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WATER TRACING TEST IN THE TIANSHENGAN REGION, YUNNAN - CHINA AT HIGH WATER LEVEL

SLEDILNI POSKUS NA OBMOČJU TIANSHENGANA, YUNNAN - KITAJSKA, OB VISOKEM VODOSTAJU

JANJA KOGOVŠEK[1] & HONG LIU[2]

[1] Inštitut za raziskovanje krasa ZRC SAZU, Titov trg 2, SI-6230 POSTOJNA, SLOVENIJA
[2] Yunnan Institute of Geography, Xiefu Rd. 20, 650223 KUNMING, P.R. CHINA

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Janja Kogovšek & Liu Hong: Sledilni poskus na območju Tianshengana, Yunnan-Kitajska, ob visokem vodostaju

Podani so rezultati sledenja na območju Tianshengan-a, Lunan v provinci Yunnan na Kitajskem. Sledenje je bilo nadaljevanje raziskav pretakanja vode na tem delu krasa v sodelovanju s kitajskimi raziskovalci v okviru slovensko-kitajskega znanstvenega sodelovanja. Sledenje je bilo izvedeno septembra 1997 ob visokem vodostaju in je pokazalo 2 krat večje hitrosti v primerjavi s pretakanjem vode na tem območju ob srednjem vodostaju julija 1996.
Ključne besede: krasoslovje, podzemno pretakanje vode, sledilni poskus, Yunnan, Kitajska.

Abstract UDC: 556.3(510)

Janja Kogovšek & Hong Liu: Water tracing test in the Tianshengan region, Yunnan - China at high water level

The results of water tracing in the Tianshengan region, Lunan, Yunnan province, China are given. This water tracing presents a continuation of water flow studies in this part of the karst based on Slovene-Chinese scientific co-operation. In September 1997 a water tracing test at high water level was carried out and showed greater velocities double compared to water flow in this area at medium water level in July 1996.
Key words: karstology, underground water flow, water tracing, Yunnan, China.

INTRODUCTION

In a three year long project within the international scientific co-operation between the Republic of Slovenia and People's Republic of China we studied the basic properties of karst water drainage in the region of Lunan, Yunnan province, China, and we carried out several water tracing tests. The project was supported by the Slovene Ministry of Science and Technology and the corresponding ministry of China. In consecutive years from 1996 to 1998 we carried out three water tracing tests of underground water in the area of Tianshengan during low, medium and high water level. We already reported the results of the first water tracing test in July 1996 at medium water level (Kogovšek et al., 1997; Kogovšek et al. 1998) and water tracing test at low water level in November 1998 (Kogovšek & Liu Hong 1999). Here follow the results of water tracing during high water level in September 1997.

The area of our researches of underground water drainage lies near the Tianshengan town, Lunan, Yunnan. The area is predominantly agricultural. The rainy season lasts from May to October when most of annual precipitation falls, followed by a long dry period. As a great amount of water is required during the dry season for irrigation of rice fields the stores in existing accumulations are not sufficient. Attempts to solve this problem are being made by construction of new superficial and underground accumulations. Our researches including water tracing tests made part of a new underground reservoir construction. By water tracing tests we established the directions of underground drainage and its velocity at single sections during different hydrological conditions.

TRACING TEST

The basic natural properties of the area

The Lunan climate is subtropical, total annual precipitation averaged 796 mm, average relative humidity 75.3% and average annual temperature 15.6 °C (for the period 1980-1992). The amount of annual precipitation varies a lot; for the mentioned period it was from 542 mm (1992) to 1066 mm (1991). There is a wet season from May to September when there is 80% of annual rainfall. The area where the groundwater tracing test was achieved covers 50 km^2 and lies in the immediate vicinity of Shi Lin, at the altitudes of 1920 m in the east and 1750 m in the west (Fig. 1).

