Transboundary Aquifers: Challenges and New Directions: Characterisation of a transboundary karst aquifer: the Classical Karst

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ABSTRACT

In the hydrogeological sense the karst aquifer of Classical Karst / Kras is a uniform unit, but politically divided between two countries. The main part of the aquifer is located in Slovenia, but the whole karst coast and the springs area are located in Italy. To understand its functioning and to preserve it properly a close co-operation between experts from both countries is necessary.
Classical Karst / Kras is a limestone plateau of 900 km^2 that extends from SE-NW direction between Brkini hills in Slovenia and Isonzo River in Italy. To understand the functioning of the transboundary karst system many researches were performed in a close co-operation between Italian and Slovene researchers. One of the primary goals was the protection of the aquifer, in which large quantities of groundwater are stored. The springs of the Timavo River are one of the highest-discharge regions in the Mediterranean region (medium discharge of 40 m^3/s, maximum of 175 m^3/s). Close to the springs, on the Slovenian side, groundwater is pumped for the supply of several municipalities. In Italy, the Sardos and Moschenizze Nord springs are still used at present for water supply of Trieste.
The hydrodynamics and chemical characteristics of springs are well known, but there is a lack of informations about autogenic and allogenic recharge. Only few data are available about hydrodynamic behavior within the hydro-structure. For these reasons the spatial hypogean development of the karst phenomena is very unpredictable. Karst voids organization is driven by several aspects: geological and structural settings, climate characteristics, geomorphological context etc. Due to the high heterogeneity of the underground karstification is still very complex to model the groundwater circulation, to define the underground karstification development and the karst voids connection especially in a mature karst.

Key words: hydrogeology, karst aquifer, karst waters management, transboundary groundwaters monitoring, Classical Karst / Kras

1. INTRODUCTION

1.1. The Classical Karst

Classical Karst / Kras is a limestone plateau of 900 km^2 that extends NW - SE 50 km long from the Isonzo River to Brkini hills near Skocjan (Slovenia). It is 15 - 20 km wide, gentle dipping toward NW from 550 m asl in Postojna and 450 m a.s.l. in Skocjan (Slovenia) to the sea level (Timavo Springs in Italy).

The plateau is mainly composed by carbonate rocks of Cretaceous to Eocene in age, which make up the so-called Comeno / Komen Unit (Placer, 1981, Cucchi et al, 1987), an important geological-structural unit involved in the Dinaric Alpine crustal shortening. The structure is a large anticline with a NW-SE axis. The northern side, where another important, Trnovo Unit (Placer, 1981) thrusts, has mild inclination and is affected by several reverse faults with a strike-slip character parallel to the axis. The southern side, has an inclination that gradually increases towards the SE as the Unit trhusts on another (the Ciceria plateau) through a series of low angle trhusts. The thickness of the sedimentary sequence is up to few thousand meters: the origin is carbonate, the top is a siliciclastic turbidite. The plateau can be considered as a carbonate prism, more or less karstified, confined at the top and at the side by impermeable formations not karstified. The state border cuts the plateau leaving in Italy about 200 km^2 with almost the all springs area, and in Slovenia, in the remaining 700 km^2, the wider and more developed sinkholes and dolines.

