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ALPINE KARST WATERS IN SLOVENIA

VODE ALPSKEGA KRASA V SLOVENIJI

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Abstract UDC: 551.44(234.323.6):556

Metka Petrič: Alpine karst waters in Slovenia

Some basic characteristics of the alpine karst waters in Slovenia are presented. By the method of hydrological balance it was estimated that their groundwater reserves can supply a spring with an average discharge 115 m^3/s. According to the comparison between the extent of the alpine karst and the EIONET-SI data base on springs it was stated, that for approximately 1200 alpine karst springs the total capacity (not the average discharge, but the amount of water that can be captured at low waters) is around 15 m^3/s. At present only some 25% of these reserves is exploited for the water supply of around 240.000 inhabitants. Due to high vulnerability and different human impacts the quality of these water resources is endangered. Therefore it is necessary to protect them with adequate measures planned on the basis of accurate hydrogeological data. Present level of protection is unsatisfactory, as the water protection decree was accepted only for one quarter of captured springs. Additionally, the expert basis for such decree was prepared for a little less than one fifth of captured springs.
Key words: alpine karst, springs, water supply, vulnerability, water quality, protection, Slovenia.

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Metka Petrič: Vode alpskega krasa v Sloveniji

Predstavljene so osnovne značilnosti alpskih kraških voda v Sloveniji. Z metodo vodne bilance sem ocenila, da njihove zaloge zadoščajo za napajanje izvira s povprečnim pretokom 115 m^3/s. Po primerjavi obsega alpskega krasa s podatki o izvirih iz baze EIONET-SI je bilo ugotovljeno, da je skupna izdatnost (ne povprečni pretok, ampak količina vode, ki jo je možno zajemati ob nizkem vodostaju) približno 1200 alpskih kraških izvirov okrog 15 m^3/s. Za vodooskrbo je trenutno izkoriščenih le okrog 25 % teh zalog, z njimi pa se oskrbuje okrog 240.000 prebivalcev. Zaradi velike ranljivosti kraških vodonosnikov in različnih človekovih vplivov je ogrožena kakovost teh vodnih virov. Nujna je zato njihova ustrezna zaščita, ki pa mora temeljiti na kakovostnih hidrogeoloških podatkih. Trenutna stopnja zaščite je nezadovoljiva, saj ima le približno četrtina zajetih izvirov sprejet odlok o varovanju, še za nekaj manj kot petino pa so že pripravljene ustrezne strokovne podlage.
Ključne besede: alpski kras, izviri, vodooskrba, ranljivost, kakovost voda, varovanje, Slovenija.

INTRODUCTION

The term alpine karst is used to describe karst in high mountain areas or in narrower sense karst in the Alps (Goldscheider 2002). For the alpine karst in Slovenia both descriptions are relevant. Around 43% of Slovene landsurface is covered by carbonate rocks, and approximately one fourth of this karstic area is in high mountains of Southern Alps (Fig. 1).

Alpine karst is an important natural resource and one of its treasures are large amounts of groundwater stored in its depths. Karst groundwater in general covers about 25% of the world's needs for drinking water (Drew & Hötzl 1999), and in Slovenia approximately half of the country is supplied by karst waters. Although a significant portion of these waters is abstracted from alpine karst, capacities of the alpine karst springs are not yet proportionately exploited. As the degree of pollution in sparsely inhabited mountainous areas is still relatively low and amount of stored groundwater is large, alpine karst aquifers are invaluable reservoirs of drinking water and important potential source also for the future.

At the same time, as highly heterogeneous and anisotropic environments they are particularly vulnerable to pollution. Due to fast infiltration and groundwater flow, which can transport pollutants rapidly in karst conduits over large distances, the rate of their self-cleaning capacity is low. To protect them properly better understanding of their characteristics and functioning is necessary.

In the article some basic characteristics of the alpine karst waters in Slovenia are summarised. Digital information on waters collected in the frame of the European Environment Information and Observation Network (EIONET) in Slovenia (EIONET-SI 2004) was used as the main source of data.

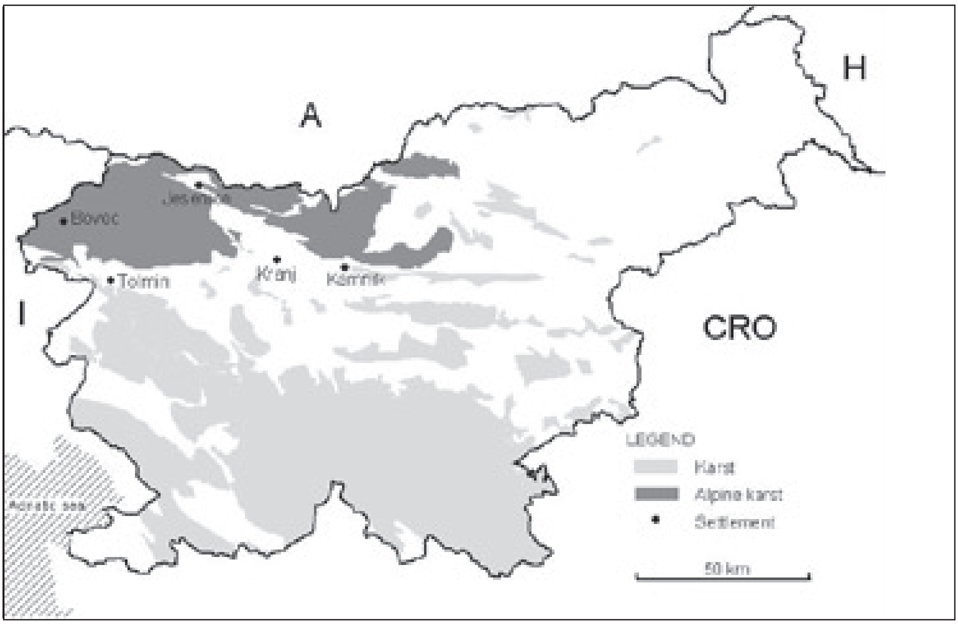

Figure 1: Karst and alpine karst areas in Slovenia.
Slika 1: Kraška in alpska kraška območja v Sloveniji.

