NAČIN PRIHRANJIVANJA I MEHANIZAM ISTICANJA VRELA STIJENE

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UVOD

Izvorište Stijene nalazi se sjeverno od Vareša. Smješteno je ispod masiva Grebena i Jabuke, a izbija u koritu rijeke Stavnje (slika 1.).

Javlja se u karbonatnom stijenskom kompleksu u kojem su na tektonskim preddispozicijama razvijeni kraški oblici.

Vrelo je stalno, ali je "razbijeno" i u užoj izvorišnoj zoni ističe na desetak mjesta.

Najznačajnije pojave su na dvije glavne, veoma bliske lokacije, označene kao Stijene "1" (nizvodno) i Stijene "2" (uzvodno vrelo). Rastojanje između njih je 4 – 5 m.

Mjerenjima su ustanovljene znatne razlike u temperaturi voda jednog u odnosu na drugo vrelo. Ovo je, samo po sebi, već određeni indikator različitog porijekla voda.

Zadatak se sastojao u utvrđivanju mogućnosti uvođenja voda izvorišta Stijene u sistem vodosnabdijevanja Vareša. Trebalo je utvrditi geološki okvir i hidrogeološke karakteristike sliva, definirati kvantitativno–kvalitativni režim vrela, te ustanoviti međusobne odnose i uticaje potoka Ponikva na vode vrela, uz definiranje mehanizma pojave i uslova zaštite vrela Stijene. U ovom radu tretiran je samo hidrološko–hidrodinamički aspekt ovog zadatka, odnosno hidrološki režim te mehanizam prihranjivanja i isticanja na vrelu.

SLIVNO PODRUČJE

Sliv vrela morfološki pripada planinskom području sa orografskom površinom od $F = 20\ km^2$. U suštini predstavlja dolinu zatvorenu planinskim vrhovima sa visinama iznad 1200 m n.m. kroz koju protiče potok Ponikva.

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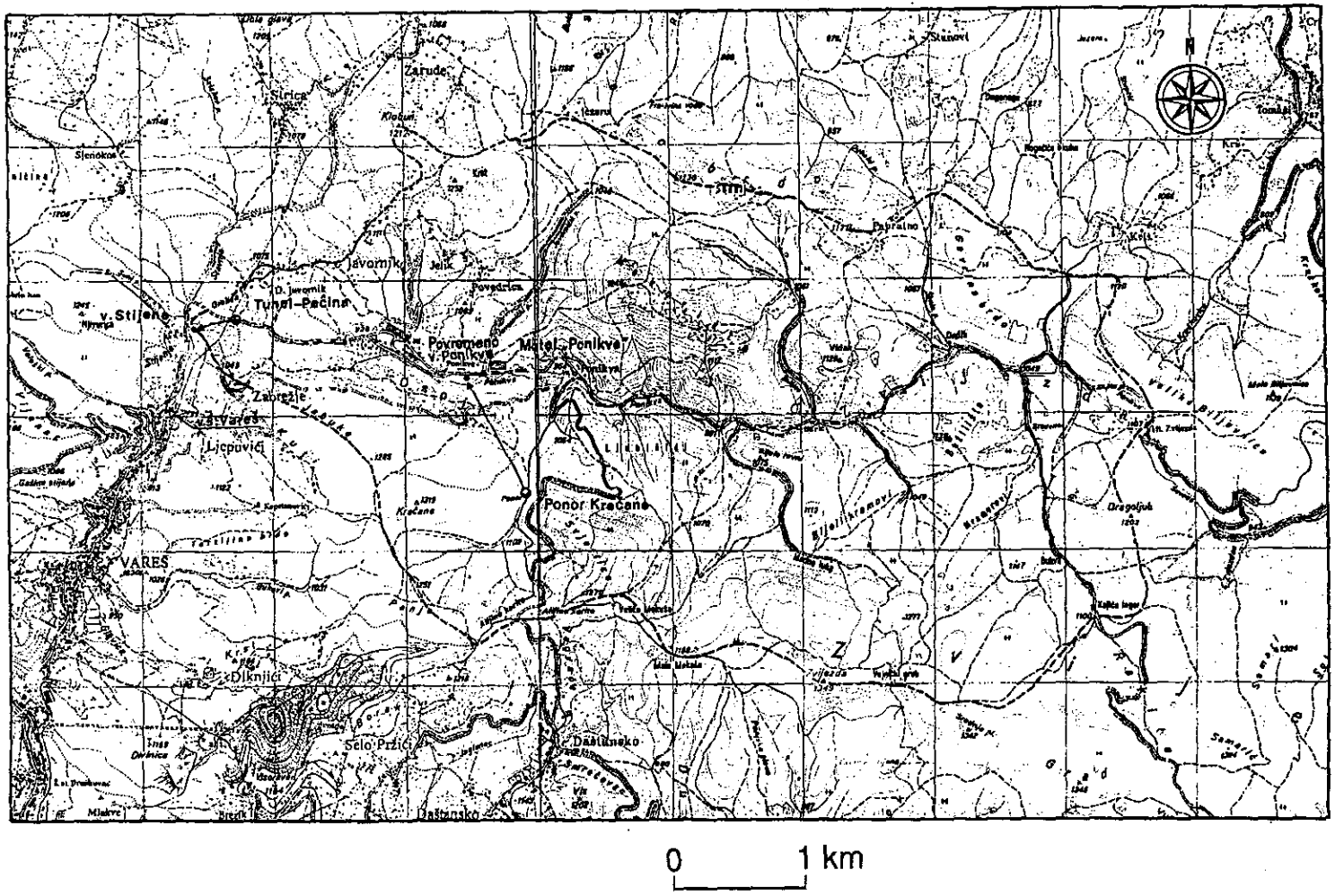

Zarude
Sirica
Javornik
Jelik
Povedrica
Tunel-Pečina
v. Stijene
Povremeno v. Ponikve
Mateli Ponikve
Zabrežje
v. Vareš
Ljepuvići
Ponor Kračane
VAREŠ
Dlknjići
Selo Pržići
Dašćansko
Dašćansko
Papratno
Dragoljuk
0
1 km

Ponikva je u krečnjačkom masivu Grebena formirala subhorizontalnu pećinu–tunel kroz koju prolazi put Vareš–Očevja–Olovo. Pećina predstavlja jedini objekat za evakuaciju površinskih voda iz sliva. Uslijed razdrobljenosti stijenskih masa, tunel–pećina sa uzvodnom dionicom korita Ponikve čini ponorsko–estavelnu zonu na dužini od 1,5 km.

