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## PRELIMINARY HYDROGEOLOGICAL RESEARCHES IN DAVORJEVO BREZNO (CLASSICAL KARST)

### ABSTRACT

*The cave called “Davorjevo brezno” is located at the southeastern border of the Classical Karst in Slovenia. Discovered in 2009, it is one of the largest caves in the Kras/Carso, currently with a depth of –319 m and a spatial development of 6,082 m (planimetric 5,550 m) surveyed. The exploration and scientific activity, both ongoing, are lead by Commissione Grotte “E. Boegan”, which also makes use of various other Italian and Slovenian explorers, technicians and specialists. Currently the explorations are aimed at the deepest area of the cave where, after having bypassed the first siphon by airways, new paleolevels of galleries have been reached at various altitudes and a new large “2<sup>nd</sup> siphon” has been recently explored by cavediver Simon Burja. The cave is a system of “basal” galleries where hypogean streams flow: these galleries are reachable from the surface after a succession of shafts. With a previous tracer test (uranine) managed by Karst Research Institute ZRC-SAZU of Postojna (Slovenia), by injecting the “first siphon”, the continuity of the waters of the Davorjevo brezno with the Trebiciano Abyss was ascertained, therefore the cave is part of the Kras/Carso hydrogeological system.*

*Due to the importance of the cave, a series of preliminary isotopic analyzes ( $\delta^{18}O$ ,  $\delta D$ ) plus temperature, pH and electrical conductivity were carried out on the internal hydrological system from June 2015 to February 2016. These latter, were follow by physico-chemical and chemical analyzes (in situ) from 2018 since 2019: moreover, a first monitoring cycle of two subterranean streams was carried out via the construction of two weirs and the installation of two CTD-Divers. The CTD Diver probes recorded continuously hydrometric height data (transformed into discharge flow), temperature and electrical conductivity  $K_{25}$  (from September 2020 to February 2021).*

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*A first scenario on the complex hydrogeology of the cave has emerged, and make possible to start, with a set of preliminary data, a new cycle (in progress 2023) of monitoring of the streams with three CTD-Divers: one of which is installed in the recently discovered water collector that leads to the “second siphon”: this latter was explored for 230 meters up to a new aerated cavity.*

**Keywords:** Karst hydrogeology, Davorjevo brezno, Classical Karst, Southwestern Slovenia

## RIASSUNTO

*Il Davorjevo brezno si trova all'estremità sud-orientale del Carso Classico, in Slovenia. Scoperto nel 2009, si è rivelato essere una delle maggiori grotte del Kras/Carso, con attualmente una profondità di -319m e uno sviluppo spaziale di 6.082 m (planimetrico di 5.550 m) rilevati. L'attività esplorativa e scientifica, entrambe in corso, è organizzata dalla Commissione Grotte “E. Boegan”, che si avvale anche di vari altri esploratori, tecnici e specialisti, italiani e sloveni. Attualmente le esplorazioni sono mirate alla zona più profonda della cavità dove, dopo aver bypassato il primo sifone per vie aeree, sono state raggiunte nuove gallerie “fossili” a varie quote e un nuovo grande secondo sifone in cui si è inoltrato lo speleosub Simon Burja. La grotta è un sistema di gallerie “basali” in cui scorrono corsi d'acqua ipogei, che si raggiungono dalla superficie dopo una successione di pozzi. Con un precedente tracer test (uranina) gestito dal Karst Research Institute ZRC -SAZU di Postojna (Slovenia), iniettando nel primo sifone, si aveva accertato la continuità delle acque del Davorjevo brezno con l'Abisso di Trebiciano, perciò la grotta fa parte del sistema idrogeologico del Kras/Carso.*

*Data l'importanza della grotta sono state eseguite, sul sistema idrologico interno, una serie di analisi (in cicli o puntuali) preliminari, isotopiche ( $\delta^{18}\text{O}$ ,  $\delta\text{D}$ ) più temperatura, pH e conducibilità elettrica da giugno 2015 a febbraio 2016, e successive misure fisico-chimiche in situ e analisi chimiche nel 2018 e 2019. Inoltre, un primo ciclo di monitoraggio di due torrenti ipogei è stato realizzato mediante la costruzione di due stramazzi e l'installazione di due CTD-Diver dove le sonde multiparametriche hanno registrato in continuità dati di altezza idrometrica (trasformati in portata), temperatura e conducibilità elettrica  $K_{25}$  da settembre 2020 a febbraio 2021.*

*Ne è emerso un primo quadro sulla complessa idrogeologia della grotta, che ha permesso di iniziare, con un corredo di dati preliminari, una nuova campagna (in corso 2023) di monitoraggio delle acque interne con tre CTD-Diver, di cui uno installato nel collettore recentemente scoperto che porta al secondo sifone, attualmente esplorato in immersione per 230 metri fino a un nuovo vano aerato.*

**Parole chiave:** Idrogeologia carsica, Davorjevo brezno, Carso Classico, Slovenia sud-occidentale.

## Introduction

The “Davorjevo brezno” (Davorjevo Abyss) 10060 S (Slovenia cave cadaster) is located on the south-eastern border of the Classical Karst in Slovenia, between the villages of Kačiče and Rodik (Fig. 1). The entrance position (WGS84) is Lat.  $45^{\circ} 38' 15.15''$  and Long.  $13^{\circ} 58' 17.9''$ , at the altitude of 511 m a.s.l. The cave is currently –319 m deep with a spatial development of 6.082 m (planimetric of 5.550 m) surveyed. Davorjevo brezno is, therefore, one of the largest caves in the Kras/Carso.

The cave, discovered in 2009, is being explored and studied by the Commissione Grotte “E. Boegan” SAG-CAI Trieste (Italy) (CGEB), in collaboration with Slovenian speleologists.



Fig. 1 – Geographical setting

## The Davorjevo brezno exploration

A first description of the cave was made by TORELLI (2013). Initial explorations hit two targets. First one, descending the “*Tihe Vode meander*”, which receives the “*Carbonari meander*” (Ramo dei carbonari/Karbonski) on the its right side and then join together the “*Veneziano meander*” (Meandro Veneziano/Beneski) and reach the first siphon (“old bottom”) at an average of 232 m a.s.l. (depth –279 m): this siphon was explored by cave diver Matej Mihailosvki down to –25 m (207 m a.s.l.). Second target was to go back from the “Veneziano” meander to the “*Papà meander-Marc’Aurelio meander*” (Meandro del papa/Ocetov-Meandro Marc’Aurelio) until reaching the quote 417 m a.s.l. (depth –94 m). The recent exploratory phase has instead allowed, with a series of ascents in the final part of the Veneziano meander, to find paleolevel empties up to fifty meters high on the stream and consequently a series of “loops” to go back down (by-passing the first siphon) to a new water collector. At this point, brand new floodwater passages “*Susi gallery*” (La Via di Susi) leads to the 2<sup>nd</sup> siphon, placed at 207 m a.s.l.

Currently, efforts have been oriented to explore via ascent climbings, various galleries that branch off from the water collector area, while two dives actions have been make with the Slovenian diver (Simon Burja and his team) in the 2<sup>nd</sup> siphon. The cave diver explore a submerged gallery 227 meters long (planimetric), up to 194 m a.s.l., from which he re-emerges at 207 m a.s.l. in a open air cave where a subsequent siphon would be located (Fig. 2).