HYDROGEOLOGICAL CHARACTERISTICS

Hydrogeological map of the alpine karst (Fig. 2) is based on data from EIONET-SI (Hydrogeological characteristics 2004). High mountainous areas in Slovenia are mostly built by carbonate rocks, predominantly by limestone and partly dolomite and dolomitised limestone of Triassic age. Rocks are well karstified and different surface and underground karst features are developed. Dominant hydrogelogical unit are well permeable karst aquifers. In some parts dolomite prevail which is characterised as slightly less permeable fissured aquifer. Porous aquifers are developed especially in river valleys filled with clastic sediments of glacial, fluvioglacial, and fluvial origin.

For high karst plateaux and mountain peaks in Slovenia abundant precipitation with average yearly values of up to 3000 mm or even more is characteristic. In many parts vegetation and soils are absent or present just in limited zones and thin layers. Therefore the share of effective infiltration is high and surface streams are rare. Mostly they are formed on less permeable dolomites or outcrops of non-carbonate rocks, and they often have torrential character. Interesting are high mountainous lakes, which also collect surface waters on less permeable rocks. High plateaux are dissected by deep valleys. Infiltrated precipitation water from recharge areas in uplands is flowing underground along the easiest paths towards the springs in these valleys. Hence in alpine karst aquifers vertical channels prevail and big altitude differences between high plateaux or peaks as recharge areas and springs in valleys as discharge points are a favourable condition for the development of deep shafts.

In the valleys at the foothills of karstic massifs the biggest alpine karst springs are situated (Fig. 2). In some places deepening of valleys was faster than lowering of water flow, therefore many karst springs are situated higher in the slopes and there waterfalls are formed. Smaller and more densely distributed are springs of fissured aquifers in which karst network is less developed and groundwater is drained more locally.

Spring waters are recharging the alpine rivers (Rivers 2004). The most important among these rivers are Soča, Sava, and Savinja, but also some tributaries of Drava, as for instance Meža, are getting water from the alpine springs (Fig. 2). The Soča river is flowing towards the Adriatic sea, and the other ones towards the Black sea. Due to specific characteristics of karst aquifers (unknown paths of underground waters, bifurcation, the changes in the size of the recharge area at different hydrological conditions) it is practically impossible to precisely define the position of watershed between the two basins, but its approximate location is shown on Figure 2 (Watersheds 2004).

In each of these river valleys there are several important springs. The ones with the highest capacities (the amount of water that can be captured at low waters) are drawn on Figure 3. For different river basins they are marked with different colours, and for different ranges of capacity with different sizes of the symbol. The Soča river springs with capacity 60 l/s, but close by the spring area it is enlarged by its left affluent Krajcarica spring. In its upper stream Soča has several other tributaries, the biggest among them are the springs Glijun and Boka, the latter with around 140 m high waterfall. On the southern edge of the alpine karst water from three important springs Tolminka, Zadlaščica and Kneža flows into the Soča river. More information about characteristics of these springs are available in literature (Janež 2002, Komac 2001, Pišljar 1992, Novak 1979, Kuščer et al. 1974).

The Sava river has two spring branches. The northern one is Sava Dolinka with the Zelenci spring. In its upper valley the tributary springs with the highest capacities are Rupe, Sence, Peričnik, Zmrzlek, Lipnik, Ovčje jame, and Veliki Javornik. At the southern branch the main springs are Savica

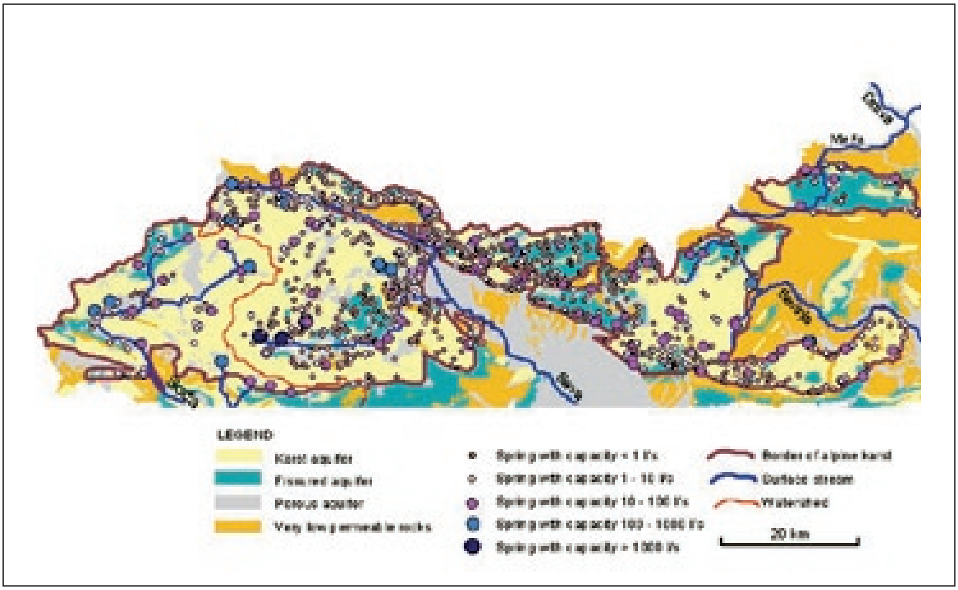

Figure 2: Hydrogeological map of alpine karst.
Slika 2: Hidrogeološka karta alpskega krasa.

