identified cases of water pollution in the area of influence of landfills in the karst. The reasons for this could lie in the dumping of so-called non-hazardous waste or the influence of dilution with water from other parts of the extensive catchment areas of karst springs (Hötzl, 1999), but above all the problem lies in the lack of suitably planned and longer-lasting monitoring of the quality of groundwater and the corresponding interpretation of such monitoring.

Landfills in the Slovenian karst

The problems of the landfill of waste and the unsuitability of existing landfills are topical issues in Slovenia. Slovenian legislation covering disposal of waste is in line with European legislation. The basic document is the *Decree on the landfill of waste* (Official Journal of the Republic of Slovenia 32/06). Among other things, this decree prohibits the sitting of a landfill on land with a highly fractured rock basis, good water permeability and indeterminate groundwater flows. The construction of new landfills in the karst is therefore not permitted, while closure and rehabilitation is envisaged for all those currently still active. They are expected to be replaced by regional centres that will use more modern technological solutions and will be constructed on more suitable sites.

In order to operate a landfill it is necessary to obtain an environmental protection permit. Among other things, this requires the submission of a programme of operational monitoring of groundwater pollution, drafted in accordance with the *Rules on the performance of operational monitoring of groundwater pollution* (Official Journal of the Republic of Slovenia 49/06, 114/09). Annex 1 to these Rules contains *Instructions on the drawing-up of a hydrogeological report for the operational monitoring programme*. These instructions provide that the report must include an account of hydrogeological conditions, a description of the zero conditions of groundwater, target hydrogeological zones, locations and a description of the setup and equipment of observation stations, observation of the levels and directions of groundwater flow, and a plan for testing the adequacy of the network of observation stations.

The instructions highlight a number of special provisions for karst areas. Thus, for example, the predominant use of natural hydrogeological objects is prescribed for the monitoring of pollution sources in the karst. Where such objects do not exist or are so far off that significant dilution of pollutants could occur en route from the pollution source, as a result of which the direct implementation of operational monitoring of groundwater is not possible, the operation of the source of pollution must cease in the shortest possible time.

In order to determine the most likely directions of groundwater flow, the instructions prescribe the use of structural mapping methods, tracer tests and observation of the chemical state of groundwater or geophysical research. In our opinion, the best results can be achieved through the parallel use of several methods, while the most exact data on the directions and velocities of underground flow are provided by tracer tests. Accounts of their successful use in practice are provided by publications in scientific and specialist publications (Eiswirth et al. 1999, Zhou et al. 2002, Petrič & Šebela 2005, Kogovšek & Petrič 2006, 2007, 2010). Our experience with the use of the results of such tests for the preparation of a programme of monitoring the impact of landfills on karst waters are presented below.

The use of tracer tests in planning the monitoring of the impacts of landfills on karst waters

We dealt with the cases of three landfills in the Slovenian karst: Mala Gora near Ribnica, Sežana and Mozelj near Kočevje (Fig. 1). When the above landfill locations were being selected, consideration was not given to the fact that these are karstified and extremely permeable areas in which leakages percolate underground almost unimpeded and flow rapidly along well developed karst conduits towards karst springs, some of which are also used to supply drinking water. Because they were built in the 1970s and 1980s they were not additionally fitted with a foundation that would limit the seepage of harmful substances into karst waters to a satisfactory extent. Currently valid legislation envisages their closure and the continuation of monitoring of the quality of groundwater in the area of influence. In order to draw up a programme for this monitoring, we used the results of three tracer tests that we carried out at the landfills between 2004 and 2006.

The areas of the landfills consist of karstified carbonate rock of Jurassic, Cretaceous or Palaeocene age covered by a thin layer of soil, interrupted in places, which offers little

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, kogovsek@zrc-sazu.si*

[2] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, petric@zrc-sazu.si*

protection. Because of these characteristics, precipitation water and the harmful substances dissolved in it sink rapidly into the vadose zone of the karst aquifer. The process of percolation of water through this zone can typically influence the transfer and retention of pollution in the karst underground. By means of a tracer test involving the injection of tracer into a highly permeable fracture on the surface, we simulated conditions of the transfer of potential pollution. All three tests were carried out in conditions when the great part of pores and fractures in the vadose zone were full of water and hydraulically connected. In this way we tested conditions when rates of flow and thus also of the transfer of potential pollution are greatest. We used a fluorescent tracer, Uranine (Tab. 1), which before injection was dissolved in a large quantity of water and following injection washed away with a few cubic metres of water from a fire service water tender (Fig. 2). We took samples manually or automatically at all springs in the area of influence of the landfills (Fig. 3), while the fluorescence of the Uranine (E_{ex}=491 nm, E_{em}=512 nm, detection limit 0.01 mg/m^3) was measured in our laboratory using a Perkin Elmer LS 30 luminescence spectrometer. At the same time we measured rainfall in the areas of the landfills at 15-minute intervals using rain gauges and, at selected springs, the discharges or water levels, which we converted into discharges using existing stage-discharge curves. For those springs for which we were in possession of discharge data, we estimated the percentage of recovered tracer. The results of the tracer tests are shown in Tab. 1 and in Figs. 1 and 4. The main underground flow from the Mala Gora landfill is in the direction of the springs along the river Krka, particularly the springs Tominčev studenec (discharges between 0.5 and 10 m^3/s), Javornikov izvir and Debeljakov izvir at the settlement of Dvor (Kogovšek & Petrič 2006), although owing to the absence of measurement of discharges, a calculation of recovered tracer is not possible at the latter locations. A small proportion of underground water with tracer flows very slowly towards the cave Podpeška jama. We observed the Globočec spring (mean discharge around 1.3 m^3/s), which supplies water to the wider area, with particular attention. The concentrations of tracer in the Globočec spring were only slightly above the detection limit, but since the signal was parallel to that in the other springs, we conclude that a small proportion (approximately 3 %) of water from the landfill also flows towards the Globočec spring, but for the most part it is fed from other parts of the catchment area.

Over the 17-month duration of the test, up to 93 % of the injected Uranine from the Sežana landfill flowed out through a spring of the

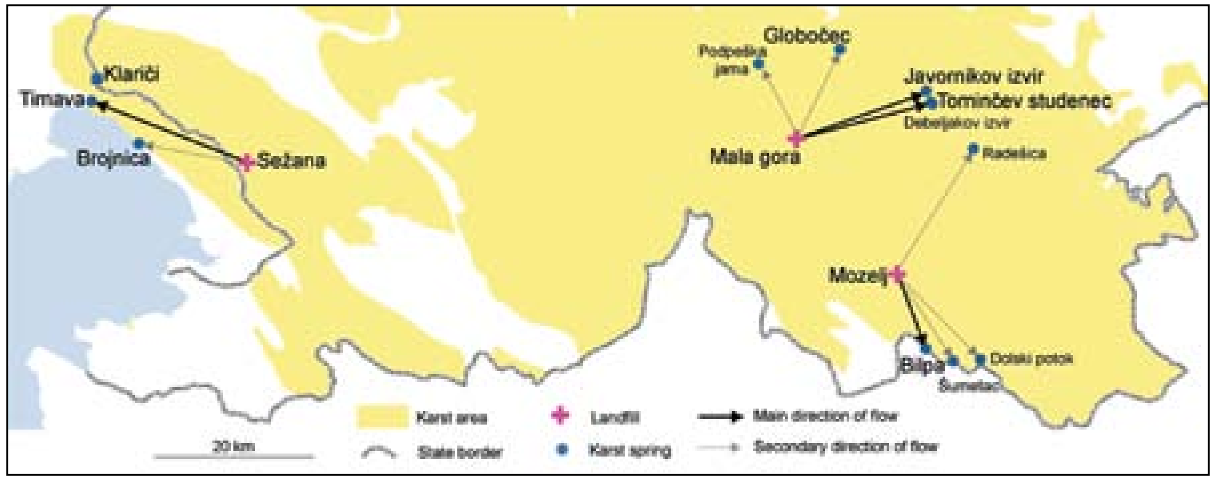

Fig. 1: Directions of flow from landfills on karst in S Slovenia as known by tracer tests.

Fig. 2: Injection of uranine on the edge of the Mozelj landfill.

Tab. 1: The characteristics and results of tracer tests (M – amount of injected tracer, L – air distance between the injection point and the spring, t_{dom} – time of detection of the maximum concentration, v_{dom} – dominant apparent flow velocity, R – tracer recovery, C_{max} – maximum concentration).

Injection point	Date of injection	M (kg)	Spring with proved connection	L (km)	t_{dom} (d)	v_{dom} (m/h)	R (%)	C_{max} (mg/m^3)
Mala Gora	14/10/04	7	Tominčev studenec	17.8	5	145		0.19
			Javornikov izvir	17.7	6	122		1.18
			Debeljakov izvir	18.0	6	126		0.08
			Globočec	12.7	5	102	3	0.09
			Podpeška jama	10.7	17	26		0.13
Sežana	20/4/05	38	Timava	21.4	23	39	93	0.48
			Brojnica	14.2	31	19		0.14
Mozelj	5/4/06	18	Bilpa	10.3	9	48	92	19
			Šumetac	13.3	56	11		0.09
			Dolski potok	15.3	56	10		0.04
			Radešica	18.7	56	14		0.03

Timava in the Gulf of Trieste on the Italian side of the border (discharges between 9.1 and 127 m^3/s), while a smaller proportion was observed in the Brojnica spring near Nabrežina/Aurisina (Kogovšek & Petrič 2007). We closely observed the Klariči pumping station, which is the main source for the supply of water to the municipalities in this area. The measured values were for the most part below the detection limit although they were over the limit in a few successive samples at short intervals more than six months after injection. This indicates the possibility, in conditions of an exceptionally high water level and a limited time period, of an extremely small proportion of the water from the landfill area (the recovered percentage of injected Uranine is just 0.003 %) reaching the pumping station in Klariči following a slow and lengthy passage through the less permeable zone of the aquifer, although the connection has not been reliably proved.

The majority of the tracer from the Mozelj landfill flowed towards the Bilpa spring (discharges of between 0.1 and 36 m^3/s). Approximately 70 % of the injected Uranine flowed out through the spring within one week of its first appearance in the spring, and almost 92 % in the three months of observation (Kogovšek & Petrič 2010). Only small concentrations of tracer were detected in other springs along the Kolpa river and in the Radešica spring by the river Krka.

Monitoring programme proposals

On the basis of the results of the tracer tests described above, we prepared proposals for a programme of groundwater quality monitoring in the areas of influence of all three landfills. For the Mala Gora landfill, the springs Tominčev studenec and Javornikov izvir were proposed as principal monitoring points. The latter two were proposed because the results of tracing (a typically higher concentration of

Fig. 3: An automatic sampler was set up at the Bilpa spring to collect samples.

Uranine) indicated that any negative impact of the landfill would appear most intensively here. The Globočec spring, as the main regional water supply source, also needs to be included in the monitoring.

The Timava spring and the Brojnica spring near Nabrežina/Aurisina were chosen for monitoring the impact of the Sežana landfill. Although the possibility of negative impacts on the Klariči pumping station is extremely small, in view of its importance we also proposed observation of this water source.

The extremely rapid flow and high concentrations of tracer in the Bilpa spring showed that this spring is most suitable for monitoring the quality of water in the area of influence of the Mozelj landfill. Since, however, the Rinža, a polluted sinking stream, also flows into the Bilpa spring, which is additionally fed by primary infiltration from the karst section of the catchment area, it will be difficult to interpret the results of monitoring adequately. We therefore proposed parallel monitoring of the Rinža sinking stream and the Bilpa spring and the evaluation of mass balances of contaminants.

The characteristics of underground flow established by means of tracer tests are also useful in determining the frequency and method of taking samples for monitoring. In order to increase the possibility of detecting pollution, it is a good idea to take samples when the largest concentration of contaminants is expected. When water levels are high, such conditions occur following even a minor rainfall event. When water levels are low, several successive rainfall events are necessary, which first fill the pores in the vadose zone with water. Only then does sufficiently intense rainfall drive the contaminants accumulated in this zone towards the springs. Since conditions in karst aquifers change very quickly and individual samplings frequently fail to show the true state of quality, it would appear sensible to organise sampling in such a way that several successive samples are taken in the selected flood wave.

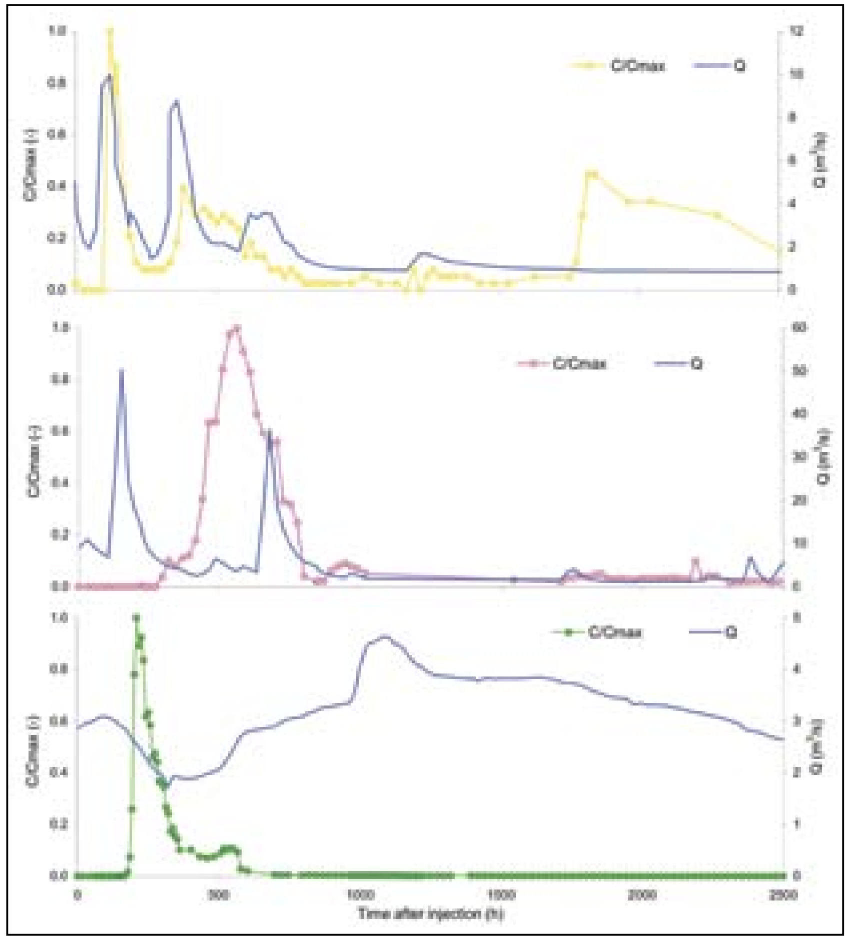

Fig. 4: Discharges and concentrations of tracer (standardised with regard to the maximum measured value) in the most important springs from the time of injection of the tracer.

General findings

Despite the fact that tracer was injected on the surface and travelled through the vadose zone, relatively high flow velocities were identified. We may conclude that there is very high vulnerability and a serious danger of pollution with harmful substances from landfill. On the other hand, we noted increases in the concentration of tracer following each more intense rainfall event even one year after injection. Although part of the tracer passes very rapidly along primary drainage channels, the remainder can remain in the vadose zone for a longer period, even for one decade or more (Kogovšek 2010), and be driven out of the system by every subsequent intense rainfall event. Similar results can be expected in the case of the washing-out of contaminants.

Tracing using artificial tracers is an extremely suitable research method for planning a monitoring programme in karst areas. It enables the selection of the most suitable monitoring points and the elaboration of an effective plan of sampling frequency and distribution.

Karst springs have large catchment areas within which the impacts of various polluters frequently interweave. For this reason, the interpretation of the results of monitoring is not simple and must be based on good knowledge of the characteristics of water flow and the transfer of contaminants through the karst aquifer towards karst springs.

References

Eiswirth M., Hötzl H., Jentsch G., Krauthausen B., 1999. Contamination of a karst aquifer by a sanitary landfill. In: Drew D., Hötzl H. (eds.), 1999. Karst Hydrogeology & Human Activities. A.A. Balkema, Rotterdam, Brookfield: 159–167.

Hötzl H., 1999. Industrial and urban produced impacts. In: Drew D., Hötzl H. (eds.). Karst Hydrogeology & Human Activities. A.A. Balkema, Rotterdam, Brookfield: 81–185.

Kogovšek J., 2010. Characteristics of percolation through the karst vadose zone. ZRC Publishing, Ljubljana: pp. 168.

Kogovšek J., Petrič M., 2006. Tracer test on the Mala Gora landfill near Ribnica in south-eastern Slovenia. Acta Carsologica, 35/2: 91–101.

Kogovšek J., Petrič M., 2007. Directions and dynamics of flow and transport of contaminants from the landfill near Sežana (SW Slovenia). Acta Carsologica, 36/3: 413–424.

Kogovšek J., Petrič M., 2010. Tracer tests as a tool for planning the monitoring of negative impacts of the Mozelj landfill (SE Slovenia) on karst waters. Acta Carsologica, 39/2: 301–311.

Petrič M., Šebela S., 2005. Hydrogeological research as a basis for the preparation of the plan of monitoring groundwater contamination – a case study of the Stara Vas landfill near Postojna (SW Slovenia). Acta Carsologica, 34/2: 489–506.

Zhou W., Beck B.F., Pettit A.J., Stephenson B.J., 2002. A groundwater tracing investigation as an aid of locating groundwater monitoring stations on the Mitchell Plain of southern Indiana. Environmental Geology, 41: 842–851.

THE IMPACT OF TRAFFIC ON KARST WATERS

Janja Kogovšek [1]

Because karst is constructed of fractured and soluble carbonate rock, the karst environment is highly vulnerable and surface pollution – unlike in the case of fluvial surface – also means pollution of karst soil and groundwater. Karst aquifers, which hold significant quantities of water in karst areas, are fed by rainwater percolating directly from the surface into the karst interior. They can also be fed by sinking streams. Groundwater then flows out onto the surface through karst springs, which are an important source of drinking water, not only in Slovenia but around the world. Traffic is among the polluters on the karst surface that threaten the quality of karst water, not only in the case of road accidents involving the spillage of large quantities of hazardous and harmful substances, but also because of the pollution caused by regular traffic flows.

The impact of a specific type of surface pollution on karst springs can only be shown by corresponding research. In cases of pollution by water-soluble substances on the karst surface or when pollution runs off into sinking streams, it is only on the basis of past research, in particular tracer tests and research into the transfer of these contaminants through carbonate rock (Kogovšek 2010), that we can conclude what springs will be polluted and what speed of transfer we can expect. Contaminants can, in fact, be stored in the vadose zone for considerable periods. Knowing the type of pollution and its degradation products tells us what we have to monitor – and what parameters – in springs inside the area of influence.

In the case of spillages of hazardous substances in railway and road accidents, and also channelled drainage from motorways, pollution is point source pollution. Although we have some knowledge of runoff pollution from motorways in ordinary conditions, we still do not possess information about the nature of runoff pollution from railway lines.

Road traffic pollution in normal conditions

Between 1992 and 1994 the Karst Research Institute studied the composition of rainfall-generated runoff from an approximately 2,200-metre section of the Razdrto–Ljubljana motorway into the oil collector near Postojna (Fig. 1). The composition of runoff from the roadway also depends on the quantity of rainwater washing the surface of the roadway, which means greater or lesser dilution of pollution accumulated on the roadway. For samples of water taken at the oil collector inflow and at the direct outflow into the karst, we determined specific electrical conductivity (EC), turbidity, chemical oxygen demand (COD – dichromate method) and biochemical oxygen demand (BOD_5), oils and chlorides content and, later, cadmium and lead content and sulphates, nitrates and o-phosphates content (Fig. 2).

Periodic analyses of runoff from the motorway in 1993 and 1994 have shown (Kogovšek 1993, 1995a) that in winter (Tab. 1) this has a perceptibly higher concentration of chlorides and sulphates, which is reflected at the same time in EC and increased turbidity and COD

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, kogovsek@zrc-sazu.si*

compared to the summer (Tab. 2), when we identified above all increased lead and cadmium content (leaded petrol was still in use at that time). With a sufficient quantity of precipitation in a single downpour, the roadway is gradually washed. This is reflected in the increasing quality of successive samples. This means that the largest quantity of pollution runs off during the initial washing, where the intensity of rainfall is significant. However, even after a good washing of the roadway following abundant and intensive rainfall, the values of the parameters did not fall below a certain level. This is not to be expected, given that constant traffic means continuous pollution.

Outflow from the oil collector directly into the karst was, in the case of small inflows to the oil collector, usually of better quality than the inflow, since sedimentation of solid particles took place in the oil collector. In the case of large inflows, the outflow was of significantly poorer quality because the sediment accumulated in the collector, to which the majority of organic pollution and heavy metals is connected, was also washed out.

The first periodic analyses of rainwater runoff from the motorway and later systematic analyses during rainfall events (Kogovšek 1993, 1995a) showed that water from the roadway is occasionally highly polluted. This knowledge probably impacted on the construction of retention ponds and purification facilities in the later construction of new motorways in Slovenia. Several generations of facilities have been developed as a result. Later analyses of water flowing into these purification facilities next to newly constructed motorways (Official Journal of the Republic of Slovenia 35/1996) have only occasionally shown an exceeding of limit values (Pintar 1998), while measurements of the composition of water during a rainfall event in October 2001 showed no exceedance at all (Kompare et al. 2002).

It is evident from all the measurements taken to date that the loading of individual sections of motorways can vary, and that only frequent and systematic measurements on sections with varying loading can give a true picture.

In view of today's knowledge of the flow and transfer of contaminants through the vadose

Fig. 1: Rainwater that washes the roadway of the motorway runs off into the oil collector, where in favourable conditions of small inflows sedimentation occurs. On the other side of the oil trap the water drains directly into the karst. Fluorescent tracer was injected into the drainage shaft of the oil trap (Gabrovšek et al. 2010).

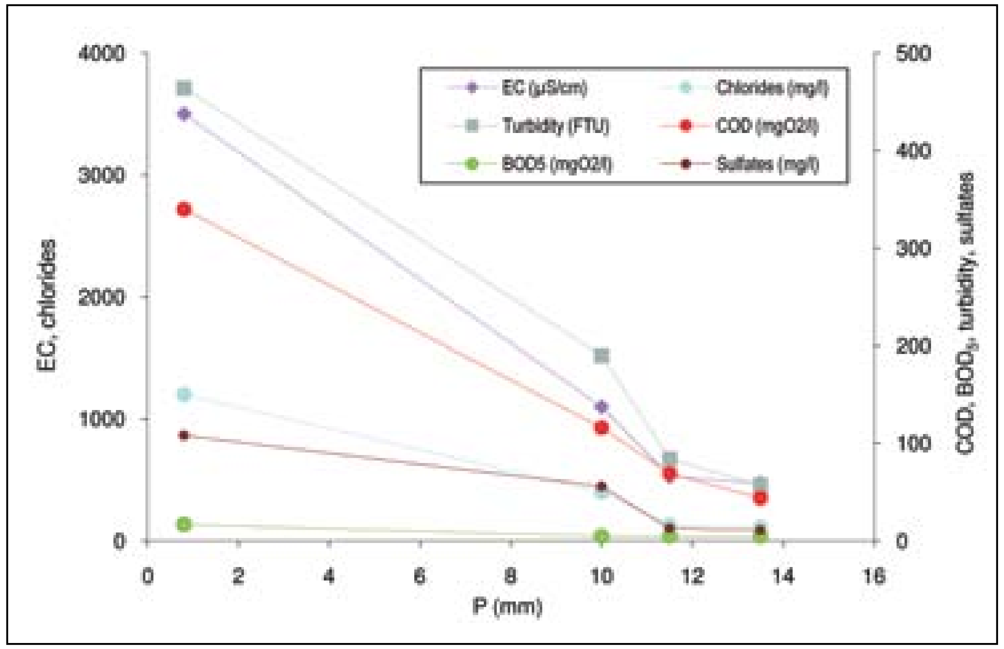

Fig. 2: Progress of measured parameters of oil collector inflow (EC, COD and BOD_5) following a precipitation event on 24 March 1993 depending on the quantity of precipitation.

Tab. 1: Results of measurements in the winter period (T – temperature, EC – specific electrical conductivity, turbidity, COD – chemical oxygen demand, BOD_5 – biochemical oxygen demand, Cl^- – chlorides, SO_4^{2-} – sulphates, Pb – lead, Cd – cadmium, NO_3^- – nitrates).

	T (ºC)	EC (µS cm^{-1})	Turbidity (FTU)	COD (mgO_2 l^{-1})	BOD_5 (mgO_2 l^{-1})	Chlorides (mg l^{-1})	Sulphates (mg l^{-1})	Pb (µg l^{-1})	Cd (µg l^{-1})	Nitrates (mg l^{-1})
Max. value	9.2	7810	780	480	45	1980	158	1790	76	19
Min. value	4.6	173	57	33	5	30	3	180	11	3
Ave. value	6.7	1920	285	150	17	520	47	680	50	8

Tab. 2: Results of measurements in the summer period (same parameters as in Tab. 1).

	T (ºC)	EC (µS cm^{-1})	Turbidity (FTU)	COD (mgO_2 l^{-1})	BOD_5 (mgO_2 l^{-1})	Chlorides (mg l^{-1})	Sulphates (mg l^{-1})	Pb (µg l^{-1})	Cd (µg l^{-1})	Nitrates (mg l^{-1})
Max. value	11.7	216	93	274	70	35	39	11100	250	10
Min. value	18.6	50	23	19	4	7	11	2280	65	2
Ave. value	15.9	126	50	113	21	18	23	3750	167	5

(unsaturated) zone of aquifers (Kogovšek 1987, 1997, 2010), where these can accumulate in the vadose zone for longer periods, periodically measured concentrations of contaminants are not a sufficient criterion for the overall pollution that runs off motorways into the environment. In order to determine the latter, in the karst region it would also be necessary to take into account the input quantity of individual contaminants in a specific time period. Particularly if outflows of such waters are in the immediate catchment area of karst springs that are used to supply drinking water, such as the spring of the Malenščica.

All the above findings dictate that for runoff from motorways in areas of the catchment areas of karst springs, the actual impact on springs should be ascertained via tracing. If a hydrological connection is confirmed, effective purification of these waters needs to be regulated before direct discharge into the karst environment, since such discharges must not be allowed to affect the quality of karst waters used as a source of drinking water. It would, however, be sensible, in the case of point source discharges of polluted waters, including motorway runoff directly into the karst, to prescribe suitably low and still acceptable permitted limit values with regard to the characteristics of the area (where and how these waters drain). Knowledge of the characteristics of flow through the karst vadose zone in the area of Postojnska jama provides a good basis (Kogovšek 2010), although transfer is also tied to the characteristics and mobility of the individual contaminants.

Spillages of hazardous substances in traffic accidents

In recent decades we have on several occasions monitored the consequences of traffic accident spillages, most frequently of petroleum products (Knez et al. 1994, Kogovšek 1995b, Kogovšek & Petrič 2002b). In cases where the accident occurs on a karst surface, we are able, on the basis of knowledge of the direction of water flow from the area in question, to establish what karst springs will be affected by this spillage. We are particularly interested in whether springs that are used to supply the population with drinking water are going to be polluted. We can, however, only predict this if the direction of underground water flows has previously been established. Accidents in petroleum products storage facilities are equally dangerous and in the past have likewise been the cause of pollution of karst waters.

The immediate vicinity of the Malenščica spring includes a motorway, a railway and a number of local roads. Traffic accidents involving spillages of hazardous substances would very probably threaten the quality of the spring. In November 2008 we carried out a tracer test involving the injection of fluorescent tracer into the oil collector by the motorway at Ravbarkomanda (Fig. 1) (Gabrovšek et al. 2010). We first observed tracer in the Unica, where a rapid increase in water flows following rainfall was followed by an increase in the concentration of tracer, while the concentration of tracer in the Malenščica increased after a delay of two days. From this we can conclude that in the case of pollution at Ravbarkomanda, this would be observed first and most markedly in the Unica and then, after a certain delay, in the Malenščica.

A number of accidents have already occurred in past years around the catchment of the Malenščica. Over 40 years ago a tanker carrying 25 m^3 of table oil overturned into a sinkhole at Ravbarkomanda near Postojna (Habič 1988). In May 1984 a major oil leak occurred at Petrol's depot near Postojna, and it was assumed that the oil had drained into the karst underground. Owing to the great likelihood of pollution of the Malenščica, a large quantity of active charcoal was obtained. Fortunately, the oil did not appear in the spring. This was one of the first serious warnings of the potential threat represented by storage facilities for petroleum products in karst areas.

Storage facilities in non-karst areas but from which watercourses flow into the karst also represent a threat. An example of this was the accident at the storage facility near Ortnek on 3 October 1998 when, during the pumping of gas oil, an unknown quantity of oil passed through the drainage system into the Tržiščica stream and from there into the karst underground (Genorio 1999). The gas oil polluted the spring of the Globočec stream for a considerable period. Close monitoring of the presence of gas oil and odour in the spring showed that the water is unusable even in the presence of odour, when its concentration is below 0.01 mg/l, which is the limit of detection of the method. A later tracer test showed the breadth of water flow from the Tržiščica sinking stream (Kogovšek & Petrič 2002a).

In October 1993 a spillage of petroleum and heating oil occurred in a karst area near Kozina, which could have also threatened the quality of water in the catchment of the Rižana. The spillage occurred during a traffic accident which saw 18 tonnes of petroleum and heating oil discharged into the surrounding area. Eyewitnesses estimated that the petroleum ran off the surface, which was covered with a small amount of debris, in approximately 20 minutes. On the basis of earlier tracer tests carried out in this area which showed the flow of groundwater from under the Brkini hills below the Matarsko podolje (Materija lowland) area into the springs of the rivers Ospapska reka, Rižana, Bračana and Mirna and the coastal karst springs in the Kvarner gulf near Opatija (Krivic et al. 1987, Krivic at al. 1989), it was concluded that petroleum could appear at all these points. The appearance of petroleum was also possible in the springs of the Timava. This accident ended happily as far as the spring of the Rižana, which is used to provide drinking water, is concerned, because the spring was not contaminated. The accident showed that the pollution of this water source could have extremely serious consequences.