The central part of the area consists of Carboniferous and Permian carbonate rocks interbedded by a narrow belt of chert sandstone and shale marls dividing the aquifer into eastern and western parts. Among carbonate rocks, well karstified and permeable limestones and oolithic limestones prevail. Karst fissure porosity is typical of them. The main drainage is thus provided by underground channels in combination with a network of fissures giving heterogeneous karst-fissure aquifer. The secondary porosity is well developed and the storage capacity is low. Close to the surface are large karst passages with permanent or seasonal water flow, accessible by numerous shafts. During low water level the passages are only partly filled with water and during drought the water table is 30 m below the surface. In wet season the water may flood the passages and even lower lying fields at the surface. After rainfall the water transports a huge amount of sediment and deposits it in the passages when water flow decreases. This is well seen by thick layers of sediments in cave chambers. The thickness of layer containing quartz sandstone and shaly marls is from 20 to 30 m. These

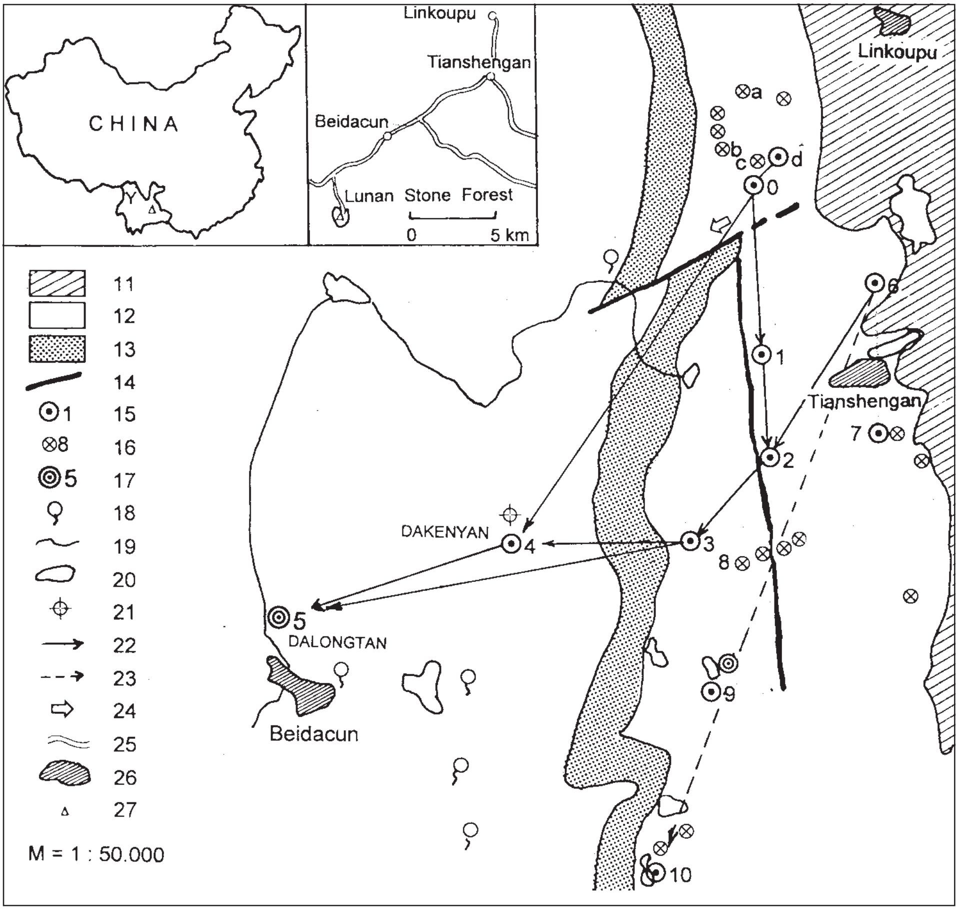

Fig. 1: Hydrogeological map (after Kogovšek et al. 1998).
11. Precambrian noncarbonate rocks, 12. Carboniferous and Permian carbonate rocks, 13. Lower Permian clastic rocks, 14. fault, 15. cave or shaft with underground water flow - a sampling point, 16. cave or shaft with underground water flow, 17. karst spring - a sampling point, 18. small spring, 19. surface stream, 20. lake or water reservoar, 21. precipitation station, 22. on the base of tracing test in November 1998 proved direction of underground water flow, 23. on the base of tracing test in July 1996 proved direction of underground water flow, 25. road, 26. village, 27. Shilin Stone Forest.
Sl. 1: Hidrogeološka karta (po Kogovšek et al. 1998).
11. predkambrijske nekarbonatne kamnine, 12. karbonske in permijske karbonatne kamnine, 13. spodnje permijske klastične kamnine, 14. prelom, 15. jama ali brezno s podzemnim vodnim tokom -mesto vzorčevanja, 16. jama ali brezno s podzemnim vodnim tokom, 17. kraški izvir - mesto vzorčevanja, 18. majhen izvir, 19. površinski tok, 20. jezero ali vodni rezervoar, 21. padavinska postaja, 22. s sledilnim poskusom novembra 1998 dokazana smer podzemnega vodnega toka, 23. s sledilni poskusom julija 1996 dokazana smer podzemnega vodnega toka, 25. cesta, 26. vas, 27. Shilin kamniti gozd.