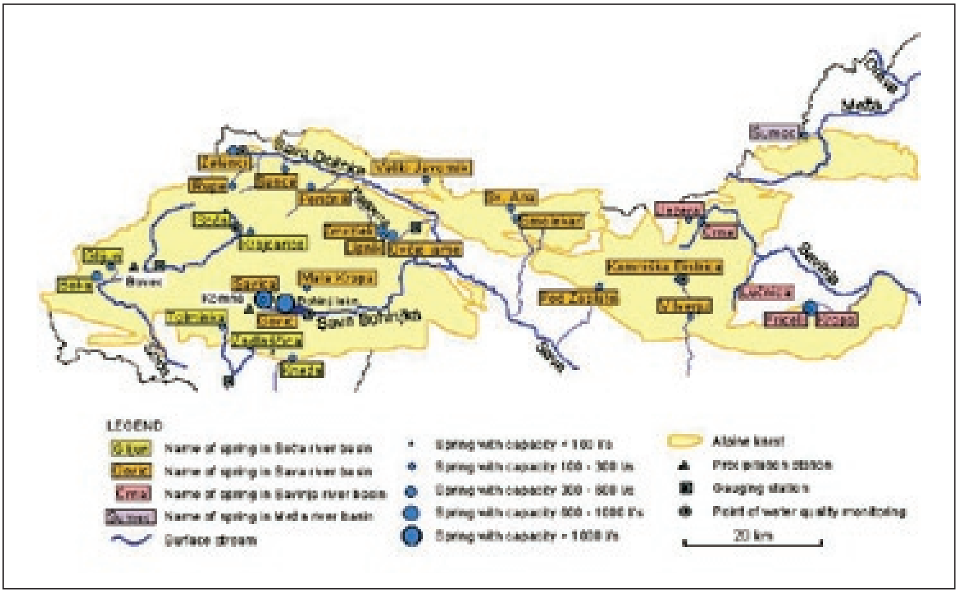

Figure 3: The most important springs of the alpine karst.
Slika 3: Najpomembnejši izviri alpskega krasa.

and Govic which recharge the Bohinj lake. From the lake water is flowing as the Sava Bohinjka river. Among its tributary springs Mala Kropa is the biggest. Downstream of the confluence of both branches three left tributaries of the Sava river are getting water mostly from the springs Sv. Ana, Smolekar, Pod Zaplato, Kamniška Bistrica, and V Iverju.

On the north-eastern side of the same karst massif is the spring area of the Savinja river. In its valley the springs with the highest capacities are Jezera, Črna, Lučnica, Fricelj, and Kropa.

Published reports about the researches of the springs in the Sava and Savinja valleys are rare, but some additional information can be found (Gams 2003, Novak 1996, Novak 1994, Lajovic 1982, Novak 1979, Melik 1961).

In the Meža valley the karst spring with the capacity above 100 l/s is the Šumec spring.

HYDROLOGICAL CONDITIONS

According to the hydrogeological map (Fig. 2) the extent of the alpine karst in Slovenia was assessed to around 2200 km^2. To evaluate the potential of outflow from this area the average yearly effective infiltration of 1620 mm was taken into account. This was calculated based on the maps of average yearly precipitation and evapotranspiration for the period 1961-1990 (Kolbezen & Pristov 1998). Using the isohyetal method the average yearly precipitation and evapotranspiration in the area of alpine karst were defined, and then the average yearly effective infiltration was calculated as the difference between these two values. In an average year infiltrated 1620 mm of water over the alpine karst area of 2200 km^2 gives the amount of stored groundwater which can supply an average discharge of around 115 m^3/s.

Stored groundwater flows out of karst aquifers through numerous springs. To show the positions of alpine karst springs (Fig. 2) the database on locations of all springs in Slovenia (Springs 2004)