Just a year later (12 October 1994) an accident occurred on the Podgrad–Kozina Road near Obrov, when almost 16 m^3 of D2 gas oil spilled from a tanker and rapidly ran off the surface (in an estimated 15 to 20 minutes) We observe that with such accidents in karst areas it is not possible to pump up the spilled substance in time to prevent its drainage into the karst. The spillage occurred in the area of the second protection zone of the Rižana catchment, approximately 1 km south-west of the sinking stream in the blind valley of Jezerina, for which a reliable connection with the sources of the Rižana and Osp rivers was established by means of tracer tests in 1986 (Krivic et al. 1989). On the basis of this knowledge, during the accident near Obrov the view was taken that the spread of pollution would be affected by rainfall and that it was therefore necessary to monitor closely the petroleum content of the Rižana catchment (Fig. 3) and, periodically, the spring of the Osp river and the springs of the Aro.

There was no rainfall for 12 days following the gas oil spillage, but then light rainfall accelerated the flow of the oil through the vadose zone of the karst, with the result that it appeared in the Rižana 14 days after the accident (Fig. 4). A further 70 mm of rainfall at the end of October caused an increase in the rate of flow of the Rižana and the following day the appearance of increased concentrations of gas oil (Kogovšek 1995b). As a result, the source of the Rižana was excluded from the water supply network for quite some time.

The speed of flow of the water containing the oil to the Rižana was 45 m/h. The significant appearance of the oil (80 µg/l) was followed by a drop in its concentration with a simultaneous gradual decrease in the rate of flow. The quantity of gas oil calculated to have drained towards the Rižana by the end of October was 88 kg, which is over half a percent of the total quantity spilled. This clearly indicates the gradual rate of discharge of such substances following each instance of heavier rainfall. When the Osp river was still active, it is highly probable that the oil also discharged through this spring.

We can conclude that discharging through the two springs took place gradually and for significantly longer than if the contaminant had been dissolved in the water.

At the time of the described accidents near Kozina and Obrov the water in the Rižana water supply system was chlorinated with gas chlorine, which in the presence of organic substances leads to the formation of carcinogenic halogenated hydrocarbons. The operators of the Rižana water supply system recognised the danger represented by accidents of this type in the catchment area of the Rižana and by subsequent chlorination, and therefore for some time now the water of the Rižana has been purified by means of ultrafiltration without added chemicals.

Since 24 October 1994 mineral oil content has also been monitored in the Sveti Ivan spring in Buzet in Croatia (Vlahović 2000). These data reveal a perceptible increase in mineral oil content and total fats between 27 and 30 October. Since measurements were not taken before the accident, we can only predict that gas oil also drained in this direction.

Analyses of accidents involving spillages of petroleum products in karst areas have contributed to a gradually improving understanding of the flow of LNAPLs (petroleum products etc.), since tracer tests using such hazardous substances are not environmentally acceptable. We have established that these substances follow watercourses and discharge through the karst springs in the catchment area of which the spillage took place. By means of the proposed tracer tests using soluble tracer directly after an accident involving the spillage of petroleum products, we could establish differences in the mode of flow which would represent a significant contribution to the better understanding of the spread of petroleum products through karst aquifers.

Fig. 3: The karst spring of the Rižana, which is used to supply drinking water, was polluted following a road accident involving a gas oil spillage near Obrov.

Conclusion

Traffic accidents involving the drainage of large quantities of hazardous substances (petroleum products, heating oil, etc.) into the karst represent a hazard for our environment and for karst waters, since even small quantities can contaminate karst springs for long periods. We still know very little about how contaminants behave in karst aquifers, despite the fact that in the case of accidents towards the end of last century the Karst Research Institute frequently took part in identifying those springs that were at risk. On the basis of observations of accidents involving spillages of petroleum products in karst areas to date, we know that they drain along the routes that rainfall follows from the surface into the karst interior and run off the surface rapidly so that this cannot be prevented. Their first appearance in springs is influenced by conditions in the soil and the vadose zone and by the rainfall that follows. Comparisons of the transfer of petroleum products and soluble tracers indicate that the subsequent mode of transfer of these substances through karst aquifers differs significantly. Above all it involves longer retention and accumulation of petroleum products and gradual washing away. In the case of more frequent accidents in a given area, the accumulation of substances in the catchment area of a spring on each occasion could lead to more permanent pollution of the spring, which could render its use impossible for a long time. When taking action in concrete cases of spillage, it is necessary to predict what karst springs will be polluted. This is connected to knowledge of flow in the area in question, in other words to tracer tests already carried out. In the case of currently spilled larger quantities of liquids in dry periods, only a small part passes rapidly through the vadose zone via the most permeable fractures, while the largest part of

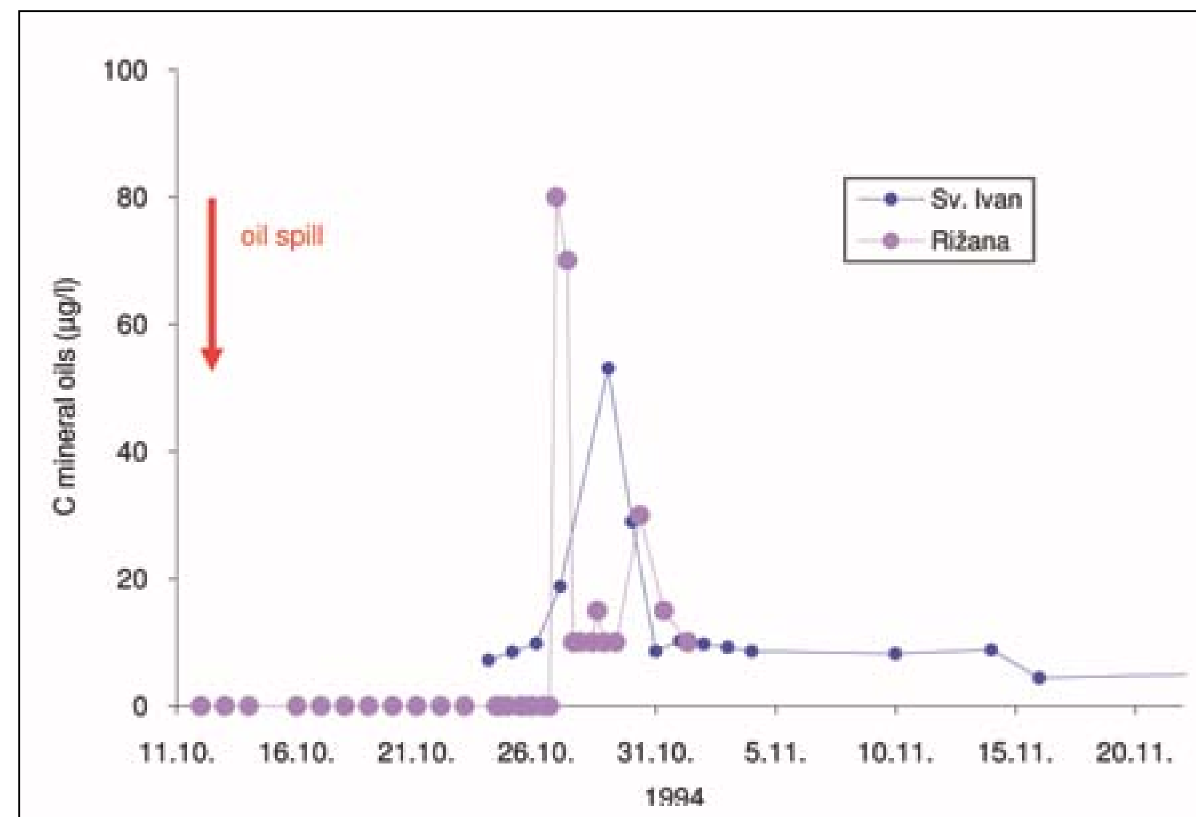

Fig. 4: The appearance near Obrov of spilt gas oil in the Rižana. Increased values in the Sveti Ivan spring in Croatia are probably also a consequence of the accident.

the substances accumulates and is later gradually pushed in the direction of springs by rainfall. Research of the flow of water through the soil and the vadose zone (Kogovšek & Šebela 2004, Kogovšek 2010) has shown that it is actually in the vadose zone of an aquifer that the longest retention of water and potential contaminants can occur, as they make their way to more permeable parts of the aquifer, where flow is significantly faster. In the case of such accidents, longer observation is therefore necessary, in accordance with hydrological and rainfall conditions. The consequences of contamination of a water source are usually serious and such sources need to be excluded from use (Kogovšek & Petrič 2002a), because even a small quantity of hazardous contaminants can pollute large quantities of drinking water.

References

Gabrovšek F., Kogovšek J., Kovačič G., Petrič M., Ravbar N., Turk J., 2010. Recent results of tracer tests in the catchment of the Unica River (SW Slovenia). Acta carsologica, 39/1: 27–37.

Genorio M., 1999. Varovanje kraških vodnih virov. Primer havarije plinskega olja v zajetju Globočec [Protection of karst water resources. The case of a gas oil spill in the catchment area of the Globočec spring]. Diploma paper. VSZ, Ljubljana: pp. 65.

Habič P., 1988. Ogroženost kraških voda zaradi izlivov škodljivih tekočin [The threat to karst waters from harmful liquids]. Ujma, 2. Ljubljana: 83–86.

Knez M., Kranjc A., Otoničar B., Slabe T., Svetličič S., 1994. Posledice izlitja nafte pri Kozini [The consequences of an oil spill near Kozina]. Ujma, 8: 74–80.

Kogovšek J., 1987. Naravno čiščenje sanitarnih odplak pri vertikalnem prenikanju v Pivki jami [Natural purification of sanitary sewage during vertical percolation in Pivka Jama]. Acta carsologica, 16: 121–139.

Kogovšek J., 1993. Kakšna je sestava voda, ki odtekajo z naših cest? [What is the composition of waters from roads in Slovenia?] Ujma, 7: 67–69.

Kogovšek J., 1995a. Podrobno spremljanje kvalitete vode, odtekajoče z avtoceste in njen vpliv na kraško vodo [Detailed monitoring of quality of motorway runoff and its influence on karst waters]. Annales, Series Historia Naturalis, 5/7: 149–154.

Kogovšek J., 1995b. The surface above Postojna Cave and its relation with the cave. The case of the Crystal Passage. Proceedings of the symposium International Show Caves and Environmental Monitoring, Frabosa soprana: 29–39.

Kogovšek J., 1995b. Izlitja nevarnih snovi ogrožajo kraško vodo. Onesnaženje Rižane oktobra 1994 zaradi izlitja plinskega olja ob prometni nesreči v Obrovu [Spillages of hazardous substances are a threat to karst waters. Pollution of Rižana in October 1994 due to a gas oil spillage in a traffic accident near Obrov]. Annales, 5/7: 141–148.

Kogovšek J. 1997. Pollution transport in the vadose zone. In: Günay G., Johnson A. I., Tezcan L., Atilla A.Ö. (Eds.). Karst waters & environmental impacts: proceedings. A.A. Balkema, Rotterdam: 161–165.

Kogovšek J., 2010. Characteristics of percolation through the karst vadose zone. Carsologica 10. ZRC Publishing, Postojna-Ljubljana: pp. 168.

Kogovšek J., Knez M., Slabe T., 1994. Poročilo o posledicah izlitja nafte pri Obrovu 12.10.1994 [Report on the impacts of an oil spill near Obrov on 12 October 1994]. Detailed expert report. Karst Research Institute ZRC SAZU, Postojna.

Kogovšek J., Petrič M., 2002a. Podzemno raztekanje vode iz ponora Tržiščice (JV Slovenija) [Underground water flow from the Tržiščica sinking stream (SE Slovenia)]. Acta carsolologica, 31/2: 75–91.

Kogovšek J., Petrič M., 2002b. Ogroženost kraškega sveta [Threats to karst areas]. In: Ušeničnik B. (Ed.), 2002. Nesreče in varstvo pred njimi. Uprava RS za zaščito in reševanje Ministrstva za obrambo, Ljubljana: 170–183.

Kogovšek J., Šebela S., 2004. Water tracing through the vadose zone above Postojna Cave, Slovenia. Environmental Geology, 45/7: 992–1001.

Kompare B., Atanasova N., Babič R., Panjan J., Bulc T., Cerar U., Rodič P., Knez M., Kogovšek J., Petrič M., Pintar M., 2002. Odvodnja avtocest in zaščita voda: analiza delovanja čistilnega objekta na krasu [Drainage from motorways and protection of waters: analysis of the operation of a water purification station analysis in the karst]. In: Vilhar M. (Ed.), 2002. 6. slovenski kongres o cestah in prometu, Portorož, 23–25 October 2002. Zbornik referatov. Ljubljana, Družba za raziskave v cestni in prometni stroki Slovenije: 93–102.

Krivic P., Bricelj M., Trišič N., Zupan M., 1987. Sledenje podzemnih vod v zaledju izvira Rižane [Water tracing in the catchment area of the Rižana spring]. Acta Carsologica, 16: 83–104.

Krivic P., Bricelj M., Zupan M., 1989. Podzemne vodne zveze na področju Čičarije in osrednjega dela Istre [Underground water connections in the area of Čičarija and central Istria]. Acta carsologica, 18: 265–295.

Pintar M., Ajdič M., Leskovšek H., 1998. Kemizem padavinske vode z avtoceste pri Divači in v Vipavski dolini [The chemistry of rainfall-generated runoff from the motorway near Divača and in the Vipava Valley]. Zbornik 4. kongresa o cestah in prometu, Portorož: 159–267.

Vlahović T., 2000. Kemizam vode kao indikator regionalnog kretanja podzemne vode u krškim vodonosnicima: izvor Sv. Ivan, Istra [The chemical composition of water as an indicator of underground water flow in a karst aquifer: Sveti Ivan spring, Istria]. Proceedings of the 2nd Croatian Geological Congress, Cavtat-Dubrovnik 17–20 May 2000, Zagreb: 827–832.

PAZINSKA JAMA AND ITS IMPACT ON THE QUALITY OF SPRINGS IN THE VALLEY OF THE RIVER RAŠA

Mladen Kuhta [1]

In view of the assumptions and processes that follow the genesis of speleological structures, these are rightly considered the privileged conduits of groundwater flow from the surface to the saturated parts of the karst aquifer, regardless of their position in the recent hydrogeological environment. This is especially true of temporary or permanent sinking streams, which are typical examples of concentrated and allogenic recharge (Ford & Williams 2007). Concentrated sinking is reflected in the size and distribution of secondary porosity, leading to the formation of underground conduits which represent zones of concentration of flow and rapid flow, often over very great distances. Studies have shown that in some karst terrain over 99 % of the total circulation of water takes place through wide underground conduits under turbulent flow conditions (Worthington et al. 2000). On the other hand, it is a well-known fact that in such conditions the chances of auto-purification are very limited, and any pollution brought underground by surface waters via sinkholes reaches the karst aquifer very quickly. For this reason, in terms of the protection of karst groundwater resources, sinking streams, either permanent or temporary, are considered extremely sensitive areas. As a consequence of complex geological conditions, central and northern Istria are characterised by highly permeable carbonate rocks and impermeable flysch. In the contact zones of these different hydrogeological environments, ponors are common, and some of them are among the largest speleological structures on the Istrian peninsula (the Rašpor, Bregi, Kolinasi ponors, etc.). One of the most famous is without a doubt Pazinska jama (Pazin cave), in which the largest sinking stream in Istria, the Pazinčica, disappears underground. Although the ponor, with its immediate surrounding area, was has been entered in the Register of Geomorphological Natural Monuments of Croatia in as early as 1964, in view of its scientific, environmental, aesthetic and cultural value (Resolution of the Republic Institute for Nature Conservation No 84/1-1964), for many years the torrential channel of the Pazinčica and Pazinska jama were basically used as an open household and industrial wastewater collector in the wider Pazin area. Not only that, but in 1997 one of the largest environmental accidents in the karst region of Croatia occurred here. For many years Pazinska jama was an example of poor treatment and a lack of concern for preserving the quality of underground water resources. Although an integrated wastewater drainage system in the catchment area of the Pazinčica has not yet been completed, the construction and putting into operation of the Pazin wastewater treatment facility in 2005 has significantly improved the situation since then.

[1] *Croatian Geological Institute, Sachova 2, 10 000 Zagreb, mladen.kuhta@hgi-cgs.hr*

Research and morphology of Pazinska jama

Pazinska jama is one of the most famous caves in Istria. The first speleological research was carried out by E. A. Martel, who in 1893, together with W. Putick of Ljubljana, made the first topographic map of the cave (Martel 1894, 1896, 1897). Information on Pazinska jama can be found in the account of M. Baratta (1920) and then in the book *Duemila Grotte* (Bertarelli and Boegan 1926) and the Italian caves register (Boegan 1930). Recent detailed geological, hydrogeological and speleological research, including topographic imaging inside the ponor (Fig. 1) was carried out by M. Malez during the summer of 1967 (Malez 1968). The length of the structure from the entrance (below the vertical wall) to the end of the siphon lake is 215 metres, at a depth of 12 metres. The entrance to the ponor is situated at approximately 185 metres above sea level and the final siphon (at low water levels) is at 173 metres above sea level.

In morphological terms, Pazinska jama is a simple speleological structure. A wide conduit with an average width of 10 metres extends in a generally south-easterly direction. The final section of the conduit extends into an underground lake (Martel's Lake), length 80 metres, average width 20 metres. The depth of water in the lake ranges from 2 m in the centre to 13 m in the depression on the eastern side of the chamber, where the structure extends in a siphon. According to data from Pazin-based caving club Speleološko društvo Istra and divers from Pula in 1975, the siphon was explored by diving up to a length of approximately 70 metres.

Hydrogeological situation

The Pazinčica is the largest sinking stream in Istria. Its catchment area of 82.9 km^2 consists of flysch, i.e. mostly impermeable, Palaeogene clastic sediments. Pazinska jama formed in permeable Cretaceous limestone, a few hundred metres downstream from the fault contact with flysch deposits. The position of the ponor is shown in the hydrogeological map of Istria in Fig. 2.

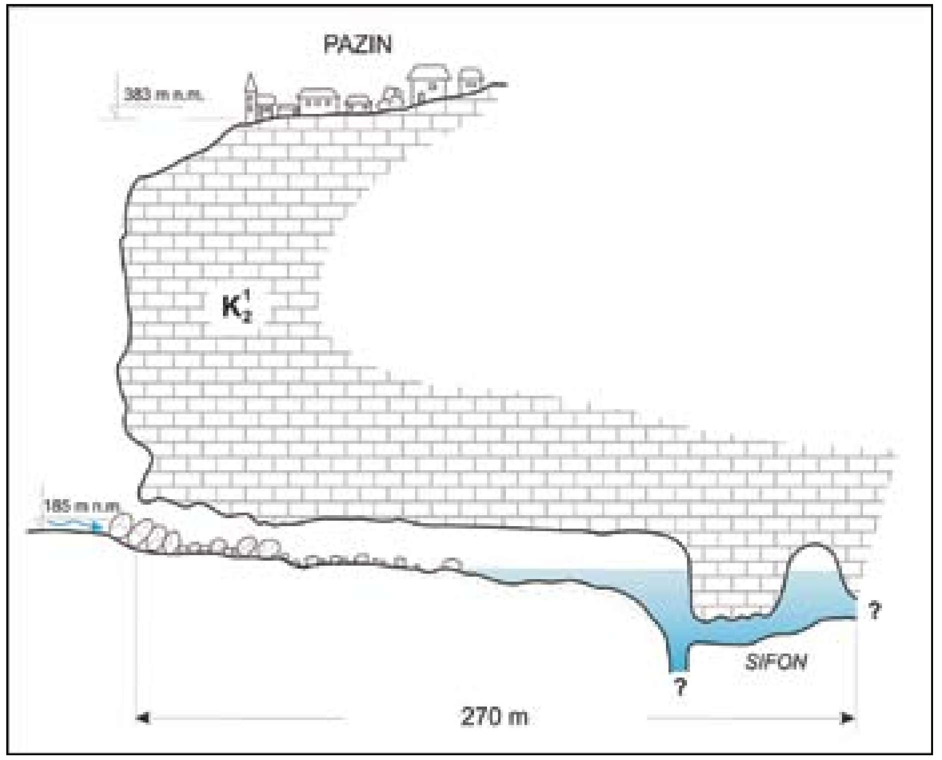

Fig. 1: Profile of the Pazinska jama ponor according to Malez (1968) and divers from Pazin (1975, from Božičević 1985)

The Pazinčica is a watercourse of torrential character. According to data from observations on the Dubravica profile, located immediately upstream of the sinking zone, for the period 1973–1993 low water levels and

rates of flow of less than 0.3 m^3/s were recorded on 54 % of days, and 133 days on which the channel was dry were recorded. For the same period, the average rate of flow was 0.815 m^3/s. In high-water periods, due to a lower sinking capacity, flooding of the ravine section is frequent. In cases of extreme inflow, the water level rises by several tens of metres. In October 1993 the water level reached 235.89 metres above sea level, in other words over 50 metres above the cave entrance. Hydrological analysis indicates that on this occasion the inflow of the Pazinčica exceeded the 100-year maximum of 166 m^3/s (Ožanić et al. 1997).
According to the findings of previous tracer tests, waters from Pazinska jama drain into springs along the right bank of the river Raša. The springs are between 12.97 and 27.9 kilometres from the ponor. Since the tests were performed in different hydrological conditions, tracer was reported in varying concentrations at different locations (Tab. 1). When considering the impact of pollution transmitted through Pazinska jama into the karst aquifer, it is important to take into account the fact that an apparent flow speed of between 0.18 and 1.54 cm/s was observed. Judging from experience to date in the Croatian part of the Dinaric Karst, these can be considered low speeds (Kuhta & Brkić 2008). Another particularly significant fact is that every tracer test revealed a reliable water connection with the Rakonek spring (8), which is connected to the water supply system of the city of Pula, with a capacity of 250 l/s.

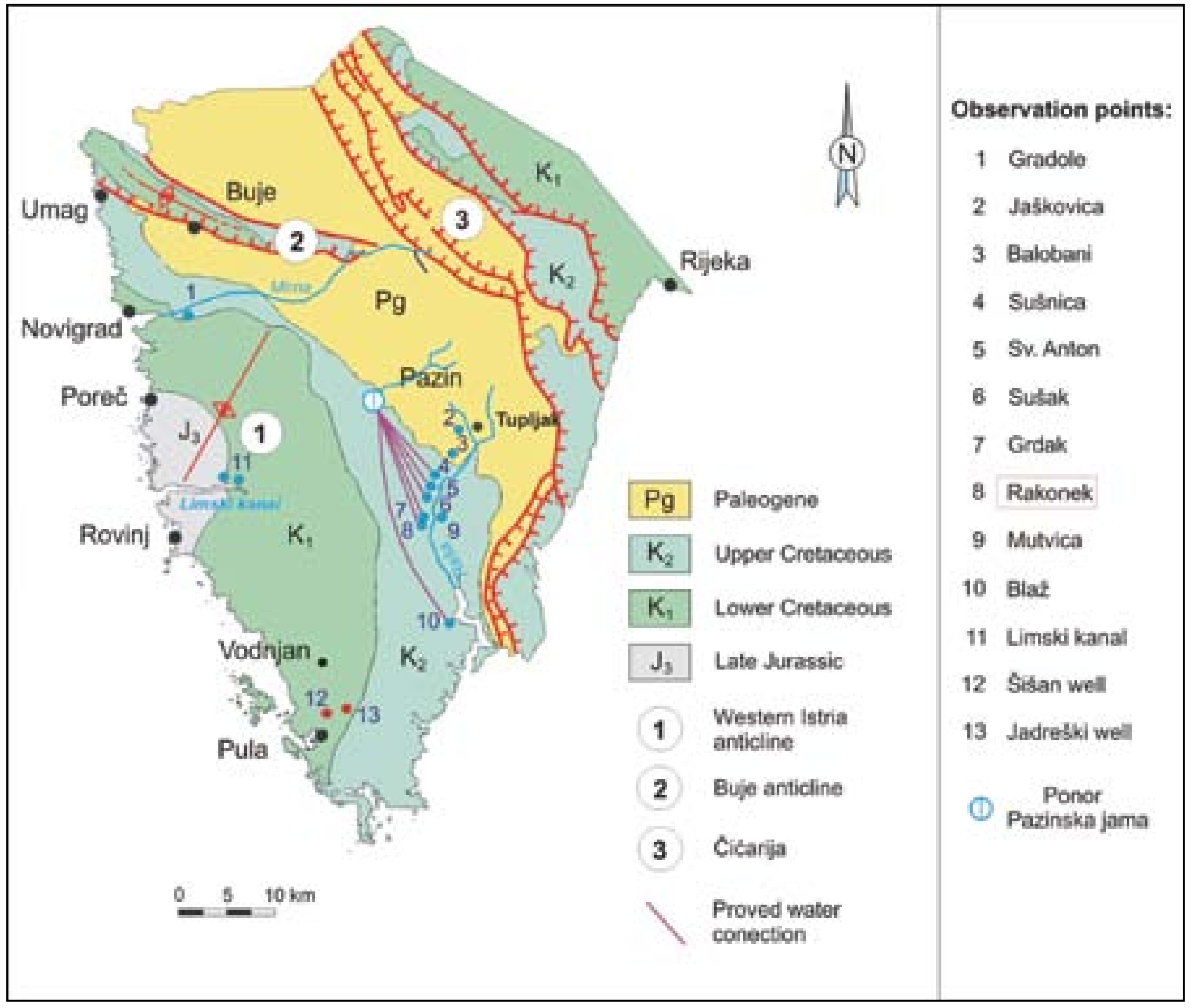

Fig. 2: Hydrogeological map of Istria, underground water connections from the Pazinska jama ponor and springs monitored following accidental pollution.

Groundwater Status

Up until 2005 the Pazinčica sinking stream was the final recipient of all wastewater from Pazin and the surrounding smaller settlements. The situation was particularly bad in the late 1980s, when a number of industrial plants were operating. During the 1990s some of these plants were decommissioned or saw a decrease in production, which resulted in a reduction of the quantity of industrial wastewater, but the situation remained highly unsatisfactory. Particularly high concentrations of pollutants were recorded during the summer months when, due to the small natural inflows in the channel of the Pazinčica, practically the only inflow to the ponor was waste water. Significant changes occurred in 2005 with the construction of a central wastewater treatment facility for the town of Pazin. Water quality in the Pazinčica

Tab. 1: Basic parameters of tracer tests from the Pazinska jama ponor.

CONTRACTOR, DATE, TRACER, QUANTITY, HYDROLOGICAL CONDITIONS	POINTS OF TRACER APPEARANCE	DISTANCE FROM SINK (km)	MAXIMUM FLOW VELOCITY (cm/s)	TRACER QUANTITY (%)
Construction Institute, November 16, 1967, Uranine, 140 kg, Low water	Sv. Antun	13.44	1.54	80
	Rakonek	18.41	0.78	5.6
	Grdak	17.68	0.78	?
	Observed but tracer not found: Sušnica, Sušak, Blaž, Pićan cave, Lim channel, and Valtura, Jedreški and Šišan wells near Pula			
"Ruđer Bošković" Institute, March 11, 1978, Tritium, 1679 Cr, High water	Sv. Antun	13.44	1.27	20
	Rakonek	18.41	1.18	7
	Grdak	17.68	1.1	12
	Sušnica	12.97	1.23	50
	Observed but tracer not found: Baloban, Bubić jama, Česuni, Blaine, Maple, Fonte Gajo, Pićan cave, Gradole, Lim canal, and Valdragone, Valtura, Jedreški, Šišan and Tivoli wells near Pula			
"Ruđer Bošković" Institute, July 8, 1981, Tritium, 37 000 GBq, Low water	Sv. Antun	13.44	0.18	4.2
	Rakonek	18.41	0.25	12.7
	Grdak	17.68	0.24	16.3
	Sušnica	12.97	0.18	9.6
	Susak	13.83	0.19	4.6
	Blaž	27.90	0.43	40
	Observed but tracer not found: Baloban, Česuni, Mutvica, Fonte Gajo, Ješkovica-Pićan cave, and Šišan and Tivoli wells near Pula			

just outside the ponor sink has been monitored since 2000 as part of the "National Monitoring of Surface Water and Groundwater Quality" project run by state-owned water utility Hrvatske Vode. The essential statistical elements of the investigated chemical parameters are shown in Tab. 2. The table also includes data obtained from the Rakonek spring, which was selected as a representative location to show the state of the springs in the valley of the Raša. For both locations particular attention was given to the data for the period 2000–2004, prior to the construction of the waste water treatment facility (WTF), and for the period 2006–2008, after the WTF came online.

The data in the table clearly show that following construction of the WTF (2005) there was a significant improvement in water quality in the Pazinčica. It should be noted here that the efficiency of the WTF and the number of connected users has increased gradually, meaning that today's situation is even better than the situation reported here. The trend of improving water quality is evident in most of the parameters considered for the Rakonek spring, and the situation is similar in other springs in the valley of the Raša. It is noticeable that if the situation before construction of the WTF is observed, these improvements are significantly smaller than those observed in the water of the Pazinčica. This shows that Pazinska jama is not the only source of groundwater contamination, but that pollution enters the underground in other parts of the catchment area.

Tab. 2: Basic statistics for selected chemical parameters of water quality from the Pazinčica outside Pazinska jama and the Rakonek spring before and after the construction of the Pazin wastewater treatment facility (WTF).

