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Hydrogeological Monitoring of Groundwater, Surface and Mine Waters in the Bukov URF in the Period 2023-2024

Final Report

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AMS	Automatic Measuring Station
GWL	Groundwater level
LV	Limit Value (Decree 252/204 Coll.)
SP	Sampling Point
Fig.	Figure
URF	Underground Research Facility
Q	Flow
CDS	Central Data Storage
Tab.	Table
Min.	Minimum
Max.	Maximum

Abstract

The final report entitled “Hydrogeological Monitoring of Groundwater, Surface and Mine Waters in the Bukov URF” describes and evaluates the hydrogeological monitoring of groundwater and surface water in the Bukov URF I area for the period 2023-2024. The hydrogeological monitoring follows on from the results of previous projects performed since 2014, and in particular the results of the comprehensive geological characterization of the Bukov URF I area completed in 2017, and the subsequent five-year regime monitoring of groundwater, surface and mine water completed in 2023.

The objective of the hydrogeological monitoring both on the surface (above the Bukov URF I area) and underground (in Bukov URF I and other locations on level 12 of the Rožná I mine at a depth of about 500 m below the surface) was to obtain information about the nature of the shallow and deep groundwater circulation, and the qualitative and quantitative parameters of these water types in time and space. Evaluation of the regime monitoring enables the mutual relationships between individual water types to be assessed and complements the knowledge acquired to-date about the characterization of the environment of their formation, flow, and accumulation.

Keywords

Bukov URF, monitoring plan, monitoring, groundwater, mine water, monitoring network, documentation points, measurement object, flow, yield, measurement profile, measuring curve, data transfer

1 Introduction

The final report describes and evaluates the hydrogeological monitoring of surface, groundwater and mine waters in the area of Bukov URF I for the period from June 2023 to March 2025.

The performed work followed up on the results of previous research work initiated in 2015 by hydrogeological mapping (Bukovská et al. 2017) and on the results of hydrogeological and hydrochemical monitoring of groundwater and mine waters (Vylamová et al. 2023) on the surface of Bukov URF and in the area of Bukov URF. The results of the archival research work were used primarily in Chapter 2 as part of the characterisation of geological and hydrogeological stie settings and in the interpretation of the results of field measurements and chemical water analyses.

The research work was conducted in accordance with the Work Contract (SO2023-030) and its integral Technical Specifications attachment defining the measured points inkling the scope and frequency of monitoring (number of points for monitoring quantity and quality), the scope of monitored analytical determinations and physical and chemical parameters and is in accordance with the Monitoring Plan (TZ 669/2023) and its Amendment No. 1 (July 2023).

The subject of the work was to evaluate the development and variability of the flow and chemical composition of groundwater and mine waters on the surface and area of Bukov URF I based on regular measurements and campaign-based water sampling and field measurements on the surface (springs, streams, boreholes) and in the area of Bukov URF I (boreholes, wall outflows, drainage channel).

Field measurements of qualitative (basic chemical analyses, trace elements, radioactive substances, physical and chemical parameters) and quantitative (yield, flow rates) parameters were taken in the period 11/2023 to 12/2024. An overview of individual monitoring points, including the scope and frequency of analyses, is provided in the following chapters.

All of the work was coordinated in cooperation with SÚRAO (project management) and DIAMO, s. p., GEAM Dolní Rožínka (technical support for entering the underground).

2 Basic characteristics of Bukov URF

Prepared according to the results and conclusions of available and submitted archival works (Bukovská et al. 2017; Vylamová et al. 2023).

2.1 Geographical characteristics

From a geomorphological point of view, the Bukov URF area belongs to the Czech Highlands province, Bohemian-Moravian system sub-province, Bohemian-Moravian Highlands region, mainly the Hornosvratecká Uplands unit, the Nedvědická Uplands sub-unit, and the Perštejnská Uplands district. Only the westernmost parts of the area of interest belong to the Křižanovská Uplands unit, the Bítešská Uplands sub-unit, the Novoměstská Foothills district (www.geoportal.gov.cz).

The main morphological element of the area of interest is the Střítež ridge and the parallel ridges and plateaus, which are limited by the valleys of the Bobrůvka and Nedvědická rivers. The morphology of the terrain surface, the network of surface watercourses and washout depressions clearly reflect the geological and tectonic structure of the area. The wider surroundings of the area of interest represent a significantly undulating landscape, largely deforested, with smaller forest units on the tops or slopes of partial hills, of a mosaic nature. It is moderately densely populated, without industrial complexes. Poor sandy soils on eluvial weathering and diluvial clays of the granitoid base are used for agriculture. The elevation of the area ranges from approximately 400–600 m above sea level. The highest elevations in the area of Bukov URF are Kraví hora (611 m above sea level), Dejmalka (603 m above sea level) and Na Skalkách (598 m above sea level). The bottoms of the shallow valleys of the Bobrůvka and Nedvědička rivers are located at an elevation of approximately 400 m above sea level. The area lies between the right-bank inflows of the Svratka River: the Bobrůvka River and the Nedvědička River (hydrological basin number 4-15-01). The following watercourses flow through the area of the Bukov URF: Bukovský Stream, Střítežský Stream and an unnamed right-bank inflows of the Nedvědička River.

Based on the climatic classification of the Czech Republic (Quitt 1971), the area of interest belongs to the MT9 area, which is characterised by a long summer, warm, dry to slightly dry, a short transitional period with a mild to slightly warm spring and slightly warm autumn, a short winter, mild, dry, with a short duration of snow cover.

The average long-term values from the period 1931-1960 from the weather station in Bystřice pod Perštejnem (554 m above sea level) are: annual air temperature 6.7 °C and annual precipitation 648 mm. The highest precipitation totals recorded at the Bukov weather station (measured since May 2015) were in August and November 2015 and in May 2016 (50 to 60 mm per month), while August and September 2015 were very dry (up to 15 mm per month) (Bukovská, Verner, 2017). Summer is short (28.5 summer days with a temperature ≥ 25 °C), the average temperature in July reaches 17.1 °C. Precipitation in the summer period is on average 383 mm. Winter is long (42.9 ice days with a max. temperature ≤ 0.1 °C; 69 days with snow cover ≥1 cm), the average temperature in January is -3.4 °C. Precipitation in the winter period is on average 252 mm. The average annual precipitation is approximately 600 mm – 700 mm and the temperature is 6–7°C (Atlas of the Czech Republic 2007). Based on monitoring the wind direction in the Dolní Rožínka Protected Area, westerly winds prevail.

2.2 Geological site settings

From the point of view of the regional geographical division of the Bohemian Massif (Mísař 1983), the Bukov URF and its wider surroundings fall into the northeastern edge of the Strážecký Moldanubian zone, which in the east passes into the Svratecký crystalline zone. (Figure 1, Figure 2)

The rock environment in the area of Bukov URF and its wider surroundings is formed by highly metamorphosed rocks of the northeastern edge of the Strážecký Moldanubian zone. Archive geological investigations (Bukovská et al. 2017) have mapped migmatitised biotite-amphibole pararules with layers of amphibolites, amphibole, and biotite migmatites. The intensity of migmatitisation is variable, stromatitic migmatites dominate, with transitions to nebulitic migmatites in places. In the migmatites, it is rarely possible to observe thin inserts of calcium-silicate rocks. The presence of veins of pegmatites and granites and hydrothermal veins is relatively common. These are mainly quartz or quartz-carbonate veins with accessory amounts of sulphides. Rocks in the vicinity of tectonic faults often bear signs of secondary mineral changes (sericitisation, kaolinisation and hematitisation of feldspars, chloritisation of biotite and amphiboles), potassic metasomatisation and epidotisation.

The geological site settings in the area of the Bukov URF are shown on the basic geological map at a scale of 1:10,000 (Vylamová et al. 2023) in Figure 1.

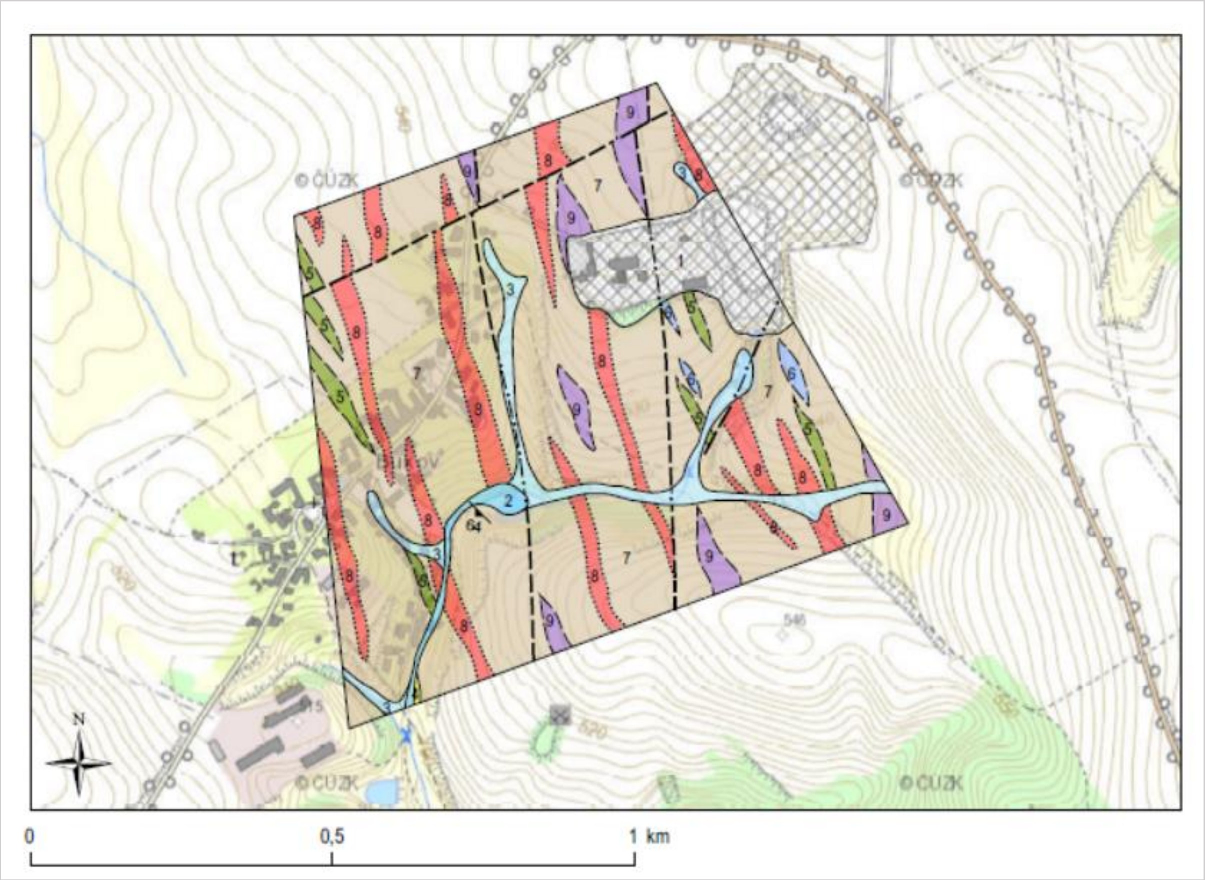
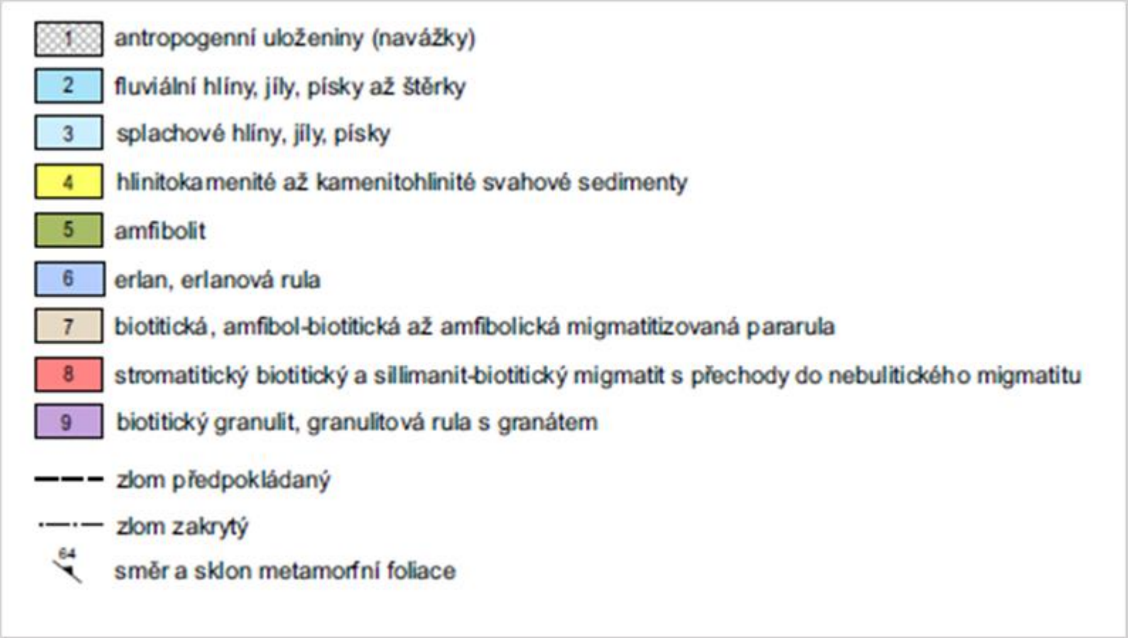


Figure 1 Basic geological map of the Bukov URF (adapted from Vylamová et al. 2023)



1 antropogenní uloženiny (navážky)
2 fluviální hlíny, jíly, písky až štěrky
3 splachové hlíny, jíly, písky
4 hlinitokamenité až kamenitohlinité svahové sedimenty
5 amfibolit
6 erlan, erlanová rula
7 biotitická, amfibol-biotitická až amfibolická migmatitizovaná pararula
8 stromatitický biotitický a sillimanit-biotitický migmatit s přechody do nebulitického migmatitu
9 biotitický granulit, granulitová rula s granátem
– – – zlom předpokládaný
·—·— zlom zakrytý
64 směr a sklon metamorfní foliace

Figure 2 Legend to the basic geological map (adapted from Vylamová et al. 2023)

2.3 Hydrogeological site settings

From a hydrogeological point of view, metamorphic rocks (crystalline rock) form a hydrogeological massif characterised by fissure permeability and groundwater circulation.

The upper parts of the crystalline rock (weathered mantle - eluvium) and Quaternary cover formations (fluvial sediments, deluvial sediments) have porous permeability.

Based on the regional hydrogeological characterisation (Olmer et al. 2006), the area of interest belongs to hydrogeological region No. 65601 - Crystalline rock in the Svratka basin - central part.

The circulation of groundwater in the crystalline rocks is mainly tied to the near-surface zone of loose rocks with secondary disconnected fissures and weathered rocks. The depth of the near-surface zone of loose fissures with active groundwater circulation ranges from 40–100 m (Bukovská et al. 2017). At greater depths, permeability is tied to fracture zones and tectonic belts.

The circulation of groundwater in the area depends on the morphology of the terrain, the heterogeneity of the saturated fissure environment, and the level of the erosion base. In the area of the Bukov URF, the erosion base is tied to the local surface flows. The groundwater level in the near-surface zone is unconfined and roughly conformable to the level of the terrain.

Groundwater is recharged mainly through infiltration of atmospheric precipitation. Natural drainage in the area of the Bukov URF occurs at the level of local surface flows (local erosion base), into fluvial sediments, at the contact of rocks with different hydraulic conductivity values or in the location of faults and tectonic zones with a drainage or, conversely, insulating function. Regional faults in a SSW-SSE direction are important for groundwater circulation (Bukovská et al. 2017), and they are lined with several springs. The second direction of the “conductive” structures is NE-SE, corresponding to diagonal dislocations of a 55–70° direction, which are described in previous investigation works as being open, covering an area of tens to hundreds of meters and a drainage function. The yields of springs tied to the shallow groundwater circulation change relatively quickly. The springs tied to deep groundwater circulation, have stable yields.

