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HYDROKARST’S ROLE IN THE KNOWLEDGE OF THE CLASSICAL KARST AQUIFER’S HYDRODYNAMIC (NE ITALY, SW SLOVENIA)

Franco Cucchi[1], Luca Zini[1], Chiara Calligaris[1], Philippe Turpaud[1], Francesca Federica Slejko[1], Francesco Treu[1], Stefano Furlani[1], Enrico Zavagno[1], Sara Biolchi[1], Marzia Michelini[1], Chiara Boccali[1], Silvia Cleva[1], Janko Urbanc[2], Tamara Ferjan Stanič[2], Janja Kogovsek[3], Metka Petric[3], Franci Gabrovšek[3], Natasa Ravbar[3], Enrico Altran[4], Stefano Piselli[4], Daniela Sciolis[4], Paolo Sossi[4], Mitja Leban[5], Giacomo Casagrande[6], Anton Brancelj[7] and Natasa Mori[7]

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Abstract: In the framework of the Italian-Slovenian transboundary cooperation program 2007-2013, the HYDROKARST Project that aims at the protection and management of the Classical Karst transboundary aquifer is being carried out. Since the second half of 1800, several studies in this research field have been realized, but Hydrokarst is an opportunity for joint work for a unique goal, enriching the knowledge of a precious resource, water. In this context, in order to better define the groundwater flow dynamics, a joint monitoring network consisting of devices for continuous recording of physical parameters as electrical conductivity, temperature and water level, was realized. For selected water points, several physico-chemical, microbiological and geochemical surveys were performed. Major ions, $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ isotopic ratio were analyzed. Fauna samples were collected. Additionally, a water-tracing test with fluorescent dye was carried out.

Key Words: Classical Karst, hydrogeology, conduit and fractured, transboundary aquifer, management, groundwater fauna

INTRODUCTION

In a complex hydrogeological setting, a hydrogeological characterization of the karst drainage basins is the key to understanding and estimating water fluxes. This operation requires the data acquisition in order to define the extent and the effects of conduit-dominated flow, multiple discrete inputs and outputs for water, and their spatial and temporal variability in recharge, storage, and flow. Water-tracing tests, realized using fluorescent dyes, are the most effective way of determining subsurface conduit connections between karst drainage features such as sinkholes and springs, directions of ground-water flow, boundaries of karst ground-water basins, and the hydraulic properties of conduits (Mull et al., 1988; White, 1993).

Spring discharges and variations in the chemical and isotopic composition allow to characterize recharge and discharges and to provide insights into the hydrostructure at basin-to-regional scales (Ford and Wiliams, 2007; White, 1993). Given that groundwater is inhabited by a wide variety of animals, ranging from larger arthropods, such as amphipods to meiofaunal, few millimeter-sized copepods and ostracods (Marmonier et al., 1993), this fauna can be a very useful indicator of groundwater hydrological connections, groundwater contamination or can serve as a tool for groundwater characterization (Sket and Bole, 1981; Malard et al., 1996; Pipan and Culver, 2007; Mori and Brancelj, 2013).

In hydrogeological studies, a fundamental mapping unit is used to characterize the spatial and temporal properties of the aquifer and to construct its conceptual model (Rosenberry and La Baugh, 2008).The study area corresponds to the Classical Karst, a carbonate plateau homeland to Timavo/Reka aquifer system (Fig. 1). The area is a transboundary site shared between Italy and Slovenia and approximately 750 km^2 wide extending, as a rectangular plateau, surrounded by non karstic features as Trieste Flysch bay (Adriatic Sea) on the SW, alluvial Friuli plain at NW, Flysch Vipava valley at NE. The plateau surface is characterized by an abundance of karst landforms, epigean and hypogean, being considered one of the best karst examples in the world (Ford and Williams, 2007) having available at least 500-600m of karstifiable rocks. The drainage basin of the Reka River covers an area of about 407 km^2. The hydrostructure is crossed by an impressive underground river that sinks in Slovenia at Škocjan sinkhole, UNESCO Heritage since 1986, and outflows on the Italian side in correspondence of Timavo Springs near Duino village.