PARAMETER		BOD_5**	Ammonium	Total nitrogen	Total phosphorus	Copper	Zinc	Lead	Iron	Total oil	Mineral oil	Total phenols	Anionic detergents	TOC***
Unit		mgO_2/L	mgN/L	mgN/L	mgP/L	µgCu/L	µgZn/L	µgPb/L	µgFe/L	mg/L	mg/L	µg/L	mg/L	mg/L
PERIOD	StVal	PAZINČICA - IN FRONT OF PONOR												
Before WTF* construction 2000 - 2004 (62 analysis)	Min	0,67	0,029	0,83	0,043	2,50	5,00	1,00	39,4	0,137	0,010	0,00	<0,001	2,25
	Max	638,00	79,700	92,32	15,990	47,00	255,00	21,50	4087,7	165,500	68,300	0,16	9,410	93,40
	Avg	105,03	20,488	26,79	2,926	20,44	55,47	7,03	492,3	15,783	1,856	0,05	1,599	20,52
	Med	6,18	3,900	6,80	0,461	20,30	44,90	5,05	234,0	2,251	0,140	0,02	0,150	11,95
	StDev	146,06	25,700	31,47	4,381	11,55	53,15	5,77	696,6	26,036	8,718	0,05	2,693	23,72
After WTF* construction 2006 - 2008 (36 analysis)	Min	0,52	0,021	0,89	0,056	<1	7,20	<1	102,20	0,036	0,003	<0,001	0,012	1,36
	Max	11,20	26,100	31,38	3,326	24,20	55,70	2,70	482,20	9,591	0,830	0,026	0,981	22,09
	Avg	3,61	3,160	5,71	0,603	10,04	28,62	2,13	238,33	1,236	0,086	0,006	0,098	5,76
	Med	2,31	0,354	2,58	0,333	7,55	26,20	2,10	215,25	0,290	0,023	0,002	0,026	3,43
	StDev	3,16	6,520	7,19	0,857	8,83	21,17	0,55	129,11	2,340	0,189	0,009	0,255	5,20
PERIOD	StVal	RAKONEK SPRING												
Before WTF* construction 2000 - 2004 (60 analysis)	Min	0,11	0,001	0,92	0,018	1,60	0,00	<1	13,7	0,009	0,001	<0,001	<0,001	0,63
	Max	1,43	0,132	4,17	0,259	26,90	270,00	13,70	1161,0	0,086	0,031	0,001	0,013	2,26
	Avg	0,64	0,021	2,39	0,079	6,05	32,77	2,73	113,0	0,025	0,008	<0,001	0,006	1,30
	Med	0,63	0,010	2,23	0,065	4,45	26,00	1,60	73,3	0,019	0,007		0,007	1,27
	StDev	0,28	0,026	0,68	0,048	5,39	43,74	3,69	190,3	0,016	0,005		0,004	0,42
After WTF* construction 2006 - 2008 (36 analysis)	Min	0,05	0,005	1,55	0,027	1,00	12,30	<1	19,90	0,002	<0,001	<0,001	<0,01	0,51
	Max	1,69	0,045	3,62	0,182	11,80	29,30	<1	556,90	0,055	0,015	<0,001	0,012	2,12
	Avg	0,56	0,015	2,62	0,059	2,16	21,88	<1	78,11	0,022	0,004	<0,001	0,012	1,11
	Med	0,52	0,016	2,64	0,051	1,00	23,25		37,65	0,017	0,003		0,012	1,06
	StDev	0,35	0,011	0,52	0,030	2,86	6,88		138,85	0,012	0,004		0,001	0,38

WTF* Water Treatment Facility BOD_5** Biological Oxigene Demand TOC*** Total Organic Carbon

The consequences of accidental pollution

In addition to the permanent pollution flowing underground through Pazinska jama and placing a burden on the karst aquifer, occasional incidents represented an even greater danger. The largest incident was caused by a ruptured pipeline between the fuel tank and the boiler at the KTI Pazinka plant, which saw a large quantity of fuel oil reach the channel of the Pazinčica. The spill occurred approximately 750 metres upstream from the cave entrance. The incident took place on 6 October 1997. Owing to the lack of accurate records on stocks and consumption at Pazinka, the amount of fuel oil to reach the aquifer cannot be accurately determined. As a result, the extent of the contamination can only be estimated from the fact that during 16 days of cleaning 421 m^3 of oily water was collected, from which 123 tonnes of heavy fuel oil was extracted (Rubinić et al. 1998).

Thanks to a timely intervention, the construction of provisional dams and extremely low water levels, only a relatively small amount of fuel oil reached Pazinska jama. According to data obtained by the Dubravica limnigraph station, located immediately upstream of the ponor area, at the beginning of the incident the average daily flow of the Pazinčica was 14 l/s, but owing to incidental losses only about 5 l/s flowed into the cave (Rubinić et al. 1998). Stable hydrological conditions allowed the natural barriers and cascades in the channel, and above all the temporary dam constructed using any available materials at the very start of the cleanup operation, to prevent large quantities of fuel oil from reaching the underground, and enabled the successful completion of the operation to clean up the channel (Fig. 3). A speleological inspection showed that around 1 m^3 of fuel oil reached the ponor, most of which was located in the final siphon lake over an area of approximately 350 m^2 (Kuhta & Božičević 1999, Kuhta 1999). In addition to the oil there were accumulations of branches, floating waste and faeces (Fig. 4), which for many years, unfortunately, have been regarded as the "normal" state of the ponor.

Fig. 3: Cleaning fuel oil from the bed of the Pazinčica

Fig. 4: Fuel oil, waste matter and faeces on the surface of Lake Martel at the end of Pazinska jama.

Although no information was available about similar incidents at that time, traces in the underground testified otherwise. Traces of heavy fuel oil were clearly visible on the rocks of the final chamber of the ponor at a height of up to 2.5 metres above the existing water level (Fig. 5). Before and during the observed pollution, the flow rate and level of the Pazinčica were extremely low; these traces of fuel oil are undoubtedly the result of previous incidents, which occurred at significantly higher water levels.

Immediately after the incident, water quality monitoring was introduced at a number of springs (Fig. 2). Besides the springs on the right bank of the Raša, with which the existence of water connections demonstrated by tracer tests, observations were made in the Mutvica spring on the left bank of the Raša, the Gradole spring in the valley of the Mirna, and the Lim Channel. The main water supply wells in the area of Pula (Šišan and Jadreški) were also sampled. Sampling dynamics were adjusted to the estimated threat and the available financial resources and, following repeated reductions in values, monitoring was terminated six and half months after the incident. Regular monitoring was only carried out of general parameters and parameters indicating the presence of fuel oil in drinking water: total fat, mineral oil, pH, turbidity, total suspended solids, dissolved oxygen content, CCP-permanganate, solvents, PAHs and phenols. In addition to water chemistry, hydrological conditions (water levels, flow rates) were also monitored at most sites. The impact of pollution was recorded in all the springs on the right bank of the Raša, and the movement of total fats, oils and mineral oils in the Pazinčica just before the ponor and in the most frequently monitored spring, the Rakonek, is shown here (Fig. 6).

It may be noted that polluted water flowed into the ponor throughout the period of observation of the channel of the Pazinčica (Fig. 6a). The highest concentrations of pollutants, hundreds of times greater than the maximum allowable concentration (MAC), were recorded in the period of low water levels immediately after the incident. Bigger water pulses and high water levels brought a reduction in the concentration of pollution in the stream. Levels rose again with the decline in the rate of flow, but the maximum values, though still well above the MAC, were significantly lower than those immediately following the incident. Approximate estimates based on recorded flow and total concentration of oils, fats and mineral oils showed that despite the preventive measures and the cleanup operation, nearly 14.5 tonnes of lipophilic substances, of which mineral oil waste accounts for 1.4 tonnes, reached the underground during the observation period (Rubinić et al. 1998).

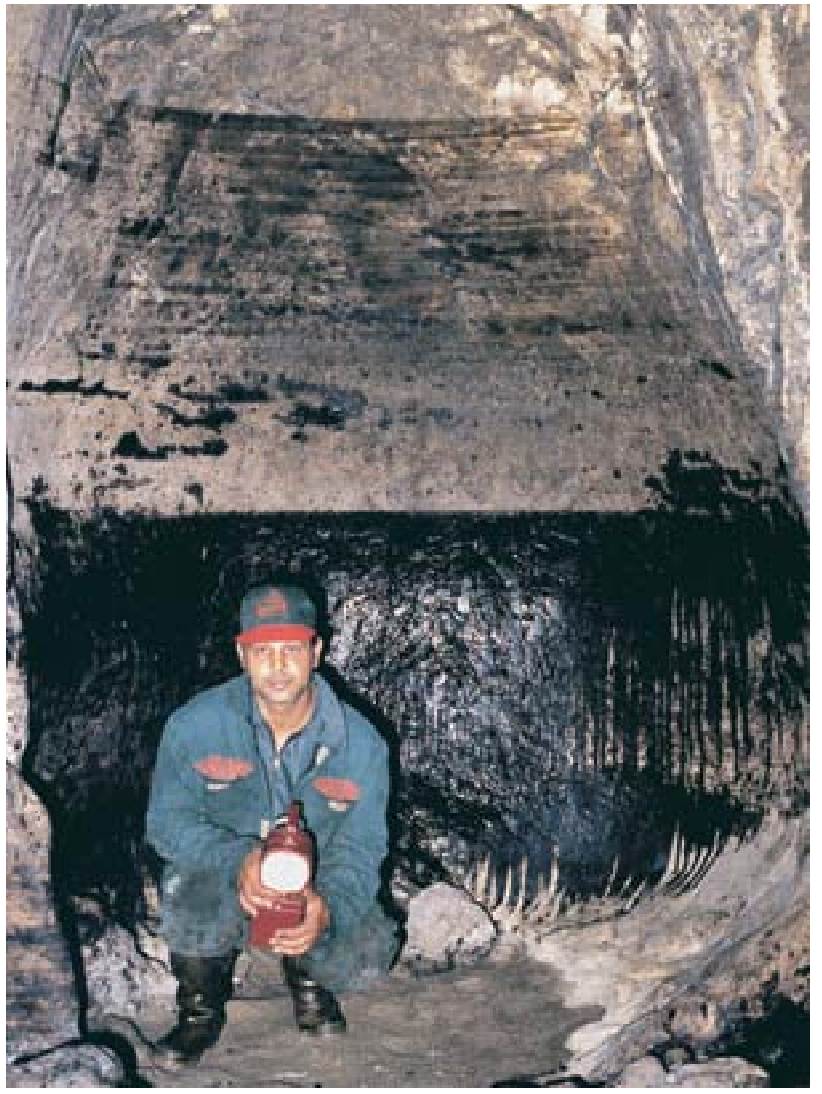

Fig. 5: Traces of previous, unrecorded accidents.

In the Rakonek spring – a similar situation was observed in other springs on the right bank of the Raša – the first reliable signs of contamination appeared ten days after the incident, and maximum values were recorded at a time of a high water pulse about two months later (Fig. 6b). Throughout the observation period an excessive mineral oil content was recorded in most of the water samples. By contrast, total oils and fats were mostly below the MAC, but excessive values were recorded during the high water pulses. The maximum values of these parameters were several tens of times higher than the MAC, but also significantly less than those observed in the water of the Pazinčica, as a result of dilution, in this case, with much cleaner inflows from other parts of the basin. It is known that increased levels of fats, oils, mineral oils, and sometimes phenols are often reported after abundant rainfall in karst springs near urban areas as a result of leaching, but in the Rakonek spring and the other observed springs on the right bank of the Raša, the increase was significantly above normal, and can therefore definitely be linked to the accidental pollution of Pazinska jama.

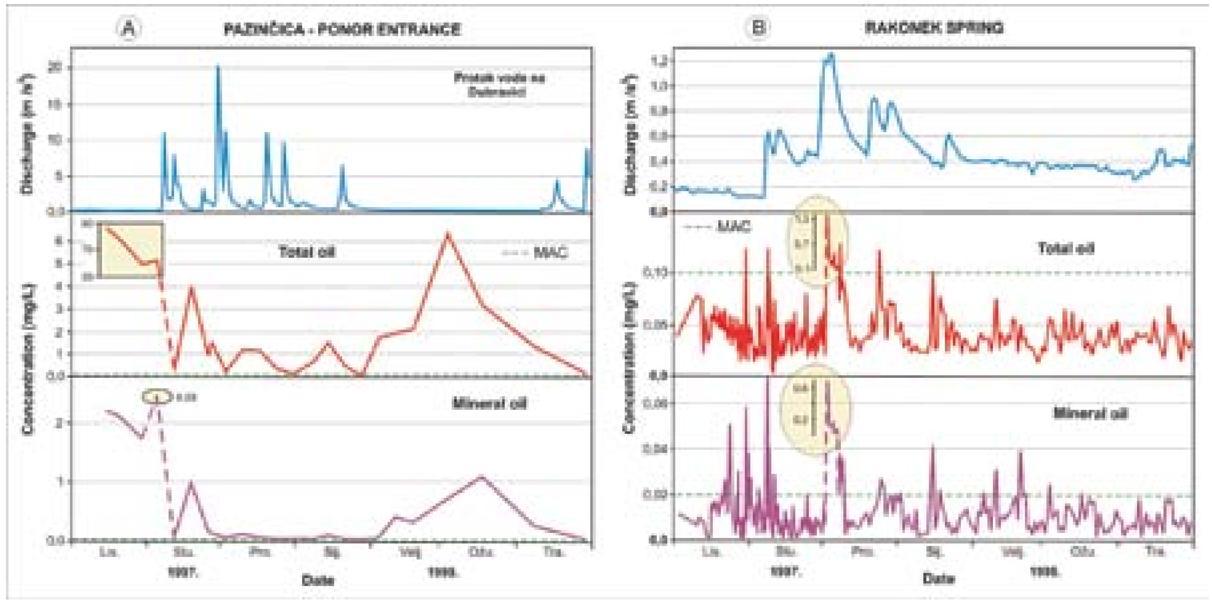

Fig. 6: Hydrographs of the Pazinčica (measured at the Dubravica measuring station) and the Rakonek spring in comparison to measured concentrations of total fat and oil and mineral oils during the monitoring period (from Rubinić et al. 1998).

Conclusion

Pazinska jama is one of the most important speleological structures in Istria. It formed at the contact of impermeable deposits of Eocene flysch and permeable Upper Cretaceous limestones. The cave functions as a ponor and the Pazinčica, the largest sinking stream in Istria, flows into it. Tracer tests have shown that water from Pazinska jama emerges in karst springs along the right bank of the river Raša. For many years the Pazinčica and Pazinska jama were the recipients of all wastewater from the town of Pazin and the surrounding area. Since there was no treatment system, water quality in the Pazinčica was very poor, especially when water levels were low. A continuous inflow of pollution affected water quality in the karst aquifer from which the above springs in the valley of the Raša are supplied, including the Rakonek spring, which contributes to the water supply of Pula.

With the construction of the Pazin wastewater treatment facility, the quality of the water in the Pazinčica has improved significantly, and this has been reflected in improvements in the springs. It thus has been shown that wastewater treatment is a fundamental requirement for the preservation of groundwater quality in karst areas. In 1997 Pazinska jama was the scene of one of the biggest environmental incidents ever to affect the karst area in Croatia. Despite the catastrophic dimensions of the incident in the Pazinčica stream, contamination levels monitored in the major springs downstream of the pollution site were significantly lower than expected. The main reason for this was the favourable hydrological conditions which allowed the removal of most of the contamination prior to its entry into the karst underground. Additionally, when water levels are very low, direct flows from Pazinska jama only account for 1 % of the total discharge at the springs along the right bank of the. In these circumstances the pollution that penetrated the aquifer despite preventive measures being taken, was diluted by clean groundwater from other parts of the catchment area on its way to the drainage area in the valley of the Raša river. The highest concentrations of contaminants in the springs were recorded during increased water pulses (the maximum was recorded two months after the incident). This is a consequence of the hydraulic principles of karst flow, according to which in high water conditions the largest quantity of water drains through the most developed systems of underground conduits, or through zones of privileged flow. In other words, in such circumstances most outflows at springs are fed through a system of conduits originally connected with Pazinska jama.

Under the given circumstances it is apparent that a major environmental incident in karst, despite occurring in the immediate vicinity of an active speleological structure, does not have to result in catastrophic consequences for groundwater quality, making it permanently unusable. With favourable hydrological conditions and timely measures, the penetration of pollution into underground conduits was prevented, but its subsequent washout during high water pulses, several months after the incident, led to the normalisation of the situation in springs located in the discharge zone.

References

Baratta M., 1920. Le Grotte di S. Canzano e di Postumia, Planina, Nanporto, La Foiba di Pisino. Boll. R. Soc. Geograf. Ital. Roma.

LV Bertarelli, Boegan E., 1926. Duemila Grotte. Milano.

Boegan E., 1930. Catasto Italiane delle Grotte. Fasc. l. Grotte delle Venezia Giulia. Trieste.

Božičević S., 1985. Morfogeneza speleoloških pojava Istre i njihova zavisnost o geološkim i hidrogeološkim uvjetima [Morphogenesis of speleological phenomena of Istria and their connection with geological and hydrogeological conditions]. PhD Thesis. Zajednički studij iz područja geologije PMF i RGN fakulteta Sveučilišta u Zagrebu, Zagreb, 1–166.

Kuhta M., Božičević S., 1999. Pazin Cave Contamination with Fuel Oil. Proceedings of the 2nd Croatian Water Conference, Dubrovnik: 1001-1008.

Kuhta M., 1999. Pazin Cave Contamination with Fuel Oil – a major environmental incident in the Karst]. Caver, 44/45: 30-34.

Kuhta M., Brkic Ž., 2008. Water Tracing Tests in the Dinaric Karst of Croatia. In: M. Taniguchi, R. Yoshioka, A. Sinner, A. Aureli (Eds.), 2008. Integrating Groundwater Science and Human Well-being. XXX Congress of IAH, Proceedings CD, Toyama, Japan.

Otte M., 1968. The ponor of the Pazinčica and its role in the underground hydrological system in central and southern Istria. Geographical Bulletin, 30: 61-77.

EA Martel, 1894. Les abimes. Explorations souterraines 1888-1893. Paris.

EA Martel, 1896. Sur de la Foiba Pisino (Istria). Compt. Rend. de Acad. des Sciences, 123, 28th December 1896th Paris.

EA Martel, 1897. La Foiba de Pisino. La Nature, Paris: p. 25.

Rubinić J., Kukuljan I., Diković S., Stipić Ž., 1998. Final report on results of water quality tests in Istria's karst springs following the accident at the ponor of the Pazinčica for the period October 1997-April 1988]. Department of Public Health of Istria, Hrvatske Vode: 1-18.

Ožanić N., Rubinic J., S. Kamber, Diković S., 1997. Environmental accident - tonnes of fuel oil in the channel of the Pazinčica. Croatian Waters: 62-63 & 85-92.

Worthington SRH, Ford DC, Beddows PA, 2000. Porosity and permeability enhancement in unconfined carbonate aquifers as a result of solution. In: Klimchouk A., Ford DC, Palmer AN, Dreybrodt (Eds.), 2000. Speleogenesis: Evolution of karst aquifers, Huntsville, Natl. Speleol. Soc: 463-472.

ASSESSMENT OF THE POSSIBLE IMPACT OF THE CONSTRUCTION OF THE DIVAČA-KOPER RAILWAY LINE ON THE QUALITY OF KARST WATERS

Metka Petrič [1] & Janja Kogovšek [2]

Karst aquifers are characterised by a heterogeneous structure where water, with any contaminants it may contain, flows quickly through major conduits but can be retained for a longer time in less permeable sections, particularly in the vadose zone, which means an accumulation of contaminants (Kogovšek 2010). It returns to the surface through karst springs. The position of watersheds between the catchment areas of individual springs changes depending on hydrological conditions. The identification of watersheds is therefore difficult and only possible through the use of various hydrogeological research methods, where the best results are provided by tracer tests. Identified directions and velocities of water flow and the recovered quantity of tracer in the individual springs in which tracer appears tell us a great deal about the mode of water flow and the transfer of water-soluble substances in the karst in given hydrological conditions.

The route of the planned Koper–Divača railway line bisects the highly vulnerable trans-boundary karst aquifer and runs close to a water source that is used to supply the coastal tourism region. In order to ascertain the flow of waters in this area and estimate the possible impacts on karst waters of the construction and operation of the line, we carried out several tracer tests using fluorescent tracers. A considerable part of the future railway will run through tunnels, something which will significantly affect the aquifer. Not only is there no protective soil layer here, as there is on the surface, a more direct contact with highly permeable karst conduits is also possible, enabling the more rapid flow and transfer of contaminants towards springs. There is also the probability that in some parts of the line, when water levels are high, the water table will rise above the level of the line, which means that all the pores in this area are filled with water and the possibility of rapid transfer of contaminants is therefore even greater.

We assessed the possible impact on karst waters of the construction of the new railway line and the importance of the position of the line within the various hydrographic zones of the karst aquifer by means of a variety of tracer tests. In the first test we injected tracer into the stream flow in a ponor; in the second we injected it directly on the karst surface, which meant that the tracer first had to pass through the vadose zone; and in the third we injected it into two boreholes deeper in the vadose zone when the water level was respectively 210 metres and 160 metres below the surface. The second and third tracer tests best illustrate the case of accidents involving the spillage of substances during construction or operation of the railway line if the concrete lining of the tunnel were to be ruptured.

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, petric@zrc-sazu.si*

[2] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, kogovsek@zrc-sazu.si*

Hydrogeological characteristics of the area

The wider area of the planned railway line between Črni Kal and Divača (Fig. 1) is characterised by an imbricate thrust structure, where bands of Eocene flysch are interspersed among carbonate rock – predominantly limestones of Upper Cretaceous and Palaeocene age. In hydrogeological terms, carbonate rock represents highly permeable karst aquifers, where underground water flow prevails. Infiltration of precipitation and the substances dissolved in it into the karst aquifer is rapid. Even more direct and rapid, however, is the input of water and possible pollution through the sinking streams, which we observe in the area of Ocizla. The bands of flysch among the limestones represent local hydrological barriers against which water can collect, thus slowing its flow. Flysch on the surface enables surface flows that sink underground on contact with karst. On the other hand flysch also acts as a hydrological barrier which causes underground karst waters to discharge onto the surface in karst springs.

Karst springs in the wider area of influence of the future railway

The largest spring in Slovenia's Primorje (Littoral) region is the Rižana, which has been used to supply water to this area since 1935. On the basis of basic geological research and numerous tracer tests (Krivic et al. 1987, 1989) the catchment area of the spring has been estimated to measure 247 km^2. The largest part of it is karstic, while the spring also receives water from the flysch Brkini hills. The Rižana spring is tied to the contact of the carbonate aquifer with the impermeable flysch rock masses along which the river Rižana then

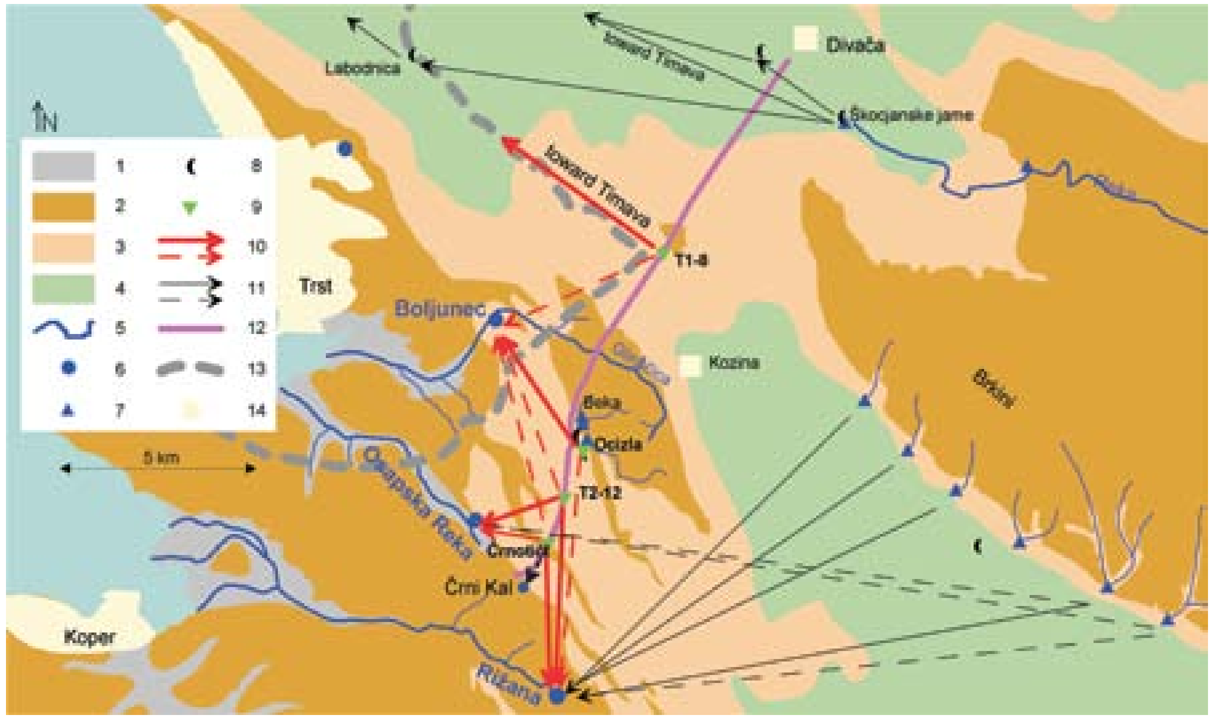

Fig. 1: Hydrogeological map of the area of the planned route in the Črni Kal-Divača section (Legend: 1. Quaternary alluvial sediments, 2. Eocene flysch, 3. Tertiary limestones and dolomites, 4. Cretaceous limestones, 5. surface flow, 6. spring, 7. injection point in previous tracer tests, 8. karst cave, 9. injection point in tracer tests on the route of the railway, 10. main and secondary direction of groundwater flow shown by tracer tests on the route of the railway, 11. main and secondary groundwater flow shown by previous tracer tests, 12. planned route of the Črni Kal-Divača section, 13. national border, 14. settlement).

drains into the Adriatic Sea. The discharges of the Rižana spring range from 0.03 m^3/s to 91 m^3/s, with a mean discharge of 4.3 m^3/s.

The Osapska reka spring, which is only active after heavy rainfall, and in which discharge can reach several m^3/s, is 5 km from the Rižana spring. It emerges in a cave at a height above sea level of 105 metres, although following rainfall several springs below the entrance to the cave are activated. This is probably a high-water overflow of waters from the catchment area of the Rižana spring (Krivic et al. 1989), related to the contact between the limestone and the very poorly permeable flysch.

On the Italian side, there are several springs in Boljunec (Italian: Bagnoli della Rosandra) in the valley of the Glinščica (Italian: Val Rosandra) at a height above sea level of around 50 metres. Two springs, Na Placu and Pri Pralnici, are permanent, while water also occasionally flows from a karst cave (the Jama spring) as a high-water overflow of the Pri Pralnici spring. The water from the Pri Pralnici spring is channelled to a nearby fish farm.

The most important source of water in the Kras region is the pumping station in Klariči, which since 1984 has been supplying drinking water to five municipalities with a total population of approximately 22,500. Three 70-metre wells with a capacity of up to 250 litres of water per second have been bored at a height above sea level of 16 metres. Research to date has shown that the primary flows of water towards the pumping station are from the north-west (Krivic 1980).

The groundwater of the Kras emerges onto the

Tab. 1: Results of previous tracer tests.

Injection point	Date	Tracer	Proven connection	Apparent flow velocity v_{dom} (m/h)	Sources
Ponor of the river Reka (Škocjanske jame)	12 December 1907	LiCl	Timava spring Brojnica spring	162 128	Timeus 1928
Ponor of the river Reka (Škocjanske jame)	28 January 1913	Uranine	Cave Labodnica	97	Timeus 1928
Ponor of the river Reka (Škocjanske jame)	3 July 1962	Uranine, Tritium	Cave Labodnica Brojnica spring Timava spring	200 50 86	Mosetti 1965
Ponor of the river Reka (Škocjanske jame)	4 September 2006	Uranine	Cave Jama 1 v Kanjaducah Timava spring	164 51	Peric et al. (unpublished)
Stream Ločica	10 April 1985	Uranine	Rižana spring	101	Krivic et al. 1987
Stream Jezerina	13 May 1986	Rhodamine	Rižana spring Osapska reka spring	29 29	Krivic et al. 1989
Stream Hotiški potok	13 May 1986	Bacteriophages P22H5	Rižana spring	25	Krivic et al. 1989
Stream Velika voda	13 May 1986	Uranine	Rižana spring Osapska reka spring	29 29	Krivic et al. 1989

surface in Italy in numerous springs around the Gulf of Trieste. The largest of them is the Timava spring, which has three main outflows. According to figures for the period 1972–1983 (Civita et al. 1995), the total discharge ranges from 9.1 m^3/s to 127 m^3/s, while the mean discharge is 30.2 m^3/s. The spring was used in the past to supply water to Trieste. Today water is pumped from the porous aquifer consisting of alluvial sediments along the river Soča/Isonzo.

Characteristics of underground water flow in the wider area

Underground flow through the Kras aquifer is mainly in the direction of the Timava (Italian: Timavo) spring in Italy, and only a small proportion of this water can also appear in other springs in the Gulf of Trieste, as shown by tracer tests in the past (Tab. 1). Through the most permeable conduits of the underground course of the Reka river, which sinks in the cave Škocjanske jame, the apparent flow velocity at different water levels (calculated taking the distance as the crow flies between the injection point and the spring) ranges from 40 to 200 m/h. Velocities are smaller through the less permeable zone within the aquifer.

The summarised results (Tab. 1) indicated a lack of adequate data regarding to the route of the future railway. Therefore, additional tracer tests were carried out, first by means of injection into the stream flow in a ponor, then directly on the karst surface and finally into boreholes along the route of the railway.

Tracer tests on the route of the future railway

In the first tracer test (29 March 2001), 3 kg of Uranine was injected into the watercourse that flows into the Jama s Slapom cave (348 metres above sea level) and is part of the Beka-Ocizla cave system where the planned route of the railway is supposed to run (Kogovšek & Petrič 2004).

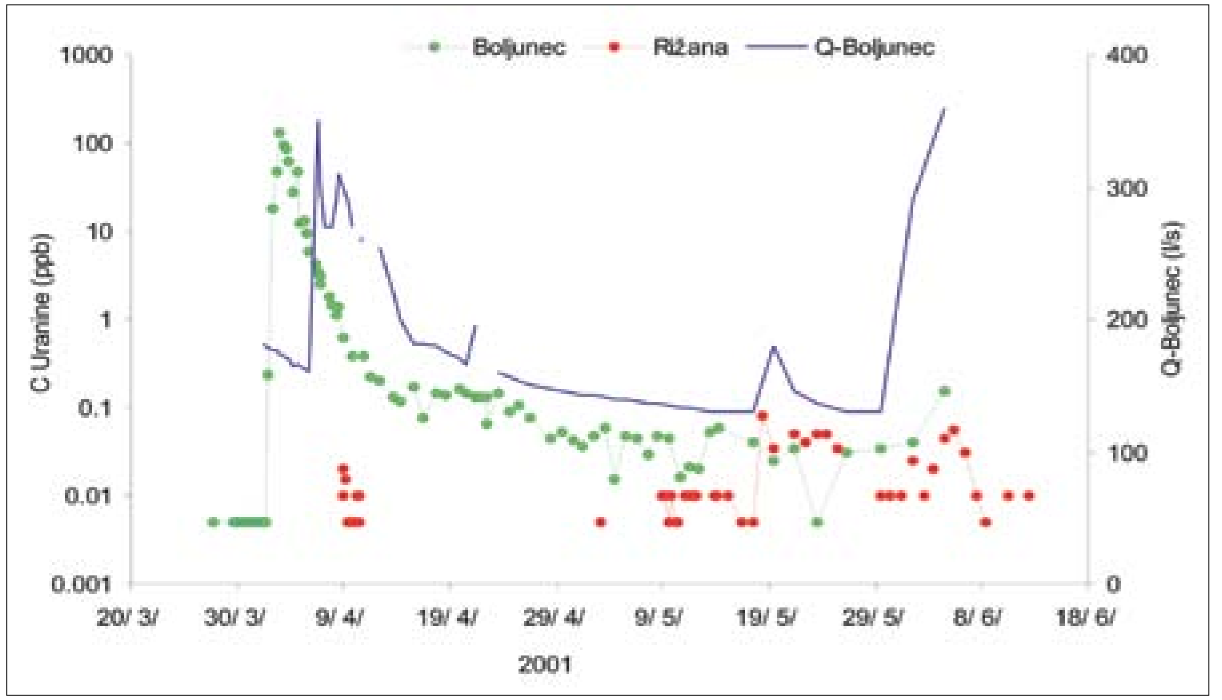

Fig. 2: Tracer breakthrough curves in the Pri Pralnici spring (Boljunec) and Rižana springs and the discharge of the Pri Pralnici spring following injection into the watercourse that disappears underground in the Jama s Slapom cave.

