

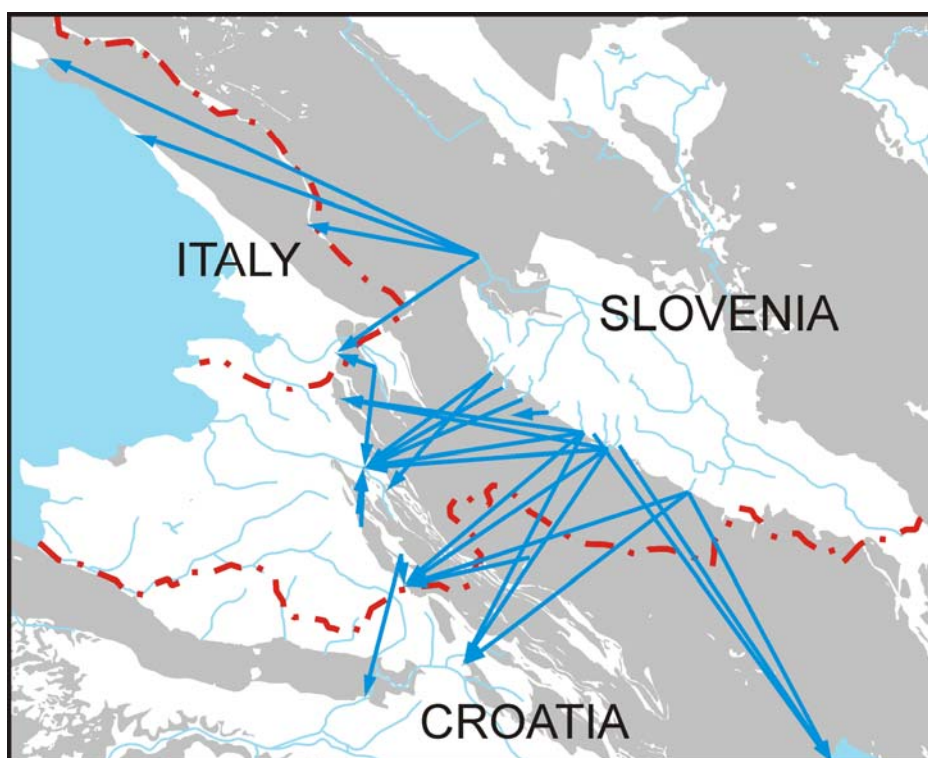
KARST RESEARCH INSTITUTE SRC SASA

Speleological Association of Slovenia
Slovenian National Commission for UNESCO
Karst Commission IGU
International Union of Speleology UIS



15th INTERNATIONAL KARSTOLOGICAL SCHOOL “CLASSICAL KARST”

Management of Transboundary Karst Aquifers



Postojna, 2007

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Cover figure

Transboundary karst aquifers (see Fig. 6 for references)

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SMART-KARST (MSCF-2005-029674)



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Project **SMART-KARST** (MSCF-2005-029674)

Within the frame of the 6th FP Action Marie Curie Conferences & Training Courses the Karst Research Institute SRC SASA is leading the project SMART-KARST: International Karstological school “Sustainable management of natural resources on karst”. The project supports five events organized in the period from 2006 to 2009. One of its main objectives is to bring together researchers of karst from different disciplines, and especially to facilitate dissemination of knowledge from experienced to early-stage researchers. Therefore at each event 45 participants in the early stage of their research career receive a grant which covers travel costs, living allowance, and registration fee. Organisation of each event is partly supported by the project.

According to the rules of the Marie Curie Action all participants are invited to complete the Assessment Questionnaire, which is designed to give the EU Commission feedback on the overall impact of the event. As our SMART-KARST project is thoroughly monitored by the European Commission, we would be very thankful to you if you could take some time and complete the questionnaire after the end of the School.

A web based application has been developed to allow the online submission of questionnaires. It is available at <http://webgate.cec.eu.int/sesam>

First you should click **MCA Questionnaires** in the left upper corner.

Then you choose: Instrument: MCA-Marie Curie Actions

Project type: SCF-Series of Events

Then click the button: Edit Questionnaire

Project ID is: 029674

Then click the button: Validate

In this way you reach a short questionnaire, which you can complete in few minutes. All information provided to the European Commission will remain anonymous and confidential.

General information

Lectures and poster presentations

Lectures will be held in the lecture room at the Cultural centre of Postojna (Kulturni dom Postojna, Prešernova ulica 1, Postojna). Presentation of posters will be held in the hall of the Karst Research Institute SRC SASA (Titov trg 2, Postojna). See schedule for details.

Excursions

Do not forget to **register your participation at excursions at the registration desk!** Seats on buses are limited. Suitable clothes and shoes for the fieldwork are required.

Departures for the excursions

Meeting point for excursions is at parking place in front of the PTC Primorka (Business Centre Primorka, see map). **PLEASE BE ON TIME!**

Beverages and food on the excursions

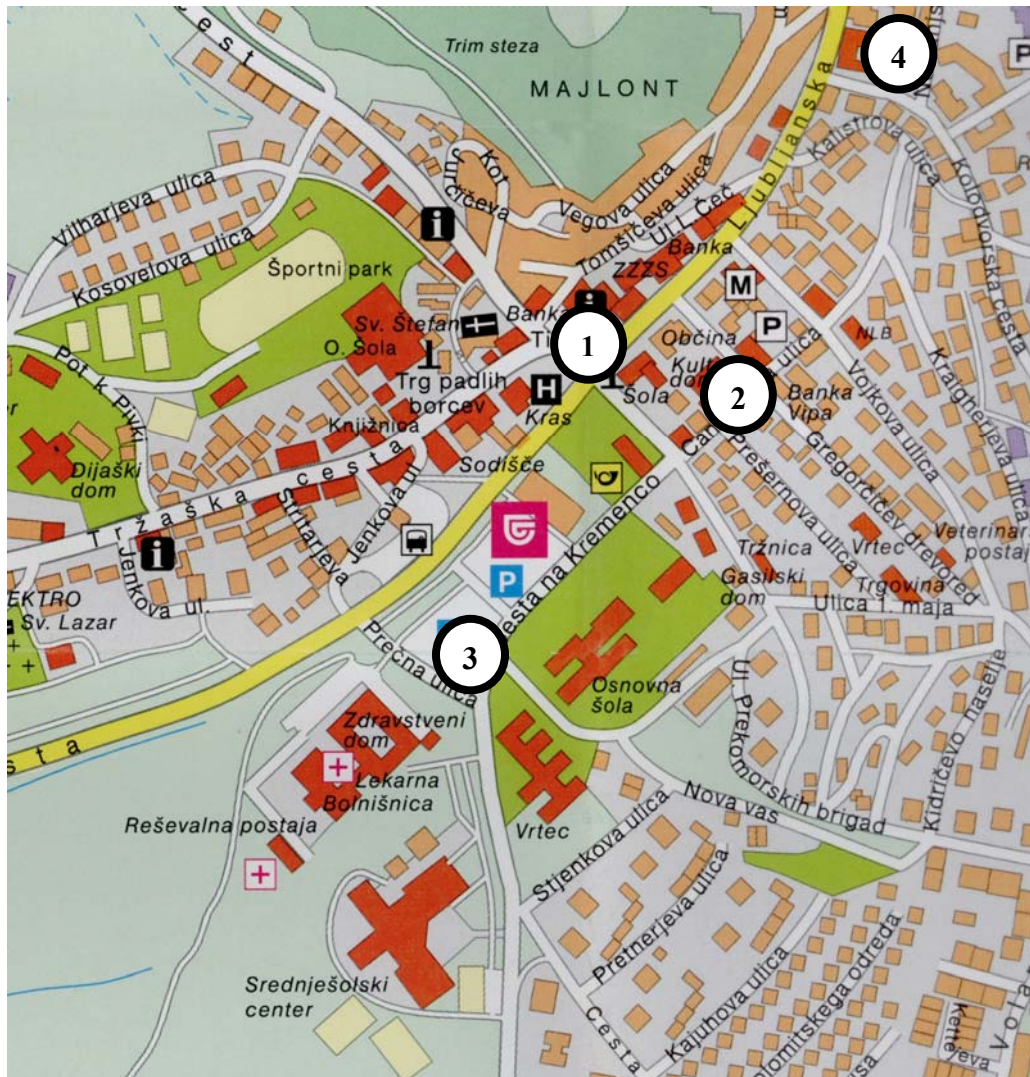
Organizer will supply some beverages for the field-trips, take some additional if you need more. During the whole day excursion on 21 June 2007 we will stop in Gračišče for the lunch break. Common lunch will be organized in a restaurant, but you can also provide your meal independently. For the lunch in the restaurant you **should register and pay in advance at the registration desk**. There you will get more detailed information about the menu and the price.

Important notice for the excursions

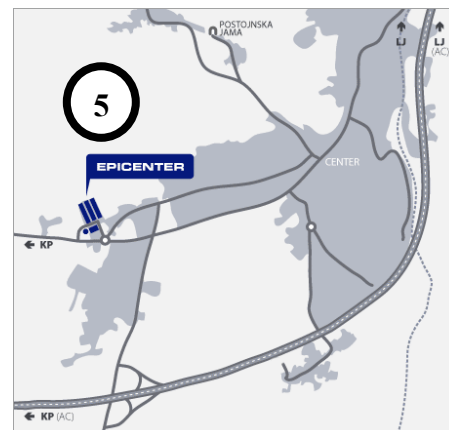
Ticks are excellent vectors for disease transmission and they populate the areas of field trips. Before going to the field trip **USE INSECT REPELLENT!** Do not forget to check yourself carefully for the presence of ticks after the excursions.



Map of Postojna (www.postojna.si)



- 1 – Karst Research Institute SRC SASA (Titov trg 2)
- 2 – Cultural Centre of Postojna (Kulturni dom, Prešernova ulica 1)
- 3 – Parking place for excursions (PTC Primorka, Novi trg 6)
- 4 – Hotel Sport (Kolodvorska cesta 1)
- 5 – TPT Epicenter (Tržaška cesta 82)



Programme

Sunday, 17 June 2007

17.00 – 19.00 Registration of participants (Karst Research Institute SRC SASA)

Monday, 18 June 2007

8.00 – 12.00 Registration of participants (Cultural Centre of Postojna)

Opening Session (Cultural Centre of Postojna)

9.00 – 9.30 Opening

Tadej Slabe, Head, Karst Research Institute SRC SASA

Mitja Bricelj, State Secretary, Ministry of the Environment and Spatial Planning of the Republic of Slovenia

Marjutka Hafner, Director, Slovenian National Commission for UNESCO

Pavel Bosák, Vice President, International Union of Speleology

Session 1 (Cultural Centre of Postojna)

9.30 – 10.30 Keynote lecture: Managing transboundary karst aquifer systems: is it some myth and more magic, than logic?

