

ÖVH-Frühjahrstagung 27.-30. Mai 2026

Hydrogeologie des dinarischen Karstes in Slowenien, Postojna

Organisation: Felix Thalheim; Führungen: Dr. Cyril Mayaud, Dr. Blaž Kogovšek, Dr. Matej Blatnik, Dr. Astrid Švara, Tinkara Mazej, Dr. Franci Gabrovšek

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TAGUNGSPROGRAMM

Mittwoch, 27.05.2026

- 17:00 Zusammentreffen im Karst Research Institute in Postojna (Titov trg 2, 6230 Postojna)
- 17:30 Einführungsvortrag: Dr. Matej Blatnik
- 18:30 Gemeinsames Abendessen (Bistro Štorja)

Donnerstag, 28.05.2026

Exkursion ganztags – Ljubljana-Einzugsgebiet Ost

- 08:30 Abfahrt Richtung Grad Snežnik
- 09:00 Exkursion Loško polje (Grad Snežnik und Golobina ponor), dann Weiterfahrt zum Cerkniško polje (optional: Aussichtspunkt Gorenje jezero), Rešeta-Ponore und Aussichtspunkt Cvinger.
- 13:00 Mittagessen (vrsl. Gostišče in pizzerija Furman, Rakek)
- 14:30 Begehung Rakov Škocjan, danach Weiterfahrt ins Planinsko polje zur Unica-Quelle und Planina-Höhle; Rückkehr etwa 17:30 Uhr
- 18:30 Gemeinsames Abendessen (z.B. Restavracija in Pizzeria Čuk)

Freitag, 29.05.2026

Exkursion ganztags, Ljubljana-Einzugsgebiet Süd (Pivka), Hydrogeologie des Javorniki-Massivs

- 08:30 Abfahrt ins obere Pivka-Tal
- 09:00 Aussichtspunkt Šilentabor, Übersicht über die Region
- 09:30 Weiterfahrt zum Palško-See (intermittierend), Besichtigung der Estavelle bei Matijeva jama, anschließend zum Petelinjsko-See; Fußweg jeweils 15 Minuten in eine Richtung
- 13:00 Mittagessen (in Pivka; entweder Gostilna pri Marti oder Picerija Herman)
- 14:00 Weiterfahrt zu den Ponoren im Planinsko Polje (30 Minuten), abschließend zu den Quellen der Ljubljana in Vrhnika; Rückkehr etwa 18:00 Uhr
- 18:30 Gemeinsames Abendessen (z.B. Picerija Minutka)

Samstag, 30.05.2026

Optionales Programm für alle, die am Samstag noch dabei sind:

Je nach Wetterlage und Interesse der anwesenden Personen: Ausflug z.B. zur slowenischen Küste oder Wanderung, später Rückkehr nach Postojna und optional Ausklang am Abend in Ljubljana (Abstimmung mit Felix)

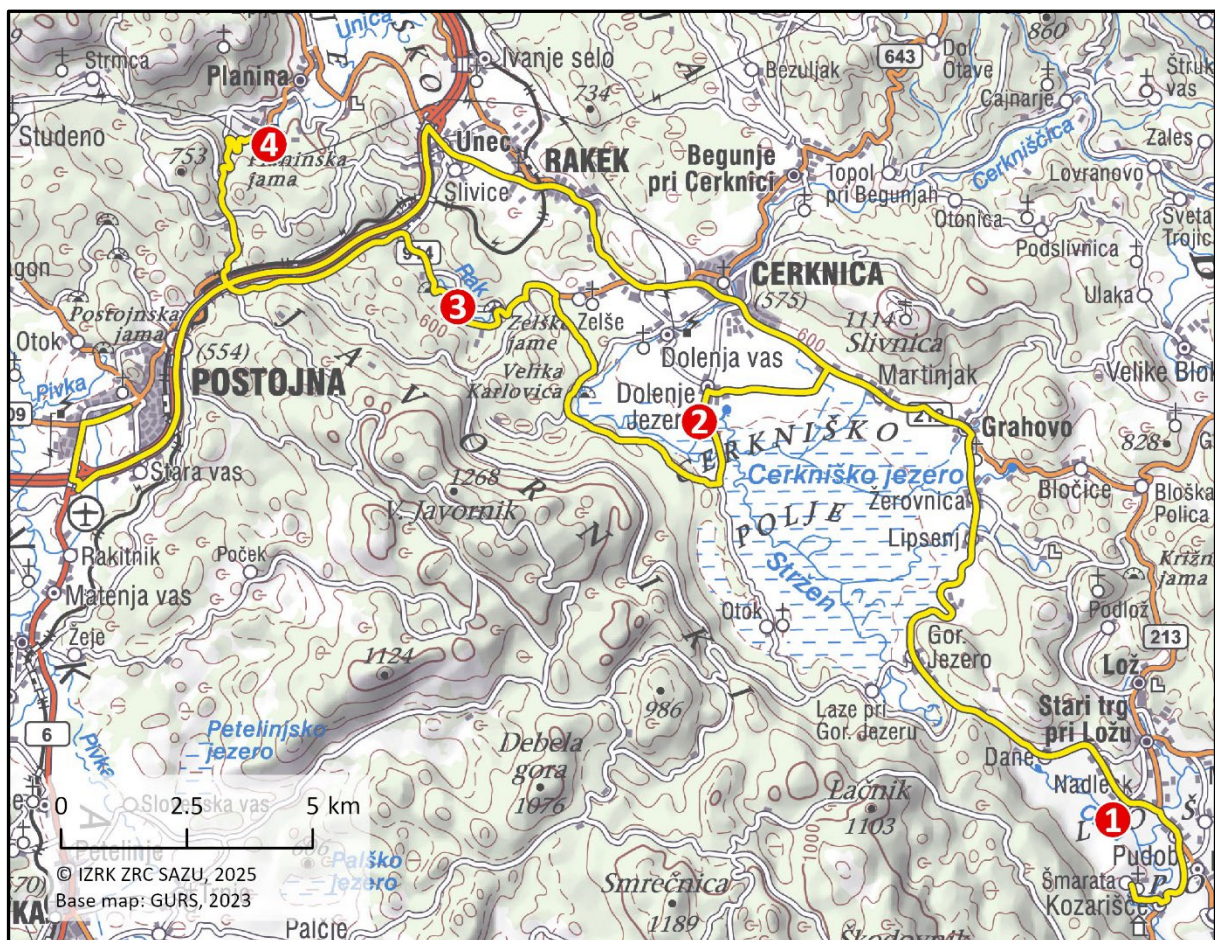
Whole-day field trip (A): HYDROLOGY OF THE RECHARGE AREA OF THE UNICA RIVER

Thursday, 28th May 2026, 8:30–18:00

Cyril Mayaud, Blaž Kogovšek, Matej Blatnik, Tinkara Mazej

Stops:

- 1 – Loško polje – The Snežnik castle and the ponor of the Golobina Cave
- 2 – Cerknjsko polje – Outflow zone of Rešeta and view point of Cvinger
- 3 – Rakov Škocjan – Hydrology of the Rakov Škocjan karst valley
- 4 – Planinsko polje – The Unica Spring and Planinska jama



GENERAL INTRODUCTION: HYDROGEOLOGY OF THE LJUBLJANICA RIVER RECHARGE AREA

The central part of the Slovenian Dinaric Karst drains to the springs of the Ljubljana River, located on the southern edge of the Ljubljana Basin (Fig. 1.1). Although the area is about 26 km of straight-line distance close to the Adriatic Sea, intense tectonic activity has triggered drainage into the Sava-Danube river basin, which flows to the Black Sea. The estimated total size of the Ljubljana

recharge area is almost 1800 km², of which about 1100 km² are karstified. The karst catchment area was delineated during an extensive tracing campaign in the 1970s (Gospodarič & Habič 1976).

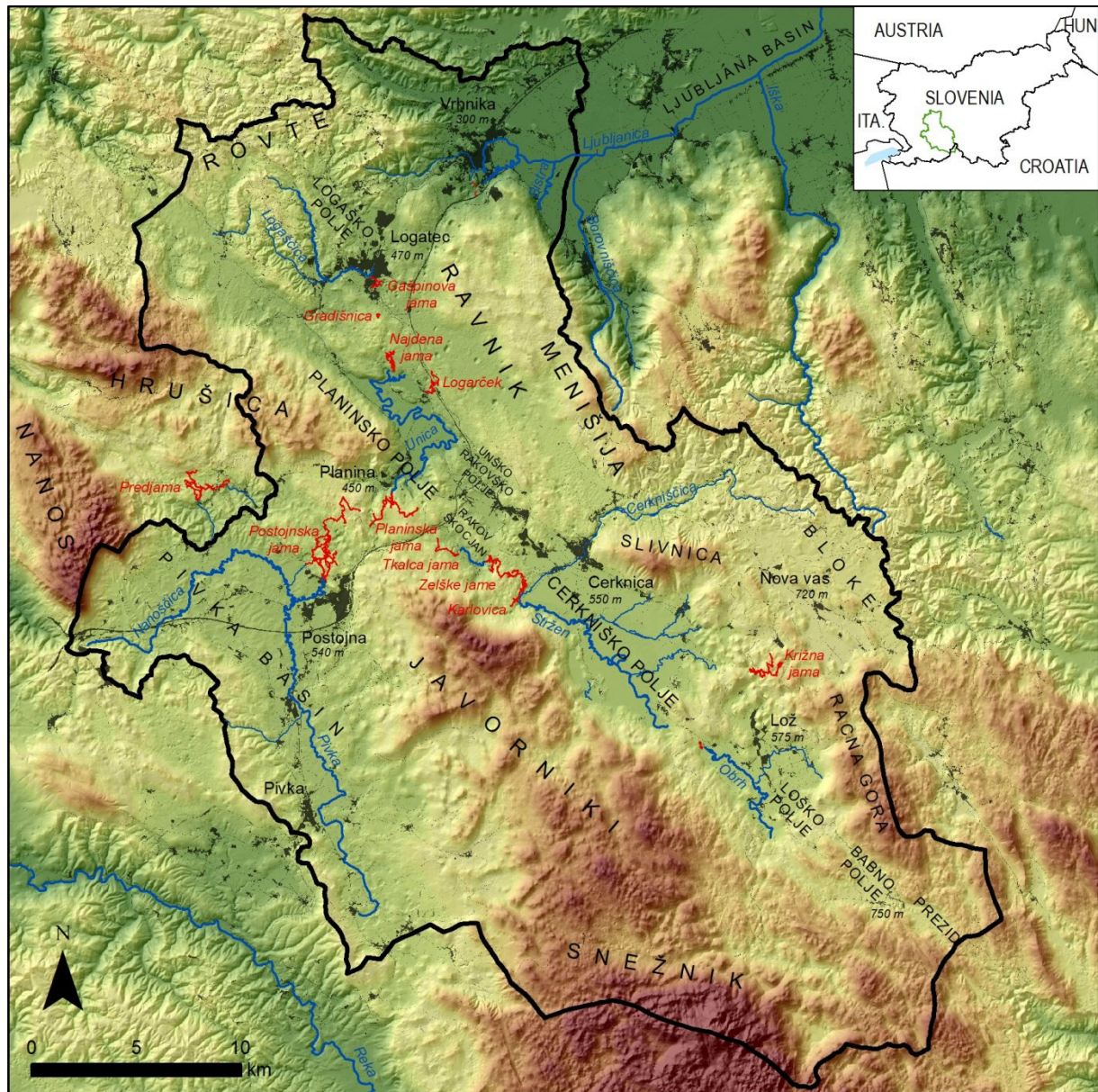


Fig. 1.1: Ljubljana River recharge area with high karstic plateaus, karst poljes and surface rivers. The main caves are shown with red lines.

The karst rocks are mostly of Mesozoic age. They are generally micritic, locally oolitic limestones and predominantly late-diagenetic dolomites. They formed on the Dinaric platform under conditions of continuous sedimentation that allowed high rock purity, generally with less than 5%, locally even only 0.1%, insoluble residues. The total thickness of the carbonate sequence is almost 7 km.

Structurally, the entire Ljubljana catchment belongs to the Adriatic Plate. The area consists of several nappes that were overthrust during the peak of the Alpine orogeny in the Oligocene in a NE to SW direction (Placer 2008; Placer *et al.* 2010). A later change in the direction of plate

movement led to the formation of the Idrija Fault Zone, a dextral strike-slip fault that crosses the area in the direction of NW-SE (Fig. 1.2) (Vrabec 1994). The Idrija Fault Zone largely determines the direction of regional flow (Fig. 1.2). In general, the steepest hydraulic gradient is oriented northwards, from the Notranjska region towards the Ljubljana Basin, which represents a regional base level. However, the fault zone acts as a barrier to groundwater flow and forces the water to surface in the poljes. At the same time, it diverts the flow in the Dinaric direction (SE-NW) (Šušteršič 2006).

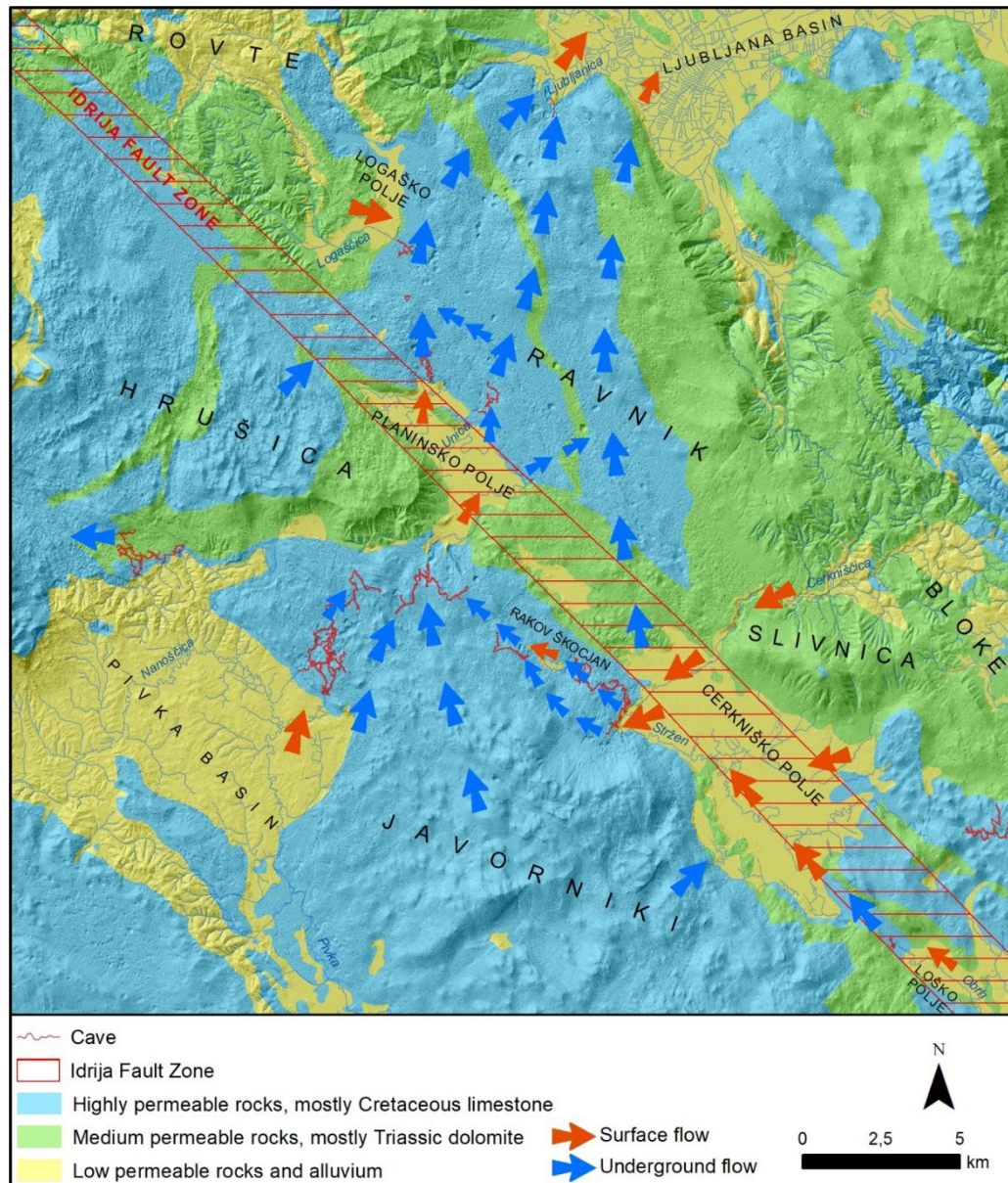


Fig. 1.2: Geology and hydrology of the Ljubljana recharge area (adapted from Krivic et al. 1976).

Several poljes have developed along the Idrija Fault Zone (Gams 1965a, 1978; Šušteršič 1996). These large flat-bottomed depressions are regularly flooded and are often the only areas where water appears at the surface. The formation of poljes is preconditioned by tectonics, in this case by the structures within the Idrija strike slip fault (e.g. pull-apart zones), but the forming mechanism is the corrosional planation at the groundwater level.