Given that the Classical Karst aquifer is exploited for drinking purposes by Slovenians and Italians, the aim of the present paper is to better define the different inputs to the groundwaters.

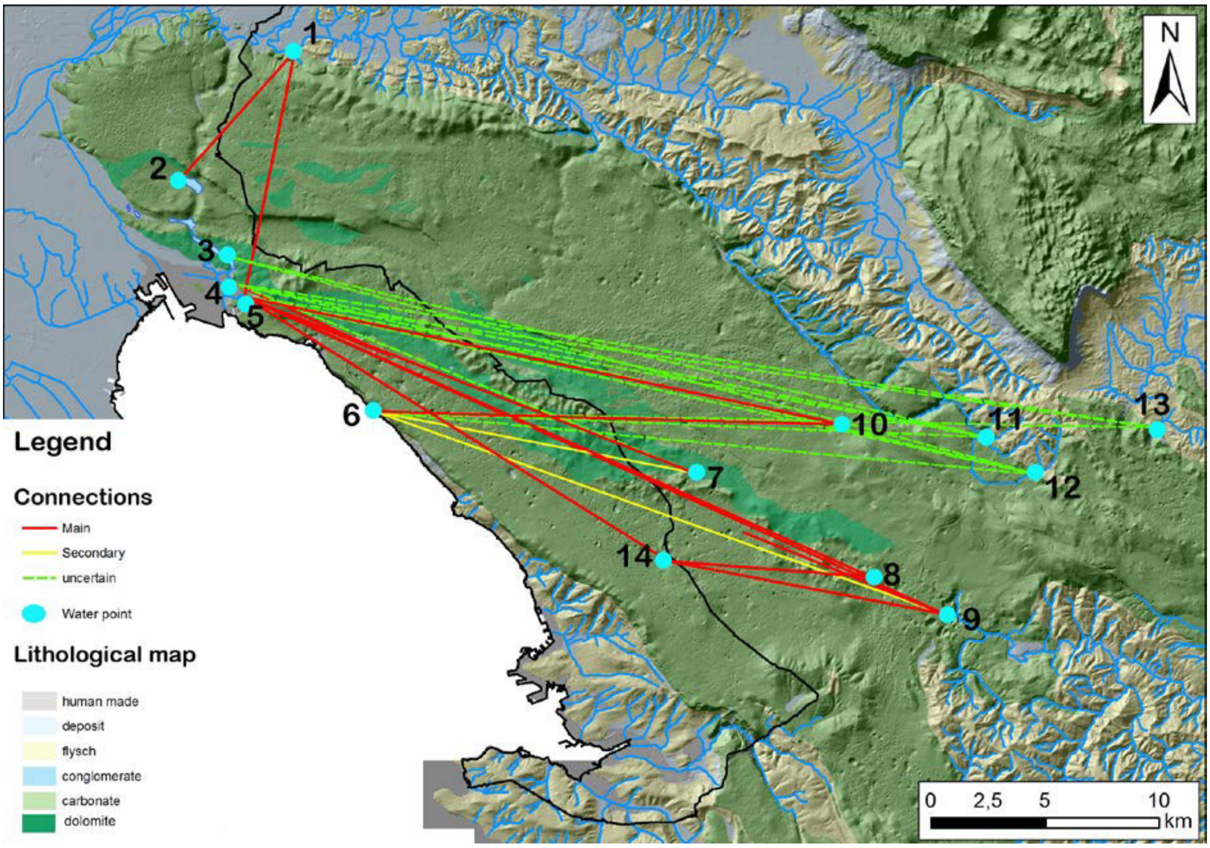

Fig. 11: The study area. 1=Vipacco/Vipava; 2=Doberdò lake; 3=Moschenizze Nord spring; 4=Sardos spring; 5=Timavo spring; 6=Aurisina/Nabrezina spring; 7=Kanjeduče cave; 8=Kačna cave; 9=Škocjan cave; 10=Storje piezometer; 11= Rasa river; 12= Senožeški river; 13= Sajevški river; 14=Trebiciano abyss.