U određenim hidrološkim uvjetima, duž ove zone moguća je direktna komunikacija površinskih i podzemnih voda. Kako se ponorska zona, odnosno tunel–pećina nalazi u neposrednom zaleđu vrela, to je realno očekivati da poniruće vode Ponikve ulaze u podzemlje i mješajući se sa ostalim podzemnim vodama, ponovo izbijaju na vrelu Stijene.

Hidrološke karakteristike izvorišta Stijene i potoka Ponikve

U cilju sagledavanja mehanizma pojave voda na vrelu Stijene, te uslova pri kojima dolazi do poniranja voda Ponikve u neposrednom zaleđu, provedeno je detaljno rekognosciranje terena i mjerenja proticaja duž korita Ponikve i rijeke Stavnje. Rezultat tih mjerenja je identificiranje izvorske i ponorske zone te lociranje stalnih mjerenih profila (slika 2.).

Na potoku Ponikva izabrana su dva mjesta za mjerenje, uzvodno i nizvodno od ponorske zone (profili 3 i 4). Razlika između proticaja na uzvodnom i nizvodnom profilu definira gubljenje ili doticanje:

$$Q_{pon} = Q_3 - Q_4$$

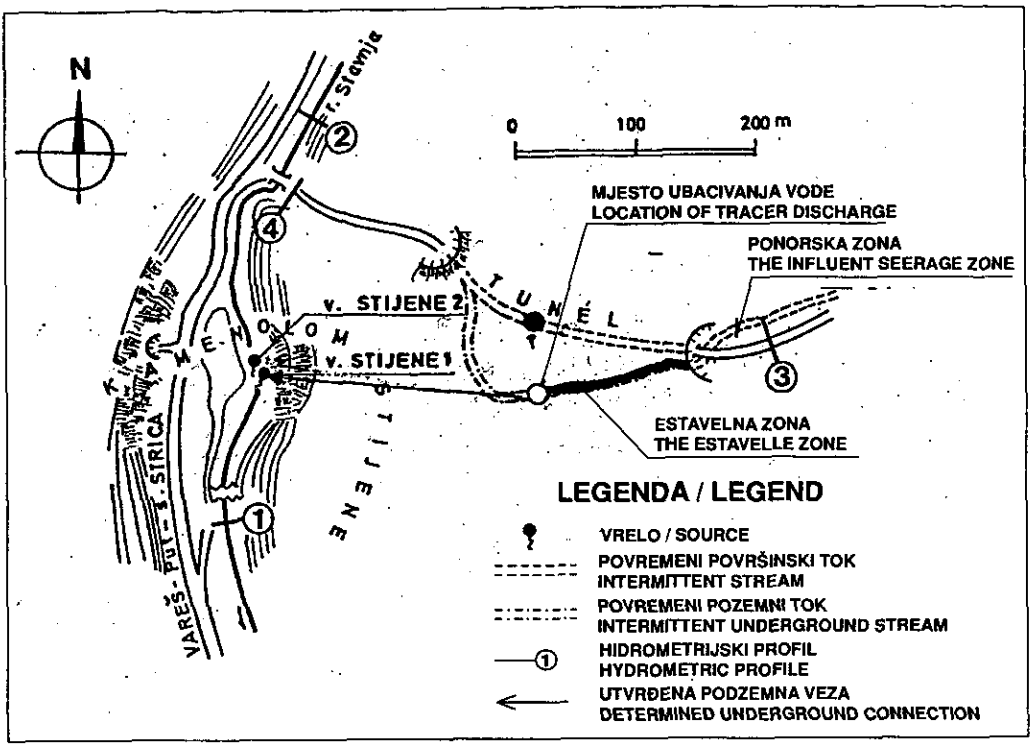
Za definiranje količine izviranja na vrelu Stijene poslužila su mjerenja razlike proticaja rijeke Stavnje uzvodno (profil 2) i nizvodno od vrela (profil 1), količina isticanja određivana je po obrazcu:

$$Q_{vrelo\ Stijene} = Q_1 - (Q_2 + Q_4)$$

Uporedo sa mjerenjima proticaja na spomenutim profilima mjeren je i proticaj rijeke Stavnje na vodomjernoj stanici Vareš. Stanica je odabrana kao reperna, s obzirom da ima definiran režim za kontinuiran niz osmatranja od 20 godina. Locirana je cca 1 km nizvodno od izvorišta Stijene. Pregled izvršenih mjerenja dat je u tabeli 1.

Mjerenjem proticaja na vrelu Stijene i potoku Ponikve, te vodomjernoj stanici Vareš, i uspostavljenim međusobnim zavisnostima uobičajenim postupkom, definirani su karakteristični proticaji Ponikve (prije ulaska u ponorsku zonu) i vrela Stijene. Dobijeni rezultati dati su u tabelama 2 i 3.

Sl. 1.: Situacija šireg područja istraživanja izvorišta i sliva vrela Stijene
Fig. 1.: Survey of the wider study area of the Stijene source and catchment area



Sl. 2.: Skica položaja kontrolnih mjernih profila
Fig. 2.: Scheme of control measurement profiles positions

Definiranje mehanizma poniranja i pojave voda

Za cjelovito sagledavanje mehanizma ponirućih i voda vrela, a u skladu sa specifičnom građom terena, predhodno je potrebno objasniti uslove formiranja i mehanizam oticanja voda unutar sliva.

Naime, vode Ponikve su posljedica površinskog, a vrela Stijene podzemnog oticanja iz jedinstvenog sliva.

Vodotok Ponikva nailazi na ponorsku zonu u donjem dijelu toka. Kako se radi o izrazito kraškom pukotinskom sistemu, ova ponorska zona u određenim situacijama ima dvojaku funkciju: pored poniranja, moguće su i situacije izviranja voda, odnosno situacija kada ponorska zona postaje estavelna.

Poznato je da u kraškom akviferu poniranje, u većoj ili manjoj mjeri, nije posljedica samo geološke građe, već i hidrodinamičkih odnosa unutar pukotinskog sistema. Zbog toga mehanizam poniranja potoka Ponikva, odnosno mehanizam izviranja vrela Stijene zavisi od niza faktora, koji su međusobno vezani i koji u određenom situacijama dolaze u interakciju.