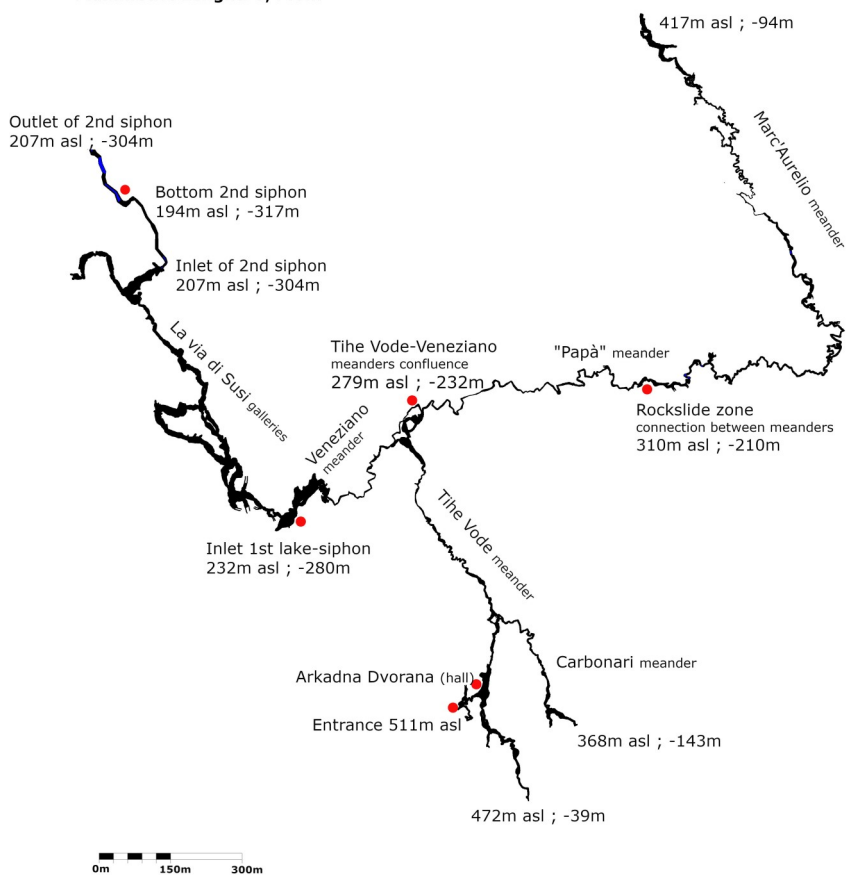
## DAVORJEVO BREZNO

S 10060

**Max Depth: -317m**

**Spatial Length: 6,032m**

**Planimetric Length: 5,440m**

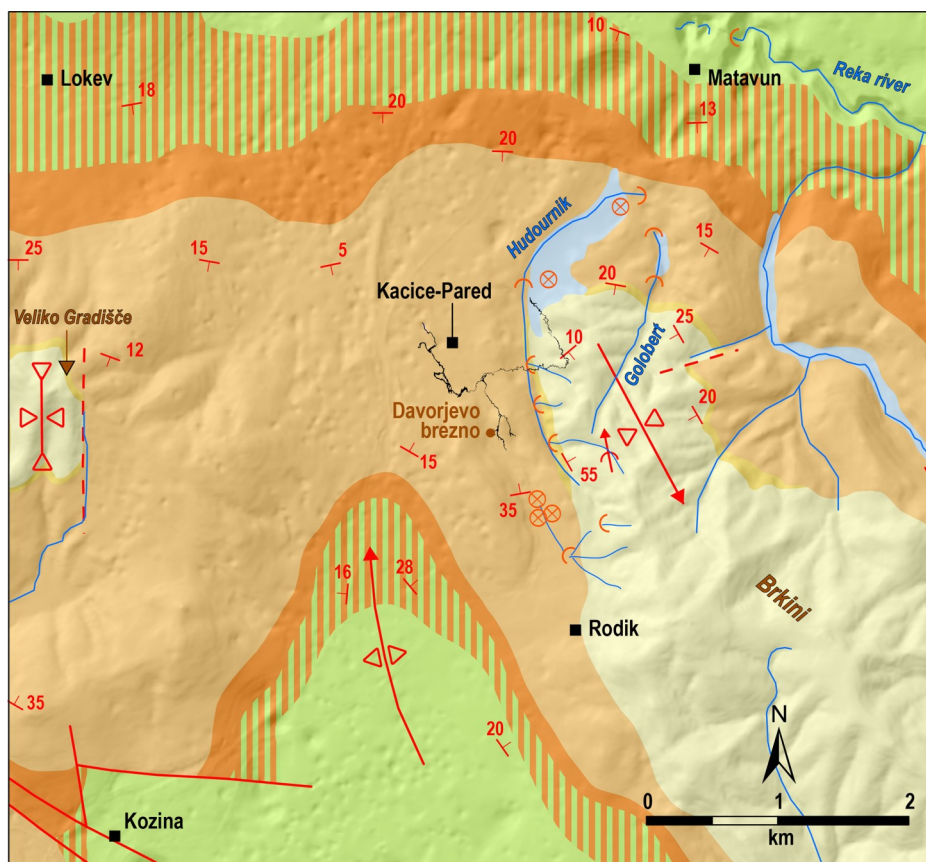


Topography

**Commissione Grotte "E. Boegan" CAI Trieste**  
**2010 – 2022**



*Fig. 2 – Plan of Davorjevo brezno.*



### Legend

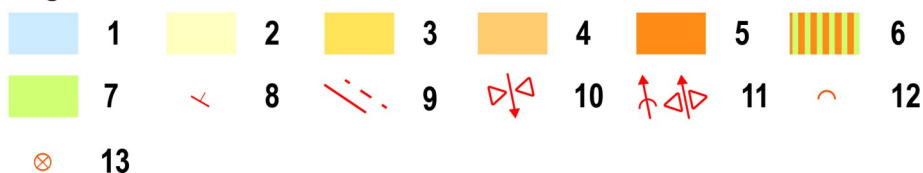


Fig. 3 – Geological map taken from PLENIČAR *et al.* (1973), JURKOVŠEK *et al.* (1996, 2016) and other geological surveys. Legend: 1 – Alluvium (Quaternary). 2 – Flysch (Eocene), alternations of marls, sandstones, breccias and conglomerates. 3 – Transitional beds (Middle Ypresian-Lower Cuisian). 4 – Alveolinid-Nummulitid Limestone (Ilerdian), stratified limestones, generally light grey-grey, mostly dark in upper part. 5 – Liburnian Formation, Slivje Limestone (Middle-Upper Paleocene), stratified limestones with frequently Miliolidae. 6 – Liburnian Formation (Maastrichtian-Paleocene *p.p.*), stratified or slab-shaped limestones, marly limestones, brecciated limestones, locally carbonaceous layers (coal). 7 – Lipica Formation (Upper Santonian-Campanian), stratified and massive limestones with Rudiste biostromes and bioherms. 8 – Dip and strike strata. 9 – Fault (established and covered). 10 – Syncline (axis and plunging). 11 – Anticline, major and minor (axis and plunging). 12 – Stream sink, ponor (in rock). 13 – Sinkhole (in alluvium). Davorjevo brezno plan in black.