rocks are poorly permeable but as they are fissured and not exceedingly thick they do not act as an impermeable barrier. Two faults are important: the Tianshengan fault trending N-S and the Shibanshou trending NE-SW. Numerous shafts and caves with underground water flow that we observed during the water tracing test, are distributed along the Tianshengan fault (Kogovšek et al. 1997).

Hydrological conditions at the time of the tracing experiment

In September 1997 the water tracing test was carried out at high water level. The discharge was several times higher than during the test at medium water level in July 1996. During the injection the discharge at Point 6 was assessed to be about 15 l/s and also an abundant trickle percolated through a thin roof. At Point d the discharge was judged to be near 100 l/s. The discharge measurements of the underground flow in the area of the water tracing test are made at the hydrological station Dakenyan only - Point 4. The artificial passage leading to water flow was partly filled up during our test as due to intensive rain a part of ceiling collapsed making access to water flow even more difficult.

During the test we measured the discharge at the points by the same dynamics as we sampled. Discharge, being on September 26 1.38 m^3/s was in increase and reached its maximum value of September 27 (2.24 m^3/s); later it decreased rather regularly until October 3 when it started to increase again. On October 8 it reached its maximum value of 1.96 m^3/s and then decreased again (Fig. 3).

Injection and sampling

The tracer, 1 kg of Uranine was dissolved in 50 l of water and injected at Point 6 - Wayaodong - on September 26, 1997 from 16.30 to 16.40. On the same day from 15.00 to 15.15. we injected at Point d 200 kg of sodium chloride.

The sampling was organised at Points 1,2,3,4,5,7,8,9 and 10. At Points 2,3,4,5,9 and 10 where we expected the appearance of tracer the sampling was more frequent during the foreseen water pulses and later more rarely. The sampling frequency is shown by Table 1. The samples were stored into plastic bottles.

Table 1: The plan of sampling (frequency - by hour).
Tabela 1: Načrt zajemanja vzorcev (frekvenca - na koliko ur).

Place of sampling Mesto vzorčevanja	**1. day** 1. dan	**2. day** 2. dan	**3. day** 3. dan	**4. day** 4. dan	**5. day** 5. dan	**6. day** 6. dan	**7. day** 7. dan	**8. day** 8. dan	**9. day** 9. dan
1	4	2	4	6	12				
2	4	2	2	4	6	12			
3	4	2	2	4	4	6	12		
4	6	2	2	2	4	6	6	12	
5	12	6	4	4	4	6	6	6	12
7	4	2	4	4	6	12			
9	6	4	4	4	4	6	6	12	
10	12	6	4	4	4	6	6	6	12