From a regional pint of view, the basic hydrogeological site settings of the aquifer, which is mainly composed of metamorphic rocks are as follows: fracture permeability, unconfined groundwater level, low transmissivity (in the order of <1×10-4 m2.s^{-1}), mineralisation of 0.3 g.l^{-1} and chemical type of water Ca-Mg-HCO3-SO4. The report from Vylamová et al. (2022) describes the Moldanubian rocks (crystalline rocks outside the weathered zone) in the wider vicinity of the Rožná mine as rocks with a permeability coefficient of k_f=0.5×10^{-9} m.s^{-1} to 0.5×10^{-10} m.s^{-1} and a k_f of veins and tectonic zones in the deposit of approximately 5×10-6 m.s-^{1}. The Strážecký Moldanubian rocks are considered to be poorly permeable. Increased permeability is manifested in areas of tectonic faults and dislocations.

The hydrogeological conditions in the deposit area were significantly influenced by deep mining at the Rožná mine. Groundwater was originally drained by springs and hidden inflow into streams and their alluvium. However, due to mining, old fractures opened up and secondary fractures (fissures) appeared, which significantly contributed to the intensive infiltration of surface and shallow groundwater into the area of the mine workings (Vylamová et al. 2022). A large area was therefore hydraulically connected by the mine workings. After draining the mine, 580 km of mine passages on 24 levels and an area of approximately 18.5 km^2 (the largest area of the mining area from 1978) act as effective groundwater drainage. The most significant changes in hydrogeological conditions occurred in the area with the greatest concentration of mine workings between the municipalities of Rozsochy and Bukov. On the surface of the terrain, changes are manifested by a decrease or even loss of the yield of springs and flows in streams. Losses of flows are most noticeable especially in the lower reaches of the Rožínka Stream and the entire Milasínský Stream, where in the past there were and still are significant losses of flows and in the case of the Milasínský Stream, with it even completely drying up (Horálková et al. 1996 in Vylamová et al. 2023). In the lower reaches of the Rožínka and Milasínský streams, the greatest decreases occur due to the collapse of abandoned mine shafts (Hájek et al. 1997b in Vylamová et al. 2023), whereby the formation of fault fractures facilitates the infiltration of water into the mine.

The flooded Olší-Drahonín mine is located close to the Rožná mine; however, the inflow of mine waters into the Rožná mine from this mine has not been recorded.

3 Monitoring plan, revision of the existing monitoring network

Archive research

During the project, research was conducted of submitted reports and documents that were the subject of previous research work with the aim of characterising the hydrogeological site settings on the surface and in the area of the Bukov URF based on the results of qualitative and quantitative monitoring and assessing the hydrochemical composition of the waters and their development (Bukovská et al. 2017; Vylamová et al. 2020, 2021, 2022, 2023). Data on the discharge of mine waters were also used (Diamo. s. p.).

Monitoring plan

The monitoring plan in the hydrogeological monitoring of groundwater, surface and mine waters (TZ 699/2023) project was prepared in accordance with the Contract for Work (SO2023-030). Its integral appendix Technical Specifications defines the monitoring points, including the scope and frequency of monitoring (number of points for monitoring quantity and quality, scope of determining parameters for basic water analyses, analyses of trace elements and radioactive substances, direct measurements of physical and chemical parameters, yield and flow rates, method of sampling), maintenance and administration of the monitoring network and weather station, metrological assurance of measuring systems, database supplementation, and evaluation of results.

Amendment No. 1 of the Monitoring Plan was prepared in relation to the technical modifications in the area of Bukov URF I during June 2024, i.e., the construction of a new documentation point (the Parshall trough) with the designation 296HGM052 in the area of BZ1-XIIJ 255 m in Bukov URF I.

The Monitoring Plan includes Data Management (data flow and electronic documentation management and results of passportisation of the measuring systems and documentation points).

Revision of monitoring network

The current monitoring network was revised in September 2023 and its results are an integral part of the Monitoring Plan as Appendix 1 (TZ 699/2023). Subsequently, control measurements, data downloads from measuring systems and necessary repairs were performed to ensure the restoration and operation of the monitoring network.

The long-term data series for the period 01/2023-6/2023, or 09/2023, was added by determining the degree of influence based on the analogy of data from archive records and professional experience (Kocman et al. 2025).

All documentation points in Bukov URF I were put into operation by 22 November 2023.

4 Hydrogeological monitoring on the surface of the Bukov URF

4.1 Qualitative and quantitative monitoring on the surface of Bukov URF I

4.1.1 Monitored objects, scope of monitoring, situation on the surface of Bukov URF I

In accordance with the Monitoring Plan, the documentation points of hydrogeological monitoring of surface waters in the Bukov URF (8 points) were qualitatively monitored within the project 2x in 2023 and 5x in 2024 (Figure 3, Table 1).

Direct field measurements of physical and chemical water parameters (water temperature, conductivity/specific electrical conductivity, pH, Eh, content of dissolved oxygen) using calibrated measuring instruments in accordance with the Monitoring Plan and Amendment No. 1 (07/2024) were part of the water sampling.

Table 1 List of documentation points on the surface of Bukov URF I

Original Name	Documentation point number according to SURAO rules	Monitoring of Quality/Quantity
PV-5	296HGM0029	Quantity
PV-6	296HGM0030	Quantity
PV-8	296HGM0031	Quantity
BP001	296HGM0032	Quantity + quality
BP005	296HGM0033	Quantity + quality
BP008	296HGM0034	Quantity + quality
BP019	296HGM0035	Quantity + quality
BP021	296HGM0036	Quantity + quality
BP022	296HGM0037	Quantity + quality
BP027	296HGM0055	Quantity + quality
Bukovský Stream	296HGM0039	Quantity + quality
Weather station	296HGM0047	Meteorological phenomena

The scope of analyses is given in Table 2.

Table 2 Scope of analyses

Basic water analysis – 2x in 2023; 5x in 2024	Na, K, Mg, Ca, Fe, Cl, F, HCO_3, NO_3, SO_4, SiO_2, NH_4, pH, conductivity
Trace elements – 2x in 2023; 5x in 2024	Al, As, Ba, P, Pb, Zn, Mn, Rb, Sr, Li, Mo, Fe
Radioactive substances – 1× year* (*total 2x, in 4/2024 and 11/2024)	Gross alpha activity, gross beta activity, U, Rn

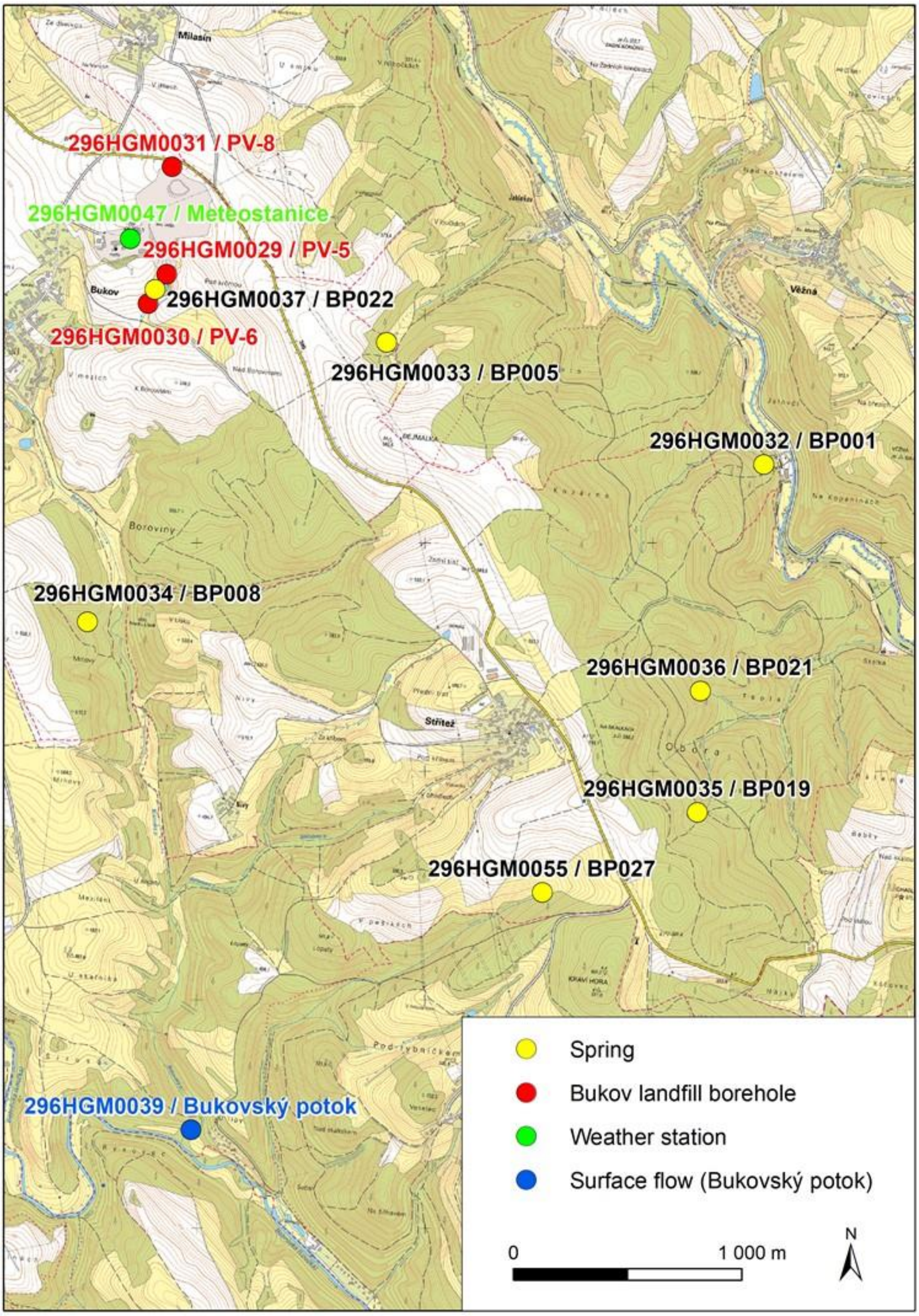


Figure 3 Overview of the hydrogeological monitoring network on the surface of Bukov URF I

4.1.2 Chemical composition of groundwater on the surface of Bukov URF I

The chemical composition of groundwater (seven springs) and surface water (Bukovský Stream) on the surface of Bukov URF I is depicted using a Piper graph and Durov graph (Figures 4 to 7). The results of the chemical analyses and measured data are included in the appendixes (Appendixes 5-7, Appendixes 9 and 10),

Hydrochemical types of water - springs

The chemical composition of groundwater in the monitored springs on the surface of Bukov URF I is influenced over time by climatic conditions (temperature, precipitation, air humidity) and anthropogenic influences (agricultural activity, i.e., fertilisation, road salting, urban and industrial emissions), which decrease with the depth of groundwater circulation.

Springs 296HGM0032 (BP001), 296HGM0033 (BP005), 296HGM0034 (BP008) and 296HGM0036 (BP021) lie nearby tectonic faults, as determined by the comprehensive geological characterisation of the area of the Bukov URF (Bukovská – Verner et al. 2017).

The total mineralisation (Table 4) of the springs ranges from approximately 228.4 mg/l (BP005) to 540.4 mg/l (BP022), pH 6.47 (BP019) to 8.52 (BP021) and conductivity between 24.5 mS/m (BP008) and 112.0 mS/m (BP022).

As shown by the Piper diagrams (Figures 4 and 6) and Durov diagrams (Figures 5 and 7), groundwater from the springs on the surface of Bukov URF I generally corresponded to waters of a calcium-sulphate ($Ca\text{-}SO_4$) hydrochemical type with a number of intermediate types from $CaMg\text{-}SO_4$ to $CaMg\text{-}SO_4HCO_3$ (Table 5). Specifically, springs 296HGM0032 (BP001), 296HGM0033 (BP005), 296HGM0034 (BP008) and 296HGM0035 (BP019) are characteristic of a porous environment and shallow groundwater circulation in the near-surface oxidation zone of crystalline rocks. In the period 2023-2024, in the groundwater of springs, except for spring 296HGM0036 (BP021), a higher proportion of SO_4^{2-} compared to HCO3-, a higher proportion of Ca^+ compared to Mg^+ and, in spring BP019, a higher proportion of chlorides was documented (Table 5, Appendix 6).

In spring 296HGM0036 (BP021), the chemical composition of groundwater with a higher content of Mg+ (38.6-52.1 mg/l) and HCO3- (184-242 mg/l, i.e., >60 %meq%) in the period 2023-2024 corresponded to the $MgCa\text{-}HCO_3SO_4$ type characterising the drainage of deeper groundwater circulation.

Groundwater from springs 296HGM0055 (BP027) and 296HGM0037 (BP022) had a higher proportion of Na^+ and chloride ions. Both springs were most likely anthropogenically contaminated by groundwater with unstable water chemical composition. Spring BP022 has been influenced for a long time by the discharge of pre-treated mine water located below the Bukov landfill. In spring BP027, it may be assumed that the chemistry of the water is influenced by the winter salting of local roads and the agricultural use of surrounding land.

Selected basic chemical parameters, trace elements

The concentrations of selected basic chemical parameters, trace elements, their minimum and maximum values and total mineralisation are given in Table 4. The total mineralisation of the springs ranged between approximately 216.6 and 703.0 mg/l and pH between 6.5 and 8.5.

The highest concentrations of nitrates, chlorides and sodium were found in anthropogenically influenced springs and ranged between 8.9 and 123.0 mg/l for nitrates (max. spring of Bukovský Stream BP022/296HGM0037), between 6.6 and 166.0 mg/l for chlorides (max. 296HGM0055 / BP027 in 11/2023) and between 8.5 and 86.5 mg/l for sodium Na (max. spring of Bukovský Stream BP022/296HGM0037)

Bukovský Stream

The surface water of Bukovský Stream 296HGM0039 (Table 3, Figures 4 and 5) in the period 2023-2024 corresponded to the chemical type $CaMg(Na)-HCO_3(SO_4Cl)$. In terms of cations, Ca^+ prevailed over Mg^+ and for the anions HCO_3^- over SO_4^{2-} (bicarbonates have prevailed since 2021).

Total mineralisation (Table 4, Appendix 7) ranged between 358.6 mg/l (02/2024) and 466.0 mg/l (09/2024), pH between 7.86 (11/2024) and 8.27 (09/2024) and conductivity between 51.1 mS/m (02/2024) and 60.4 mS/m (09/2024).

The chemical composition of the surface water of Bukovský Stream has long been influenced by the mine water discharged from the pre-treatment station of the Bukov mine.

Development of the chemical composition of groundwater – selected anions and cations

Selected monitored parameters of the chemical composition of groundwater (springs) and surface water of Bukovský Stream for the period 2023-2024 including archive data from the beginning of monitoring of individual documentation points are included in the appendixes (Appendix 3-10).

The temporal development of selected parameters of the chemical composition of groundwater of springs and surface water of Bukovský Stream (calcium, sodium, magnesium, sulphates, bicarbonates, nitrates, chlorides) including archive data are shown in graphs (Figures 8 and 9, Appendixes 6 and 9).

From the point of view of the temporal development of chemistry, changes in chemistry in the period 2014-2018 for springs are shown using Piper and Durov diagrams (Figures 4-7, Appendixes 6). Figures 8 and 9 show the temporal development of groundwater chemistry in springs 296HGM0035 (BP019) and 296HGM0036 (BP021) in the period 2014-2018, as an example. The graphical representation of the chemistry of both springs shows differences in the chemical composition of groundwater and in the representation of ions. In spring BP021 ($Mg-HCO_3$), bicarbonates and magnesium predominated, whereas in BP019 ($CaMg-SO_4Cl$) calcium, sulphates and chlorides (>20% meq.) predominated.