HYDROGEOLOGICAL CHARACTERIZATION

In 1995, the researchers of the Trieste University – D.M.G.jointly with Slovenian researches, began with the study of the Timavo/Reka hydrodynamics in order to enrich the knowledge of the Classical Karst aquifer. In this framework, a monitoring network made of devices for continuous recording of physical parameters (electrical conductivity, temperature and water level) and sampling surveys was updated.

The main caves reaching groundwaters were analyzed as well as the available piezometers and the recognized lakes and springs. The aquifer recharge is represented by: 1) a concentrated allogenic recharge due to Reka River inputs, 2) a diffuse autogenic recharge due to effective precipitations, and 3) a diffuse allogenic recharge due to the Isonzo River contribution (Zini et al., 2013).

As defined by the data recorded at Timavo/Timava and Sardos/Sardoč springs, contributions from the different sectors of the hydrostructure, differ due to the water flow regime: in high water flow, Reka and effective precipitations represent the main inputs, while during low water flow regime, Isonzo/Soča groundwater input prevails.

$\delta^{18}O$ values confirm this hypothesis: especially during springtime, Isonzo/Soča waters have $\delta^{18}O$ values more negative than the rainfall (on the Clasical Karst area) and Reka river (Doctor et al., 2000). In this period in fact, Isonzo/Soča is fed by snow melting waters. During low water regime, more negative values are recorded in the entire spring area, except Aurisina, which is considered to be free from the influence of Isonzo/Soča waters.

The major ion analysis indicates that surface- and ground-waters have similar chemical composition, belonging to the Ca-HCO_3 and Ca-Mg-HCO_3 hydrofacies. No meaningful differences are observed during low- and high-water flow regime.

On the basis of electrical conductivity (EC) and Mg/Ca molar ratio instead, it is possible to recognize a defined draft trend in the waters (Fig. 2). To better understand this correlation, three sampling surveys realized in three different regimes were analyzed: September 2012 (red –very low water), April 2013 (green –after the peak flood event) and January 2013 (blue –during a flood event). During very low water regime, Isonzo/Soča inputs are prevailing over the others enhancing low EC values and high Mg/Ca molar ratio. Reka influence is recognizable only at Aurisina spring (7) and Trebiciano Abyss (8). The situation changes during flood events: at Aurisina (7) and Timavo (6) the contribution of Reka river, characterized by low Mg/Ca ratios and high EC values prevails. Moschenizze Sud (4) and Sardos (5) are influenced by Isonzo/Soča waters and Reka River in different proportions according to different regimes. The other spring points are characterized by the Isonzo/Soča inputs. A separate discussion is required for Klariči pumping station (10) tapping the water at about -30/-50m a.s.l. During low water regime it is heavily influenced by Isonzo/Soča inputs. During floods, an increased EC is observed, mainly due to the increased Cl value that ranges from 13.5 mg/l up to 60 mg/l.