In general, the water follows the SE-NW direction with surface flow on the poljes and groundwater flow in-between (Fig. 1.3). Additional water enters the flow system at numerous springs draining the areas of the Snežnik and Javorniki mountains in the south of the Idrija Fault Zone. Several sinking rivers draining dolomite or flysch areas also contribute to this system (Gams 2004). Along the way toward the Ljubljana springs, the altitude of the poljes drops from about 750 m to 450 m (Fig. 1.3). The streams that flow through them have different names: Trbuhovica, Loški Obrh, Stržen, Rak, Pivka and Unica. Apart from a relatively small amount of water flowing directly from Cerklješko Polje to the springs of the Ljubljana River, most of the water comes to the surface along the southern edge of Planinsko Polje. Along its eastern and northern edges, the water sinks back underground and flows northwards to several large and many small springs aligned along the southern edge of the Ljubljana Basin, which is connected to the gradual tectonic subsidence of the area (Krivic *et al.* 1976; Gams 2004). The average annual discharge of the Ljubljana springs is 38.6 m³/s. An additional amount of water drains from the low- to medium-permeable Rovte plateau and contributes to the Ljubljana springs by sinking into the ponors of Logaško Polje (Mihevc *et al.* 2010).

There are almost 1600 known caves located in the recharge area of the Ljubljana River (Cave register 2019). Most of them are accessible fragments of a fossil underground drainage system (Habič 1973; Gospodarič 1981; Šušteršič 1999, 2002). The average cave length is 48 m and the depth 18 m. However, the largest cave systems are water-active and sum a total of about 80 km of epiphreatic channels that have been explored and documented (Fig. 1.3).

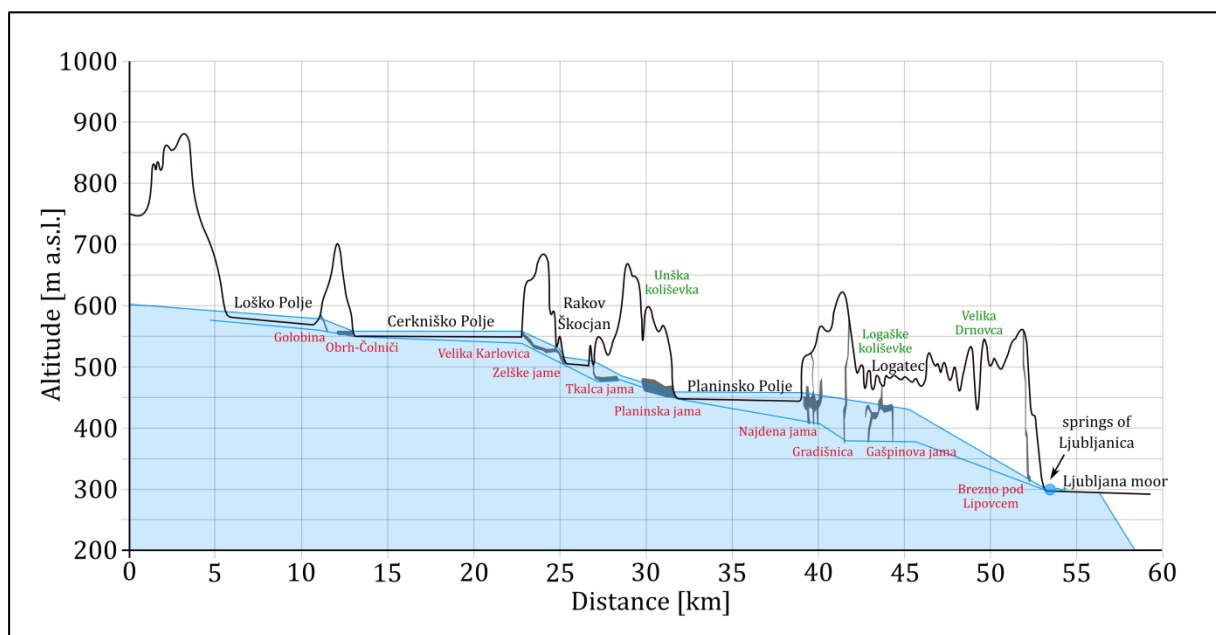


Fig.

1.3: Cross section of Ljubljana River recharge area following an initially SE-NW trend along the Idrija Fault Zone between Loško and Planinsko Polje, and turning N from Planinsko Polje toward the Ljubljana springs near Vrhnika. The major caves are indicated in red, large collapse dolines in green.

LOŠKO POLJE

Loško Polje is located on the southeast of the Notranjska region (Fig. 1.4) and is a typical example of overflow polje. The polje is bordered by the Javorniki massif on the west, the Snežnik massif and Babno Polje on the south, Cerklješko Polje on the northwest, the Loški Potok and Račna Gora massifs on the east, and by the Bloke plateau on the north (Fig. 1.4). The polje surface is about 6 km long and about 4 km large. Its floor is rather flat with altitudes comprised between 570 and 580 m, while the surrounding plateaus culminate between 800 and 1.000 m. Its flanks are surrounded by dense forests that have been used for logging since centuries. Loško Polje is a densely populated polje with more than 2,900 inhabitants living in 16 small settlements widespread on its whole surface. The villages of Stari Trg pri Ložu, Lož, Pudob, Kozarišče and Markovec are the most populated. In a geological point of view (Fig. 1.4), the polje floor is constituted of quaternary sediments while its surrounding hills are alternating between limestone and dolomitic rocks respectively of Cretaceous and Triassic ages (Krivic *et al.* 1976). The polje is aligned along the major Idrija fault zone that crosses Slovenia in a typical Dinaric southeast-northeast orientation (Vrabec 1994).

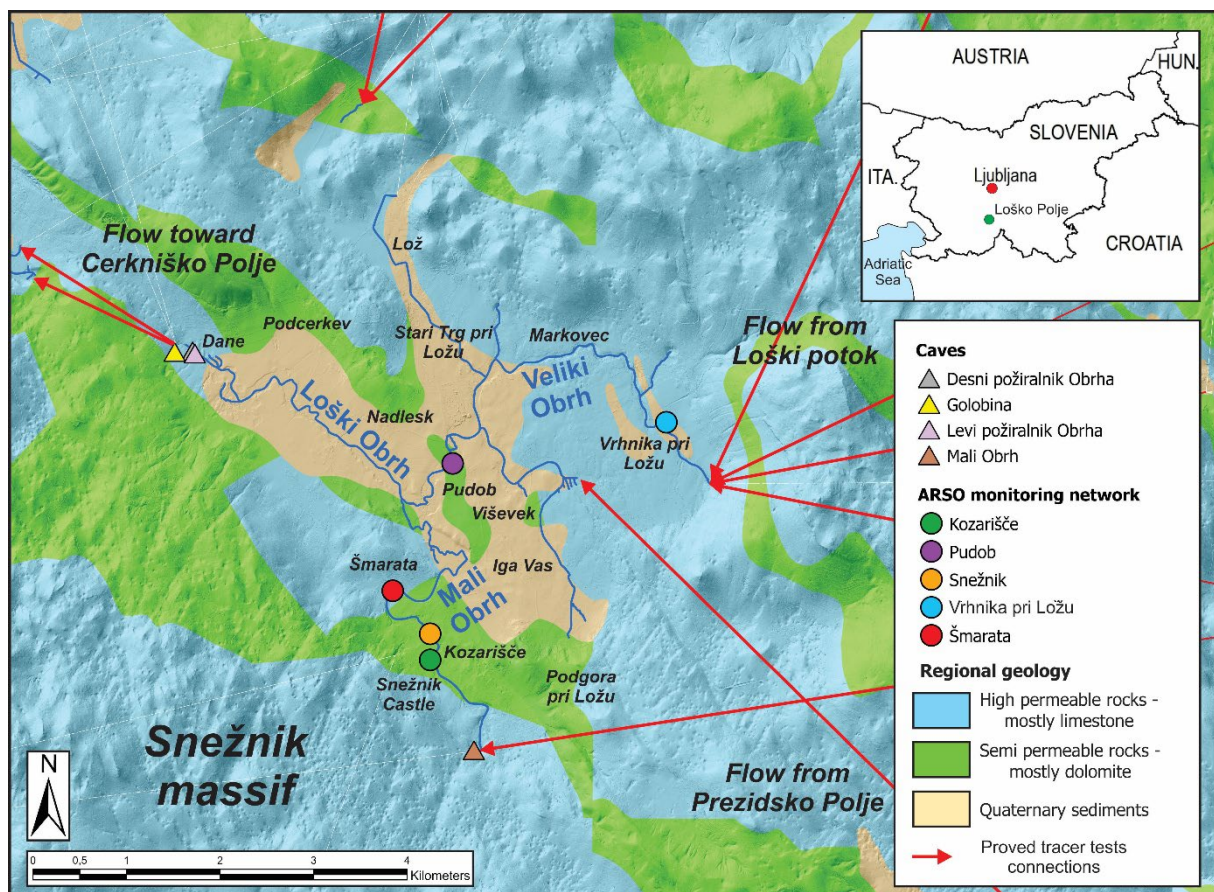


Fig. 1.4: Simplified hydrogeological map of Loško Polje. Current and past monitoring stations managed by the Slovenian Environment Agency ARSO (ARSO 2025) are indicated.

Loško Polje is recharged by several karst springs. Among them, the Veliki Obrh and Mali Obrh springs are the two most important. The Veliki Obrh spring is located on the polje eastern border upstream from the village of Vrhnik pri Ložu, and drains mostly water from the region of

Loški Potok (Šerko 1946; Gams 1965b; Fajfar 2006; Janez 2011). The Mali Obrh spring is located upstream from the village of Kozarišče (Fig. 1.5a) and the Snežnik Castle on the polje southern border. This spring receives the vast majority of its water from the Snežnik plateau but also drains water from the Loški Potok region (Šerko 1946).



Fig.

1.5: Field impressions of Loško Polje. (a) The Kozarišče Bridge near the Snežnik Castle (Photo: C. Mayaud). (b) The Mali Obrh River near its spring (Photo: C. Mayaud). (c) The Loški Obrh River sinking a few meters before the cave Levi požiralnik Obrha (Photo: C. Mayaud). (d) The artificial entrance of the Golobina Cave (Photo: C. Mayaud). (e) Excavating work at the entrance of the Golobina Cave in the 1930s (Source: <http://stareslike.cerknica.org>; picture from the personal collection of Janez Škrbec; author unknown). (f) Flood

of 1907 near the village of Pudob (Source: <http://stareslike.cerknica.org>; picture from the collection of Župnišče Stari Trg; author Dragutin Žagar).

Several other small springs are located on the polje eastern and southern sides, and drain respectively water from Prezidsko Polje located further east in Croatia and from the Snežnik massif (Gams 1965b). The Mali Obrh and Veliki Obrh springs form respectively the Mali Obrh and Veliki Obrh Rivers (Fig. 1.5b), that flow across the polje for about 5.5 km and 6.5 km before to merge as Loški Obrh River after the village of Pudob. Under normal water situation, the Loški Obrh flows for about 3.4 km toward the northwest and disappears in the caves Desni polžiralni Obrha and Levi polžiralnik Obrha that are located on its streambed (Fig. 1.4 & Fig. 1.5c). Under higher water situations and floods, these two ponors have not the capacity to swallow all the water. The Loški Obrh continues then to flow for about 190 m before to sink into the large entrance of the Golobina Cave (Fig. 1.5d). Then, the water flows in the underground cave network before to emerge at the Cemun and Obrh springs that are located at a respective airline distance of 1.6 km and 2 km on the southeastern side Cerkniško Polje (Šerko 1946; Gams 1965b).

In an attempt to improve the outflow capacity of the polje and reduce the impact of high floods, the last 350 m of the Loški Obrh River has been artificially widened and channelized in 1906 (Fig. 1.5e). At this occasion, the large artificial entrance of the Golobina Cave has been dug out at the end of the channel. As the new entrance of the Golobina Cave is about 8 meters below its natural entrance, this helped reducing the duration of the floods in the polje, improving considerably the life of its inhabitants (Fig. 1.5f).

Daily water level and discharge of the Veliki Obrh and Mali Obrh Rivers have been recorded at irregular intervals by the Slovenian Environment Agency ARSO (ARSO 2025). For discharge, the Mali Obrh River has been monitored at the stations Kozarišče (between 1961 and 1969), Šmarata (between 1973 and 1988) and Snežnik (between 1954 and 1975). The discharge of the Veliki Obrh River has been recorded for longer periods at the stations of Pudob (between 1952 and 1989) and Vrhnika pri Ložu (between 1961 and 2022). Conversely, the water level dataset is much longer but still recorded at an irregular interval for the stations of Pudob (between 1931 and 1989) and Snežnik (between 1936 and 1975). The station of Vrhnika pri Ložu registered both water level and discharge during the same time interval, while the stations of Kozarišče and Šmarata recorded the water level for a year longer (respectively between 1961-1969 and 1973-1989). Finally, the Karst Research Institute monitors the large water level fluctuations happening in the Cave Mali Obrh since Autumn 2019. The data collected gives a very valuable information about the hydrological behaviour of the Javorniki and Snežnik karst massifs under low water situation.

Because of its hydrogeological configuration with one single outflow zone, Loško Polje is subject to large floods events. The floods negatively impact the life of the polje inhabitants and the nearby villages may remain inundated for weeks. When looking at the hydrological dataset collected by the Slovenian Environment Agency ARSO (ARSO 2025), it can be seen that the Veliki Obrh River might reach a maximum discharge above 32.9 m³/s at Vrhnika pri Ložu and 39.4 m³/s at Pudob, while the maximum discharge of the Mali Obrh River is of 22.5 m³/s at the Snežnik station, of 22.6 m³/s at the Kozarišče station, and of 19.6 m³/s at the Šmarata station. This led to a maximum total inflow of about 60 m³/s entering the polje during the largest floods events. The same dataset shows that high floods occurred in the polje in 1965, 1966 and two times in 1979. For both 1979 floods, the water level surpassed the elevation of 572 m for about 12 days.

Other major flood events comprise the floods of 1851, 1907, 1933, 1934, 1939, 1949, 1954 and 2000 (Černivec *et al.* 2008). Among them, the flood of 1851 reached a record with a maximum elevation indicated by a flood water mark near the entrance door of the Snežnik Castle. More

recently, the floods of January and November 2014 were also very large and inundated the lowest parts of the villages of Pudob, Kozariče, Markovec and Šmarata for several days. Their respective maximum elevations are also shown on the outside wall of the Snežnik Castle.

For the last flood that occurred in Loško Polje in March 2025, a maximum water level of 574 m could be estimated by measuring the elevation of the flood-line marker near the artificial entrance of the Golobina Cave with the mobile application FloodWatch (Fig. 1.6a & Fig. 1.6b). The flood situation in the polje the 20.03.2025 could be seen via satellite image (Fig. 1.6c), while the maximum flood extension based on the water level measured with FloodWatch could be computed (Fig. 1.6d).

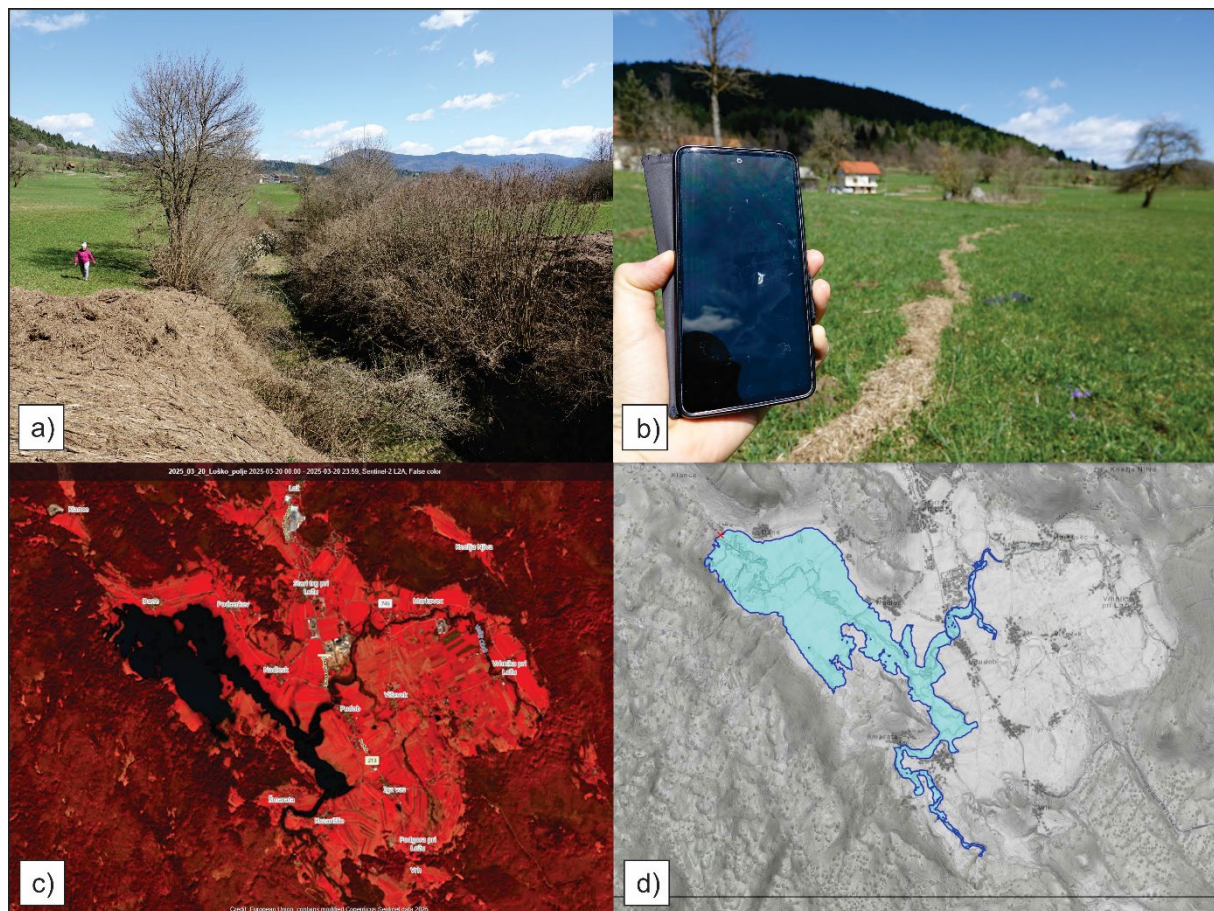


Fig.