Table 3 Overview of chemical types of groundwater of springs and surface water of Bukovský Stream on the surface of Bukov URF I in the period 2023-2024

ID	Date	≥20 %	≥20 %	≥20 %	≥50 %	Predominant ions	Chemical type 20 %
BP001	11_23	Ca, Mg,Na	SO4, HCO3	Ca, Mg,Na-SO4, HCO3		SO4-Ca-HCO3-Mg-Na	CaMg-SO4HCO3
BP001	12_23	Ca, Mg,Na	SO4, HCO3	Ca, Mg,Na-SO4, HCO3	-SO4(53 %)	SO4-Ca-HCO3-Mg-Na	CaMg-SO4HCO3
BP001	02_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(51 %)-SO4(71 %)	SO4-Ca-Mg-HCO3	CaMg-SO4HCO3
BP001	04_24	Ca, Mg	SO4,HCO3	Ca, Mg-SO4,HCO3	Ca (50.2 %)-SO4(70 %)	SO4-Ca-Mg-HCO3	CaMg-SO4HCO3
BP001	06_24	Ca, Mg, Na	SO4, HCO3	Ca, Mg, Na-SO4, HCO3	Ca(47.6 %)-SO4(54.2 %)	SO4-Ca-HCO3-Mg-Na	CaMgNa-SO4HCO3
BP001	09_24	Ca,Mg,Na	SO4,HCO3	Ca,Mg,Na-SO4,HCO3	-SO4(52.1 %)	SO4-Ca-HCO3-Mg-Na	CaMgNa-SO4HCO3
BP001	11_24	Ca,Mg,Na	SO4,HCO3	Ca,Mg,Na-SO4,HCO3	-	SO4-Ca-HCO3-Mg-Na	CaMgNa-SO4HCO3
BP005	11_23	Ca, Na, Mg	SO4, HCO3	Ca, Na, Mg-SO4, HCO3	Ca(52 %)-SO4(60 %)	Ca-SO4-HCO3-Na-Mg	CaNaMg-SO4HCO3
BP005	12_23	Ca, Na, Mg	SO4, HCO3	Ca, Na, Mg-SO4, HCO3		SO4-Ca-HCO3-Na-Mg	CaNaMg-SO4HCO3
BP005	02_24	Ca,Na,Mg	SO4,HCO3	Ca,Na,Mg-SO4,HCO3	Ca(52.5 %)-	Ca-SO4-HCO3-Na-Mg	CaNaMg-SO4HCO3
BP005	09_24	Ca,Na,Mg	SO4,HCO3	Ca,Na,Mg-SO4,HCO3	Ca(51.5 %)-	Ca-SO4-HCO3-Na-Mg	CaNaMg-SO4HCO3
BP005	04_24	Ca, Mg,Na	SO4,Cl	Ca, Mg,Na-SO4,Cl	Ca (54.6 %)-SO4(52 %)	SO4-Ca-Cl-Mg-Na	CaMg-SO4Cl
BP005	06_24	Ca, Na, Mg	SO4, HCO3	Ca, Na, Mg-SO4, HCO3	Ca(50.2 %)-SO4(47.3 %)	Ca-SO4-HCO3-Mg-Na	CaNaMg-SO4HCO3
BP005	11_24	Ca,Na,Mg	SO4,HCO3	Ca,Na,Mg-SO4,HCO3	Ca(52.5 %)-	Ca-SO4-HCO3-Na-Mg	CaNaMg-SO4HCO3
BP008	11_23	Ca, Mg,Na	SO4, HCO3	Ca, Mg,Na-SO4, HCO3	Ca(52 %)-SO4(56 %)	SO4-Ca-HCO3-Mg-Na	CaMg-SO4HCO3
BP008	12_23	Ca, Na, Mg	SO4, HCO3	Ca, Na, Mg-SO4, HCO3	Ca(52 %)-SO4(60 %)	SO4-Ca-HCO3-Na-Mg	CaMg-SO4HCO3
BP008	02_24	Ca,Mg	SO4	Ca,Mg-SO4	Ca(57.7 %)-SO4(73.2 %)	SO4-Ca-Mg	CaMg-SO4
BP008	09_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(58.6 %)-SO4(57.7 %)	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BP008	04_24	Ca, Mg	SO4,HCO3	Ca, Mg-SO4,HCO3	Ca (56.7 %)-SO4(72 %)	SO4-Ca-Mg-HCO3	CaMg-SO4HCO3
BP008	06_24	Ca, Mg	SO4, HCO3	Ca, Mg-SO4, HCO3	Ca(57.2 %)-SO4(61 %)	SO4-Ca-HCO3-Mg	CaMg-SO4HCO3
BP008	11_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(56.75%)-SO4(56.2 %)	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BP019	11_23	Ca, Na, Mg	SO4, HCO3	Ca, Na, Mg-SO4, HCO3	Ca(50 %)-SO4(64 %)	SO4-Ca-Na-Mg-HCO3	CaMg-SO4HCO3
BP019	12_23	Ca, Mg	SO4	Ca, Mg-SO4	Ca(54 %)-SO4 (65 %)	SO4-Ca-Mg	CaMg-SO4
BP019	02_24	Ca,Mg	SO4,Cl	Ca,Mg-SO4,Cl	Ca (56 %)-SO4(67.6 %)	SO4-Ca-Mg-Cl	CaMg-SO4Cl
BP019	04_24	Ca, Mg	SO4,Cl	Ca, Mg-SO4,Cl	Ca (55.9 %)-SO4(68 %)	SO4-Ca-Mg-Cl	CaMg-SO4Cl
BP019	06_24	Ca, Mg	SO4	Ca, Mg-SO4	Ca(55.8 %)-SO4(65.4 %)	SO4-Ca-Mg	CaMg-SO4
BP019	09_24	Ca,Mg	SO4, HCO3	Ca,Mg-SO4, HCO3	Ca(56.2 %)-SO4(65.7 %)	SO4-Ca-Mg-HCO3	CaMg-SO4HCO3
BP019	11_24	Ca,Mg	SO4	Ca,Mg-SO4	Ca(55.8 %)-SO4(65.6 %)	SO4-Ca-Mg	CaMg-SO4
BP021	11_23	Mg, Ca	HCO3, SO4	Mg, Ca-HCO3, SO4	Mg(65 %)-HCO3(65 %)	HCO3-Mg-SO4-Ca	MgCa-HCO3SO4

ID	Date	≥20 %	≥20 %	≥20 %	≥50 %	Predominant ions	Chemical type 20 %
BP021	12_23	Mg, Ca	HCO3, SO4	Mg, Ca-HCO3, SO4	Mg(61 %)-HCO3(60 %)	HCO3-Mg-SO4-Ca	MgCa-HCO3SO4
BP021	02_24	Mg,Ca	HCO3,SO4	Mg,Ca-HCO3,SO4	Mg(65.8 %)-HCO3(59.8 %)	Mg-HCO3-SO4-Ca	MgCa-HCO3SO4
BP021	04_24	Mg, Ca	HCO3,SO4	Mg, Ca-HCO3,SO4	Mg (65 %)-HCO3(67 %)	HCO3-Mg-SO4-Ca	MgCa-HCO3SO4
BP021	09_24	Mg,Ca	HCO3, SO4	Mg,Ca-HCO3, SO4	Mg(56.3 %)-HCO3(65.2 %)	HCO3-Mg-SO4-Ca	MgCa-HCO3SO4
BP021	06_24	Mg, Ca	HCO3, SO4	Mg, Ca-HCO3, SO4	Mg(64.6 %)-HCO3(66 %)	HCO3-Mg-SO4-Ca	MgCa-HCO3SO4
BP021	11_24	Mg,Ca	HCO3,SO4	Mg,Ca-HCO3,SO4	Mg(64.1 %)-HCO3(64.5 %)	HCO3-Mg-SO4-Ca	MgCa-HCO3SO4
BP022	12_23	Ca	HCO3, SO4	Ca-HCO3, SO4	Ca(63 %)-HCO3(55 %)	Ca-HCO3-SO4	Ca-HCO3SO4
BP022	02_24	Ca,Na	Cl,SO4,HCO3	Ca,Na-Cl,SO4,HCO3	-	Cl-Ca-Na-SO4-HCO3	CaNa-ClSO4HCO3
BP022	04_24	Na,Ca	Cl,HCO3	Na,Ca-Cl,HCO3	-Cl(54 %)	Cl-Na-Ca-HCO3	NaCa-ClHCO3
BP027	11_23	Na, Ca	Cl	Na, Ca-Cl	Na(56 %)-Cl(78 %)	Cl-Na-Ca	NaCa-Cl
BP027	12_23	Na, Ca	Cl	Na, Ca-Cl	Na(53 %)-Cl(75 %)	Cl-Na-Ca	NaCa-Cl
BP027	02_24	Na,Ca	Cl	Na,Ca-Cl	Na(56.6 %)-Cl(79.8 %)	Cl-Na-Ca	NaCa-Cl
BP027	04_24	Na, Ca	Cl	Na, Ca-Cl	Na (59.8 %)-Cl(74 %)	Cl-Na-Ca	Na Ca-Cl
BP027	06_24	Ca, Na	Cl	Ca, Na-Cl	Ca(68.9 %)-Cl(66.6 %)	Ca-Cl-Na	CaNa-Cl
BP027	09_24	Na,Ca	Cl,HCO3	Na,Ca-Cl,HCO3	Na(52.2 %)-Cl(66 %)	Cl-Na-Ca-HCO3	NaCa-ClHCO3
BP027	11_24	Na,Ca	Cl	Na,Ca-Cl	Na(56.8 %)-Cl(75.2 %)	Cl-Na-Ca	NaCa-Cl
Bukovský p.	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(51 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
Bukovský p.	12_23	Ca, Mg	SO4, HCO3	Ca, Mg-SO4, HCO3	Ca(52 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
Bukovský p.	02_24	Ca,Mg,Na	SO4,HCO3,Cl	Ca,Mg,Na-SO4,HCO3,Cl	-	Ca-SO4-HCO3-Mg-Cl-Na	CaMgNa-SO4HCO3Cl
Bukovský p.	04_24	Ca,Mg,Na	HCO3,SO4	Ca,Mg,Na-HCO3,SO4	Ca(51 %)-	Ca-HCO3-SO4-Mg-Na	CaMgNa-HCO3SO4
Bukovský p.	06_24	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(54.8 %)-HCO3(45.9 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
Bukovský p.	09_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(51.8 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
Bukovský p.	11_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(50.3 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4

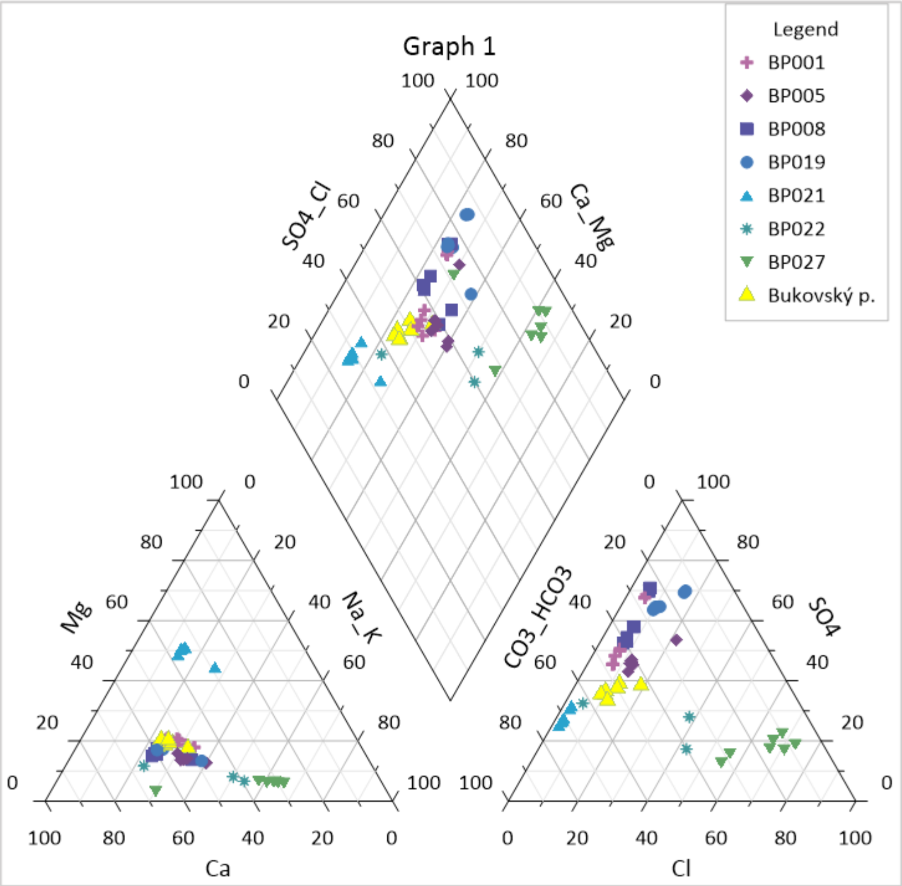


Figure 4 Piper diagram of the composition of water on the surface of Bukov URF I in the period 2023-2024

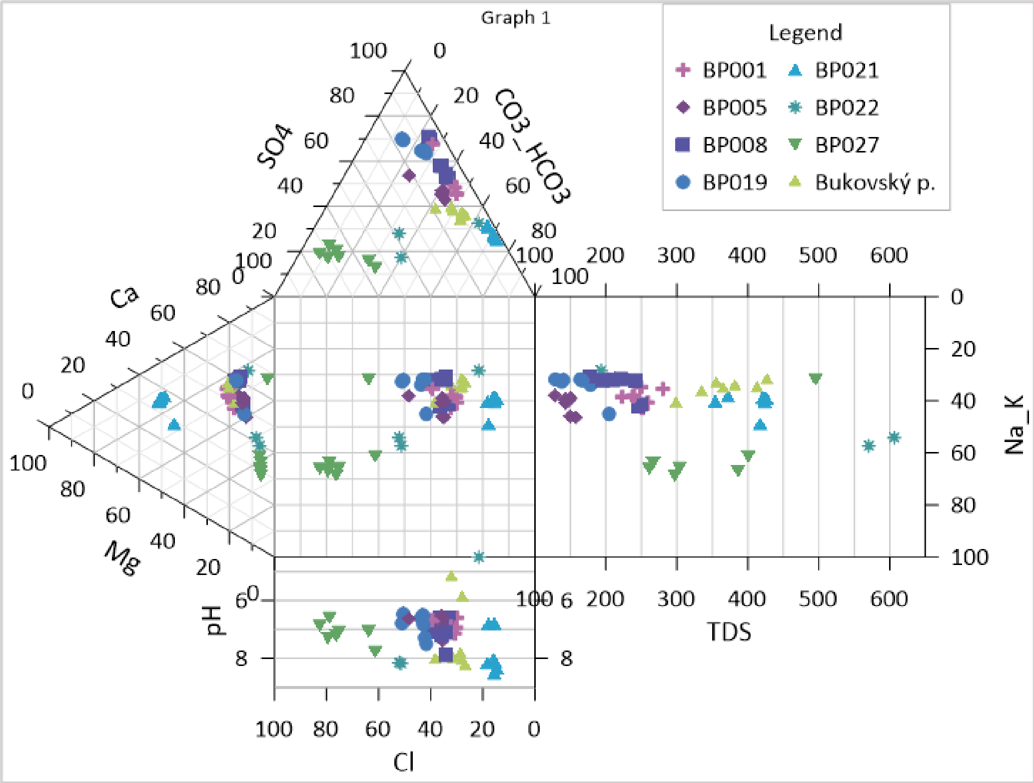


Figure 5 Durov diagram of the composition of water on the surface of Bukov URF I in the period 2023-2024