Shammy Puri

10.30 – 11.00 *Coffee Break*

11.00 – 11.20 Management of aquifer of the Eastern Herzegovina on the example of formal and informal borders

Jasminko Mulaomerović, Jasmina Osmanković, Ivo Lučić

11.20 – 11.40 Transboundary aquifers: some case studies from Switzerland

Philipp Häuselmann

11.40 – 12.00 Decision support system as a management tool for karst aquifers

Saška Vidmar, Barbara Čenčur Curk

12.00 – 14.00 *Lunch break*

Session 2 (Cultural Centre of Postojna)

14.00 – 15.00 Keynote lecture: The importance of the Dinaric aquifer for regional development

Mitja Bricelj

15.00 – 15.20 Proposed methodology of mapping groundwater vulnerability and contamination risk for the protection of karst aquifers in Slovenia

Nataša Ravbar, Nico Goldscheider

15.20 – 15.50 *Coffee Break*

- 15.50 – 16.10 Study of the Mia Mt. karst aquifer (Friuli Venezia Giulia - Italy)
W. Boschin, G. Casagrande, F. Cucchi, A. Rossi, E. Zavagno, L. Zini
- 16.10 – 16.30 Hydrogeology of the Pribojska banja spa thermal karst groundwaters
Ana Vranješ, Djuro Milanković, Nevena Savić, Dejan Milenić
- 16.30 – 16.50 Environmental impact assessment in South Eastern part of Kučaj Mountains
Branislav Petrović

Tuesday, 19 June 2007

Session 3 (Cultural Centre of Postojna)

- 9.00 – 10.00 Keynote lecture: Mediterranean karst resources management: a specific method to assess water resources and to define water management scenarios**
Nathalie Doerfliger
- 10.00 – 10.20 Groundwater flow in the karst aquifer in East Mediterranean region
Tamer Nassar
- 10.20 – 10.50 *Coffee Break*
- 10.50 – 11.10 Karst water course tracing between ponor and springs: the Reka river example, Karst, SW Slovenia – NE Italy
Borut Peric, Franci Gabrovšek, Janja Kogovšek, Walter Boschin, Hans Krafft
- 11.10 – 11.30 Possibilities and problems of discharge measurements in karst areas - examples from the South Franconian Alb (Germany)
Brummeisl Christian, Schober Simon, Trappe Martin
- 11.30 – 11.50 Flow and vulnerability of groundwater in the discontinuous carbonates of the crystalline complex, Jeseniky region (Czech Republic)
Jan Kukačka, Viola Altová, Jiří Bruthans, Ondřej Zeman
- 11.50 – 14.00 *Lunch break*
- 14.00 – 19.00 Half-day excursion: Hydrogeological characterisation and vulnerability mapping in the Podstenjšek catchment**
Nataša Ravbar

Wednesday, 20 June 2007

Session 4 (Cultural Centre of Postojna)

- 9.00 – 10.00 Keynote lecture: The importance of physico-chemical methods for the management of transboundary karst aquifers**
Hans Zojer

10.00 – 10.20 Monitoring underground streams of transboundary Slovak-Hungarian cave systems Domica-Baradla, the Slovak part
Dagmar Haviarová

10.20 – 10.50 *Coffee Break*

10.50 – 11.10 Assessment of physico-chemical quality of karst water and its sustainable management
Vinod Kumar Jena, B. Ambade, K. S. Patel

11.10 – 11.30 Hydrogeochemical monitoring of the Kutumsar Cave and management of karst water resources
Nitin Kumar Jaiswal, K. S. Patel

11.30 – 11.50 Hydrologic connections and dynamics of water movement in the trans-boundary Classical Karst aquifer: evidence from frequent chemical and stable isotope sampling
Daniel H. Doctor

11.50 – 13.45 *Lunch break*

13.45 – 16.00 Poster session (Karst Research Institute SRC SASA)

17.00 – 18.30 Visit to the Postojnska jama Cave

Thursday, 21 June 2007

8.00 – 19.00 Whole-day excursion: Management of karst aquifers in the area between Trieste and Kvarner bays (Slovenian-Croatian transboundary region)
Water supply company Rižanski vodovod Koper
Janja Kogovšek, Metka Petrič, Josip Rubinić

20.00 Reception at the Institute (Karst Research Institute SRC SASA)

Friday, 22 June 2007

8.00 – 12.30 Half-day excursion: Transboundary karst aquifer of Kras (Slovenian-Italian transboundary area)
Borut Peric, Franci Gabrovšek, Franco Cucchi, Nataša Ravbar

Poster session

Development of spring cave in breccia conglomerate of Zarinabad (east of Khoramabad, Lorestan, Iran)

M. Ahmadipour, A. Shamasi

Application of remote sensing in analysis of land of water resource in Algeria

Zegrar Ahmed

Turistic caves in Polish Tatra Mts.

Grzegorz Barczyk, Zbigniew Ładygin

Scallops in Tekavčja jama

Špela Bavec

Remote sensing based geospatial information systems for cross-border water management

Mateja Breg

Possibilities and problems of discharge measurements in karst areas - examples from the South Franconian Alb (Germany)

Christian Brummeisl, Simon Schober, Martin Trappe

Hydro-ecological problems of alpine karst in Triglav National Park mountain huts: estimation of constructed wetlands applicability

Bojan Erhartič

Study and management of intermunicipal karst aquifers in the region of Alvaizere

João Forte

The comparison of different methods for intrinsic vulnerability mapping on Krvavec area

Grega Juvan, Barbara Čenčur Curk

Function of bedding planes on the karstification of the "Dent de crolles" carbonated massif (Isère, France)

Eloïse Kiefer, Annie Arnaud-Vanneau, Elisabeth Carrio-Schauffhauser

Some examples of land use in Airee and Candeeiros Mountain Ranges National Park, Portugal

Violetta Krzaczek

Transboundary problem with Vjetrenica Cave: one area, two features

Ivo Lučić, Simone Milanolo

Hydrogeological investigations in the watershed of the spring Kakma, southern Croatia

Natalija Matić, Mladen Trutin, Boris Munda

An evaluation of annual couplets in a stalagmite from a flank margin cave on a mid-ocean island

Cristina Montana Puscas, Paul Aharon

The dynamic of the collapse sinkhole within the anthropic salt karst from Ocnele Mari, Romania

Magdalena Năpăruș

Influence of karst springs on the water quality of the Altmühl River in south Franconia (Germany)

Eva Olmo Gil, Martin Trappe

Vertical caves of high mountainous karst, as complex, poligenetic systems. Examples of Wielka Sniezna (western Tatra Mts.), Foran del Mus (Julian Alps, Italy), Pierre Saint Martin (Pyrenees, France)

Patrycja Pawlowska- Bielawska

Hummocky Karren - a new type of Karren?

Lukas Plan

Ponor phenomena at Bloke

Barbara Primc

Feasibility of using Bolje sestre and Karuc springs for water-supplying from the point of view of water quality

Dragan Radojević, Neda Dević, Stanka Filipović

Groundwater vulnerability mapping of Vidrovan watersource catchment using modified PI method

Milan Radulović

Floods on Planinsko polje

Uroš Stepišnik

Hydrogeological explorations of Mt. Papuk karst aquifer, NE Croatia

Andrej Stroj, Mladen Kuhta

Submerged speleothems - expect the unexpected. Examples from the Eastern Adriatic coast (Croatia)

Maša Surić, Branko Jalžić, Donat Petricoli

Legal aspects of the groundwater usage in the karst region of Minas Gerais, Brazil

Luiz Eduardo Panisset Travassos, Isabela Dalle Varela

Underground water temperature correlations at two measurement sites in Postojnska cave system

Janez Turk

Water quality in selected caves in Croatia

Magdalena Ujević, Dalibor Paar, Darko Bakšić, Damir Lacković

Length of the caves in Slovenia

Timotej Verbovšek

Study of the Late-Holocene evolution of the physical environment of Belgium by means of isotopic geochemical research on speleothems

Tim Verfaillie, S. Verheyden, E. Keppens

International Project Science Across the World »Drinking-water«

Suzana Vidmar

Hydrogeology of the Pribojska banja spa thermal karst groundwaters

Ana Vranješ, Djuro Milanković, Nevena Savić, Dejan Milenić

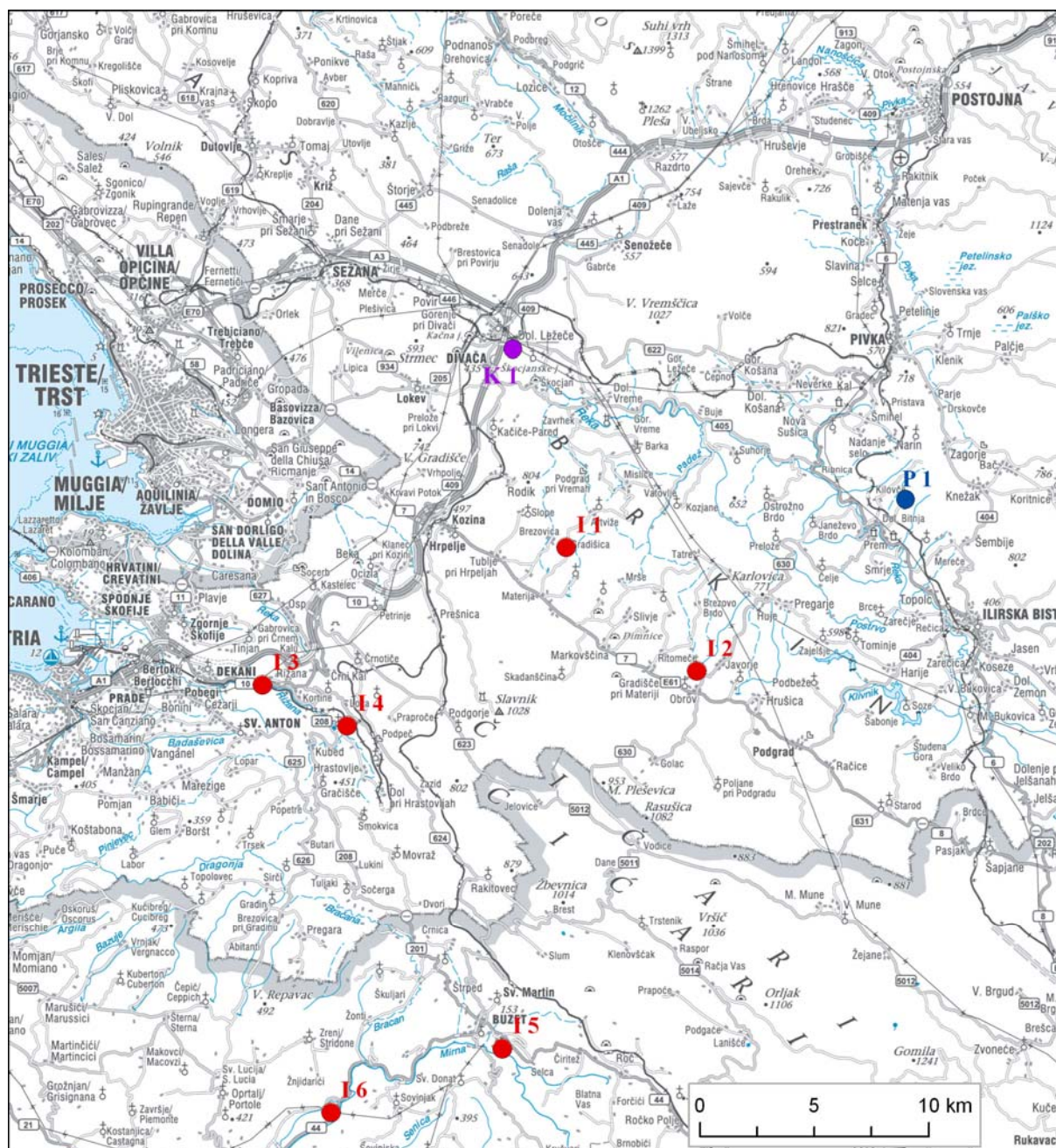
Water flow pattern and mean residence time in unsaturated zone above the Ochozská Cave in the Moravian Karst (Czech Republic) with emphasis on soil layer influence

Helena Vysoká, Jiří Bruthans, Ondřej Zeman

Paleomagnetic data from Postojnska jama-Planinska jama system (Classical Karst, Slovenia): review

Nadja Zupan Hajna, Andrej Mihevc, Petr Pruner, Pavel Bosák

Excursions



HALF-DAY EXCURSION, 19 June 2007, Podstenjšek catchment:

P1- Podstenjšek karst spring.

WHOLE-DAY EXCURSION, 21 June 2007, Karst area between Trieste and Kvarner bays:

I1-Gradišnica, view on the blind valleys of Matarsko podolje, I2-Hotična blind valley, I3-Rizana water treatment plant, I4-Rizana karst spring, I5-Sv. Ivan karst spring, I6-Bulaž karst spring.

HALF-DAY EXCURSION, 22 June 2007, Kras:

K1-Škocjanske jame Caves-ponor of the Reka river.

HALF-DAY EXCURSION, 19 June 2007

HYDROGEOLOGICAL CHARACTERISATION AND VULNERABILITY MAPPING IN THE PODSTENJŠEK CATCHMENT

Nataša Ravbar

Karst Research Institute SRC SASA, Titov trg 2, SI-6230 Postojna, Slovenia.

The Podstenjšek karst springs

Karst springs of the Podstenjšek are situated near the Šembije village under the Snežnik mountain in south-western Slovenia. Karst water outflows in five permanent springs. At high waters numerous smaller springs are activated also. At times of extremely high water conditions water also bursts from the cave of Kozja luknja, which is situated 35 m above the springs. All the water joins in a common stream, called the Podstenjšek stream. After approximately three kilometres it flows into the Reka river as its right tributary. Since 1992 one of the springs has been captured for local drinking water supply. The Podstenjšek water source is not yet protected, even though the expert basis for the water source protection and the proposal of the decree on water protection zones have already been made.