The tracer test was carried out during a period of medium water levels (Fig. 2). The tracer appeared strongly with declining discharges in springs in Boljunec, in the permanent Pri Pralnici spring and in the Jama overflow spring, but not in the nearby Na Placu spring. The apparent dominant flow velocity vdom (regarding to the maximum achieved concentration) into the springs in Boljunec was 32.7 m/h. The presence of Uranine was not established in the Glinščica/Rosandra or in the Osapska reka spring, which received water from the cave Osapska jama until the end of April. Tracer appeared in the Rižana spring with a larger delay and less strongly. The first traces of Uranine were detected after approximately 10 days (v_{dom}= 29 m/h), while a marked increase in concentration was only identified 50 days after injection. By the beginning of June (in two months) around 91 % of the injected tracer had discharged through the two springs in Boljunec, while 2 % had discharged through the Rižana spring.

This means that only a small part of the water from the Beka-Ocizla cave system drains towards the Rižana spring at medium water levels and it was not possible to demarcate the catchment area of the Rižana spring more accurately. We therefore carried out a new tracer test on 1 December 2009, when the water level was high, injecting 3 kg of Uranine on the surface in the vicinity of the Črnotiči quarry (Fig. 3).

The tracer test showed (Fig. 4) that precipitation from the injection area mainly flows in the direction of the Rižana spring (87 % of tracer discharged in a month) and the Osapska reka spring (11 %), while a small proportion of precipitation drains more slowly towards the Pri Pralnici spring in Boljunec and two springs in Črni Kal (Kogovšek & Petrič 2010). In conditions of relatively good saturation of the vadose zone before injection, apparent dominant flow velocities vdom of between 3 and 32.7 m/h were established. Tracer flowed fastest in the direction of the Osapska reka spring (Fig. 5). Flow towards the Rižana spring was also relatively fast (v_{dom}= 21.7 m/h) and two major tracer pulses formed. We were able to supplement preliminary findings on water flow from the Beka-Ocizla cave system towards the springs in Boljunec with the finding that further south the main direction of underground water flow turns towards the south and west in the direction of the Osapska reka and Rižana springs.

In order to obtain a more accurate definition of the position of the watersheds between the most important springs, in November 2010 we carried out a combined tracer test involving the injection of two different fluorescent tracers in the exploration boreholes T1-8 and T2-12 (Kogovšek et al. 2011), drilled along the planned route. As part of the test we measured precipitation, as well as the level in the Osapska reka and the Pri Pralnici spring in order to calculate discharges and the quantity

Fig. 3: Injection of Uranine on the surface by the Črnotiči quarry.

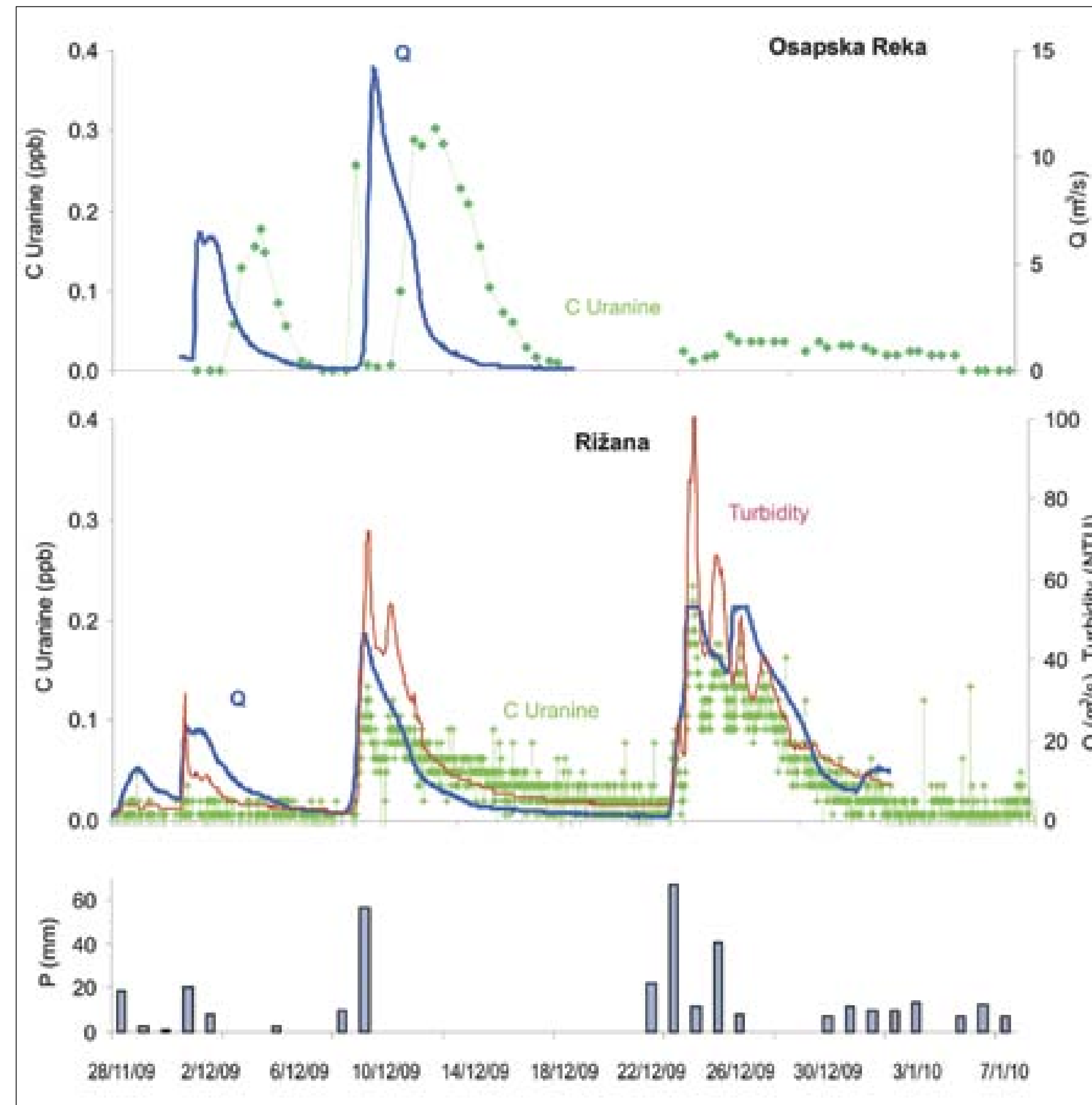

Fig. 4: Appearance of Uranine in the Osapska reka and Rižana springs and theirdischarge and measured precipitation following injection by the Črnotiči quarry.

of recovered tracer. The day before injection, researchers from the Geological Survey of Slovenia carried out a recharge test in both boreholes which demonstrated the good permeability of the rock. On 18 November 2010 we injected 4 kg of Uranine into borehole T2-12, flushing it with 3 m^3 of water, and 305 g of Amidorhodamine G into borehole T1-8, flushing it with 4 m^3 of water.

The Uranine injected into borehole T2-12 spread widely. We detected it in the Osapska reka, in the Pri Pralnici and in the Rižana springs, following abundant rainfall and an increase in discharges. It appeared most strongly in the Osapska reka spring, in slightly lower concentrations in the Pri Pralnici spring in Boljunec, in the lowest concentrations in the first tracer pulse in the Rižana spring and in high concentrations following subsequent rainfall. Tracer was not recorded in the other observed springs.

The injection of tracer into borehole T2-12 showed that at high water levels, water from this area drains in the direction of the Osapska reka, Rižana, and Pri Pralnici spring at velocities of between 60 and 10 m/h. Tracer appeared first (in just over three days) and most intensively following rainfall in the Osapska reka spring, where the bulk of the tracer that discharged through this spring appeared with 11 days of injection. The simultaneous appearance of tracer in the Rižana spring was in significantly lower concentrations, although it appeared more strongly following subsequent more plentiful rainfall in two larger flood pulses. The transfer of tracer through the Rižana spring was a more lengthy process. The appearance of Uranine in the Pri Pralnici spring was strongest following the first rainfall, after which its concentration fell with some fluctuation. After two and a half months, over 76 % of the injected tracer had discharged through the springs, to begin with mostly through the Osapska reka spring and in the second half of the observation period through the Rižana spring (Fig. 6).

Fig. 5: Very high water level in the Osapska reka spring, where we monitored the appearance of the injected Uranine.

Less than 10 % of the injected tracer from borehole T1-8 appeared in the springs in Boljunec, for which reason we conclude that for the most part waters from this area drained in a north-westerly direction towards the Timava spring. We did not monitor the presence of tracer in the Timava spring since because of the strong dilution along the groundwater flow (injected quantity 305 g) we would not have been able to detect it.

Conclusion

The results of older tracer tests were supplemented by the findings of the more detailed tests along the route of the future railway, allowing us to conclude that the impact of the railway in the area between Divača and slightly to the north of borehole T1-8 could be reflected above all in the springs of the Timava and the Brojnica at Nabrežina/Aurisina. South of this section of the railway, there is a possible impact on the Rižana and Osapska reka springs and on the Pri Pralnici and Jama springs in Boljunec/Bagnoli della Rosandra. From the Beka-Ocizla sinking stream area, we expect the strongest impact in the springs in Boljunec, since a good direct connection exists and the transfer of substances also occurs in periods without rainfall and increase of discharges. Further south, we expect an impact on the Osapska reka and the Rižana springs. At high water levels, first an impact on the Osapska reka spring and then, with a slight delay, an impact on the Rižana spring, which, however, lasts longer because the dynamics of the transfer of substances through the Rižana spring are strongly affected by rainfall. It will therefore be necessary to carry out monitoring at all these springs while work is under way and once the line is open to traffic, with a particular emphasis on the Rižana spring, which is used to supply the population with drinking water.

On the basis of the results of tracer tests in the lower part of the Divača–Črni Kal section, which has shown a good water connection with the Rižana spring and therefore its potential vulnerability, the planners have proposed a solution whereby this part of the tunnel is waterproofed, in this way preventing the contact of potentially contaminated waters with the karst aquifer.

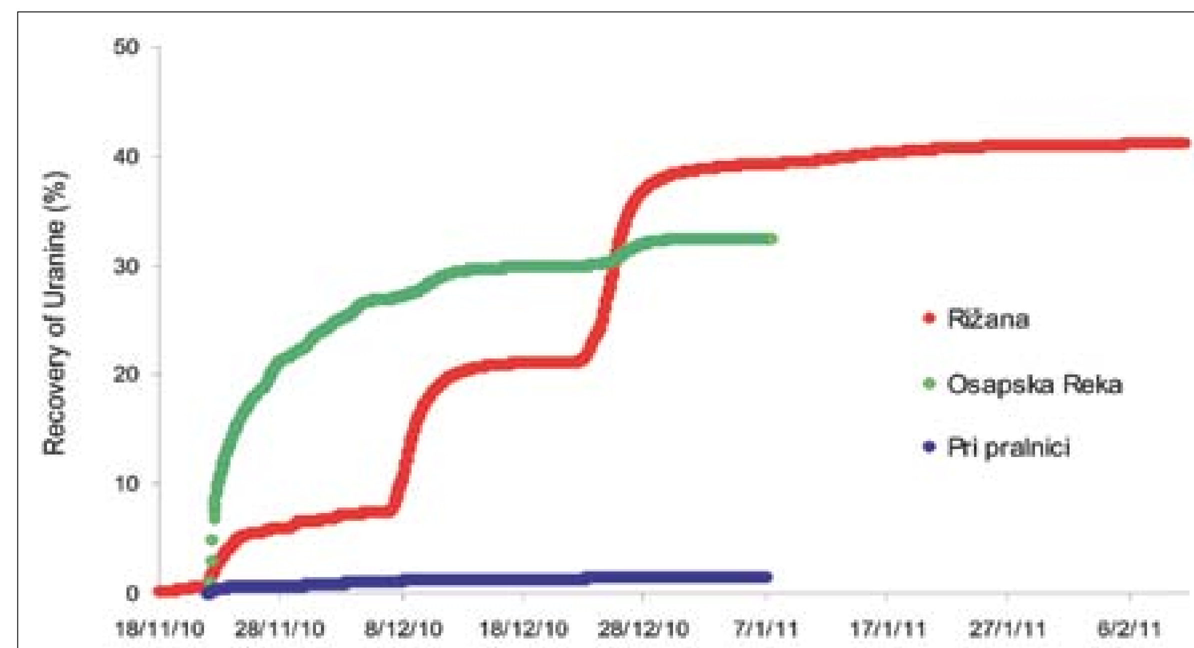

Fig. 6: Recovered tracer in the test with the injection in borehole T2-12.

References

Civita M., Cucchi F., Garavoglia S., Maranzana F., Vigna B., 1995. The Timavo hydrogeologic system: an important reservoir of supplementary water resources to be reclaimed and protected. Acta Carsologica, 24 (International Symposium "Man on Karst", Postojna 23–25 September 1993). SAZU, Ljubljana: 169–186.

Kogovšek J., 2010. Characteristics of percolation through the karst vadose zone. ZRC Publishing, Ljubljana: pp. 168.

Kogovšek J., Petrič M., 2004. Advantages of longer-term tracing – three case studies from Slovenia. Environmental Geology, 47: 76–83.

Kogovšek J., Petrič M., 2010. Rezultati sledilnega poskusa na območju nove dvotirne proge Trst-Divača v spodnjem delu odseka Črni Kal-Divača [Results of water tracing in lower part of the Črni Kal–Divača section of the new double-track Trieste–Divača railway]. Detailed expert report. Archives of IZRK ZRC SAZU: pp. 17.

Kogovšek J., Petrič M., Turk, J., 2011. Rezultati sledilnega poskusa v vrtina T1-8 in T2-12 [Results of water tracing in boreholes T1-8 and T2-12]. Detailed expert report. Archives of IZRK ZRC SAZU: pp. 17.

Krivic P., 1980. Poročilo o hidrogeoloških raziskavah z osnutkom odloka o varstvenih pasovih vodnih virov pri Brestovici na Krasu [Report on hydrogeological investigations and draft decree on water protection zones at Brestovica on the Karst plateau]. Detailed expert report. Geološki zavod Ljubljana, Ljubljana.

Krivic P., Bricelj M., Trišič N., Zupan M., 1987. Sledenje podzemnih vod v zaledju izvira Rižane [Water tracing in the catchment area of the Rižana spring]. Acta Carsologica, 16: 83–104.

Krivic P., Bricelj M., Zupan M., 1989. Podzemne vodne zveze na področju Čičarije in osrednjega dela Istre [Underground water connections in the area of Čičarija and central Istria]. Acta Carsologica, 18: 265–295.

Mosetti F., 1965. Nuova interpretazione di un esperimento di marcatura radioattiva del Timavo. Bolletino di geofisica teorica ed applicata, 7/27: 218–243.

Timeus G., 1928. Nei misteri del mondo sotterraneo. Alpi Giulie, 29/1: 1–40.

LEGAL PROTECTION OF KARST WATER SOURCES

Nataša Ravbar [1]

Karst occurs on carbonate rock (limestone, dolomite) which is very permeable due to its high porosity. Fissuring and crushing enable immediate infiltration of rainwater into the underground. In a dispersed manner, precipitation water percolates down the fissures and channels in the bedrock. Consolidated streams that gather water on non-karst surfaces also sink into the karst subsurface. Underground waters then flow together to form larger streams that continue toward springs through karst channels (Figs. 1 and 2). Peculiar landforms and underground caves are characteristic of these landscapes, and also that rivers and streams usually do not flow on the surface.

Due to the high porosity of the rock karst can store large volumes of groundwater. For thousands of years, karst springs have played an extremely important role in water supply, irrigation, and power generation due to the exceptional quality and quantity of the water (springs can achieve discharge values of several tens of m^3/s). Karst aquifers currently supply about 25 % of world population with water. They are additionally important because of the exceptional diversity and unique biodiversity of underground water ecosystems (Gibert et al. 1994, Bakalowicz 2005, Ford and Williams 2007).

Karst is characterized by usually absent or very thin protective cover of soil and sediment, which accelerates infiltration. Compared to the groundwater in granular aquifers (e.g., in gravel plains), the velocity of water flow through karst conduits is very high, reaching up to several hundred meters per hour. Due to the complexity of connections and extreme changes in different hydrological conditions, the courses of underground water in karst are practically unknown. Relative to different groundwater levels, the water from a single area can flow in a variety of directions and manners. There are frequently connections and intersections of water paths over large distances (up to many tens of kilometers). The flow is often turbulent, in limited conditions of aeration and reduced biological activity (White 2002, Ford and Williams 2007, Worthington 2009).

As a result of such specific characteristics of infiltration and water percolation, karst aquifers are extremely vulnerable to contamination in comparison with other aquifers. The absence of a thicker layer of soil or sediment and vegetation cover prevents pollutants from degrading chemically, biologically, or physically in the course of percolation. The more important karst springs usually have a large catchment area, and the high groundwater flow velocities cannot guarantee the sufficient decomposition of contaminants. Furthermore, a greater distance from the water source does not necessarily mean less danger from contamination. A turbulent flow often means the mobilization of insoluble contaminants and prevents their retention. In anaerobic conditions the rapid flow reduces the possibility of biodegradation.

As a result, the self-cleansing capacities of groundwater in karst are very low and limited to a considerable degree. Karst water sources must therefore be managed appropriately and carefully (Ravbar 2007).

[1] Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, natasa.ravbar@zrc-sazu.si

Water-related policies in selected countries

Many national regulations concerning the protection of underground waters are based on different criteria for demarcating water protection zones (Van Waegeningh 1985, Cività 2008, Goldscheider 2010). In this respect, the European Union is a good example since it prescribes common guidelines for member countries in various fields of legislation. In the field of water-related policies, the Water Framework Directive (WFD, 2000/60/EC) and the Ground Water Directive (GWD 2006/118/EC) stipulate the protection of water and the use of a regional approach for research, implementing measures, and monitoring conditions in the field of water management.
Despite this, different provisions for the protection of drinking water sources apply in different European countries. The regulations differ mainly regarding the travel times of groundwater to the water sources. In Switzerland, for example, the inner protection zones of granular aquifers are demarcated by a travel time of ten days. In Germany and France, the travel time is fifty days, in Austria sixty days, and in Ireland a hundred days.
In some countries legislation provides special guidelines to protect karst water sources. For example, in Switzerland and in Ireland the concept of groundwater vulnerability mapping has already been successfully used for protection zoning (for more details see chapter "Groundwater vulnerability assessment" in this book).
In Slovenia, the demarcation of water protection zones with corresponding regimes is prescribed by the Waters Act (Official Gazette of the RS, No. 67/02) and the Rules on the Criteria for the Designation of a Water Protection Zone (Official Gazette of the RS, No. 64/04), which both comply with European guidelines. The inner zone is determined on the basis of the retention time and dilution of contaminants in the underground from the point of input to the capture point with a 50-day isochrone for the protection of groundwater in granular or fissured aquifers. For the protection of water sources in karst aquifers protection zones are delineated by a 12-hour isochrone.

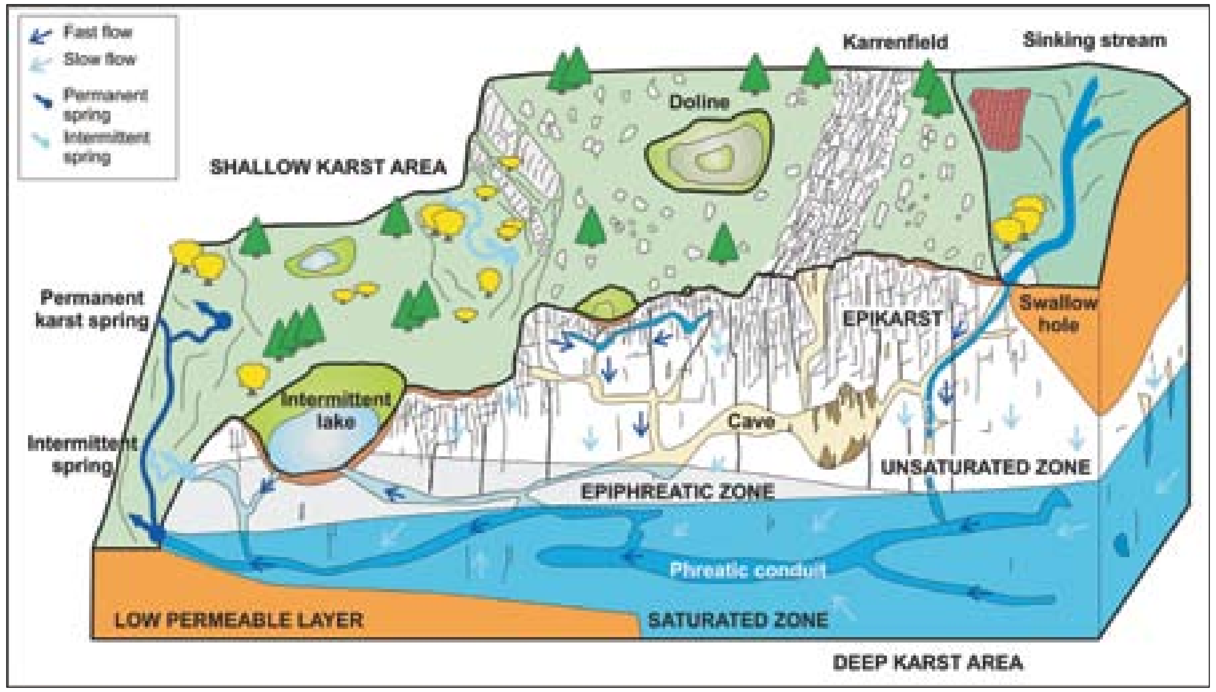

Fig. 1: Conceptual model of karst aquifer and groundwater flow (from Ravbar 2007).

Many existing policies have drawbacks and are not completely suitable for protecting water sources in karst. Furthermore, each country establishes its own environmental policies so there are many national regulations regarding the protection of underground water that are based on different criteria for determining water protection zones. This individual approach to legislation in the field of protecting water sources whose catchment areas stretch across state borders is problematic for various reasons.

Transboundary karst aquifers

Because karst aquifers usually cover vast areas (up to several hundred km^2) and are distributed around the world, they often stretch across political boundaries. In Europe alone, where carbonate rock comprises 35 % of the earth's surface (Zwahlen 2004), karst is found in almost every country and karst water resources are strategic natural resources of a number of countries.
Due to the diverse approaches used to determine water protection zones, the methods for protecting individual water resources are not directly comparable. In different countries the resulting protection measures relative to specific encroachments can therefore be dissimilar and present different requirements. This can cause problems in planning encroachments such as road and rail routes that stretch across state borders.

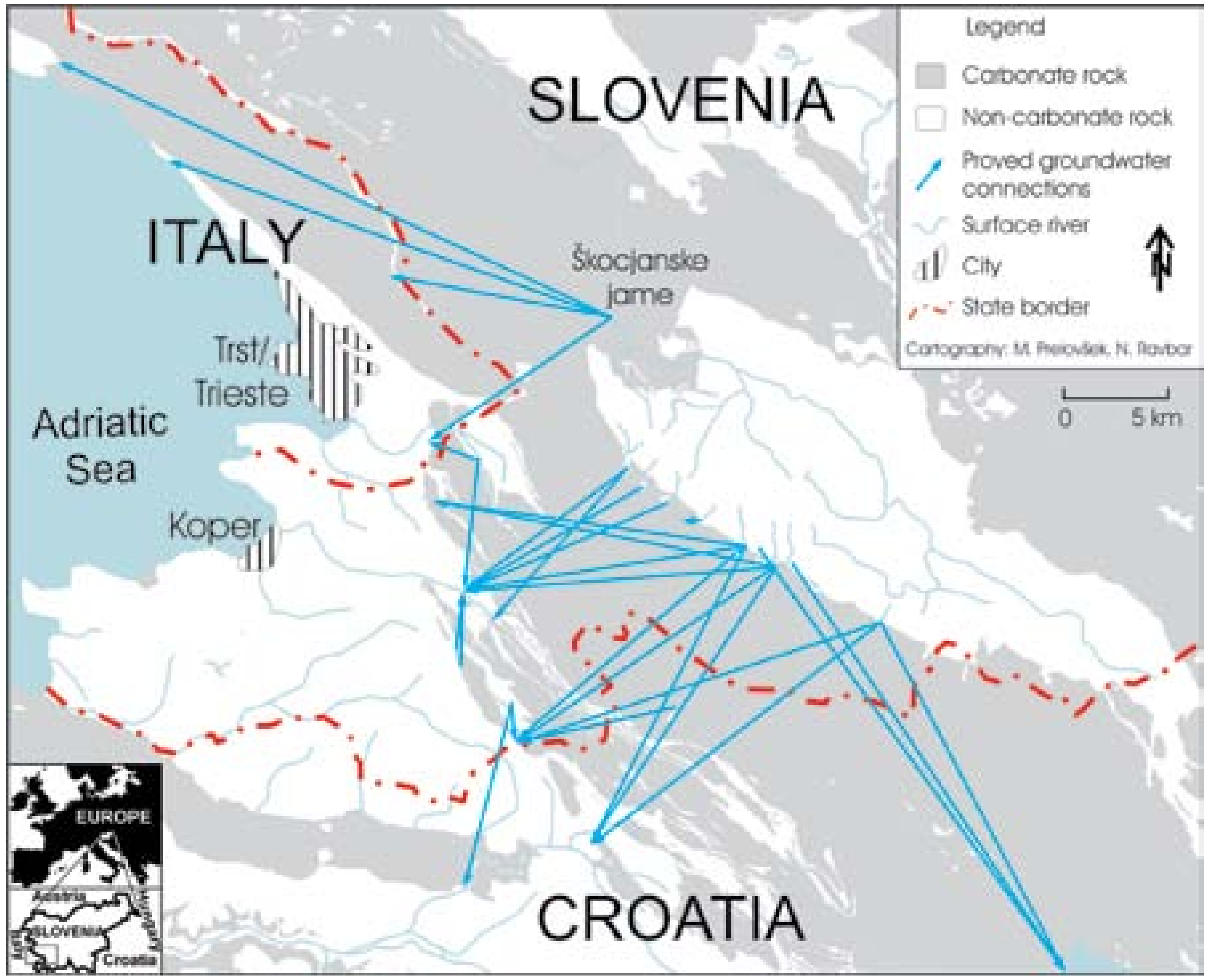

Fig. 2: Hydrogeological map of SW Slovenia showing transboundary karst aquifers and proved groundwater flow connections.

Due to the above described special characteristics of groundwater flow in karst different types of land use, spatial planning, and environmental protection legislation on opposite sides of the border can present an obstacle to the sustainable management of water resources. Their comprehensive protection is therefore of priority importance. However, the implementation of this task usually ends at interstate borders, which is frequently reflected in the poor quality of many water sources.

Because the protection of water resources is always only under the jurisdiction of the country where the source is located, the result is often the inadequate protection and management of the source and its catchment area.

In Slovenia, extensive karst areas of the Alps and the Dinaric mountains extend into neighbouring countries and feed important springs on both sides of the border (Fig. 2). Improper protection of the water resources is reflected in the inadequate protection and consequently poor quality of the springs. One example of such poor practice is catchment area of the Rižana river spring that supplies Slovenia's coastal region with drinking water (Fig. 3). Its protection is insufficient because in the part of the catchment area that lies in the territory of neighbouring Croatia, the application of a water protection zone and regime has not been adopted (Kovačič 2003). A similar case of poor protection can be observed in the larger part of the catchment area of the Timava River spring near Monfalcone, Italy, which lies in Slovenia.

In the area of the Dinaric karst that stretches across the countries of former Yugoslavia and Albania there are several examples of transboundary aquifers (Kresic 2009, Stevanović 2010). The Ombla, one of the largest karst springs, is located in Croatia and is exploited for supplying the city of Dubrovnik with drinking water. The greater part of its 600 km^2 catchment area stretches across neighbouring Bosnia and Herzegovina. The Trebišnjica sinking river flows across Popovo polje in Bosnia and Herzegovina and feeds the Ombla spring (Figs. 4 and 5). When the Trebišnjica was dammed for a hydroelectric power plant, the mean discharge values of the Ombla dropped from 34 to 24 m^3/s. Transboundary aquifers feed the Jadro spring as well, which supplies the city of Split with drinking water, the Rječina spring that supplies the city of Rijeka, both in Croatia, etc.

Fig. 3: The karst spring of the Rižana river that has been utilized since the early 19th century and today supplies between 100,000 and 120,000 people (very high water level; photo: M. Petrič).

Additional recommendations on improvement of groundwater protection

Unlike Swiss or Irish legislation many national acts on groundwater protection do not sufficiently consider the special characteristics of water flow in karst. Such protection approaches are therefore not appropriate and an alternative must be utilised. More details on this topic are described in chapter "Groundwater vulnerability assessment".

Furthermore, the issues of transboundary aquifers were already highlighted at the international karstological symposium hosted in Postojna by the Karst Research Institute in 2007. So far, however, no country or scientific institution has addressed the problems described above or proposed a comprehensive solution for managing transboundary karst water resources.

Management strategies must also consider the available quantities for exploitation that may cause unacceptable environmental impacts, such as sinkhole development and collapses, and salinization (Drew and Hötzl 1999). However, the economical and ecological solution for the assurance of adequate quality and quantity of drinking water is above all based on economical consumption. This issue has also not been sufficiently addressed in the many existing national water protection strategies.

Fig. 4: The Popovo polje in Bosnia and Herzegovina across which flows the Europe's largest sinking river, the Trebišnjica river (photo: N. Ravbar).

Fig. 5: The Ombla spring is located on the Adriatic coast near the town of Dubrovnik. It has been utilized for the water supply since 1897 (photo: A. Mihevc).