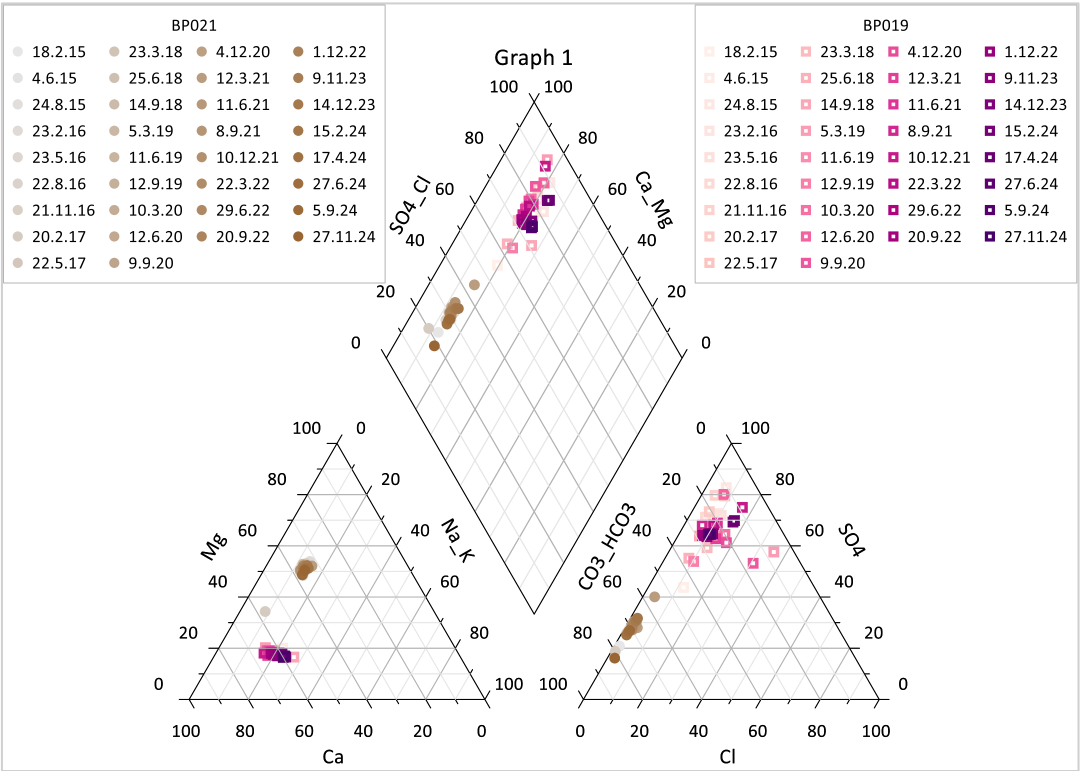


Figure 6 Piper diagram of the time evolution of chemistry - springs 296HGM0035 (BP019), 296HGM0036 (BP021)

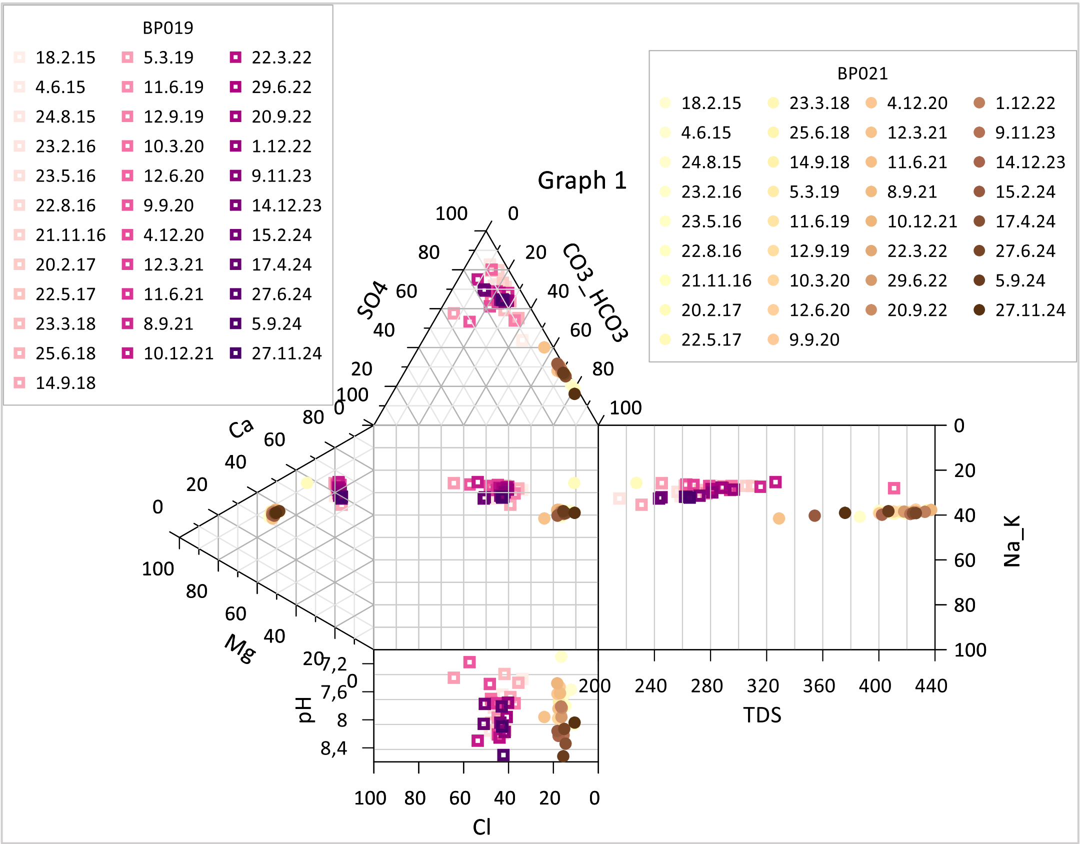


Figure 7 Durov diagram of the time evolution of chemistry - springs 296HGM0035 (BP019), 296HGM0036 (BP021)

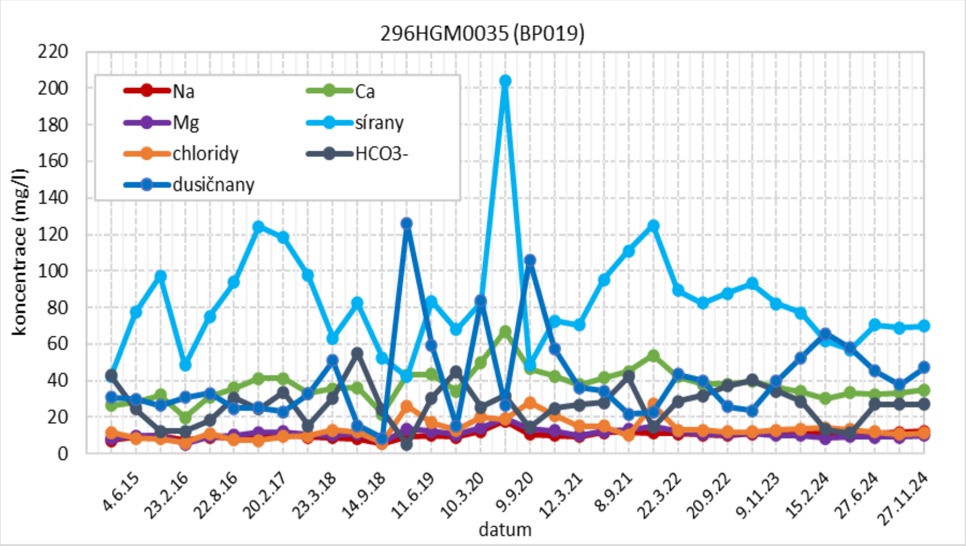


Figure 8 Development of groundwater composition of spring 296HGM035 (selected cations and anions)

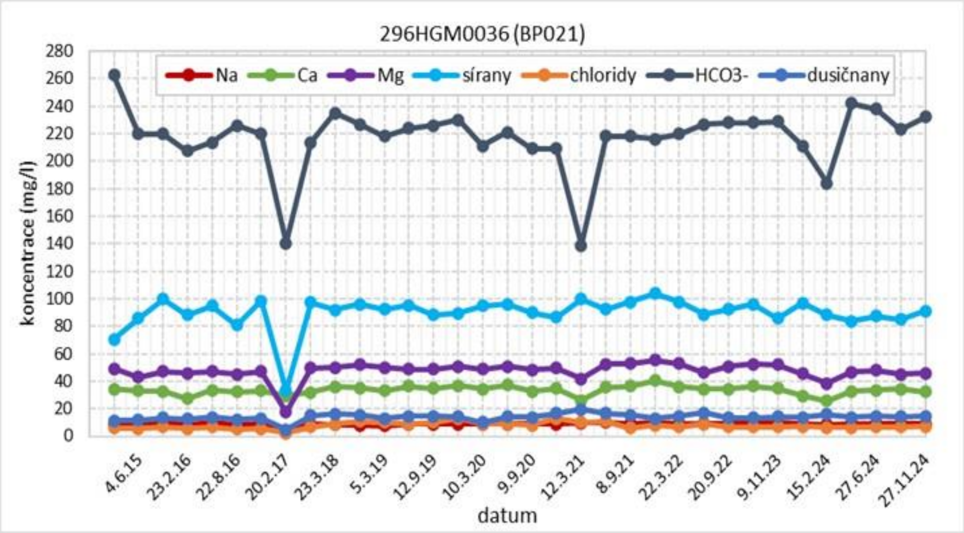


Figure 9 Development of groundwater composition of spring 296HGM0036 (selected cations and anions)

Table 4 Chemical composition of groundwater of springs and surface water of Bukovský Stream (min., max., average) in the period 2023-2024

ukazatel		**pH**	**vodivost**	**KNK 4,5**	**Na**	**K**	**NH$_4^+$**	**Ca**	**Mg**	**sírany**	**chloridy**	**dusičnany**	**fluoridy**	**SiO$_2$**	**HCO$_3^-$**	**As**	**Pb**	**Zn**	**Ba**	**Al**	**Fe**	**Mn**	**Mo**	**Sr**	**Pcelk.**	**Li**	**Rb**	**TDS**
objekt	**datum**		µS/cm (20°C)	mmol/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l	mg/l	mg/l	ug/l	ug/l	mg/l	mg/l	ug/l	mg/l
BP001	MIN	6,68	405,00	0,71	15,60	2,65	*<0,050*	36,40	14,40	68,80	9,10	22,70	<0,2	21,60	43,20	*<5*	*<5*	*<2*	106,00	*<10*	*0,01*	*0,001*	*<2*	123,00	*<0,05*	0,0017	*<20*	298,51
	MAX	7,50	484,00	1,40	17,70	3,38	*<0,050*	45,80	17,20	137,00	13,00	74,90	<0,2	31,60	85,50	*<5*	*<5*	21,00	127,00	227,00	0,48	0,011	*<2*	161,00	*<0,05*	0,0037	*<20*	359,85
	PRŮMĚR	6,96	433,43	1,11	16,69	3,00	*<0,050*	39,56	15,23	93,20	11,30	44,71	<0,2	23,93	67,74	*<5*	*<5*	7,93	117,71	63,86	0,09	0,004	*<2*	141,71	*<0,05*	0,0026	*<20*	315,76
BP005	MIN	6,53	284,00	0,32	11,00	1,53	*<0,050*	*23,90*	6,45	41,20	11,50	43,80	<0,2	22,70	19,20	*<5*	*<5*	*<2*	67,90	21,00	0,03	0,005	*<2*	104,00	*<0,05*	0,0035	*<20*	220,78
	MAX	6,96	328,00	0,69	16,00	4,40	0,054	29,00	8,08	46,70	16,60	70,00	<0,2	46,10	42,10	*<5*	*<5*	28,00	87,90	251,00	1,06	0,048	*<2*	147,00	0,053	0,0118	*<20*	245,91
	PRŮMĚR	6,72	298,86	0,61	14,04	2,14	0,054	26,71	7,15	43,71	12,70	50,07	<0,2	33,87	37,40	*<5*	*<5*	11,10	76,46	89,66	0,26	0,016	*<2*	118,86	0,053	0,0089	*<20*	228,39
BP008	MIN	7,07	*245,00*	0,54	12,20	1,89	*<0,050*	34,70	9,01	76,20	7,40	23,10	<0,2	17,30	32,80	*<5*	*<5*	*<2*	59,90	15,40	0,02	0,005	*<2*	128,00	*<0,05*	*0,0016*	*<20*	249,66
	MAX	7,88	398,00	1,10	13,80	3,58	0,117	43,60	12,80	117,00	12,20	36,70	<0,2	25,30	67,00	<10	<10	23,50	124,00	3 150,00	4,78	0,090	<3	175,00	0,075	0,0075	16,8	304,21
	PRŮMĚR	7,34	357,57	0,87	13,07	2,58	0,117	40,19	10,78	92,59	10,36	29,57	<0,2	19,04	52,80			10,05	71,21	514,73	0,78	0,028		152,00	0,075	0,0041	16,8	272,56
BP019	MIN	*6,47*	322,00	*0,19*	10,90	1,16	*<0,050*	30,30	8,57	56,80	10,70	37,90	0,29	23,10	11,40	*<5*	*<5*	*<2*	*13,70*	53,50	0,01	0,002	*<2*	106,00	*<0,05*	0,0072	*<20*	219,28
	MAX	7,29	349,00	0,56	12,40	1,78	*<0,050*	36,50	10,20	82,00	14,20	65,90	0,36	33,30	34,20	*<5*	*<5*	5,90	16,90	891,00	0,83	0,017	<12,5	125,00	<0,625	0,0119	*<20*	252,73
	PRŮMĚR	6,80	335,71	0,40	11,57	1,45	*<0,050*	33,57	9,52	69,53	12,50	49,51	0,31	25,26	24,09	*<5*	*<5*	4,65	15,17	196,76	0,15	0,006		114,29		0,0104	*<20*	237,80
BP021	MIN	8,04	487,00	3,01	*8,48*	2,59	*<0,050*	25,70	38,60	83,70	*6,60*	13,90	<0,2	35,00	184,00	*<5*	*<5*	*<2*	26,60	22,80	< 0,05	0,010	*<2*	*67,10*	*<0,05*	<0,005	*<20*	405,73
	MAX	8,52	564,00	3,97	9,78	3,99	*<0,050*	34,80	52,10	97,00	7,40	15,70	<0,2	51,50	242,00	*<5*	*<5*	4,20	36,20	103,00	0,26	0,037	*<2*	100,00	*<0,05*	0,0144	*<20*	487,45
	PRŮMĚR	8,23	544,00	3,68	9,11	3,45	*<0,050*	31,86	45,90	88,29	6,84	14,51	<0,2	38,84	221,17	*<5*	*<5*	4,20	32,74	50,66	0,12	0,018	*<2*	86,17	*<0,05*	0,0115	*<20*	461,84
BP022	MIN	7,86	300,00	1,48	9,72	4,71	*<0,050*	31,70	*5,64*	47,20	7,60	*8,88*	<0,2	7,82	90,40	*<5*	*<5*	2,00	50,00	18,00	0,02	0,001	*<2*	104,00	*<0,05*	<0,001	*<20*	*216,56*
	MAX	8,17	1 120,00	2,33	86,50	30,20	*<0,050*	85,10	16,30	113,00	154,00	123,00	<0,2	9,47	142,00	*<5*	*<5*	16,90	92,60	455,00	0,59	0,027	*<2*	358,00	<0,10	0,0014	*<20*	702,98
	PRŮMĚR	8,06	846,67	2,02	60,51	17,00	*<0,050*	67,13	12,08	73,83	104,20	73,19	<0,2	8,60	123,13	*<5*	*<5*	7,30	74,37	165,90	0,21	0,010	*<2*	266,33		0,0014	*<20*	540,42
BP027	MIN	6,87	592,00	0,21	56,20	*0,85*	*<0,050*	30,80	6,46	*30,20*	105,00	16,80	<0,2	9,36	12,90	*<5*	*<5*	*<2*	32,10	15,00	0,09	0,020	*<2*	128,00	*<0,05*	<0,005	*<20*	333,03
	MAX	7,78	795,00	1,42	82,40	2,71	0,399	168,00	9,26	39,80	166,00	63,20	<0,2	17,70	86,60	*<5*	*<5*	23,60	71,50	266,00	6,39	0,553	*<2*	256,00	0,757	0,0037	*<20*	559,39
	PRŮMĚR	7,21	677,14	0,63	70,19	1,51	0,202	56,26	7,56	35,47	132,67	47,23	<0,2	12,79	38,33	*<5*	*<5*	10,03	43,97	79,93	1,23	0,167	*<2*	164,14	0,757	0,0023	*<20*	403,25
Bukovský p.	MIN	7,86	511,00	1,47	19,90	4,59	<0,050	43,90	15,50	81,20	27,10	9,64	<0,2	17,60	89,90	<5	<5	<2	86,70	41,00	0,08	0,010	<2	162,00	0,072	<0,005	<0,5	358,52
	MAX	8,27	604,00	2,77	23,40	5,90	<0,050	71,40	24,10	112,00	40,10	41,40	<0,2	30,60	169,00	<10	<10	13,70	200,00	2 680,00	3,80	0,240	32,4	278,00	0,23	0,0168	9,51	466,04
	PRŮMĚR	8,10	564,14	2,30	21,70	5,41	<0,050	58,69	20,53	98,93	31,86	19,38	<0,2	22,24	139,48			5,73	118,27	583,54	0,87	0,063	17,5	223,86	0,115	0,0111	9,51	420,98
prameny	*MIN*	*6,47*	*245,00*	*0,19*	*8,48*	*0,85*	*<0,050*	*23,90*	*5,64*	*30,20*	*6,60*	*8,88*	*<0,2*	*7,82*	*11,40*	*<5*	*<5*	***<2***	*13,70*	*<10*	*0,01*	*0,001*	*<2*	*67,10*	*<0,05*	*0,0016*	*16,80*	*216,56*
	MAX	8,52	1 120,00	3,97	86,50	30,20	0,399	168,00	52,10	137,00	166,00	123,00	0,36	51,50	242,00	<10	<10	28,00	127,00	3 150,00	6,39	0,55	**<12,5**	358,00	0,757	0,0144	16,80	702,98

4.1.3 Direct measurements of physical and chemical parameters on the surface of Bukov URF I

The measured values of the minimum, maximum and average values of the monitored parameters (Table 5) in the surface waters of Bukov URF I in the period 2023-2024 ranged as follows:

- pH between 6.27 (BP019) and 8.70 (BP022),
- Water temperature between 3.7 °C (BP027) and 19.6 °C (BP027),
- Conductivity between 275 uS/cm (BP022) and 1,100 uS/cm (BP022),
- ORP between -27 mV (BP027) and 174 mV (BP005),
- Dissolved oxygen between 3.82 mg/l (BP001) and 17.61 mg/l (BP027).