Geological and hydrological settings of the catchment area and surroundings

The catchment area of the Podstenjšek springs occupies moderately karstified limestone and limestone breccias of Cenomanian age and limestone of Palaeocene age that are overthrust to the impermeable flysch layers of Eocene age. Limestone of Lower Cretaceous age, containing very high percentage of CaCO₃ (93-98%) but very poor in fossils, prevails. The underlying flysch layers consist of marl, clay and sandstone (Šikić *et al.* 1972, Šikić & Pleničar 1975). In the uplifted dry valley at the outskirts of the catchment there is periglacial material deposited in the dolines (Fig. 1).

Due to the underlying impermeable rocks a shallow karst aquifer is formed. In response to precipitation events or snowmelt fast and strong hydrologic variations of groundwater table appear, whereas it fluctuates for several tens of meters.

There is no permanent surface stream recharging the springs, however, owing to groundwater fluctuations and weak connections between different karst conduits, two intermittent lakes appear whenever groundwater level is sufficiently high. However, these lakes appear very rarely – the Šembijsko Jezero appears approximately once every two years, while the appearance of the Nariče has only been recorded twice in years 1929 and 2000 (Kovačič & Habič 2005).

Shallow chromic Cambisol that is interwoven with Rendzina layers is unevenly spread and appears in patches. The thickest layers of soils can be found in the bottom of the concave relief shapes, while the rest of the surface is pretty rocky. Larger area is mainly overgrown with forest and meadows or is used for extensive pasturing.

Precipitation is distributed relatively equally throughout the year, and practically no month is climatically dry. The amount of the precipitation in the studied area ranges between 1,500 and 1,600 mm per year, however, the amount increases towards the east due to the orographic barrier.

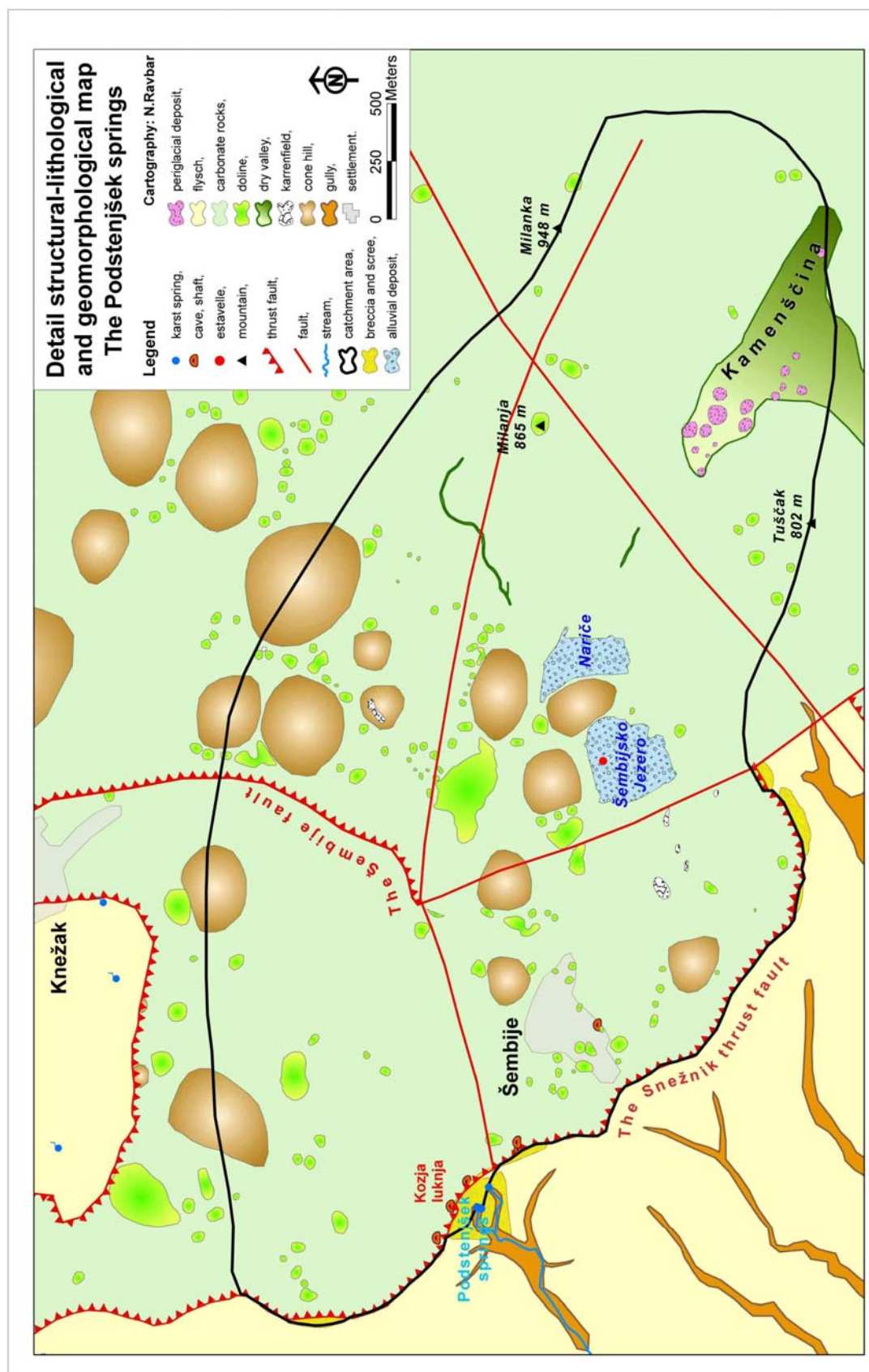


Figure 1: Detail structural-lithological and geomorphological map of the Podstenjšek springs catchment area and surroundings.

Hydrological characteristics of the Podstenjšek springs

The springs demonstrate typical karst hydrological regime with very high short-term flow rates and prolonged periods of medium and low waters. The lowest observed discharge was 6 l/s and the highest was 1.6 m³/s. The average discharge is about 140 l/s. The ratio between low, medium and high waters is thus approximately 1:26:267, which is one of the highest ratios recorded among Slovene springs.

In contrast, the springs do not show high water temperature variations. Water temperature ranges between 9 and 10.6°C in the same period. According to the almost constant water temperature being almost identical to the mean annual air temperature of the area (9.6°C) we can deduce to longer residence times for the underground water.

Specific electrical conductivity ranges between 366 and 487 µS/cm. In general, rapid changes of discharge are followed by distinctive changes of conductivity and smaller but noticeable changes in water temperature, which also reflects the significant karst character of the Podstenjšek springs.

The springs have torrential properties and are characterised by extremely fast reactions to hydrological events – the extreme peaks of the discharges appear within a short time after excessive precipitation events. Usually the discharges of the Podstenjšek springs start to increase with a delay of just few hours or even less. However, some reactions of the springs to the intensive recharge show an interesting and peculiar positive correlation between the discharge and electrical conductivity values (Fig. 2).

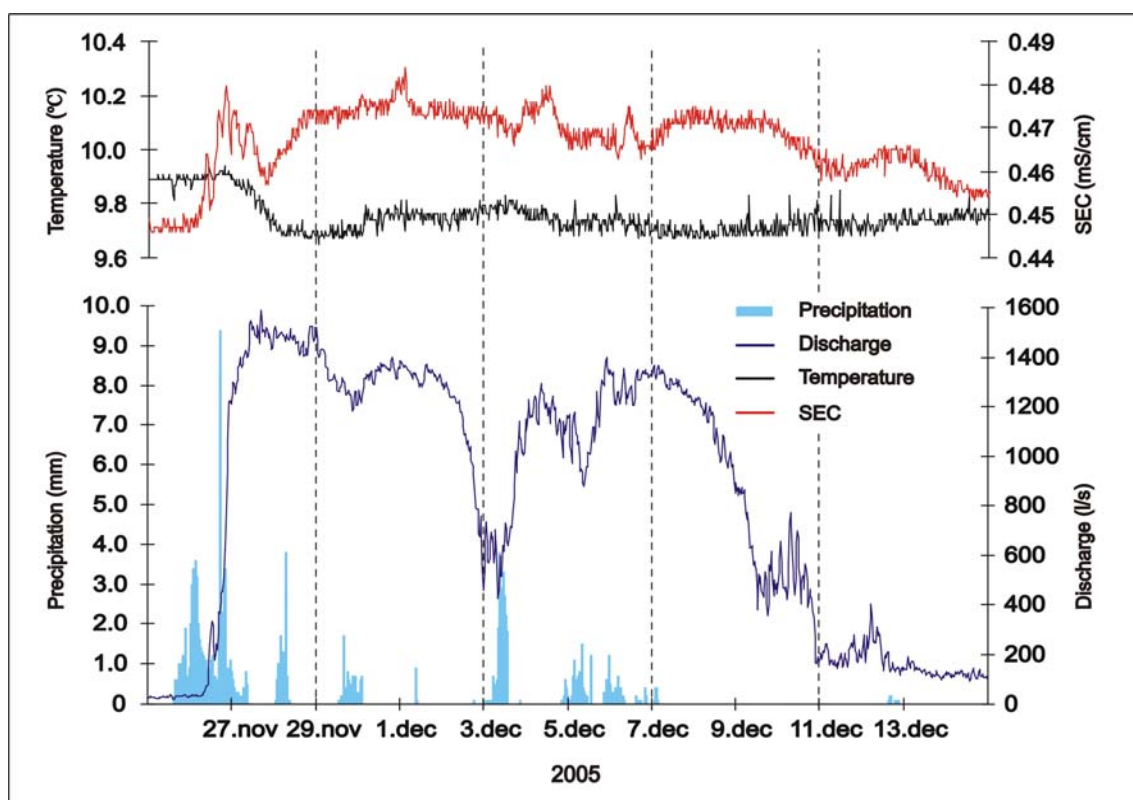


Figure 2: Hydrograph of the Podstenjšek springs in the period between 25th November and 15th December 2005 supplemented by precipitation data gained from the Slovene Environmental Agency (MOP ARSO 2007). Half hour values are displayed on the graph.

Such behaviour could indicate the variations of the catchment size and contribution of other parts of the aquifer. When groundwater level in the Javorniki-Snežnik aquifer is sufficiently high the Podstenjšek becomes an overflow spring and its catchment boundary expands towards the north, northeast and east. Parts of the aquifer with higher groundwater electrical conductivity values (from the Javorniki and Pivka valley and/or from the Milanka mountain) are then also drained by the Podstenjšek (Fig. 3). In addition to larger recharge quantities, greater catchment area also explains very high discharge variations of the Podstenjšek (Ravbar 2007).

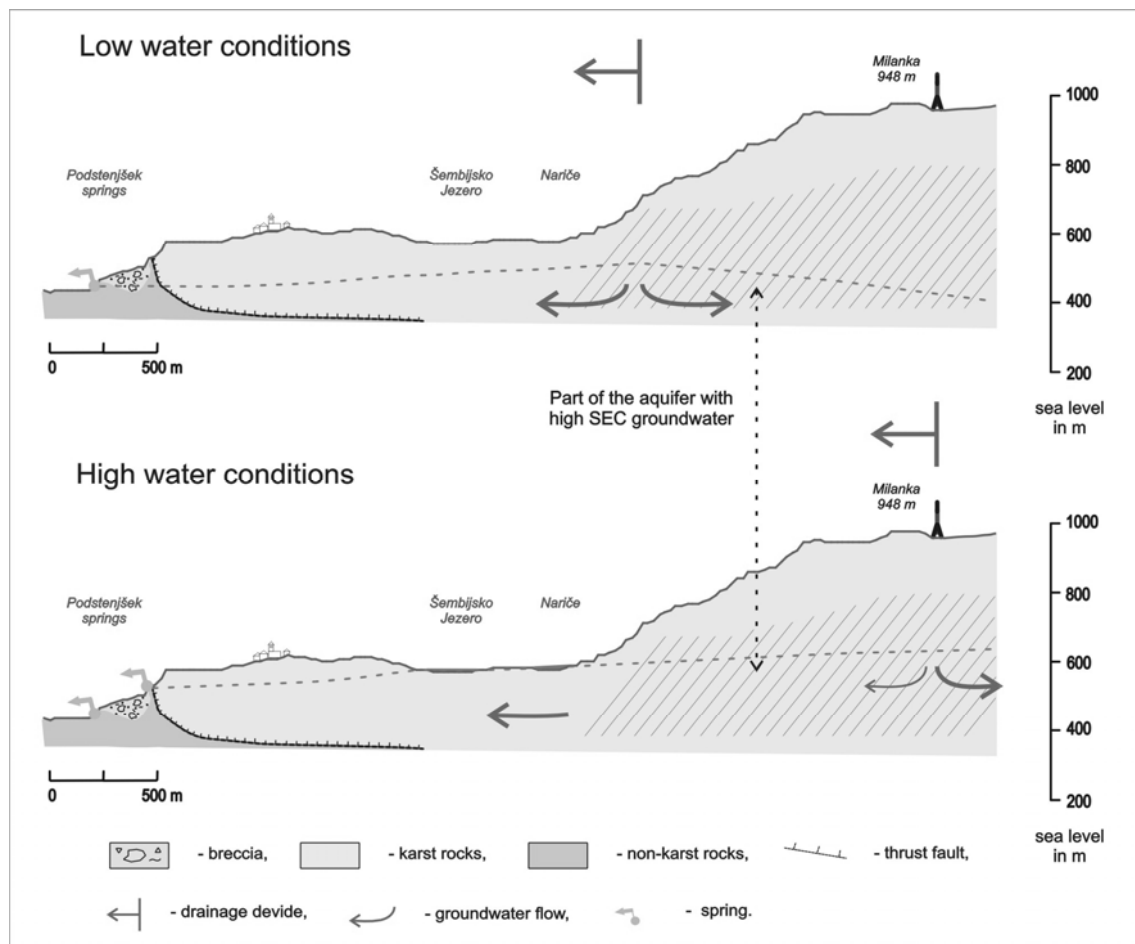


Figure 3: Variable drainage divide during low and high water conditions.