## Geological and geomorphological setting of the area

The Davorjevo brezno area is located between the E slope of Mt Gradišče/Castellaro (742 m a.s.l.) and the W slope of the Brkini hills chain. Near the entrance of the cave, begins the small blind valley of Globoki potok which descends N and NE into Dansko polje, where lies the sinkhole called Mejame (MIHEVC, 1989). Immediately N of Dansko polje, there are the large dolines Dol Sokolak (bottom at 360m a.s.l.) and Dol Globočak (bottom at 350 m a.s.l.), with the artificial tunnel that leads to Tiha jama (at a.s.l. 315-310 m) part of the Škocjanske jame/San Canziano (MIHEVC, 2001). The Davorjevo brezno galleries are about 3 km far from the entrance of the Reka/Timavo river in the Škocjan Caves.

The area in which the Davorjevo brezno develops (Fig. 3) is located at the transition between the Alveolinid-Nummulitid Limestone (Ilerdian), followed by the Transitional beds (Middle Ypresian-Lower Cuisian), and the Flysch, Eocene (PLENIČAR, 1960; PLENIČAR *et al.*, 1973; JURKOVŠEK *et al.*, 1996, 2013, 2016). The area is characterized by the border of the SSE-NNW gentle anticline dipping to SSE forming the East slope of “Danski kras” (Kacice area) and the border of the SSE-NNW syncline in Flysch of Brkini hills (Upper Ypresian to Middle Lutetian) (MIKES *et al.*, 2006). Below the closure of the Brkini hills, where the Flysch is characterized by small NNE-SSW folds and faults, some passages of the Davorjevo brezno develop in the stratigraphically inferior limestones (therefore below the marly-arenaceous Flysch). Alveolinid and Nummulitid Limestone outcrops are stratified around SE-NW dipping about 15° NE, up to subhorizontal attitudes. In the area, of specific interest is the Dansko polje (blind valley of Dane) where the Hurdournik and Golobert temporary streams converge, with sinkholes in alluvial rocks. At the bottom of the Dansko polje lies the Mejame cave (in Italian literature “*Inghiottitoio di Dane*”), a sinkhole –170 m deep up to a lake-siphon at 225 m a.s.l. (MIHEVC, 1989), active only during exceptional floods, due the fact that the Golobert stream is captured about 400 m before, by an obstructed sinkhole.

More precisely, Davorjevo brezno extends immediately SW of Dansko polje and, from existing data, the area corresponds to the NW termination of the Brkini syncline. In the marly-arenaceous Flysch, more deformed, there are minor folds having the same axis, while in the carbonate outcrops the strata attitudes are congruent to the structure and dipping a few degrees up to about 15° towards the SE quadrant. The stratigraphy of Davorjevo brezno is still very little known (geological sampling is in progress). The upper part of the cave develops in the Alveolinid and Nummulitid Limestone (DROBNE, 1977), but the deeper parts should be in the formations stratigraphically at the bottom (HAMRLA, 1959) since in these zone there are strata with frequent lenses and coal nodules (Liburnian Formation).

## **The subterranean hydrography of Davorjevo brezno**

Davorjevo brezno is a cave in which several perennial and ephemeral streams converge: these streams are triggered during infiltration events due to rainfall. The main perennial streams flow in the Carbonari meander (Fig. 4) which comes from the southeast and flows into that one of the Tihe Vode meander (Fig. 5) having approximately the same direction; another stream flows down from the Papà and Marc'Aurelio meanders, a long branch of the cave that goes towards ENE bending and then to NW.

A part of the Marc'Aurelio stream develops below the Flysch. These streams flow into the Veneziano meander (Fig. 6) forming a high multi-level gallery, with a general direction towards SW, which ends in the first siphon (at an altitude of 232 m a.s.l.) (Fig. 7).

We are now in the system of galleries that should be defined as basal and active. The water collector reached downstream the Susi gallery (Fig. 8) has a greater flow rate and it develops, contrary to the Veneziano meander, towards NW. Currently, the supposed continuity between this collector and the waters of the first siphon has not yet been ascertained. Furthermore, for the calculation of the flow rates, the contribution of a stream from unknown origin is assumed (which probably comes from a gallery obstructed by rock landslide) due to a series of measurements carried out with the ionic method (with Easy-Flow instrument, 14 July 2019). The flow rate of the main water collector was 22.7 L/s against 4.5 L/s at the Veneziano meander.

## **Preliminary hydrogeological and physico-chemical researches**

The particular subterranean hydrography of Davorjevo brezno, located in the watershed area between the Karst/Kras aquifer and that of north-western Istrian mountain (Italy/Slovenia), was the reason for starting hydrogeological research.

A first research campaign was carried out between the years 2015-2017 by means of seasonal isotopic analyzes (rainwater and groundwater) of  $\delta^{18}\text{O}$  and  $\delta\text{D}$  and other physico-chemical parameters (BRUN & CORAZZI, 2017; BRUN, 2018). The results demonstrate a rapid drainage, with vertical outflows in the first part of the cave, which have an isotopic affinity with infiltration waters, between c.a.  $\delta^{18}\text{O}\text{‰}$   $-6$  and  $-7$ . A second type of water characterizes the stream of Carbonari meander with  $\delta^{18}\text{O}\text{‰}$  between  $-7.6$  and  $-8.2$ . A third type of water characterizes the stream of Tihe Vode-Papà-Veneziano meanders with intermediate isotopic values, around  $\delta^{18}\text{O}\text{‰}$   $-7.3$  and  $-7.7$ . It is therefore suggested that the water of Carbonari meander may come from higher altitudes than those of the Danski kras and Dansko polje, perhaps partly stored in the marly-arenaceous Flysch.

In 2018 a tracer test coordinated by the Karst Research Institute ZRC-SAZU of Postojna (Slovenia) (KRI) was performed, injecting 3 kg of uranine into the 1<sup>st</sup> siphon (Fig. 9) of the Davorjevo brezno (at the time, the 2<sup>nd</sup> siphon was not yet discovered) and 3 kg of naphthionate in the "T2-18" borehole, located about 7.5 km SW of the Davorjevo



brezno. Uranine was found in Jama 1 v Kanjaducah and in the Trebiciano Abyss (PETRIČ *et al.*, 2020; ARSO, 2023), thus in correspondence with streams coming from the Reka/Timavo karst basin (BRATOS *et al.*, 2018). Previously a tracer test was performed injecting amidorhodamine G in the T1-8 borehole (PETRIČ & KOGOVŠEK, 2011) 3.8 km WSW from Davorjevo brezno and detecting the fluorescent dye at Lavatoio spring/Pri pralnici in Bagnoli (Italy) at foot of Mt Carso, demonstrating that between T1-8 and Davorjevo brezno there is the aforementioned watershed. The Lavatoio spring/pri pralnici is a perennial spring for juxtaposed permeability dam with minimum flows 6 L/s, averages 75 L/s and maximum 191 L/s (BALLARIN *et al.*, 1994).