The development of physical and chemical parameters (pH, conductivity, water temperature, dissolved oxygen, redox potential) for the period 2018-2024 was shown in graphs and on a geological map (Appendixes 3 and 8).

Table 5 Direct measurements on the surface of Bukov URF I in the period 2023-2024 (overview of min., max., average)

2023-24		**T**	**pH**	**Conductivity**	**O_2 diss.**	**ORP**
Point	Unit	°C		µS/cm	mg/l	mV
BP001	Min	7.4	6.61	400	*3.82*	16
	Max	14.0	8.64	492	10.29	139
	Average	9.7	7.42	448	7.30	77
BP005	Min	7.0	6.40	282	4.94	21
	max	13.7	7.22	338	10.71	**174**
	Average	9.8	6.74	299	6.65	112
BP008	min	6.2	7.42	343	10.40	70
	max	18.6	7.92	379	13.64	118
	Average	9.6	7.67	366	12.19	89
BP019	min	7.3	*6.27*	318	4.98	24
	max	14.7	7.25	350	12.00	112
	Average	9.8	6.75	329	7.79	86
BP021	min	5.9	7.52	439	12.79	37
	max	11.9	8.50	557	15.02	101
	Average	8.1	8.16	523	13.63	70
BP022	min	5.3	7.40	*275*	12.40	11
	max	9.8	**8.70**	**1 100**	13.56	58
	Average	9.8	6.56	319	2.10	39
BP027	min	*3.7*	7.16	580	8.41	*-27*
	max	**19.6**	7.89	795	**17.61**	109
	Average	8.6	7.53	673	12.72	44
Bukovský Stream	min	4.3	8.15	504	12.25	60
	max	16.5	10.01	601	17.02	99
	Average	8.6	8.66	550	14.47	79
Springs	*Min.*	*3.7*	*6.27*	*275*	*3.82*	*-27*
	Max.	**19.6**	**8.70**	**1 100**	**17.61**	**174**

Springs, Bukovský Stream	Min.	3.7	6.27	275	3.82	-27
	Max.	19.6	10.01	1 100	17.61	174

Springs

Generally, the values of all monitored physical and chemical parameters in groundwater of springs in the period 2023-2024 fluctuated (Table 5, Appendixes 3 and 8). The most stable in the long term was spring 296HGM0036 (BP021).

As an example, the report includes graphs of the development of physical and chemical parameters of two springs - representatives of shallow and deeper groundwater circulation: shallow circulation spring 296HGM035/BP019 (Figure 10) and deeper circulation spring 296HGM0036/BP021 (Figure 11).

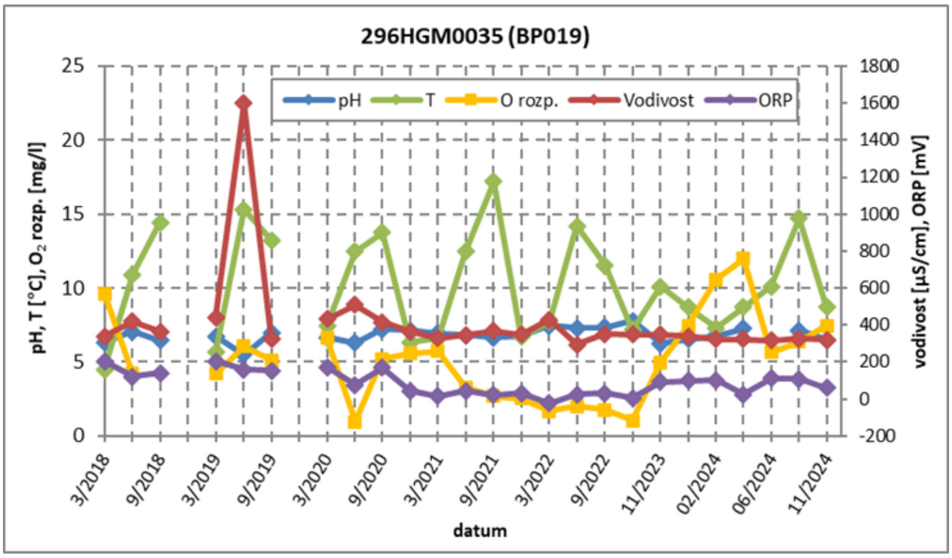


Figure 10 Development of the physical and chemical parameters of the groundwater from spring 296HGM0035

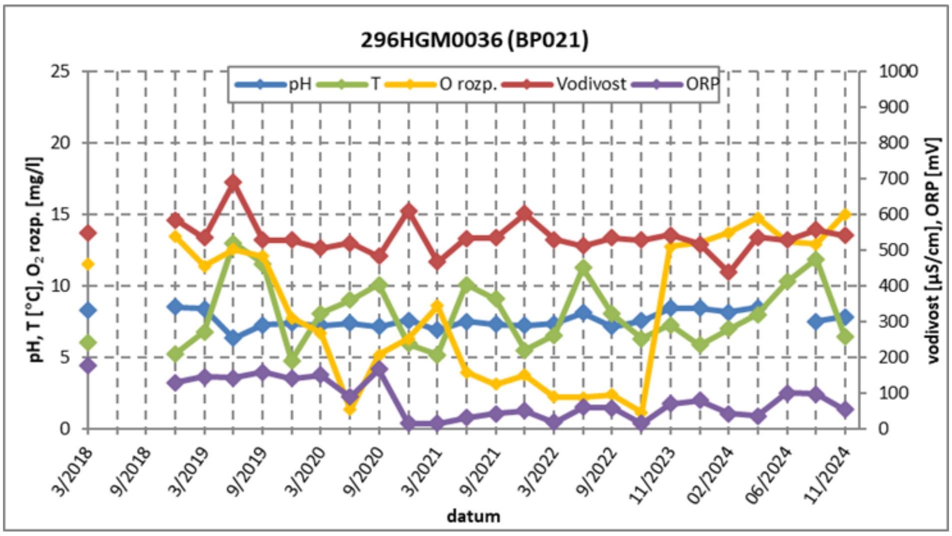


Figure 11 Development of the physical and chemical parameters of the groundwater from spring 296HGM0036

Bukovský Stream

In the period 2023-2024, the values of the physical and chemical parameters in Bukovský Stream 296HGM0039 (Table 5) ranged as follows:

- pH 8.15 (11/2023) to 10.01 (11/2024),
- Water temperature 4.3 °C (12/2023) to 16.5 °C (06/2024),
- Conductivity 504 µS/cm (02/2024) to 601 µS/cm (09/2024),
- Dissolved oxygen 12.25 mg/l (06/2024) to 17.02 mg/l (11/2024),
- ORP 60 mV (06/2024) to 99 mV (09/2024).

In the water of Bukovský Stream in 2024, the values of the physical and chemical parameters fluctuated depending on the size of the water flow and its chemical composition influenced by the discharge of pre-treated mine waters (Appendixes 3 and 8).

4.1.4 Radiology

Groundwater samples for the determination of radioactive substances were taken from three documentation points – from springs 296HGM0032 (BP001) and 296HGM 0037 (BP022) and from Bukovský Stream 296HGM0039 (Table 6).

Table 6 Radiological analysis - the surface of Bukov URF I in the period 2018-2024

Documentation point	Documentation point	Sample date	Gross alpha activity	Gross beta activity	Radon (Rn 222)	Dissolved uranium
SÚRAO	DIAMO	Unit	Bq/l	Bq/l	Bq/l	µg/l
296HGM0032	BP001	9/2018	<0.06	0.17	127	<1
	BP001	9/2019	<0.04	0.12	81.7	0.35
	BP001	9/2020	<0.05	0.1	101	0.33
	BP001	9/2021	0.16	0.16	102	0.19
	BP001	9/2022	<0.04	0.1	89.6	0.3
	BP001	4/2024	<0.04	0.14	85.1	0.16
	BP001	11/2024	<0.04	0.12	98.7	0.23
296HGM0037	BP022	9/2018	1.19	1.46	4.1	10.9
	BP022	9/2019	<0.04	0.48	<5.0	12.9
	BP022	9/2020	<0.08	0.37	<5.0	8.69
	BP022	4/2024	0.68	1.02	<5.0	59.2
	BP022	11/2024	dry	dry	dry	dry
296HGM0039	Bukovský stream	9/2018	0.34	0.4	1.1	7.63
	Bukovský stream	9/2019	0.2	0.22	<5.0	9.36
	Bukovský stream	9/2020	<0.09	0.11	<5.0	2.8
	Bukovský stream	9/2021	<0.06	0.1	<5.0	3.77
	Bukovský stream	9/2022	0.06	0.14	<5	3.65
	Bukovský stream	4/2024	<0.04	0.15	<5	2.46

Documentation point	**Documentation point**	**Sample date**	**Gross alpha activity**	**Gross beta activity**	**Radon (Rn 222)**	**Dissolved uranium**
SÚRAO	**DIAMO**	**Unit**	**Bq/l**	**Bq/l**	**Bq/l**	**µg/l**
	Bukovský stream	11/2024	<0.04	0.15	<5.0	2.3
Decree 422/2016 Coll.			0.2	0.5	100	15

The measured values of the monitored radioactive substances were compared with the limits specified in Decree 422/2016 Coll. (Decree on radiation protection and security of radionuclide sources). Their comparison with the legislative limits (investigation level for total volumetric activity α 0.2 Bq/l and for total volumetric activity β 0.5 Bq/l and for reference values ^{222}Rn 100 Bq/l and dissolved uranium 15 µg/l) are shown in Table 6.

4.1.5 Direct measurements – spring yields, Bukovský stream flow rates, groundwater levels in hydrogeological boreholes

Direct measurements on the surface of Bukov URF I (quantitative monitoring) were performed with a frequency of 1x quarterly at a total of 11 points, i.e., 7 springs, 1 surface stream, 3 hydrogeological boreholes (Table 1, Figure 3) with a frequency of 2 measurements in 2023 and 5 measurements in 2024.

Measurements of yield/flow were part of each water sample collection and direct measurements of physical and chemical water parameters (water temperature, conductivity, pH, ORP, dissolved oxygen).

Direct measurements – spring yield

The measured minimum and maximum values and average values of yield and flow rates in the period 2023-2024 (Table 7), graphically (Figure 12) are part of the annexes (Appendixes 4, 8, 10).

Table 7 Direct measurements on the surface of Bukov URF I – measured values of yield/flow (l/s)

Original point name/ SÚRAO		**Yield 2023-24 (l/s)**	**Date**	**Yield to 2022 (l/s)**	**Date**	**Comparison/trend**
BP001	Min.	0.01710	IX.24	**0.005**	III.18	↑
296HGM0032	Max.	0.04630	VI.24	0.03	III.21	↑
	Average	0.02764		0.016		↑
BP005	Min.	0.01700	XI.23	0.021	IX, XI.22	↓
296HGM0033	Max.	0.19560	IV.24	0.07	III.21	↑
	Average	0.04903		0.041		↑
BP008	Min.	0.01500	XI.23	0.01	IX.18	↑
296HGM0034	Max.	0.10556	II.24	0.14	VI.21	↓
	Average	0.04567		0.053		↓
BP019	Min.	0.01500	XI.23	0.008	VI.20	↑
296HGM0035	Max.	0.17973	II.24	0.08	IX.20	↑
	Average	0.05271		0.027		↑
BP021	Min.	0.38590	IX.24	0.204	III.18	↑
296HGM0036	Max.	0.52770	II.24	**0.50**	III.21	↑
	Average	0.41748		0.081		↑
BP022	min	0.05710	IV.24			

Original point name/ SÚRAO		Yield 2023-24 (l/s)	Date	Yield to 2022 (l/s)	Date	Comparison/trend
296HGM0037	max	0.70390	XII.23			
	Average	0.03685				
BP027	Min.	0.07480	IX.24	0.078	XII.22	↓
296HGM0055	Max.	1.81820	XII.23	0.385	VI.21	↑
	Average	0.69427		0.212		↑
Bukovský stream	Min.	14.34300	VI.24			
296HGM0039	Max.	53.06200	II.24			
	Average	26.77086				

The spring yields in the period 2023-2024 (Table 7, Appendix 4) ranged in the order of 0.015 l/s (BP008, BP019) to 1.8182 l/s (BP027). From the comparison of the results of direct yield measurements (Table 7, Figure 12), it is evident that the yields of all springs in the period 2023-2024 increased slightly from 11/2023 to approximately 02/2024 (BP001, BP008, BP019), possibly to 04/2024 (BP005, BP027), spring BP022 in 11/2023 and from 06/2024 was dry.

The yields of seven springs on the surface of Bukov URF I for the period 2023-2024 (Appendix 4 and 8) may be divided into two categories according to the average yield values (l/s)

- 0.1-1.0 l/s for two springs 296HGM0055 (BP0027), 296HGM0036 (BP021),
- 0.01-0.1 l/s for five springs 296HGM0032 (BP001), 296HGM0033 (BP005), 296HGM0034 (BP008), 296HGM0035 (BP019) and 296HGM0037 (BP022).