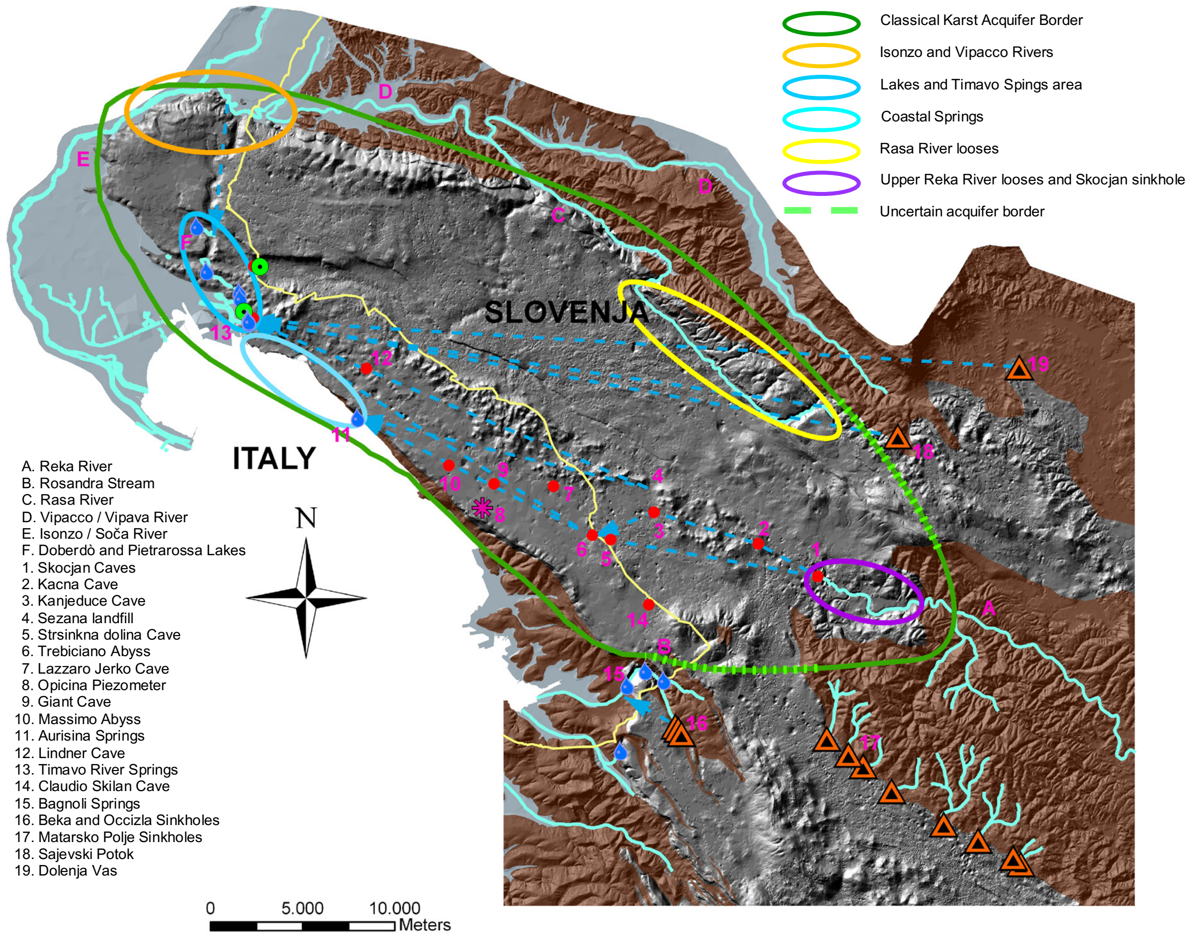

Figure 1: Hydrogeological map of the area. Limestone in grey; flysch in brown; green points are water supplies; blue drops are springs; triangles are sinkholes; red points are caves; asterisk is the deep piezometer; dotted blue lines are verified water connections by tracers.

1.2. The Classical Karst aquifer

The average rainfall in the Classical Karst and in the Vipacco / Vipava watershed varies from 1000mm/y along the coast to about 1800 mm/y in the hinterland. At this rate of rainfall corresponds an average evapotraspiration rate varying from 450 to 750 mm. Reka watershed has an average rainfall of about 2000-2600 mm/y, higher values of rainfall are typical of Isonzo mountain basin in which prevail rates of 2000 mm/y with wide areas at even higher rates of 3200 mm/y.

The corresponding hydrogeological model recognize, in principles, three zones with a hydrogeological significance:

1. transfer zone from epigean to hypogean flow, where water from non karstic valleys sinks underground;

2. the Karst Plateau. Allogenic water flows deep below the surface along well karstified epiphreatic phreatic zone. The autogenic water fron precipitation passess up to 400 m thick vadose zone to reach the level of groundwater;

3. the spring area where waters comes to light and flow to the sea. This last zone correspond to an area rich in lakes and springs, including Timavo Springs.

The first zone is fed by the water belonging to the superficial Notranjska Reka (upper Timavo River), Isonzo / Soča and Vipacco / Vipava Rivers watershed. The Reka (about 330 km^2 of watershed), was born on the Mt. Dletvo slopes at the border between Slovenia and Croatia, and flows for about 40 km on marly arenaceous sediments until Škocjan where it sink into a magnificent complex of underground channels of the Škocjan cave system, a natural monument nowadays in the list of UNESCO World Heritage. The mean discharge evaluated 8 km upstream the sinkhole (hydrometric station of Cerkvenikov Mlin) in the time interval 1961-1990 is reported to be 8,26 m^3s^{-1}, with a minimum (18.08.1988) of 0,18 m^3s^{-1} and a maximum value (16.05.1972) of 305 m^3s^{-1} (Environmental Agency of the Republic of Slovenia, 2010).