In 2018 and 2019 during two explorations, respectively in winter (November 27, 2018) and in summer (July 14, 2019), in situ physico-chemical measurements were performed and water samples were collected and then chemical analyzed (CORAZZI, 2020; PRELOVSEK, 2020), with the collaboration of the Karst Research Institute ZRC-SAZU of Postojna (Slovenia). The samplings were carried out in various points of the Davorjevo brezno, from 40 m below the entrance up to the 2<sup>nd</sup> siphon, taking both percolation water and subterranean streams.



Fig. 4 – Outlet of Carbonari meander stream, the floor consists of calcareous debris and calcareous and arenaceous pebbles (photo Peter Gedei).



The CO<sub>2</sub> in the cave shows airflow typical of the winter and summer periods, with the currently known entrance serving as the upper entrance. The CO<sub>2</sub> concentration is not much higher than the external one, which is 0.04%, but higher than the other epigenic caves in the surroundings, indicating a combined effect of an important CO<sub>2</sub> source and a weak/moderate air circulation. This air circulation mainly affects the sub-vertical part of the cave, due to the intrusion of external air, while the hydrologically active galleries appear to be less ventilated or more influenced by the CO<sub>2</sub> source. For example, in summer in the Arkadna hall (after the initial shafts) the CO<sub>2</sub> content is 0.7% (compared to 0.3% at 40 m below the entrance) while at the two siphons at about 300 m depth the CO<sub>2</sub> content is 1.7%. For comparison, the CO<sub>2</sub> contents in deep caves of the Classical Karst, such as the Lipiška jama and the Skilan Cave, showed values between 1.1% and 1.8% at depths ranging from about 40 to 100 m, while at greater depths, among 150 and 250 m, values from 2.7% to 3.3% (DAMBROSI, 2015).

During these first investigations the water temperature and the electrical conductivity EC (K<sub>25</sub>) were not much different in winter (10.5 °C and 543±29 µS/cm) and in summer (10.6 °C and 493±41 µS/cm). Both parameters are within expectations for the surface altitude above the cave and are characteristic of widespread autogenic recharge. A slightly lower EC during the summer survey with lower flow rates, unusual, may have been deter-



*Fig. 5 – Tihe Vode meander with typical meander erosion (photo Peter Gedei).*

minated by the seasonal climatic trend. The pH was between 7.16–7.25 during the winter survey while in the summer it was between 7.20–7.87, which can be related of the CO<sub>2</sub> concentration in the cave.

The Ca/Mg ratio 11.7–30.1 indicates a lower distribution of dolomite in the drainage basin, expected from the lithological characteristics surrounding the cave (limestone, marly-arenaceous rocks). In winter, the water was slightly supersaturated respect to the calcite, with a saturation index (SI<sub>C</sub>) between 0.03–0.18, while in the summer, the SI<sub>C</sub> shows similar values in the hydrologically active basal gallery (0.01–0.10), and on the contrary higher values in the waters of Arkadna hall with SI<sub>C</sub> 0.51: 40 m below the entrance, SI<sub>C</sub> shows value to 0.63. This is caused by the degassing of CO<sub>2</sub> in the water, that increases the saturation index. In the hydrologically active basal gallery, the source of CO<sub>2</sub> in the air can derive from water containing CO<sub>2</sub> in equilibrium with a concentration of 1.7% and 1.5–1.6% respectively during the winter and summer. The percolation water has a CO<sub>2</sub> concentration very similar to the one before degassing, however, due to the intense degassing of CO<sub>2</sub> from the percolating water during the second survey (caused by the intrusion of external air), the equilibrium CO<sub>2</sub> concentration in the flowing water in the gallery, decreases to 0.3–0.6 %. During the winter survey, the minimal degassing of CO<sub>2</sub> from the percolating water resulted in a similar concentration of CO<sub>2</sub> in the cave water and air, as well as a SI<sub>C</sub> close to equilibrium (0.05–0.15).



Fig. 6 – Stream of Veneziano meander with pool indicating high levels reached by floods (photo Igor Ardetti).



Water samples relativity near the cave entrance (e.g. Carbonari meander) show light pollution ( $\text{Cl}^-$  3.8 mg/L,  $\text{NO}_3^-$  5.4 mg/L,  $\text{PO}_4^{3-}$  0.09 mg/L), but it increases downstream and in particular in the 2<sup>nd</sup> siphon ( $\text{Cl}^-$  7.7 mg/L,  $\text{NO}_3^-$  9.1 mg/L,  $\text{PO}_4^{3-}$  0.12 mg/L). This indicates a fecal contamination of the terminal water collector (from unknown origin). Considering the marly-arenaceous rocks east of Davorjevo brezno as a probable source area of sulphates, the downstream decrease of  $\text{SO}_4^{2-}$  from 11.2 to 5.0 mg/L. This is



*Fig. 7 – The lake of 1st siphon explored up to 25 meters deep (photo Peter Gedei).*



*Fig. 8 – The water collector (Susi gallery) at the entrance of 2nd siphon (photo Domagoj Korais).*

in accord with the concentration of  $\text{SO}_4^{2-}$  between 1.9 and 3.8 mg/L in the percolation water of shafts and subvertical passages of Davorjevo breznó in limestones.

### Preliminary hydrogeological research using CTD-Diver probes

In year 2020, we designed a more detailed hydrogeological study of Davorjevo breznó.

Two weirs (thin-walled triangular type) were built onsite, respectively at the Carbonari meander (Fig. 10) and Veneziano meander streams (Fig. 11): two CTD-Diver probes, supported by a Baro-Diver probe (Eijleikamp) were installed in the formed water basin. A third CTD-Diver was placed later on, in the meantime discovered Susi gallery main water collector (data not on present paper). For the possible relationships, the data of the daily flows (Q) and the meteoric data of the ARSO weather/hydraulic stations on the Reka/Timavo (Slovenia), were acquired. Rainfalls at “Škocjan” station (420 m a.s.l.) are in mm/rain/30 minutes and Reka river discharges at “Cerkvenikov mlin” station (341.7 m a.s.l.) are in  $\text{m}^3/\text{s}$ .

The CTD-Divers installed on September 13, 2020, scheduled for data acquisition every 5 min. intervals, recorded up to February 27, 2021, (167 days). The water level data (pressure calibrated with the Baro-Diver data) obtained at the two weirs, 1<sup>st</sup> weir (I W) at Carbonari meander and 2<sup>nd</sup> weir (II W) at Veneziano meander (near the first siphon) were transformed, by applying a known formula, into flow rates (Q L/s). Temperatures are in T °C ( $T_w$ ). The electrical conductivity (EC) of water went gauged to specific  $K_{25}$  ( $\mu\text{S}/\text{cm}$ ).



Fig. 9 - The Veneziano meander immediately before the lake of the 1st siphon, where the uranine injection was made for the tracer-test (photo Louis Torelli).

At the two weirs, the flow rates higher than the respective crests, have been estimated through simulation, therefore they are not absolute values but simply reference values: so they should be read with such references. At I Weir, flow rates up to 189 L/s were measure, while at II Weir flow rates were marked up to 243 L/s.