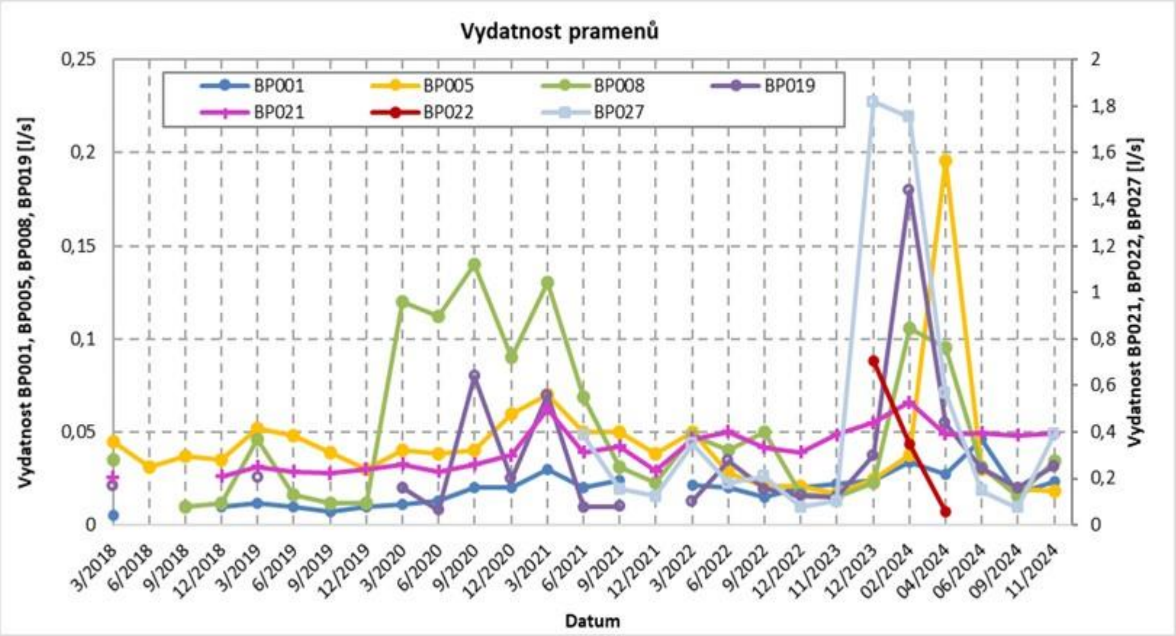


Figure 12 Development of spring yield on the surface of Bukov URF I – direct measurements in the period 2023-2024

Development of chemistry and yield

The development of chemistry and yield is shown at individual documentation points using graphs (Appendix 9). The temporal development of chemistry and yield shows changes in the representation of sulphates and HCO3- in the spring of 2024, specifically with increasing yield of springs at 296HGM0032 (BP001), 296HGM0034 (BP008) an increase in sulphates and a decrease in HCO_3^-; at 296HGM0035 (BP019) a decrease in sulphates and HCO_3^- and at 296HGM0036 (BP021) a relatively stable development corresponding to deeper circulation.

For springs 296HGM0032 (BP001), 296HGM0033 (BP005), 296HGM0034 (BP008), 296HGM0036 (BP021) and 296HGM0037 (BP022), shallow groundwater circulation with precipitation water supplementation may be inferred also based on higher nitrate contents.

As an example, the report presents the time evolution of chemistry and yield for shallow circulation springs 296HGM0035 (BP019) and deeper circulation springs 296HGM0036 (BP021) in Figures 13 and 14.

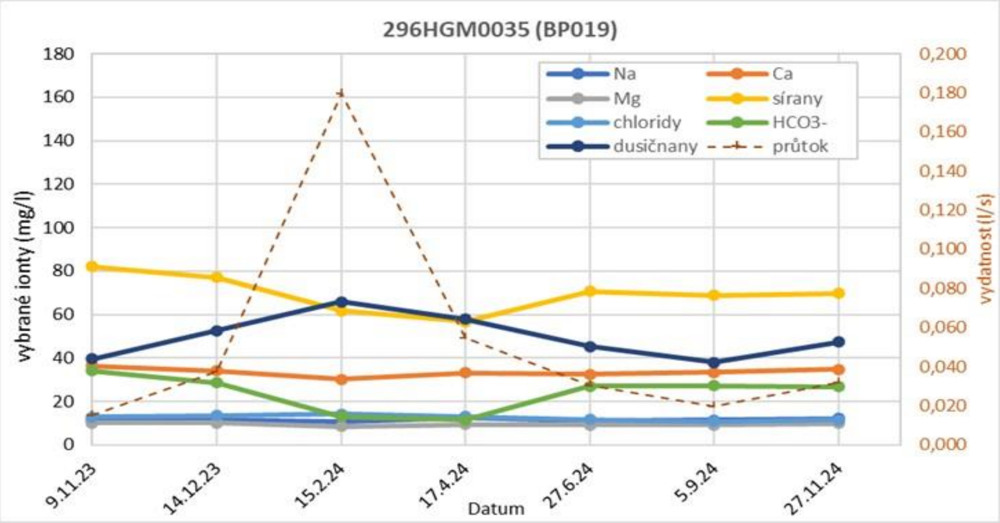


Figure 13 Development of groundwater chemistry and spring yield in the period 2023-2024 - 296HGM0035

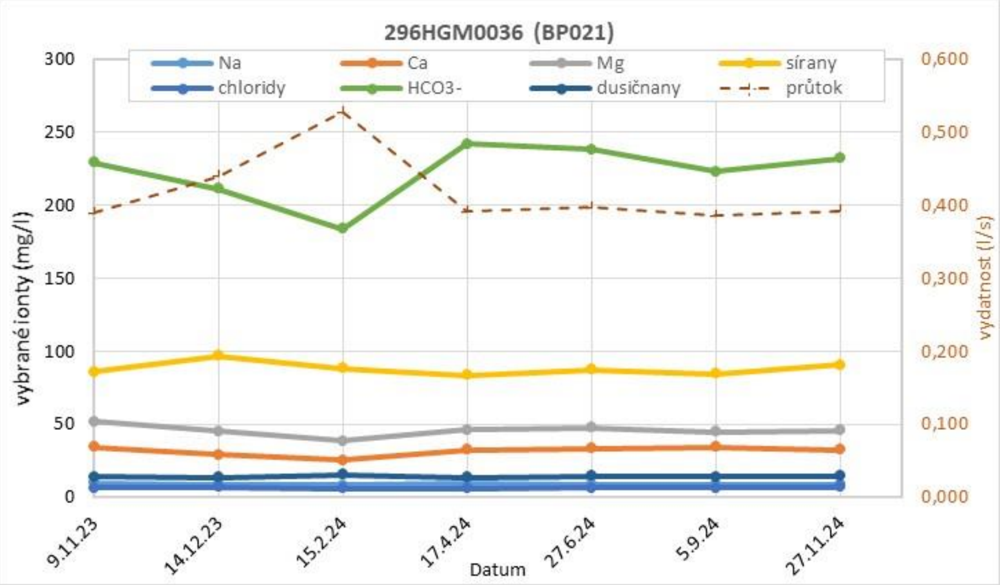


Figure 14 Development of groundwater chemistry and spring yield in the period 2023-2024 - 296HGM0036

Direct measurements - flow of the Bukovský stream

Flow rates in Bukovský Stream, significantly influenced by the discharge of mine water, ranged between 14.343 l/s (06/2024) and 53.062 l/s (02/2024) in the period 2023-2024 during the direct measurements and sampling (Table 7). Additional direct flow measurements using a hydrometer (14-79 l/s) were performed to update the specific flow curve.

Direct measurement of groundwater levels - hydrogeological boreholes

The groundwater level (GWL) in hydrogeological boreholes (PV-5 depth 10.43 m below ground, PV-6 depth 11.52 m bgl, PV-8 depth 17.51 m bgl) located at the Bukov landfill (Figure 3, Table 8) were measured manually using a level gauge.

In the period 2023-2024 groundwater level in PV boreholes continued to fluctuate (Table 8, Figure 15) depending on climatic conditions. Groundwater level in boreholes was at its highest level since 2015, except for the initial targets in 04/2015 in 2021 (significant rainfall). The lowest groundwater level for the period 2023-2024 was in borehole PV-8 and the highest in boreholes PV-5 and PV-6 in 04/2024.

Table 8 Direct measurements on the surface of Bukov URF I in the period 2023-2024 – GWL (m from SP) in PV boreholes

Borehole (original name)	SURAO No.	Date	Groundwater level (m from SP)	Changes in GWL: - reduction, + increase (m)	Comment
PV-5	296HGM0029	09/11/2023	10.18	0.71	
PV-5		14/12/2023	**10.73**	-0.35	**Min. GWL**
PV-5		15/02/2024	7.60	2.93	
PV-5		17/04/2024	*6.77*	*0.83*	*Max. GWL*
PV-5		26/06/2024	8.51	-1.74	
PV-5		04/09/2024	9.40	-0.89	
PV-5		28/11/2024	9.38	0.02	
PV-6	296HGM0030	09/11/2023	8.72	-1.17	
PV-6		14/12/2023	**8.94**	-0.22	**Min. GWL**
PV-6		15/02/2024	8.02	0.92	
PV-6		17/04/2024	*6.79*	*1.23*	*Max. GWL*
PV-6		26/06/2024	7.04	-0.25	
PV-6		04/09/2024	8.15	-1.11	
PV-6		28/11/2024	8.01	0.14	
PV-8	296HGM0031	08/11/2023	13.50	-1.11	
PV-8		14/12/2023	13.73	-0.23	
PV-8		15/02/2024	**14.14**	**-0.41**	**Min. GWL**
PV-8		17/04/2024	13.22	0.92	
PV-8		26/06/2024	*12.46*	*0.76*	*Max. GWL*
PV-8		04/09/2024	12.49	-0.03	
PV-8		28/11/2024	12.67	-0.18	

Comment: SP – sampling point (height of Fe casing in m above the terrain)

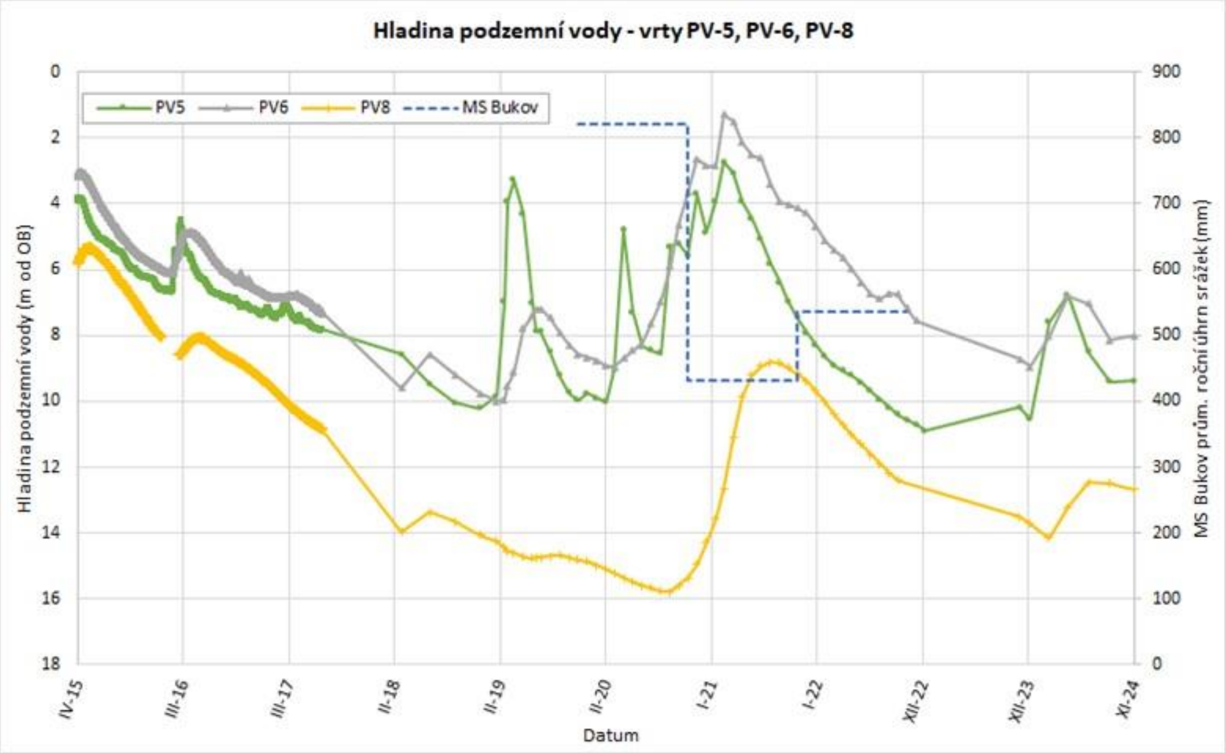


Figure 15 Groundwater level 2023-2024 on the surface of Bukov URF I in boreholes PV-5, PV-6, PV-8

4.2 Qualitative and quantitative monitoring in the area of Bukov URF I

4.2.1 Monitored objects, scope of monitoring, location of inflows

In the area of the Bukov URF on level 12 of the Rožná mine, qualitative monitoring was performed at 12 documentation points and from June 2024 at 13 points (Table 10, Figures 17 and 18).

The frequency of water sampling in the area of Bukov URF I was 7x in the period 2023-2024, i.e., 2x in 2023 (November, December) and 5x in 2024 approximately after 2 months (February, April, June, September and November). Water sampling in the area of Bukov URF I was performed by collecting water directly from the outflows from the rock massive or boreholes through collection troughs (Figure 16). Within each water sample collection, direct measurements of physical and chemical parameters (pH, Eh, conductivity, dissolved oxygen, water temperature) were performed.

The range of analyses determinations is given in Table 9.

Table 9 Range of analyses:

Basic water analysis – 2x in 2023; 5x in 2024	Na, K, Mg, Ca, Fe, Cl, F, HCO_3, NO_3, SO_4, SiO_2, NH_4, pH, conductivity
Trace elements – 2x in 2023; 5x in 2024	Al, As, Ba, P, Pb, Zn, Mn, Rb, Sr, Li, Mo,
Radioactive substances – 1× year (*total 2x, v 4/2024 a 11/2024)	Gross alpha activity, gross beta activity, dissolved U, ^{222}Rn

The schematic locations of the documentation points in the area of Bukov URF (level 12 of the main) including their changes are shown in Figure 17 and Figure 18**.**

Table 10 Overview of documentation points included in the monitoring in the area of Bukov URF, including changes

Point No.	Original name	Documentation point number according to SÚRAO	Name of the part of the mining operation according to DIAMO rules	Monitoring Quantity/quality	Measurement
1	Total outflow	296HGM0001	BZ-XIIJ	Quantity	Automatic
2	BK23	296HGM0002	BZ-XIIJ	Quantity + quality	Automatic
3	BK06	296HGM0003	BZ-XIIJ	Quantity + quality	Automatic
4	BK6b	296HGM0004	BZ-XIIJ	Quantity	Automatic
5	BK7	296HGM0005	BZ-XIIJ	Quantity + quality	Automatic
6	BK29+BK33	296HGM0006	BZ-XIIJ	Quantity	Automatic
7	BK15	296HGM0007	BZ-XIIJ	Quantity + quality	Automatic
8	BK18(S1)	296HGM0008	VrK-1	Quantity + quality	Automatic
9	BK31	296HGM0010	BZ1-XII	Quantity + quality	Automatic
10	BK32	296HGM0011	BZ1-XII	Quantity	Automatic
11	BK34(S14)	296HGM0012	BZ1-XII	Quantity	Automatic

Point No.	Original name	Documentation point number according to SÚRAO	Name of the part of the mining operation according to DIAMO rules	Monitoring Quantity/quality	Measurement
12	BK35	296HGM0013	BZ1-XII	Quantity + quality	Automatic
13	S20	296HGM0015	ZK-3S	Quantity	Automatic
14	BK38	296HGM0017	ZK-3S	Quantity + quality	Automatic
15	S21	296HGM0016	ZK-3S	Quantity	Automatic
16	BK26	296HGM0018	BZ1-XII	Quantity + quality	Automatic
17	BK27 (S2)	296HGM0019	BZ1-XII	Quantity + quality	Automatic
18	S23	296HGM0042	PŠ1-123	Quantity + quality	Manual
19	S25	296HGM0044	PŠ1-123	Quantity + quality	Manual
20	BZ1-XIIJ 255 m	296HGM0052	BZ1-XII	Quantity + quality	Manual