Slovene Approach to groundwater vulnerability and contamination risk mapping

The Slovene Approach is based on the Spanish COP method of intrinsic vulnerability assessment (Vías *et al.* 2002, Andreo *et al.* 2006), which presented the most complete interpretation of the COST 620 methodology. However, the method has been substantially modified, complemented and extended for source vulnerability mapping. The proposed approach offers a new possibility to integrate surface and groundwater protection. Furthermore, temporal hydrological variability has been integrated in the concept of vulnerability mapping for the first time (Ravbar & Goldscheider 2006). The Slovene Approach also provides comprehensive risk analyses based on the assessment of intrinsic vulnerability, contamination hazard and the importance of the source or resource (Fig. 4).

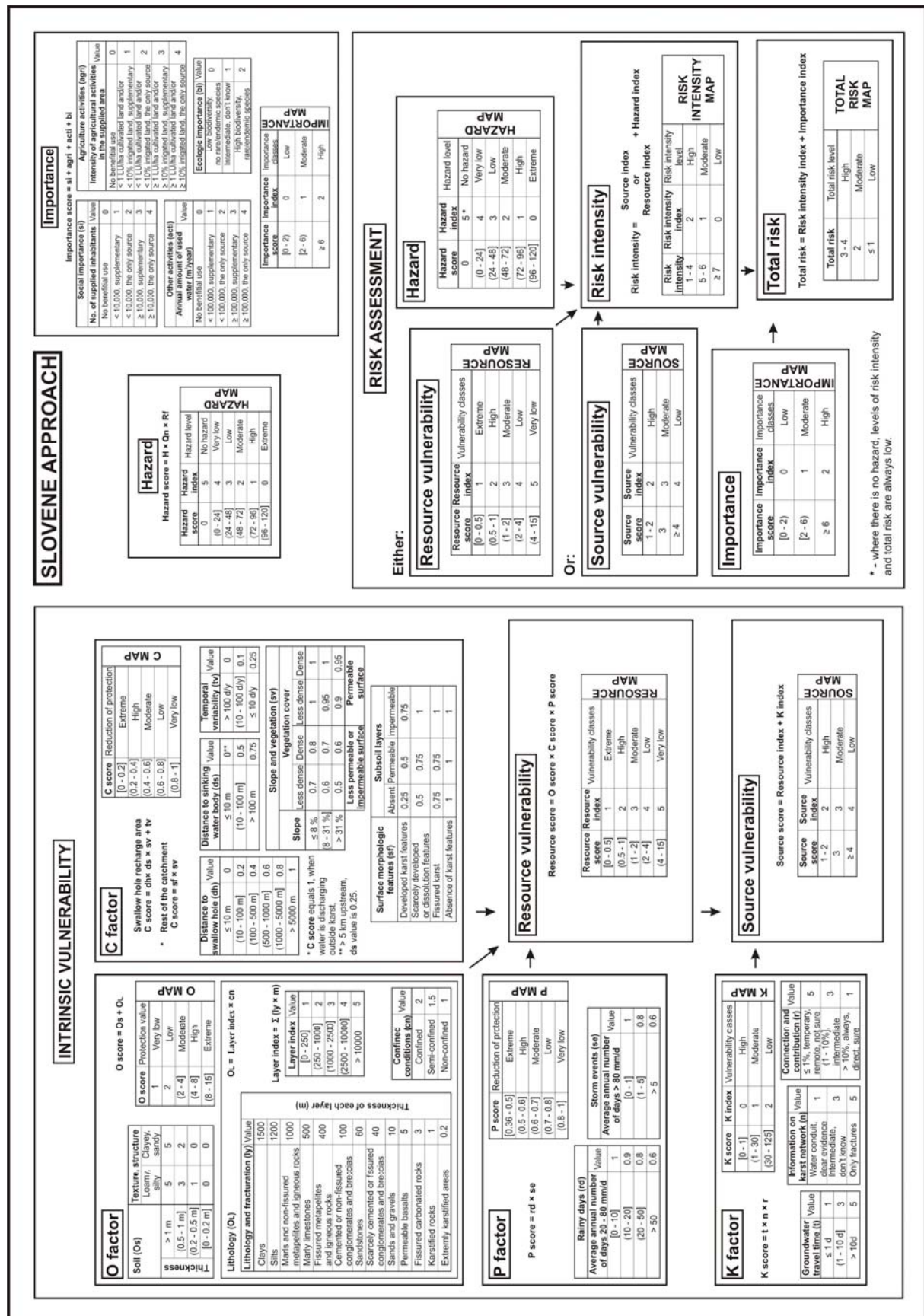


Figure 4: Assessment scheme for the intrinsic vulnerability and contamination risk mapping proposed according to Slovene Approach.

Application to the Podstenjšek springs catchment and validation of the results

For the catchment delineation and application of the Slovene Approach, a holistic research of the test site has been done, including tracer tests, detail structural-lithological and geomorphological mapping, electrical resistivity imaging, as well as hazard mapping. Continuous monitoring of the springs' physico-chemical characteristics has been performed for the hydrograph analyses, water balance calculation and aquifer behavior comprehension (Ravbar 2007).

The catchment can be subdivided into an inner and an outer zone. In the area that is always, directly and fully contributing to the discharge of the springs (i.e. the inner zone) the geomorphological features (karren, highly fractured areas, caves, karst edge) and outcrops along the roads where soil cover is absent or rarely exceeds 20 cm are identified as highly vulnerable. High degree of vulnerability is also assigned to the estavelle (shown in the zoomed inset) where occasional indirect infiltration occurs. Moderate vulnerability has been assigned to the bare karst landscape or karst covered by shallow soils, as well as to the karren and dry valleys in the area of the partial or occasional contribution to the springs (i.e. the outer zone). Bottoms of intermittent lakes and dolines covered by thicker soils or sediments are of low vulnerability, as well as rest of the area of the partial and/or occasional contribution.

The hazards found in the test site are mainly classified as low or very low, however, in more than half of the area no hazards have been identified. In the Šembije village, the only settlement in the catchment, there are 209 inhabitants. The houses are linked to the public sewage system since 1998 and connected to the wastewater treatment plant. The intensity of agricultural activity is relatively low. However, there are some waste disposal and excavation sites.

The importance of the source has been evaluated as medium. By superimposing source vulnerability, hazard and source importance maps, the total contamination risk has been obtained. In general, the contamination risk strongly depends on the hazard level and its distribution. Most of the catchment is exposed to low risk, only urban areas, roads, dumps and excavation sites represent medium degree of contamination risk (Fig. 5).

The source vulnerability map shows zones of low, medium and high degree of vulnerability, which can be the basis for the protection zoning. However, vulnerability maps are conservative simplifications of natural conditions, therefore the results need to be validated.

By carrying out two multi-tracer tests we examined and verified the adequacy of vulnerability class distribution and gained additional information on the mechanism of the potential contaminant transport in different hydrological conditions. The first experiment, carried out in March 2006, was made under high water conditions and was followed by several intense precipitation events so that immediate infiltration and transport of tracers towards the springs took place. Two tracers were injected (injection points A and B). The second experiment, carried out in November 2006, was made under low water conditions. Not until 15 days after the injection a more efficacious rain event occurred. Four tracers were injected in four locations (injection sites 1-4, Fig. 5).

The validation with tracer tests confirmed that the Slovene Approach for intrinsic vulnerability assessment delivers plausible results. Furthermore, the validation also justifies the integration of hydrological variability into vulnerability mapping.

The study has shown the new Slovene Approach gives justified results. Thus, it could be proposed as the basis for the delineation of karst source protection zones, and included to the state protection schemes. Although the method considers karst-specific infiltration conditions, it is not restricted solely to karst but can also be used in non-karst areas. Moreover, since we believe that vulnerability methods should not be restricted to the individual countries'

borders, the Slovene Approach could be a basis for the further work concerning groundwater protection elsewhere.

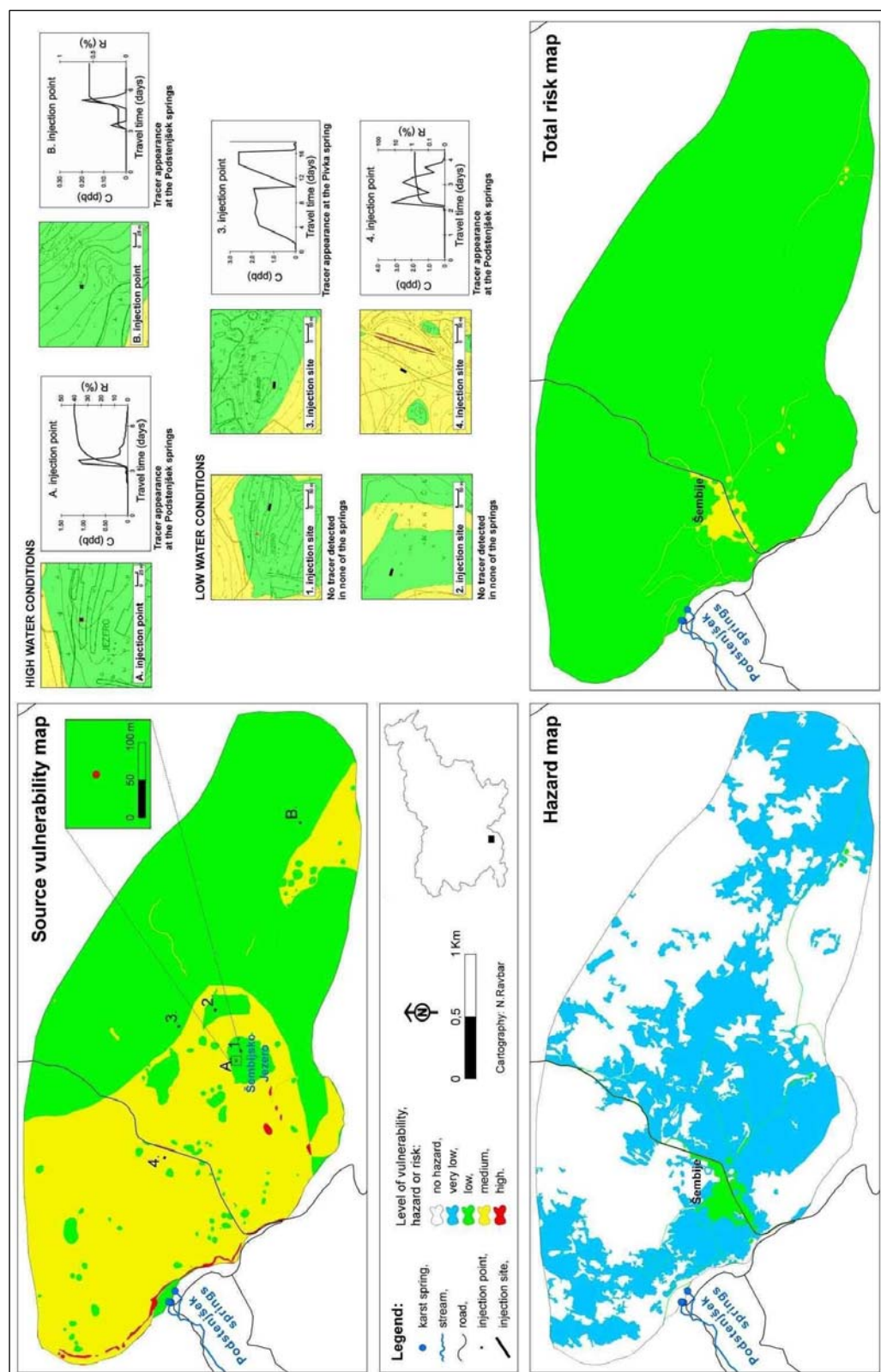


Figure 5: Source vulnerability, hazard and total risk map of the Podstenjšek water source including validation results.