Used methods

The sample analyses related to chloride level were done by Wenqing Wu from the Geographic Institute, Kunming. The fluorescence analyses by luminiscent spectometre LS 30 (E_{ex} = 492 nm, E_{em} = 515 nm) of water samples from Points 3, 4, 5, 9, and 10 were done at the Karst Research Institute in January 1998, while the sample analyses from Point 2 only in July 2000. We envisaged that the analyses of samples from Points 3, 4, 5, 9 and 10 would provide the expected information relating to flow velocity yet the results showed additional directions of flow at high water level compared to low and medium water level; this required additional checking.

RESULTS

Sodium chloride

Due to great dilution only slight increase in NaCl concentration was recorded at Points 2 and 3. The maximum concentration of 3.4 mgCl$^-$/l appeared 10 hours after the injection at Point 2 and after 16 hours (5.1 mgCl$^-$/l) at Point 3. The flow velocity calculated on this basis was for Point 2 about 9 cm/s, from Point 2 to Point 3 almost 6 cm/s. In July 1996 at medium water level water flowed to Point 2 twice as slowly, by 4.7 cm/s, and from Point 2 to Point 3 even slower, 2.2 cm/s.

Minimal chloride level increase at Point 4 was recorded slightly earlier than at Point 3, as happened with Uranin appearance from Point 6. We may only suspect that during high water level a more direct connection exists between Point **d** to Point 4; the connection between Point 6 and Point 4 was indicated by Uranin.

Uranin

By sampling at Points 9 and 10 we tried to establish the potential underground water connection with Point 6. A water tracing test in July 1996 had indicated some possibility for such a link.

In September 1997 we recorded at spring 9 a minimally increased signal of fluorescence. The Uranin signal was so faint that it could not be certainly attributed to injected Uranin. We may conclude that even if a connection between the Points 6 and 9 exists it is both at medium and high water level insignificant and may be neglected.

Slightly more distinctive was Uranin appearance at spring 10, where on September 29 three times in 10 hours a slightly increased Uranin value (0.035, 0.04 and 0.175 ppb) was recorded. The flow velocity calculated on this basis would be 2.7 cm/s (Table 2). Later a single Uranin level increase was recorded. Thus we think that during high water level the connection between Points 6 and 10 exists but is not significant.

At Point 2 Uranin reached its maximum value (10 ppb) 12.5 hours after the injection in Point 6. Calculated water flow velocity to Point 2 was 4.4 cm/s (Table 2). Maximum concentration at Point 2 is noticeably lower than at Point 3. Yet the fluorescence analyses of these samples were made more than 2 years later. Samples were kept in plastic bottles and thus the adsorption to bottle and solid particles in sample are possible as in this time water transported a great amount of solid particles which may be the cause for fluorescence decrease during the time. According to water tracing curve at Points 2 and 3 we may suggest a very probable travel of tracer with water from Point 2 to Point 3 (Fig. 2).

Table 2: Air distances (L), time of tracer travel (t_{dom}) and dominant velocities (v_{dom}); ($v_{dom\ 96}$): velocities - tracing experiment in July 1996.
Tabela 2: Zračne razdalje (L), čas potovanja sledila (t_{dom}) in dominantne hitrosti (v_{dom}); ($v_{dom\ 96}$) hitrosti - sledenje julija 1996.