Tabela 1.: Pregled rezultata hidrometrijskih mjerenja na širem području izvorišta

Datum mjerenja	V.S. Vareš h (cm)	PROTICAJ Q (m^3/s)					
		Ponikva uzvodno od tunela profil 3	Kanal – izlaz iz tunela profil 4	Stavnja uzvodno od V.S. profil 2	Stavnja nizvod. od V. Stijene profil 1	Stavnja V.S. Vareš	Vrelo Stijene
01.10.1991.	28	0	0	0.0073	0.013	0.118	0.106
10.10.1991.	33	0	0	0.0095	0.120	0.130	0.110
17.03.1992.	47	0.475	0.149	0.270	0.950	0.989	0.531
08.05.1995.	–	–	–	0.247	0.475	0.490	0.230
05.07.1996.	30	0.0245	0	0.0169	0.162	0.171	0.145
01.08.1996.	28	0.0065	0	0.0096	0.111	0.115	0.101
08.11.1996.	38	0.309	0.150	0.214	0.690	0.720	0.326
24.11.1996.	57	1.30	1.29	0.653	2.55	2.650	0.607
07.03.1997.	36	0.274	0.124	0.092	0.508	0.540	0.292
13.03.1997.	32	0.204	0.044	0.059	0.34	0.355	0.235
17.05.1997.	29	0.134	0.015	0.032	0.304	0.318	0.257
22.05.1997.	29	0.083	0	0.025	0.231	0.240	0.206

Tabela 2.: Karakteristični proticaji potoka Ponikva na profilu uzvodno od ponorske zone

PROSJEČNI VIŠEGODIŠNJI PROTICAJ	PROSJEČNI PROTICAJ Q (m^3/s) RANGA POJAVE T (GODINA)			
	2	5	10	20
0.385	0.356	0.483	0.496	0.534
PROSJEČNI MINIMALNI PROTICAJ	MINIMALNI PROTICAJ Q (m^3/s) RANGA POJAVE T (GODINA)			
	2	5	10	20
0.064	0.066	0.036	0.023	0.013
PROSJEČNI MAKSIMALNI PROTICAJ	MAKSIMALNI PROTICAJ Q (m^3/s) RANGA POJAVE T (GODINA)			
	2	5	10	20
5.56	5.05	7.60	9.60	11.70

Tabela 3. Karakteristični proticaji vrela Stijene

PROSJEČNI VIŠEGODIŠNJI PROTICAJ	PROSJEČNI PROTICAJ Q (m^3/s) RANGA POJAVE T (GODINA)			
	2	5	10	20
0.440	0.420	0.474	0.482	0.488
PROSJEČNI MINIMALNI PROTICAJ	MINIMALNI PROTICAJ Q (m^3/s) RANGA POJAVE T (GODINA)			
	2	5	10	20
0.136	0.138	0.109	0.097	0.088

Iznalaženje i pojedinačno definiranje uslova pri kojima se događa poniranje i situacija kada ono prestaje, te definiranje karaktera izviranja voda na vrelu i spoznaja uzročno–posljedične veze između ove dvije pojave, u suštini predstavlja definiranje mehanizma poniranja odnosno izviranja.

U skladu sa navedenim postavkama, odgovarajućim mjerenjem proticaja potoka Ponikva na ulazu i izlazu iz ponorske zone tunel–pećina, te uspostavljanjem zavisnosti proticaja Ponikve na ulazu u ponorsku zonu i količine koja ponire–izvire, dobiven je dijagram prikazan na slici 3.

Identificirana veza jasno ukazuje da se poniranje voda u zoni tunel–pećina odvija dok proticaj Ponikve na ulazu u ponorsku zonu (profil 3) ne dostigne vrijednost od Q = 1.3 m^3/s. Tog momenata prestaje poniranje i daljnim povećanjem doticanja iz sliva, ponorska zona postaje izvorska.

Uspostavljeni odnos proticaja vrela Stijene – V.S. Vareš na rijeci Stavnji (slika 4.) ukazuje da vrelo Stijene ima ograničenu pukotinsku provodnost, te da je maksimalni proticaj vrela ograničen.

Na osnovu uspostavljene veze na vrelu maksimalni proticaj pri pojavi velikih voda može dostići vrijednost oko 2 m^3/s. Daljnje povećanje proticaja na vrelu Stijene nije moguće, te se evakuacija voda iz sliva odvija preko estavelne zone u tunel–pećini i najvećim dijelom površinski, potokom Ponikva. Iz tog razloga, u velikim vodama proticaj u pećini se multiplicira. Sa jedne strane vodama Ponikve, a sa druge, izviranjem podzemnih voda u estavelnoj zoni. Posljedica je plavljenje tunela–pećine što ugrožava normalno odvijanje saobraćaja na putu Vareš – Olovo.

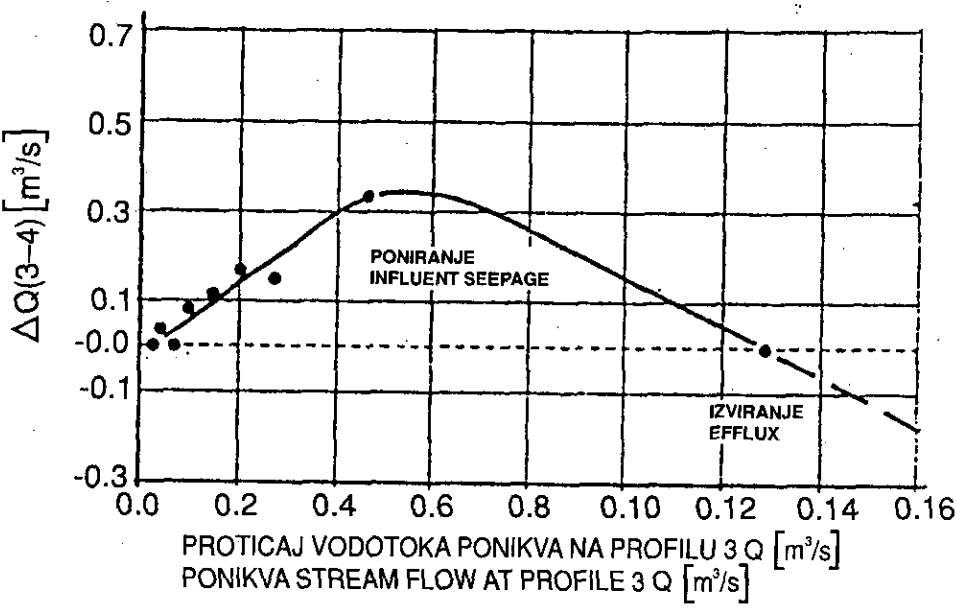


TABELA MJERENJA
TABLE OF MEASUREMENTS

DATUM DATE	Q PROFIL 3 Q PROFILE 3 Q [m³/s]	Q PROFIL 4 Q PROFILE 4 Q [m³/s]	ΔQ [m³/s]
01.10.1991.	0	0	0
10.10.1991.	0	0	0
17.03.1992.	0.475	0.149	0.326
05.07.1996.	0.024	0	0.024
01.08.1996.	0.006	0	0.006
24.11.1996.	1.30	1.295	0.005
07.03.1997.	0.204	0.044	0.16
17.05.1997.	0.134	0.015	0.119
22.05.1997.	0.083	0	0.083