*Fig. 10 – Installation of I Weir in the Carbonari meander designed for minor discharges (Photo Igor Ardetti).*

modulation of the infiltrative events than that of the Veneziano meander (Fig. 14). The electrical conductivity is fairly uniform between I W (Fig. 15) and II W (Fig. 16), but it must be considered that the Carbonari meander water (I W) flows upstream compared with the CTD-Diver installed at the Veneziano meander water (II W) and therefore there is a process of mixing and homogenization. The average EC values at the Carbonari meander (I W) is around 520–530  $\mu\text{S}/\text{cm}$  and at the Veneziano meander (II W) around 500–530  $\mu\text{S}/\text{cm}$ , which are typical values of karst waters, i.e. infiltration/flow in the limestones of the Classical Karst. However, at I W there are decreases up to 290  $\mu\text{S}/\text{cm}$  and increases up to about 800  $\mu\text{S}/\text{cm}$ , while at II W there are decreases up to 350  $\mu\text{S}/\text{cm}$  and increases up to 630  $\mu\text{S}/\text{cm}$ . These variations are dependent on rainfall events, responding quickly and probably removing saturated stored water (Figs. 17 and 18). The temperatures, also related to the Reka river discharges, show a rapid fall in winter.

This research is still preliminary and right now (2023) is ongoing with three

Generally, the Davorjevo brezno vadose and epiphreatic passages are subject to significant and rapid flow variation, closely related to rainfall events and outflows from the Reka basin. Normally floodwaters can reach at I W (Fig. 12) discharges of 150 L/s and, estimated, at most of 270 L/s: at II W (Fig. 13) discharges went close to about 250 L/s and estimated at most of 800 L/s. Generally, the discharge of the Carbonari meander (I W) presents a greater



*Fig. 11 – Installation of II Weir in the Veneziano meander designed for higher discharges (Photo Igor Ardetti).*

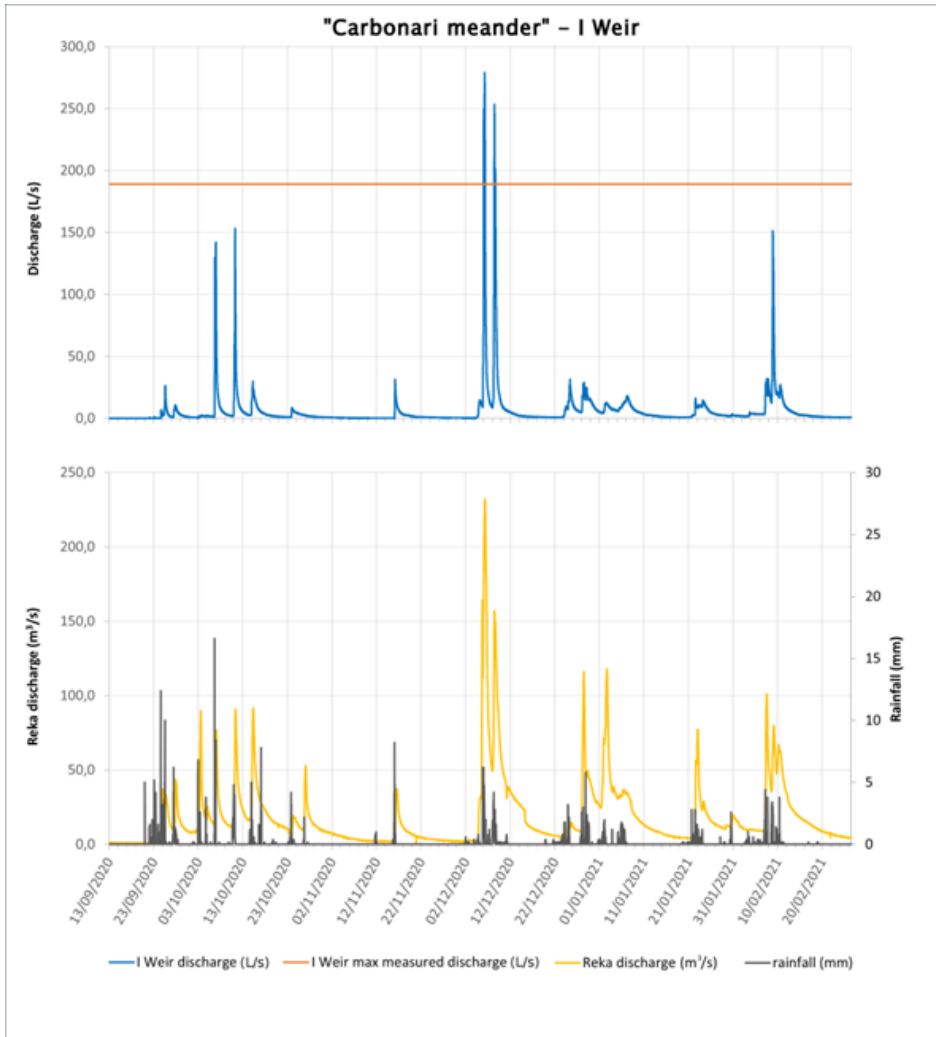


Fig. 12 – Relationship between discharge of I Weir, Reka river discharge and precipitations.

CTD-Divers at work, two installed in the same points mentioned and one installed in the water collector of Susi gallery, in order to obtain more complete data. Therefore, only a few examples of the typical phenomena encountered during this first cycle of measurements are here explain and goes as follows.

Example in winter at the I Weir: rainy event on February 7, 2021, starting at h 07:00, at the same time at the Carbonari meander 3.4 L/s,  $T_w$  10.39° and EC 512  $\mu$ S/cm. At h 15:00, with a total of 5.6 mm of rain, the flow rate exceeds 4.0 L/s with  $T_w$  10.41 and EC 512  $\mu$ S/cm, at h 22.50 with a further 15.4 mm of rain, the flow rate reaches peak 29.1 L/s,  $T_w$  10.40° and EC 456  $\mu$ S/cm. In this specific case, piston flow phenomena are not marked, but a very rapid response to the input of newly infiltrated water is appreciable.