References

Bakalowicz M., 2005. Karst groundwater: a challenge for new resources. Hydrogeology Journal, 13/1: 148–160.

Cività M., 2008. An improved method for delineating source protection zones for karst springs based on analysis of recession curve data. Hydrogeology Journal, 16: 855–869.

Drew D., Hötzl H. (eds.), 1999. Karst Hydrology and Human Activities. Balkema, Rotterdam.

Ford D.C., Williams P.W., 2007. Karst hydrogeology and geomorphology. Wiley, Chichester.

Gibert J., Danielopol D.L., Stanford J.A., 1994. Groundwater Ecology. Academic Press, San Diego.

Goldscheider N., 2010. Delineation of spring protection zones. In: Kresic, N. & Z. Stevanovic (eds.). Groundwater Hydrology of Springs. Engineering, Theory, Management and Sustainability. Butterworth-Heinemann, Burlington: 305–338.

Groundwater Directive (GWD) 2006/118/EC. URL: http://ec.europa.eu/environment/water/water-framework/groundwater.html.

Kovačič G., 2003. The protection of karst aquifers: the example of the Bistrica karst spring (SW Slovenia). Acta Carsologica, 32/2: 219–234.

Kresic N., 2009. Groundwater resources: Sustainability, management and restoration. Macgraw-Hill, New York.

Ravbar N., 2007. The protection of karst waters, a comprehensive Slovene approach to vulnerability and contamination risk mapping. Ljubljana.

Rules on the Criteria for the Designation of a Water Protection Zone. Official Gazette of the RS, No. 64/04. Ljubljana.

Stevanović Z., 2010. Major springs of Southeastern Europe and their utilization. In: Kresic N., Stevanovic Z. (eds.). Groundwater Hydrology of Springs. Engineering, Theory, Management and Sustainability. Butterworth-Heinemann, Burlington: 389–410.

Van Waegeningh H.G., 1985. Overview of the protection of groundwater quality. In: Matthess G., Foster S.S.D., Skinner A.C.H. (eds.). Theoretical background, hydrogeology and practice of groundwater protection zones. IAH Contributions to Hydrogeology 6, Hannover.

Water Framework Directive (WFD) 2000/60/EC. URL: http://ec.europa.eu/environment/water/water-framework/index_en.html

Waters Act. Official Gazette of the RS, No. 67/02. Ljubljana.

White W.B., 2002. Karst hydrology: recent developments and open questions. Engineering Geology, 65/2: 85–105.

Worthington S.R.H., 2009. Diagnostic hydrogeologic characteristics of a karst aquifer (Kentucky, USA). Hydrogeology Journal, 17/7: 1665–1678.

Zwahlen F. (ed.), 2004. COST Action 620, Vulnerability and Risk Mapping for the Protection of Carbonate (Karstic) Aquifers, Final report COST Action 620. Brüssel, Luxemburg.

GROUNDWATER VULNERABILITY ASSESSMENT: THE EXAMPLE FROM SLOVENIA

Nataša Ravbar [1]

The criteria for protecting water sources are usually based primarily on the distance from the water source or the velocity of the groundwater flow (see also chapter "Legal protection of karst water sources" in this book). In granular aquifers, the velocity of groundwater flow is very low, less than ten meters per day. The diameters of water protection zones therefore measure only a few hundred meters. In contrast, the retention times of water in karst aquifers are short (a few hours to a few days), which means a limited capacity for contaminant degradation and the microorganisms to die off. At the same time, greater distance from the water source does not necessarily mean greater safety from contamination. Consequently, consideration of velocity and distance alone is not sufficient criteria for the mitigation of karst water sources contamination because protection zones would therefore have to cover several tens to several hundreds of km^2 or even entire catchment areas (Goldscheider 2010).

Often, the protection requirements do not consider the special characteristics of water flow in karst (Fig. 1) such as the heterogeneity and complexity of recharging the aquifers, the changes in the velocity and direction of water flow under diverse hydrological conditions, etc. (Doerfliger et al. 1999, Goldscheider et al. 2000, Ravbar 2007 and others). Furthermore, insufficient attention has been devoted to the criteria for demarcating water protection zones of karst water sources. In most cases, the delineation has been based only on the available geological data; studies have rarely been conducted to deal specifically with the way karst aquifers are recharged, and few tracer tests have been carried out in the catchment areas of water sources (Ravbar and Kovačič 2006).

The ineffective and inadequate protection of karst water sources therefore often originates in the lack of knowledge about the specific hydrogeographical and other characteristics of heterogeneity of particular aquifers (Ford and Williams 2007). In many cases, determining the extent of individual water protection zones fails also to consider the extreme vulnerability of karst to contamination. The role of protective layers and the development of the karst network are usually not considered when determining source protection zones. Furthermore, it is crucial to take into account the existence of allogenic recharge and infiltration into swallow holes. These factors significantly influence the degree of vulnerability (Zwahlen 2004, Goldscheider 2005).

In karst, different hydrological conditions result in changed velocities and directions of water flow. The extent of catchment areas is subject to change as well, which plays also an important role in the designation of water protection zones, but is only rarely considered (Bonacci 1999, Bakalowicz 2005, Göppert and Goldscheider 2008, Gabrovšek et al. 2010, Ravbar et al. 2011).

[1] *Karst Research Institute, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Titov trg 2, SI-6230 Postojna, Slovenia, natasa.ravbar@zrc-sazu.si*

The concept of groundwater vulnerability

To effectively protect the most sensitive areas of karst aquifers, some European countries use the concept of mapping or assess the degree of vulnerability in determining water protection zones. Assessing contamination risk is increasingly employed in land use planning (Vrba and Zaporozec 1994). To this end, guidelines for such assessments (Daly et al. 2002, Zwahlen 2004) were elaborated in the framework of the international COST Action 620 project in which several European countries took an active part.

On these foundations, numerous methods for assessing and mapping the vulnerability of karst groundwaters were developed that took into account differences between individual karst aquifer systems, accessibility of data, and economic capabilities. These methods were used and tested at various test sites around the world on a number of occasions. Some of the most frequently used are the EPIK Method (Doerfliger and Zwahlen 1998), the PI Method (Goldscheider et al. 2000) and the COP Method (Vías et al. 2006). Reviews of different methods have been done by several authors, including Zwahlen (2004), Ravbar (2007), Goldscheider (2010), and others.

In Slovenia, for this purpose, the so-called "Slovene approach" was developed and tested. This method takes the special features of Slovenia's karst into consideration and is adapted to Slovene legislation (Ravbar and Goldscheider 2007).

Slovene approach

The Slovene approach (Ravbar and Goldscheider 2007) follows the European guidelines for protection of groundwater in carbonate aquifers most comprehensively (Figs. 2-4). The method includes the assessment of vulnerability and

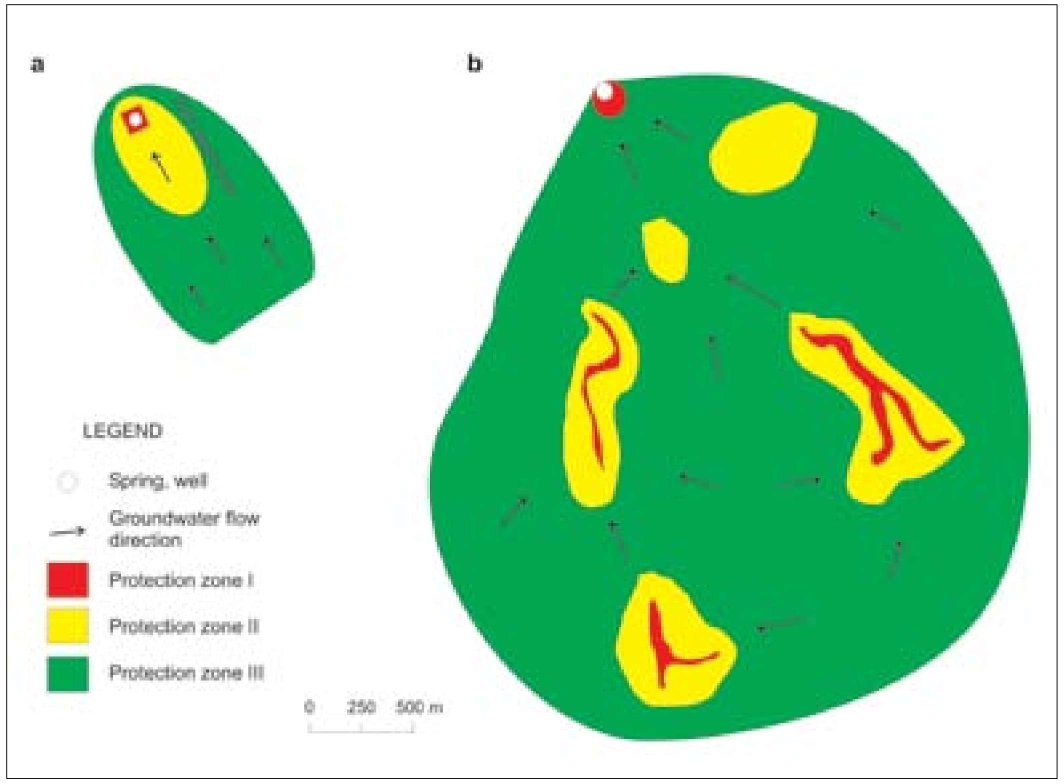

Fig. 1: Arrangement of source protection zones a) based on transit time or distance criteria, typically in granular aquifers and b) considering special characteristics of water flow in karst aquifers.

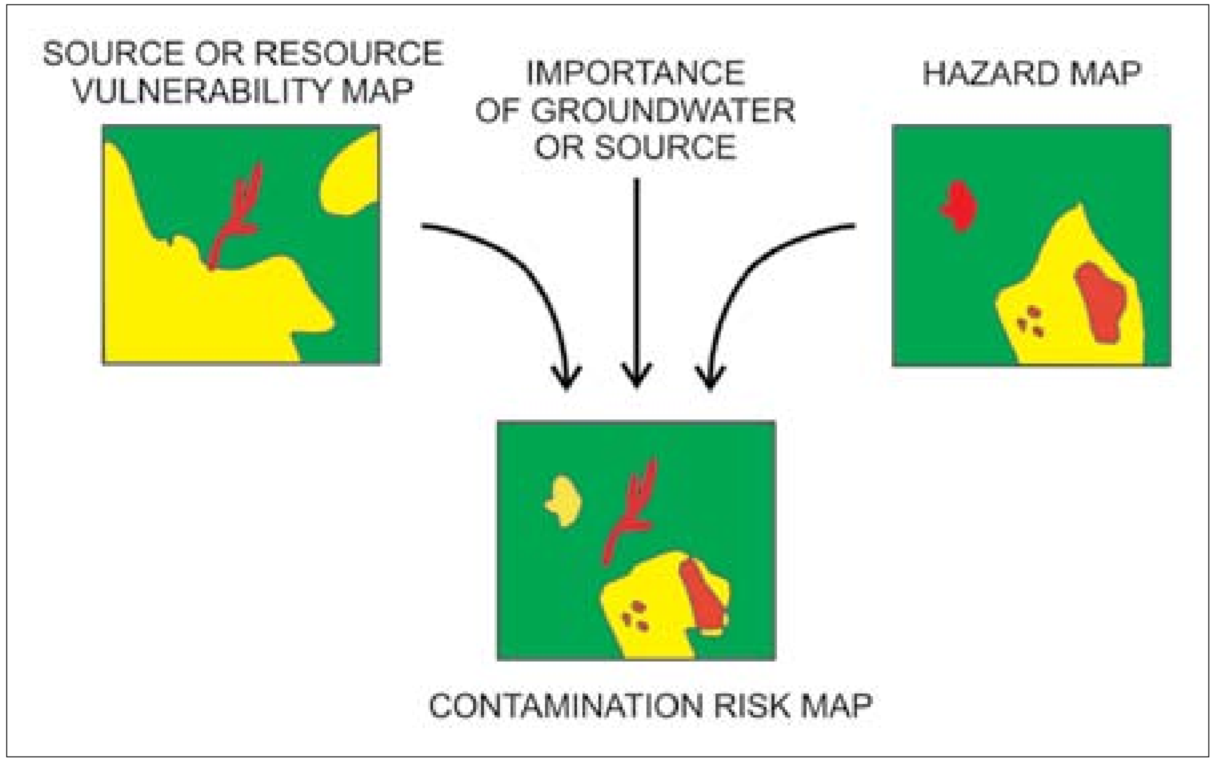

Fig. 2: *Groundwater vulnerability and risk to contamination assessment scheme.*

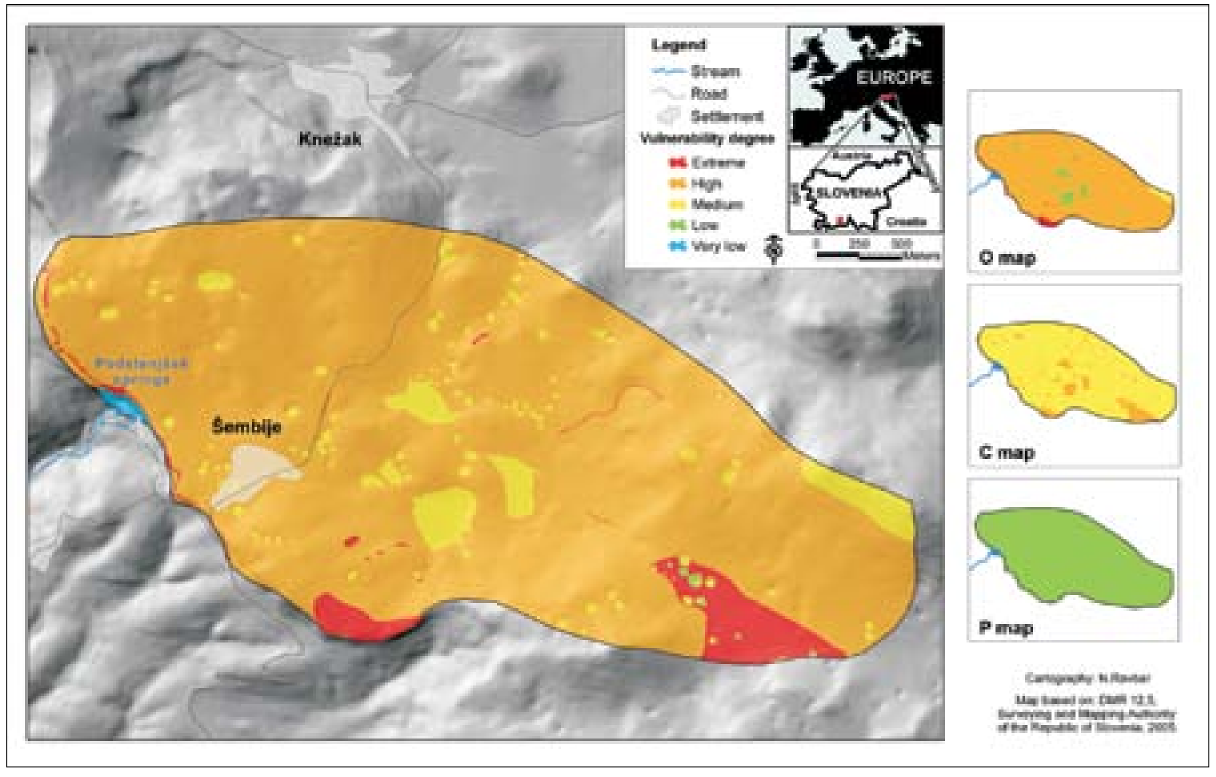

Fig. 3: *Example of groundwater resource (aiming to protect the whole groundwater body) vulnerability map according to the Slovene Approach (Ravbar 2007).*

degree of hazard. These two assessments form the basis for calculating the contamination risk to groundwater or water sources. The final result of the natural vulnerability assessment can be transformed into water protection zones. The identification of the most vulnerable areas and areas with the highest risk of contamination allows the optimization of water protection zones, appropriate and prudent management of water sources, and a foundation for planning the monitoring of water quality.
Unlike other methods, in assessing the vulnerability of groundwater the Slovene approach considers the water flow under different hydrological conditions and offers a possibility of linking the protection of surface waters and groundwater. The Slovene approach is the only one to offer the possibility of assessing the importance of groundwater or water sources on a basis of which it is possible to predict potential damage and elaborate a priority list of rehabilitation measures.

The Slovene approach ranks among extremely sophisticated methods because its application does require a large amount of data, time, financial, and technical sources. Moreover, validity tests on the acquired results showed that compared with simpler methods the use of such a method is quite reasonable because it provides more reliable and less subjective results (Ravbar and Goldscheider 2009).

Conclusions

However, many studies have demonstrated that the application of different methods for vulnerability mapping at any given time at the same testing site produced different or even contradictory results despite the use of the same data (e.g., Gogu et al. 2003, Vías et al. 2005, Neukum and Hötzl 2007, Ravbar and Goldscheider 2009, and others). Unless the results are verified it is not certain which

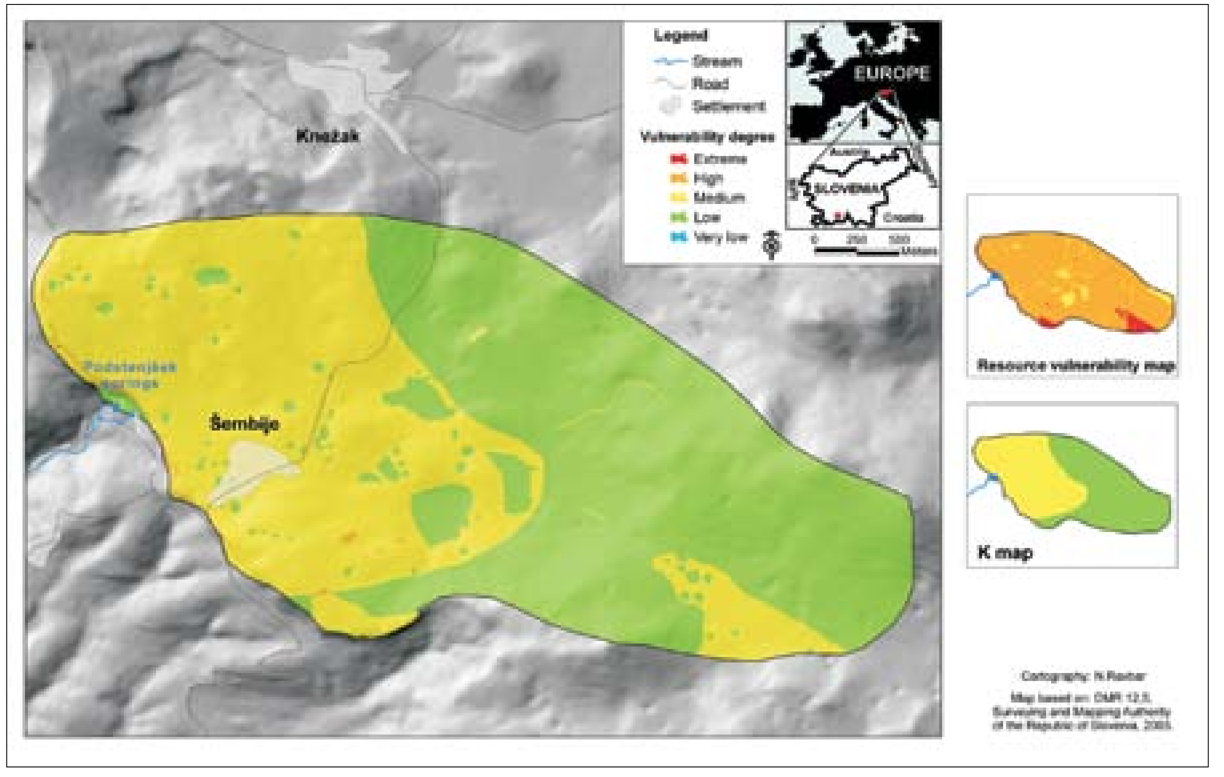

Fig. 4: *Example of source (aiming to protect a particular spring or well) vulnerability map according to the Slovene Approach (Ravbar 2007).*

method produces the most reliable results.

Because water protection provisions require limitations to urban development and activities, the assessment of vulnerability must be objective and guarantee credibility. This calls for the independent validation of vulnerability maps, which so far has not become standard practice. In addition, a uniform validation procedure has to be developed in future (Goldscheider et al. 2001, Andreo et al. 2006).

References

Andreo B., Goldscheider N., Vadillo I., Vías J.M., Neukum Ch., Sinreich M., Jiménez P., Brechenmacher J., Carrasco F., Hötzl H., Perles J.M., Zwahlen F., 2006. Karst groundwater protection: First application of a Pan-European Approach to vulnerability, hazard and risk mapping in the Sierra de Líbar (Southern Spain). Science of the Total Environment, 357: 54–73.

Bakalowicz M., 2005. Karst groundwater: a challenge for new resources. Hydrogeology Journal, 13/1: 148–160.

Bonacci O., 1999. Water circulation in karst and determination of catchment areas: example of the River Zrmanja. Hydrological Sciences Journal, 44/3: 373–386.

Daly D., Dassargues A., Drew D., Dunne S., Goldscheider N., Neale N., Popescu C., Zwahlen F., 2002. Main concepts of the European Approach for (karst) groundwater vulnerability assessment and mapping. Hydrogeology Journal, 10/2: 340–345.

Doerfliger N., Jeannin P.Y., Zwahlen F., 1999. Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). Environmental Geology, 39/2: 165–176.

Doerfliger N., Zwahlen F., 1998. Practical Guide. Groundwater Vulnerability Mapping in Karstic Regions (EPIK). Swiss Agency for the Environment, Forests and Landscape, Bern.

Ford D.C., Williams P.W., 2007. Karst hydrogeology and geomorphology. Wiley, Chichester.

Gabrovšek F., Kogovšek J., Kovačič G., Petrič M., Ravbar N., Turk J., 2010. Recent results of tracer tests in the catchment of the Unica River (SW Slovenia). Acta Carsologica, 39/1: 27–38.

Gogu R.C., Hallet V., Dassargues A., 2003. Comparison of aquifer vulnerability assessment techniques. Application to the Neblon river basin (Belgium). Environmental Geology, 44/8: 881–892.

Goldscheider N., 2005. Karst groundwater vulnerability mapping – application of a new method in the Swabian Alb, Germany. Hydrogeology Journal, 13: 555–564.

Goldscheider N., 2010. Delineation of spring protection zones. In: Kresic N., Stevanovic Z. (eds.). Groundwater Hydrology of Springs. Engineering, Theory, Management and Sustainability. Butterworth-Heinemann, Burlington: 305–338.

Goldscheider N., Hötzl H., Fries W., Jordan P., 2001. Validation of a vulnerability map (EPIK) with tracer tests. In: Mudry J., Zwahlen F. (eds.). 7th Conference on Limestone Hydrology and Fissured Media, Besançon, France, 20th-22nd September 2001. University de Franche-Comté, Besançon: 167–170.

Goldscheider N., Klute M., Sturm S., Hötzl H., 2000. The PI method – a GIS-based approach to mapping groundwater vulnerability with special consideration of karst aquifers. Zeitschrift für angewandte Geologie, 46/3: 157–166.

Göppert N., Goldscheider N, 2008. Solute and colloid transport in karst conduits under low- and high-flow conditions. Ground Water, 46/1: 61–68.

Neukum C., Hötzl H., 2007. Standardization of vulnerability maps. Environmental Geology, 51: 689–694.

Ravbar N., 2007. The protection of karst waters, a comprehensive Slovene approach to vulnerability and contamination risk mapping. Ljubljana.

Ravbar N., Engelhardt I., Goldscheider N., accepted. Anomalous behaviour of specific electrical conductivity at a karst spring induced by variable catchment boundaries: the case of the Podstenjšek spring, Slovenia. Hydrological Processes, DOI: 10.1002/hyp.7966

Ravbar N., Goldscheider N., 2007. Proposed methodology of vulnerability and contamination risk mapping for the protection of karst aquifers in Slovenia. Acta Carsologica, 36/3: 461–475.

Ravbar N., Goldschieder N., 2009. Comparative application of four methods of groundwater vulnerability mapping in a Slovene karst catchment. Hydrogeoly Journal, 17: 725–733.

Ravbar N., Kovačič G., 2006. Karst water management in Slovenia in the frame of vulnerability mapping. Acta Carsologica, 35/2: 73–82.

Vías J.M., Andreo B., Perles J.M., Carrasco F., 2005. A comparative study of four schemes for groundwater vulnerability mapping in a diffuse flow carbonate aquifer under Mediterranean climatic conditions. Environmental Geology, 47/4: 586–595.

Vías J.M., Andreo B., Perles J.M., Carrasco F., Vadillo I., 2006. Proposed method for groundwater vulnerability mapping in carbonate (karstic) aquifers: the COP method. Application in two pilot sites in Southern Spain. Hydrogeology Journal, 14/6: 912–925.

Vrba J., Zaporozec A. (eds.), 1994. Guidebook on mapping groundwater vulnerability. International association of hydrogeologists, Hannover.

Zwahlen, F. (ed.), 2004. COST Action 620, Vulnerability and Risk Mapping for the Protection of Carbonate (Karstic) Aquifers, Final report COST Action 620. Brüssel, Luxemburg.

IMPORTANCE OF BIOSPELEOLOGICAL RESEARCH FOR PROTECTION OF CAVE FAUNA AND THEIR HABITATS – EXAMPLE BASED ON THE PROJECT KARST UNDERGROUND PROTECTION ON THE ISTRIAN PENINSULA

Roman Ozimec [1], Slavko Polak [2], Jana Bedek [1], Valerija Zakšek [3]

The Istrian peninsula is located in southern Europe. It is located in the Adriatic Sea, the most northern part of Mediterranean basin. Geopolitically, Istria belongs to Croatia, Slovenia and Italy, and has a total surface area of 3,476 km^2. Three main geomorphological units can be identified in Istria: the inner, deep Dinaric mountain limestone unit called *white Istria*, the external lower karst plateau unit known as *red Istria* and, between them, a hydrological barrier, generally water proof flysch zone, known as *grey Istria* (Krebs 1907). Nearly 70 % of the Istrian peninsula is situated on limestone rocks, and is typically karst landscape with underground water flow and a variety of karst phenomena.

Recently, over 2,000 caves have been identified, mostly in karst parts of the Istrian peninsula, but with very interesting caves developed at the points of contact with flysch rocks. The caves in Istria are inhabited by several endemic, rare, endangered and protected animals: hydrobiid snail Istriana mirnae; amphipod and isopod crustaceans *Niphargus echion*, *Thaumatoniscellus speluncae* and *Monolistra jalzici*; millipede *Eupolybothrus obrovensis* and *Verhoeffodesmus fragilipes*; false scorpion *Troglochthonius doratodactylus*; several cave beetle species as *Leptodirus hochenwartii*, *Croatodirus bozicevici*, *Prospelaeobates vrezeci*, *Pauperobythus globuliventris*; and the European cave salamander *Proteus anguinus* ssp. nov. Even biospeleological research in Istria began in the second half of the 19th century with the work of Croatian, German, Italian and Slovenian biologists such as Gustav Joseph, Ivan Andrej Perko, Adolf Stošić, Josef Stussiner and Antonio Valle (Joseph 1882, Perko 1906, Pretner 1973), and continued by many other biologists during the 20th century, cave fauna has still not been systematically explored and evaluated. Unfortunately, due to many reasons, caves, especially groundwater cave habitats, together with cave animal populations are endangered.

Active protection measurements are required and a defined and controlled use that respects all the protection measures. Within the scope of the Karst Underground Protection (KUP) project, which is financed by the OP IPA Slovenia-Croatia 2007–2013 programme, led by the Istrian Region with the Natura Histrica as the Croatian partner, and Karst Research Institute ZRC SAZU as the Slovenian partner, the adequate protection of Istria karst with biospeleological research and accompanied activities has been established. This project is a logical continuation of the Underground Istria project (www.underground-istria.org), which was financed by the EU, implemented by the Istrian Region, and finalised in October 2008. The project was carried out exclusively within the Region of Istria, but during the project's implementation, the possibility of cooperation with institutions dealing with karst and caving at a national level in Croatia and Slovenia was demonstrated. The aim of KUP, as a continuation project, is to expand on the accomplishments of the Underground Istria project and establish a network of institutions in the field of environmental protection and karst research at national and regional levels, in close collaboration with NGOs. For very first time, a biospeleological component has been included in project.

[1] *Croatian Biospeleological Society (CBSS), Demetrova 1, HR-10 000 Zagreb, Croatia*
[2] *Notranjska museum Postojna, Ljubljanska 10, SI-6230 Postojna, Slovenia*
[3] *University of Ljubljana, Biotechnical Faculty, Department of Biology, Večna pot 111, 1000 Ljubljana, Slovenia*

Overall objective and the purposes of the project

The overall objectives of the two-year KUP project, which began in 2009, are as follows:

1. To protect and improve karst phenomena, especially caves and cave habitats in the border areas of Croatia and Slovenia in the Istrian peninsula.
2. To implement biospeleological research into the conservation planning.
3. To strengthen cooperation and the joint actions undertaken by regional and national institutions with regard to environmental protection in Croatia and Slovenia.
4. To carry out an inventory of and to plan the management of caves located in the project area in order to ensure their continued sustainability.
5. To increase awareness of the promotion of the natural landscape and the geographical particularities of the karst areas of the Istrian peninsula through workshops, public presentations for local people and Karstological School "Classical Karst".

In addition, the implementation of project will provide cross-border cooperation of institutions responsible for karst research and monitoring in Slovenia and Croatia, as well as his improvement. The highest value of the project is the establishment of a joint supervision of the karst area, which extends to the territory of both countries, but also establishing a biospeleological database for the Istrian peninsula region.

The project predicts that in an area with rich subterranean fauna, such as Istria, we can expect high levels of subterranean biodiversity, important contribution to knowledge of cave fauna of the area, same as discovery of new taxa for science. Recently, molecular studies on cave fauna showed a high level of cryptic diversity, especially in the Dinaric Karst (and the Istrian peninsula), therefore further molecular studies on some taxa are necessary. Moreover, one of the important purposes of the project is to recognise and register the diversity of cave animals in Istria. The important purpose is also to educate the local population, and especially local speleologists, on importance of subterranean fauna and its protection together with their living environment. Some cave taxa can be useful for the future monitoring of cave habitats and general cave animals populations.