1.6: The flood of March 2025. (a) Accumulation of flood material above the artificial entrance of the Golobina (Photo: C. Mayaud). (b) Flood line marker showing the flood maximum near the entrance of the Golobina and the hamlet of Škrilje (Photo: C. Mayaud). (c) Satellite image on false colours (bands B8, B4 and B3) taken the 20.03.2025 of the flooded situation in Loško polje (Source: Copernicus Sentinel data, 2025). (d) Flooded situation on Loško Polje for the flood of March 2025 drawn with the help of the mobile application FloodWatch (Photo: C. Mayaud).

CERKNIŠKO POLJE

Cerkniško Polje is the largest karst polje in Slovenia (Gams 1978, 2004). It is often called Cerkniško Jezero (Lake of Cerknica) because of its regular floods (Fig. 1.7a). When full, the intermittent lake covers up to 26 km² out of 38 km² of the polje's total area. The bottom of the lake is

at an average altitude of 550 m. Its intermittency has attracted many scholars since 1600 including the polihistorian Valvasor, who published his famous study of the Cerknjško Jezero in 1689 (Shaw & Čuk 2015). The main part of the polje is underlain by Upper Triassic dolomite at its N, E and SE borders. The areas to the W and NW, on the other hand, are mainly underlain by Cretaceous limestone (Fig. 1.2).



Fig. 1.7: (a) Flooded Cerknjško Jezero (Spring 2013) (Photo: C. Mayaud). (b) Ponors of Rešeta during low flow conditions (Summer 2017) (Photo: M. Blatnik).

The polje is regularly flooded for several months (Fig. 1.8), mostly in autumn, winter and spring (Kovačič & Ravbar 2010). On average, the water is above the level of 550.3 m for about 10.2 days per year, which corresponds to a flooded area of 21.84 km² (Ravbar *et al.* 2021). The main inflows into the polje come from a series of karst springs called Žerovniščica, Šteberščica and Stržen, located on its eastern and southern borders. The springs on the SW side (e.g. Suhadolca, Vranja

jama) are recharged by the Javorniki massif and add a lot of water during floods. In addition, an important allogenic component arrives from the Cerknjščica River, which drains a dolomitic area of about 44 km² in the east (Gams 2004). Finally, several estavelles (e.g., Vodonos) also contribute to the inflow into the polje.

In addition to the estavelles, several ponor zones located in the inner part of the polje drain a certain amount of water directly (Fig. 1.7b) to the springs of Ljubljana (Krivic *et al.* 1976), while the main ponors are aligned along the W side of the polje, with the caves Velika and Mala Karlovica being the most prominent. These caves extend for over 8.5 km between Cerknjško Polje and the Rakov Škocjan karst valley. So far, only a small section between Velika Karlovica and Zelške Jame (located in Rakov Škocjan) is unexplored as an important collapse zone is located there. Recent studies have shown that at low to medium water levels (Gabrovšek *et al.* 2010; Ravbar *et al.* 2012, Kogovšek 2022), a large part of the water sinking into the ponor of Mala Karlovica reaches the Kotliči springs in the middle of Rakov Škocjan and a smaller part reaches Zelške Jame, which would be the most logical direction.

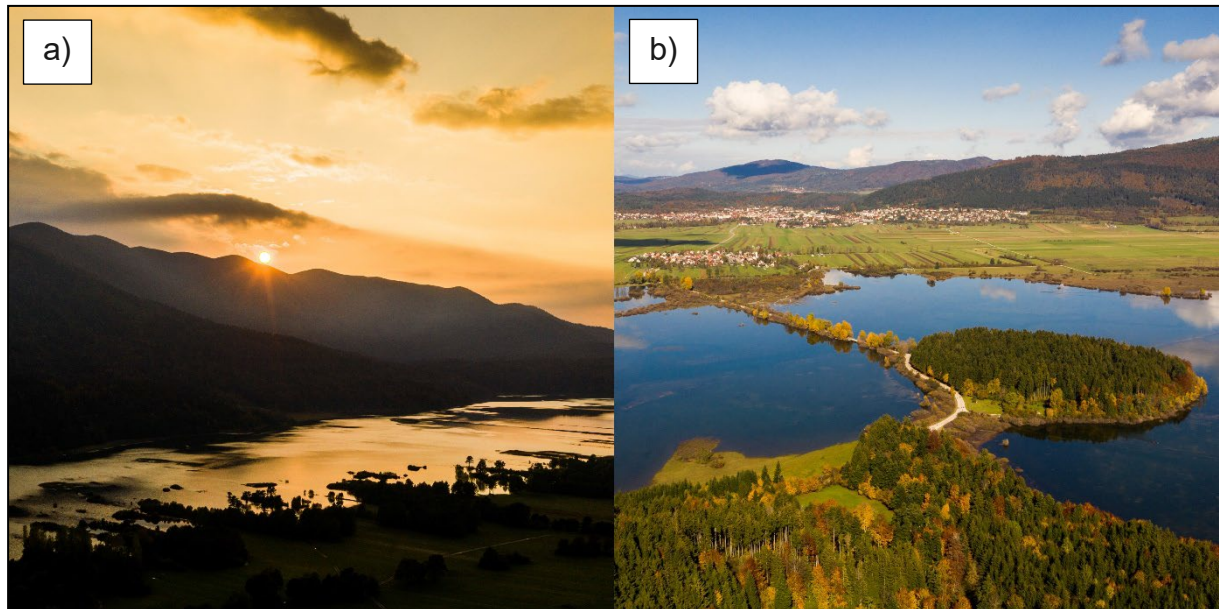


Fig. 1.8: Cerknjško Jezero. a) Lake and Javorniki Mountains at sunset. b) View toward the village of Dolenje jezero (Photos: M. Blatnik; RI-SI-EPOS).

In the last centuries, several plans were made to change the hydrological behaviour of the polje, but none was completed. In the 1960s, a plan to transform Cerknjško Jezero into a permanent lake was initiated. The entrances to the caves Velika and Mala Karlovica were closed with concrete walls and a 30 m tunnel was built to connect Karlovica to the surface. However, a minor impact on water retention during dry periods was found assessed (Shaw & Čuk 2015).

The analysis of long-term meteorological data on the Cerknjško polje and its recharge area showed that the annual amount of precipitation in the last 70 years didn't change significantly, but its distribution over the year is more uneven – there is an increase in autumns (which were already abundant with rain before), whereas other seasons of the year have less rain (Blatnik *et al.* 2024, 2025a). The general amount of snow is lower, which results in lower snow retention. Additionally, the mean annual temperature is increasing, which means that evapotranspiration is also increasing. The result is lower effective precipitation (Fig. 1.9) with more uneven seasonal distribution (Fig. 1.10),

which altogether with past human interventions modify significantly the hydrological dynamics on surface flows and lake on the Cerkniško Polje.

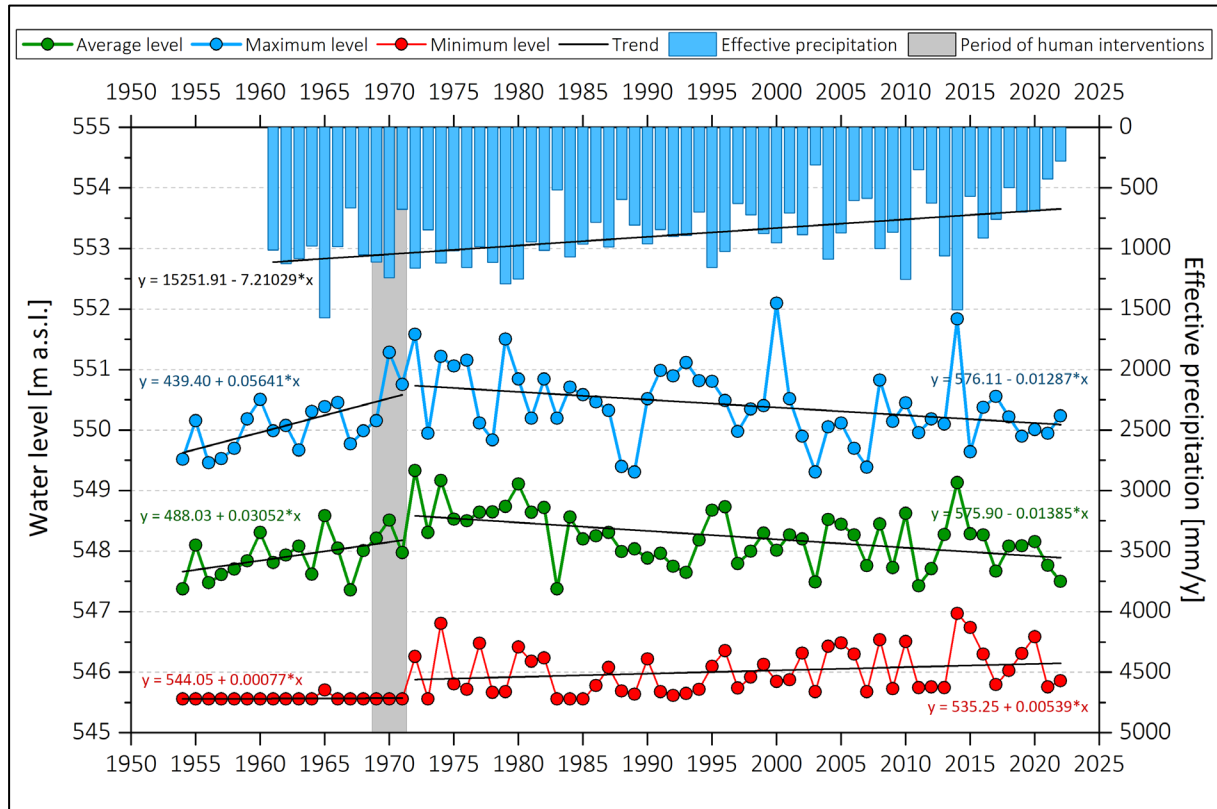


Fig.

1.9: Average, minimum and maximum water levels for individual years and calculated trends for the Dolenje Jezero hydrological station, 1954–2022. The grey belt indicates a period with the most intensive human activities for extended flooding periods.

Long term hydrological measurements on the Cerkniško polje (implemented at the hydrological station Dolenje Jezero) show that before 1970 the general water level was low (human interventions were focused to the more efficient drainage), whereas in the 1970s the water level was significantly higher due to the permanent lake generation experiment). After abandoning the experiment, some artificial barriers have been removed so the water level was gradually dropping. From 1980 on, the pattern in the water level dynamics was mostly following the meteorological dynamics (Blatnik *et al.* 2024, 2025b; Fig. 1.9). The changes in the seasonal water level dynamics is mostly represented by the increase or stagnation of the water level in autumns and winter, whereas during springs and summers significant drop in the water level is observed (Fig. 1.10). This unfortunately results in the higher frequency of hydrological extremes, which are represented in more frequent very high floods and also more frequent and longer droughts. These changes further affect the biodiversity and habitat types distribution and composition, where some changes were already noted (Blatnik *et al.* 2024, 2025b).

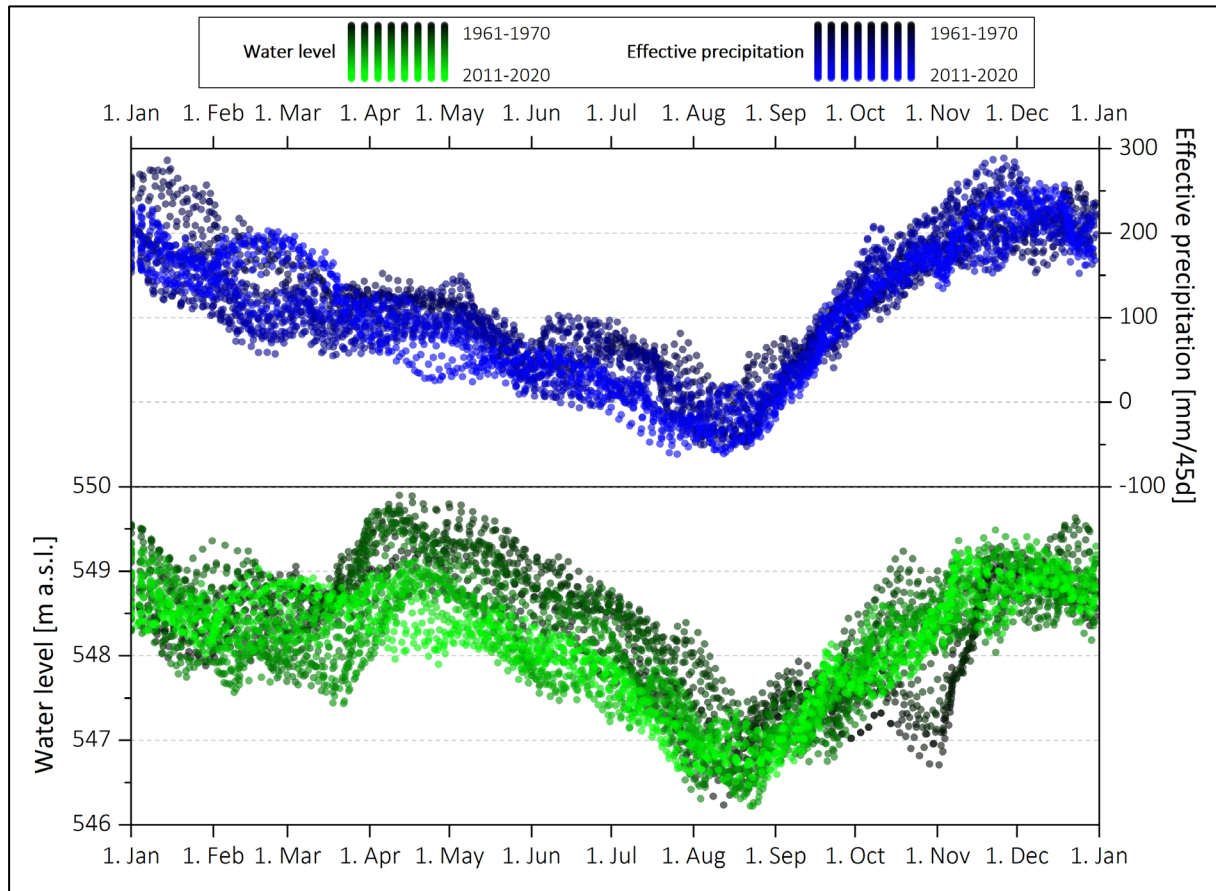


Fig.

1.10: Distribution of the effective precipitation (blue dots) and water level (green dots) over the year according to moving averages for 10-year periods between 1961 and 2022.

RAKOV ŠKOCJAN KARST VALLEY

After sinking in in the main ponors of Cerkniško Polje, the water surfaces in an about 1.5 km long and 200 m wide karst valley called Rakov Škocjan (Fig. 1.11). On the upstream side (SE) the water emerges as the Rak River from the cave Zelške Jame. Zelške Jame is about 5 km long and ends in the large collapse doline of Velika Šujca, where the water arrives from Cerkniško Polje via the Karlovica cave system. The entrance area of Zelške Jame is a fragmented system of channels and collapse dolines. The most prominent feature is Mali Naravni Most (Small Natural Bridge; Fig. 1.12a), where an impressive narrow arch, which was part of the former cave ceiling, crosses the collapse doline (Gams 2004).