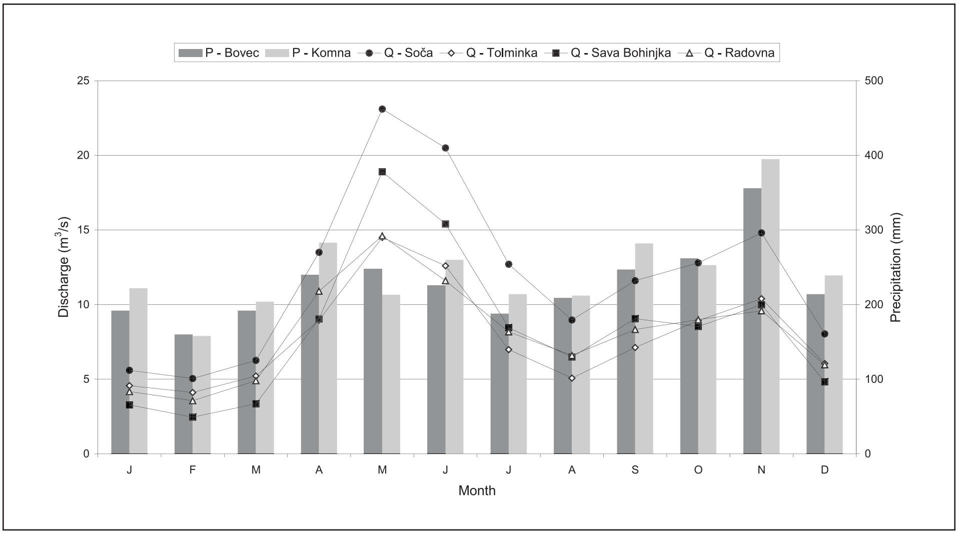

Figure 4: Mean monthly precipitation and discharges.
Slika 4: Srednje mesečne padavine in pretoki.

was compared with the extent of the alpine karst. Their rank of capacity (not the average discharge, but the amount of water that can be captured at low waters) is marked with the size and colour of the symbol. In described way estimated total number of alpine karst springs is approximately 1200 and their total capacity is around 15 m^3/s. Among them 26 springs have the capacity of more than 100 l/s.

The hydrological regime of the springs is strongly influenced by the amount and time distribution of precipitation in the recharge area. To illustrate this the comparison between mean monthly precipitation (Zupančič 1995) in two precipitation stations in the area of alpine karst and mean monthly discharges (Kolbezen & Pristov 1998) of four streams that are recharged by alpine karst springs is presented (Fig. 4). The locations of precipitation and gauging stations are shown on Figure 3.

Precipitation is abundant all year round, with the distinctive maximum in November and other autumn months. The average values are high also in the spring period. Considerably lower amounts of precipitation are measured during the winter. In general the distribution of discharges is in accordance with the precipitation, but a significant increase of discharges is characteristic for the spring months. This reflects an important influence of the snow cover. In the high mountainous area the share of precipitation in the form of snow is great in autumn and winter. The number of days when the area is covered with snow is more than 200 per year in the highest parts, and is greater than 100 practically for the whole area of the alpine karst (Karta o trajanju snežne odeje 2004). On the surface accumulated snow is manifested in reduced discharges of springs. Although these are minimal during the winter, still important quantities of water are flowing out of the alpine karst aquifers. Intensive melting of snow cover usually starts in April. Due to abundant precipitation and melted water the discharges of alpine karst springs are significantly increased in the period from April to June.

IMPORTANCE FOR WATER SUPPLY

Alpine karst springs are important sources of drinking water. Their advantages are high altitudes and high discharges, low pollution in recharge areas and with this connected good water quality. Based on the data from EIONET (Springs 2004) it was possible to define the share of captured alpine karst springs. From the total number of 1200 springs with the capacity of 15 m^3/s, around 400 springs with the capacity of 3.8 m^3/s are captured for the water supply (Fig. 5). Comparing these numbers we can conclude that their capacities are not yet proportionately exploited and that their potential is still very high also for the future.

Information on the distribution of water supply system (Water Supply Areas 2004), and data on the location of settlements and the number of inhabitants in them (Settlements 2004) were used in the assessment of the importance of the alpine karst springs for the water supply. On Figure 5 all captured springs are marked with the blue and red points. The settlements (only those with more than 100 inhabitants), which are supplied with water from these springs, are presented with brown squares – the size of the square is dependent on the number of inhabitants. According to the comparison of both data sets we can conclude that the alpine karst springs supply 315 settlements with total more than 227.000 inhabitants. This number could be increased to around 240.000 if we consider also the inhabitants from smaller settlements with less than 100 residents.

RISK OF CONTAMINATION

The quantity of stored groundwater in the alpine karst is large, but different human activities already endanger its quality. The risk of contamination depends on the intrinsic vulnerability of aquifers and on the hazard afforded by potentially polluting activities (COST 620 Final Report 2004). The intrinsic vulnerability describes the inherent geological and hydrogeological characteristics of aquifers which determine the sensitivity of groundwater to contamination by human activities. Due to their structure alpine karst aquifers are highly vulnerable. Thin soils or even absence of soils, point recharge in dolines, shafts and swallow holes, as well as concentration of flow in epikarst and vadoze zones enable fast infiltration. Through well developed karst channels fast underground transport over large distances is possible. The residence time is short and the processes of contamination attenuation (filtration, adsorption, chemical and microbiological decay) are less effective.

The second element is the hazard which depends on the potential contamination loading. In the alpine karst favourable condition is low density of population. Still human activities represent potential threat. Well developed in high mountains is tourism which brings additional number of people to certain areas. Such places are skiing resorts with their infrastructure (large number of ski lifts, improper storage of fuels, unsuitable quality of water used for making artificial snow, cutting down in forests, waste waters from hotels and ski lodges, etc.), mountain huts (especially waste waters) and in some places holiday houses. Agriculture in high mountainous areas is extensive, but still some active mountain pastures represent a certain hazard (improper manuring). Also illegal garbage dumps can pose an additional threat.