The purposes of biospeleological research activity in the framework of the KUP are as follows:

1. To classify and evaluate the number of species with estimation of population size.
2. To identify and register potentially new cave species.
3. To define endangerment of cave (troglobitic) animals and cave habitats.
4. To define and evaluate the ecological conditions (Fig. 1) in different cave habitats in selected six caves in Slovenia and six caves in Croatia.
5. To educate the local population on the importance of cave fauna and its protection, together with their environment.
6. To educate speleologists more detailed about cave fauna and their habitats.

7. To prepare material and scenario for a documentary movie on the biospeleological characteristics and research conducted on the Istrian peninsula.
8. To publish scientific and popular articles on the subject of the cave fauna of the Istrian peninsula.

Methods and targets of biospeleological research

At the beginning, project plan was developed and research team established same as list of selected caves created (Tab. 1). As we are working on cross-boundary project, biospeleological team is composed of two Croatian and two Slovenian biospeleologists. Caves are selected according to several aspects as: unique location, diverse habitats, known high biodiversity, type localities, interesting taxa, potential or actual threats, necessarily monitoring and other.
Biospeleological research is based on evaluated methodology which has been developed during our research of Dinaric karst in recent decades and can be divided into three parts:

1. Cabinet part: the collection of literature and analyses; preparation for fieldwork with research plane; book of filming preparation; analyses of field work data and material; biospeleological data base preparation; partial and final report preparation.
2. Field work: cave prospection's; climate measurements; fauna collecting; photo documentation of habitats (Fig. 2), research process and cave fauna performing; montage of instruments for permanent measure; field work diary preparation.
3. Results presentations: public debates and lectures; workshops; informative publications and posters; articles publications.

The basic targets of the biospeleological part of the project are as follows:

1. To physically explore the caves in order to determine the exact position, name, topographic images, as well as the zero state of the object.

Fig. 1: Measurement of selected ecological characteristics in Piskovica cave habitat with set of mobile instruments (photo: R. Ozimec).

2. To carry out cave prospection in light of their geological, hydrological and geomorphological characteristic; paleontological and archaeological features same as history of research.
3. To define the types of cave habitats and to measure their ecological characteristics.
4. To carry out a taxonomic, ecological, biological and biogeographical analysis of identified species of cave fauna with an emphasis on endemic, rare possible new species for science.
5. To create a production database in the form of a digital biospeleological cadastral with all established taxa and with accompanying photo documentation.
6. To determine the degree of threat and the proposed protective measures for caves and fauna.
7. Temporary reports and overall evaluation study for the each cave and correlation with the same phenomena in the region and the wider area.
8. To produce the final study with suggestions for further specialist research, and to protect and develop the monitoring system.
9. To raise awareness of cave fauna to the local population, speleologists and general

Tab. 1: List of selected 12 caves included into project, with general speleo-morphological data.

No.	Cave	Length (m)	Depth (m)	Remark
1.	Markova jama, Tar, HR	291	82	Protected as a geomorphologic natural monument since 1986
2.	Pincinova jama, Poreč, HR	100	85	Protected as a zoological natural monument since 1986
3.	Piskovica cave, Gologorica, HR	1,036	38	World's biggest cave in terms of flysch sediments
4.	Jama kod Burići, Kanfanar, HR	100	127	Located near to a tobacco factory (TDR)
5.	Ročka špilja, Roč, HR	100	12	Located in the middle of village
6.	Radota jama, Vodice, SLO/HR	200	142	Located on the SLO/CR border, the closest cave to the planned speleological house in Vodice village
7.	Račiška pečina, Račice, SLO	304	29	Ex-military storage, paleontological site
8.	Polina peč, Obrov, SLO	365	40	Endangered cave, proposed for closing
9.	Medvedjak cave, Materija, SLO	1,092	129	Cave with 40 m entrance shaft, accessible to cavers only
10.	Dimnice cave, Materija, SLO	6,020	134	Tourist cave
11.	Jama pod krogom, Mlini, SLO/HR	570	25	Spring cave located on the SLO-CR border
12.	Kubik cave, Gradin, SLO	292	10	Cave located in flysch sediments

public using the following methods: creating informative publications, holding workshops, holding public debates and lectures, and publishing scientific papers related to cave fauna.
10. Theoretical and technical support for documentary film on cave fauna in the Istrian peninsula.

Preliminary results of biospeleological research
Due to the fact that the project will run until the end of 2011, at the moment, only preliminary results can be revealed.
In all, four field work trips have been conducted in all twelve of the selected caves, according to research plans and methodology. During the fieldwork conducted, we cooperated with several speleologists, but also local population in Slovenia and Croatia, same as specialist for filming, cave diving and others.
In all caves we have performed habitat analyses, same as climate measurements with set of mobile instruments and have installed stationary instruments for climate measurement.
Very rich cave fauna has been collected with many rare and endemic taxa (Fig. 3, Fig. 4), but also some new taxa for science. The most important fauna, preliminarily identified, are presented in Tab. 2.
According to the Red book of Croatian cave dwelling fauna (Ozimec et al. 2009), many established taxa are threatened, some of which we have found new localities and populations for. Some previously described taxa have been detected for Slovenian or Croatian cave fauna for the first time and some taxa have been found for first time since they have been described.
All field work diaries are finalised and two reports are prepared: Inception report and Progress report, last with evaluation study for four caves, two in Slovenia and two in Croatia. In some caves, several threats have been detected. Physical devastation for Ročka špilja, Račiška pečina and Dimnice cave; waste deposits in Ročka špilja, Račiška pečina, Markova jama and Jama kod Burići (Fig. 5). In some caves, cave fauna is threatened due to fauna collecting and traps leaving, especially Ročka špilja cave, Dimnice cave and Polina peč.
At the moment most endangered caves are Jama kod Burići near Kanfanar

Fig. 2: Macro photography in Piskovica cave (photo: R. Ozimec).

Fig. 3: Verhoeffodesmus fragilipes*, the endemic cave diplopode for the Istrian peninsula (photo: R. Ozimec).*

Fig. 4: Troglochthonius doratodactylus*, first record for Slovenian cave fauna (photo: R. Ozimec).*

Tab. 2: List of selected 12 caves with important fauna and taxa described (Type locality).

No.	Cave	Important fauna	Type locality
1.	Markova jama, Tar, HR	*Zospeum spelaeum schmidti, Niphargus spinulifemur, Stalita* sp., *Laemostenus* sp., Sommer birth bat colony of *Myotis myotis* with over 1,000 specimens.	*Pauperobythus globuliventris*
2.	Pincinova jama, Poreč, HR	*Troglocaris planensis, Niphargus hebereri, Niphargus steueri, Monolistra* sp., *Sphaeromides virei, Hadzia fragilis, Laemostenus cavicola romualdi*	*Proteus anguinus* ssp. nov.
3.	Piskovica cave, Gologorica, HR	*Zospeum* sp., *Dina krasense Monolistra bericum hadzii, Niphargus krameri, Chthonius* sp., *Neobisium* sp. nov., *Lithobius* sp. nov. *Verhoeffodesmus gracilipes, Typhloiulus* sp.	-
4.	Jama kod Burići, Kanfanar, HR	*Alpioniscus strasseri, Troglochthonius doratodactylus, Chthonius* sp. nov., *Stalita* sp.	-
5.	Ročka špilja, Roč, HR	*Alpioniscus strasseri, Chthonius* sp., *Neobisium* sp., *Niphargus krameri, Monolistra bericum hadzii, Typhlotrechus bilimeki istrus, Bathysciotes khevenhulleri, Machaerites* sp., *Typhloiulus* sp.	*Verhoeffodesmus gracilipes*
6.	Radota jama, Vodice, HR	*Eupolybothrus obrovensis, Eukoenenia* sp., *Neobisium* sp., *Chthonius* sp., *Laemostenus elongatus elongatus, Mesostalita* sp., *Machaerites* sp.	-
7.	Račiška pečina, Račice, SLO	*Typhlotrechus bilimeki istrus, Laemostenus cavicola, Leptodirus hochenwartii, Bathysciotes khevenhuelleri, Prospelaeobates vrezeci, Niphargus stygius, Titanethes dahli, Troglochthonius doratodactylus*	-
8.	Polina peč, Obrov, SLO	*Typhlotrechus bilimeki istrus, Anophthalmus schmidti istriensis, Laemostenus cavicola, Leptodirus hochenwartii, Neobisium* sp., *Chthonius* sp., *Nicoletiella* sp.	*Machaerites novissimus*
9.	Medvedjak , Materija, SLO	*Zospeum* sp., *Typhlotrechus bilimeki istrus, Laemostenus cavicola, Lemostenus elongatus, Eukoenenia* sp., *Troglochthonius* sp., *Chthonius* sp., *Neobisium* sp.	*Prospelaeobates vrezeci*
10.	Dimnice cave, Materija, SLO	*Typhlotrechus bilimeki istrus, Anophthalmus spectabilis istrus, Laemostenus cavicola, Leptodirus hochenwartii, Oryotus schmidti subtedentatus, Brachydesmus inferus, Neobisium spelaeum istriacum, Neobisium reimoseri histricum, Stalita* sp., *Niphargus krameri, Titanethes dahli, Zospeum isselianum, Zospeum kusceri*	*Eupolybothrus obrovensis, Anophthalmus spectabilis istrianus, Oryotus schmidti subdentatus*
11.	Jama pod krogom, Mlini, SLO/HR	*Marifugia cavatica, Sphaeromides virei virei, Troglocaris planinensis, Niphargus steueri*	*Troglocaridicola istriana*
12.	Kubik cave, Gradin, SLO	*Zospeum* sp., *Bathysciotes khevenhuelleri, Niphargus krameri, Monolistra* sp.	-

and Markova jama near Tar, due to throw of dead cattle into the caves and in consequence, organic deposits with high air percentage of CO_2, especially in Jama kod Burići, where we have measured between 1.73 and 2.14 % of CO_2, what is healthy danger. Necessary of active protection of caves, same as future preventive protection is stressed in Progress Report.

Very rich photo documentation is performed, including many macro photography of cave fauna, for some of taxa for the very first time. Cave filming is also performed, according to scenario plan, including some particularly striking underwater filming in Pincinova jama.

This biospeleological project, which took place within the framework of the KUP project, was presented during the 20th International Conference on Subterranean Biology in Postojna, Slovenia in August 2010 (Ozimec et al. 2010).

Fig. 5: Cattle rest in Jama kod Burići (photo: R. Ozimec).

Conclusion

We can conclude using an example based on the Karst Underground Protection project in the Istrian peninsula; biospeleological research is necessary to define the status of the following: cave habitats, cave biodiversity, cave taxa populations, potential and active threats, and protection measures. Biospeleological research and results, together with filming and photo documentation, have high educational and promotional potential, not least in terms of the provision of new scientific data.

References

Joseph G., 1882. Systematisches Verzeichnis der in den Tropfstein-Grotten von Krain einheimischen Arthropoden nebst Diagnosen der vom Verfasser entdeckten und bisher noch nich beschriebenen Arten. Berl. Entom. Z.: pp. 26.

Krebs N., 1907. Die Halbinsel Istrien Landeskundliche Studie, Geograph. Abhandl. hg. v. A. Penck IXj2, Leipzig.

Ozimec R., Bedek J., Gottstein S., Jalžić B., Slapnik R., Štamol V., Bilandžija H., Dražina T., Kletečki E., Komerički A., Lukić M., Pavlek M., 2009. Crvena knjiga špiljske faune Hrvatske (Red book of

Croatian cave dwelling fauna). Ministarstvo kulture, Državni Zavod za zaštitu prirode, Zagreb: 1–371.
Ozimec R., Polak S., Bedek J. & Zakšek V., 2010. Biospeleological component of the project KUP (Karst Underground Protection) in Istra Peninsula. In: Moškrič A., Trontelj P. (eds.), 2010. Abstract book, 20th International Conference on Subterranean Biology, Postojna, Slovenia, 29th August – 3rd September, 2010: 89–90.
Perko I. A., 1906. Speleologia, Il Tourista, 11/(1–4): 43–85.
Pretner E., 1973. Koleopterološka fauna pećina i jama Hrvatske s historijskim pregledom istraživanja (Fauna Coleopterologica SubterraneaCroatiae mit einer Geschichtlichen übersicht der Forschungen). Krš Jugoslavije, 8/6: 101–239.

ARE WE GUARANTEEING THE FAVOURABLE STATUS OF THE *PROTEUS ANGUINUS* IN THE NATURA 2000 NETWORK IN SLOVENIA?

Andrej Hudoklin [1]

The *Proteus anguinus* or olm is defined as a vulnerable species on the IUCN Red List of Threatened Species. Its population trend in Slovenia is assessed as decreasing. Key threats are all types of pollution of karst areas, causing a decline in the extent and quality of the olm's habitat. The greater part of the Slovenian population of the species is included in the European ecological network Natura 2000: the 55 most important locations within 26 special protection areas. An assessment was made of the status of the species within the context of the Natura 2000 network. Since the habitat of the olm in the catchment areas of karst springs is to a large extent inaccessible, we made use of indirect indicators to assess status: the quality of groundwater and some sinking streams and other published data and field data. Assessment of the status of habitats showed that 28 locations (45 %) have a favourable status, 24 (38 %) have an unfavourable status and 11 (17 %) are undefined. Owing to various forms of pollution, the habitat of the species continues to decline in quality. In addition to unremediated old impacts (Kočevsko polje, the Krupa, the Krka, the Jelševnik spring), new focuses have been registered, to a large extent the consequence of intensive agriculture and unregulated disposal of municipal waste (the shallow karst in Bela Krajina, the area around Stična, the underground Pivka and the Cerkniščica, and locally also the Reka). The habitat of the narrowly distributed subspecies known as the black olm in Bela Krajina is most at risk. The unfavourable situation requires a more active approach which should include an inventory of the population, the establishment of monitoring and addressing of current problems.

The olm – the showpiece species of nature protection in Slovenia

Subterranean habitats in Slovenia are among the richest in the world in terms of the number of cave-dwelling species. Aquatic fauna is the most richly represented of all, with 200 species, while terrestrial fauna, with 150 species, is second only to the more southern parts of the Dinaric Karst (Sket & Zagmajster 2004). The most famous of the cave-dwellers is the "human fish", more properly known as the proteus or olm (*Proteus anguinus*; Fig. 1), which at between 25 and 30 cm in length is the largest cave animal in the world and the only cave vertebrate in Europe. The amphibian is a Dinaric endemic species that lives in underground waters from the basin of the river Soča/Isonzo near Trieste in Italy, across southern Slovenia and south-western Croatia to the river Trebišnjica in Herzegovina (Sket 1997). Two subspecies live in Slovenia: the white olm (*Proteus anguinus anguinus* Laurenti, 1768), which represents the largest part of the population, and the black olm (*Proteus anguinus parkelj* Sket & Arnzten, 1994), which is however only known in the karst

[1] *Institute for Nature Conservation, Adamičeva 2, 8000 Novo Mesto, andrej.hudoklin@zrsvn.si*

of the Bela Krajina region. Genetic research into kinship relations among olm populations (Gorički 2006) has identified six apparently independent evolutionary lines in the areas of Istria, Dalmatia and Herzegovina, Bosanska Krajina, Lika, SW Slovenia and SE Slovenia.

Population assessment

The olm population in Slovenia is believed to be declining, although its exact size is not known. The number of specimens observed in well-known and frequently visited locations has fallen (Poboljšaj 2001). There are several reasons for the reduction in the olm population. The key threats are represented by all types of pollution of the karst region (intensive agriculture, industrial and municipal waste and emissions, urbanisation, fly-tipping) in the area of influence of groundwater and sinking streams, all of which reduce the quality of the habitat and, consequently, reduce it in size. Toxic and hazardous substances representing a particular threat to the habitat include artificial fertilisers, pesticides, heavy metals and other pollutants (Bulog et al. 2002, Bressi 2004). Another negative factor can be the irresponsible exploitation of groundwater for industry and agriculture, in this way reducing groundwater stocks. Increased mortality owing to forcible removal for the purposes of trade and collecting is apparently no longer perceived to be a current threat, although suspicions that such activities continue are still present in many areas. In individual cases genetic pollution has been recorded as a result of transporting specimens to different locations (Bressi 2004, Hudoklin, unpublished).

Protection status of the species

Both subspecies of the olm are protected by the Decree on the Protection of Wild Fauna (Ur. l. RS 46/2004). In the Rules on the inclusion of threatened plant and animal

Fig. 1: *Olm (*Proteus anguinus*; photo: S. Polak).*

species in the Red List (Ur. l. RS 82/2002), the white olm is defined as a vulnerable subspecies, while the black olm is merely defined as a rare subspecies that is potentially at risk because of high endemism or limited range. The species is also designated as vulnerable on the Red List of the International Union for Conservation of Nature (IUCN 2008) for similar reasons.
At the EU level, the olm is included in Annex II and Annex IV to the Habitats Directive (92/43/EEC). Slovenia is therefore obliged to maintain the species and its habitat in a favourable state of conservation through protection and definition of the special protection areas that constitute the Natura 2000 network. Other cave fauna included in Annexes II and IV of the Directive are the beetle *Leptodirus hochenwartii* and the stygobiont bivalve *Congeria kusceri*, while other cave-dwelling species are covered within the Directive by habitat type 8310 Caves not open to the public.

The olm in the Natura 2000 network

The majority of karst river ecosystems in Slovenia are included in the European ecological network Natura 2000. In addition to surface streams, in several cases (e.g. the rivers Krka, Ljubljanica, Rinža and Kolpa), their karst catchment areas and springs are also partially defined. These are a treasury of diverse subterranean aquatic fauna, headed by the olm. A selection of the 63 most important locations (Sket 2000) among the almost 160 recorded locations (Sket 1997) served as a basis for defining Natura 2000 areas for the olm; 55 key locations were incorporated into the Natura 2000 network as part of 26 special protection areas. In our view, the absence of more recent data has meant that locations in the surroundings of Planina pri Stari Vrhniki, Stična, Lož, Kočevje and the valley of the Črmošnjica are included to an inadequate extent. An isolated location on the western edge of the area – the spring of the Vipava – has also been overlooked, although it is expected that this will be incorporated into the Natura 2000 network by an amendment to the Decree, along with Kačna jama, a cave near Divača.
The protection objectives of Natura 2000 areas emphasise the preservation, maintenance or improvement of existing characteristics of inanimate and animate nature that contribute to the favourable status of the plant and animal species and habitat types because of which the area was defined. Natura 2000 can therefore be a good tool for the more effective protection of the olm, and one that it is worth exploiting to a greater extent.

Status assessment

The Habitats Directive (79/409/EEC) binds EU Member States to monitor, evaluate and report on the conservation status of species and habitats. The olm is a habitat specialist among cave fauna by virtue of its distribution, distinctiveness and place in the food chain, and as such would be an extremely suitable indicator species of the state of subterranean habitats. Its ecological requirements are, in fact, covered by the ecological requirements of the majority of aquatic cave-dwelling species and it could therefore be defined as a focal species or even as an umbrella species. Its protection is also indirectly guaranteed by the protection of a large number of other species and of subterranean biodiversity as a whole. Since its habitat in the subterranean catchment areas of karst springs is to a large extent inaccessible to human beings, only indirect indicators are available for the assessment of the favourable status of the species, in the first place groundwater quality and other information on the state of the habitat and the population.
At the national level, no systematic monitoring of groundwater quality tied to locations of the olm or other cave fauna has been set up. To a limited extent we are able to use the results of nationwide monitoring of surface

water and groundwater quality, which has been taking place since 2007 in accordance with the requirements of the Water Directive. This monitoring determines ecological and chemical status for surface water, and chemical and quantitative status for groundwater. Groundwater monitoring covers 136 springs, including 11 that are olm habitats. Relevant data from surface water monitoring include those that define the ecological and chemical status of some sinking streams (Pivka, Unica, Ljubljanica, Rinža, Reka).
The following sources were used in assessing the quality of groundwater:

- Assessment of the ecological and chemical status of water in Slovenia for the period 2006–2008 by Slovenian Environment Agency (ARSO; ARSO 2010a),
- Groundwater quality in Slovenia in 2009 (ARSO 2010b),
- data from the monitoring of physical and chemical parameters carried out since 2000 in the black olm habitat in Bela Krajina by the Department of Biology from the Faculty of Biotechnology at the University of Ljubljana,
- other articles cited in sources and data from the Slovene Caves Register of the Caving Association of Slovenia, the Institute for Nature Conservation, and local enthusiasts.

Nationwide water quality monitoring is carried out on the basis of the Waters Act, the Environment Protection Act and a series of secondary regulations transposing the requirements of European directives on surface and groundwater into Slovenian law. The Slovenian regulations setting out the monitoring method and the criteria for assessing water status are the Rules on monitoring surface water status (Ur. l. RS 10/09), the Rules on monitoring groundwater (Ur. l. RS 31/09), the Decree on surface water status (Ur. l. RS 14/09) and the Decree on groundwater status (Ur. l. RS 25/09) (ARSO 2010b). From the point of view of threats to cave fauna, the presence of increased quantities of nitrates, heavy metals and metalloids, and pesticides (Bulog 2009) is particularly important. We consider the quality standards or value thresholds from the Decree on groundwater quality standards (Ur. l. RS 100/05) to be adequate for the majority of parameters. The exception is nitrates, where the value threshold of 50 mg/l (the norm for groundwater and drinking water) is unacceptable for the olm. Concentrations of nitrates in non-polluted waters are usually not higher than 1 mg per litre. They are present in groundwater in Slovenia in quantities lower than 10 mg of NO_3^- per litre. Increased nitrates content is the consequence of human activities, above all agriculture, and the unregulated drainage of municipal wastewater. In higher concentrations nitrates are harmful to human health because they are converted in the digestive tract, via toxic nitrites, into ammonia (Kranjc 2009). Research (Bulog 2009, Rouse et al. 1999, Blaustein 1998) likewise shows that nitrogen-based artificial fertilisers (ammonium nitrate, potassium nitrate and sodium nitrate) together with pesticides contribute decisively to a decline in the amphibian population. Nitrates in the form of sodium nitrate have a very harmful effect, above all on larval stadia and neotenic forms like the olm, which are permanently in an aquatic environment. Interestingly, until the transition to so-called European standards in 1997, the permitted threshold in Slovenia was 10 mg NO_3^-/l. In view of the above, we consider that waters in which a level of 10 mg NO_3^-/l is exceeded are extremely unfavourable for the olm population.

Assessment criteria

Locations for which data on the ecological chemical status of groundwater or ponor water or other published data are available were assessed

as *favourable / unfavourable* if groundwater quality *corresponds / does not correspond* to the criteria of the Decree on groundwater quality standards (Ur. l. RS 100/05). In order to assess groundwater quality from the point of view of nitrates, we used a lower value than the prescribed value, namely 10 mg NO_3^-/l. In our assessment we also took into account other accessible data on the current status of the habitat and population.
Locations for which suitable data were not available were assessed on the basis of an assessment of the situation in the catchment area of springs as *favourable* / unfavourable** (polluters *are not / are* present in the catchment area) or remained *undefined* (assessment was not possible).
Tab. 1 gives the results of the assessment of groundwater quality status for the 57 olm locations included in the Natura 2000 network and six locations that are in their area of influence.
With regard to the criteria set out above, we assessed that 28 locations (45 %) have a favourable status, 24 (38 %) have an unfavourable status and 11 (17 %) are undefined.

Tab. 1: *Status review 2010.*

ID	LOCATION / NATURAL FEATURE	NATURA 2000 AREA	STATUS ASSESSMENT	COMMENT
844	Temenica, spring in Luknja	Ajdovska planota	favourable	ARSO - groundwater monitoring
46148	Bobnova jama	Bobnova jama	favourable*	ARSO - chemical status of neighbouring spring (Tominčev Izvir) with similar catchment area is good
48262	Dobličica, spring	Dobličica	favourable	ARSO - groundwater monitoring
1189	Globočec, spring	Globočec	favourable	ARSO - groundwater monitoring
40270	Matijeva jama	Javorniki - Snežnik	favourable*	no data, forested catchment area
40630	Bilpa 1	Kočevsko	favourable	ARSO - groundwater monitoring
40079	Mrzla jama pri Ložu	Kočevsko	favourable*	no data, catchment area uninhabited, analyses (Kogovšek, 1998)
41999	Vodna vama v Jelendolu	Kočevsko	favourable*	no data, catchment area uninhabited
41178	Kozja luknja	Kozja luknja	favourable	Karst Research Institute, (Ravbar 2007, Kogovšek 2006)
43728	Stršinka	Karst	favourable	no data, catchment area uninhabited
40786	Drča jama	Karst	favourable*	no data, Brestovica reservoir nearby
40843	Med jamah	Karst	favourable*	no data, catchment area uninhabited
8607	Spring in Debeljakova loka	Krka	favourable	ARSO - chemical status of neighbouring spring (Tominčev Izvir) with similar catchment area is good
48181	Poltarica	Krška jama	favourable	ARSO
45426	Pumpa in Dobravice	Lahinja	favourable*	no data, forested catchment area
46185	Malo Okence, spring	Ljubljansko Barje	favourable	ARSO - chemical status of groundwater (V. Močilnik) and ecological status (Unica, Ljubljanica) are good
45513	Veliko Okence, spring	Ljubljansko Barje	favourable	ARSO - chemical status of groundwater (V. Močilnik) and ecological status of surface waters (Unica, Ljubljanica) are good
7611	Veliki Močilnik, spring	Ljubljansko Barje	favourable	ARSO: chemical status of groundwater is good

ID	LOCATION / NATURAL FEATURE	NATURA 2000 AREA	STATUS ASSESSMENT	COMMENT
40890	Mrzla jama pri Prestranku	Mrzla jama pri Prestranku	favourable*	no data, catchment area uninhabited
40800	Škratovka	Notranjska Triangle	favourable	ARSO - chemical status of neighbouring spring (Malenščica) with similar catchment area is good
40068	Gradišnica	Notranjska Triangle	favourable	ARSO, ecological status of the Unica good
40028	Logarček	Notranjska Triangle	favourable	ARSO, ecological status of the Unica good
40259	Najdena jama	Notranjska Triangle	favourable	ARSO, ecological status of the Unica good
40778	Požiralnik 2 v Škofovem lomu	Notranjska Triangle	favourable	ARSO, ecological status of the Unica good
40088	Vranja jama	Notranjska Triangle	favourable	ARSO, ecological status of the Unica good
4484	Rinža, spring near Slovenska vas	Rinža	favourable	ARSO - groundwater monitoring
45000	Divje jezero	Trnovski Gozd - Nanos	favourable	ARSO - chemical status of neighbouring spring (Podroteja) with similar catchment area is good
41752	Vipava, spring	Trnovski Gozd - Nanos	favourable	ARSO - groundwater monitoring
3697	Jelševnik, spring	Dobličica	unfavourable	BF - groundwater monitoring, other sources
380	Krupa, spring	Gradac	unfavourable	ARSO - groundwater monitoring
40535	Jama v Šahnu	Kočevsko	unfavourable	ARSO - ecological status of surface waters, Rinža - poor
40012	Željnske jame	Kočevsko	unfavourable	pollution (Sket 1972, Kranjc 1976)
40118	Vodna jama	Kočevsko_SPA	unfavourable	pollution (Sket 1972, Kranjc 1976)
40119	Vodna jama 2 pri Klinji vasi	Kočevsko_SPA	unfavourable	pollution (Sket 1972, Kranjc 1976)
42696	Vodna Jama 3 pri Klinji vasi	Kočevsko_SPA	unfavourable	pollution (Sket, 1972, Kranjc 1976)
0	Trata, Kočevje	Kočevsko_SPA	unfavourable	filled with rubble during construction
40187	Kotarjeva prepadna	Kotarjeva prepadna	unfavourable*	rubbish dump in entrance section, settlement in catchment area
40276	Jama 1 v Kanjaduce	Karst_SPA	unfavourable	(Mihevc & Rijavec 2006)
40955	Kačna Jama	Karst_SPA	unfavourable	(Mihevc & Rijavec 2007)
0	Jožetova Jama	Krka	unfavourable*	no data, cave filled up, farmland and settlement in catchment area
8607	Vrhovski Studenc	Krka	unfavourable	pollution (Institute of Public Health of the Republic of Slovenia.
40074	Krška jama	Krška jama	unfavourable	ARSO - groundwater monitoring
40067	Velika Karlovica	Notranjska Triangle	unfavourable*	ARSO, ecological status of the Cerkniščica is very poor
40747	Postojnska jama cave system	Notranjska Triangle	unfavourable	ARSO, ecological status of the Pivka upstream of the ponor is poor
40471	Črna jama	Notranjska Triangle	unfavourable	ARSO, ecological status of the Pivka upstream of the ponor is poor
40472	Pivka jama	Notranjska Triangle	unfavourable	ARSO, ecological status of the Pivka upstream of the ponor is poor
40820	Magdalena jama	Notranjska Triangle	unfavourable	ARSO, ecological status of the Pivka upstream of the ponor is poor
40102	Erjavščica	Notranjska Triangle	unfavourable	cave filled up with waste
4529	Otovski Breg, spring	Stobe – Breg	unfavourable	BF - groundwater monitoring, other sources

ID	LOCATION / NATURAL FEATURE	NATURA 2000 AREA	STATUS ASSESSMENT	COMMENT
8663	Pački Breg, spring	Stobe – Breg	unfavourable	BF - groundwater monitoring, other sources
41404	Stobe	Stobe – Breg	unfavourable	BF - groundwater monitoring, other sources
3542	Virski studenec, spring	Vir pri Stični	unfavourable	BF - groundwater monitoring, other sources
1962	Obršec, spring	Dobličica	undefined	no data, settlement and vineyards in the catchment area
380	Krupa, spring near Moverna vas	Gradac	undefined	no data, settlement in the catchment area, agriculture
4526	Zelenec, Dobindol	Springs of the Sušica	undefined	no data, settlement in the catchment area, agriculture
43898	Zelenka	Kompoljska jama - Potiskavec	undefined	no data on the status of sinking streams in the catchment area
40025	Kompoljska jama	Kompoljska jama - Potiskavec	undefined	no data on the status of sinking streams in the catchment area
40054	Potiskavška jama	Kompoljska jama - Potiskavec	undefined	no data on the status of sinking streams in the catchment area
40150	Lučka jama	Lučka jama	undefined	no data on the status of sinking streams in the catchment area
40748	Planinska jama	Notranjska Triangle	undefined	ARSO, ecological status of the Pivka upstream of the ponor is poor; because of underground tributaries (Rak) and mixing of water, status difficult to assess
42163	Petanska jama	Petanjska jama	undefined	no data on the status of sinking streams in the catchment area
40017	Podpeška jama	Podpeška jama	undefined	no data on the status of sinking streams in the catchment area
40571	Viršnica	Radensko polje - Viršnica	undefined	no data on the status of sinking streams in the catchment area

Favourable status

Among locations with favourable status, assessments deriving from the results of the chemical status of groundwater and the ecological status of surface water prevail. It is encouraging that the results of the recent report on groundwater quality in Slovenia in 2009 (ARSO 2010b) are positive, with the chemical status for bodies of water in the coastal area, the Karst with the Brkini hills, the area of the karstic Ljubljanica and the Dolenjska region (with the exception of the sources of the Krka and the Krupa) being identified as good. Favourable status is therefore recorded in a large part of the underground Unica and Reka rivers, in the catchment area of the Dobličica, the Temenica, the Rinža and the Vipava, and in springs in the catchment area of which the forest-covered Dinaric range is the prevailing influence.