Isonzo / Soča River watershed is large (about 1600 km^2 in Slovenia) and articulated (the main channel extends approximately 100 km) with abundant water due to the high rainfall. The average discharge (data coming from the hydrometric station of Solkan) in the time interval 1961-1990 is reported to be 95,5 m^3s^{-1}, with a minimum (30.10.1985) of 5,58 m^3s^{-1} and a maximum value (1.11.1990) of 2134 m^3s^{-1}.

Vipacco / Vipava watershed is less extensive (about 594 km^2) and has less water supply. The average discharge (hydrometric station of Miren) in the time interval 1961-1990 is reported to be 17,9 m^3s^{-1}, with a minimum (12.09.1954) of 1,15 m^3s^{-1} and a maximum value (28.09.1965) of 353 m^3s^{-1} and it is largely fed in turn by karst springs placed at the foot of the Trnovski Gozd plateau (Environmental Agency of the Republic of Slovenia, 2010).

Side losses that feed the karst aquifer in the Isonzo River sector mainly occur along a dozen kilometres long section, just downstream from the confluence with Vipacco / Vipava River: from a quantitative point of view, the sinkholes should contribute at least 10 m^3s^{-1} to the karst system.

The second sector is the Classical Karst that contains, what is generally called, the hypogean Timavo net, that surely has an articulated development, with several drainage ways and with frequent changes in direction of the main outflow.

This is an intensely karstified area characterized by the high density of caves and surface karst morphotypes. In the limited area of the Italian Karst (about 200 km^2) there are over than 3500 known caves (of which over 150 have a development for more than a hundred meters and a dozen develops for a thousand meters), 80 sinkholes more than 100 meters wide, and limestone pavements with total surface area of several km^2.

The hypogean Timavo course should have a development of 70-80 km, with frequent changes of direction in the preferential flows. The travel time under high water level conditions, is about two days.

During the low and mean water conditions the water table is at altitude of 2 - 5 m a.s.l. at the headwater area of Monfalcone – Jamiano – Sistiana (Ita), at 12 – 13 m in the Prosecco (Ita) – Sesana (Slo) area and at about 150 – 190 m in the Kačna Jama at Divaca (Slo). The surface of the water table is irregular due to high differences in hydraulic conduictivity. During the periods of high water level the amplitude in the epiphreatic zone is, as said, variable, not only depending from the extend and type of high water level power, but also depending on the speed side transmission pulse. It is not said, in fact, that the gaps are sufficiently continuous, connected and wide to allow the whole hypogean volume to always be completely filled. The water in Trebiciano abyss rises up to 110m a.s.l. Similar level rise and dynamics is observed also in Lazzaro Jerko cave, Strsinkna dolina cave and Kanjaduce cave. In the upper caves, Kačna and Skocjan, the level is controlled by local restrictions and therefore exibit different dynamics. High fluctations of water level are present in Massimo abyss and in the Linder cave.

The third sector corresponds to the spring system of Timavo at San Giovanni di Duino, from Doberdò and Pietrarossa lakes, from the springs that feed Lisert and Moschenizze channels (an area of about 30 km^2), from the marine-coastal springs scattered along about 8 km of the coast of the Trieste Gulf. These are waters coming from different watershed but hydraulically interconnected, with an estimated total average discharge of 40 m^3s^{-1}, and a maxima up to 175 m^3s^{-1}. At San Giovanni di Duino, Timavo springs consist of four pools collected in three "brances": their average discharge is about 35 m^3s^{-1}, with a minimum of 10 m^3s^{-1} and a maximum of 150 m^3s^{-1}. Speleologists investigations revealed a well developed complex caves system explored to -83 m below the sea level and total length of more than 1500 m. Two pumping station used for the water supply are positioned in this sector: the Klariči pumping station, used for the water supply on Slovenian side and the one for Trieste aqueduct (Randaccio station) that uptakes the waters from three springs (Sardos, Timavo and Moschenizze Nord).