Slika 3.: Zavisnost proticaja potoka Ponikva na ulazu u ponorsko–estavelnu zonu tunel–pećina i količine poniranja u njoj

Fig. 3.: Interdependency between the Ponikva stream flow at the entrance point of the tunnel–cave influent seepage–estavelle zone, and its seepage quantity

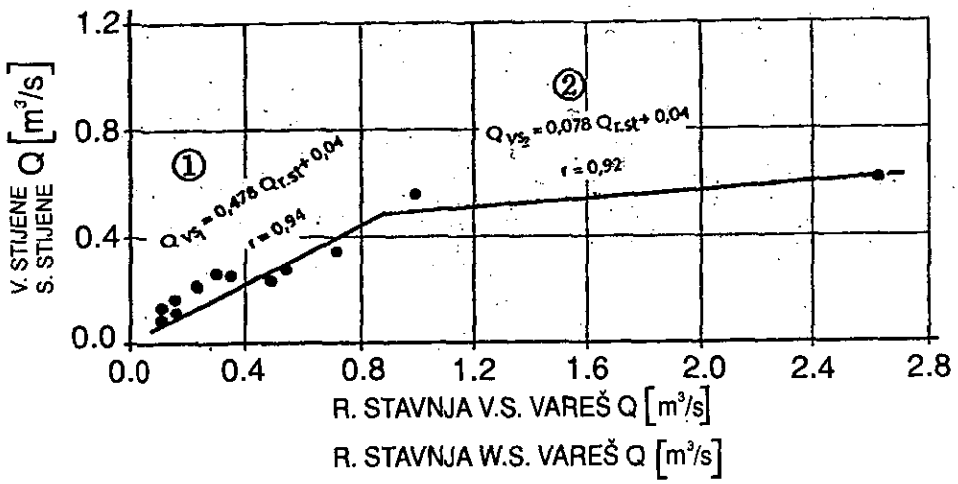


TABELA MJERENJA
TABLE OF MEASUREMENTS

DATUM DATE	PROTICAJ Q[m³/s] FLOW Q[m³/s]	
	V.STIJENE S. STIJENE	R. STAVNJA V.S. VAREŠ R. STAVNJA w.S. VAREŠ
01.10.1991.	0.1O6	0.118
10.10.1991.	0.110	0.130
17.03.1992.	0.531	0.989
08.05.1995.	0.230	0.490
05.07.1996.	0.145	0.171
01.08.1996.	0/101	0/115
08.11.1996.	0.326	0.720
24.11.1996.	0.607	2.650
07.03.1997.	0.292	0.540
13.03.1997.	0.235	0.355
17.05.1997.	0.257	0.318
22.05.1997.	0.206	0.240

Sl. 4.: Zavisnost proticaja vrela Stijene i proticaja na V.S. Vareš
Fig. 4.: Interdependency between the Stijene source flow and the flow in the Vareš W. S.

Definiranje pravca toka podzemne vode i načina prihranjivanja

Za utvrđivanje pravca prihranjivanja, te uticaja ponirućih voda i njihovih miješanja sa vodama vrela, urađena su odgovarajuća obilježavanja ponorskih i ponorsko–estavelnih zona u neposrednom slivu vrela Stijene u četiri navrata. Dvije serije bojenja izvedene su neposredno u ponorsko–estavelnoj zoni pećina–tunelu. Jedno bojenje obavljeno je na području motela "Ponikva" kontinuiranim upuštanjem obilježivača u vodotok Ponikvu. Namjera je bila identificiranje eventuano dispergiranog poniranja. Obavljeno je i obilježavanje u ponoru Krečane na udaljenosti cca 2,5 km od vrela Stijene (sika 1. i 2.).

Bojenja obavljena pećini–tunelu, te bojenje obilježavanjem vodotoka Ponikva imala su kao rezultat pojavu boje na vrelu "1". Niti u jednom slučaju nije bilo pojave boje na vrelu "2", pa čak ni u tragovima. Šematski prikaz tlocrta pećine–tunela sa ponorima i šematski prikaz vrela "1" i "2" dati su na slikama 5. i 6.

Dobijeni rezultati potvrđuju da ponorsko–estavelna zona pećina–tunel u situaciji srednje malih voda direktno komunicira samo sa vrelom "1" (slika 6. i tabela 4.).

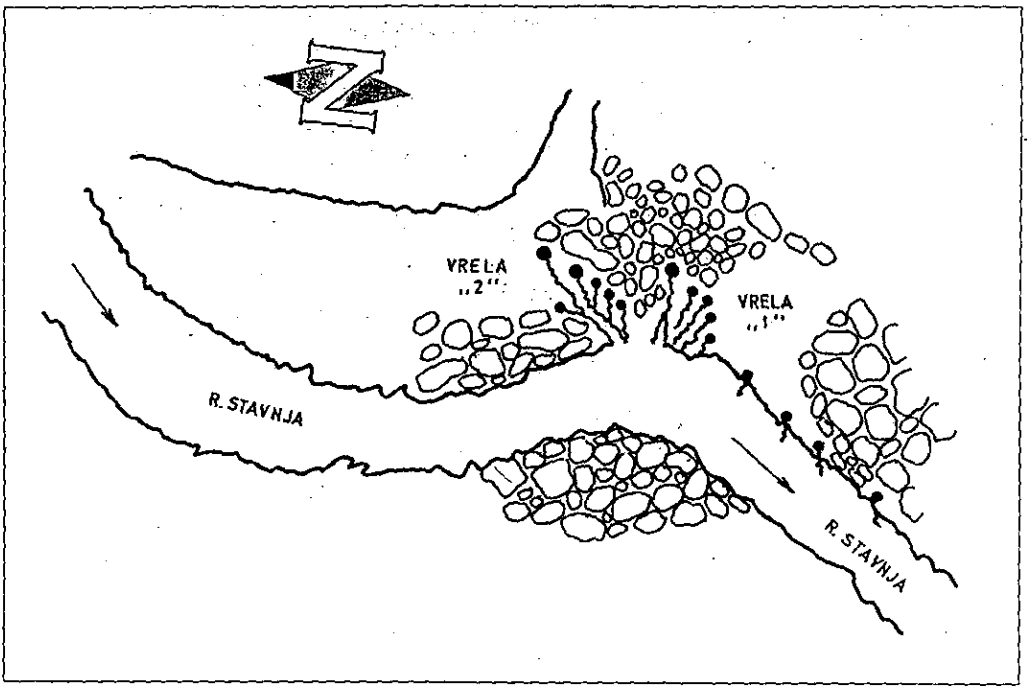
Bojenje je ponovljeno i u godišnjem minimumu voda. Rezultat je bio isti.