Unfavourable status

The status assessment highlighted 24 locations of the species. The key data here came from surface water and groundwater quality monitoring (ARSO 2010a, ARSO 2010b), revealing the problematic status of the underground Pivka, the Cerkniščica and the Krka. The list was supplemented by a number of old impacts (Kočevsko polje, Krupa, Jelševnik, Vir pri Stični) and other current data (the shallow karst in Bela Krajina, local pollution of the Reka). Brief commentaries on locations with unfavourable status are given below.

Source of the Krka: Increased levels of various pesticides have been recorded at the source of the Krka since 2007. In 2009 extremely high levels of atrazine, metolachlor, simazine, prometryne, terbuthylazine, terbutryn, metamitron, isoproturon, metazachlor and other pesticides were identified. In individual samples terbuthylazine contents were six times higher and metamitron contents almost nine times higher than the standard (ARSO 2010b). The focuses of pollution have not yet been identified and several sources of pollution are possible in the wider hydrogeological catchment area of the spring. In order to identify and locate sources of pollution with certainty, the surface section of the catchment area – under pressure from agriculture – which drains into the aquifer in the ponors of the Dobravka (Beznica cave below Zagradec) and the Šica (Zatočne jame near Račna) and impacts on the regime and quality of the source of the Krka, will also be included in the monitoring programme. ARSO, in conjunction with the Caving Association of Slovenia, is already carrying out recording and cleanup of polluted caves in the catchment area.

Source of the Krupa: The habitat of the species is represented by the underground catchment area of the spring. From 1962 to 1984 the Iskra condenser factory in Semič polluted the karst hinterland of the spring with highly toxic and carcinogenic PCBs (polychlorinated biphenyls). Following a lengthy period of remediation, the impact of PCBs on the environment has been greatly reduced but they are still present in the river sediment (Polič et al. 2000). The standard is also exceeded in surface water (ARSO 2010a). Despite the fact that the scale of pollution of the source of the Krupa has been known for over 30 years, since it is one of the most PCB-polluted rivers in Europe, impacts on cave fauna have remained unresearched. Recent research (Pezdirc, Heath, Bizjak-Mali & Bulog, paper currently being prepared) determined PCB levels in individual tissues of an olm from this location and in river sediments. Total PCB concentrations in individual tissues samples of the olm ranged from 160 µg/g to almost 1,600 µg/g dry weight, which is at least 26 times higher than in animals from unpolluted locations. Total PCB concentrations in samples of sediments from the river Krupa ranged from 5 µg/g to almost 60 µg/g dry weight and still indicate a high PCB impact on the region.

Kočevsko polje: Negative impacts of pollution were noted in the period following the World War II. Discharges of liquid manure from the pig farm in Klinja vas entirely destroyed rich olm populations in streams flowing just below the surface on the northern edge of the Kočevsko coal basin (Vodna jama, Vodna jama pri Klinji vasi 2 and 3), which from here descend rapidly into the deeper zones of the Rog massif (Sket 1972, Kranjc 1976, Novak 1987). Poor ecological status was also recorded for the Rinža (ARSO 2010a), which appears in a number of caves on the eastern margin of Kočevje (Jama v Šahnu). Additional pressure is contributed by surface waters draining underground from the impermeable Pleistocene sediments of the former mining basin. For decades Rudniški potok (Pit Stream) drained into the nearby caves of Željnske jame (Željne caves) and by the time the coalmine was abandoned had entirely filled the lower levels of the cave with mud from the screening process (Novak 1987), in this way exterminating the local olm population (Sket 1972, Kranjc 1976). Although the caves are actually outside the Natura 2000 area, the negative impact was carried by polluted ponor water to the subterranean habitat of the species which, because of bifurcation, reaches all the way to the Kolpa and the Krka. The consequences of this ecological disaster have never been expertly evaluated or included in any remediation programme.

The underground Reka: Up until 1986 the Reka was heavily polluted, above all because of discharges from a factory producing organic acids and asbestos-cement boards in Ilirska Bistrica. Following closure of this factory, or rather the opening of a new production plant, the quality of the water improved perceptibly. Recent measurements of the quality of water below Ilirska Bistrica (ARSO 2010b) rate it as adequate. The underground river is exposed to at least two major known polluters. Water from the Divača treatment plant flows into Kačna jama, while water from the Sežana treatment plant flows into the Bjekovnik cave, after which a waterfall with water from the treatment plant appears in Jama 1 v Kanjeducah (Cave 1 in Kanjeduce). Analysis reveals a big difference in the chemical properties of the two types of water. Water taken from the underground river shows increased values for all parameters, but does not deviate significantly from the values of the Reka upstream of the ponor of the Škocjanske jame. Values are, however, greatly increased in the water of the waterfall. These values indicate extremely heavy pollution with organic substances. The water in the waterfall had up to 207 mg/l of nitrates, while because of dilution a significantly lower nitrates content (8 mg/l) is recorded in the main channel of the Reka in the same cave (Mihevc & Rijavec 2006). A suspicion of genetic pollution has also been recorded in the Škocjanske jame: 40 years ago, according to oral information from Debevec (Bressi 2004), several dozen specimens of olm from the Postojna-Planina cave system (where they had been brought for the purposes of presenting the species) are believed to have escaped into the underground river. The consequences or any cross-breeding with autochthonous populations have not been verified.

Jelševnik: Between 1989 and 1993 foundry sand from the Belt foundry was dumped in a sinkhole 700 metres from the spring and washed underground. Analysis showed that underground water contained high levels of aromatic hydrocarbons, phenols and iron. The silting-up of the underground with foundry sand in which sharp-edged quartz grains prevailed damaged the skin of olms moving over the sediment. The majority of specimens found on the surface died as a result of infection of the damaged mucous membrane and osmotic problems (Sket 1993). The problem eased following a partial cleanup of the dump in 1993. There is still, however, an alarming accumulation of heavy metals in the tissues of the olm. Analysis (Bulog 2002) has shown that black olms in Jelševnik had significantly increased values for arsenic and zinc in the skin and for zinc in the liver. The concentration of arsenic in the skin was 42 times higher than in the underground water of its habitat and as much a 65 times higher than in the skin of the unpigmented species from Kompoljska jama (Kompolje cave). The reason for the increased concentrations can be traced to the arsenic-containing sediments in the catchment area of the spring that are still present underground from the former dump of the Belt foundry. The arsenic is most probably the consequence of the use of pesticides in agriculture. It is also important to realise that the olm can live for several tens of years, and therefore the long-term accumulation of metals and other pollutants in its tissues can seriously threaten its survival in the location.

Jelševnik, Stobe, Otovski Breg and Pački potok: Several years (from 2000) of monitoring physical and chemical parameters in these springs (Bulog 2009) indicate a trend of increased pollution with nitrogen compounds, particularly nitrates, which are frequently in a range of between 10 and 20 mg/l. In the Jelševnik spring, the location of the pigmented subspecies of the olm, nitrate values in the past ranged between 1.1 and 9.7 mg/l but in the spring and autumn of 2010 they reached values of over 15 mg/l. The problem began to intensify after 2009 when renewable energy company Bioenerg d.o.o. of Domžale began producing biogas slurry at the Lokve biogas plant near Črnomelj. It produces around 24,000 tonnes of slurry per year which, in view of its Class 1 environmental quality status, is also used in the catchment area of karst springs in the shallow Bela Krajina karst plain which are important from the point of view of biodiversity. The slurry is distributed free of charge to farmers who express an interest and has therefore frequently been applied without regard for the restriction on yearly application and previously drawn up fertilisation plans. There have also been several cases of point source spillages of several tonnes of slurry. The excessive pressure on the environment has been confirmed by analysis of soil samples (agriculture inspector), while eloquent proof of the saturation of groundwater with nutrients is the proliferation of algae in karst springs.

A proportionate increase in phosphate values has also been noted (Boris Bulog, oral source, September 2010). Groundwater rarely contains more than 0.1 mg/l of phosphates unless it is polluted. Previous measurements of orthophosphate content in the Jelševik spring ranged from 0.01 to 0.13 mg/l and only exceeded the upper value on four occasions between 2000 and 2009, while the highest value was recorded in the Pački potok spring (up to 2.7 mg/l). Measurements taken in the remediated intermittent spring in April 2010 showed a strong increase in orthophosphate content to 1.26 mg/l, while in 2011 the measured values of phosphates in the Jelševnik reached values close to 2 mg/l (Boris Bulog, oral source, April 2011). Phosphates are present in fertilisers and detergents and consequently we find them in surface waters and in groundwater, where they discharge with wastewater. Slurry and municipal wastewater contain phosphates and nitrates that are released during the decomposition of organic substances. We find phosphates and nitrates in effluent from the food industry, while large quantities are also released into the environment with artificial fertilisers used in agriculture.

Following a campaign by the local Proteus organisation from Črnomelj, on 6 April 2011 the Agriculture, Forestry and Food Inspectorate decided that farmers would no longer be allowed to use the slurry from the biogas plant because it contains too much zinc and cadmium. Limit values of heavy metals are exceeded by such a margin that biogas slurry does not fall into environmental quality Class 1 but rather into Class 2, for which it is necessary to obtain an environmental permit. This resolved the issue of slurry from the biogas plant, but heavily polluted slurry from the neighbouring pig farm will continue to be used on agricultural land, according to the criteria of good agricultural practice. A solution for the protection of vulnerable groundwater in the shallow Bela Krajina karst will clearly have to be guaranteed at the normative level – by setting stricter limit values of key pollutants.

<u>Vir pri Stični:</u> Local inhabitants have for several years been drawing attention to the problem of pollution of the karst catchment area of this spring, which is famous as the first known location in which *Proteus anguinus* was found (Tatjana Kordiš, Vir pri Stični, oral source). Intensive agriculture and illegal discharges from the sewer system into the underground are particularly problematic. In 2003 and 2004 the Department of Biology carried out several measurements of physical and chemical parameters (Boris Bulog, oral source) and identified high exceedances of nitrates (over 25 mg/l) and phosphates (over 2.3 mg/l). Remediation of focuses has not been carried out, and monitoring is not taking place of water quality and the olm population.

<u>Vrhovski Studenec:</u> An olm was observed in the spring a decade ago (Emil Glavič, Prapreče near Žužemberk, oral source). In 1996 and 1997 the Institute of Public Health determined that the water was heavily polluted with coliform bacteria of faecal origin. Discharges of wastewater that flows freely into the underground from the nearby village of Vrhovo have also occasionally been observed.

<u>The karst basin of the Ljubljanica (the Notranjska Triangle):</u> The habitat of the species is represented by the underground waters of the rivers Pivka, Rak and Unica, with several locations. In the course of nationwide monitoring of surface water and groundwater, some results of assessments of the ecological status of surface waters/sinking streams have proved to be problematic for the area. The Cerkniščica is assessed as very poor, while the Pivka between Prestranek and Postojnska jama is assessed as poor. Consequently, the habitat of the species in the related ponor section is rated as unfavourable. The situation in Planinska jama is still uncertain. The polluted waters of the Pivka mix with the moderately polluted water of the Rak below the confluence. The Rak is in fact fed by clean water from the area of the Javorniki hills and polluted water from Cerknica lake. As a result, the assessment of both groundwater and surface waters between Planinsko polje and the springs of the Ljubljanica is good. The underground Unica is certainly also under pressure from the intensive fertilising of Planinsko polje using problematic chicken manure. Because the Unica frequently floods, large quantities of fertiliser are washed underground (Bojana Fajdiga, oral source).

Undefined locations

A lack of data meant that we were unable to assess 11 locations. Undefined locations predominate in the catchment area of the springs of the upper course of the Krka (Lučki dol, Radensko polje, Dobrepolje) because no data is available on the quality of sinking streams (the Bistrica, Tržiščica, Rašica and Šica) or on water in caves. The list also includes a few smaller springs in the catchment area of which potential polluters are registered (Obršec, Sušica, Petanska jama), and also the Unica (Planinska jama), the problems of which are presented in the context of the karstic Ljubljanica.

Conclusion

Assessment of the status of olm habitats showed that 28 locations (45 %) have a favourable status, 24 (38 %) have an unfavourable status and 11 (17 %) are undefined. We may conclude that the Natura 2000 network does not guarantee a favourable status for the olm in Slovenia. Owing to various forms of pollution, the habitat of the species continues to decline in quality. In addition to several unremediated old impacts (Kočevsko polje, the Krupa, the Krka, the Jelševnik spring), new focuses have been registered, to a large extent the consequence of intensive agriculture and unregulated disposal of municipal waste (shallow karst in Bela Krajina, the area around Stična, the underground Pivka and the Cerkniščica, and locally also the Reka).

With regard to the situation so far identified, the most threatened habitat is that of the narrowly distributed subspecies the black olm in Bela Krajina, something confirmed by the physical and chemical parameters of groundwater and concentrations of heavy metals in animal tissues. A similar conclusion may be reached for the population in the underground catchment area of the river Krupa.

Owing to the inaccessibility of the underground habitat, the consequences of the catastrophic destruction of populations on the eastern edge of Kočevsko polje (Željnske jame and the water caves near Klinja vas) remain unexplained.

The fact that no data is available on water quality, let alone the status or trend of the population, for a series of locations where an impact is to be expected in catchment areas as a result of urbanisation and agriculture is a cause for concern.

The assessment of the status of the species carried out in 2007 as part of reporting under the Habitats Directive (MOP 2008) rated it as inadequate (U1). This year's assessment simply widens the number of problematic locations, which in several cases are even becoming more problematic, and therefore the status of the species in both the Continental and Alpine biogeographic regions is still ranked as inadequate.

In view of the situation that has been identified, the following measures will be necessary in order to improve the status:

- in the first place, carry out a comprehensive survey of the state of olm populations as soon as possible,

- in conjunction with experts, establish a methodical approach to monitoring the species,
- include significant and threatened species locations and some sinking streams in nationwide surface water and groundwater quality monitoring,
- promote the remediation of locations where an unfavourable status has been identified,
- consistent application of environmental legislation, particularly legislation deriving from the Nitrates Directive and the Decree concerning the protection of waters against pollution caused by nitrates from agricultural sources (Ur. l. RS 113/09),
- re-verification of the limit value of nitrates concentration (50 mg/l) in groundwater in the case of vulnerable aquifers such as shallow karst,
- increase public awareness in problematic areas,
- protect the most threatened areas.

Acknowledgements

Thanks are due to the following for their assistance in collecting field data and preparing the assessments: Dr Boris Bulog (Department of Biology, Faculty of Biotechnology, University of Ljubljana), Mitja Prelovšek (Karst Research Institute ZRC SAZU), Martina Kačičnik Jančar, Bojana Fajdiga, Martina Stupar and Lara Jogan (Institute for Nature Conservation), and Tatjana Kordiš and Emil Glavič (experts on local conditions).

References

Agencija RS za okolje [Slovenian Environmental Agency] (ARSO), 2010a. Ocena ekološkega in kemijskega stanja voda v Sloveniji za obdobje 2006 do 2008. Ministrstvo RS za okolje in prostor, Agencija RS za okolje, Ljubljana.

Agencija RS za okolje [Slovenian Environmental Agency] (ARSO), 2010b. Kakovost podzemne vode v Sloveniji v letu 2009. Ministrstvo RS za okolje in prostor, Agencija RS za okolje, Ljubljana.

Blaustein A.R., Wake D. B., 1998. The Puzzle of Declining Amphibian Populations. Scientific American, 272: 52–57.

Bulog B., Mihajl K. et al., 2002. Trace element concentrations in the tissues of *Proteus anguinus* (Amphibia, Caudata) and the surrounding environment. Water air soil pollut., 136/(1-4): 147–163.

Bulog B., 2007. Okoljske in funkcionalno-morfološke raziskave močerila (*Proteus anguinus*). Proteus, 70/3: 102–109.

Bulog B., 2009. Ocena okoljskega onesnaženja kraškega podzemlja v Jelševniku pri Črnomlju in vpliv na črno podvrsto močeril (*Proteus anguinus parkelj*, Amphibia, Proteidae). Report. Biotehniška fakulteta, Oddelek za biologijo, Ljubljana.

Bressi N., 2004. Underground and unknown: updated distribution, ecological notes and conservation guidelines on the Olm *Proteus anguinus anguinus* in Italy (Amphibia, Proteidae) Italian Journal of Zoology, 71: 55–59.

Gorički Š., 2006. Filogeografska in morfološka analiza populacij močerila (*Proteus anguinus*). PhD Thesis. Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za biologijo.

Kogovšek J., 2006. Fizikalno-kemične značilnosti izločanja travertina – primer Podstenjška (Slovenija). Acta Carsologica, 35/1: 47–54.

Kranjc A., 1976. Poskus valorizacije kraških votlin v občini Kočevje z naravovarstvenega vidika. Varstvo narave 9: 3–20.

Kranjc M., 2009. Kazalci okolja v Sloveniji. Nitrati v podzemni vodi. http://kazalci.arso.gov.si/?data=indicator&ind_id=183.

Mihevc A., Rijavec J., 2006. Poročilo o analizi vzorcev iz Jame 1 v Kanjeducah (kat. št. 276). Naše jame, 46: 131–133.

Ministrstvo RS za okolje [Ministry of the Environment and Spatial Planning] (MOP), 2008. Report on Implementation Measures (Article 17, Habitats Directive). 8310 Caves not open to the public. http://cdr.eionet.europa.eu/si/eu/art17/envrk11za.

Novak D., 1987. Podzemeljski vodni tokovi na Dolenjskem. In: Dolenjski kras 2. JK Novo Mesto: 23–27.

Poboljšaj K., 2001. Dvoživke (Amphibia). In: Kryštufek B., Bedjanič M., Brelih S., Budihna N., Gomboc S., Grobelnik V., Kotarac M., Lešnik A., Lipej L., Martinčič A., Poboljšaj K., Povž M., Rebeušek F., Šalamun A., Tome S., Trontelj P., Wraber T., 2001. Raziskava razširjenosti evropsko pomembnih vrst v Sloveniji. Prirodoslovni muzej Slovenije, Ljubljana: 682.

Polič S., Leskovšek H., Horvat M., 2000. Onesnaženje kraške reke Krupe s PCBji. Acta Carsologica, 29/1: 141–152.

Ravbar N., 2007. The protection of karst waters: a comprehensive Slovene approach to vulnerability and contamination risk mapping. Ljubljana-Postojna, ZRC SAZU: 254.

Rouse J.D., Bishop C.A., Struger J., 1999. Nitrogen pollution: an assessment of its threat to amphibia survival. Environmental Health Perspectives, 107/10.

Sket B., 1972. Zaščita jamske favne se ujema z življenjskimi interesi prebivalstva. In: Peterlin S. (ed.), 1972. Zelena knjiga o ogroženosti okolja v Sloveniji: 137–140.

Sket B., 1993. Biološko (speleobiološko) poročilo. In: Žerjal E. et al., 1993. Sanacija odlagališča livarskih peskov Bezgovec – identifikacija in določitev stopnje onesnaženja (I. faza) in predlog ukrepov (II. faza). Elaborat, št. 12/36-93. Zavod za zdravstveno varstvo, p.o., Inštitut za varstvo okolja – Tehnološki center, Maribor.

Sket B., 1997. Distribution of *Proteus* (Amphibia: Urodela: Proteidae) and its possible explanation. Journal of Biogeography, 24: 263–280.

Sket B., 2000. Pregled in izbor jam v Republiki Sloveniji, ki so pomembne za ohranjanje podzemske favne. Expert's detailed report.

Sket B., Zagmajster M., 2004. How to inventory and evaluate biologically important subterranean world heritage? The case of Slovenia. Acta Carsologica, 33/2: 28.

RED BOOK OF DINARIC CAVE FAUNA – AN EXAMPLE FROM CROATIA

Roman Ozimec [1]

The Dinaric karst area is a 650 km long and up to 150 km wide, covers a total of approximately 60,000 km^2 and forms the largest continuous karst landscape in Europe (Mihevc et al. 2010). The Dinaric ridge is located between the Adriatic sea to the south and the Pannonian basin to the north, and between the SE Alps to the west and the Taurid Mountains to the east, spread in a NW–SE direction, from Trieste in Italy and Slovenia in the northwest, through Croatia, Bosnia & Herzegovina and Montenegro, to northwest Albania in the southeast, with small isolated parts distributed in Kosovo and Serbia.

The Dinaric ridge has been confirmed many times over to have the highest biodiversity of cave fauna in the world (Vandel 1964, Culver & Sket 2000), with caves with over 100 cave-dwelling taxa (Ozimec & Lučić 2010). However, a lack of systematic research and synthesis of the Dinaric ridge obstructs the general validation and importance of this recognized world cave fauna 'hot spot'.

In the meantime, advancing civilisation is leading to bigger and more intense impacts on the natural environment, including the karst areas. Consequently, Dinaric cave habitats and fauna, although theoretically highly protected, are starting to be threatened by anthropogenic influences. For this reason, definition of threats, comprehensive lists of cave taxa endangered, and measures for habitat and taxa protection are now necessary for all the Dinaric countries. One of most important documents in this regard is the Red Book, classifying taxa into different categories of perceived risk following the IUCN (International Union for the Conservation of Nature and Natural Resources) species list. Each Red Book deals with a specific taxonomical or ecological group of living organisms, with data added as follows: local name, English name, Latin name, synonyms, taxonomical classification (*classis, ordo, familia*), global endangered category, national endangered category, distribution, description and biology of taxa, threat causes, existing legal protection, and proposed legal protection.

As the first Red Book of Dinaric – indeed worldwide – cave dwelling fauna, the *Red Book of Croatian Cave Dwelling Fauna* (Ozimec et al. 2009) provides systematic analyses of Dinaric cave fauna, and many conclusions can be adopted to the whole Dinaric range.

Biodiversity and endemism of Croatian cave fauna

In the paper by Gottstein et al. (2002), a total of 469 true cave taxa, troglobionts and stygobionts, were confirmed for Croatia, with a ratio of approximately 35 % stygobionts and 65 % troglobionts. Insects (Insecta) with 122 taxa dominate in the structure of the cave fauna, with an absolute majority of beetles (Coleoptera) with 106 taxa (approx. 87 % of Insecta and 23 % of total). These are followed by the arachnids (Arachnida) with 113 taxa, dominated by the false scorpions (Pseudoscorpiones) with 53 taxa and the spiders (Araneae) with 45 taxa. The crustaceans (Crustacea) are represented by 97 taxa, with the most common being amphipods (Amphipoda) with 54 taxa and isopods (Isopoda) with 40 taxa. These are followed by the snails (Gastropods) with 74 taxa, the millipedes (Myriapoda) with 26 taxa, and other fauna groups (Tab. 1). Given that Croatia contains a high percentage of the Dinaric ridge, this applying to all three biogeographically zones, north, middle and south (Ozimec et al. 2009), those relations can be recognized as an approximate model for whole dinaric region.

In the paper by Bedek et al. (2006), it was established that 338 taxa have been described from 206 caves in Croatia. Virtually all of these species are endemic to the Dinaric mountain range, and about 80 % of the described species have been found only within Croatia. Since then, a large number of new cave species of Croatian fauna have been discovered and many of them new to science. Some of these new taxa have now been described and the current number of described taxa in Croatia according to *The Cave Type Localities Atlas of Croatian Fauna* (Fig. 1) is 399 taxa described from 254 caves (Jalžić et al. 2010). The total number of cave-dwelling taxa in Croatia is now estimated at over 570, with many new taxa still not described and not included (though generally this does not affect the overall picture of the structure of the cave fauna).

The endemism of cave species is exceptionally pronounced and virtually all the species of true cave fauna are endemic to the Dinaric ridge. Their endemism can be analysed from several aspects, of which three are described below.

A. Geographic aspect:

A1. North Dinaric endemics: endemic taxa spread from the northern end of the Dinaric range to the Una River–Zrmanja River fracture;

A2. Central Dinaric endemics: endemic taxa spread from the Una River–Zrmanja

Tab. 1: Structure of cave fauna in Croatia (according to Gottstein et al. 2002).

Groups of Stygobites	Number	Groups of Troglobites	Number
Porifera	2	Gastropoda	22
Hydrozoa	1	Aranea	45
Turbellaria	9	Pseudoscorpiones	53
Gastropoda	54	Opiliones	8
Bivalvia	1	Acarina	6
Polychaeta	1	Palpigrada	1
Oligochaeta	5	Isopoda	16
Hirudinea	2	Myriapoda	22
Crustacea		Chilopoda	3
Copepoda	10	Diplopoda	23
Ostracoda	2	Collembola	10
Syncarida	2	Diplura	3
Isopoda	24	Coleoptera	104
Amphipoda	54	Diptera	3
Decapoda	4		
Thermosbaenacea	1		
Amphibia	1		
TOTAL	173		316

[1] *Croatian Biospeleological Society (CBSS), Demetrova 1, HR-10 000 Zagreb, Croatia, E-mail: roman.ozimec@hbsd.hr*

River fracture to the Neretva River fracture;

A3. South Dinaric endemics: endemic taxa spread from the Neretva fracture to the border of the Dinarid range with the Taurid Mountains.

Within each of these three biogeographic regions, there are numerous microregions inhabited by many cave species which are local (microregional) endemics, species spread over a very small area or endemics of smaller regional entities, often of one or several mountain ranges, islands, microregions or even individual localities (refuges; Fig. 2).

B. Geopolitical aspect: endemic taxa can be defined according to their belonging to a certain geopolitical entity or country. According to country, Dinaric fauna can be described as belonging to Italy, Slovenia, Croatia, Bosnia & Herzegovina, Montenegro, Albania, Kosovo and Serbia. Each country can be divided according to internal geopolitical units, such as canton, parish, county or city.

C. Development aspects: represents an analysis of the endemic taxa according to the age of the endemism; amongst the cave fauna, we recognize endemic taxa that are:

C1. Paleoendemic: endemics of great age, *'living fossils'*, or relict forms that originated in a certain geological period and no longer have any original relatives. These commonly have a disjunctive distribution and represent a monotypic genus, i.e. a genus with only one species. The threatened cave fauna in Croatia in this category are as follows: Ogulin cave sponge (*Eunapius subterraneus*), Dinaric cave clam (*Congeria kusceri*), Dinaric tube-worm (*Marifugia cavatica*), mirabile troglochthonius and the Northern Dinaric troglochthonius (*Troglochthonius mirabilis*; *Troglochthonius doratodactylus*), olm (*Proteus anguinus*) and many other paleoendemics.

Fig. 1: Example page from The Cave Type Localities Atlas of Croatian Fauna (according to Jalžić et al. 2010).

C2. Neoendemic: as a result of geographical isolation of populations in cave habitats, new taxa arise through development and evolution and are described as neoendemic. Phylogenetic analysis of cave false scorpion taxa confirmed that numerous cave species of the genera *Chthonius* and *Neobisium* arose from original epigeic species, i.e. their common relatives. The situation is similar with beetles of many genera (*Anophthalmus, Duvalius, Neotrechus, Spelaeobates, Speonesiotes, Machaerites*), isopods (*Alpioniscus*), amphipods (*Niphargus*), and other (Ozimec et al. 2009).

Threat causes of Dinaric cave fauna

Threats to the cave fauna of the Dinaric ridge include minor natural factors such as periodic flooding, cave collapse or filling by sediments, but much more important are anthropogenic factors:

1. <u>Physical devastation of caves and cave habitats:</u> primarily due to quarrying activities, road building, industrialisation and rapid urbanisation. This can even cause complete physical destruction, or filling of caves with waste or construction materials. This is a concern throughout the Dinaric ridge, but is particularly pronounced in the coastal Adriatic

Fig. 2: Map of Dinaric mountain range with borders of Croatia and biogeographic regions borders (according to Ozimec et al. 2009).

region. Physical devastation also occurs during large hydrotechnical projects that can cause devastation in speleological structures ranging from complete destruction to flooding. Threats to aquatic cave habitats and aquatic cave fauna due to hydrotechnical works are reduction of the catchment area, land amelioration and disturbances to the natural flooding system of karst fields, changes in direction of watercourses, flooding of caves and water pumping. These contribute to significant decrease in habitat health, microclimatic and ecological changes (warming, reduction of dissolved oxygen, reduction or increase of the share of organic matter), right up to the complete loss of aquatic habitats in caves. There are also cases of laying concrete or asphalt on the upper layers over caves, which reduces the filtration of water and nutrients into cave habitats.

2. <u>Pollution of cave habitats:</u> direct pollution includes the common dumping of inorganic and organic waste in caves, and especially pits (Fig. 3), including the disposal of waste water. This can lead to the flooding of cave habitats, or to the heating effect that waste waters can have on sinking waters and aquatic cave habitats. Indirect pollution includes increased concentrations of heavy metals, detergents and pesticides in cave habitats, especially in aquatic habitats as a result of polluted water. This pollution can occur following the disposal of waste in external karst habitats, and particularly in surface karst waters. Due to the porosity of the karst massif, soluble and mobile matter enters into the underground by filtration and is carried by karst waters over a wider area, as recorded by cavers (Marković et al. 2010). It should be noted that, especially in the past, in karst areas it is common for sanitary water to be drained directly, without any chemical or biological treatment, into caverns opened during excavation for residential houses. Aquatic habitats are exceptionally vulnerable to pollution. Very small amounts of pollutants, such as oil or pesticides, are sufficient to cause catastrophic consequences in a stygobiont population throughout the entire aquatic habitat. One additional form of pollution resulting from the last wars in region is explosive devices thrown into caves, which still represents a grave danger for cavers.

Fig. 3: Waste disposed into pits can move deep into cave habitats (Photo: B. Jalžić).

3. <u>Inappropriate adapting and use of caves in tourism:</u> in caves adapted for tourism, processes of laying concrete and building can devastate or at least physically reduce individual cave habitats. Due to increased light, changes can occur to the cave microclimate, causing growth of organic vegetation (*lampenflora*) composed of fungi, algae, moss, ferns and even higher plants. Due to the heating effects of lighting or excessive visitor numbers, the air temperature in smaller caves can increase. Excessive visitor numbers can increase the carbon dioxide concentrations in the atmosphere, which can lead to acidification of cave water. Finally, the passage of visitors through caves leads to the accidental killing of cave fauna specimens. Insufficient supervision with monitoring in tourism-equipped caves can thus lead to various forms of degradation of cave habitats.