Relation - Razdalja	L (m)	t_{dom} (h)	v_{dom} (cm/s)	$v_{dom\ 96}$ (cm/s)
6 - 2	2000	12,5	4,4	3,3
6 - 2 - 3	3250	18,5	4,9	
2 - 3	1250	6	5,8	2,2
3 - 5	4100	22	5,2	2,7
4 - 5	2450	28	2,4	3,1
6 - 4	4500	8,5	14,7	3
6 - 2 - 3 - 5	7350	40,5	5,0	2,7
6 - 9	4050	72	1,6	0,6
6 - 10	6100	62,5	2,7	

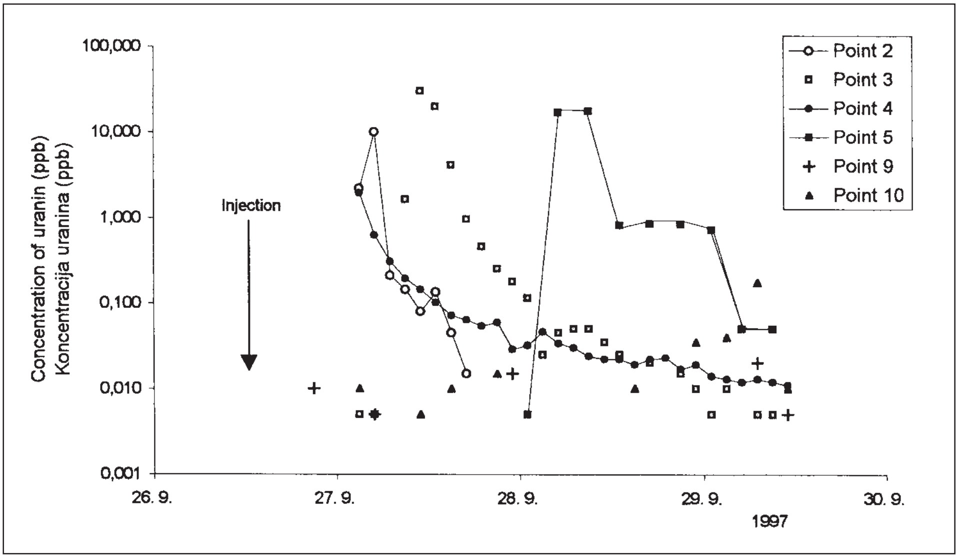

Fig. 2: Water tracing at high water level in September 1997: Uranin tracing curve at Points 2,3,4, and 5.
Sl. 2: Sledenje ob visokem vodostaju septembra 1997: sledilne krivulje uranina na točkah 2,3,4 in 5.

At Point 3 a distinctive water tracing pulse was formed; the first appearance of Uranin in concentration 1.64 ppb was recorded 16.5 hours after the injection and in the following two hours the maximum value in this water tracing pulse (30 ppb) was reached. Then the Uranin concentration decreased to increase again 18 hours after the maximum to 0.05 ppb and then decreased quickly below the limit of detection. The calculated velocity of water flow from Point 6 to Point 3 was, related to maximum Uranin concentration (flow direction 6-2-3) 4.9 cm/s, and in section 2 to 3 5.8 cm/s (Table 2).

The highest concentration of 1.95 ppb at Point 4 was recorded 10.5 hours after the injection. Figures 2 and 3 show that it lies in a steeply decreasing part of the water tracing curve. Related to water tracing in 1996 we presumed the consecutive water flow through the Points 2 and 3 to 4 and thus later appearance of Uranin and this is why the preliminary sample was taken 6 hours in advance. This sample showed no traces of Uranin. Thus we presume that the maximal concentration occurred one or two hours before recorded highest value and that the virtual maximal value was higher. The calculated water flow velocity from Point 6 to Point 4 was almost 15 cm/s. As the Uranin appeared at Point 4 earlier than at Points 2 and 3 the only possible explanation lies in fast and direct high water outflow from Point 6 towards Point 4 and slower in already known direction through Point 3. However it is surprising that the water pulse was not more distinctive at Point 4 as one may suppose regarding the results at medium (Kogovšek et al. 1996) and low (Kogovšek & Liu Hong 1999) water tracing test.

It seems probable that at high water level water discharges both from Point 3 towards Point 4 and also directly towards the Dalongtan spring - Point 5; the same confirm two distinctive consecutive proportionate water tracing curves at these two Points (3 and 5). The flow velocity from Point 3 directly to Point 5 would be 5.2 cm/s. In any case these are established connections and several open questions related to water flow during high water level essentially deviating from water flow during medium and low water level must be checked in future.