Figure 16 Collection troughs

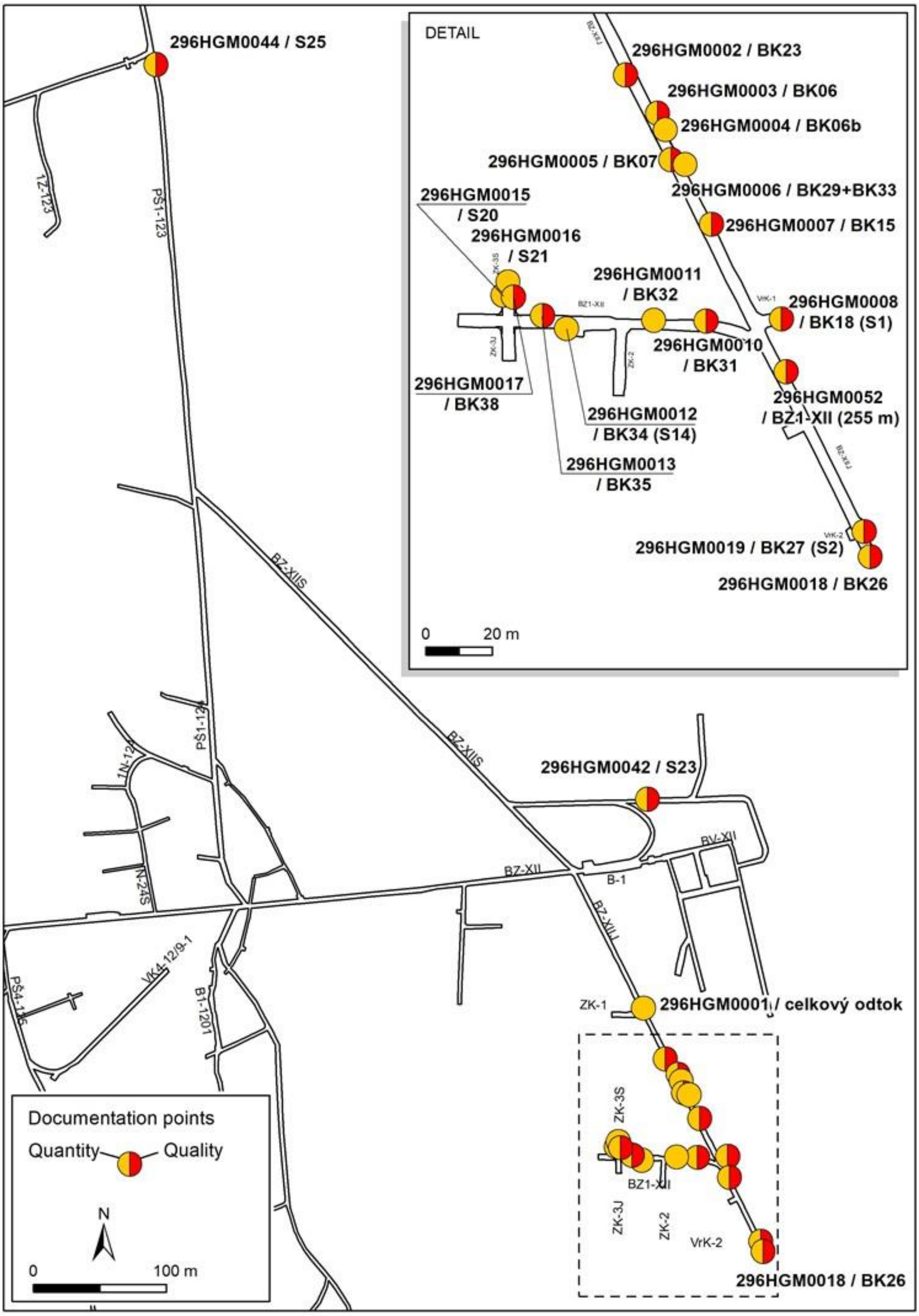


Figure 17 Schematic situation of the monitored area on level 12 of the mine in the period 2023-2024

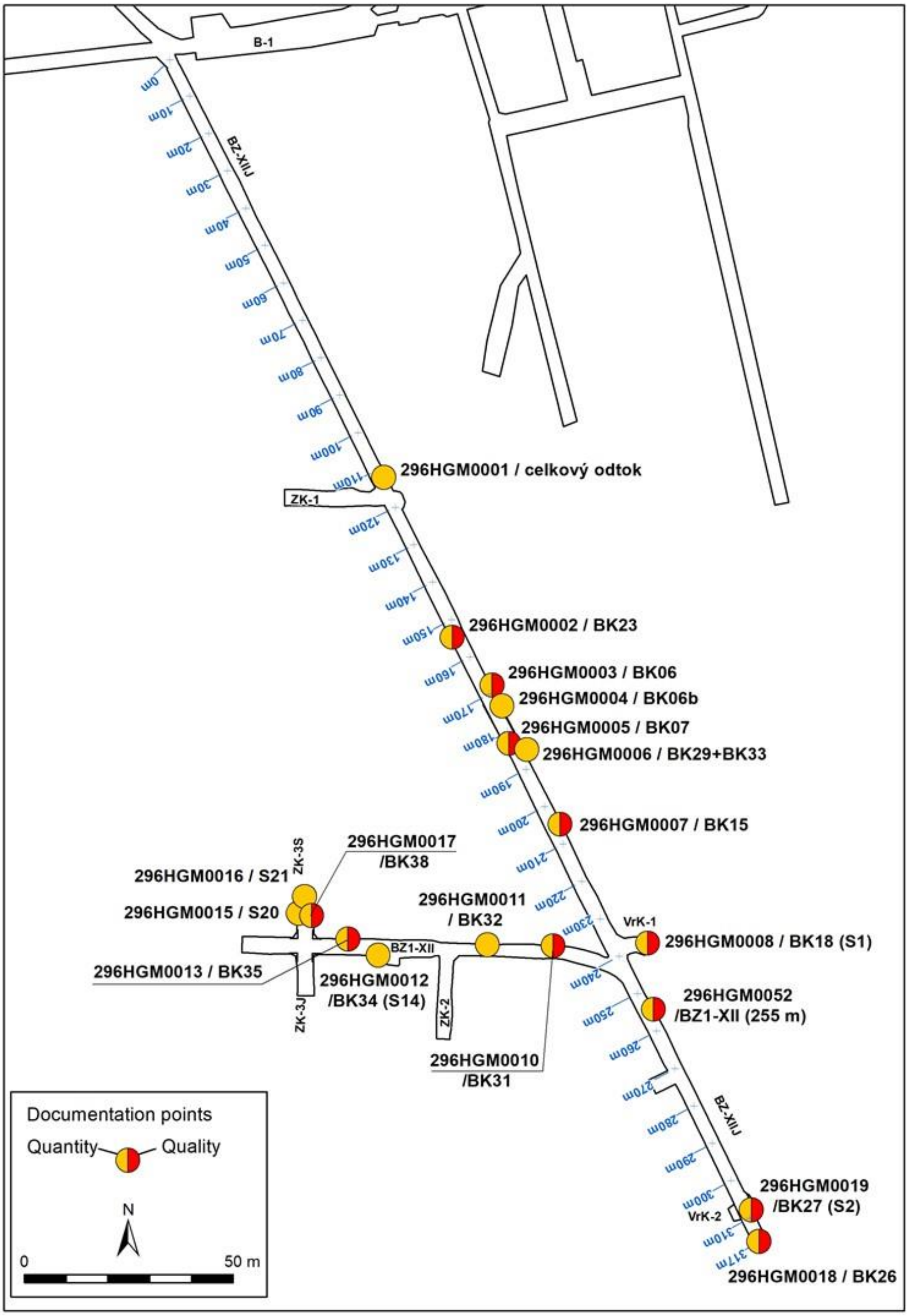


Figure 18 Schematic situation in the area of Bukov URF I in the period 2023-2024

4.2.2 Chemical composition of groundwater in the area of Bukov URF I

According to Bukovská et al. (2017), changes in the chemical composition of groundwater in the area of Bukov URF I on level 12 of the mine (550 m below ground level) depend on the depth of their occurrence, changes in the environment of their flow, and the residence time in the rock environment. In the open areas of the mine, the inflowing groundwater enters the oxidising environment due to the flow and stagnation of groundwater. The ongoing ion exchange changes the composition of groundwater.

In the groundwater of the inflows to the area of Bukov URF I (Table 11) in the period 2023-2024, cations Ca^+ prevailed over Mg^+ and the anions HCO_3^- over SO_4^{2-}, hydrochemical types CaMg-HCO_3SO_4(Cl) to CaMg-SO_4HCO_3 typical groundwater for the reducing environment of the crystalline structure in the Bukov URF. In boreholes 296HGM0042 (S-23) and 296HGM0044 (S-25), Na^+ and HCO_3^- predominated, hydrochemical types NaCa-HCO_3 to Na-HCO_3SO_4(Cl) typical of practically stagnant waters deep below erosion bases in Bukov URF I.

The chemical composition of groundwater inflows to URF I is shown using a Piper diagram (Figure 19, Figure 21) and Durov diagram (Figure 20).

Measured values of the monitored parameters in the period 2023-2024 are part of the appendixes (Appendix 3 to Appendix 10).

Table 12 shows the minimum, maximum and average values of the monitored parameters of chemical composition (basic analysis, Trace elements) of inflows to Bukov URF I for the period 2023-2024.

Table 11 Overview of hydrochemical types of groundwater in the area of Bukov URF I in the period 2023-2024

ID	Date	≥20 %meq%	≥ 20% meq%	≥20 % meq%	≥50 % meq%	Predominant ions	Chemical type 20 % equi.
BK06	11_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(59 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK06	12_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(62 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK06	02_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(62.4 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK06	04_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(62.2 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK06	06_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(59.7 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK06	09_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(60.9 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK06	11_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(60.8 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK07	11_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(61 %)-	Ca-HCO3-SO4-Cl-Mg	CaMg-HCO3SO4Cl
BK07	12_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(62 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK07	02_24	Ca,Mg	SO4,HCO3,Cl	Ca,Mg-SO4,HCO3,Cl	Ca(62.8 %)-	Ca-SO4-HCO3-Mg-Cl	CaMg-SO4HCO3Cl
BK07	04_24	Ca,Mg	SO4,HCO3,Cl	Ca,Mg-SO4,HCO3,Cl	Ca(61.8 %)-	Ca-SO4-HCO3-Mg-Cl	CaMg-SO4HCO3Cl
BK07	06_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(59.5 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK07	09_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(61 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK07	11_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(61.7 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK15	11_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(61 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK15	12_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(61 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK15	02_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(62.2 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK15	04_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(61 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK15	06_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(59.6 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK15	09_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(60.6 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK15	11_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(60.7 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK18 (S-1)	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(58 %)-HCO3(65%)	HCO3-Ca-SO4-Mg	CaMg-HCO3SO4
BK18 (S-1)	12_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(59 %)-HCO3(63%)	HCO3-Ca-SO4-Mg	CaMg-HCO3SO4
BK18 (S-1)	02_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(60.7 %)-HCO3(62.9%)	HCO3-Ca-SO4-Mg	CaMg-HCO3SO4
BK18 (S-1)	04_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(58.9 %)-HCO3(64 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK18 (S-1)	06_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(56.5 %)-HCO3(64.5 %)	HCO3-Ca-SO4-Mg	CaMg-HCO3SO4
BK18 (S-1)	09_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(57.8 %)-HCO3(64.8 %)	HCO3-Ca-SO4-Mg	CaMg-HCO3SO4
BK18 (S-1)	11_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(58.9 %)-HCO3(64.5 %)	HCO3-Ca-SO4-Mg	CaMg-HCO3SO4
BK23	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(60 %)-HCO3(54 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4

ID	Date	≥20 %meq%	≥ 20% meq%	≥20 % meq%	≥50 % meq%	Predominant ions	Chemical type 20 % equi.
BK23	12_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(61 %)-HCO3(53 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK23	02_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(61.3 %)-HCO3(53 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK23	06_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(59.1 %)-HCO3(55.6 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK23	09_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(59.3 %)-HCO3(55.1 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK23	04_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(60.2 %)-HCO3(54 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK23	11_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(59.3 %)-HCO3(53.7 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK26	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(61 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK26	12_23	Ca, Mg	HCO3, SO4, Cl	Ca, Mg-HCO3, SO4, Cl	Ca(59 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK26	02_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(61.4 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK26	04_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(59 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK26	06_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(57.1 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK26	09_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(58. 8%)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK26	11_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(59.8 %)-HCO3(40.3 %)	HCO3-Ca-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BK27 (S-2)	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(56 %)-HCO3(53 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK27 (S-2)	12_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(57 %)-HCO3(52 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK27 (S-2)	02_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(57.9 %)-HCO3(51 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK27 (S-2)	04_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(56.9 %)-HCO3(52 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK27 (S-2)	06_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(54.6 %)-HCO3(53.8 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK27 (S-2)	09_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(55.7 %)-HCO3(53.5 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK27 (S-2)	11_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(56.6 %)-HCO3(51.8 %)	Ca-HCO3-SO4-Mg	CaMg-HCOSO4
BK31	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(62 %)-HCO3(51 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK31	12_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(62 %)-HCO3(51 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK31	02_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(62.5 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK31	04_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(61.8 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK31	06_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(60.2 %)-HCO3(51.6 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK31	09_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(60.8 %)-HCO3(51.2 %)	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK31	11_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(60.8 %)-HCO3(50.2 %)	Ca-Mg-HCO3-SO4	CaMg-HCO3SO4
BK35	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(62 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK35	12_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(63 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK35	02_24	Ca,Mg	HCO3,SO4	Ca,Mg-HCO3,SO4	Ca(63.4 %)-	Ca-HCO3-SO4-Mg	CaMg-SO4HCO3

ID	Date	≥20 %meq%	≥ 20% meq%	≥20 % meq%	≥50 % meq%	Predominant ions	Chemical type 20 % equi.
BK35	04_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(62.4 %)-SO4(50.3 %)	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK35	06_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(62 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK35	09_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(61.5 %)-	Ca-HCO3-SO4-Mg	CaMg-SO4HCO3
BK35	11_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(61.8 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK38	11_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(62 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK38	12_23	Ca, Mg	HCO3, SO4	Ca, Mg-HCO3, SO4	Ca(62 %)-	Ca-HCO3-SO4-Mg	CaMg-HCO3SO4
BK38	02_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(63.3 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK38	04_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(62.2 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK38	06_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(62 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK38	09_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(61.2 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
BK38	11_24	Ca,Mg	SO4,HCO3	Ca,Mg-SO4,HCO3	Ca(61.2 %)-	Ca-SO4-HCO3-Mg	CaMg-SO4HCO3
S23	11_23	Na, Ca	HCO3	Na, Ca-HCO3	Na(61 %)-HCO3(87 %)	HCO3-Na-Ca	NaCa-HCO3
S23	12_23	Na, Ca	HCO3	Na, Ca-HCO3	Na(62 %)-HCO3(85 %)	HCO3-Na-Ca	NaCa-HCO3
S23	02_24	Na,Ca	HCO3	Na,Ca-HCO3	Na(62.5 %)-HCO3(84.7 %)	HCO3-Na-Ca	NaCa-HCO3
S23	04_24	Na,Ca	HCO3	Na,Ca-HCO3	Na(63 %)-HCO3(82 %)	Na-HCO3-Ca	NaCa-HCO3
S23	06_24	Na,Ca	HCO3	Na,Ca-HCO3	Na(64.7 %)-HCO3(83.8 %)	HCO3-Na-Ca	NaCa-HCO3
S23	09_24	Na,Ca	HCO3	Na,Ca-HCO3	Na(61.9 %)-HCO3(84.1 %)	HCO3-Na-Ca	NaCa-HCO3
S23	11_24	Na,Ca	HCO3	Na,Ca-HCO3	Na(61.4 %)-HCO3(82.2 %)	HCO3-Na-Ca	NaCa-HCO3
S25	11_23	Na	HCO3, SO4	Na-HCO3, SO4	Na(97 %)-HCO3(53%)	Na-HCO3-SO4	Na-HCO3SO4
S25	12_23	Na	HCO3, SO4	Na-HCO3, SO4	Na(97 %)-HCO3(51%)	Na-HCO3-SO4	Na-HCO3SO4
S25	02_24	Na	HCO3,SO4,Cl	Na-HCO3,SO4,Cl	Na(97.3 %)-	Na-HCO3-SO4-Cl	Na-HCO3SO4Cl
S25	04_24	Na	HCO3,SO4,Cl	Na-HCO3,SO4,Cl	Na (97 %)-	Na-HCO3-SO4-Cl	Na-HCO3SO4Cl
S25	06_24	Na	HCO3,SO4,Cl	Na-HCO3,SO4,Cl	Na(97.5 %)-	Na-HCO3-SO4-Cl	Na-HCO3SO4Cl
S25	09_24	Na	HCO3,SO4,Cl	Na-HCO3,SO4,Cl	Na(97 %)-	Na-HCO3-SO4-Cl	Na-HCO3SO4Cl
S25	11_24	Na	HCO3,SO4	Na-HCO3,SO4	Na(97 %)-HCO3(51 %)	Na-HCO3-SO4	Na-HCO3SO4
BZ1-XIIJ 255 m	06_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(57.2 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BZ1-XIIJ 255 m	09_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(58 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl
BZ1-XIIJ 255 m	11_24	Ca,Mg	HCO3,SO4,Cl	Ca,Mg-HCO3,SO4,Cl	Ca(58.7 %)-	Ca-HCO3-SO4-Mg-Cl	CaMg-HCO3SO4Cl