Uticaj Ponikve na kvalitet voda sa elementima zaštite vrela Stijene

U tunel–pećini, pored saobraćajnice izgrađeni su i drugi infrastrukturni objekti. Pojave ekscesnih plavljenja (jednom u dvije do tri godine) izazivaju znatne materijalne štete. Rješavanje ovog problema u uskoj je sprezi sa rješavanjem neposredne zaštite vrela Stijene.

Najveći broj potencijalnih zagađivača lociran je u dijelu sliva u kome se primarno formira površinsko oticanje tako da sva eventualna zagađenja, najvećim dijelom dospijevaju u vodotok Ponikvu.

Dotičući do ponorsko–estavelne zone u tunel–pećini vode ulaze u podzemlje. Kako tunel–pećina predstavlja jedini objekat za evakuaciju površinskih voda iz sliva, to zbog izgrađene saobraćajnice i poremećenih prirodnih odnosa unutar tunela, isti često biva plavljen. Plavljenjem, vode Ponikve odlažu suspendirane materije i druga onečišćenja koja donose iz sliva. Prestankom poplave i ponovnim aktiviranjem ponorske zone, onečišćenje ulazi u podzemlje. Pored toga, saobraćaj motornih vozila uz transport raznih vrsta tereta, također predstavlja izvor zagađenja.

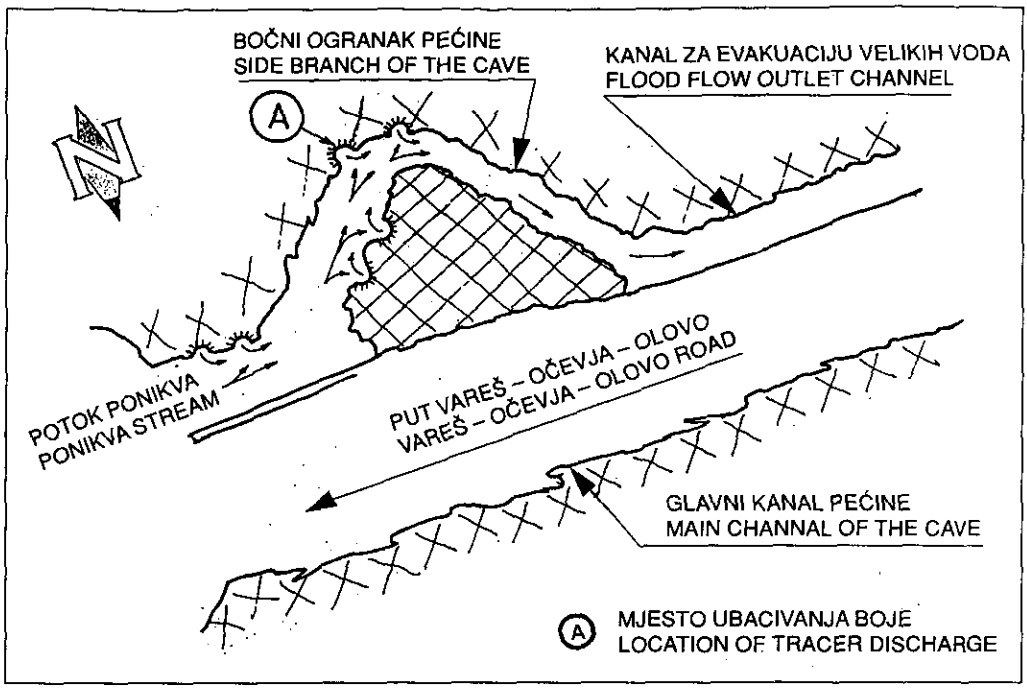


Sl. 5.: Šematski prikaz tlocrta pećine–tunel
Fig. 5.: Schematic survey of the cave–tunnel ground plan

Temparatura vode na vrelu Stijene 1 upućuje na zaključak da postoji komunikacija voda vrela sa površinskim vodama u neposrednoj blizini. Uočeno je da su oscilacije u temperaturi posljedica godišnjeg doba, odnosno spoljne temperature zraka. Istovremeno mjerenje temperature vode Ponikve prije ulaza u ponorsko–estavelnu zonu pećina–tunel održava određenu suglasnost u trendu, samo je po apsolutnoj vrijednosti u zimskom periodu niža, a u ljetnom nešto, pa čak i znatno veća od temeperature vode vrela Stijene 1. Ovo ukazuje da vode Ponikve ulazeći u ponor i mješajući se sa podzemnim vodama utiču na temperaturu podzemne vode.

Temperatura vode vrela Stijene 1 je u nekim hidrološkim situacijama sličnija vodi vodotoka Ponikve (zimski period, nešto veći proticaj), a u nekim momentima temperaturi vode vrela Stijene 2 (ljetni period i manji proticaj Ponikve).

Istovremeno povećanje mutnoće u vodotoku (44 NTU) i vrelu Stijene 1 (15 NTU) kao i utrošak $KMnO_4$ ukazuju na njihovo direktno komuniciranje.



Sl. 6.: Šematski prikaz izvorišta Stijene
Fig. 6.: Schematic survey of the Stijene source

Stoga, iznalaženje adekvatnog rješenja za višenamjensko korištenje objekta tunel–pećine, te obezbjeđenja nesmetane evakuacije velikih voda uz kontrolu poniruđih voda, ima veliku važnost za zaštitu vrela

ZAKLJUČCI

U smislu faktički ustanovljene argumentacije, van svake je sumnje slijedeće:

- prethodnim višekratnim istraživanjima utvrđeno je da prosječne male vode vrela Stijene ne padaju ispod 100 l/s;
- isticanja su razbijenog tipa;
- ne radi se o jednom koncentriranom kraškom vrelu nego o sistemu vrela i izvora situiranih na mjestima "izdanjivanja" podzemnih kanala;
- rastojanja pojedinih vrela i izvora unutar zone isticanja na dužini oko 50 m su relativno kratka i ne prelaze 10 m međusobnih udaljenosti;
- dvije od ukupno šest registriranih izvorskih pojava imaju dominantan karakter vrela;

Tabela 4.: Pregled rezultata obilježavanja ponorskih zona u slivu

Datum obilježavanja	07.03.97	13.03.97	14.03.97	17.03.97
Vrijeme ubacivanja boje (sati) Mjesto ubacivanja boje	12^{00} pećina –tunel	10^{10} pećina –tunel	10^{20} –10^{40} vodotok Ponikva profil "motel"	11^{30} ponor Krečane
Količina ubačene boje (kg)	0.6	0.4	1.5	2.5
Mjesto pojave boje	vrelo Stijene	vrelo Stijene	vrelo Stijene	povremeno vrelo uzvodno od pilane u Ponikvi
Proteklo vrijeme od pojave boje t (min)	105	230	270	2640
Proteklo vrijeme od pojave max. koncentracije t (min)	200	320	70	3720
Udaljenost od mjesta ubacivanja do mjesta pojave boje t (min)	200	200	–	1000
Brzina toka na osnovu prve pojave boje (m/s)	3.8×10^{-2}	1.45×10^{-2}	–	6.35×10^{-3}
Brzina toka na osnovu maximalne pojave boje (m/s)	1.8×10^{-2}	1.04×10^{-2}	–	4.5×10^{-3}
Proticaj r. Stavnje na V.S. Vareš $Q(m^3/s)$	0.292	0.235	0.210	0.257