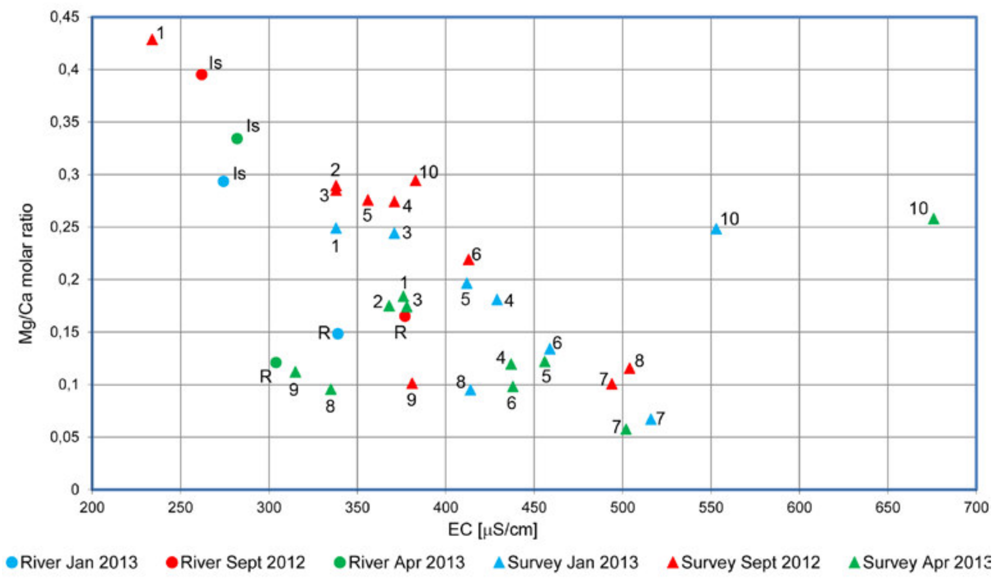

Fig. 12: EC vs. Mg/Ca molar ratio during different water regimes. Is=Isonzo River, R=Reka River. 1=Doberdò, 2=Pietrarossa, 3=Moschenizze Nord, 4=Moschenizze Sud, 5=Sardos, 6=Timavo, 7=Aurisina, 8=Trebiciano Abyss, 9= Škocjan cave, 10= Klariči pumping station (B4).

WATER TRACING WITH FLUORESCENT TRACERS

First tracer tests in the Classical Karst area were carried out at the beginning of the 20th century and a considerable number of tracings have been performed since then. Most of them were focused on the underground flow of the Reka River between the sinkhole in the Škocjan caves and the Timavo/Timava and Aurisina/Nabrežina springs (Timeus, 1928; Mosetti, 1965; Peric, 2012). Apparent flow velocities of approximately 47 m/h at low waters, 109 to 164 m/h at mean waters, and more than 300 m/h at high waters were calculated based on the results of the tracer tests. Underground flow from the sinking points of the Vipacco/Vipava River in Vrtoče and from the Isonzo/Soča plain (Bidovec, 1967, Cancian, 1987) through the karst of Doberdò to the Timavo/Timava spring and some adjacent springs was proved. The connections between the Timavo/Timava springs and the sinking streams of Sajevškipotok, Senožeškipotok and Raša were indicated by some tracer tests (Habič, 1989), however the results were not published. In April 2005, the tracer was injected at the surface near the Sežana landfill (Kogovšek and Petrič, 2007). It had to pass through approximately 200 m thick vadose zone first, and the dominant apparent flow velocities of 39 m/h towards the Timavo/Timava spring and of 19 m/h towards the Aurisina/Nabrežina spring indicate very high permeability of the vadose zone in this part of Classical Karst. Continuous outflow of tracer in the flood waves following the precipitation events was proved by the measurements of tracer concentrations even 16 months after the injection. The total share of recovered tracer through the Timava spring was 93%.

Additional information about the characteristics of groundwater flowing through the Classical Karst aquifer was obtained by a new multi-tracer test in the frame of the Hydrokarst project. On April 10, 2013, uranine was injected in a 200 m deep borehole near Štorje, and amidorhodamine G at the surface near Sela na Krasu. The two tracers were washed with 14 m^3 and 10 m^3 of water respectively. Following intensive precipitation in previous days, the discharges of karst waters were in recession at the time of injection. The water was sampled at 8 springs, 1 cave and in 4 boreholes.

Uranine was detected at the Timavo/Timava and Aurisina/Nabrežina springs (Fig. 3). Until the end of January, 2014, approximately 63% of injected uranine was recovered at the Timavo/Timava springs. Since no discharge data for the Aurisina/Nabrežina spring are available, for this spring such assessment is not possible. Although we expected the appearance of amidorhodamine G in the Klariči pumping station, no tracer was detected there. As relatively low amount of this tracer was injected, its absence in the Timavo/Timava and Sardos/Sardoč springs was expected.