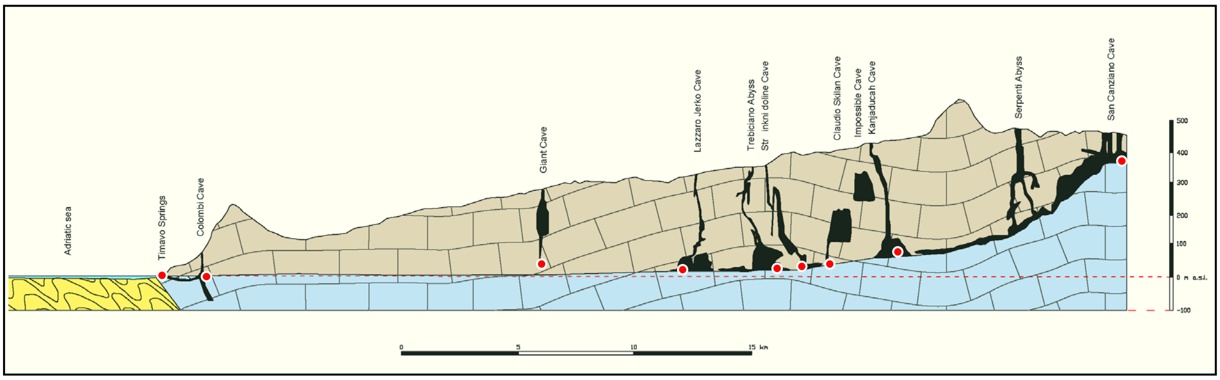

Figure 2: Simplified cross-section of the Classical Karst aquifer. Flysch in yellow; limestone in grey; caves in black; water in pale blue; red points are monitoring stations.

2. RESULTS

The Geosciences Department and the Park Skocjanske Jame with the collaboration of Karst Research Institute realized a continuous monitoring network to study the water dynamics by placing sensors at the sinkhole, in several caves and at the uptake works. The monitoring network is shared, since the involved subjects are exchanging the data measured in the respective studied areas. Are measured in continuum discharges/levels, conductivity and temperature.

The data analysis highlights the circulation complexity inside the hydrostructure: during the flood the flow is conditioned by the Reka River regime while, during low-water, the circulation is more influenced by the infiltration due to the rainfall and from the Isonzo River contribution. The circuit connecting Skocjan cave with Timavo springs is characterized by a series of large pipes that allow the flood impulse transfer within 1-3 days.

The monitoring carried out showed that during the floods the most part of the circuits are under pressure and only a comparative analysis for levels and conductivity permits to correctly evaluate the water transit times. Infact, if the rising water level in the caves is simultaneous due to the increasing hydraulic load upstream, the changes in conductivity are different from site to site and allow to intercept the incoming flooding water and to estimate correctly the propagation water velocity (Fig. 3 and 4).