Vulnerability of the alpine karst is high and in spite of relatively low hazard pollution has a noticeable influence on the water quality. Published results of the water quality analyses of individual springs are rare, because regular analyses are performed only by the water supply companies on captured springs. But according to the articles which summarise their results (Janež 2002, Komac 2001, Novak 1996, Novak 1979) the water quality is assessed as good regarding the chemical composition. More problems are connected with the microbiological quality which is often endangered by communal waste waters or agricultural activities. More data are available for the surface streams on which regular monitoring is performed by the Environmental Agency of the Republic of Slovenia (Combined Estimate on River Quality 2004). In Slovenia surface streams are classified in four quality classes according to the results of basic physico-chemical analyses, concentrations of heavy metals, organic micropollutants, and microbiological and saprobiological analyses. Also hydrometeorological conditions in the time of sampling are considered. In the quality class 1 unpolluted streams (possible to use as drinking water after basic treatment) are placed. The boundary between good and

Stream / Year	1994	1995	1996	1997	1998	1999	2000
Sava Dolinka (Zelenci)	1-2	2	-	2-(3)	2-(3)	1-2	(1)-2
Sava Bohinjka (Bohinj Lake)	2	2	-	2	2	1-2	2
Kamniška Bistrica (spring)	1-2	1-2	1-2	1-(2)	1-(2)	1	1-(2)
Soča (spring area)	1-2	1-2	1-(2)	-	-	-	1-2

Table 1: Quality of surface streams in the years 1994-2000.
Tabela 1: Kakovost površinskih vodotokov v letih 1994-2000.

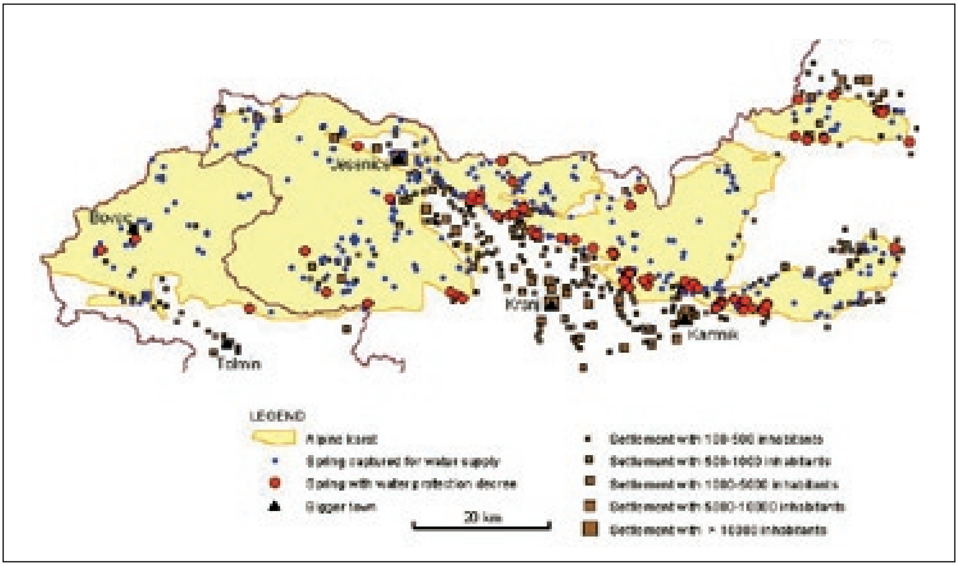

Figure 5: Alpine karst springs as important sources of water supply.
Slika 5: Alpski kraški izviri kot pomemben vir za vodooskrbo.

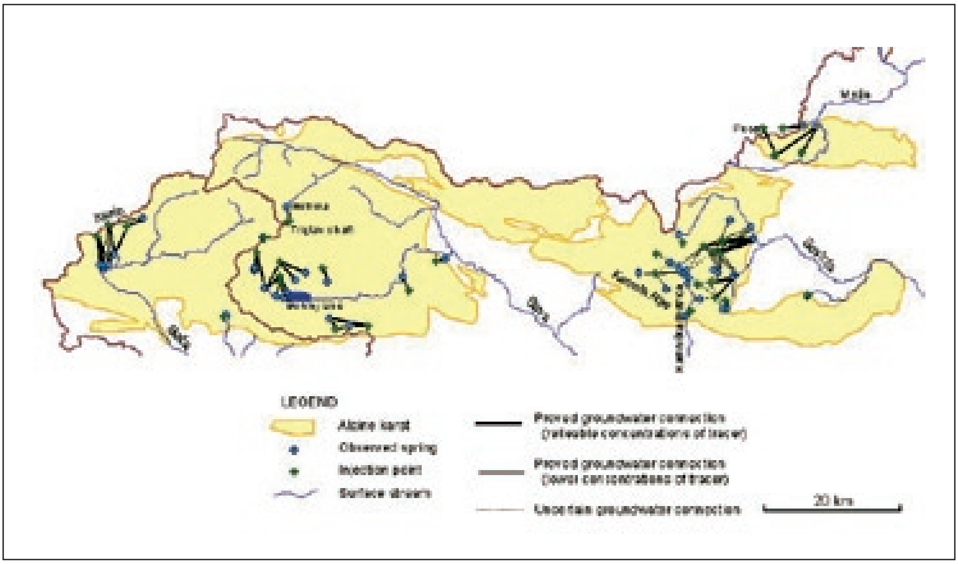

Figure 6: By tracing tests proved groundwater connections in the alpine karst (Sources of information: Audra 2000, Urbanc & Brancelj 2000, Trišič et al. 1997, Novak 1996, Habič 1990, Novak 1990).
Slika 6: S sledilnimi poizkusi dokazane podzemne vodne zveze v alpskem krasu (Viri informacij: Audra 2000, Urbanc & Brancelj 2000, Trišič et al. 1997, Novak 1996, Habič 1990, Novak 1990).

bad quality is the boundary between class 2 and class 2-3. In the years from 1994 to 2000 the upper streams of the rivers recharged by the alpine karst springs were mostly placed in the quality classes 1 or 1-2. Their quality was lower downstream mostly due to the pollution from urban areas and the quality classes 2 or 2-3 were defined. For some of the measurement points (Fig. 3) the comparison of the assessed quality in the years 1994-2000 is presented in Table 1.