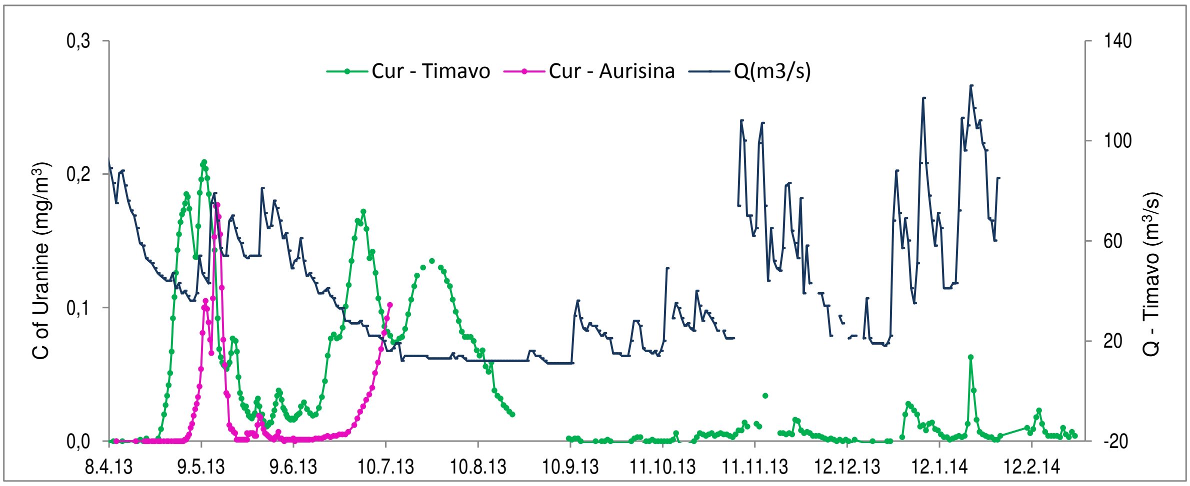

Fig. 13: The tracer breakthrough curves of the Timavo/Timava and Aurisina/Nabrežina springs, and the discharges of the Timavo/Timava Springs (discharges measured by the ACEGAS company).

However, tracer tests can be carried on not only using chemical substances, but also taking advantage of natural tracers such as electrical conductivity (EC), temperature and fauna.

EC and temperature values, can be followed using some meaningful points as Škocjan sinkhole, Trebiciano Abyss (with the monitoring station positioned at 330 m of depth inside the cave) and Timavo/Timava Springs. Analysing the graphs obtained from the recorded data, the possibility emerges to follow the changing values also during floods comparing the transit times with the ones calculated by the tracer tests. While flooding at Škocjan sinkhole to a rapid increased discharge is associated to a decrease in EC and temperature values. The wave amplitude assumes a lower value at Trebiciano Abyss measuring point. At Timavo/Timava spring, the signal amplitude is even more decreased also due to the Isonzo/Soča influence. During floods analysing the peak delay among Škocjan, Trebiciano and Timavo Spring water transit times were evaluated to be 200–800 m/h between Škocjan and Trebiciano and 150–500 m/h between Trebiciano and Timavo Spring, highlighting a circulation having a prevailing conduit character. The calculated transit times are in agreement with the ones obtained through the tracer tests, considering also that these last ones are not usually realized during floods, so the calculated times are lower than the one recorded by the data logger devices (Zini et al., 2014).

The first faunistic investigations of the Timavo/Reka system are dating back to early 30s in the last century (Stammer, 1932), where almost 100 species were recorded from the underground waters. The analyses of the data from the literature and of newly obtained data collected during HYDROKARST project with over 600 records together gave the insight into distributional patterns of groundwater species and their ecological preferences. Many species, especially Copepoda (Crustacea) are occurring along all Timavo/Reka system, from Škocjanskejame Cave to Timavo springs and can be found also in the Isonzo/Soča hydrological system, whereas some species were collected only at limited sampling points.