References

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WHOLE-DAY EXCURSION, 21 June 2007

MANAGEMENT OF KARST AQUIFERS IN THE AREA BETWEEN TRIESTE AND KVARNER BAYS (Slovenian-Croatian transboundary area)

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Transboundary karst aquifers in the area between Trieste and Kvarner bays

Slovenia is a typical karst country in which carbonate rocks cover around 43 % of the land. Karst water resources are especially important as they supply around half of the Slovene citizens with drinking water. Therefore the researches of karst waters have been an important task in the past and are becoming more and more important also for the future. The main question is how to use and protect karst water resources properly. To be efficient in this it is necessary to consider specific characteristics of karst aquifers. Due to their heterogeneous structure and complex functioning (unknown routes of the underground flow, bifurcation, the changes in the size of the recharge area at different hydrological conditions, ...) it is by no means an easy task to identify these characteristics. One of the biggest problems is how to define the borders of the recharge area of individual karst springs. And scientific problem becomes also political when these recharge areas spread across two or more countries.

In the south-western part Slovenia borders on two countries: Italy and Croatia. In the area between the Trieste bay and the Kvarner bay of the Adriatic sea state borders cross karst aquifers which are important sources of drinking water in all three countries. The biggest towns in the area are supplied by groundwater from these aquifers (e.g. Koper and other towns on the Slovene Coast from the Rižana karst spring, Rijeka in Croatia from several karst springs, among them also Riječina and Zvir, Buzet in Croatia from Sv. Ivan spring). One exception is Trieste in Italy. In the past the Timava karst spring was captured for the water supply of this town but due to the deterioration of its quality new sources were found in porous aquifers of the Soča/Isonzo alluvium. Common characteristic of mentioned karst springs is their transboundary character. At least partly their recharge area is in one country and abstraction point in the other. Therefore mutual and transboundary research activities and further management measures are indispensable. In the past first steps in this direction were made through different forms of scientific co-operation between research institutions from different countries, and on legal and institutional levels further activities are enhanced by the recommendations of the EU Water Framework Directive.

Hydrogeological characteristics

In a geotectonic sense the area between Trieste and Kvarner bays is in the boundary area between External Dinarides and Adriatic foreland (Placer 1999). The structure of thrust sheets with the alternation of Upper Cretaceous and Palaeocene carbonate rocks and Eocene flysch is characteristic. In well permeable limestones karst aquifers with dominant underground water flow are developed, and for flysch areas with very low permeability surface drainage net is

characteristic. Hydrogeologically important are areas on the contacts between these two units where karst groundwater outflows through karst springs or surface streams from flysch sink into karst aquifers through ponors.



Figure 6: Hydrogeological map of the area between Trieste and Kvarner bays of the Adriatic sea (Legend: 1. Karst-fissured aquifer, 2. Porous aquifer, 3. Very low permeable rocks, 4. Karst spring, 5. Surface stream, 6. Location of oil spillage, 7. Main, secondary and uncertain underground water connection, 8. State border (Sources of digital data: Geological Survey of Slovenija, EIONET)

The Reka river springs in the area of Eocene flysch near Zabiče village. It flows on the surface towards the contact with Cretaceous and Palaeocene limestone where it sinks underground into the world famous Škocjanske jame Caves and flows through the karst aquifer of Kras towards the springs in Trieste bay. The catchment area upstream the ponor is combined of surface drainage on Eocene flysch of the Brkini area and karst aquifer of the southern part of the Snežnik mountain (mostly Cretaceous limestone, partly also Palaeocene limestone). In the total area of around 350 km² around 28 % is karstic. Karst water emerges through several karst springs, the most important among them are Bistrica and Podstenjšek springs near Ilirska Bistrica. Additional inflows are numerous surface tributaries from flysch areas on both river banks. The discharges of the Reka river in this upper part range between 0.18 and 305 m³/s, with the mean discharge of 8.26 m³/s (Kolbezen & Pristov 1998).

The hills of Brkini represent a surface watershed between the Reka river and the Rižana spring. The recharge area of the Rižana spring covers the surface of 245 km² and is predominantly karstic, but also sinking streams from the flysch of the southern edge of Brkini

flow underground towards it. At this edge Eocene flysch is in the contact with Cretaceous and Palaeocene limestones of the Matarsko podolje and Podgora. Several small surface streams from the flysch sink underground and additionally recharge the karst aquifer. The main outflow of the karst aquifer is the Rižana spring, which is situated on the contact with very low permeable flysch rocks. The discharges of the Rižana spring range between 0.03 and 91 m³/s, and the mean discharge is 4.3 m³/s (Kolbezen & Pristov 1998). The Rižana river flows further on the flysch surface towards the Adriatic sea. The same karst aquifer recharges also the springs of Osapska Reka, as well as the Boljunec spring in Italy. And by tracer tests also groundwater flow towards the springs in Croatia (e.g. Mlini, Bulaž, Sv. Ivan, springs near Opatija) was proved.

Proved underground water connections

Detailed study of the Rižana catchment with three series of combined tracer tests was performed in the years from 1985 to 1987 (Krivic *et al.* 1987, Krivic *et al.* 1989). Tracings of sinking streams near Gračišče (rhodamine) and Smokovska vala (bacteriophages) in karst area southern of the Rižana spring, and near Brezovica (uranine) and Male Loče (KCl) in the north-western part of Brkini area (Figs. 6 and 7) were carried out in April 1985. Although several springs in the broader area on Slovenian and Croatian side of the border were sampled, tracers were detected only in the Rižana spring. Apparent velocity of groundwater flow from Brezovica was 104 m/h, from Gračišče 18 m/h, and from Smokovska vala 11 m/h. Concentrations of the potassium chloride were around the detection limit, so for the sinking stream in Male Loče no reliable connection was confirmed.

At combined tracer test performed in May 1986 in the Brkini area rhodamine injected into the sinking stream in the Jezerina blind valley and bacteriophages injected into the sinking stream near Hotična appeared at the Rižana spring with the apparent velocities of 26 and 30 m/h. Rhodamine as well as uranine injected into the sinking stream at Male Loče were detected also at the Osapska Reka with the velocities of 30 and 33 m/h. Based on the results and detected increased concentrations of tracers also connections of the sinking streams in Jezerina and Male Loče with the springs Mlini and Sv. Ivan, as well as the springs near Opatija are possible.

Uranine injected in May 1987 into the Račice in the Brkini area and rhodamine injected in Dane in the Čičarija region in Croatia were detected in the springs near Opatija only with apparent flow velocities of 40 and 88 m/h respectively. Bacteriophages from the Movraž in the karst area south-eastern from the Rižana spring reappeared at Mlini and Bulaž springs with velocities of 18 m/h and 50 m/h.

In March 2001 a small sinking stream of the Beka-Ocizla Cave system south-western from Kozina was traced with uranine (Kogovšek & Petrič 2004). Main underground water connection with apparent flow velocity 33 m/h towards the Boljunec spring in Italy was proved. Only a weak connection with the Rižana spring was indicated (recovered 2 % of the injected tracer).

Several tracer tests were performed also in the Croatian part of the recharge area of karst springs Bulaž and Sv. Ivan in order to define borders of their catchments.

Contact karst of the Matarsko podolje and the Hotična blind valley

Flysch Brkini hills are in their south-western side in the contact with karst area of Matarsko podolje, which is built of Palaeocene and Cretaceous limestones (Figs. 6 and 7). On 20 km

long contact, in which carbonate rocks dip steeply below the flysch, surface waters from flysch sink underground into karst aquifer. Characteristic karst feature of this area are blind valleys with corrosion widened bottoms. Altogether 17 small surface streams drain the area of around 30 km². Catchments of individual sinking streams vary from 0.5 to 13.2 km². The altitudes of ponors are between 490 and 510 m a.s.l. Some ponors continue in the karst caves ending by the siphons of captured water in the altitudes between 370 and 430 m a.s.l. The deepest cave is 150 m deep, and the longest is 6 km long (Mihevc 1994)

Several tracer tests, described in previous chapter, were performed in the area in order to define the directions of groundwater flow of these sinking streams. From the north-western part waters are flowing mainly towards the springs of Rižana and Osapska Reka, and from the south-eastern part towards the springs in the Kvarner bay in Croatia. The waters from ponors in between can flow in either direction, and also towards some inland karst springs in the catchment of the Mirna river (Fig. 6).

Hotična is one of smaller blind valleys at the southern edge of the Brkini hills. Surface stream from flysch sinks into karst underground through the Hotiške ponikve Cave, which is 362 m long and 144 m deep. Entrance is in a rocky wall which closes the blind valley. In first 15 m the cave is horizontal, then it continues with several sections of vertical or inclined shafts, and it ends in a siphon lake.

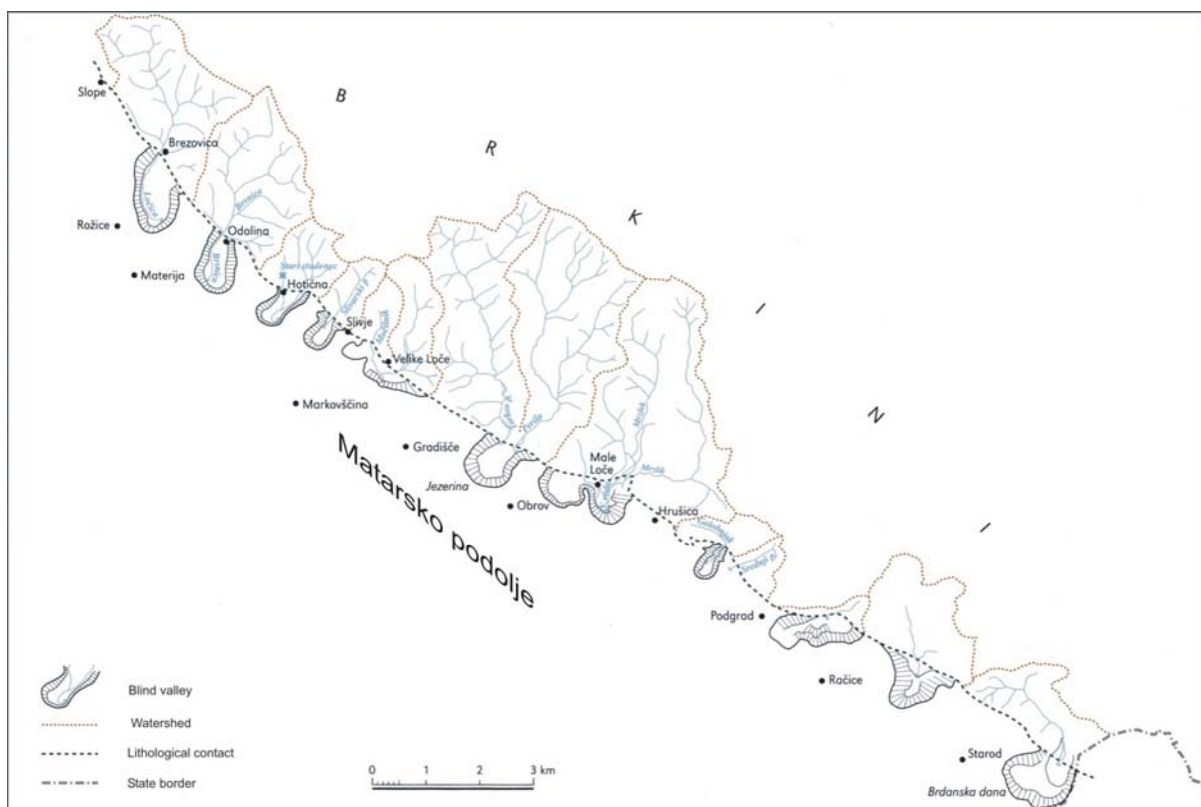


Figure 7: Contact karst at the southern edge of Brkini hills (Gams 2003).