At spring 5 - Dalongtan we succeeded in taking the entire tracing pulse (Fig. 2). The first Uranin appearance was recorded on September 28 at 1.00. The concentration increased in 8 hours to the maximum value 17.4 ppb, the peak of the pulse lasted for 4 hours. The Uranin concentration decreased fast and persisted at a level between 0.81 to 0.72 ppb for 16 hours and then started to decrease slowly. On October 1 the concentration decreased below the detection limit. A smaller tracing pulse was recorded again on October 7 to 9, when maximal value was 0.035 ppb in the decreasing part of tracing pulse. This repeated intensive Uranin rinsing was due to an abundant rain in the beginning of October; this rain caused the first visible increase of discharge after the first water tracing pulse that followed the injection. However we recorded smaller Uranin concentration variations during the whole decreasing part of the first water tracing pulse which was probably due to rain contributing to Uranin rinsing but not to a distinctive increase in discharge.

If in the first peak of the water tracing pulse at Point 5 the Uranin from Point 3 was reflected, which seems more probable according to curve's shape, then the flow velocity from Point 3 to Point 5 was 5.2 cm/s; if, however the peak reflected also the Uranin from Point 4, the flow velocity between Points 4 and 5 was at the most 2.4 cm/s, seeming that high water level slowed down the drainage through this passage.

For certain we can confirm that the flow velocity from Point 6 to Point 5 with regard to maximal achieved Uranin concentration was 5.0 cm/s if we assume the consecutive flow over Points 2, 3 to 5 compared to drainage at medium water level (water tracing in July 1996) twice as fast.

Returned Uranin quantity

The tracer analysis at Point 4 where the peak of the tracing curve is missed and measurements of discharge at the same Point at high water level in September 1997 allowed the calculation of returned quantity of the injected Uranin. Fig. 3 shows how Uranin passed the Point 4. During the first tracing pulse (6 days) only 60 g of Uranin reached this Point which is only 6%. If we add the estimated Uranin quantity reaching the supposed peak of the tracing curve the returned quantity may be two or even three times greater. Nevertheless it is obvious that most of the Uranin did not reach the Point 4 but flowed into Point 5. Of course rinsing continued. In the case of water tracing at medium water level in July 1996 more than 50% of injected tracer came through Point 4 in one week. This also shows that a part of Uranin avoided Point 4; the calculation of returned Uranin quantity for Point 5 would yield this maximal value, but alas, we do not have data about discharge at this Point. This shows the limited permeability of underground water passages from Point 3 to Point 4 which was already indicated by smallest velocity of flow in this section at medium water level.