4. <u>Global climate change:</u> a recent study entitled *Climate Change and its Consequences for Society and the Economy in Croatia* (Landau et al. 2009), carried out by the United Nations Development Programme in Croatia, outlined how real this threat is, stating that it is likely that changes in the quantity of precipitation, temperature, soil moisture and the frequency of extreme weather events will all impact on caves (Landau et all. 2009). We can expect an increase in the medial annual temperature, more frequent temperature extremes and reduced amounts of precipitation, with an increasingly non-uniform distribution of precipitation through the year. Expected consequences for cave habitats are the following: increasing underground temperatures, reduced underground water levels and significant desiccation (reduction of the moisture content). Consequently, some changes in cave fauna structure and range restriction for some taxa can be expected.
Another consequence is that with rising sea levels, part of the coast will be submerged and sea water will intrude into coastal freshwater aquifers. Potentially threatened areas are the western coast of Istria, Vransko Lake on the island of Cres (the Vransko Lake Nature Park), the lower Neretva delta, the Raša, Zrmanja, Krka and Cetina rivers, the island of Krapanj and


Pokupska vrpčarka
Pokuplje ribbon millipede
Brachydesmus croaticus Strasser, 1942

Fig. 4: Example page from the Red Book of Croatian Cave Dwelling Fauna (according to Ozimec et al. 2009).

the cities of Nin, Split, Starigrad, Šibenik, Zadar and Dubrovnik (Landau et all. 2009).

5. Collecting of cave taxa: cave taxa are also threatened by inappropriate and illegal collection of cava fauna. This threat is particularly pronounced if traps with attracting agents are set for longer periods. It should be noted that some collectors set hundreds of traps, thus catching thousands of individuals of some species. Furthermore, when a very large number of traps are set, often some are forgotten, or the collectors fail to return to pick them up. In these traps, it is not uncommon to find thousands of dead specimens. The most threatened are populations of beetles (Coleoptera), because some groups are easily attracted to traps and there are large numbers of collectors. The most threatened are type locality caves, especially with many taxa described or with very rare taxa.

The Red Book of Croatian Cave Fauna

All the validly described cave fauna (troglobionts and stygiobionts) of Croatia were checked and defined according to the IUCN methodology: IUCN Red List of Threatened Species, Categories & Criteria (Version 3.1, 2001), Guidelines for Using the IUCN Red List Categories & Criteria (Version 7.0, August 2008) and IUCN Red List Guidelines for Application of IUCN Red List Criteria at Regional Levels (Version 3.0, 2003). The classification of direct threats has been taken from the IUCN-CMP Unified Classification of Direct Threats (Version 1.0, 2006) and its annex listing eleven categories of direct threats and two categories of stresses (negative impacts). The proposed protection measures are taken from the IUCN-CMP Unified Classification of Conservation Actions (Version 1.0, June 2006) in the annex listing the seven fundamental conservation actions (Ozimec et al. 2009).

Finally, the Red Book of Cave Fauna of Croatia (Fig. 4) includes 186 taxa from 16 classes, 29 orders and 54 families. According to threat status, the largest number of taxa, more than 37 % (70 taxa) are vulnerable (VU), followed by critically endangered taxa (CR) with around 35 % (60 taxa), and with endangered (EN) with slightly over 26 % (49 taxa). For 1 % (2 taxa) there are not sufficient data to determine the threat status (DD). Endemism of the cave fauna is highly pronounced, with more than 73 % (136 taxa) of the threatened taxa endemic to Croatia, the majority of these stenoendemic, widespread in very restricted range. About 25 % (47 taxa) of the threatened taxa are endemic to the Dinaric area, distributed in the area of other Dinaric countries, primarily Slovenia, Bosnia & Herzegovina and Montenegro. Only 3 species (1.6 %) are not endemic to the Dinaric area (Fig. 5). The basic division of cave fauna into terrestrial and aquatic fauna shows that 60 % (109 taxa) of the Red Book are terrestrial, troglobiont taxa, while 40 % (77 taxa) are aquatic, stygobiont fauna (Ozimec et al. 2009).

Areas important for the protection of Croatian cave fauna are the following: the Ogulin–Plaški Plateau, Mount Velebit, Mount Biokovo, the Dubrovnik coastal area (part of the Paleoombla area), the Konavle region and the central and southern Dalmatian islands.

The assessment procedure has found the following specific threats to Croatian cave fauna:

- the particular threat to aquatic habitats and aquatic cave fauna due to water pumping and hydrotechnical projects and the extreme vulnerability of the water media and aquatic fauna populations to pollution, indicated by a higher percentage in the Red Book than in cave fauna structure;
- threats to fauna of Dinaric tube worm (*Marifugia cavatica*) tied colonies (marifugial fauna);
- threats to the Adriatic areas, i.e. the coastal karst belt (terrestrial and islands), due to pronounced urbanisation of the coastal belt and the heavy tourism and recreational load;
- threats to fauna in caves located near transport routes, inhabited areas, industrial structures, quarries, etc.;
- threats to fauna in caves equipped for tourism, frequently visited or used for other commercial purposes, or if there is a high possibility that they will be equipped for tourism or used for other purposes;
- threat to caves situated in areas polluted by landmines, lying directly along state borders or in military areas due to their inaccessibility and the inability to conduct systematic monitoring and obtain an overview of the state of the habitat and populations within;
- threats due to collection and setting of traps with attractants (beetles, some snails, etc.).

Several important protection measures are proposed:

- to include all type localities of cave fauna in the national Ecological Network CRO-NEN;
- to establish Strict Nature Reserve status for some important caves and cave systems;
- to define and incorporate protection measures into official Concessionary Contracts for tourist caves and caves used for other commercial purposes;
- to establish management for species through habitat and population monitoring and to study their possible wider distribution;
- ex-situ protection by inclusion in the gene bank;
- implementation of educational and promotional programmes (educational info-panels, mandatory programme in the primary education system);
- courses and workshops on protecting species should be held in administrative units and non-governmental associations;
- information dissemination through the national, private and local media about the need to protect species and methods of protection;
- enforcing the regulations on illegal visits and illegal dumping of waste with high fines.

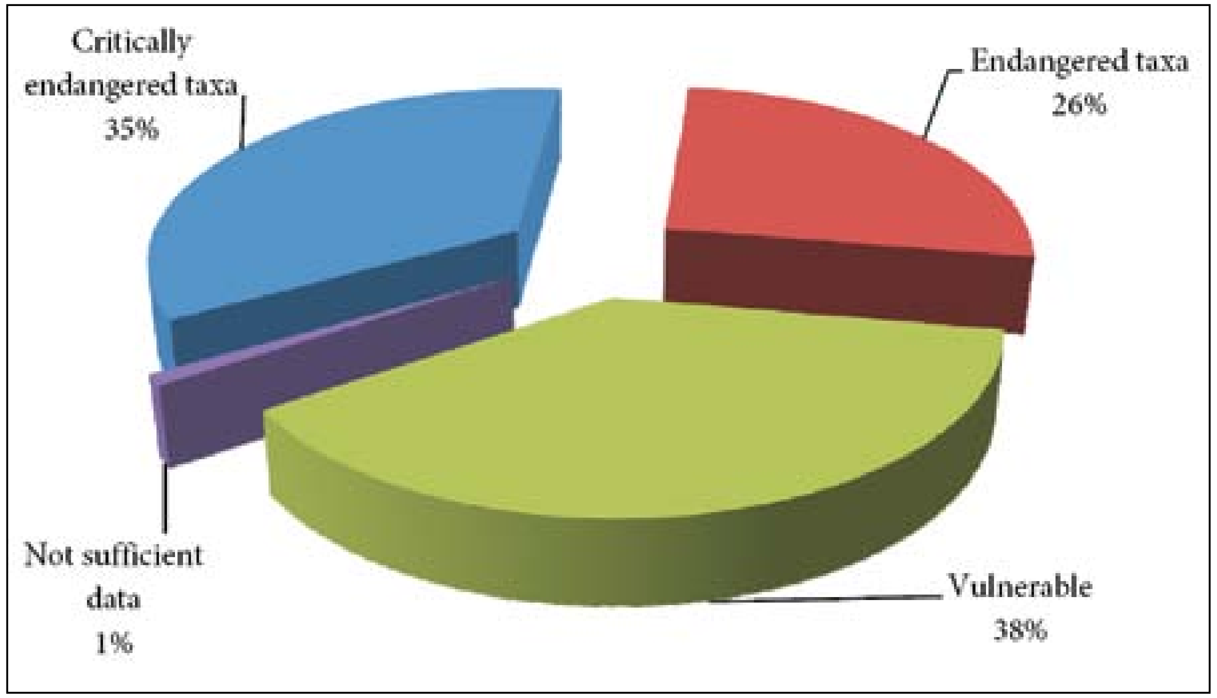

Fig. 5: Division of threatened cave fauna of Croatia according to IUCN categories (according to Ozimec et al. 2009).

Conclusion

This example based on the *Red Book of Croatian Cave-Dwelling Fauna* shows that the Dinaric cave fauna is the richest in the world (Culver & Sket 2000), regularly stenoendemic, with very restricted distribution, and threatened by several negative anthropogenic influences, especially the stygobionts and aquatic habitats. Systematic biospeleological research and protection measures are needed, in which it is necessary to define the following: the general biodiversity of Dinaric cave fauna; the distribution range and endemism of Dinaric cave fauna; exact name, position and status of type localities; and potential and active threats and protection measures for habitats and taxa. Red Books for other states in the Dinaric range are necessary to identify the most endangered taxa and habitats, and thus areas important for protection, in order to ensure integral protection of Dinaric cave fauna as a whole.

References

Bedek J., Gottstein Matočec S., Jalžić B., Ozimec R., Štamol V., 2006. Katalog tipskih špiljskih lokaliteta faune Hrvatske (Catalogue of Cave Type Localities of Croatian Fauna), Natura Croatica, 15/Suppl. 1: 1–154.

Culver D. C., Sket B., 2000. Hotspots of subterranean biodiversity in caves and wells, Journal of Caves and Karst Studies, 62/1: 11–17.

Gottstein Matočec S. (ed.), Bakran-Petricioli T., Bedek J., Bukovec D., Buzjak S., Franičević M., Jalžić B., Kerovec M., Kletečki E., Kralj J., Kružić P., Kučinić M., Kuhta M., Matočec N., Ozimec R., Rađa T., Štamol V., Ternjej I., Tvrtković N., 2002. An overview of the cave and interstitial biota of Croatia, Natura Croatica, 11/Suppl. 1: 1–112.

Landau, S., Legro, S, Vlašić, S. (eds.), 2009. A Climate for Change: Climate Change and its Impacts on Society and Economy in Croatia. UNDP Croatia, Zagreb: 1–270.

Jalzić B., Bedek J., Bilandžija H., Cvitanović H., Dražina T., Gottstein S., Kljaković-Gašpić F., Lukić M., Ozimec R., Pavlek M., Slapnik R., Štamol V., 2010. Atlas špiljskih tipskih lokaliteta faune Republike Hrvatske (The Cave Type Localities Atlas of Croatian Fauna). Svezak 1. Hrvatsko biospeleološko društvo – Državni zavod za zaštitu prirode, Zagreb: 1–261.

Marković D., Ozimec R., Trenc N., Lukić T., 2010. Problem of unallowable disposal of waste in the speleological objects in the Dinaric Karst area of Croatia. Zbornik radova. Međunarodna konferencija Upravljanje opasnim i neopasnim otpadom u regiji (international conference on hazardous and nonhazardous waste management in the region), Zenica 11–13 February 2010, Sarajevo: 398–409.

Mihevc A., Prelovšek M., Zupan Hajna N. (eds.), 2010. Introduction to the Dinaric Karst. Institut za raziskovanje krasa ZRC SAZU, Postojna: 1–71.

Ozimec R., Bedek J., Gottstein S., Jalžić B., Slapnik R., Štamol V., Bilandžija H., Dražina T., Kletečki E., Komerički A., Lukić M., Pavlek M., 2009. Crvena knjiga špiljske faune Hrvatske (Red Book of Croatian Cave-Dwelling Fauna). Ministarstvo kulture, Državni Zavod za zaštitu prirode, Zagreb: 1–371.

Ozimec R., Lučić I., 2010. The Vjetrenica cave (Bosnia & Herzegovina) – One of the world's most prominent biodiversity hotspots for cave-dwelling fauna, Subterranean Biology, 7: 17–23.

Vandel A., 1965. The Biology of Cavernicolous Animals. Pergamon Press, Oxford: 1–525.

POVZETEK

Prva tri poglavja publikacije podajajo splošen pogled na ranljivost, pritiske, pomen in na varovanje podzemnega krasa z vidika speleologije, hidrogeologije ter speleobiologije. Tako Prelovšek ugotavlja, da je podzemni kras zaradi majhnih letnih klimatskih sprememb in starosti izjemno ranljiv. Kljub temu se nanj izvajajo različni pritiski, od katerih velja omeniti zlasti posege v jame urejene za turistični obisk in jame, kjer se izvaja »jamski treking«. Čeprav so jame v Sloveniji zavarovane na visokem nivoju z Zakonom o varovanju podzemnih jam ter v okviru nekaterih zavarovanih območij, se v njih še vedno opažajo prekomerni pritiski kot posledica preteklih in sedanjih aktivnosti.
V drugem poglavju Petričeva podaja osnovne značilnosti kraških vodonosnikov ter ugotavlja njihovo ranljivost. Nadalje navaja načine njihovega varovanja, pri čemer se osredotoča predvsem na poznavanje smeri in značilnosti podzemnega pretakanja voda ter s tem na ocenjevanje njihove ranljivosti, s čemer lahko primerno načrtujemo življenje na krasu z vidika varovanja podzemnih voda in ustrezno ukrepamo ob primerih onesnaženja.
Polak in Pipanova uvodoma poudarjata kompleksnost podzemnega krasa kot habitata, ki poleg jam vključuje tudi za človeka neprehodne razpoke in pore. Navajata različne grožnje podzemnemu habitatu in živalstvu, kot so izkoriščanje mineralnih surovin, rudarjenje, gradnja infrastrukture, razvoj jamskega turizma, spremembe kvalitete in količinske razpoložljivosti vode, direktni vpliv človeka ter klimatske spremembe.
Mihevc v prvem poglavju posameznih primerov pritiskov in varovanja podzemnega krasa podaja potek in posledice kopičenja skoraj 200 let trajajočih posegov v podzemni kras na primeru Postojnske jame. Tako navaja primere lomljenja kapnikov, načine osvetljevanja jame, razvoj jamske infrastrukture in direktne vplive s strani obiskovalcev. Ugotavlja, da je po skoraj dvesto letih intenzivne turistične rabe Postojnska jama še vedno enkratna, lepa, zanimiva in relativno dobro ohranjena.
Podoben je prispevek Cerkvenikove za Škocjanske jame, katerih intenziven razvoj poteka ravno tako skoraj dve stoletji. Navaja zgodovino rabe jame od prazgodovine do danes s poudarkom na raziskovanju ter upravljanju s Škocjanskimi jamami kot turističnimi jamami v zadnjih dveh stoletjih. Podrobneje so opisani infrastrukturni posegi, zgodovina turističnega obiska, načini zaščite jame skozi zgodovino ter pogled v upravljanje z jamo v bodoče.
Prelovšek opisuje zgodovino raziskovanja Križne jame in njen turistični razvoj. Posebej se usmerja na neposredno in posredno ogroženost Križne jame, ukrepe za preprečevanje netrajnostnih poškodb v njej ter sedanji način vodenja turistov skozi jamo. Sedanje upravljanje z jamo navaja kot zgleden primer turističnega upravljanja s srednje obiskano jamo v Sloveniji.
Specifičen primer negativnega vliva na jamo podaja Mulec v poglavju o lampenflori, to je razrastu nižjih in višjih rastlin na osvetljenih površinah jam. Navaja vzroke za razvoj lampenflore ter njene značilnosti, na podlagi katerih lahko ukrepamo zoper nezaželen razrast rastlin predvsem v turističnih jamah, kjer je pojav lampenflore kljub izboljšani tehnologiji osvetljevanja še vedno pereč.
O izvajanju klimatskega in biološkega monitoringa v Postojnski jami piše Šebela. Podaja osnove, ki so pripeljali do beleženja klimatskih in bioloških parametrov s strani Inštituta za raziskovanje krasa ZRC SAZU. Avtorica navaja mesta, kjer se monitoring izvaja, in nabor parametrov, ki se na teh mestih merijo. Podani so rezultati meritev zlasti v času organizacije jaslic ter napotki za trajnostno upravljanje s Postojnsko jamo.

Knez in Slabe v prispevku o varovanju jam pri gradnji avtocest v Sloveniji podajata spoznanja pri gradnji odsekov avtocest preko kraških območij Slovenije. Posebej so izpostavljeni odseki preko Krasa, Dolenjske in Vipavske doline. Navedeni so ukrepi za ohranjanje čim večjega števila jam, kot je to med gradnjo mogoče.
Pri delih v kamnolomih se pogosto naleti na kraške jame, s čemer se v prispevku ukvarja Zupan Hajnova. Opisani so pomembnejši kamnolomi apnenca, jame, ki so se odprle pri širjenju kamnolomov, podrobneje pa je predstavljen primer Osovniške jame odkrite leta 2001 v kamnolomu Pijovci. Pri tem podaja opis jame, predlaga seznam ukrepov za njeno varovanje in stanje leta 2010.
V poglavju o čiščenju kraških jam Prelovšek opisuje vzroke za onesnaževanje podzemnih jam, zgodovino čiščenj slovenskih jam ter sedanje stanje na področju onesnaževanja jam. Posebej izpostavlja primer čiščenja jam v EU projektu Varovanje podzemnega krasa.
Tudi na legalnem odlagališču zbrani odpadki lahko predstavljajo problem za onesnaževanje okolja, v kolikor je odlagališče postavljeno na kraška tla. S tem problemom se ukvarjata Kogovškova in Petričeva, ki na osnovi izvedenih sledilnih poskusov s treh deponij odpadkov na krasu oblikujeta predloge za učinkovito spremljanje in varstvo podzemnih kraških voda.
Vpliv na vode imajo tudi prometnice na krasu. Kogovškova na podlagi fizikalno-kemičnih analiz meteornih vode s cestišč ter občasnih nesreč pri prevozu nevarnih snovi ugotavlja obstoječe pritiske na podzemni kras ter ukrepe, ki so potrebni za oceno tveganja onesnaženosti zlasti pitnih vodnih virov.
Kuhta obravnava primer onesnaženja reke Pazinčice s kurilnim oljem leta 1997. Ker gre za vdor onesnaženja skozi ponorno Pazinsko jamo, se je onesnaženje zaradi širokih kraških kanalov hitro preneslo na okoliške vodne vire. Čeprav se je z ukrepi zadržalo znatni del kurilnega olja že pred Pazinsko jamo, avtor natančno opisuje izmerjene vplive na nižje ležečih kraških izvirih, kjer je bil vpliv zaradi razredčevanja vzdolž toka sicer pod pričakovanjem.
Potencialne vplive med gradnjo in v času obratovanja drugega železniškega tira Divača-Koper ugotavljata Petričeva in Kogovškova predvsem preko sledilnih poskusov, ki so osnova za ugotavljanje glavnih in stranskih smeri pretakanja podzemnih voda ter njihove hidrološke značilnosti. Seveda se pred opisovanjem na novo izvedenih sledilnih poskusov opirata tudi na pretekla spoznanja o hidrogeološki zgradbi in že dokazani smeri podzemnih vodnih tokov.
S primerjavo pravnih evropskih pristopov pri varovanju pitnih podzemnih voda se ukvarja Ravbarjeva. Posebej izpostavlja prekomejno varovanje kraških vodonosnikov, ki na mnogih delih Evrope oz. sveta še vedno ni ustrezno rešeno.
Z varovanjem pitnih voda je povezano tudi kartiranje ranljivosti, ki izpostavlja najbolj občutljiva območja krasa, kjer so kakršni koli posegi človeka še najmanj zaželeni. Ravbarjeva podrobneje izpostavlja slovenski pristop h kartiranju ranljivosti in ogroženosti podzemnih kraških voda.
Ozimec s sod. opisuje pomen biospeleoloških raziskav na krasu, izpostavlja pa kot primer načrt sklopa aktivnosti in preliminarne rezultate biospeleoloških raziskav v slovenski in hrvaški Istri v okviru EU projekta Varovanje podzemnega krasa.
Z vprašanjem varovanja močerila se ukvarja Hudoklin, ki preko preteklih pritiskov, analiz vode in podatkov drugega terenskega opazovanja ugotavlja, da se populacija močerila kljub ustreznemu pravnemu varstvu verjetno zmanjšuje. Temu so krivi preveliki pritiski na kraško vodo preko onesnaževanja s hranili, težkimi kovinami in obstojnimi organskimi snovmi.
Zadnji članek Ozimca se nanaša na Rdečo knjigo podzemnega dinarskega živalstva. V članku izpostavlja izjemno bogastvo podzemne dinarske favne, njeno endemičnost ter sklop petih groženj, ki ji pretijo. V nadaljevanju podaja metodologijo določanja ogroženosti in seznam ogroženih skupin živali. Pri tem Rdečo knjigo navaja kot dokument, ki lahko preko poznavanja biodiverzitete in njene ogroženosti poda ukrepe za boljše integralno varovanje podzemne favne in njenega habitata.

SAŽETAK

Prva tri poglavlja izdanja pružaju opći pogled na ranjivost, pritiske, važnost i čuvanje podzemnog krša s aspekta speleologije, hidrogeologije i speleobiologije. Prelovšek tako zaključuje da je podzemni krš zbog malih godišnjih klimatskih promjena i starosti iznimno ranjiv. Usprkos tome na njega se vrše različiti pritisci od kojih treba spomenuti naročito zahvate u jame uređene za turističke posjete i jame u kojima se izvodi »speleo treking«. Iako su jame u Sloveniji zaštićene Zakonom o zaštiti podzemnih jama, u okviru nekih zaštićenih područja, u njima se još uvijek primjećuju prekomjerni pritisci kao posljedica prošlih i sadašnjih aktivnosti.
U drugom poglavlju, autorica Petrič navodi osnovne značajke krških vodonosnika te utvrđuje njihovu ranjivost. Zatim navodi načine njihove zaštite, a pritom se usredotočuje prvenstveno na poznavanje smjerova i značajki podzemnih prelijevanja voda te time i na ocjenjivanje njihove ranjivosti, čime se na primjeren način može planirati život na krškom tlu s aspekta zaštite podzemnih voda i poduzimanja odgovarajućih mjera u slučaju zagađenja.
Autori Polak i Pipan uvodno naglašavaju složenost podzemnog krškog svijeta, kao habitata koji osim jama, uključuje i za čovjeka neprohodne pukotine i pore. Navode različite faktore koji ugrožavaju podzemni habitat i životinjski svijet, poput iskorištavanja mineralnih sirovina, rudarenja, izgradnje infrastrukture, razvoja spelo turizma, promjene kvalitete i količinske raspoloživosti vode, izravnog utjecaja čovjeka te klimatskih promjena.
Mihevc u prvom poglavlju o pojedinim primjerima pritisaka i zaštite podzemnog krša na primjeru Postojnske jame razmatra tijek i posljedice intenziviranja zahvata u podzemni krš u zadnjih 200 godina. Tako navodi primjere loma stalaktita, opisuje različite načine rasvjete jama, opisuje razvoj spiljske infrastrukture i izravne utjecaje posjetitelja na same lokalitete. Zaključuje da je nakon gotovo dvjesto godina intenzivnog turističkog korištenja, Postojnska jama još uvijek jedinstvena, lijepa, zanimljiva i relativno dobro očuvana.
Sličan je doprinos autorice Cerkvenik u vezi sa Škocjanskim jamama, čiji se intenzivni razvoj također odvija gotovo dva stoljeća. Navodi povijest korištenja jame od prapovijesti do danas, s naglaskom na istraživanju te upravljanju Škocjanskim jamama kao turističkim jamama u posljednja dva stoljeća. Detaljnije su opisani infrastrukturni zahvati, povijest turističkih posjeta, načini zaštite jame tijekom povijesti te uvid u upravljanje jamom u budućnosti.
Prelovšek opisuje povijest istraživanja Križne jame i njezin turistički razvoj. Posebno se bavi neposrednom i posrednom ugroženošću Križne jame, mjerama za sprječavanje neodrživih oštećenja u njoj te sadašnjim načinom vođenja turista kroz jamu. Sadašnje upravljanje jamom navodi kao idealan primjer turističkog upravljanja jame srednje posjećenosti u Sloveniji.
Specifičan primjer negativnog utjecaja na jamu navodi Mulec u poglavlju o lampenflori, odnosno razrastanju nižih i viših biljaka na osvijetljenim površinama jama. Navodi uzroke razvoja lampenflore te njezine značajke, na osnovi kojih se mogu poduzimati mjere protiv neželjenog širenja biljake prvenstveno u turističkim jamama, u kojima pojava lampenflore, usprkos boljoj tehnologiji rasvjete, još uvijek nije riješena.
Šebela piše o provođenju klimatskog i biološkog praćenja u Postojnskoj jami. Predstavlja osnove koje su dovele do bilježenja klimatskih i bioloških parametara od strane Instituta za istraživanje krša ZRC SAZU. Autorica nabraja mjesta na kojima se provodi praćenje i parametre koji se mjere na tim mjestima. Navode se rezultati mjerenja, posebice tijekom organizacije jaslica te upute za održivo upravljanje Postojnskom jamom.
Knez i Slabe u doprinosu o zaštiti jama prilikom izgradnje autocesta u Sloveniji navode spoznaje do kojih se došlo pri izgradnji dionica autocesta preko krških područja u Sloveniji. Posebno su

ispostavljene dionice preko Krasa, Dolenjske i Vipavske doline. Navedene su mjere za očuvanje što većeg broja jama tijekom gradnje.

Autorica Zupan Hajn u svojem se prilogu bavi dijelovima u kamenolomima u kojima se često otkrivaju krške jame. Opisani su važniji kamenolomi vapnenca, jame koje su se otvorile prilikom proširenja kamenoloma, a detaljnije je predstavljen primjer Osovniške jame otkrivene 2001. godine u kamenolomu Pijovci. Navodi se opis jame, predlaže se popis mjera za njezinu zaštitu i stanje 2010. godine.

U poglavlju o čišćenju krških jama Prelovšek opisuje uzroke njihovog zagađenja, povijest čišćenja slovenskih jama te trenutačno stanje na području zagađenja jama. Posebno se naglašava primjer čišćenja jama tijekom projekta Europske unije Zaštita podzemnog krša.

I otpad odložen na službenim odlagalištima može predstavljati problem za zagađenje okoliša, ako se odlagališta nalaze na krškom tlu. S tim se problemom bave autorice Kogovšek i Petrič, koje na osnovi izvedenih pokusa praćenja s tri deponija otpada na krškom tlu predlažu načine učinkovitog praćenja i zaštite podzemnih krških voda.

Utjecaj na vode imaju i prometnice na kršu. Autorica Kogovšek na osnovi fizikalno-kemijskih analiza oborinskih voda s cesta te povremenih nesreća prilikom prijevoza opasnih tvari utvrđuje postojeće pritiske na podzemni krš te mjere koje su potrebne za ocjenu rizika zagađenja, posebice izvora pitke vode.

Kuhta obrađuje primjer zagađenja rijeke Pazinčice lož uljem 1997. godine. Budući da je riječ o prodoru zagađenja kroz Pazinsku jamu s ponornicom, zagađenje se zbog širokih krških kanala brzo prenijelo na okolne izvore vode. Iako se mjerama uspjelo zadržati znatan dio lož ulja još prije prodora u Pazinsku jamu, autor detaljnije opisuje izmjerene utjecaje na niže ležećim krškim izvorima, gdje je utjecaj zbog razrjeđivanja uzduž tijeka bio ispod očekivanja.

Potencijalne utjecaje tijekom gradnje i u vrijeme rada drugog željezničkog kolosijeka Divača-Kopar autorice Petrič i Kogovšek utvrđuju prvenstveno putem pokusnih praćenja koji su osnova za utvrđivanje glavnih i sporednih smjerova prelijevanja podzemnih voda te njihovih hidroloških značajki. Prije opisa novoizvedenih pokusnih praćenja oslanjaju se, naravno, i na ranije spoznaje o hidrogeološkoj strukturi i već dokazanom smjeru podzemnih vodenih tokova.

Usporedbom pravnih europskih pristupa pri zaštiti pitkih podzemnih voda bavi se autorica Ravbar. Posebno naglašava prekograničnu zaštitu krških vodonosnika koji u mnogim dijelovima Europe, odnosno svijeta, još uvijek nije na odgovarajući način riješeno.

Sa zaštitom pitke vode povezana je i izrada karata ranjivosti koje prikazuju najosjetljivija područja krša na kojima su bilo kakvi zahvati čovjeka najmanje poželjni. Autorica Ravbar detaljnije naglašava slovenski pristup izradi karata ranjivosti i ugroženosti podzemnih krških voda.

Ozimec i suradnici opisuju značaj biospeleoloških istraživanja na kršu, a kao primjer naglašavaju plan sklopa aktivnosti i preliminarne rezultate biospeleoloških istraživanja u slovenskoj i hrvatskoj Istri u okviru projekta Europske unije Zaštita podzemnog krša.

Pitanjem zaštite čovječje ribice bavi se Hudoklin, koji na osnovi pritisaka u prošlosti, analiza vode i podataka iz drugog terenskog promatranja zaključuje da se populacija čovjekove ribice usprkos odgovarajućoj pravnoj zaštiti vjerojatno smanjuje. Krivnja za to su preveliki pritisci na kršku vodu zagađenjem putem gnojenja, teškim metalima i dugotrajnim organskim tvarima.

Zadnji članak Ozimeca odnosi se na Crvenu knjigu podzemnog dinarskog životinjskog svijeta. U članku se naglašava iznimno bogatstvo podzemne dinarske faune, njezina endemska značajka te sklop pet faktora ugrožavanja koje joj prijete. U nastavku navodi metodologiju definiranja ugroženosti i popis ugroženih životinjskih skupina. Pri tome Crvenu knjigu označava kao dokument koji poznavanjem bioraznolikosti i njezine ugroženosti pruža mjere za bolju integralnu zaštitu podzemne faune i njezinog habitata.