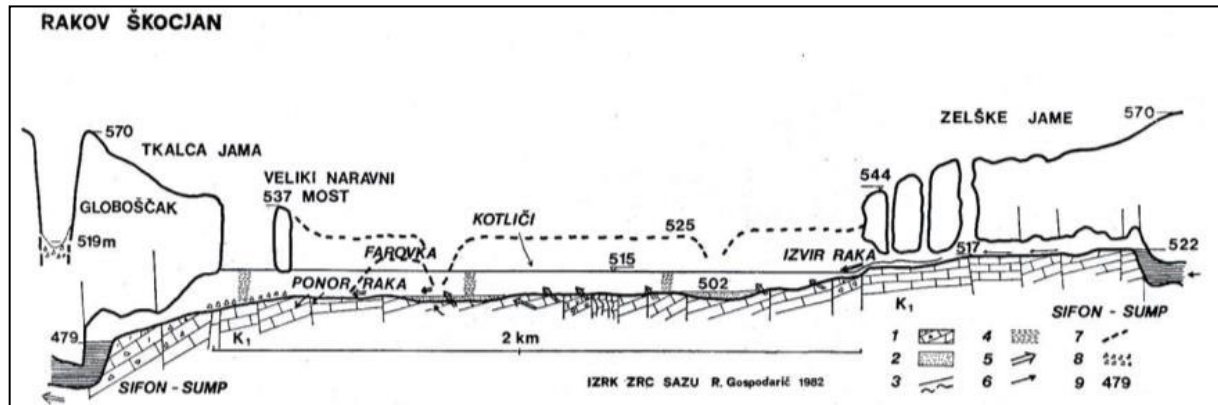


Fig. 1.11: Cross-section of the Rakov Škocjan karst valley between the Rak spring at Zelške Jame and the terminal ponor in Tkalca Jama. Legend: 1. rocky bottom; 2. alluvia; 3. fault zone; 4. flood level in 1982; 5. karst spring; 6. water flow directions; 7. terraces; 8. boulder rocks; 9. altitude.

Downstream, the valley widens and several springs (Fig. 1.12b) located along the SW side of the valley (e.g. Kotliči, Prunkovec) form perennial or intermittent tributaries of the Rak River. The valley narrows an impressive natural bridge called Veliki Naravni Most (Big Natural Bridge; Fig. 1.13b). The height of the bridge is comprised between 9.5 and 17 m, its width is between 15 and 23 m and the length is of 56 m. The rocky arch is made of thick-bedded and anticline-folded Lower Cretaceous limestone.



Fig. 1.12: Rakov Škocjan karst valley. a) The arch of Mali Naravni Most. b) Kotliči spring at the beginning of a hydrological event (Photos: M. Blatnik).

After Veliki Naravni Most, the channel opens into a 150 m long canyon that ends at the entrance to Tkalca Jama, an almost 3 km long explored cave that drains the water towards Planinsko Polje. The connections of the Rak with the water from Cerknisko Polje and with the Unica Springs at Planinsko Polje have been proven by several tracer campaigns under different hydrological conditions (Gabrovšek *et al.* 2010; Ravbar *et al.* 2012). An important flow constriction is present before the first siphon of Tkalca Jama and allows flooding to occur regularly in the Rakov Škocjan karst valley. The floods can reach a height of 19 m above the cave entrance (located at 496 m; Fig.

1.13c), and large parts of the Rakov Škocjan karst valley are frequently inundated (Drole 2015; Fig 1.13a). Before World War 1, Rakov Škocjan was a private park owned by the Windischgrätz family, while between the First and Second World Wars the Italians used it as a military site. Since 1949 Rakov Škocjan has been is a Landscape Park open to the public.



Fig. 1.13: a) Flooded Rakov Škocjan Karst Valley in October 2020, b) Veliki Naravni Most (Big Natural Bridge) during dry period in summer; and c) during high water event in winter (Photos: M. Blatnik; RI-SI-LifeWatch).

PLANINSKA JAMA

Planinska Jama (Planina Cave) is a large spring cave located on the southern edge of Planinsko Polje (Fig. 1.14a). The cave is about 6.6 km long and consists mostly of large active river passages with cross-sections often larger than 100 m² (Fig. 1.15). The cave is known to be the confluence of two important regional rivers (Fig. 1.14b & Fig. 1.15): the Pivka River, which drains a

large allogenic catchment through the Postojnska Jama (Gabrovšek *et al.* 2010; Kaufmann *et al.* 2016, Kogovšek 2022) and reaches the confluence with the cave via the Pivka Branch, and the Rak River, which carries water from Rakov Škocjan and Cerkniško Polje via the Rak Branch. Finally, a large amount of water also flows into the Rak Branch via the siphon of the Javornik Current, which is located below the Mysterious Lake (Fig. 1.15) (Kaufmann *et al.* 2020). The water exits the cave under the common name Unica River with a discharge between 0.2 and 90 m³/s (Kogovšek 2022).

The different parts of the aquifer that feed the Unica spring show considerable differences in water contribution (Savnik 1960, Kogovšek 2022). During high water conditions, there is a groundwater divide in the Javorniki Mountains. The water discharges through the western, eastern and northern edges of the massif. Then the nearby Malenščica spring, which is mainly fed by the autogenic Javorniki water and allogenic water from the Rakov Škocjan reaches a maximum discharge of 9-10 m³/s (Kogovšek 1999; Kovačič 2010, 2011). As the spring is damped, the Rak Branch is activated and acts as an overflow, while the Unica spring also receives water from the Pivka Branch. At low-flow, after the Cerkniško Jezero is drained, the outflow is solely directed towards the Malenščica spring, while the Unica spring is fed exclusively by the Pivka Branch (Kaufmann *et al.* 2020, Kogovšek 2022). The inversion of the flow direction between the Mysterious Lake and the Malenščica spring was numerically simulated with a pipe flow model (Kaufmann *et al.* 2020).

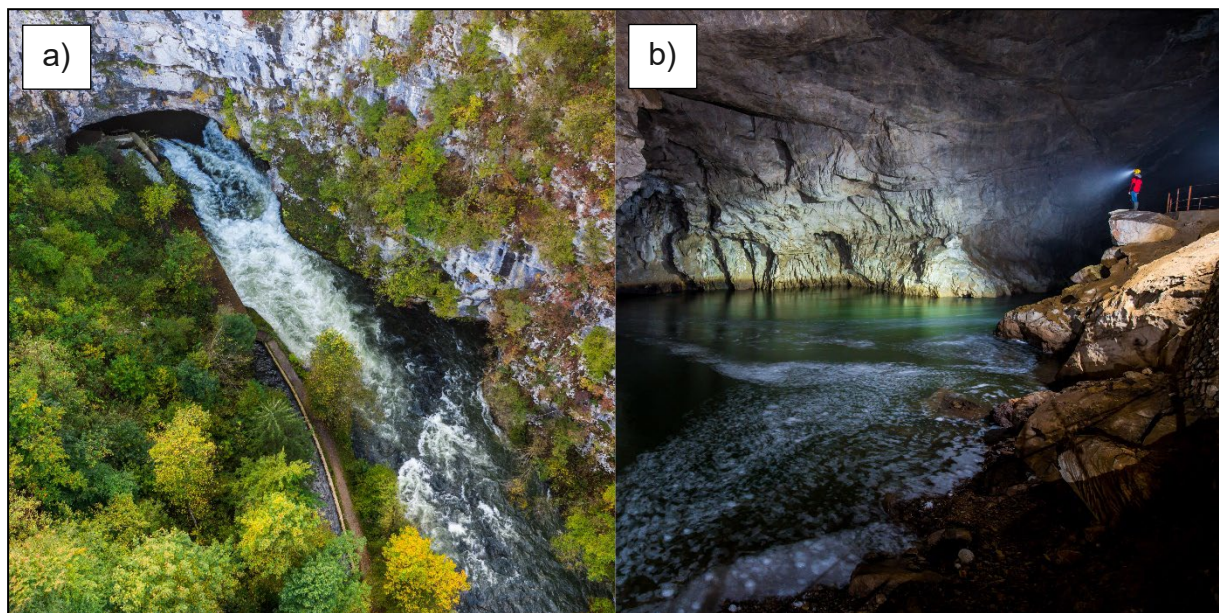


Fig. 1.14: Planinska Jama. a) Cave entrance (Photo: M. Blatnik; RI-SI-EPOS). b) Confluence of the Pivka and Rak Branches (Photo: M. Blatnik).

There are also differences in flow velocities between low and high flow conditions (Petrič *et al.* 2018). In general, the apparent dominant flow velocities in the karst aquifer are five times higher during high water (between 20 and 25 m/h) than during low water conditions (~ 4 m/h). In the well-developed conduit networks of Karlovica-Zelške Jame, Tkalca-Planinska Jama and Postojnska-Planinska Jama, flow velocities were up to fifty or even ninety times higher during high water (between 170 and 1000 m/h) compared to the velocities observed during low water (~ 4-23 m/h) (Petrič *et al.* 2018).

The research conducted in Planinska Jama over the last three years focused mainly on studying the hydrological behaviour of the Javornik Current (Gabrovšek *et al.* 2019), a partially explored siphon that connects to the Rak Branch in the so-called Mysterious Lake (Fig. 1.14b & Fig. 1.15). For this purpose, water pressure, electrical conductivity and water temperature were automatically recorded in both Mysterious Lake and the Javornik Current sump. The main objective was to find out whether the water coming out of the siphon is suitable for human consumption, to be used as a back-up reservoir for the municipalities of Postojna and Pivka (Gabrovšek *et al.* 2019).

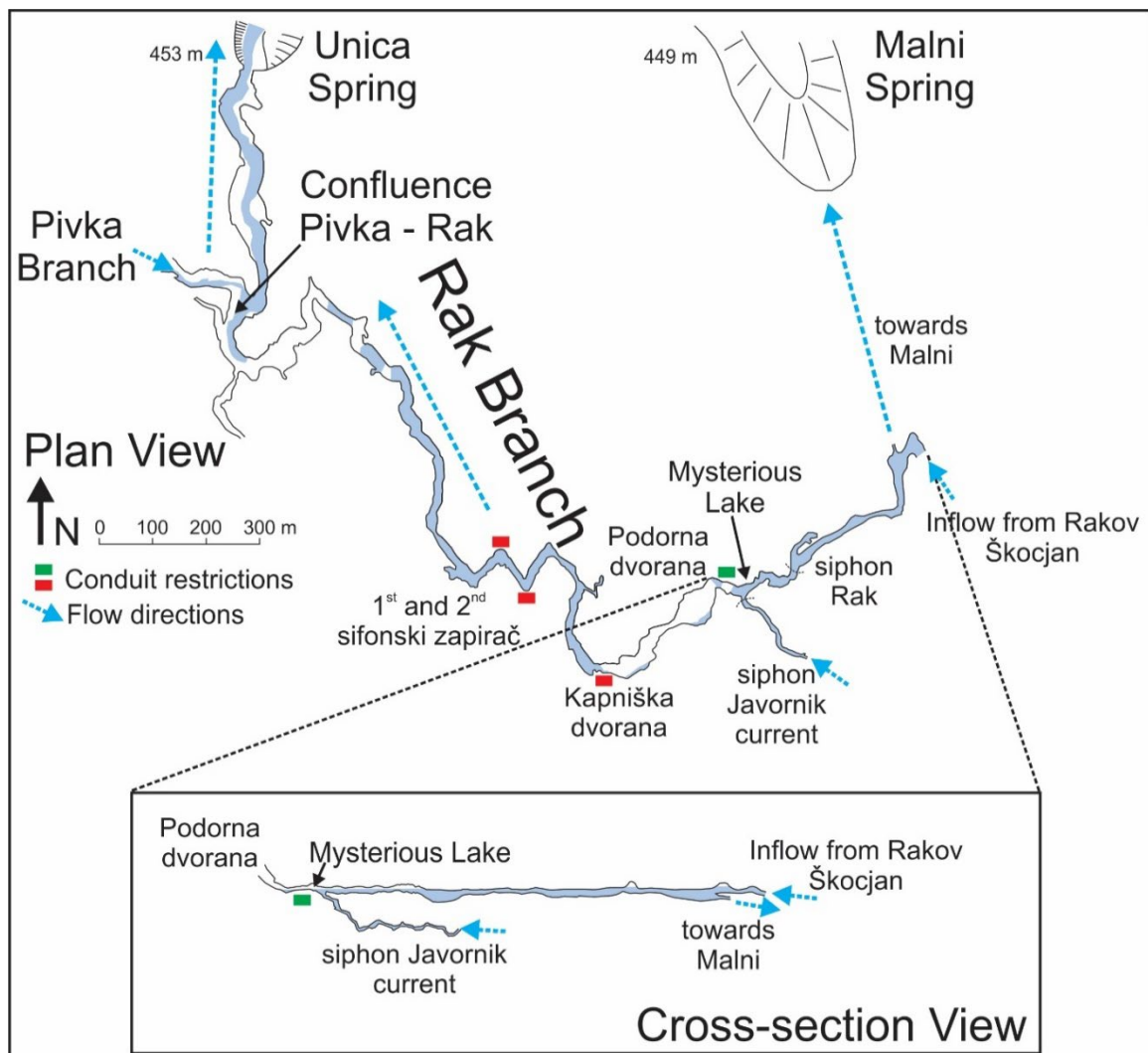


Fig. 1.15: Plan and cross-section view of the explored passages of the Rak Branch. The constrictions described in the text are indicated in red and green (Gams 2004; Kaufmann *et al.* 2020).

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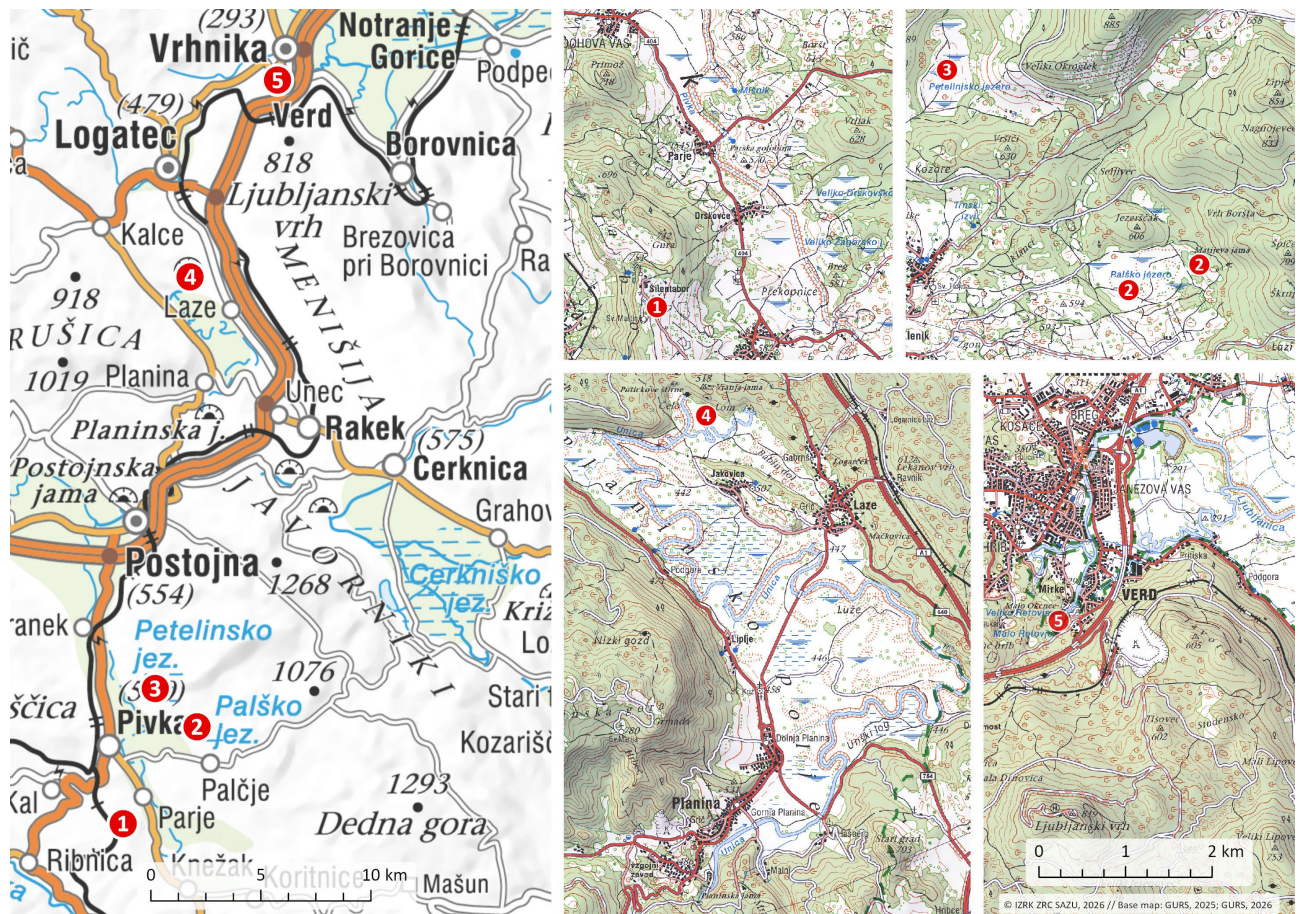
Whole-day field trip (B): HYDROGEOLOGY OF THE UPPER PIVKA VALLEY, PLANINSKO POLJE AND THE LJUBLJANICA SPRINGS

Friday, 29th May 2026, 8:30–20:00

Cyril Mayaud, Blaž Kogovšek, Astrid Švara and Franci Gabrovšek

Stops:

- 1 – Viewpoint of Šilentabor – Geology and hydrogeology of the Upper Pivka Valley
- 2 – The intermittent lake Palško jezero and the estavelle Matijeva jama
- 3 – The intermittent lake Petelinjsko jezero
- 4 – Ponors of Planinsko Polje. The polje hydrology
- 5 – The Ljubljana Springs in Vrhnika



INTRODUCTION

The Pivka Valley is a large depression laying between the high karst plateaus of the Slovene Dinaric Karst (Nanos, Hrušica, Javorniki; all ~1250 m asl), the lower plateau of Slovenski Ravnik (600 – 700 m asl) and the Snežnik Mountain (1796 m asl). The northern part of the valley, i.e., the Lower Pivka Valley consists of noncarbonate flysch rocks, where superficial drainage prevails. The

southern part, i.e., the Upper Pivka Valley is constituted of carbonate Cretaceous layers belonging to the Snežnik thrust sheet that lies over the Palaeocene and Eocene layers of the Komen thrust sheet. The displacement of the Snežnik thrust sheet over the Komen one is estimated to be of about seven kilometres. However, the intensity of the thrusting is less distinctive towards the northwest (Placer 1981).