Rižana karst spring as an important source of drinking water

The Rižana karst spring is situated at the contact of the karst aquifer and flysch at an altitude of 70 m a.s.l (Fig. 8). Its discharges range from 0.03 to 91 m³/s, and the mean discharge is 4.3 m³/s (Kolbezen & Pristov 1998). The recharge area of 245 km² (Krivic *et al.* 1987) is composed of thrust sheets involving an alternation of Upper Cretaceous and Palaeocene

limestones and Eocene flysch. The largest part of the area is karstic, but the spring is also recharged from the ponors of the Brkini flysch area. A transboundary character of the catchment is indicated by the fact that 17 km² of it spreads on the Croatian territory.



Figure 8: *The Rižana karst spring (Photo: N. Ravbar).*

Water from the Rižana river has already been used in the early 19th century, when Rižana valley has still been the granary of Trieste. In 1935 coastal water supply system was built. Rižana spring was captured and supplied all bigger cities at coast. Development of the coastal area and increasing consumption of drinking water dictated spread of the water supply system. Average annual quantity of water pumped from Rižana in the past few years is 192 l/s. Since 1965 water near Sečovlje with a common capacity of 100 l/s was pumped also. In 2001 this source was abandoned. Since 1970 subsequent 150 l/s of water from Gradole spring in Croatia, which is maintained by Istria water supply, is captured. Connection to Kras water supply built in 1994 offers up to 200 l/s of water, when needed.

Since 1994 more than 99 percent of the population in the studied area is connected to the public water supply, among which the cities of Koper, Izola and Piran have been completely supplied. Out of tourist season 80,000 people and during the season more than 120,000 people are supplied. Joint quantity of consumed water in households is 3.9 millions m³, while joint quantity of consumed water in economics is 2.15 millions m³ water per year. The biggest consumers of water in the coastal area are port Luka Koper, that uses 150,000 m³ water per year, hotels, health resort, food, car and other industry (Ravbar 2003).

Water at the Rižana spring is not suitable for drinking before proper treatment. Therefore in the water plant nearby a process of ultrafiltration is used. It is a physical procedure and chemical substances are used only for the cleaning of membranes. With ultrafiltration suspended matter and all particles larger than 0.01 micron are removed from water (turbidity, organic macromolecules, microorganisms) and after treatment water is suitable for drinking.

Protection of the Rižana spring

Four protection zones in the recharge area of the Rižana spring (Fig. 9) were defined based on detailed geological and hydrogeological research, as well as three combined tracer tests

(Krivic *et al.* 1989). In 1988 a Decree on protection zones of the Rižana spring and measures for water protection was issued. Problem is that this Decree was legally accepted only by the Municipality of Koper, which covers one third of the recharge area. Due to the conflicting interests in land use planning the rest is not legally protected.

Difficulties in drinking water of the Coastal region are mainly in a serious ecological hazard of the existing water sources. Apparent velocity of groundwater in the Rižana spring hinterland depends on hydrological situation and directions of underground streams, but still it was proved, that it ranges between 11 to 520 m/h (Krivic *et al.* 1987). Even though an influential area and protection zones of the Rižana karst spring are defined, Koper-Hrpolje-Kozina railway still passes the first protection zone, in immediate vicinity of the spring. Some other local, regional and main roads and trails pass the second protection zone and eventual traffic accident could cause strong contamination of the Rižana and some other nearby springs.

Illegal dumps could strongly burden karst water as well. Waste water that leaks out, flow directly into karst, into drinking water storage. Šebenik reports, that in 1994, when removal of waste was organized only in Kozina and its surrounding, there were still 18 illegal dumps with average volume of 36 m³ in Matarsko podolje and 14 illegal dumps with average volume of 7 m³ in Podgorski kras, which is in the Rižana springs immediate vicinity (Šebenik 1994).

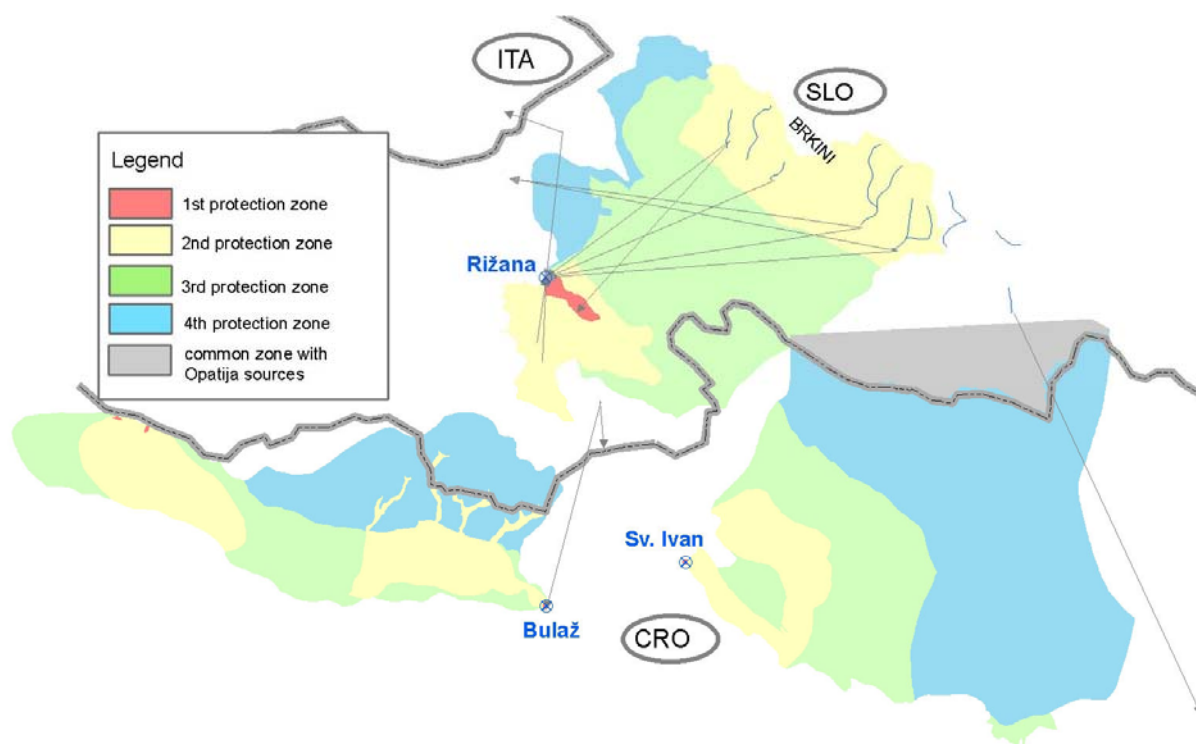


Figure 9: Protection zones of the Rižana, Sv. Ivan and Bulaž springs (Source of digital data: EIONET, Građevinski fakultet Rijeka).

Sv. Ivan karst spring

The Sv. Ivan karst spring is located in the valley of the upper part of Rijeka flow. Water outflows from limestone and flowing through impermeable flysch and Quaternary clay emerges at the surface at the altitude of 47 m a.s.l. (Figs. 10 and 11). Total capacity of the spring ranges between 0.13 and 2.15 m³/s, and mean discharge is 0.818 m³/s (Rubinić *et al.* 2006). Due to a limited capacity of outflow at the main spring of Sv. Ivan, the overflow at

high waters is through an intermittent spring Tombazin, which is located approximately 1 km south-eastern. The Sv. Ivan spring was captured for the water supply in 1933, and it is the first bigger karst spring connected to the Istria regional water supply system. The mean quantity of pumping is 0.175 m³/s, and additional to the main spring also some smaller springs are included.

Protection zones were defined based on tracer tests and hydrological analyses. Apparent flow velocities are relatively high and they range between 11 and 400 m/h. Based on performed hydrological studies (Bonacci & Magdalenic 1993) the extent of the potential (fictive) catchment of the spring is 60 km². But due to the complex nature of recharge and discharge of the Sv. Ivan spring, and considering the needs to protect the whole area, it was decided within the programme of the protection of drinking water resources in the region of Istarska županija, the total protected area is 103 km². To this area also smaller part of the total of 146 km² of common recharge zone of the sources of Opatija is added. It partly spreads on the Slovenian territory and has therefore a transboundary character.

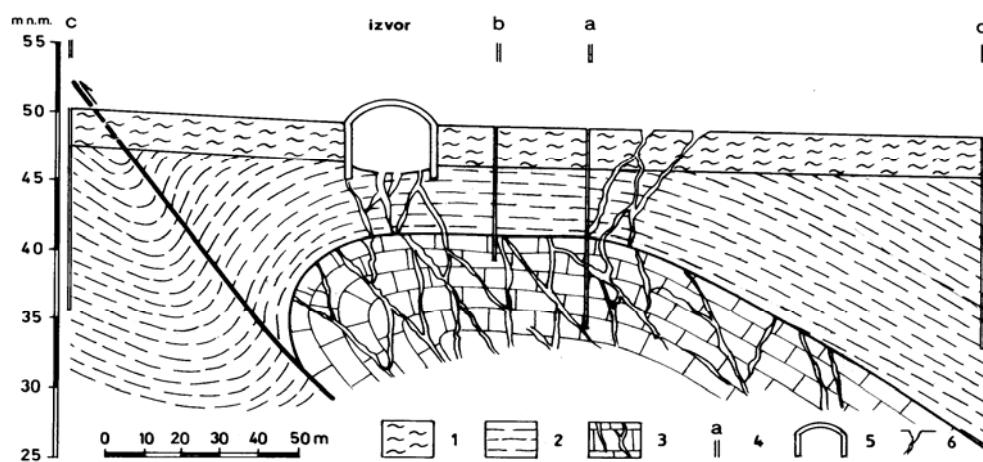


Figure 10: Hydrogeological profile of the Sv. Ivan spring (Legend: 1-Quaternary clays, 2-Flysch layers, 3-Karstified limestones, 4-Exploration borehole, 5-Capping bell; 6-Intermittent springs (Source: Hidroprojekt-ing 2000).



Figure 11: Karst spring Sv.Ivan.

The spring is still one of the most important sources of drinking water in the Istria region. Its biggest problem is frequent appearance of extremely high turbidity with maximum values of up to 2000 NTU. It is caused by important share of surface recharge from flysch areas during high waters, as well as fast flow and transport of matter through the karst aquifer. Suspended

particles are also carriers of physico-chemical and bacteriological pollutants (Mihalić *et al* 2006).

Bulaž karst spring

The Bulaž spring is located at the beginning of the wide middle part of the Mirna river at the edge of the anticline of northern Istria, which cuts several flysch surface streams of the Zrenj plateau. It is a typical karst spring, situated at the edge of the valley at the contact of Cretaceous limestone and Quaternary sediments (Fig. 12). At the surface it has a shape of a lake or water eye with the diameter of 50 m and the altitude of outflow of 15 m a.s.l.. Maximal depth of the spring is 25 m, which is 10 m below sea level. In the lake water from the extensive karst catchment outflows through 3 channels.

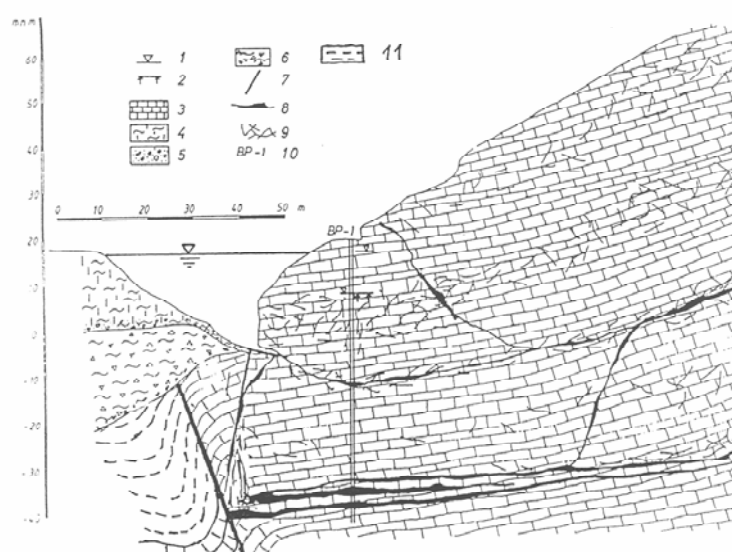


Figure 12: Detailed hydrogeological profile of the Bulaž spring (1-Water level at the spring, 2-Level of aquifer top, 3-Limestone, 4-Clay, 5-Breccia, 6-Fault, 8-Caverns, 9-Fissures, 10-Exploration borehole) (Source: RGN fakultet 1989).