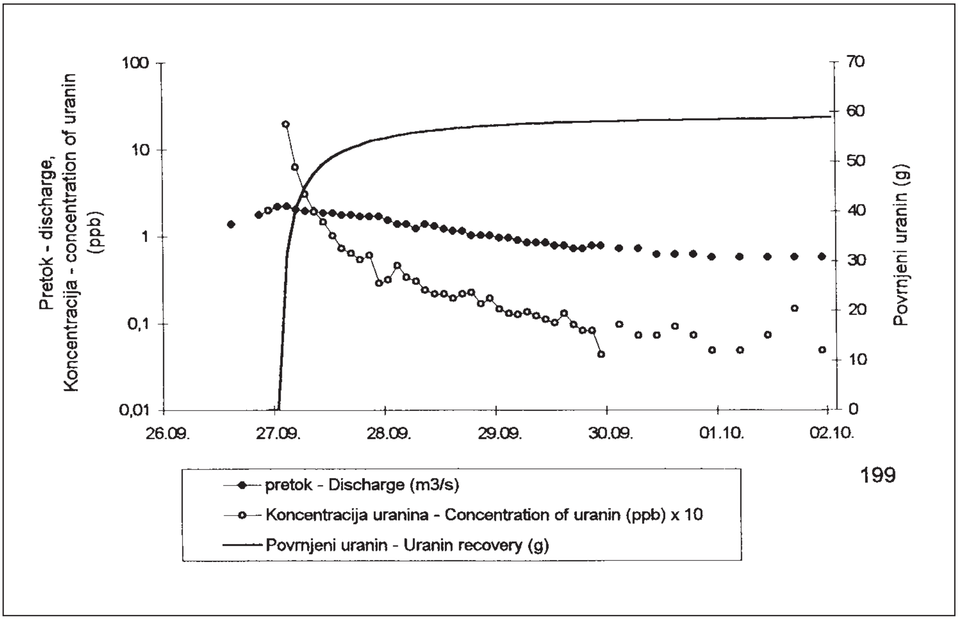

Fig. 3: Point 4 - Dakenyan: discharge curve, water tracing curve and returned Uranin curve.
Sl. 3: Točka 4 - Dakenyan: krivulja pretoka, sledilna krivulja in krivulja povrnjenega uranina.

The estimation of water tracing and recommendations

Obvious fast water flow in the treated area of karst during high water level demands a more detailed calculation of the returned tracer and also more complete curves, more frequent sampling, every hour or even every half hour. Newly stated water flow directions at high water level with extremely high velocities conditioned the formation of some water tracing pulses during the time

Photo 1: On September 26, 1997 we injected 1 kg of uranine at Point 6 - Wayaodong.
Foto 1: Dne 26. septembra 1997 smo injicirali 1 kg uranina na točki 6 - Wayaodong.

*Photo 2: On September 26, 1997 we injected 200 kg of sodium chloride at Point **d**.*
*Foto 2: Na točki **d** smo injicirali 200 kg natrijevega klorida.*

when we did not expect the tracer appearance and we were sampling at longer intervals as recommended. In future the uniform labelling of samples with number of sampling point and exact time of sampling by parallel noting is important.

CONCLUSIONS

The water tracing by sodium chloride gave useful results only in the initial part of water flow. Up to Point 2 and further on to Point 3 water flowed 2 to 3 times faster at high water level than at medium level and almost 10 times faster than at low water level at the end of November 1998.

Water tracing by Uranin showed a poor connection of underground water from Point 6 to Point 10, while connection with Point 9 is questionable and may be neglected. Water tracing showed that at high water level there is, beside water drainage towards Points 2, 3, 4,and 5, also a direct connection from Point 6 to Point 4 (velocity 14.7 cm/s) and from Point 3 to Point 5 (velocity 5.2 cm/s). Determined flow velocity from Point 6 to Dalongtan spring - Point 5 (6-2-3-5) was 5 cm/s which is twice faster than at high water level (maximal discharge 2.24 m^3/s) than at medium water level (maximal discharge 0.902 m^3/s). A direct connection from Point 6 to Point 4 allows a great drainage (14.7 cm/s) as was recorded during the medium water level in section d-0.

The returned Uranin quantity at Point 4, estimated as slightly more than 10% is low, as probably the most of Uranin flowed directly over Point 3 into Dalongtan spring - Point 5.

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SLEDILNI POSKUS NA OBMOČJU TIANSHENGANA, YUNNAN - KITAJSKA, OB VISOKEM VODOSTAJU

Povzetek

V okviru mednarodnega znanstvenega sodelovanja med Slovenijo in Kitajsko je bilo v okviru raziskav pretakanja vode v krasu na območju Stone foresta izvedeno septembra 1997 sledenje ob visokem vodostaju. Sledenje je dopolnilo spoznanja o podzemnem pretakanju vode v tem delu kitajskega krasa ob nizkem in srednjem vodostaju (Kogovšek et al. 1997, Kogovšek & Liu Hong 1999).