From a hydrological point of view, the most significant unit is the Javorniki-Snežnik plateau, which is a deep diffuse karst. It is characterised by an immediate infiltration of rainwater underground and fast vertical drainage in different directions towards the springs located on the border of the plateau, where the groundwater generally flows rapidly through karst conduits. Consequently, the Javorniki-Snežnik massif drains towards both Adriatic and Black Seas (Fig. 2.1). The southeastern part of the massif drains in the direction of Croatia and the Riječina River (Biondić et al. 2004; Prestor et al. 2004), whereas the northeastern part belongs to the recharge area of the Ljubljana River (Habič 1989; Kogovšek et al. 1999; Petrič et al. 2018). In addition, the northern part of the massif also partly drains towards the Vipava springs via several swallow holes (Habič 1989; Kogovšek et al. 1999). Finally, the southwestern part of the massif belongs to the catchment of the Reka River (Habič 1989; Kogovšek 1999; Ravbar & Goldscheider 2007).

In the west of the Upper Pivka Valley, the flysch layer acts as an impermeable barrier for the groundwater that runs from the Javorniki-Snežnik massif (Figs. 2.1 & 2.2). This partly prevents its draining towards the Reka River. Therefore, the major part of the water coming from under the Snežnik Mountain rebounds against the flysch barrier and flows northwards towards the Pivka spring, and further to the Unica and Malenščica springs that recharge Planinsko Polje (Petrič & Kogovšek 2005, Petrič et al. 2018). The underground water level strongly oscillates depending from precipitation and snowmelt: at low water conditions, the hydraulic gradient is inclined solely towards Cerkniško and Planinsko poljes, whereas it is also inclined towards the Pivka Valley at high water levels (Gospodarič 1989).

HYDROGEOLOGY OF THE UPPER PIVKA VALLEY

Because of the underlying flysch rocks, a shallow karst aquifer exists below the Upper Pivka Valley (Fig. 2.2). Under low water conditions, the Upper Pivka Valley is dry and water is assumed to flow towards the Javorniki Mountains to reach the Unica and Malenščica springs. When a hydrological event occurs, the regional groundwater level can rise for more than 50 m and the Pivka River emerges (Figs. 2.3 & 2.4), reaching discharges surpassing 20-25 m³/s at the gauging station of Prestranek. Up to 17 intermittent lakes might appear due to the rise of the regional groundwater level. In addition, several temporary springs recharging the Pivka River and/or the intermittent lakes are also activated (Kovačič & Habič 2005). Finally, innumerable fissures and voids pour out water from the aquifer and contribute to flood the Valley's depressions. During recession periods, the water sinks back to the underground through the same fissures and voids, which consequently act as small estavelles and greatly contribute to empty the intermittent lakes. Additionally, numerous swallow holes are activated. Finally, the Pivka River also seeps and sinks underground at different locations in its riverbed.

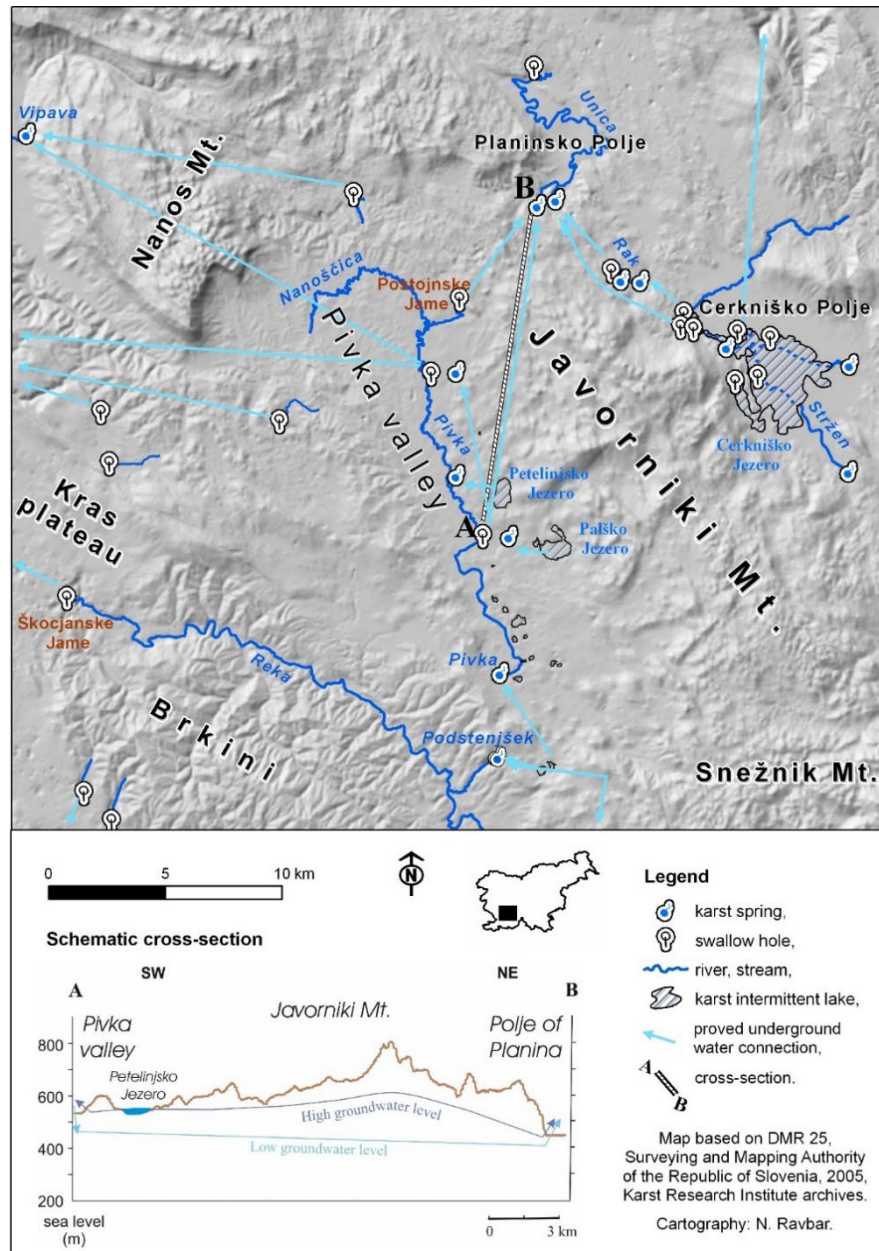


Fig. 2.1: Hydrological map of the region around the Upper Pivka Valley with the underground connections proved by tracer tests, and a schematic cross-section of the area during low- and high-water conditions (Ravbar 2013).

As the Karst Research Institute is involved in the search for a backup drinking water supply for the municipalities of Postojna and Pivka (21.000 inhabitants), hydrogeological investigations in the Upper Pivka Valley started again in Autumn 2016. The cave Matijeva jama was one of the locations selected as a potentially promising candidate due its location upward the main sources of pollution and because water is permanently standing in its large siphon. Therefore, a hydrogeological station measuring automatically the water level, specific electric conductivity (SEC) and water temperature at a 30 min interval had been installed in the siphon of Matijeva jama in October 2016. This station remained the only one installed in the Upper Pivka Valley until August 2018, when another monitoring station was mounted in the cave jama v Ždinku within the frame of a pumping

test investigating the reaction of Matijeva jama under low water levels. However, a malfunction of the data logger recording the pressure prevented retrieving the first year of water levels in jama v Ždinku. Therefore, effective water levels measurements in this cave started only after August 2019.

Since October 2019, the monitoring network operating in the Upper Pivka Valley has been considerably extended to reach currently thirteen stations monitoring water levels, conductivity and temperature at a half hour interval (Figs. 2.2 & 2.3). The first station was installed in Petelinjsko jezero, followed by the Trnje spring in June 2020. In February 2021, monitoring was extended again with the installation of two stations in Parsko jezero and at the Mišnik spring, while Malo Drškovsko jezero was monitored for the first time in May 2021. Finally, the borehole of Žeje and the Pivka spring were respectively equipped in March and September 2022. By being the northern and southernmost monitored points, these stations improved the geographical coverage of the monitoring network. These data are interpreted together with the conductivity measured in Matijeva jama and jama v Ždinku.

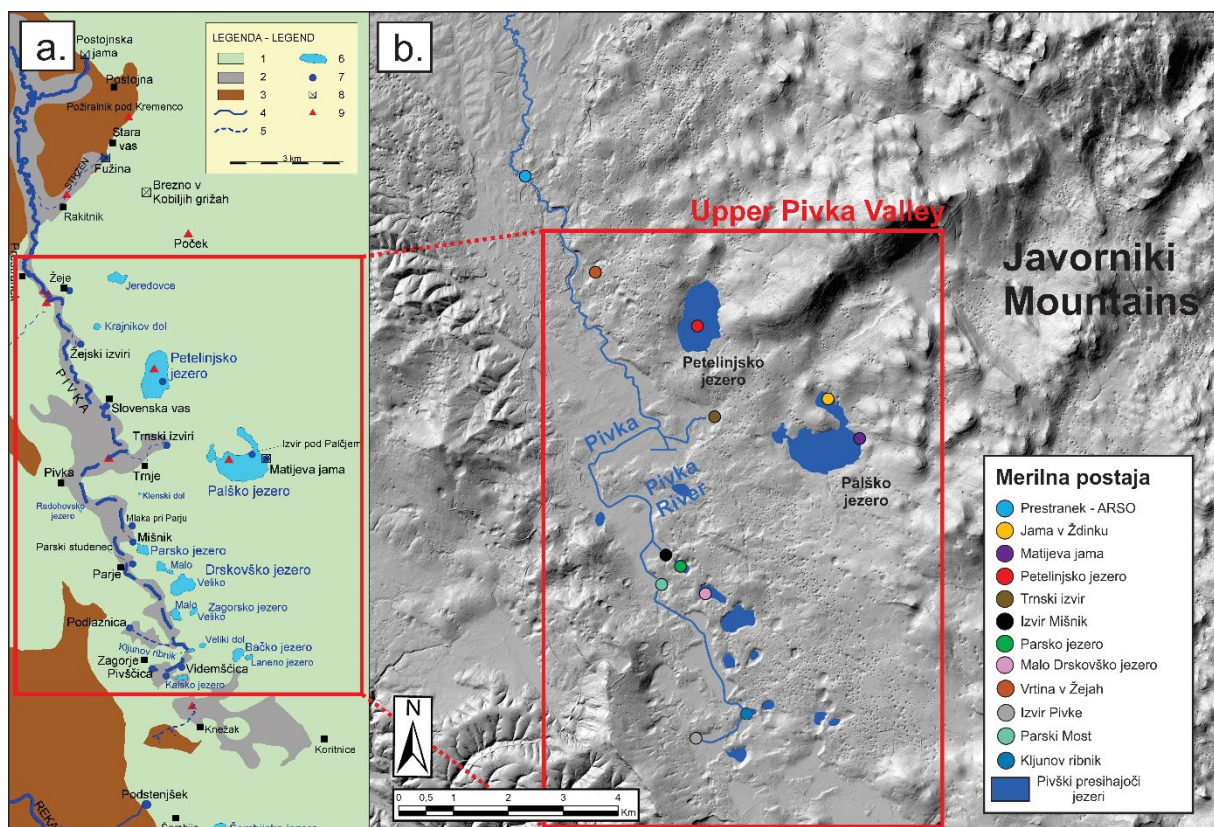


Fig. 2.2: (a) Hydrogeological map of the Pivka Valley (Petrič & Kogovšek 2005). Legend: 1. Karst aquifer, 2. Porous aquifer, 3. Very low permeable rocks, 4. Surface flow, 5. Intermittent surface flow, 6. Intermittent Lake, 7. Major spring, 8. Water cave, 9. Injection point. (b) Map presenting the monitoring network currently installed in the Upper Pivka Valley. The maximum extension of the intermittent lakes is drawn after Ravbar et al. (2021).

Because water is temporarily present at the surface of the Upper Pivka Valley, the stations Petelinjsko jezero, Trnje spring, Parsko jezero, Mišnik spring and Malo Drškovsko jezero record only the hydrogeological fluctuations occurring during high water periods (Figs. 2.3 & 2.4). Therefore, it has to be kept in mind that the hydrological signal recorded at the surface provides only a partial information compared to the data recorded by the stations located within the aquifer. Moreover, the lack of appropriate places to fix the data-loggers in the intermittent lakes implies to install the stations

only when a high-water period is forecasted. This happens mostly in a period going from autumn to late spring.

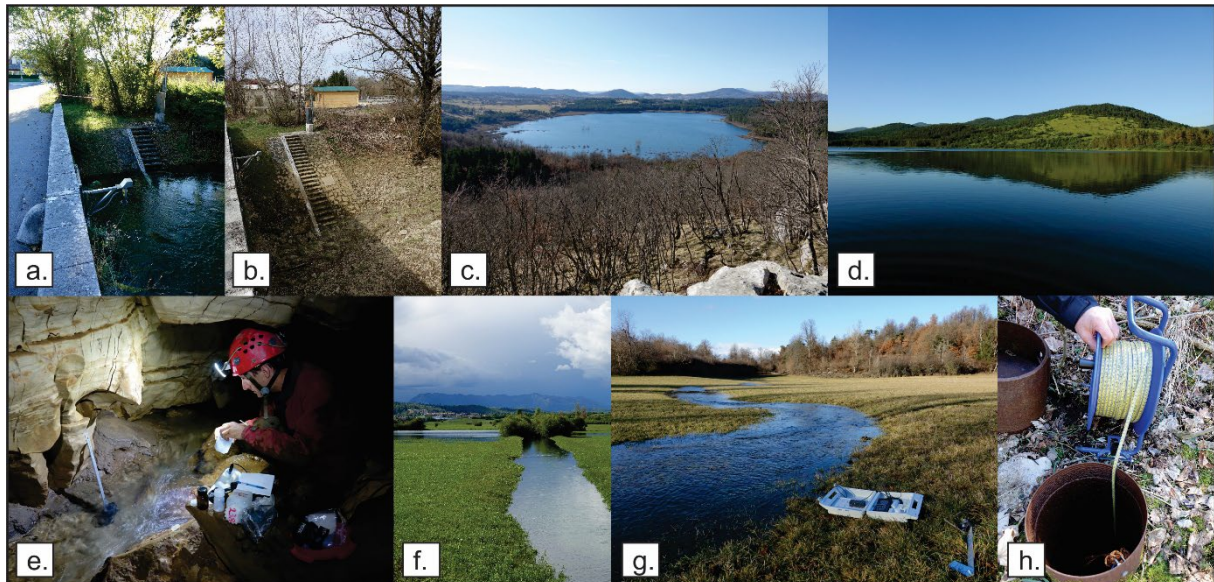


Fig. 2.3: Field impressions of the Upper Pivka Valley (Photos: C. Mayaud). (a) The Pivka River at the station of Prestranek (owned by the Slovenian Environment Agency, ARSO) during a flood. (b) The same station at low water conditions. (c) Flooded Palško jezero. (d) Flooded Petelinjsko jezero. (e) Water sampling in jama v Ždinku. (f) The Mišnik spring during a flood. (g) Parsko jezero at the beginning of a flood. (h) The borehole of Žeje.

Fig. 2.4 shows the water levels recorded in the Upper Pivka Valley for the period going from February to June 2022. On the one hand, the three stations located in the aquifer present important water level fluctuations, which can reach more than 50 m during the strongest floods (Kovačič & Habič, 2005). The similar reaction of these stations proves that the rise of water level is occurring homogeneously at a regional scale. On the other hand, the stations installed in the intermittent lakes and temporary springs activate simultaneously with the rise of water level in the aquifer. However, their behavior during the recession is different, as they last longer at higher level than the stations located in the aquifer. Such difference can be of about two weeks for Petelinjsko jezero and surpass 10 days for the Mišnik spring. The main explanation is that the decrease of the hydraulic gradient reverses the main flow direction underground toward the Javorniki mountains and the Malenščica spring, even if an effect of the alluvial sediments presents on the valley floor on the recession should be acknowledged. These data are expected to provide meaningful information on the water level fluctuations in the aquifer upper parts.