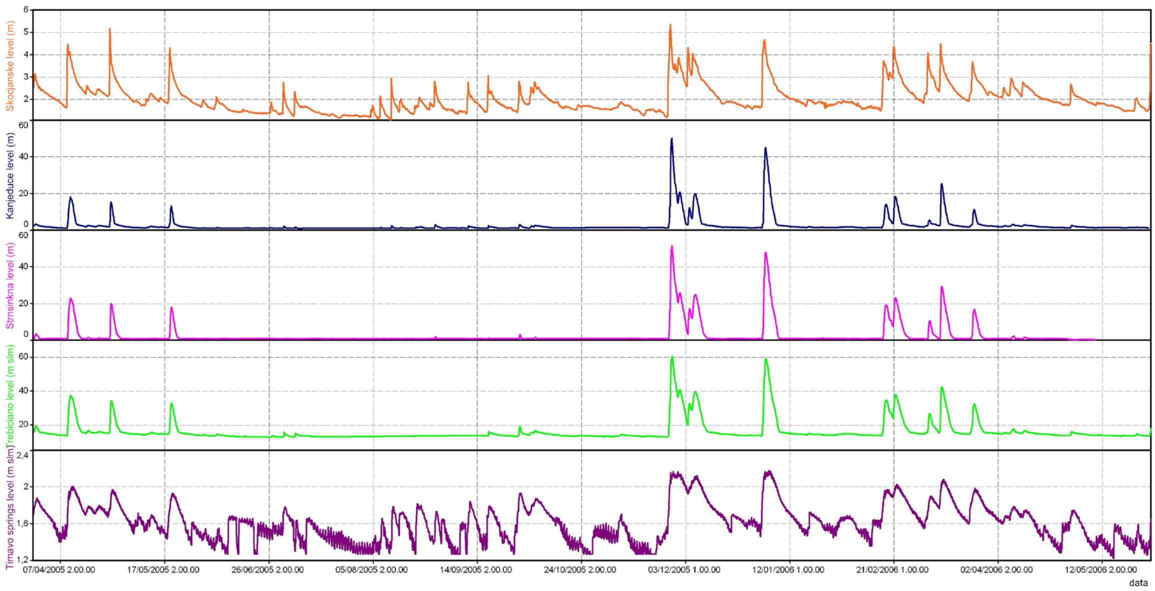

Figure 3: Water level in Škocjan cave (orange), Kanjaduce cave (blue), Stršinkna cave (magenta), Trebiciano abyss (green) and Timavo springs (violet).