- oba dominirajuća vrela podjenake izdašnosti situirana su jedno pored drugog na udaljenosti 3 – 4 m;
- kao što se ne radi o samo jednom vrelu u pojavnom smislu, tako se i prihranjivanje ne vrši samo jednom "glavnim" kanalom i iz samo jednog pravca;
- na vrelu Stijene se podzemne vode prazne spletom pukotina, kaverni i tektonski raslabljenih zona (rasjeda) situiranih u nekoliko međusobno različito povezanih nivoa;
- dio takvog podzemnog sistema koristi Ponikva u glavnoj zoni poniranja (u pećini Ponikva);
- ostvarujući komunikaciju sa vrelom Stijene ponorska zona periodski ima funkciju estavele;

- obilježavanjem je utvrđeno da se poniruće vode Ponikve javljaju samo na nizvodnom vrelu (Stijene 1) i sekundarno na pratećim, ali opet nizvodnim izvorima, i niti jedan put na vrelo Stijene 2 ili uzvodnom potezu;
- očito, riječ je o dva mehanizma unutar jedinstvenog sistema (zone) isticanja;
- posredno, zaključuje se da je kapacitativnost, odnosno propusna sposobnost spleta kanala neujednačena i evidentno manja od količina voda koje površinski i podzemno sezonski gravitiraju vrelima;
- periodski dolazi do estavelnog rada iz podzemnih kanala, a višak dotičućih voda Ponikve protiče tunel–pećinom prema Stavnji;
- u periodu povlačenja i opadanja voda, dakle u sušnim sezonama kada se izjednače količine dotičućih i poniručih voda, nastupa momenat prelaska Ponikve u cjelosti u podzemlje, a nizvodni otvoreni vodotok u pećini presahne; takva je situacija kada proticaj Ponikve opadne ispod količine Q 100 l/s.
- prelaskom Ponikve u podzemno tečenje, trend pražnjenja i opadanja nivoa podzemnih voda nastavlja se retrogradno duž vodotoka;
- u uzvodnom pravcu presušuje jedan po jedan ponor duž cijelog segmenta korita usječenog u krečnjacima;
- proizlazi da su vrelo Stijene "2" primarno, starije, pravo kraško vrelo koje ne komunicira s Ponikvom i ima vlastiti režim i mehanizam isticanja;
- u pogledu prihranjivanja vrelo Stijene "2" najvjerovatnije koriste dublje situirane, starije kraške puteve ispod Ponikvi kojima dotiču vode iz zaleđa sa većih udaljenosti i većih dubina, te se na osnovu pojave voda i geoloških analiza, koja je rađena a ovdje nije prikazana, zaključuje da je vrelo Stijene "2" nesumnjivo uzlaznog karaktera; a vrelo Stijene "1" preovlađujuće gravitacijskog tipa;
- proizlazi da se u pogledu koncepcijskog rješenja i načina izvedbe vodozahvata sa izvješnošću, decidirano može ustvrditi da pažnju valja usmjeriti na vrelo Stijene "2" dok u pogledu tretmana i zaštite zahvaćenih voda, ista treba biti okrenuta vrelu Stijene "1".

LITERATURA

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FEEDING AND EFFLUX MECHANISM OF THE STIJENE SOURCE

Nijaz Zerem

INTRODUCTION

The Stijene source is situated to the north of Vareš. It is at the foot of the massif of Greben and Jabuka, and spouts in the riverbed of Stavnja (Fig. 1).

It is located in the carbonate rock complex where karstic forms developed as a result of tectonic predispositions.

The source is constant, but it is "dispersed" and spouts at about ten places within the narrow source zone.

Its most important spouting points are the two main, mutually close locations, marked Stijene "1" (downstream) and Stijene "2" (upstream source). Distance between the two locations is 4 – 5m.

Measurements have shown considerable differences between the water temperature of the two sources. This finding by itself is indicative of different origin of their waters.

Our task was to explore possibilities of introducing of the Stijene source waters into the Vareš water supply system. We were therefore to determine the geological frame and hydrogeological characteristics of the catchment area, define the quantitativo–qualitative regime of the spring, its mutual relation with the Ponikva stream and effect of the stream on the spring waters, as well as the mechanism and conditions of the Stijene source protection. This paper focused only on the hydrologico–hydrodynamical aspect of the task i.e. it treated the hydrological regime and the source feeding and efflux mechanisms.

THE CATCMENT AREA

Morphologically, the catchment area belongs to the mountain region with total orographical area of F = 20 km^2. It essentially represents a valley cut by the flow of the Ponikva stream and surrounded by mountain ridges reaching altitude of above 1200 m.

The Ponikva stream has in the Greben limestone massif formed a subhorizontal cave–tunnel through which the road Vareš – Očevja – Olovo passes. The cave represents the only outlet object of the catchment area of surface waters. As a result of rock mass disintegration, the tunnel–cave together with the upstream section of the Ponikva riverbed, creates an influent seepage–estavelle zone long 1.5 km.

Under certain hydrological conditions, there is a possibility of direct interaction between surface waters and groundwaters in this zone. Since the influent seepage zone

i.e. the tunnel–cave is situated immediately at the rear of the source, it is only natural to expect that the influent stream waters of Ponikva in their underground flow mix with other groundwater streams and again spout at the Stijene source.

Hydrological Characteristics of the Stijene Source and Ponikva Stream

With a view to analyzing of the water efflux mechanism of the Stijene source, and conditions enabling influent seepage phenomenon of the Ponikva waters at the source rear, we have performed a detailed reconnaissance of the terrain and measurements of flow along the river beds of the Ponikva stream and Stavnja river. The result of these measurements was identifying of the efflux and influent seepage zones and locating of the constant measurement profiles.

In the Ponikva stream, we have chosen two locations for measurements, placed upstream and downstream from the influent seepage zone (profiles 3 and 4). The difference between flow at the upstream and downstream profile shows loss or influx:

$$Q_{\text{influent seepage}} = Q_3 - Q_4$$

In order to determine the quantity of the Stijene source efflux, we have measured the differences between the River Stavnja upstream (profiles 2 and 4) and downstream flow (profile 1). The quantity of efflux was calculated based on the following formula:

$$Q_{\text{Stijene spring}} = Q_1 - (Q_2 + Q_4)$$

Parallel to the measurements of flow at the above–mentioned profiles, we have also measured the flow of Stavnja in the Vareš water meter station. The station was chosen as a benchmark since it has an determined regime for continual observation in the course of 20 years period. It is situated approximately 1km downstream of the Stijene source. Survey of the performed measurements is presented in Table 1.