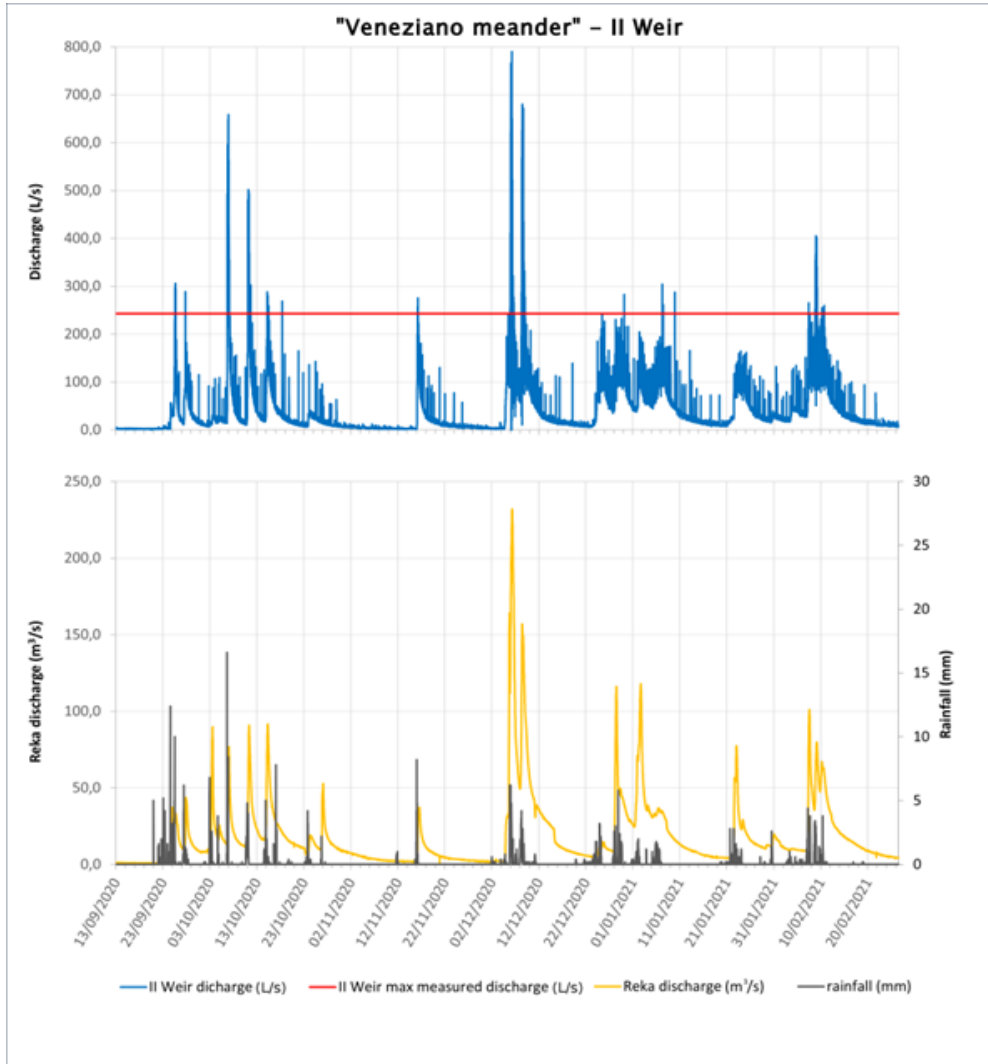


Fig. 13 – Relationship between discharge of II Weir, Reka river discharge and precipitations.

A particular phenomenon is observed between the days December 5-7, 2020. On December 6, h 07:00 (at I W:  $Q$  10.3 L/s,  $EC$  492  $\mu\text{S}/\text{cm}$ ,  $T_w$  10.37°) a rainfall event begins and ends on December 7, h 01:00 with a total of 77 mm of rain (at I W:  $Q$  95 L/s,  $EC$  364  $\mu\text{S}/\text{cm}$ ,  $T_w$  9.95°) (SEMERARO *et al.*, 2023) (Fig. 19). The flood peak at I W is reached at December 6, h 20:15 with  $Q$  279.0 L/s,  $EC$  304  $\mu\text{S}/\text{cm}$ ,  $T_w$  9.42°, therefore with hydrodynamics similar to the previous one. The difference, however, is that the day before the beginning of rainy event, December 5, h 04:50, an  $EC$  peak appears with 796  $\mu\text{S}/\text{cm}$  ( $Q$  1.78 L/s) while there was an insignificant quantity of rain, just equal to 1.8 mm. But during this increase in electrical conductivity set within a long period of very scarce local rainfall (only 6.6 mm of rain from November 16 to December 5, precipitations have af-



affected the upper part of the Reka's catchment (weather stations of Ilirska Bistrica and Klana respectively 20 and 35 km from Škocjan) determined on December 5, at the Cerkevnikov mlin station, from an average discharge around  $2.2 \text{ m}^3/\text{s}$  to an increase (h 08:30) higher than  $3 \text{ m}^3/\text{s}$  which goes higher than  $6 \text{ m}^3/\text{s}$  (h 09:30) (Fig. 20). In the first hypothesis, we consider, as causes, some hydraulic loads of the karst aquifer in the upstream area of Davorjevo brežno, which would cause the expulsion of highly mineralized waters (piston flow) stored in the reservoir. The aforementioned Reka flood event will reach its peak on December 6, at h 20:00, with  $232 \text{ m}^3/\text{s}$  (hydrometric height 527 cm).

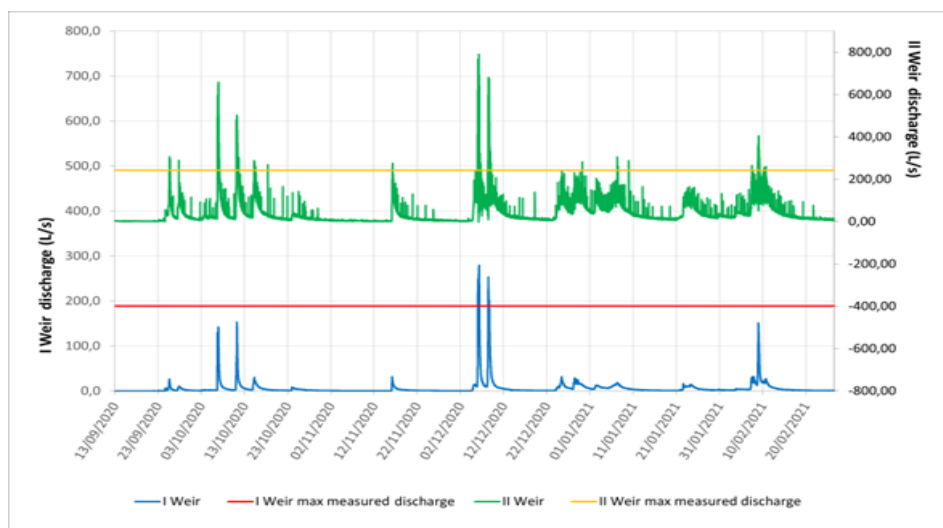


Fig. 14 – Relationship between the discharges of I Weir and II Weir.

In this event, the II Weir shows a similar behaviour (Fig. 21). However, while the EC curves are almost homogeneous between the WI and WII streams, the flow rate is modulated in the Carbonari meander and much less modulated, impulsive and greater in the Veneziano meander.

The source areas that determine the Davorjevo brežno hydrography are still unknown and represent an important question. It is probable that they also belong to the marly-arenaceous Flysch rock areas (Brkini hills). In fact, alluvial sediments in the cave comes from these lithologies (TORELLI, 2013), while the dissolved  $\text{SiO}_2$  content of the subterranean waters is  $6.0\text{--}7.5 \text{ mg/L}$  (MERLAK, 2009, 2013), a relatively high value which tends to take into consideration the surrounding marly-arenaceous lithological facies, and this is in accordance with the of sulphate values in the Davorjevo brežno groundwater (PRELOVSEK, 2020). The Flysch rock masses permeability is generally low, since the presence of clay minerals significantly lowers the degree of free drainage (MARINOS & HOEK, 2001). However, especially in the Brkini Flysch where the presence of arenaceous layers is not secondary, there are highly pervasive fractures facilitate the drainage and consequently the rock mass permeability.