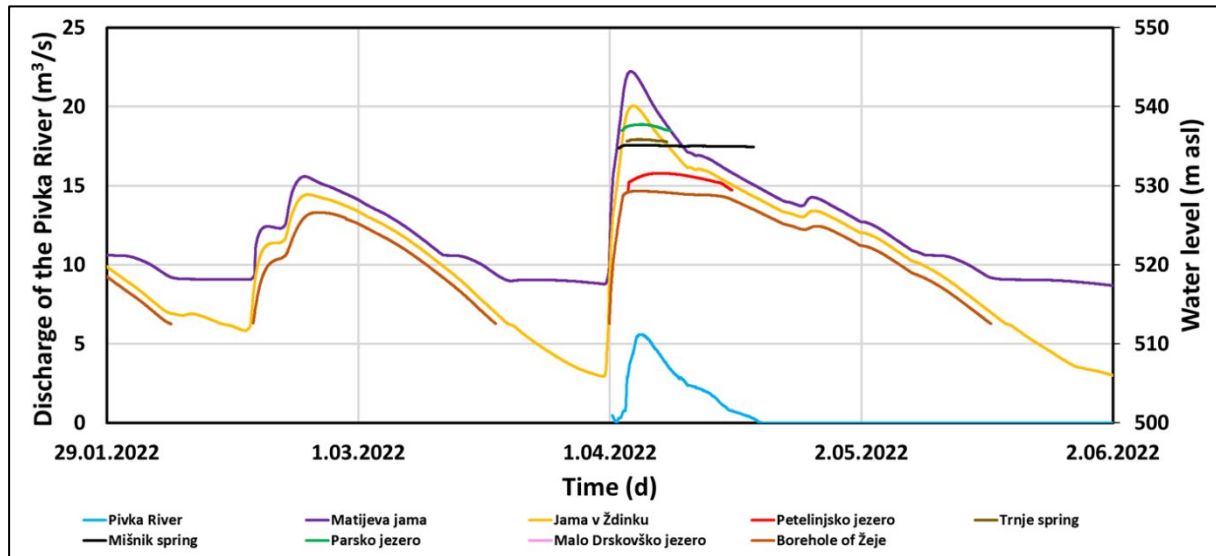


Fig. 2.4: Water level dynamics recorded in the Upper Pivka Valley during the period going from February to June 2022.

THE INTERMITTENT LAKES OF THE UPPER PIVKA VALLEY

The intermittent lakes of the Upper Pivka Valley appear simultaneously with the rise of the regional groundwater level (Figs. 2.2 & Fig. 2.4). The two largest of them are Palško jezero and Petelinjsko jezero, which can respectively cover a maximum flooded surface of about $\sim 1.9 \text{ km}^2$ and $\sim 0.7 \text{ km}^2$ (Kovačič & Habič, 2005). In addition, numerous smaller lakes extend over a few hectares (Ravbar & Šebela 2004). The flood duration and frequency are specific for each lake, mostly depending on the yearly amount of precipitation, on the elevation of the lake bottom and of its location in the valley. Some of the lakes may appear several times per year, while others occur only during exceptionally wet periods, maybe a few times in a decade (Kovačič & Habič 2005; Kirn 2016; Ravbar et al. 2021). Among others, Petelinjsko jezero is the lake with the longest flooding duration, which can last for more than 200 days per year. The flooding duration of the four intermittent lakes monitored is presented in Tab. 2.1 for the hydrological years 2021-2022 and 2022-2023. As it can be seen, the important difference in total precipitation (855 mm registered in 2021 – 2022 opposed to the 1755 mm registered in 2022 – 2023) strongly correlate with the number of days flooded. Therefore, the flooding duration is up to four times longer for Petelinjsko jezero and Parsko jezero in 2022-2023. Similarly, while Malo Drskovško jezero remained dry in 2021-2022, it was flooded for one and half month in 2022-2023. Such difference in flooding duration shows the extreme importance of the precipitation regime on the appearance of the lakes, which might greatly affect this water-sensitive ecosystem (Ravbar & Pipan 2022). Indeed, many animal and vegetal species rely on the appearance of water to survive.

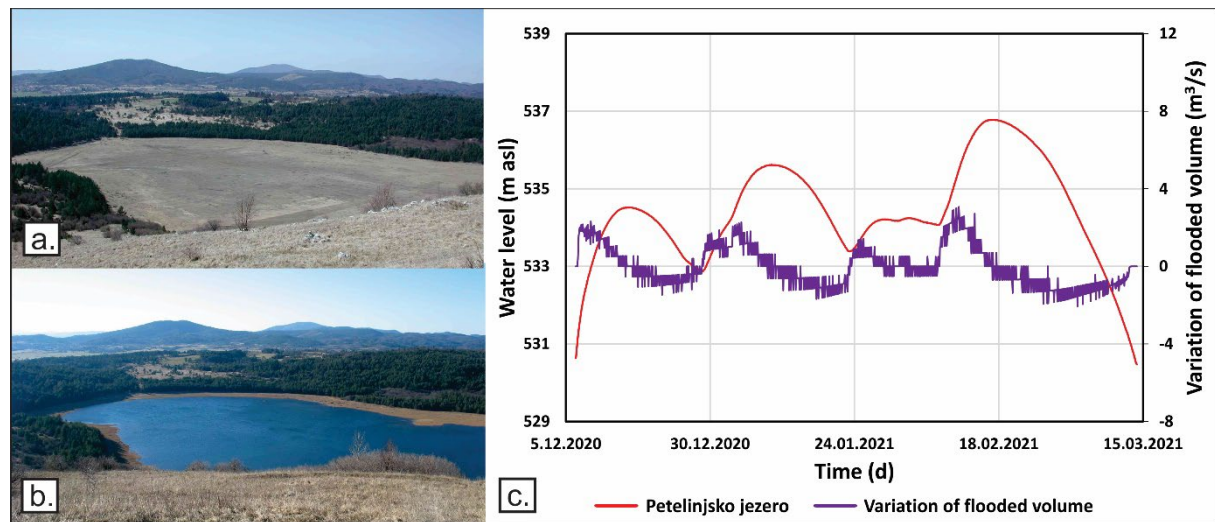
Hydrological year	01.09.2021 – 31.08.2022	01.09.2022 – 31.08.2023
Total precipitation (mm)	855	1755.8
Lake name	Number of days flooded	
Petelinjsko jezero	46	185
Palško jezero	1	47

Parsko jezero	20	106
Malo Drskovško jezero	0	47

Tab. 2.1: Total yearly precipitation measured at the Postojna rain gauge and flooding duration of the lakes Petelinjsko jezero, Palško jezero, Parsko jezero and Malo Drskovško jezero during the hydrological years 2021-2022 and 2022-2023.

Many intermittent lakes represent a unique and precious type of karst groundwater dependent ecosystem. However, the floods represent a risk to human health, the environment and economic activity. For this reason, international treaties such as the Ramsar Convention on Wetlands, and regional legislative framework; such as the EU Water Framework Directive and the EU Floods Directive; envisage their management through the preparation of maps of inundation areas. Slovenia has a basis for this in the Water Act. The procedure for determination of intermittently flooded karst areas, which takes into account the extent, duration and frequency of flooding, includes the identification of data sources and processing methods proposed in Ravbar et al. 2021. Accordingly, a map of the flooded areas in the Upper Pivka Valley has been published in this work (Fig. 2.2).

Finally, the water balance of Petelinjsko jezero, Parsko jezero and Malo Drskovško jezero was computed for each recorded flood event (Fig. 2.5) using the technique presented in Mayaud et al. (2022). During the recorded period, the maximum inflow entering Petelinjsko jezero was of about $3.75 \text{ m}^3/\text{s}$, while its maximum outflow was of $-2.65 \text{ m}^3/\text{s}$. For Parsko and Malo Drskovško jezero, these numbers were respectively smaller. The water balance of Palško jezero will be done in the future, as the rating curve of Matijeva jama has to be established at first.



2.5: The intermittent lake Petelinjsko jezero (for location see Figs. 2.1 & 2.2). (a) At low groundwater level, the karst hollow is dry. (b) When the groundwater level rises, the depression is flooded and forms a lake (Photos: N. Ravbar). (c) Water level and water balance of the lake for the flood going from December 2020 to March 2021.

MATIJEVA JAMA

Matijeva jama is a large estavelle located on the eastern side of Palško jezero that provides an important part of the lake inflow and outflow (Figs. 2.2 & 2.6). The cave entrance is a $2 \times 2 \text{ m}$ large opening, which continues with an approximately 20 m deep shaft. It is followed by a narrow passage

that steps down to a larger hall (10x10x10 m) and ends with a siphon. At low water conditions, the water level is located at about 516 m asl. The water level fluctuations at this location might exceed almost 50 m and the cave is able to discharge or swallow several m³/s of water depending on the hydrological situation (Kovačič & Habič 2005).

Between summer 2017 and summer 2022, four diving actions have been carried out in Matijeva jama (Fig. 2.6). The exploration showed that the cave has an about 100 m long first siphon that is followed by a larger room splitting into two branches. The northern branch terminates immediately with another siphon that is too narrow to be explored, whereas the southern branch ends with a shaft whose bottom goes below the level of the siphon. A team of three cave divers aimed to explore it in summer 2022, but had the surprise to find it without water due to extremely dry conditions. They were able to walk further in the horizontal passage for about 100 m, and were stopped by another 20 m deep shaft that had water at its bottom. Without this dive, the length of the newly explored part of the cave is of about 150 m, which makes the total length of the cave reaching 200 m (Fig. 2.6). Important perspectives for further exploration remain.

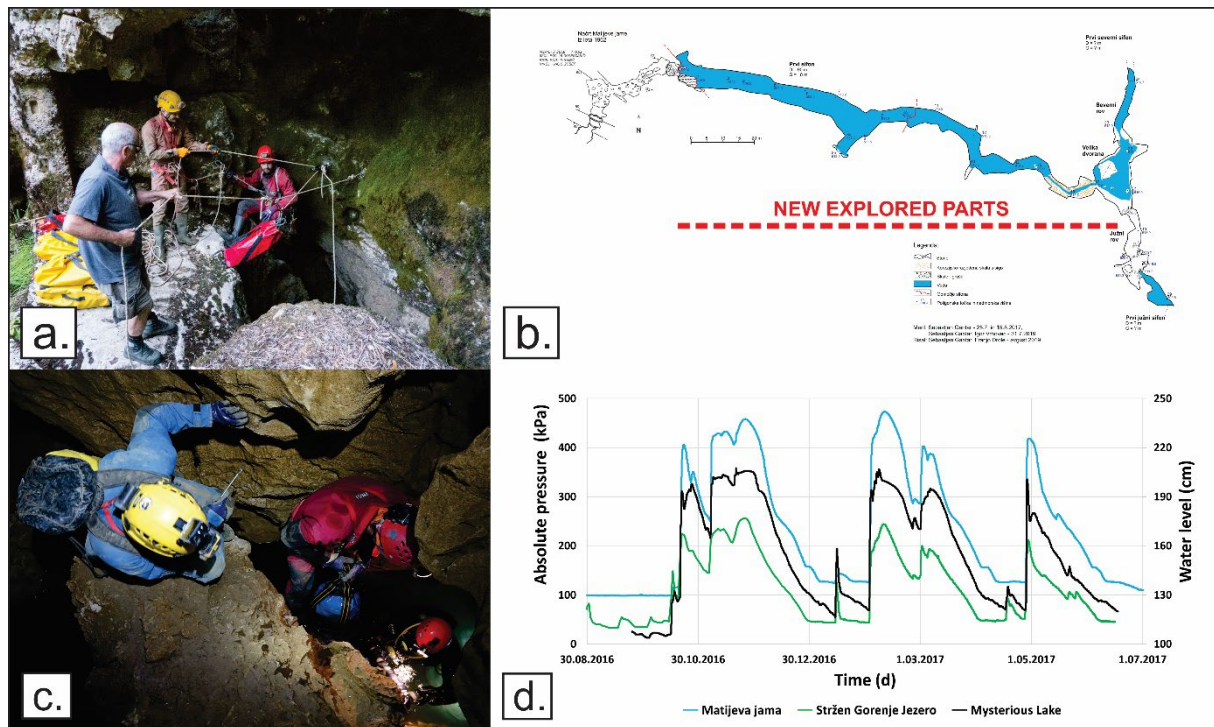


Fig.

2.6: (a) Entrance of Matijeva jama (Photo: B. Kogovšek). (b) Map of Matijeva jama showing the new parts of the cave that were explored during the dives of August 2017 and July 2019 (Cave Register 2023). (c) Diving action in July 2019 (Photo: C. Mayaud). (d) Water pressure registered in Matijeva jama compared to other monitoring stations located in Cerkniško polje and Planinska jama.

Up to eighteen high water periods where Palško jezero was partly or entirely flooded have been registered since August 2016. In general, the flooding begins with a steep rise of the water level in the siphon and responds fast to rain event (Fig. 2.6d). A comparison with other groundwater monitoring stations located on the eastern side of the Javorniki massif (Gorenje Jezero) as well as in Planinska jama (Mysterious Lake) about 15 km northward, shows that all monitoring points react almost simultaneously, proving that they all belong to the same hydrogeological unit. Palško jezero starts to be flooded when the water level reaches the entrance of Matijeva jama at an elevation of

545 m asl. The flood in the lake can last from a few days to two months, reaching an altitude of 20 m above the cave entrance, as for the floods of December 2000 and February 2014 (Kovačič & Habič 2005; Kirn 2016).

PUMPING TEST IN THE FIRST SIPHON OF MATIJEVA JAMA

A pumping test was performed in Matijeva jama in August 2018 to determine if the siphon represents a perched water body and would be thus less convenient for water exploitation (Gabrovšek *et al.* 2019). Additional purposes were to determine the aquifer permeability as well as the size of the siphon and the rate of filling of the underground channels of Matijeva jama. In order to check if the pumped water would eventually flow back to the cave, and because we were interested in the hydraulic connection of the bottom of Palško jezero with Matijeva jama, a multi-tracer test was simultaneously carried out (Fig. 2.7).

The combined pumping and tracer test showed an immediate flow from the depleted water back into to cave, with a maximum recharge flowrate of almost 9 L/s arriving in the siphon. This proves that the bottom of Palško jezero, where agricultural activity predominates, is very well permeable and has a direct connection to the cave. As soon as the release location of the pumped water was prolonged farther away from the cave entrance (Fig. 2.7c), the recharge flowrate decreased to 0.6 L/s and the drawdown increased again.

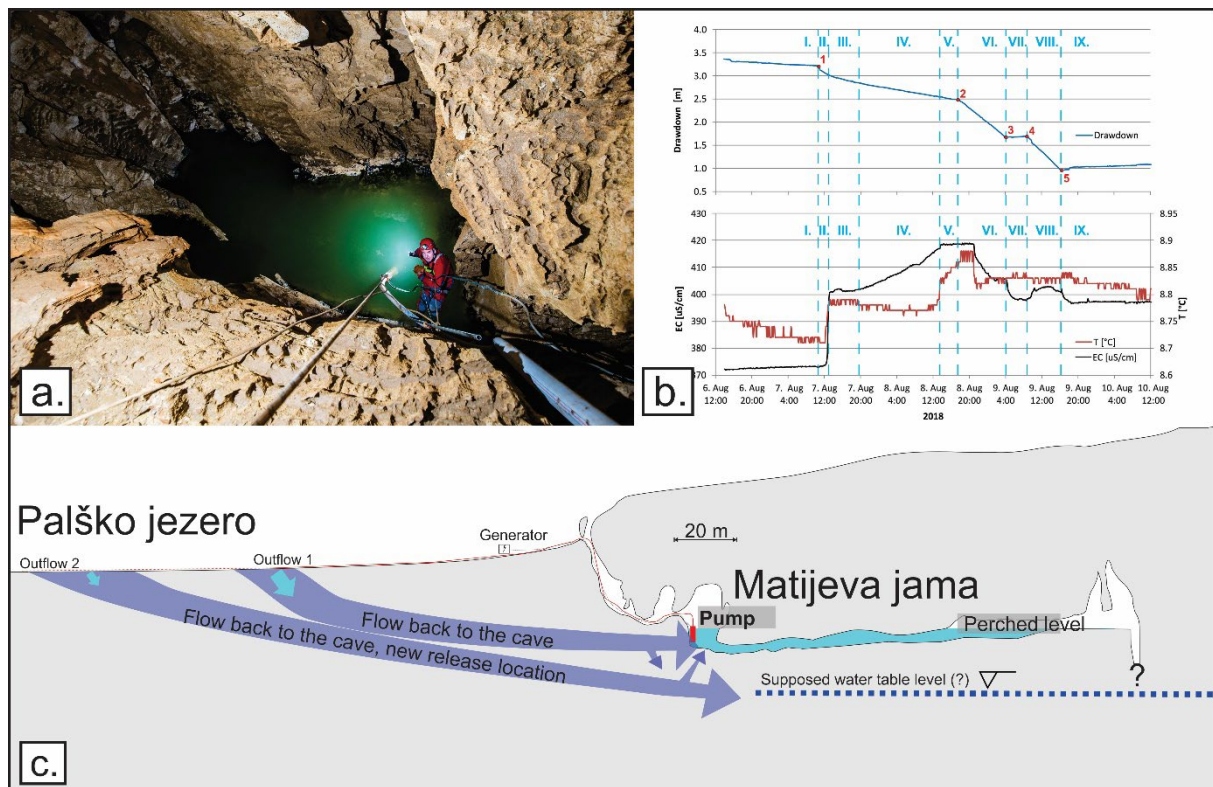


Fig. 2.7: Pumping test in Matijeva jama. (a) View of the siphon. (b) Drawdown and physico-chemical parameters monitored during the different pumping phases. (c) Cross-section of the conceptual hydrogeological model between Palško jezero and Matijeva jama during the pumping test.