According to the perform studies (RGN fakultet 1984) the area of the Bulaž catchment is 105 km², of which 62 km² is on karst and 43 km² on flysch. Several small surface streams from the Zrenj plateau (with individual recharge areas from several km² to 11.5 km²) ends their flow in ponors at the contact with limestone and in this way recharge the Gradole spring. A part of these streams has upper parts of the streams in Slovenia, therefore protection zones extend across the border. In 1987 a tracer test was performed with the injection into the ponor near Movraž (Krivic *et al.* 1989). Obtained concentrations of tracer in the Bulaž spring were around the detection limit, so the connection, although uncertain, can be defined. These results indicate more complex hydrological characteristics of this area and the possible existence of distant underground water connections which also cross the state borders in the broader observed area.

The overflow capacity of the Bulaž spring has a wide range between 0.042 and 38 m³/s, and the average is 2 m³/s. Since 1985, and especially since 1988 (when new capture system was built) the Bulaž spring has been a reserve source of the Istria water supply system. At present only low quantities of water are pumped (in average 8 l/s), but during drought they can increase in short periods also to 160 l/s. The pumping station is activated only during longer

dry summer periods (not every year) in the way that pumped water is transported directly into the water supply system or through the pipeline to the capture of the Gradole spring in the lower part of the Mirna valley, where they are also properly treated.



Figure 13: The Bulaž spring.

Traffic accidents with spillage of hydrocarbons

Due to the car accident near Kozina 18 tons of petroleum and fuel oil flew into karst in October 1993 (Knez et al. 1994). Several springs in the area of influence were monitored, but no concentrations above allowed values were detected.

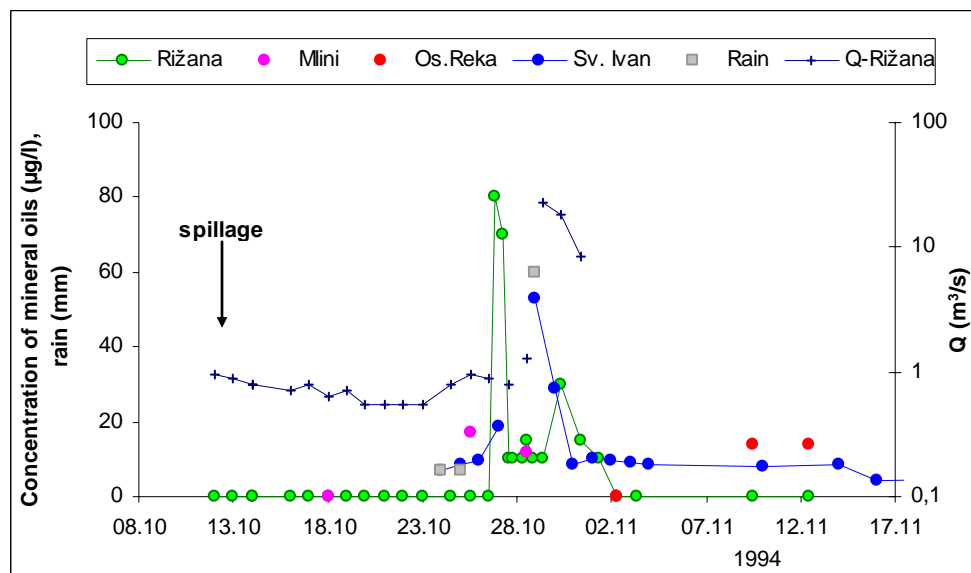


Figure 14: Measured concentrations of mineral oils in karst springs after the spillage in a traffic accident near Obrov in October 1994.

But contamination of the Rižana spring was actually experienced in October 1994 after a spillage of 16 m³ of gas oil in a traffic accident on a road near Obrov within the second protection zone (Kogovšek 1995). Also the springs of Osapska Reka, as well as Mlini and Sv. Ivan in Croatia (Vlahović 2000) were polluted. Due to the contamination with gas oil (up to 80 µg/l) the Rižana spring had to be taken out of use as a water-supply. Gas oil appeared after

precipitation (Fig. 11), and the transport velocity was 45 m/h. Based on previous experience we can infer that the gas oil was discharging over a lengthy period after every precipitation event. At that time the water was treated with chlorine gas, which also resulted in the formation of carcinogenic derivatives. This was one of the reasons for changing the water treatment method for the Rižana water-supply system to that of ultra-filtration.

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HALF-DAY EXCURSION, 22 June 2007

TRANSBOUNDARY KARST AQUIFER OF KRAS (Slovenian-Italian transboundary area)

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Hydrogeological characteristics of the Kras area

Kras is a limestone plateau, lying above the Trieste bay (Fig. 15). It is 50 km long, up to 13 km wide and is stretching in NW – SE direction. Hydrogeologically uniform karst aquifer is politically divided between two countries - Slovenia and Italy. The main part of the aquifer is in Slovenia, but the whole karst coast and the springs are in Italy.

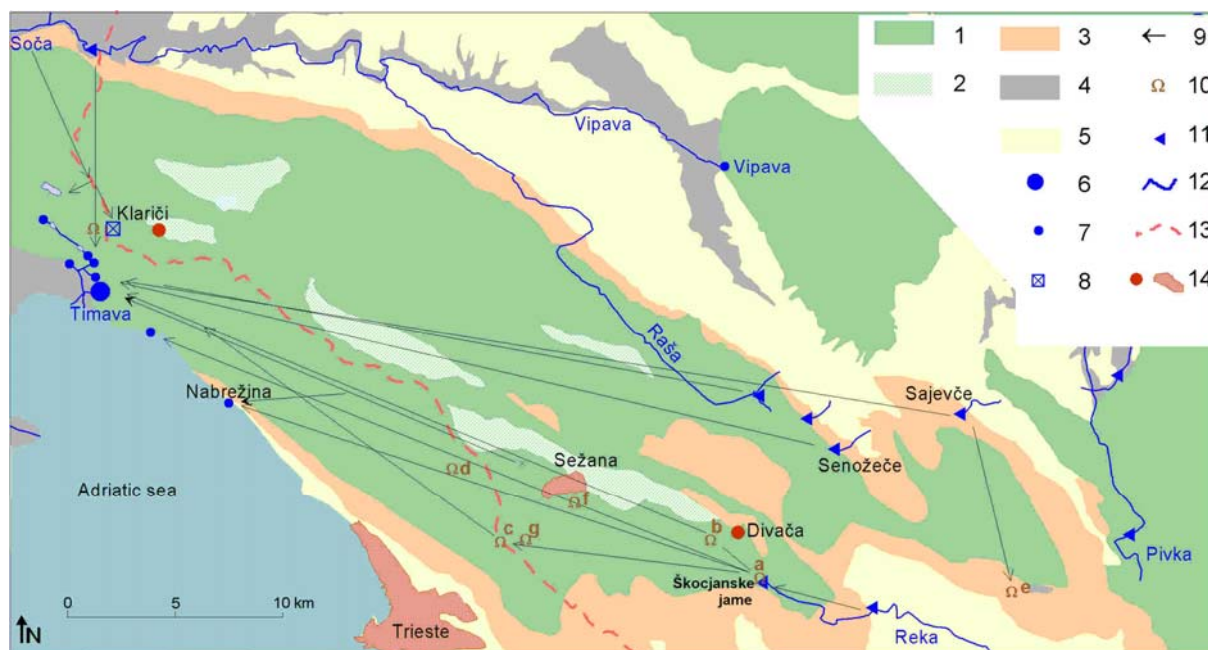


Figure 15: Hydrogeological map of the Kras area (Legend: 1. Cretaceous limestone, 2. Cretaceous dolomite, 3. Palaeocene limestone, 4. Porous aquifer, 5. Very low permeable Eocene flysch, 6. Timava spring, 7. Spring, 8. Pumping station, 9. Underground water connection, proved by tracer test, 10. Karst cave (a. Škocjanske jame, b. Kačna jama, c. Labodnica, d. Lazzaro Jerko, e. Gabranca, f. Jama 1 v Kanjaducah, g. Brezno v Stršinkni dolini), 11. Sinking stream, 12. Surface flow, 13. State border, 14. Settlement).

Kras belongs to Adriatic-Dinaric tectonic plate, to the region of Outer Dinarides. In the narrower sense it belongs to a smaller tectonic unit called the Trieste-Komen anticlinorium, which consists of several smaller anticlines and synclines with folds trending in the NW-SE (Dinaric) direction (Kranjc 1997). The most distinctive faults that cut this area in the Dinaric direction are the Raša fault which crosses the northern edge of Kras and the Divača fault in its central part. Position of the springs and caves with permanent water flow is connected with

some smaller faults in the NE-SW direction, which influence the orientation of groundwater flow.

Cretaceous and Tertiary carbonate deposits mainly of shallow, warm-water carbonate shelf environments are characteristic for the Kras area. The central part is built by well karstified and well permeable Cretaceous limestone and partly dolomite in the thickness of more than 1000 m (Fig. 15). Dolomite layers are slightly less permeable and may play, if they are thicker, a role of a relative isolator. To the north, south and east the Cretaceous carbonate rocks pass into bedded and tabular limestones of Palaeocene age, which are also fissured and karstified. The carbonate massif is surrounded by very low permeable Eocene flysch which acts as an important hydrogeological barrier. There where flysch is interrupted numerous springs in the Trieste bay of the Adriatic sea appear. In the north-western part the Kras aquifer is in contact with the porous aquifer of alluvial sediments deposited along surface streams of Soča and Vipava.

The biggest among the springs are the Timava springs with discharges from 9.1 m³/s to 127 m³/s, and mean discharge 30.2 m³/s in the period 1972-1983 (Civita *et al.* 1995). Three big submerged mouths are connected by a network of passages that reach a depth of about 80 m. The average water level is around 2.4 m above the sea level. They demonstrate typical karst hydrological regime with fast reactions on precipitation and sharp discharge peaks, and with longer periods of medium and low waters (Fig. 16). In the past Timava was captured for Trieste water supply, but due to the low quality of water other sources are now used. Several smaller springs are located further inland at the altitudes from 0.4 to 12 m above the sea level. Especially interesting are submarine springs along the coast between Timava springs and Trieste. The most important is the Brojnica near the village Nabrežina (Aurisina), which has been captured for the water supply since 1857, and then abandoned in 1977.

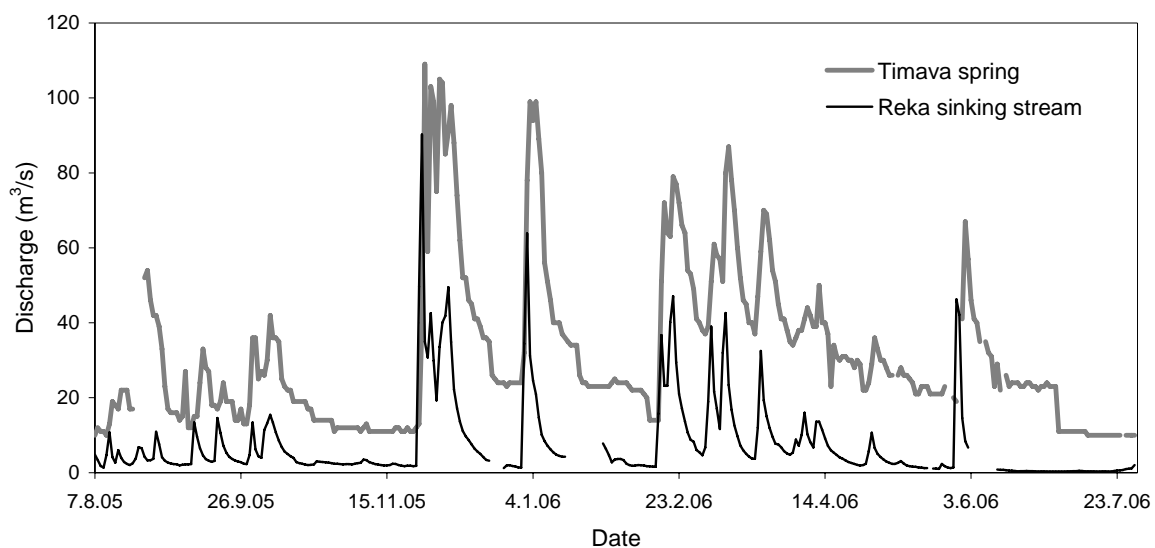


Figure 16: Discharges of the Reka sinking stream and the Timava spring in the year 2005/06 (Sources of data: Environmental Agency of the Republic of Slovenia, ACEGAS Trieste).