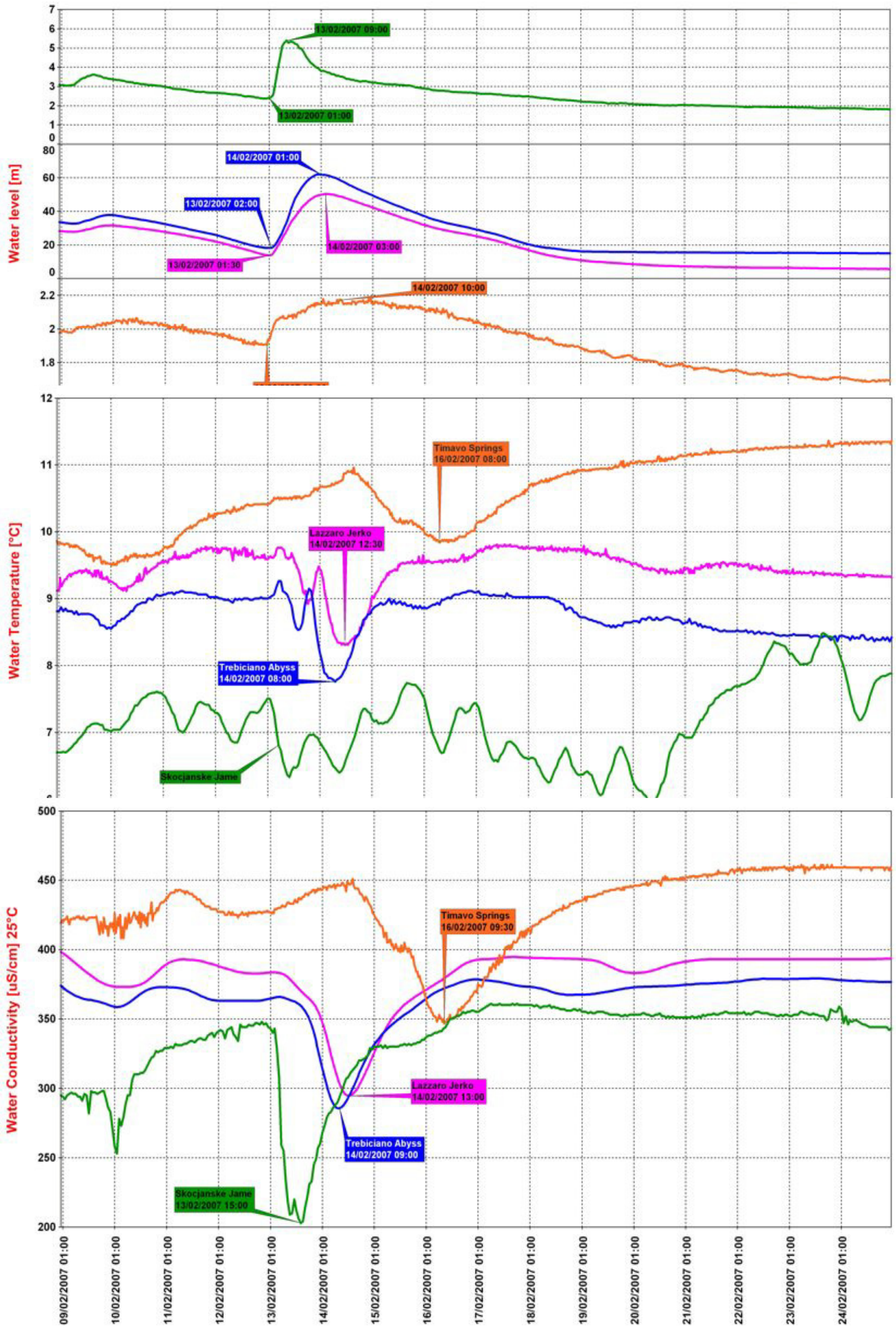

Figure 4 Water monitoring (level, water temperature and conductivity) in Škocjan cave (green), Trebiciano abyss (blue), Lazzaro Jerko cave (magenta) and Timavo springs (orange).

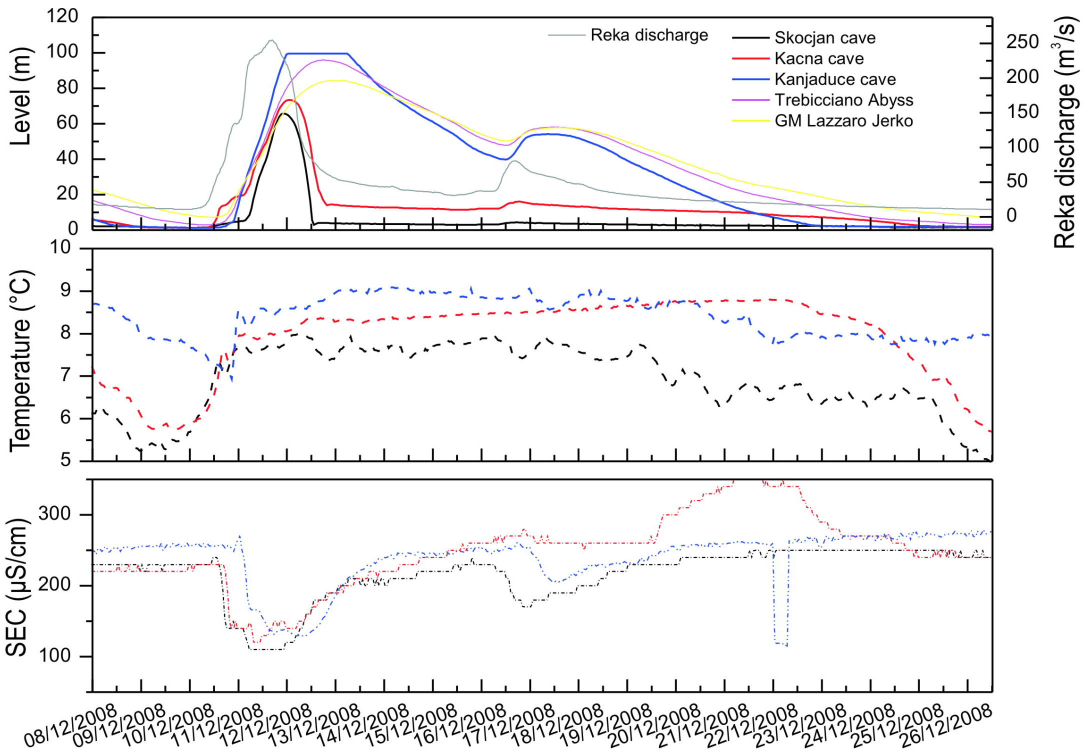

Figure 5 Level, water temperature and conductivity in Škocjan cave, Kacna cave, Kaniaduce cave, Trebiciano abyss, Lazzaro Yerko cave, during highest flood pulse in December 2008.

Different is the northern sector - Iamiano (Ita) and Miren (Slo) where the circulation is dispersed and lower flows are underlined. The beginning of the floods is often delayed compared to the outfall and it is partially due to the water tamponage coming from the Reka – Timavo circuit.

3. CONCLUSIONS

Classical Karst waters have for a long time been a strategic resource for the economical and social development of this region. In the springs area are located the uptake works for the Slovenian (Klariči station 250 l/s) and Trieste aqueducts (Sardos and Moschenizze Nord springs about 250 l/s) are located. The water quality is good, and the amount of the reserve is high, but as highlighted by the monitoring surveys and the tracing tests, is a highly vulnerable resource.