The results of the pumping test showed that despite Matijeva jama belongs to the regional water body at high water level, the first siphon of the cave belongs to an isolated perched aquifer under low water conditions (Fig. 2.7). In addition, the proven connection of the siphon with the lake surface makes it vulnerable to any pollution that would occur in the lake vicinity. Therefore, the known water bodies of Matijeva jama are not suitable for exploitation.

MONITORING THE CAVE JAMA V ŽDINKU

Jama v Ždinku is located in a clearing approximately 900 m NW from Matijeva jama. The cave was explored during the pumping test implemented in Matijeva jama in August 2018, where all caves nearby were investigated to check for the presence of water. After discovering its hydrogeological importance, jama v Ždinku was immediately mapped and equipped with a data-logger measuring pressure, SEC and water temperature at a half-hour interval. The cave has a total length of 356 m and a depth of 43 m. The cave begins with a 10 m squeeze followed by a 20 m shaft. Then, a succession of narrow passages interrupted by several small chambers conduct to a 15 m long channel that ends into a collapse at the elevation of 503 m asl. A small stream remains active in this part of the cave during low water periods. Similarly, to Matijeva jama, jama v Ždinku acts as an estavelle. The water level dynamics in both caves is comparable, with an amplitude that might reach 50 m (Fig. 2.4). However, slight differences mostly due to the hydrogeological configuration of both caves exist at low and high-water levels.

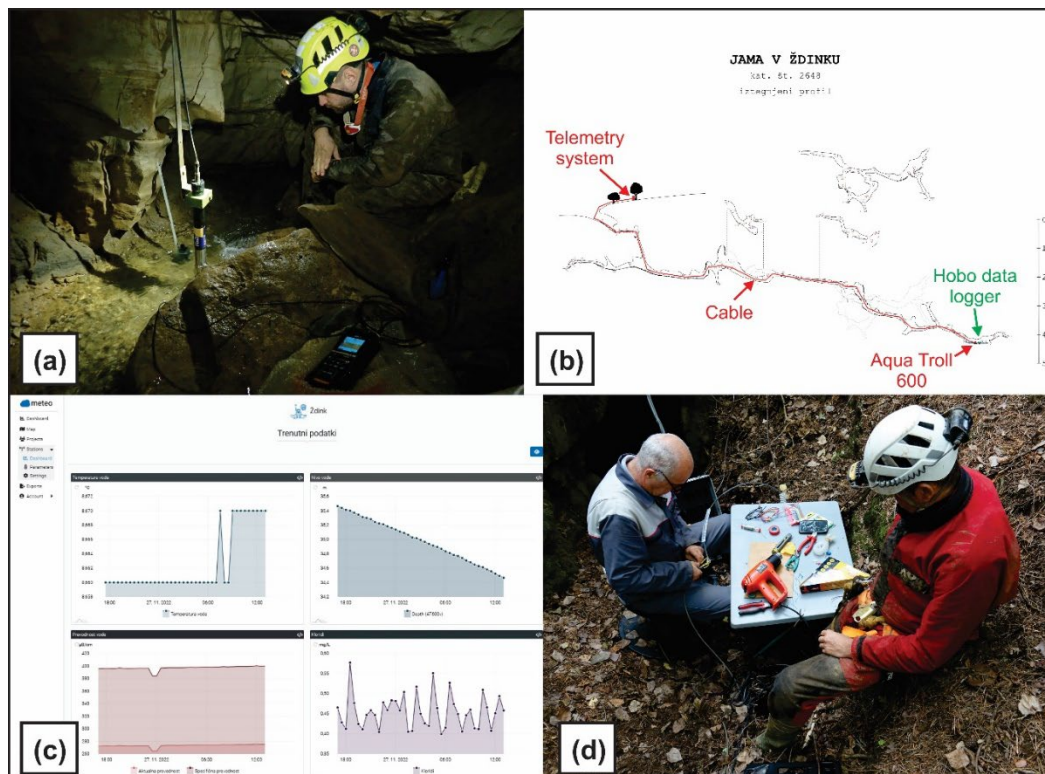


Fig. 2.8: (a) Aqua TROLL 600 multi-parameter probe installed in the active cave stream running at the bottom of jama v Ždinku. (b) Cave profile with location of the instrument and cable up to the surface. (c) Visualization of the recorded data. (d) Maintenance work after the cable connecting the probe to the surface was cut by a wild animal.

Since August 2021, a multiparameter sonde Aqua TROLL 600 has been installed in the active cave stream flowing in the lower parts of jama v Ždinku (Fig. 2.8a). The instrument is fixed at the same height than the data-loggers measuring since August 2018. Up to 9 parameters (namely water level, temperature, specific electric conductivity, turbidity, salinity, water density, TDS, chloride concentration and rhodamine WT concentration) are continuously measured at a half hourly interval.

The probe transmits the recorded data to a VuLink telemetry system located above the cave entrance via a 200 m long cable (Fig. 2.8b). Then, the data are sent at a four-hour interval to an online database, and can be accessed by a computer or a smartphone (Fig. 2.8c). The installation of the Aqua TROLL 600 allowed knowing the hydrogeological conditions in the aquifer in an almost-live situation. This is considerably helpful to know when a flood is going to occurs, as it provides crucial information to manage the monitoring network in the Upper Pivka Valley. However, the device is more sensitive than classical data-loggers, especially due to the cable transmitting the data to the surface. The latter was cut by a wild animal in August 2022 and needed some precautions maintenance to work again (Fig. 2.8d).

Period	Summer 2019	Summer 2020	Summer 2021	Summer 2022
Number of days when the water level was below 504.15 m asl	35>20.1	8.0	103.2	94.0

Tab. 2.2: Number of days where the water level in jama v Ždinku passed below the elevation of 504.15 m asl.

Because an active cave stream is still running in the lowest part of jama v Ždinku under low water conditions, this cave was viewed as a good candidate for being the back-up drinking water supply. Therefore, the hydrogeological investigations were completed by an assessment of the water quality and quantity. Discharge measurements of the stream implemented during each visit in the cave ranged between 60.5 L/s and 6.6 L/s. This variability shows the necessity to continue further the hydrogeological analyses to better understand the behavior of the cave and evaluate the sustainability of its groundwater reserves.

Such observation is supported by an analysis of the recorded low water levels (Tab. 2.2). During the summer 2021, the lowest level was of 2.8 cm above the sensor. As the smallest recorded discharge corresponds to a level of 10.8 cm, it can be concluded that the discharge of the cave stream should have been significantly smaller than 6.6 L/s at that time. However, it is surprising to note that the stream remained active after 100 days under extremely low levels. Conversely, the access to the stream at the bottom of jama v Ždinku can become questionable when the hydrological year has a total amount of precipitation significantly higher. This happened in summer 2020 where the water level was only 8 days below 504.15 m asl (Tab. 2.2). Such hydrogeological situation gives only a short interval to access the data logger and retrieve the data.

PLANINSKO POLJE

Planinsko Polje is a typical example of overflow structural polje (Gams 1978; Šušteršič 1996). The polje largest springs are located on its southern side and recharge the Unica River that sinks in two major outflow zones located along the polje eastern and northern borders (Savnik 1960) (Fig. 2.9). The polje surface is slightly undulating and about 10 km² large, with a bottom elevation mostly comprised between 444.5 m and 450 m (Blatnik *et al.* 2017). Apart from the wetlands close to the Unica, the polje is used for field crops and grass. Three settlements are located on the elevated slopes around Planinsko Polje, which is surrounded by forested karst plains at elevations between 520 m and 600 m. and by mountains reaching up to 1.000 m after.

Planinsko Polje has formed along the Idrija Fault Zone. Its southern and western borders mostly consist of Upper Triassic Main Dolomite, while its two main springs are located within a band of cretaceous limestone in the south. The average thickness of the alluvium cover is about 4 m (Breznik 1961; Ravnik 1976). The polje bedrock base is dominantly Upper Triassic Main Dolomite, whereas its eastern and northern sides include most of the ponors and are composed of highly karstified Cretaceous limestone (Čar 1982).

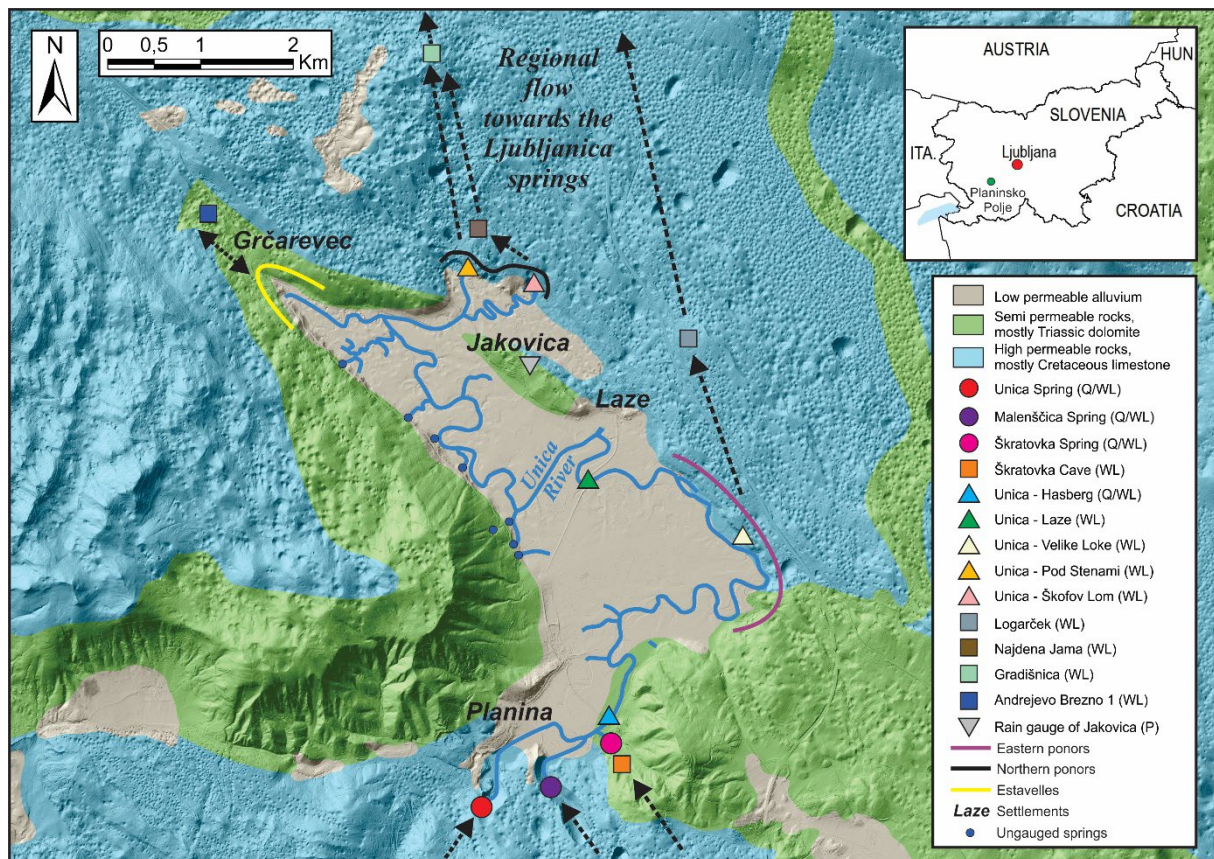


Fig. 2.9: Hydrogeological map of Planinsko Polje and the monitoring network that has been installed in its surrounding area. The upper right insert shows the regional position of the area in Slovenia.

Besides Planinska Jama, the most important recharge input is the Malenščica spring ($Q_{\min} = 1.1 \text{ m}^3/\text{s}$, $Q_{\text{mean}} = 6.7 \text{ m}^3/\text{s}$, $Q_{\max} = 9.9 \text{ m}^3/\text{s}$; Frantar 2008), which receives water from Rakov Škocjan and the Javorniki mountains. The Malenščica spring is used as a water supply for more than 21,000 inhabitants (Petrič 2010). The Unica River flows rather uninterrupted over the polje's surface for the first 7 km (Fig. 2.10a). Along its course in proximity to the eastern border, it loses water along a 2

km long reach due to the presence of several groups of ponors and zones of intense leakage (Fig. 2.10b). The water sinks into well-expressed ponors, along lines of diffuse discharge into fractures and small dissolutional openings, as well as into small blind valleys entrenched into the sediment (Fig. 2.11). A study carried out by Blatnik *et al.* (2017) revealed new details on the location and capacity of the eastern ponor zone, with a total outflow capacity of about 18 m³/s and individual outflow ranging between 1.0 and 5.6 m³/s at each group of ponors. After 2 km of flow along the eastern border, the river crosses the polje and follows the western border. Then the Unica turns northeast towards the second ponor zone that are distributed along the polje northern border. The capacity of the northern group of ponors was estimated between 40 and 60 m³/s (Šušteršič 2002).

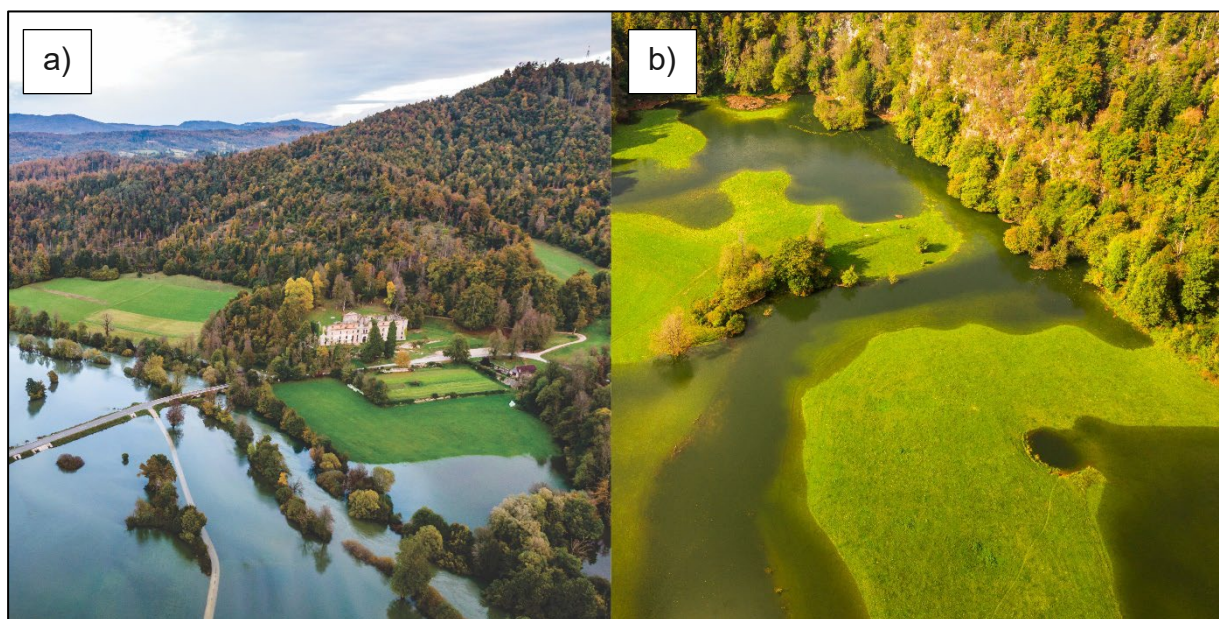


Fig. 2.10: Flooded Planinsko Polje. (a) Hasberg Bridge and castle. (b) Northern ponors (Photos: M. Blatnik; RI-SI-LifeWatch).

Similarly to Cerkniško Polje, Planinsko Polje can be flooded up to several times per year (Kovačič & Ravbar 2010). The period with the greatest probability that an extreme flood occurs is the coldest part of the year, tied to the mid-autumn rainfall peak, winter rains and snowmelting (Fig. 2.10a & Fig. 2.12). Although historical data are difficult to compare to current regular measurements, several extreme floods have been recorded in the past such as in 1801, in 1851/52; when the water level presumably reached an elevation between 456 and 458 m; and in 1923 when water level reached 453.4 m (Gams 1980). In February 2014, the floods reached an altitude of 453.2 m and 72 million cube meters of water were stored in the polje (Frantar & Ulaga 2015). The lake extended over 10.3 km² and more than forty houses and other facilities have been flooded (Mihevc 2014).



Fig. 2.11: Two of the many ponors draining Planinsko Polje. (a) Velike Loke located at the eastern border. (b) So-called Putick's Well (Putickova štirna) located at the terminal outflow zone at the northern border (Photos: M. Blatnik).

During the period between 1954 and 2014, high waters on the polje occurred on average 37.9 days per year (Ravbar *et al.* 2018). The longest periods the polje has been overflown were recorded in 1960 (altogether 137 days) and in 2014 (altogether 126 days). An event of high waters lasts on average for ten days, but can also be as long as 78 days such as the flood that occurred in autumn and winter 2000/01 (Ravbar *et al.* 2018).



Fig. 2.12: Planinsko Polje under various hydrological situations (Photos: M. Blatnik).

In a recently published work, Mayaud *et al.* (2019) listed and tested the parameters that could potentially control flooding in poljes. Lately, the same authors reconstructed the polje water (Mayaud *et al.* 2022). To do so, water levels measured on the polje surface and ponor zones, a new rating curve of the Unica at Planinska Jama and a 1 m resolution DEM of the polje surface have been used (Fig. 2.13).