The karst aquifer of Kras, which is drained through described springs, is recharged mainly by the primary infiltration of precipitation through well karstified surface. Average yearly precipitation on Kras vary from 1400 to 1650 mm, and average yearly evapotranspiration from 700 to 750 mm (Kolbezen & Pristov 1998).

Very important source of recharge is also the Reka river which sinks into the Škocjanske jame Caves at south-eastern border of Kras (Fig. 15). As it was proved by numerous tracer tests (Timeus 1928, Mosetti 1965, Gemiti 1994) it reappears again in the springs of the Trieste bay.

The Reka river gathers the water from the area of more than 350 km², mostly with surface drainage network on Eocene flysch. The rest is Mesozoic karst area, which is drained through 4 karst springs into the Reka surface stream. In the period 1961-1990 the minimal measured discharge of the Reka river was 0.18 m³/s and the mean discharge 8.26 m³/s (Kolbezen & Pristov 1998). The length of the underground flow is about 41 km. The underground water of Reka river, between swallow hole and springs, is accessible in some deep caves only, such as Kačna jama, Jama 1 v Kanjaducah, Brezno v Štršinkni dolini, Labodnica (Grotta di Trebiciano) and Grotta Lazzaro Jerko.

Additionally some other sinking streams from the surrounding area recharge the Kras aquifer (Fig. 15). Inflows from the rivers Soča, Vipava and Raša, and from some smaller streams out of the karst basin (Sajevče brook at the southern border of the Postojna basin, sinking streams near Dolenja Vas and Senožče) were proved by tracing with environmental and artificial tracers (Timeus 1928, Bidovec 1967, Cancian 1987, Habič 1989, Habič 1990, Civita *et al.* 1995). Results of combined chemical and isotopic analysis confirmed important influence of the Soča river (Flora & Longinelli 1989, Urbanc & Kristan 1998). Water from the sand and gravel sediments in the Soča river basin enters into the karstified limestones of Kras along the long contact between both aquifers. Especially during longer periods without precipitation and low hydraulic pressures of the karst aquifer such inflow from the Soča basin effectively compensates insufficient primary recharge on Kras.

Drinking water supply on the Kras plateau

On the Slovene territory of Kras, there are no superficial streams and also there are no springs suitable to be captured. In recent decades the development of drilling technology provides the possibility of reaching the underground water several hundred meters deep. Water supply company Kraški Vodovod pumps up to 250 l/s of water from the boreholes near Klariči which have been connected to the Kras water supply system since 1983. Since 1994 the system has been linked with the system of Rižana water supply and thus the surplus pumped water may also be used to supply the Slovene Littoral.

The biggest economic problem on the Kras plateau in the past used to be the drinking water supply, which has also been one of the reasons for the scarce settling of the Kras plateau.

Today the Water Supply Company provides drinking water to households and industry on the Kras plateau and the quantity is sufficient to supply the coastal region in the summer months as well. Water supply is founded on effective karst groundwater pumping near Klariči. Some water is captured from karst springs under Nanos Mountain as well. The Water Supply Company supplies more than 22,500 inhabitants out of the tourist season. A basic question of drinking water supply on Kras plateau is how to assure a suitable water quality and quantity and how to reduce water losses in the supply network.

Inadequate upkeep of the old pipelines causes damage and enormous losses of more and more valuable water. Therefore the Water Supply Company must invest more into maintenance and reconstruction of the system.

Karst groundwater, which is pumped, is organically polluted due to its vast recharge area. It is also endangered by contamination because of unsuitable transport system and hazardous spills of dangerous substances in its catchment area and dumping in a direct recharge area. Water capacities of the source are not yet completely exploited though.

In water supply planning in future, numerous other local water resources linked to traditional ways of water supply need to be considered. Eventual rainwater usage for garden irrigation or car washing, and purified wastewater usage for communal activity (street washing) or for the needs of farming and industry (as technological water) is not excluded.

Škocjanske jame Caves – ponor of the Reka river

At the end of the surface flow on flysch the Reka river flows on limestone through 4 km long gorge, which ends with the entrance into the famous Škocjanske jame Caves, which are enlisted in the UNESCO World Heritage (Kranjc 1997). Upstream from the cave are two big collapse dolines: Velika dolina (165 m deep) and Mala dolina (120 m deep), which are separated by a natural bridge as a remnant of a cave ceiling (Fig. 17). Above the Mala dolina at the top of a steep rocky wall the Škocjan village is situated. Near the village is 60 m deep Okroglica shaft, which reaches the underground Reka flow. In the bottom of Velika dolina the Reka river finally sinks underground at the altitude 317 m a.s.l., flows through the cave (water flow in the cave is 3.5 km long, length of all channels in the cave is 6.2 km) and emerges again in the springs of the Trieste bay. At extremely high waters underground channels are not able to swallow the inflowing water of the Reka river, which results in floods. The highest registered level of water in Velika dolina was 132 m above the siphon at the end of the cave (altitude 214 m). In the vicinity of the ponor there are several collapse dolines and blind valleys, which indicate changes of the location of flow in the past.

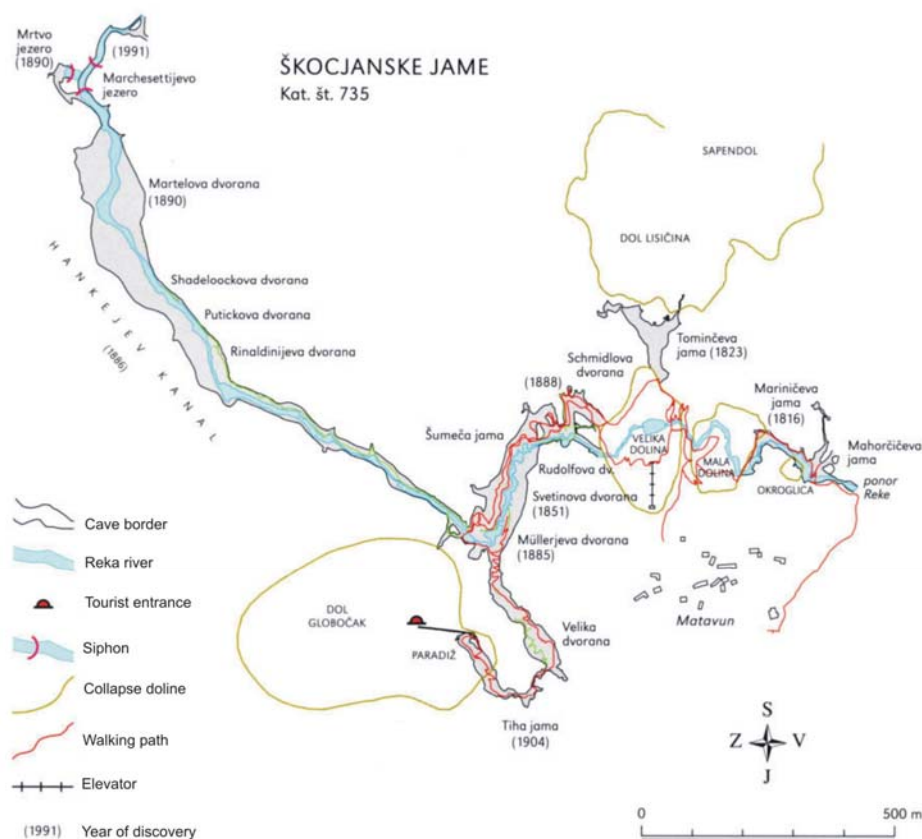


Figure 17: Plan of the Škocjanske jame Caves (Drole 1999)

The Reka river sinks underground also in the limestone riverbed upstream the main ponor. In 1982 a ponor (5x10 m big, 27 m deep) was formed due to a collapse in the riverbed and during low water conditions the total flow of Reka river was disappearing into this ponor. At present the ponor is filled with sediments, but still around 1 m³/s sinks underground through it and then further below the accessible galleries of the Škocjanske jame.

Monitoring of flood pulses

In the frame of the Interreg project Monitoring of the underground flow of Reka river continuous logging of water levels and temperatures in four deep caves with underground Reka flow (Fig. 18) was established in spring 2005. The focus of the study is the epiphreatic zone, characterized by a high flow variability of the Reka river as the main allogenic inflow into the aquifer. The results are indicating a fast passage of a flood wave along a well developed conduit system. In more details results and conclusions are presented in the article (Gabrovšek & Peric 2006).

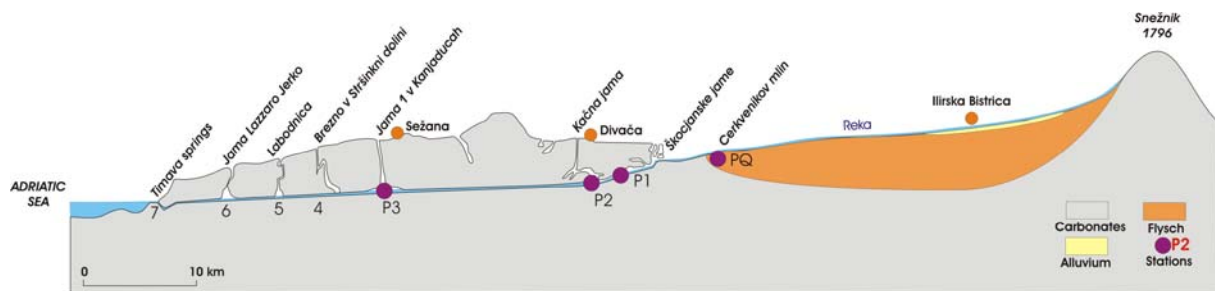


Figure 18: Cross-section of the Kras plateau with main geological formations, caves and measurement points (Gabrovšek & Peric 2006).

Continuous monitoring of physical parameters of the subsurface Reka flow is organized also on the Italian side of the Kras aquifer (Cucchi & Zini 2002). Based on more than 100 flood events, a distinction was made between three principal types of flood waves, characterized by the presence or absence of inflow from the sources that feed the Timava river system: namely the Reka river, Brestovica basin and Soča-Vipava rivers basin. The temperature and conductivity changes indicate that the underground flow is fast (even more than 800 m/h) and continuous. The results indicate a “direct drainage” along Škocjan-Labodnica/Trebiciano-Lazzaro Jerko.

Tracer test in 2006

The water course between the ponor, deep shafts and springs was studied also by tracer test carried out during low water conditions. 5 kg of uranine were released in the Reka flow at the contact of flysch and limestone. First analyses show that the speed of tracer transport along the flow is influenced by the local gradient and discharge. The tracer concentration curve in the Škocjanske jame was unevenly distributed, while it was much more extended and monotonous in the Jama 1 v Kanjeducah Cave. The presence of the tracer was scarce in the Labodnica/Grotta di Trebiciano Cave and it was recorded in the Timava springs only 32 days after it had been released.

Water quality of the sinking Reka river

In the past also the Timava springs and the Reka river in its upper stream course were captured for the water supply, but due to the fast decrease of the water quality in the second part of the previous century such use was limited. One of the reasons was heavy pollution of the Reka river, which transported the pollutants through its sinking point in the Škocjanske jame Caves into the karst aquifer and the Timava springs as its main outlet point. Mostly due

to the industry in the upper part of the Reka valley it was a "dead" river containing minimal quantities or even no dissolved oxygen. Organic pollution reached such an extent that for its partial degradation it used all the available oxygen in the water (Kogovšek 1999). Fortunately some factories were closed down or renovated, and in few years the water quality of the river has significantly increased. Still the problems of pollution remain and its quality is now regularly monitored. In Slovenia 4 classes are used to describe the quality of the surface streams on the base of the principal physical–chemical analyses, analyses of heavy metals and organic micropollutants, and microbiological and saprobiological analyses. In the time of its lowest quality the Reka river was placed in the 4th class, and according to the results from the year 2000 (EuroWaterNet Slovenia 2003) it has recovered into the 2nd – 3rd class, which is still not characterised as good quality. Although the input of pollutants due to the human activities is significantly lower, the banks of the river are permeated with toxic substances, which are gradually washed into the river.

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