By means of measurements of the flow in the Stijene source and Ponikva stream, as well as in the Vareš water meter station, and based on their interdependence measured through the usual procedure, we have defined the characteristic flows of Ponikva (before entering the influent seepage zone) and the Stijene source. The results are presented in Tables 2 and 3.

Defining of Water Influent Seepage and Efflux Mechanisms

In order to provide a thorough understanding of influent seepage and efflux waters mechanisms, and due to the specific constitution of the terrain, it is necessary to begin with explanation of the conditions of water forming and runoff mechanisms within the catchment area.

The fact is that the Ponikva waters are the result of surface, and the Stijene spring waters of underground water runoff in the single catchment area.

Table 1.: Survey of the results of hydrometric measurements in the wider source area

Date of Measurement	W.S. Vareš h (cm)	FLOW Q (m^3/s) Ponikva upstream of the tunnel Profile 3	Channel – exit from the tunnel Profile 4	Stavnja upstream of the W.S. Profile 2	Stavnja downstream od of the Stijene source Profile 1	Stavnja W.S. Vareš	Stijene source
01.10.1991.	28	0	0	0.0073	0.013	0.118	0.106
10.10.1991.	33	0	0	0.0095	0.120	0.130	0.110
17.03.1992.	47	0.475	0.149	0.270	0.950	0.989	0.531
08.05.1995.	–	–	–	0.247	0.475	0.490	0.230
05.07.1996.	30	0.0245	0	0.0169	0.162	0.171	0.145
01.08.1996.	28	0.0065	0	0.0096	0.111	0.115	0.101
08.11.1996.	38	0.309	0.150	0.214	0.690	0.720	0.326
24.11.1996.	57	1.30	1.29	0.653	2.55	2.650	0.607
07.03.1997.	36	0.274	0.124	0.092	0.508	0.540	0.292
13.03.1997.	32	0.204	0.044	0.059	0.34	0.355	0.235
17.05.1997.	29	0.134	0.015	0.032	0.304	0.318	0.257
22.05.1997.	29	0.083	0	0.025	0.231	0.240	0.206

Table 2.: Characteristic flows of the Ponikva stream at the profile upstream of the influent seepage zone

AVERAGE FLOW IN SEVERAL YEARS	AVERAGE FLOW Q (m^3/s) OCCURRENCE RANK T (YEAR)			
	2	5	10	20
0.385	0.356	0.483	0.496	0.534
AVERAGE MINIMUM FLOW	MINIMUM FLOW Q (m^3/s) OCCURRENCE RANK T (YEAR)			
	2	5	10	20
0.064	0.066	0.036	0.023	0.013
AVERAGE MAXIMUM FLOW	MAXIMUM FLOW Q (m^3/s) OCCURRENCE RANK T (YEAR)			
	2	5	10	20
5.56	5.05	7.60	9.60	11.70

Table 3.: Characteristic flows of the Stijene source

AVERAGE FLOW IN SEVERAL YEARS	AVERAGE FLOW Q (m^3/s) OCCURRENCE RANK T (YEAR)			
	2	5	10	20
0.440	0.420	0.474	0.482	0.488
AVERAGE MINIMUM FLOW	MINIMUM FLOW Q (m^3/s) OCCURRENCE RANK T (YEAR)			
	2	5	10	20
0.136	0.138	0.109	0.097	0.088

Stream flow of Ponikva encounters an influent seepage zone in its lower course. Since the area represents a characteristic karstic fissure system, under certain conditions, this influent seepage zone can have two separate functions: in addition to the influent stream, there is also a possibility of water spouting i.e. situations when the influent seepage zone becomes an estavelle zone.

It is a well–known fact that influent seepage in karstic aquifer is more or less not only the consequence of its geological substance, but also a result of hydrodynamical relations within the fissure system. It is for this reason that the influent seepage mechanism of the Ponikva stream and the efflux mechanism of the Stijene source, depend on a number of interrelated factors that in certain situations interact.

Identifying and defining of individual conditions whereby influent seepage takes place and situations wherein it stops, as well as defining of the character of the spring water efflux and further establishing of the cause and effect relation between these two phenomena, essentially represents the defining of influent seepage and efflux mechanisms in themselves.

Based on the stated postulations, adequate measurements of the Ponikva stream flow at the points of entrance and exit from the tunnel–cave influent seepage zone, and the determined interdependency between the Ponikva flow at the entrance into the influent seepage zone, and the seeping–spouting water quantity, we were able to present the chart on Figure 3.

The identified relation clearly indicates that the water influent seepage in the tunnel–cave zone takes place until the Ponikva flow at the entrance point of the influent seepage zone (profile 3) reaches the value of $Q = 1.3\ m^3/s$. It is at this point that the influent seepage stops and through further increase of influx from the catchment area, the influent seepage zone becomes a spring zone.

The determined relation between the Stijene source flow and the flow in the Vareš water meter station (W. S.) on the Stavnja river (Figure 4), indicates that the Stijene source has a limited fissure conduction, and that the maximum spring flow is limited.

The established relation indicates that the maximum flow at the source in case of flood flow, can reach the value of approximately 2 m^3/s. Further growth of the Stijene source flow is not possible, so that the catchment water outlet takes place through the estavelle zone in the tunnel–cave and for the most part through surface flow, i.e. the Ponikva stream. It is for this reason that at times of flood flow, the flow in the cave is multiplied on the one hand by waters of Ponikva, and on the other by spouting of groundwaters in the estavelle zone. The consequence of this phenomenon is flooding of the tunnel–cave, which hinders the regular traffic activity on the road Vareš – Olovo.

Defining of the Groundwater Course and the Way of Feeding

With a view to defining of the course of feeding, and the influence of the influent stream waters and their mixing with the spring waters, we have for four times marked certain influent seepage and influent seepage–estavelle zones in the immediate catchement area of the Stijene source. Two series of paint marking were done in the immediate influent seepage–estavelle zone of the cave–tunnel. One series was performed in the area of the "Ponikva" motel by means of continual discharge of marker tracer into the Ponikva stream flow. Our intention was to identify a potential dispersive seepage. The marking was also performed in the Krečana sinkhole approximately 2.5 km distant from the Stijene source (Figure 1 and 2).