In the compared years there is no significant trend in changes in the water quality of the selected streams. But in general we can say that with development of new human activities the risk of contamination increases and proper protection measures should be planned and carried out in order to preserve and even improve the water quality.

WATER PROTECTION

Based on the data about protected water resources (Protected Water Resources 2004) it is possible to assess the actual status of the water protection of alpine karst waters in Slovenia. Amongst around 400 springs captured for the water supply the water protection decree was accepted for less then 100 springs with the capacity around 1.8 m^3/s. On Figure 5 their locations are marked with red points. For additional 75 springs with the total capacity 0.4 m^3/s a proposal for such decree was prepared. It is obvious that still a lot of work has to be done in order to protect the alpine karst waters against pollution. And to do it properly good co-operation between researchers, planners and lawmakers is necessary. To ensure the efficiency of the plan of protection measures first an expert opinion about the characteristics and functioning of karst water system should be prepared. At present this is a difficult task because quality hydrogeological data about alpine karst aquifers are missing. Complex researches in high mountains were rare in the past due to distant locations with uneasy access, large parts of uninhabited areas and limited time in which the field work is possible in the cold climate typical for the Alps.

To demonstrate these problems a review of the performed tracing tests in the alpine karst is presented on Figure 6. Besides basic geological and hydrogeological researches the tracing tests are an important and relatively fast method for more precise delineation of recharge areas and better understanding of characteristics of underground flow and transport. In the Slovene alpine karst the tracing tests with all together 32 injection points were carried out in the past years. Different methodologies were used and different goals were sought. With the first test connection between the Triglav shaft and the Bistrica spring was proved (Gams 1966). Several tests were performed also in the background of the springs near the Bohinj lake (Novak 1990, Trišič et al. 1997). Especially interesting are the tracings in the border areas with neighbouring countries. One such study area is the Kanin mountain ridge which is drained towards the springs in Slovenia and in Italy (Audra 2000, Cucchi et al. 1997, Novak 1990), and the other one the Peca mountain at the border between Austria and Slovenia (Habič 1990). In both cases we can talk about transboundary aquifers, for which the question of water protection is due to sometimes different interests and principles of two countries even more complex.

The most thoroughly investigated is a part of the Kamnik Alps. In the years 1990-1994 the Geological Survey of Ljubljana carried out a series of tracing tests (Novak 1996). From different injection points on the karst plateau groundwater is flowing towards numerous karst springs in the valleys of Savinja and Kamniška Bistrica (a tributary of the Sava river). By obtained results a complex functioning of the karst aquifer was proved. As the tracer was travelling from one injection point towards several springs, so should an eventual pollution endanger different springs on a broader area.

Tracing tests can very efficiently simulate groundwater flow and transfer of substances and as such they were proved to be a very useful tool for the planning of water protection. But even though relatively large number of tracings was carried out in the Slovene alpine karst, it can be seen on Figure 6 that obtained results yield data about groundwater flow for only a small part of this area.

Problem is similar with other research tools. The lack of proper data about the nature and functioning of alpine karst aquifers is the first obstacle which we encounter in the process of planning of water protection measures. In the future systematic hydrogeological reserches are necessary in order to overcome these problems efficiently.

CONCLUSIONS

The alpine karst waters in Slovenia are a very important water resource. At present they are only partly exploited, mostly because of a low density of population in high mountains and relatively large distances from the big cities. But due to the increased needs for water, reduced availability of other reserves due to pollution, and also because of the influences of climate changes their importance will grow in the future. Therefore it is essential to properly protect them in time. Not just captured springs, but also all other potential water sources. Already at present different human activities endanger their quality, and we can predict that in the next years these threats will even increase.

Alpine karst aquifers are complex and very vulnerable systems. A comprehensive knowledge about their functioning is necessary in order to ensure the effectiveness of the measures for their protection. But the problem is the lack of already existing proper data. Systematic researches of larger areas are very rare and often only incomplete data are available. The boundaries of recharge areas are often defined approximately and on the basis of insufficient data. More detailed geological and hydrogeological researches are carried out only for some of the most important springs. Hydrological measurements are limited to larger surface streams. Analysis of water quality is necessary for captured springs, but for potential water resources it is more an exception than a rule. Hence, more systematic and carefully planned researches are necessary in the future in order to set quality expert basis for water protection measures. Regarding the proposed protection zones and measures the decrees for water protection have to be prepared in the next step. But it should be emphasised that these are just a legal frame and that for a successful implementation of protection measures the public awareness of the value and vulnerability of the alpine karst water resources, and of the importance and necessity of their protection is essential.

REFERENCES

Audra, P., 2000: Le karst haut du Kanin (Alpes Juliennes, Slovénie-Italie). Karstologia, 35, 27-38.