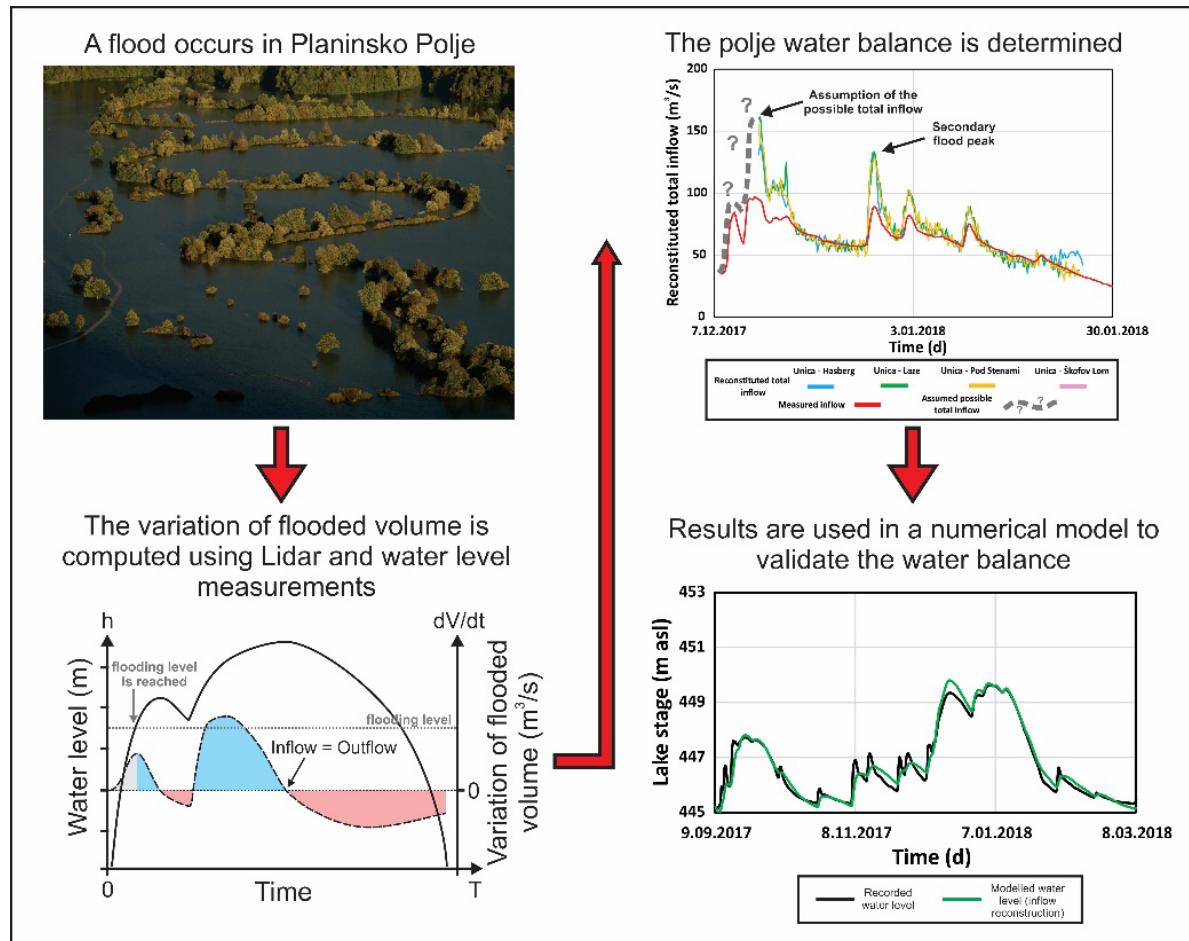


Fig. 2.13: Procedure employed to reconstruct the water balance of Planinsko Polje (Mayaud et al. 2022).

Water level and temperature have been monitored in all active caves between Planinsko Polje and Ljubljana basin in years from 2006 to 2009 and from 2015 on (Turk 2010; Gabrovšek & Turk 2010; Blatnik *et al.* 2019; Blatnik *et al.* 2020). Data loggers have been installed in 8 caves (Logarček, Vetrovna Jama, Najdena Jama, Gradišnica, Gašpinova Jama, Brezno pod Lipovcem, Andrejevo Brezno 1, Veliko Brezno v Grudnovi Dolini) and three ponors on the rim of Planinsko Polje (Velike Loke, Pod Stenami, Škofov Lom). Fig. 2.14 presents the recorded dynamics of underground water in March and April 2018.

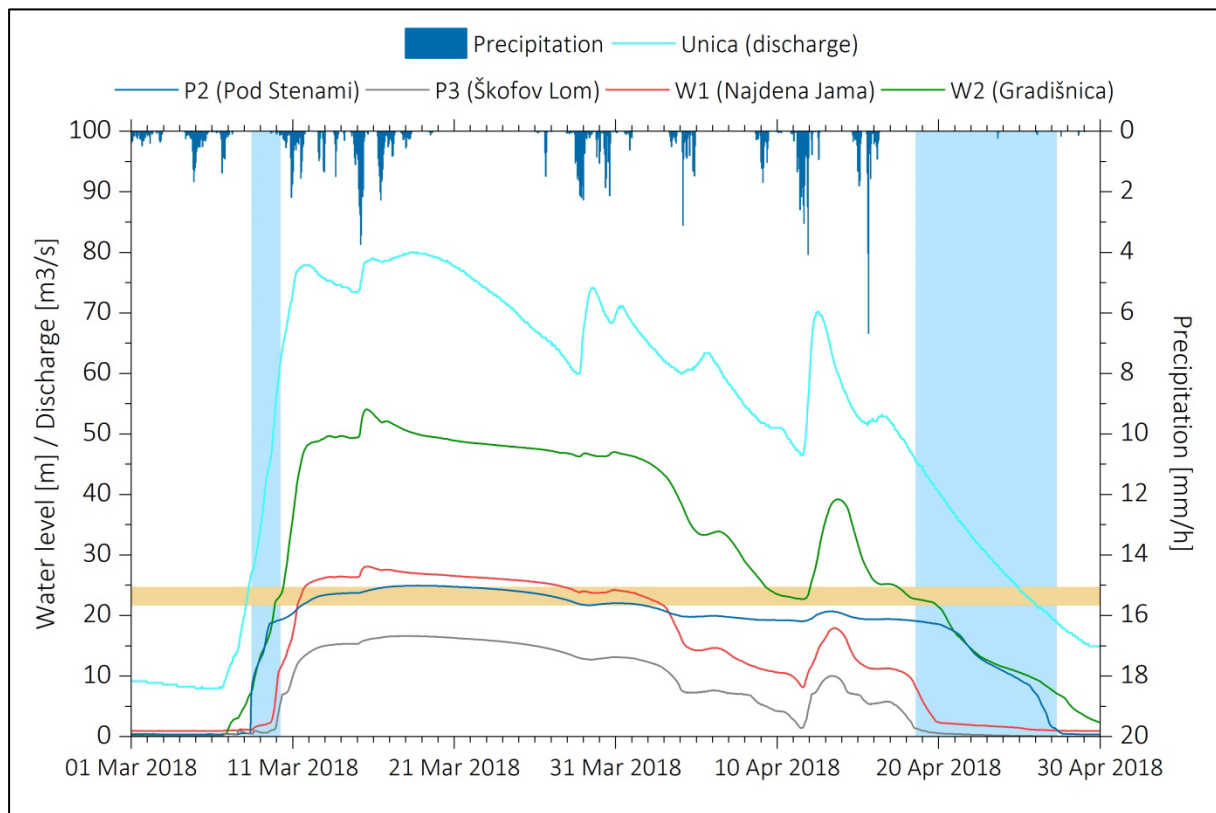


Fig.

2.14: Water level dynamic in selected caves between Planinsko Polje and Ljubljana springs during high water event in March and April 2018. Blue areas denote different response of water level change; orange area denotes temporal slower increase (decrease of water level in cave Gradišnica).

THE SPRINGS OF LJUBLJANICA

The water of the Ljubljana karst catchment emerges at many springs located near Vrhnika, at the rim of the Ljubljana Basin. The line of spring generally follows the contact of Jurassic limestone and Quaternary sediments underlain by Triassic dolomite (Celarc *et al.* 2013) (Figs. 2.15). Most important springs are aligned along the gradually retreating pocket valleys of Močilnik and Retovje. The springs at Močilnik ($Q_{av} \approx 6-7 \text{ m}^3/\text{s}$) feed Mala (=small) Ljubljana and springs at Retovje ($Q_{av} \approx 16 \text{ m}^3/\text{s}$) feed Velika (=big) Ljubljana, the main tributaries related to karst springs of the Ljubljana River. Easterly, another tributary Ljubija ($Q_{av} \approx 6-7 \text{ m}^3/\text{s}$) is also fed by several springs. The easternmost set of springs at Bistra are already positioned in Triassic dolomites and add on average $7 \text{ m}^3/\text{s}$ to the last true karstic tributary of Ljubljana. Mean annual discharge of the Ljubljana karst springs is about $24 \text{ m}^3/\text{s}$ (Gospodarič & Habič 1976).

Temperature monitoring at springs have shown, that major springs show similar temperature dynamics, however, easternmost spring at Bistra differs quite substantially from the others (Fig. 2.16). The temperature lag is higher and the hydrograph lacks short-time disturbances. This indicates longer retention time (Blatnik *et al.* 2019). Water tracing in in 1970s also revealed, that the direct flow from the Cerkniško Polje, mostly goes to the Bistra springs (Gospodarič & Habič 1976) (Fig. 2.17).

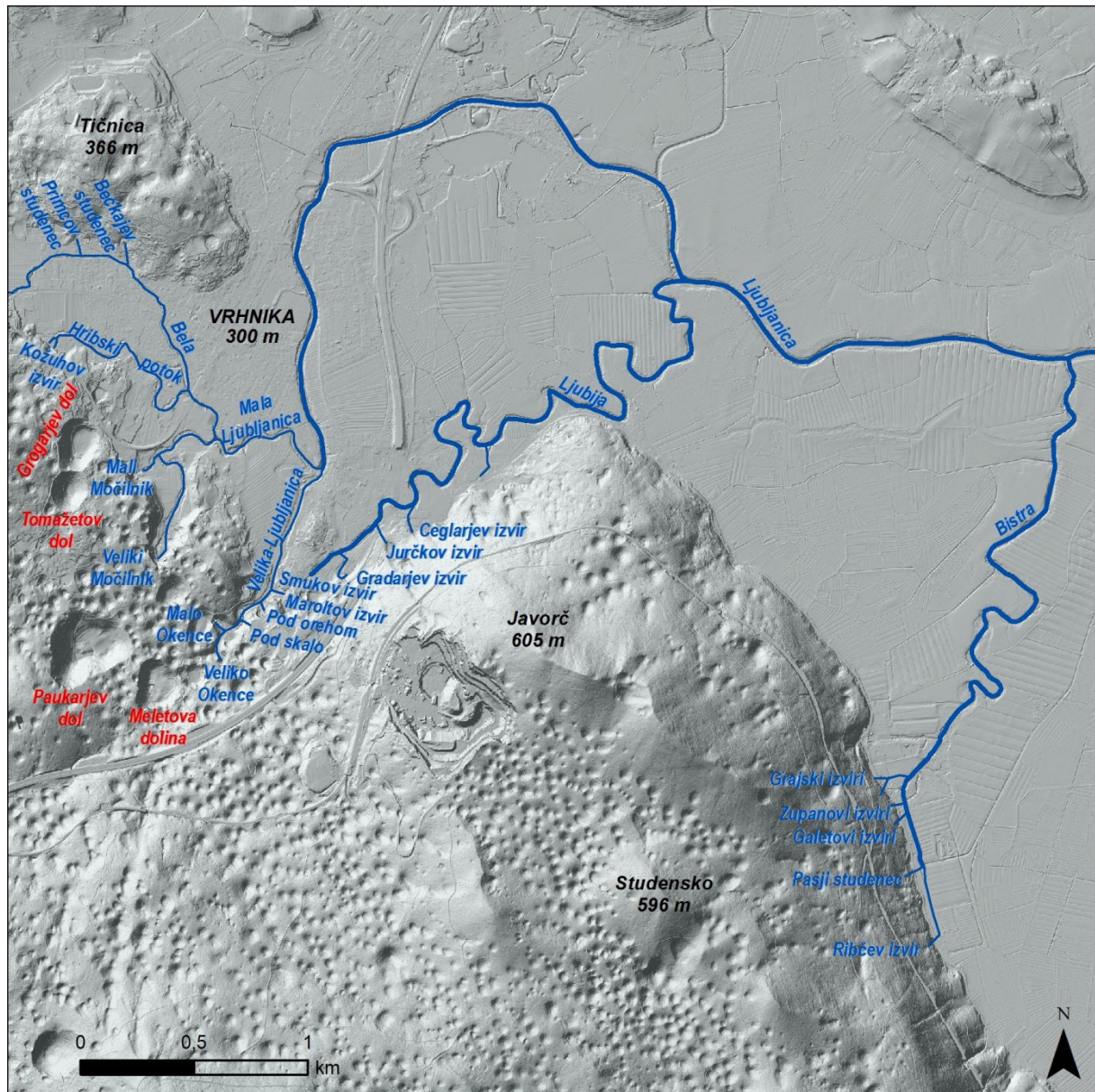


Fig.

2.15: Location of collapse dolines and Ljubjanica springs near Vrhnika.

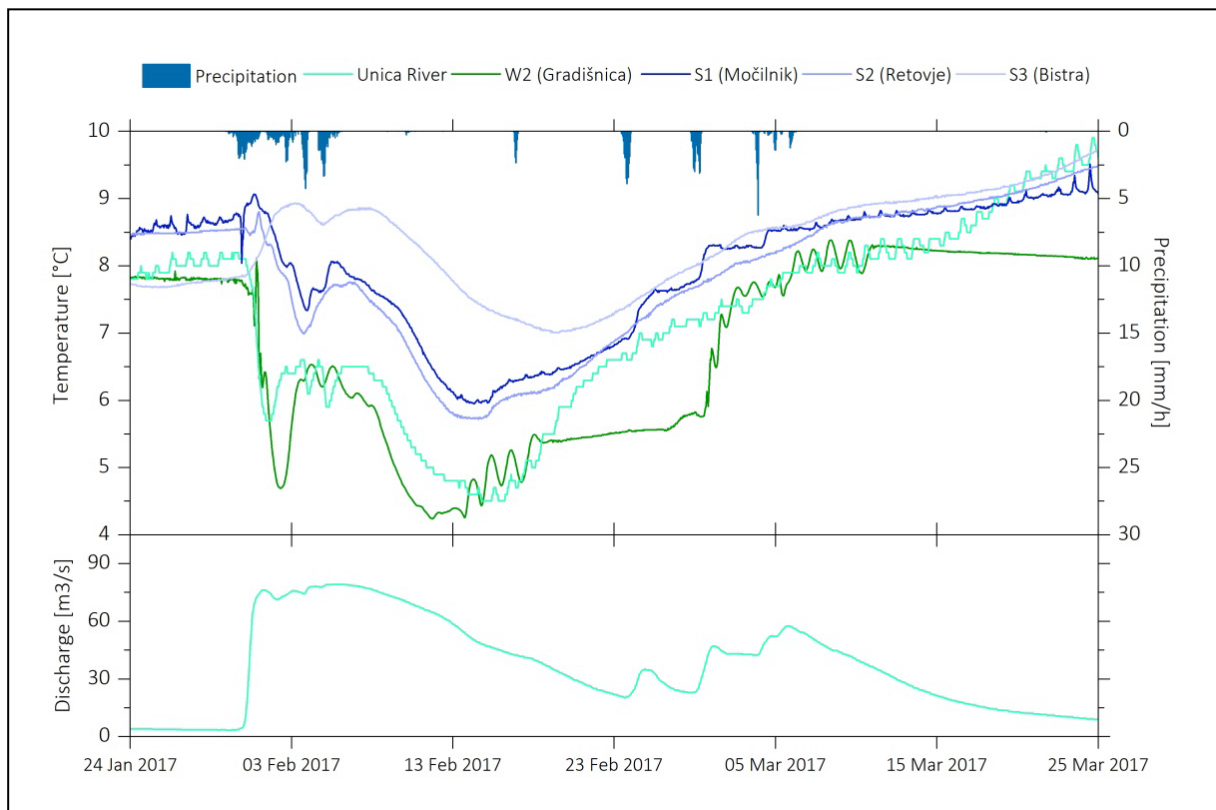
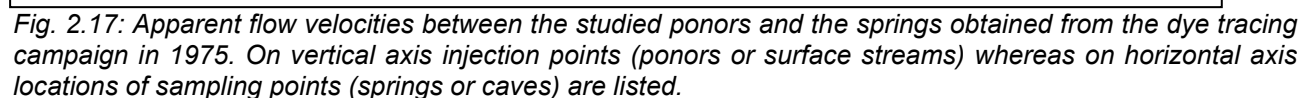


Fig. 2.16: Temperature hydrographs at springs of Ljubljana compared to the cave Gradišnica and Unica River.



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