The last tracing test performed near a landfill close to Sežana in Slovenia (n. 4 in figure 1) showed up an increasing in karst permeability and the lack of protection afforded by the unsaturated zone. (Kogovšek J. & Petrič M. 2007). Only 12 days after the injection, the tracer was detected at the Timavo springs and 31 days after at the Aurisina springs. During floods, pollution from Reka river can reach the springs in 2-3 days.

In the last years, thanks to the fall of borders, the urbanization in the Karst area has increased a lot with a growth of commercial and industrial activities.

The risk of pollution is rising, but real collaboration between the Italian and Slovenian institutions in order to define the security zones to protect the Classical Karst aquifer has not yet started. A policy border that secures the resource that is essential for any future development for the aquifer protection is still missing.

Instead, the researchers from the two countries are already collaborating, as highlighted in the present paper, creating the first concrete step to increase the knowledge to protect the territory.

REFERENCES

Casagrande G., Cucchi F., Zini L. (2005): Hazard connected to railway tunnel construction in karstic area: applied geomorphological and hydrogeological surveys. *Natural Hazards and Earth System Sciences, Vol. 5, Num. 2, 2005,* 243-250.

Civita M., Cucchi F., Eusebio A., Garavoglia S., Maranzana F. Vigna B. (1995): The river Timavo: an important supplementary water resource which needs to be protected and regained. *Acta Carsologica, XXIV, 1995,* 169-186, Ljubljana.

Covelli S., Cucchi F., Mosca R. (1998): Monitoring of percolation water to discriminate surficial inputs in a karst aquifer. *Environmental Geology 36, (3-4) December 1988*, 296-304, Springer-Verlag,Germany.

Cucchi F., Forti F., Finocchiaro F. (1987): Carbonate surface solution in the Classical Karst. *Int. J. Speleology, 16 (3-4, 1987):* 125-138.

Cucchi F., Forti P., Marinetti E., Zini L. (2000): Recent developments in knowledge of the hydrogeology of the "Classical Karst". *Acta Carsologica, Vol. 29, No. 1-4*, Ljubljana 2000, 55-78.

Cucchi F., Forti P., Zini L. (2005): The vulnerability of complex karst hydrostructures: Problems and perspectives. *Geofisica Internacional (2004), Vol. 43, Num. 4*, pp533-540.

Cucchi F., Franceschini G., Zini L., (2008): Hydrogeochemical investigations and groundwater provinces of the Friuli Venezia Giulia Plain aquifers, northeastern Italy. Environ. Geol. 55: 985-999. Vol. 55, Nb. 5, September 2008. DOI 10.1007/s00254-007-1048-4.

Cucchi, F., Marinetti, E., Potleca, M. & L. Zini, (2001): Influence of geostructural conditions on the speleogenesis of the Trieste Karst (Italy).- *Geologica Belgica, 4, 3-4,* 241-250.

Cucchi, F., Pirini Radrizzani, C. & N. Pugliese, (1987): The carbonate stratigraphic sequence of the Karst of Trieste (Italy). - *Mem. Soc. Geol. Ital., XL*, 35-44.

Cucchi, F. & L. Zini, (2002): Underground Timavo River monitoring (Classical Karst).- *Acta Carsologica, 31, 1,* 75-84.

Cucchi F., Zini L. (2007): Le acque del Carso Classico. In *L'acqua nelle aree carsiche in Italia,* a cura di F. Cucchi, P. Forti & U. Sauro*, Mem. Ist. It. Spel., serie II, Vol. XIX,* 33-40, Bologna 2007.

Environmental Agency of the Republic of Slovenia (2010): *http://www.arso.gov.si/vode/*

Furlani S., Cucchi F., Forti F., Rossi A. (2009): Comparison between coastal and inland Karst limestone lowering rates in the northeastern Adriatic Region (Italy and Croatia). *Geomorphology 104 (2009)*, 73-81.

Gabrovšek, F. & Peric, B. (2006): Monitoring the flood pulses in the epiphreatic zone of karst aquifers: The case of Reka river system, Karst plateau, SW Slovenia. *Acta carsologica, No. 35/1,* pp. 35-45, Ljubljana.

Kogovšek, J. & Petrič, M. (2007): Directions and dynamics of flow and transport of contaminants from the landfill near Sežana (SW Slovenia*). Acta carsologica, No. 36/3,* pp. 413-424, Ljubljana.

Placer, L., 1981: Geologic Structure of S.W. Slovenia.- *Geologija, 24/1,* 27-60.