Combined Estimate on River Quality, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm

COST 620 Final Report, 2004. COST Action 620: Vulnerability and risk mapping for the protection of carbonate (karst) aquifers. URL (quoted 13.2.2004): http://capella.unine.ch/chyn/pdf/FinalReportCOST620.pdf

Cucchi, F. & F. Gemiti & P. Manca & R. Semeraro, 1997: Underground water tracing in the east part of the karst Canin massif (Led Zeppelin Abiss) (Western Julian Alps).- Ipogea, 2, 141-150.

Drew, D. & H. Hoetzl, 1999: Karst hydrogeology and human activities. Impacts, consequences and implications.- IAH-International contributions to hydrogeology, A.A. Balkema, p. 322, Rotterdam, Brookfield.

EIONET-SI, 2004. EuroWaterNet Slovenia. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm

Gams, I., 1966: Poročilo o barvanju v Dimnicah in Triglavskem breznu v letu 1964.- Acta carsologica, 4, 151-156.

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

Goldscheider, N., 2002: Hydrogeology and Vulnerability of Karst Systems – Examples from the Northern Alps and the Swabian Alb.- Schriftenreihe Angewandte Geologie Karlsruhe, p. 236, Karlsruhe.

Habič, P., 1990: Sledenje kraških voda v Sloveniji.- Geografski vestnik, 61, 3-20, Ljubljana.

Hydrogeological Characteristics, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm

Janež, J., 2002: Veliki kraški izviri v zgornjem Posočju (Karst springs in the upper Soča valley).- Geologija, 45/2, 393-400, Ljubljana.

Karta o trajanju snežne odeje, 2004: URL (quoted 12.2.2004): http://www.arso.gov.si/podro~cja/vreme_in_podnebje/napovedi_in_podatki/dni_s_snegom.html

Kolbezen M. & J. Pristov, 1998: Surface streams and water balance of Slovenia.- MOP-Hidrometeorološki zavod Republike Slovenije, p.98, Ljubljana.

Komac, B., 2001: The karst springs of the Kanin massif.- Acta geographica, 41, 7-43, Ljubljana.

Kuščer, D. & K. Grad & A. Nosan & B. Ogorelec, 1974: Geološke raziskave Soške doline med Bovcem in Kobaridom (Geology of the Soča valley between Bovec and Kobarid).- Geologija, 17, 425-476, Ljubljana.

Lajovic, A., 1982: Govic.- Naše jame, 23-24, 5-15, Ljubljana.

Melik, A., 1961: Vitranc, Zelenci in Bovško (Geomorfološke študije iz zah. Julijskih Alp).- Geografski zbornik, 6, 287-332, Ljubljana.

Novak, D., 1979: Nekatere raziskave podzemeljskih voda Alpskega krasa (Investigation of underground waters in alpine region of Slovenia).- Naše jame, 20, 31-36, Ljubljana.

Novak, D., 1990: Novejša sledenja kraških voda v Sloveniji (Recent tracings of karstic waters in Slovenia).- Geologija, 33, 461-478, Ljubljana.

Novak, D., 1994: Oskrba s pitno vodo v občini Kamnik.- Geografski vestnik, 66, 145-160, Ljubljana.

Novak, D., 1996: Podzemeljske vode v Kamniških in Savinjskih Alpah (Underground waters in

Kamnik and Savinja Alps).- Geologija, 37/38, 415-435, Ljubljana.
Pišljar, M., 1992: Hidrogeološko zaledje in varstvena območja izvira Zadlaščica (Water catchment and protection areas of the Zadlaščica spring).- RMZ, 39/1-2, 167-180, Ljubljana.
Protected Water Resources, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm
Rivers, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm
Settlements, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm
Springs, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm
Trišič, N. & M. Bat & J. Polajnar & J. Pristov, 1997: Water balance investigations in the Bohinj region.- In: Kranjc, A. (Ed.). Tracer Hydrology 97: proceedings of the 7th International Symposium on Water Tracing, Portorož, Slovenia, 26-31 May 1997. 295-298, A.A. Balkema, Rotterdam.
Urbanc, J. & A. Brancelj, 2000: Sledilni poizkus v Jezeru v ledvici, dolina Triglavskih jezer (Tracing experiment in the Ledvica Lake in the Triglav Lakes Valley).- Geologija, 42, 207-214, Ljubljana.
Water Supply Areas, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm
Watersheds, 2004. EIONET-SI. URL (quoted 27.1.2004): http://nfp-si.eionet.eu.int/ewnsi/index.htm
Zupančič, B., 1995: Klimatografija Slovenije 1961-1990, Padavine.- MOP-Hidrometeorološki zavod RS, p. 366, Ljubljana.

VODE ALPSKEGA KRASA V SLOVENIJI

Povzetek

Alpski kras, ki ga gradijo predvsem apnenci ter deloma dolomiti in dolomitizirani apnenci triasne starosti, pokriva okrog 11 % slovenskega ozemlja (Sl. 1). Glavna hidrogeološka enota so dobro prepustni kraški vodonosniki (Sl. 2). Ponekod prevladujejo dolomiti z značilnostmi nekoliko slabše prepustnih razpoklinskih vodonosnikov.