DISCUSSION AND CONCLUSIONS

Data collected allowed to study the hydrogeology of the area and to highlight the contribution to the flow from different parts of the hydrostructure. During floods most part of the circuits are under pressure and only comparative levels and EC analysis permits to evaluate the residence times properly. In fact, if the rising water level in the caves is simultaneous, EC changes from site to site, due to the different karst type allow to intercept the incoming flooding waters and to estimate the propagation water velocity. So in the Classical Karst area, it is possible to identify two different sectors, one mainly influenced by the Reka/Timavo system (south-eastern) and the other more influenced by the Isonzo/Soča circulation (western). The circuit connecting Škocjan cave with Timavo springs is characterized by a series of conduits allowing the flood impulse transfer within 1 to 3 days. In the western sector, the circulation is dispersed and base flows are present: in some cases, flood beginning is often delayed when compared to the spring's outflow. These data, are also supported by tracer tests results that verified the fast circulation occurring through conduits mainly present in the joining area between Škocjan sinkhole and Timavo and Aurisina springs. But also other systems can be used to better define the underground circulation as the fauna analysis: Copepoda (Crustacea) were found along all Timavo/Reka system. These species can help to understand the origin of the sampled waters–whether the water flows along Timavo/Reka underground system or it flows from the Isonzo/Soča alluvial aquifer (Stoch and Dolce, 1994). For example, sampling of fauna at Brestovica pumping station demonstrated the presence of faunal elements from Timavo/Reka system such as *Limnosbaenafinki* (Mestrov & Lattinger-Penko, 1969) as well some elements from the Isonzo/Soča alluvial aquifer such as species *Elaphoidellaphreatica* (Chappuis 1925). Those results indicate mixing of waters from two aquifers (karst *versus* alluvial).

The geochemical contribution to the study, underlines also a vertical variation in waters distribution highlighted by the chloride behavior. The increase in chloride concentration observed only at Klariči water point (10), foresee a deep waters contribution being the result of a possible mixing with deep fossil marine waters. We have to remember that not far away from the spring area (less than 1 km), a thermal spring is present where the carbonatic reservoir consists of Miocene marine paleo waters (Petrini et al., 2013).

The emerging hydrogeological conceptual model, as a result of the jointed multidisciplinary study, is a useful background tool that helps define the safeguard area of the tapped water points in order to preserve, for the future generations, the quality of the high vulnerable karst groundwaters.

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GROUNDWATER SUSTAINABLE USE, PROTECTION AND REMEDIATION

WATER MANAGEMENT OF THE CLASSICAL KARST AQUIFER (NE ITALY, SW SLOVENIA)

Franco Cucchi[1], Luca Zini[1], Chiara Calligaris[1], Philippe Turpaud[1], Francesca Federica Slejko[1], Francesco Treu[1], Stefano Furlani[1], Enrico Zavagno[1], Sara Biolchi[1], Marzia Michelini[1], Chiara Boccali[1], Silvia Cleva[1], Janko Urbanc[2], Tamara Ferjan Stanič[2], Janja Kogovsek[3], Metka Petric[3], Franci Gabrovšek[3], Natasa Ravbar[3], Enrico Altran[4], Stefano Piselli[4], Daniela Sciolis[4], Paolo Sossi[4], Mitja Leban[5], Giacomo Casagrande[6], Anton Brancelj[7] and Natasa Mori[7]

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Abstract: Classical Karst is a broad area located between the north-eastern Italian sector and the south-western Slovenian side. The area is about 40 km long and 15 wide (SE-NW direction) bounded by the Isonzo/Soča and Vipacco/Vipava rivers, by the Pivka River basin, Cicarija structure and the Gulf of Trieste. The plateau, slightly inclined towards NW, consists of limestone lithotypes deeply karstified. Rainfall and surface waters are immediately swallowed by the karst bedrock, where a network of caves is developed, transferring vertically the waters through the epikarst and vadose zone and collecting them in the aquifer characterized by large horizontal or sub-horizontal conduits quickly transporting the waters to the spring's area.

Data analysis obtained from Classical Karst groundwater monitoring networks highlights the complexity of the hydrostructure. In this framework, the Hydrokarst Project (Italy-Slovenia's transboundary cooperation program 2007-2013), is focused on the joint protection and management of the transboundary aquifer through quantitative and qualitative monitoring. One of Hydrokarst's outputs is the shared GeoDatabase collecting all the available and newly obtained geological, hydrological, hydrodynamic, geochemical and biological data. Unified maps as the Integrated Vulnerability Map obtained from the collected, validated and analyzed data are the common base to prepare cooperation agreements able to promote and implement action focused on the protection areas identification and realization. This common vision implements strategies able to prevent and/or reduce risks in emergencies. In this framework, also the support to the water consumption's reduction as the efficiency of the water network management and the improvement of drinking water quality, guarantee, to the future generations, an abundance of good quality waters.

Key Words: Classical Karst, hydrogeology, conduit and fractured, transboundary aquifer, groundwater sustainable use, protection, management

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