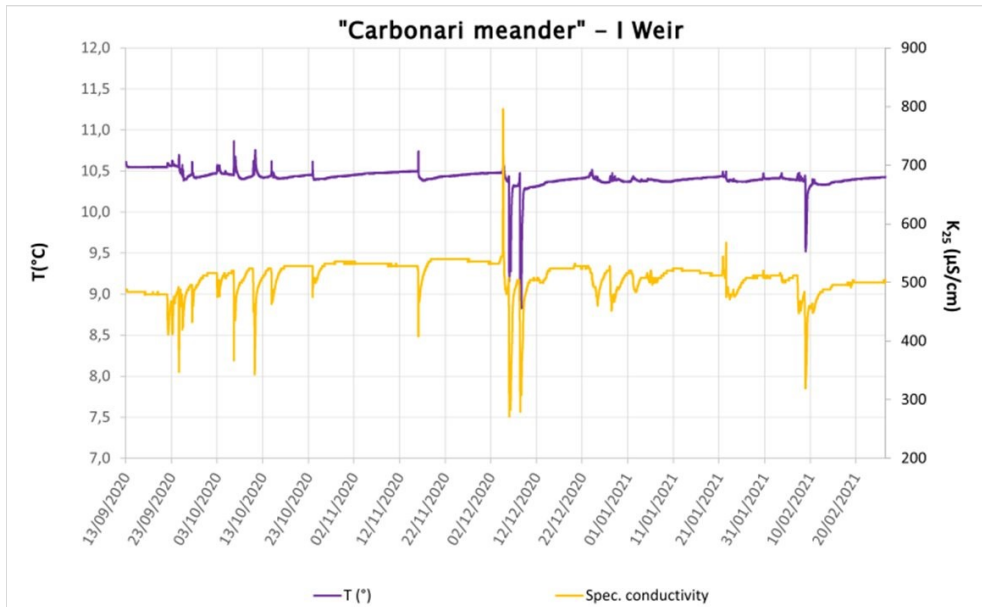


Fig. 15 – Relationship between water temperature and electrical conductivity of I Weir.

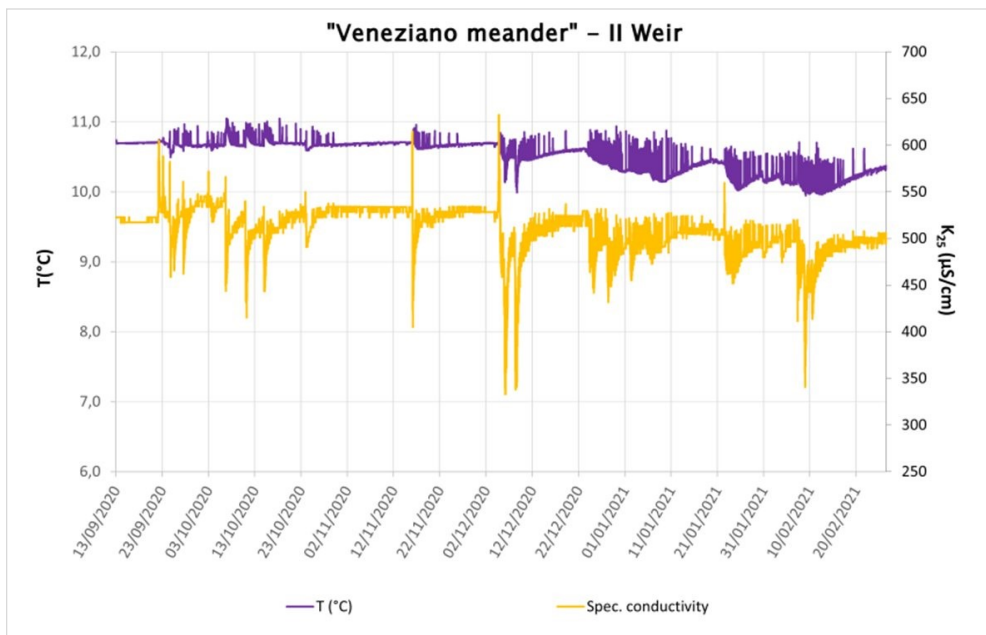


Fig. 16 – Relationship between water temperature and electrical conductivity of II Weir.

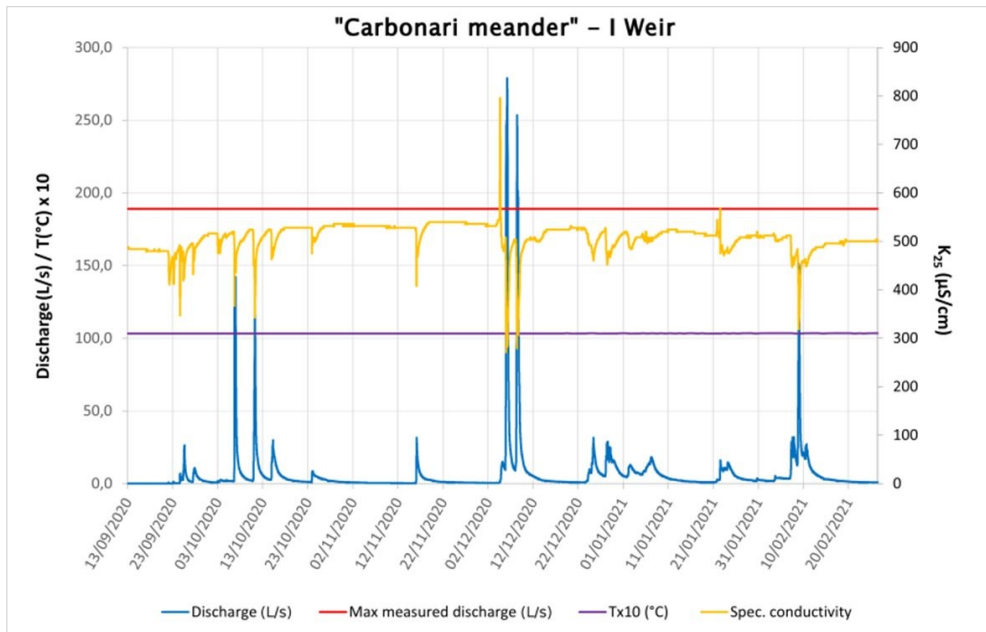


Fig. 17 – Relationship between discharge and electrical conductivity of I Weir.

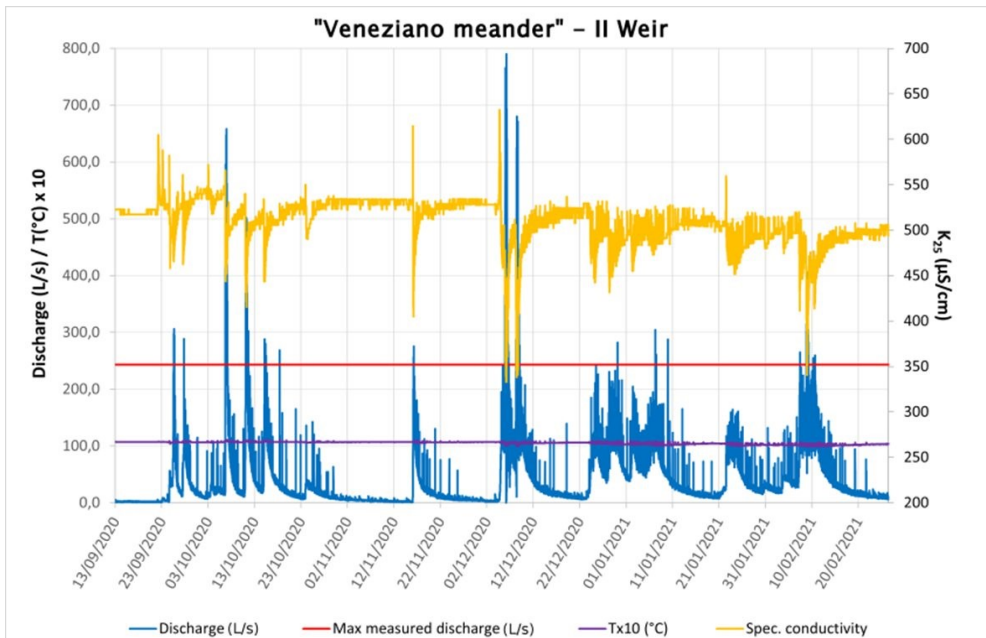


Fig. 18 – Relationship between discharge and electrical conductivity of II Weir.