Povprečne letne padavine na območju slovenskega alpskega krasa dosegajo 3000 mm. Zaradi redke pokritosti z vegetacijo in majhnih debelin prsti je delež efektivne infiltracije velik in površinski tokovi so redki. Med visoke planote so vrezane globoke doline in znotraj visokogorskega napajalnega zaledja infiltrirana voda se pretaka podzemno proti izvirom v teh dolinah (Sl. 2). Manjši in bolj gosto razporejeni so izviri v razpoklinskih vodonosnikih, v katerih je kraška mreža manj razvita in je pretakanje podzemne vode bolj lokalno. Alpski kraški izviri (nekateri najpomembnejši so prikazani na sliki 3) napajajo alpske reke kot so Soča, Sava, Savinja, Meža in druge. Soča odteka proti Jadranskemu morju, ostale naštete pa proti Črnemu morju. Približen potek razvodnice med obema bazenoma je prikazan na sliki 2.

Na osnovi hidrogeološke karte (Sl. 2) je bil obseg alpskega krasa v Sloveniji ocenjen na 2200 km^2, s primerjavo kart povprečnih letnih padavin in evapotranspiracije v obdobju 1961-1990 pa povprečna letna efektivna infiltracija na 1620 mm. Z upoštevanjem obeh vrednosti sem izračunala, da bi zaloge podzemne vode v alpskem krasu lahko stalno napajale izvir s povprečnim pretokom 115 m^3/s.

Na sliki 2 sta prikazana položaj in izdatnost (ne povprečni pretok, ampak količina vode, ki jo je možno zajemati ob nizkem vodostaju) vseh izvirov znotraj alpskega krasa. Približno 1200 izvirov ima skupno izdatnost okrog 15 m^3/s in med njimi je 26 izvirov z izdatnostjo preko 100 l/s. Hidrološki režim izvirov se v splošnem ujema z razporeditvijo padavin, opazno pa je značilno povečanje pretokov spomladi zaradi taljenja pozimi nakopičene snežne odeje (Sl. 4).

Alpski kraški izviri so trenutno le delno izkoriščani za vodooskrbo, predvsem zaradi redke poseljenosti v visokogorju in relativno velikih oddaljenosti od večjih mest. Od skupaj 1200 izvirov s skupno izdatnostjo 15 m^3/s jih je zajetih okrog 400 s skupno izdatnostjo 3,8 m^3/s (Sl. 5). Če upoštevamo samo naselja z več kot 100 prebivalci, se z alpsko kraško vodo oskrbuje 315 naselij s skupno več kot 227.000 ljudmi. Če temu prištejemo še manjša naselja, se številka poveča na okrog 240.000 prebivalcev.

Zaloge podzemne vode v alpskem krasu so torej velike, človekovi vplivi pa že ogrožajo njeno kakovost. Ranljivost alpskih kraških vodonosnikov je velika (hitra infiltracija in hiter prenos snovi daleč stran od točke vnosa, kratek zadrževalni čas in zato manj učinkoviti procesi samoočiščevanja). Bolj ugodna lastnost je majhna obremenjenost zaradi redke naseljenosti, kljub temu pa človekove dejavnosti predstavljajo potencialno grožnjo. V visokogorju je dobro razvit turizem (smučišča s celotno infrastrukturo, planinske koče, ponekod počitniške hišice). Kmetijstvo je ekstenzivno, vendar predvsem aktivni gorski pašniki predstavljajo določeno nevarnost. Dodatna obremenitev so divja odlagališča odpadkov.

Opisane obremenitve se že odražajo na kakovosti vode. Predvsem gre za bakteriološko onesnaženje zaradi komunalnih odpadnih vod in kmetijstva. V tabeli 1 so zbrani podatki o kakovosti nekaterih površinskih vodotokov, ki jih napajajo alpski kraški izviri. Za obdobje 1994-2000 so bili zgornji tokovi teh vodotokov uvrščeni v kakovostni razred 1 (voda ob morebitni dezinfekciji primerna za pitje) do 1-2. Po toku navzdol se njihova kakovost zmanjša zaradi onesnaženja iz urbanih območij in pade v kakovostni razred 2 ali 2-3.

Zaradi nevarnosti onesnaženja je potrebno načrtovati ustrezne ukrepe za varovanje. Trenutno ima le približno četrtina zajetih alpskih kraških izvirov s skupno izdatnostjo okrog 1,8 m^3/s sprejet odlok o varovanju (Sl. 5). Še za dodatnih 75 izvirov s skupno izdatnostjo 0,4 m^3/s je pripravljen predlog takega odloka.

Predlogi odlokov o varovanju morajo temeljiti na ustreznih strokovnih podlagah, ki upoštevajo značilnosti delovanja kraških vodonosnih sistemov. Problem je pomanjkanje kakovostnih hidrogeoloških podatkov za območje alpskega krasa. Kot primer so prikazani rezultati opravljenih sledilnih poizkusov, ki jih uspešno uporabljamo za simulacijo toka podzemne vode in prenosa snovi. Čeprav je število opravljenih poizkusov na območju alpskega krasa v Sloveniji relativno veliko (Sl. 6), pa so bili na ta način pridobljeni podatki o podzemnem toku le za posamezne predele. Podobno je z drugimi raziskovalnimi metodami. V prihodnje bodo zato kot osnova za izdelavo strokovnih podlag za varovanje alpskih kraških vodonosnikov potrebne bolj sistematične in natančno načrtovane raziskave.

Naslednja faza je sprejetje odloka o zaščiti, ki pa je samo zakonski okvir varovanja. Za uspešno uveljavitev ukrepov je namreč bistvenega pomena, da se tudi širša javnost zaveda vrednosti in ranljivosti alpskih kraških voda ter pomena in nujnosti njihovega varovanja.