Discharges of marker tracer in the cave–tunnel, and the one in the Ponikva stream flow, resulted in occurrence of tracer at the source "1". There was, however, no occurrence of tracer at the source "2", not even of the tracks. Schematic survey of the ground plan of the cave–tunnel with sinks and schematic survey of the sources "1" and "2" are given in Figures 5 and 6.

The acquired results confirm that the cave–tunnel influent seepage–estavelle zone at times of low flow directly interacts only with the spring "1" (Figure 6 and Table 4).

Marking was repeated at time of the annual minimum flow. The result was the same.

Influence of Ponikva on the Quality of Water
and Elements of the Stijene Source Protection

In addition to the road, other infrastructural facilities were also built in the tunnel–cave. The excessive floods (occurring once in two to three years) thus cause considerable material damage. Solving of this problem is closely related to finding solution for immediate protection of the Stijene source.

Table 4.: Survey of results of marking of the catchment area influent seepage zones

Date of marking	07.03.97	13.03.97	14.03.97	17.03.97
Time of tracer discharge (hour) Place of tracer discharge	12^{00} Cave–tunnel	10^{10} Cave–tunnel	10^{20}–10^{40} Ponikva flow Profile "motel"	11^{30} Sink–hole Krečane
Quantity of discharged tracer (kg)	0.6	0.4	1.5	2.5
Place where paint occurred	Stijene source	Stijene source	Stijene source	Periodically the source upstream from Ponikva saw–mill
The time passed from tracer occurrence t (min)	105	230	270	2640
The time passed from occurrence of maximum concentration t (min)	200	320	70	3720
Distance between the place of tracer discharge and its occurrence t (min)	200	200	–	1000
Flow speed as based on the first paint occurrence	3.8×10^{-2}	1.45×10^{-2}	–	6.35×10^{-3}
Flow speed as based on the maximum paint occurrence (m/s)	1.8×10^{-2}	1.04×10^{-2}	–	4.5×10^{-3}
Flow of the R. Stavnja in the W. S. Vareš Q(m^3/s)	0.292	0.235	0.210	0.257

The greatest number of potential pollutants is situated in the catchment area where surface flow is formed, so that any potential pollution agents mainly affect the Ponikva stream.

As they flow towards the influent seepage–estavelle zone in the tunnel–cave, the waters enter the underground system. Since the tunnel–cave is the only outlet object of the cathcment area surface waters, it is frequently flooded as a result of the road construction and interruption of the natural relations within the tunnel. While flooding, the waters of Ponikva deposit suspended materials and other contaminating agents carried from the cathcment area. Once the flooding stops and the influent seepage zone becomes active again, pollution agents enter the underground water system. Moreover, motor vehicle traffic and transport of various kinds of cargo, represent another source of pollution.

By means of measuring of the Stijene "1" source water temperature, we reached the conclusion that there is an interaction between the spring waters and surface waters

flowing in their immediate vicinity. We observed that temperature oscillations are the result of seasonal changes, i.e. of the air temperature. Measurement of the Ponikva stream water temperatures in the same season shows certain consistency. Its absolute value is only in winter period lower, and in summer somewhat, even considerably higher than the water temperature of the Stijene "1" source. This indicates that the Ponikva stream waters, entering the seepage zone and mixing with groundwaters, influence their temperature.

Under certain hydrological conditions, the Stijene "1" source water temperature is closer to the water temperature of the Ponikva stream (winter period, higher flow), and at other times it is closer to the Stijene "2" source water temperature (summer period, lower flow of Ponikva).

At the same time, increase of the surface water flow turbidity (44 NTU) and water turbidity at the Stijene "1" source (15 NTU), as well as their consumption of $KMnO_4$, are again indicative of their direct interaction.

It is for this reason that finding of the adequate solution for multi–purpose usage of the tunnel–cave, and ensuring of free outlet of flood flow waters with simultaneous control of the influent stream waters, is of essential importance for protection of the spring.

CONCLUSION

Based on the established facts, it is past all doubt that:

- The previous repeated research studies have established that the average low flow of the Stijene source never falls below 100 l/s;
- Its efflux is of dispersed type;
- It is not only one concentrated karstic source, but represents a system of springs and sources situated at points of underground channels "sprouting";
- Distances between individual springs and sources within the efflux zone long about 50 m, are relatively small and do not exceed 10 m distance;
- Two out of the total of six registered sources have dominant spring character;
- Both dominating springs are of comparable productivity and are situated within distance of 3 – 4 m;
- In the same way that this is not a single spring in its appearance, its feeding is also not provided through only one "main" channel and from only one direction;
- At the Stijene source, the groundwaters seep through a network of fissures, caverns and tectonically faulted zones (faults) situated at several variously interconnected levels;

- A part of such underground system is used by the Ponikva stream in the main influent seepage zone (in Ponikva cave);
- Through interaction with the Stijene source, the influent seepage zone periodically assumes an estavelle function;
- By means of water marking, we have established that the influent stream waters of Ponikva occur only at the downstream source (Stijene "1") and secondarily at other accompanying, again downstream sources, and never at the Stijene "2" or any other upstream spring;
- There are obviously two mechanisms within a single efflux system (zone);
- We have indirectly reached the conclusion that the capaciousness, i.e. channel capacity in the underground network, varies and that it is evidently smaller than the quantity of waters that both, on the surface and through influent seepage, seasonally gravitate towards the sources;
- There is a periodical estavelle activity in the underground channels; as for the surplus of the influx Ponikva waters, it flows through the tunnel–cave towards Stavnja;
- Periods of water decline and low flow i.e. droughty seasons, when quantities of influx and influent seepage waters become equal, are times when Ponikva waters as a whole flow downwards, whereas the surface downstream water flow in the cave drains; this happens when the Ponikva stream flow falls below Q 100 l/s;
- With transition of Ponikva to influent stream, the tendency of decline and fall of groundwaters level continues retrogradely along the stream flow;
- In upstream area, sink–holes drain one by one along the whole river bed carved in limestone;
- Following from this is the conclusion that the Stijene "2" source is a primary, older, real karstic source that does not interact with Ponikva and has its own efflux regime and mechanism;
- As regards the feeding, the Stijene "2" source most probably uses deeper, older karstic channels under Ponikva, through which waters flow from background, from larger distance and depth; thus, based on the water occurrence and geological analyses that although done, have herein not been presented, we conclude that the Stijene "2" source undoubtedly of ascending type, whereas the Stijene "1" source is predominantly of gravitational type;
- Following from the above, we can ascertain with a great deal of conviction that with respect to conceptual solution and realization of water tapping, the attention should be directed to the Stijene "2" source, whereas the same attention should be given to the Stijene "1" source when focusing on the water treatment and protection.



Pećina–tunel, ulazni dio
Cave–tunnel, entrance part



Vrelo Stijene
Stijene source