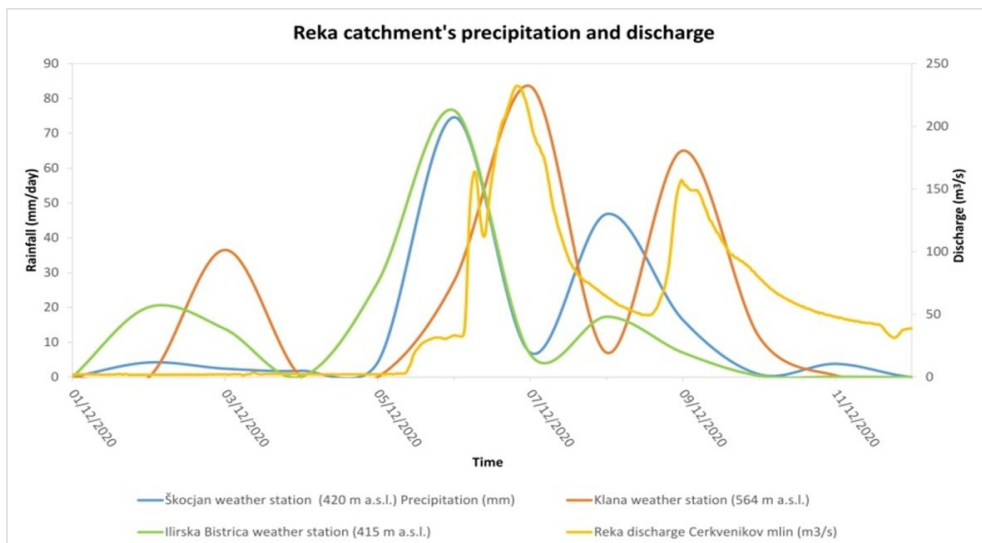


Fig. 19 – Precipitation of Weather stations on Reka catchment (Slovenia and Croatia) and Reka river discharge near Škocjan. Flood period between 5 and 10 December 2020.

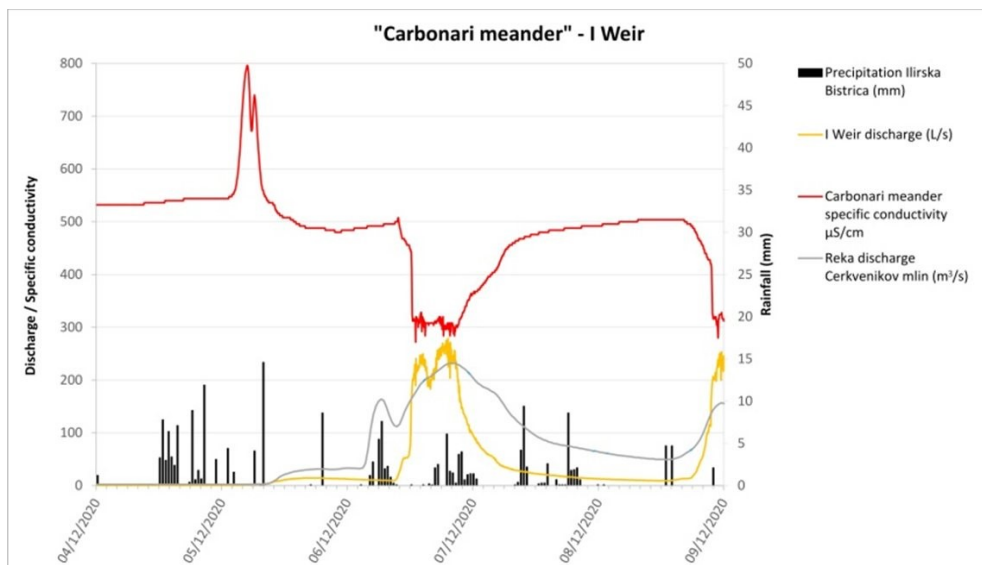


Fig. 20 – Flood event at I Weir from 5 to 7 December 2020.

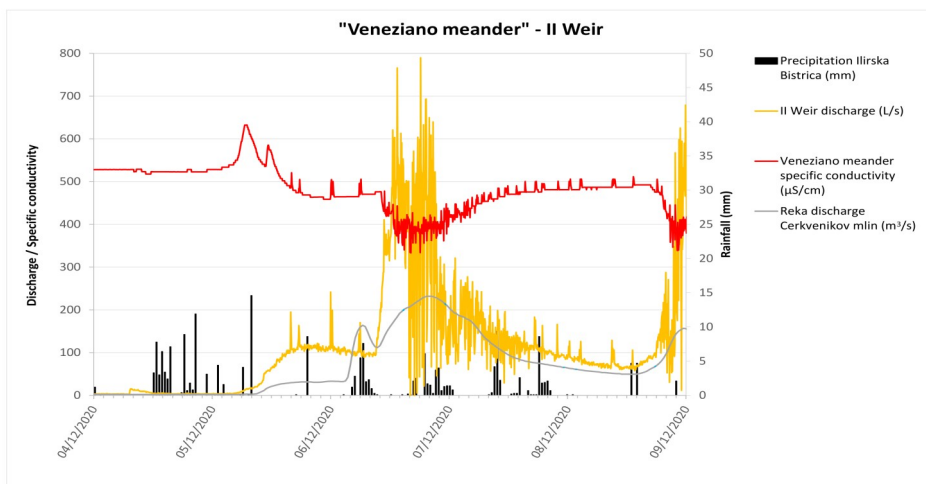


Fig. 21 – Flood event at II Weir from 5 to 7 December 2020.



Fig. 22 – The water collector (Susi gallery) that reaches the 2nd siphon, approximately at 220-215 m a.s.l. probably by now epiphreatic zone (photo Domagoj Korais).

The subterranean hydrography and the altitudes reached are very significant aspects. The 1<sup>st</sup> siphon is at 232 m a.s.l., the 2<sup>nd</sup> siphon at 207 m a.s.l. while the maximum depth (submerged) quote reaches 191m a.s.l. The siphon in Mejame is at 225 m a.s.l., while the one in Škocjanske jame/Grotte di San Canziano is at 169 m a.s.l. Even in consideration of the position of Davorjevo brezno (south compared of these two amentioned caves), i.e. towards the aforementioned underground watershed and of the characteristics of its siphons (long submerged conduits interspersed with aerated conduits), it is reasonable to hypothesize that these cave passages (Fig. 22) are now in the epiphreatic/phreatic zone.

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