Osrednji del obravnavanega območja gradijo karbonske in permske karbonatne kamnine, med njimi pa je ozek pas kremenovih peščenjakov in skrilavih laporjev, ki vodonosnik deli na vzhodni in zahodni del. Glavne drenažne poti predstavljajo podzemni kanali, ki v kombinaciji z mrežo razpok gradijo heterogen kraško-razpoklinski vodonosnik. Pomembna sta tudi prelom Tianshengan v smeri S-J in prelom Shibanshou v smeri SV-JZ (Kogovšek et al. 1998).

Sledenje ob visokem vodostaju smo izvedli septembra 1997, ko smo sledili injicirali na točki **d** in na točki 6. Na točki 6 je bil pretok ob injiciranju ocenjen na okoli 15 l/s, na točki **d** pa na blizu 100 l/s. Edine meritve pretoka vodnega toka na obravnavanem območju, ki potekajo na točki 4 - Dakenyan, so pokazale maksimalni pretok v času sledenja 2.24 m^3/s. Na točki 6 - Wayaodong smo injicirali 1 kg uranina, na točki d pa 200 kg NaCl.

Zaradi velikih pretokov in sledečih močnih razredčitev je dalo sledenje z NaCl uporabne rezultate le v začetnem delu vodnega toka. Pretakanje do točk 2 in 3 je bilo 2- do 3-krat hitrejše kot ob srednjem vodostaju julija 1996.

Sledenje z uraninom je pokazalo na slabo povezavo podzemnih voda s točke 6 v smeri točke 10, medtem ko je vodna zveza s točko 9 vprašljiva, oz. zanemarljiva. S sledenjem smo tudi ugotovili, da odteka voda s točke 6 ob visokem vodostaju poleg v že znani smeri točk 2, 3, 4 do točke 5 (slika 1), kar smo ugotovili že s sledenji ob nizkem in srednjem vodostaju, tudi po direktnejši povezavi s točke 6 v točko 4 (hitrost 14.7 cm/s), kot tudi s točke 3 v točko 5 (hitrost 5.2 cm/s). Ugotovljena hitrost pretakanja od točke 6 do izvira Dalongtan - 5 (6-2-3-5) je bila 5 cm/s, kar pomeni 2-krat hitrejše pretakanje voda ob visokem vodostaju (maksimalni pretok 2.24 m^3/s) kot ob srednjem vodostaju (maksimalni pretok 0.902 m^3/s). Neposredna zveza s točke 6 do točke 4 omogoča zelo hitro pretakanje (14.7 cm/s), podobno kot smo ob srednjem vodostaju zabeležili na odseku d-0 (tabela 2).

Povrnjena količina uranina na točki 4 v času sledilnega vala - 6 dni (slika 3), ki jo ocenjujemo na nekaj več kot 10 %, je nizka. Spiranje se je seveda še nadaljevalo, vendar je verjetno večina uranina s točke 6 odtekla neposredno prek točke 3 v izvir Dalongtan - točka 5. V primeru sledenja ob srednjem vodostaju julija 1996, je v enem tednu skozi točko 4 priteklo več kot 50 % injiciranega sledila. Tudi to kaže, da je del uranina obšel točko 4, oziroma, da bi izračun povrnjene količine uranina za točko 5 dal tisto največjo vrednost, vendar žal nimamo podatkov o pretoku za to točko. To kaže na omejeno prepustnost podzemnih vodnih kanalov s točke 3 v točko 4, ki jo je delno nakazala že najmanjša hitrost pretakanja na tem odseku ob srednjem in nizkem vodostaju.

Sledenje je pokazalo, da je pretakanje vode na tem območju ob visokem vodostaju bistveno drugačno, kot ob srednjem in nizkem vodostaju. Ponovitev sledenja s podrobnim vzorčevanjem na vseh točkah in ob znanih pretokih vsaj še za točko 5, bi lahko podrobneje pokazalo količinski prenos sledila, oz. deleže vode, ki se pretaka v določenih smereh ob visokem vodostaju.