Table 12 Chemical composition of groundwater of inflows into the area of Bukov URF I (min., max., average) in the period 2023-2024

ukazatel		**pH**	**vodivost**	**KNK 4,5**	**Na**	**K**	**NH4+**	**Ca**	**Mg**	**SO4**	**chloridy**	**dusičnany**	**fluoridy**	**SiO2**	**HCO3-**	**As**	**Pb**	**Al**	**Zn**	**Mn**	**Fe**	**Ba**	**Mo**	**Sr**	**Pcelk.**	**Li**	**Rb**	**TDS**
objekt	**datum**		**µS/cm (20°C)**	**mmol/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**ug/l**	**ug/l**	**ug/l**	**ug/l**	**mg/l**	**mg/l**	**ug/l**	**ug/l**	**ug/l**	**mg/l**	**mg/l**	**ug/l**	**mg/l**
BK06	MIN	7,99	404,00	1,92	*11,70*	2,55	<0,050	48,20	11,90	61,90	29,90	<0,27	0,21	28,50	117,00	<5	<5	<10	<2	0,002	0,005	179,00	<2	133,00	<0,0500	0,022	<20	316,56
	MAX	8,24	528,00	2,22	16,60	2,90	<0,050	60,90	15,90	85,00	39,10	<0,27	0,27	40,20	135,00	<5	<5	<10	11,60	0,180	0,022	197,00	7,80	241,00	<0,0500	0,029	<20	384,05
	PRŮMĚR	8,14	440,00	1,99	12,77	2,73	<0,050	51,44	12,74	68,67	32,30	<0,27	0,23	32,13	121,29	<5	<5	<10	6,25	0,055	0,011	187,43	4,10	159,00	<0,0500	0,025	<20	333,36
BK07	MIN	8,12	605,00	2,37	18,00	3,06	<0,050	70,20	17,90	100,00	50,60	<0,27	<0,200	28,40	144,00	<5	<5	<10	4,70	<0,00050	0,017	136,00	2,70	240,00	<0,0500	0,027	<20	450,22
	MAX	8,25	**654,00**	2,46	19,20	3,50	<0,050	78,50	18,40	143,00	**55,20**	<0,27	0,33	40,20	150,00	<5	<5	12,70	66,10	0,023	0,622	156,00	3,40	290,00	<0,0500	0,038	<20	490,33
	PRŮMĚR	8,19	634,57	2,44	18,57	3,23	<0,050	75,64	18,16	115,29	52,94	<0,27	0,33	31,84	148,43	<5	<5	11,35	18,69	0,006	0,154	146,14	3,16	270,57	<0,0500	0,032	<20	463,55
BK15	MIN	8,13	531,00	2,37	16,00	2,86	<0,050	62,80	15,90	86,70	40,50	<0,27	<0,20	30,40	144,00	<5	<5	<10	6,50	0,002	0,030	190,00	<2	206,00	<0,0500	0,027	<20	407,78
	MAX	8,33	599,00	2,48	16,90	3,26	<0,050	68,40	17,00	114,00	41,80	<0,27	0,35	42,40	152,00	6,40	<5	706,00	492,00	0,399	23,400	**336,00**	2,60	241,00	**0,18**	0,034	<20	452,21
	PRŮMĚR	8,23	559,71	2,43	16,56	2,98	<0,050	66,54	16,30	95,79	41,07	<0,27	0,27	33,64	148,29	6,40	<5	706,00	78,51	0,060	4,766	217,14	2,37	229,00	0,18	0,029	<20	422,12
BK18(S-1)	MIN	8,00	352,00	2,27	12,80	2,42	<0,050	38,40	9,48	41,60	12,60	<0,27	0,20	33,30	138,00	<5	<5	<10	<2	0,065	0,030	63,90	<2	116,00	<0,0500	0,022	<20	292,58
	MAX	8,24	378,00	2,34	13,60	2,84	<0,050	42,90	10,10	46,20	14,10	<0,27	0,26	**46,60**	143,00	<5	<5	<10	3,70	0,071	0,051	69,70	<2	137,00	<0,0500	0,031	<20	313,13
	PRŮMĚR	8,11	359,71	2,31	13,20	2,61	<0,050	40,84	9,82	43,59	13,54	<0,27	0,22	36,91	140,71	<5	<5	<10	3,70	0,067	0,036	67,27	<2	128,86	<0,0500	0,026	<20	300,28
BK23	MIN	8,01	385,00	2,08	13,10	2,15	<0,050	43,90	10,40	48,80	23,10	<0,27	<0,20	28,50	127,00	<5	<5	<10	<2	0,017	0,021	147,00	<2	157,00	<0,0500	0,021	<20	301,79
	MAX	8,13	403,00	2,16	13,90	3,32	<0,050	47,20	10,80	56,20	25,70	<0,27	0,28	39,80	132,00	<5	<5	23,60	4,70	**0,462**	0,574	178,00	**12,60**	188,00	<0,0500	0,028	<20	319,73
	PRŮMĚR	8,09	392,00	2,12	13,64	2,50	<0,050	45,59	10,59	52,63	24,23	<0,27	0,24	31,70	129,14	<5	<5	18,05	3,02	0,104	0,205	156,86	3,98	169,43	<0,0500	0,023	<20	309,64
BK26	MIN	8,07	422,00	1,96	12,10	2,25	<0,050	51,40	12,10	63,40	28,90	<0,27	<0,20	27,90	119,00	<5	<5	<10	<2	0,001	0,003	178,00	3,30	147,00	<0,0500	0,023	<20	319,85
	MAX	8,27	544,00	2,24	17,70	2,78	<0,050	66,00	16,30	108,00	44,20	<0,27	0,25	41,60	137,00	<5	<5	<10	3,60	0,055	0,049	188,00	8,60	271,00	<0,0500	**0,039**	<20	411,88
	PRŮMĚR	8,13	518,43	2,17	16,20	2,58	<0,050	59,80	15,47	90,17	39,50	<0,27	0,25	31,73	132,57	<5	<5	<10	3,33	0,009	0,010	184,14	7,29	230,14	<0,0500	0,030	<20	387,33
BK27 (S-2)	MIN	8,05	415,00	2,18	15,30	2,20	<0,050	43,70	12,10	57,40	24,20	<0,27	<0,20	31,20	133,00	<5	<5	<10	<2	0,077	0,045	135,00	4,20	184,00	<0,0500	0,026	<20	324,95
	MAX	8,22	436,00	2,25	16,50	2,54	<0,050	49,10	13,80	66,20	27,10	<0,27	0,25	43,60	137,00	<5	<5	<10	8,00	0,094	0,170	146,00	5,10	226,00	<0,0500	0,034	<20	343,08
	PRŮMĚR	8,09	415,38	2,21	15,90	2,37	<0,050	46,53	12,70	61,96	25,05	<0,27	*0,19*	35,30	134,75	<5	<5	<10	8,00	0,080	0,069	140,75	4,69	202,00	<0,0500	0,028	<20	332,98
BK31	MIN	8,09	460,00	2,33	12,90	2,24	<0,050	53,30	13,10	71,90	24,50	<0,27	<0,200	30,70	142,00	<5	<5	<10	3,30	0,001	*0,002*	192,00	<2	186,00	<0,0500	0,026	<20	356,73
	MAX	8,29	491,00	2,42	13,50	2,86	<0,050	58,40	13,90	86,80	26,90	<0,27	0,25	43,90	147,00	<5	<5	13,20	12,60	0,010	0,047	201,00	<2	228,00	<0,0500	0,035	<20	376,50
	PRŮMĚR	8,20	469,43	2,37	13,24	2,50	<0,050	55,77	13,61	76,81	25,36	<0,27	0,23	34,70	144,43	<5	<5	13,20	5,79	0,002	0,017	198,29	<2	206,86	<0,0501	0,028	<20	365,61
BK35	MIN	8,10	605,00	2,38	17,90	3,00	<0,050	76,80	18,10	111,00	39,40	<0,27	0,34	27,80	145,00	<5	<5	<10	34,60	0,001	0,052	123,00	2,60	326,00	<0,0050	0,026	<20	448,94
	MAX	8,30	650,00	2,52	18,90	3,54	<0,050	80,70	**18,90**	**175,00**	41,90	<0,27	0,34	38,20	154,00	**27,30**	<5	147,00	1520,00	0,034	**26,300**	255,00	2,90	**356,00**	0,15	0,037	<20	511,20
	PRŮMĚR	8,22	636,86	2,46	18,27	3,23	<0,050	79,04	18,49	137,14	40,07	<0,27	0,34	30,69	150,00	27,30	<5	62,87	272,61	0,007	4,217	147,43	2,74	338,00	0,15	0,030	<20	480,85
BK38	MIN	8,01	401,00	2,40	18,00	2,88	<0,050	73,70	17,10	110,00	40,20	<0,27	<0,20	26,90	147,00	<5	<5	<10	181,00	0,002	0,011	132,00	2,00	292,00	<0,0500	0,028	<20	448,03
	MAX	8,31	649,00	**2,53**	19,20	**3,66**	<0,050	**81,20**	18,70	172,00	42,80	<0,27	0,34	39,30	**154,00**	<5	<5	36,20	337,00	0,087	0,399	145,00	2,80	347,00	<0,0500	0,036	<20	**511,54**
	PRŮMĚR	8,18	594,14	2,46	18,47	3,18	<0,050	77,57	18,20	132,71	41,09	<0,27	0,34	30,74	149,86	<5	<5	23,34	231,86	0,022	0,136	138,71	2,50	331,29	<0,0500	0,030	<20	471,60
S23	MIN	8,10	*259,00*	2,03	36,00	0,87	<0,050	13,20	2,89	*12,50*	*<5,0*	<0,27	0,32	17,60	124,00	<5	<5	<10	<2	0,003	0,004	*0,01*	<2	171,00	<0,0500	0,007	<20	*213,77*
	MAX	8,35	270,00	2,25	37,60	1,15	0,06	15,00	3,12	19,80	5,00	<0,27	0,41	24,30	137,00	<5	<5	12,70	15,00	0,008	0,048	10,60	<2	208,00	<0,0500	0,011	<20	234,06
	PRŮMĚR	8,26	263,43	2,18	36,61	0,97	0,06	14,39	3,01	15,80	5,00	<0,27	0,36	19,60	133,29	<5	<5	12,70	15,00	0,003	0,011	7,63	<2	191,00	<0,0500	0,008	<20	224,21
S-25	MIN	8,87	352,00	*1,84*	69,10	*0,62*	<0,050	*1,60*	*0,02*	41,40	20,20	<0,27	0,30	*15,30*	*78,30*	<5	<5	10,00	20,50	<0,00050	0,004	3,99	<2	*23,60*	<0,0500	0,002	<20	242,35
	MAX	**9,53**	384,00	1,93	**74,10**	0,68	<0,050	1,88	0,06	52,80	21,60	<0,27	**0,48**	22,70	102,00	<5	<5	12,20	75,90	<0,00050	0,012	6,58	<2	27,30	<0,0500	0,003	<20	259,33
	PRŮMĚR	9,27	366,29	1,89	71,94	0,64	<0,050	1,74	0,04	45,20	21,01	<0,27	0,40	17,97	90,71	<5	<5	11,18	39,63	<0,00050	0,007	5,40	<2	25,39	<0,0500	*0,002*	<20	249,00
BZ1-XII 255 m	MIN	8,06	484,00	2,20	16,00	2,42	<0,050	52,40	14,50	76,40	34,60	<0,27	<0,20	29,80	134,00	<5	<5	<10	<2	0,032	0,030	160,00	5,70	206,00	<0,0500	0,026	<20	363,78
	MAX	8,25	493,00	2,22	16,80	2,67	<0,050	56,30	14,90	82,60	36,10	<0,27	0,25	41,20	135,00	<5	<5	<10	3,10	0,037	0,037	169,00	6,50	258,00	<0,0500	0,037	<20	384,97
	PRŮMĚR	8,13	488,67	2,21	16,30	2,57	<0,050	54,97	14,70	79,17	35,23	<0,27	0,25	33,77	134,67	<5	<5	<10	3,10	0,034	0,034	163,67	6,20	233,33	<0,0500	0,030	<20	371,95
2023-24	MIN	7,99	259,00	1,84	11,70	0,62	0,06	1,60	0,02	12,50	*<5,0*	<0,27	0,19	15,30	78,30	<5	<5	<10	<2	<0,00050	0,002	0,01	<2	23,60	<0,0500	0,002	<20	213,77
	MAX	**9,53**	**654,00**	**2,53**	**74,10**	**3,66**	**0,06**	**81,20**	**18,90**	**175,00**	**55,20**	<0,27	**0,48**	**46,60**	**154,00**	**27,30**	<5	**706,00**	**1520,00**	**0,462**	**26,300**	**336,00**	**12,60**	**356,00**	**0,18**	**0,039**	<20	**511,54**

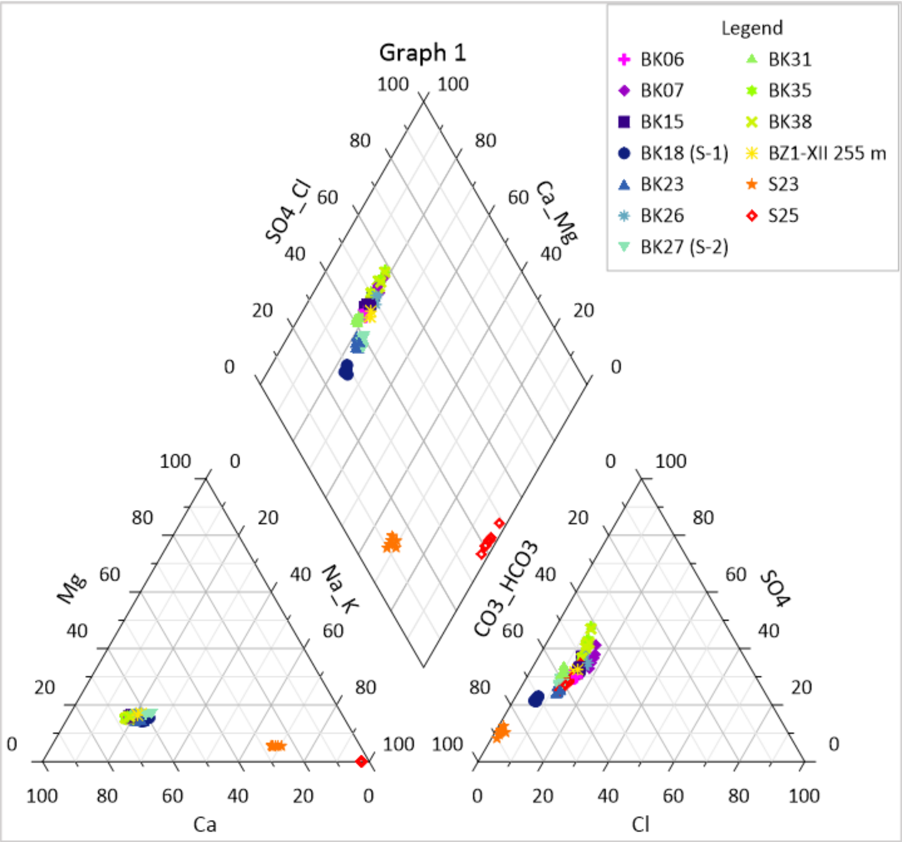


Figure 19 Piper diagram of the chemical composition of inflows in the area of Bukov URF I in the period 2023-2024

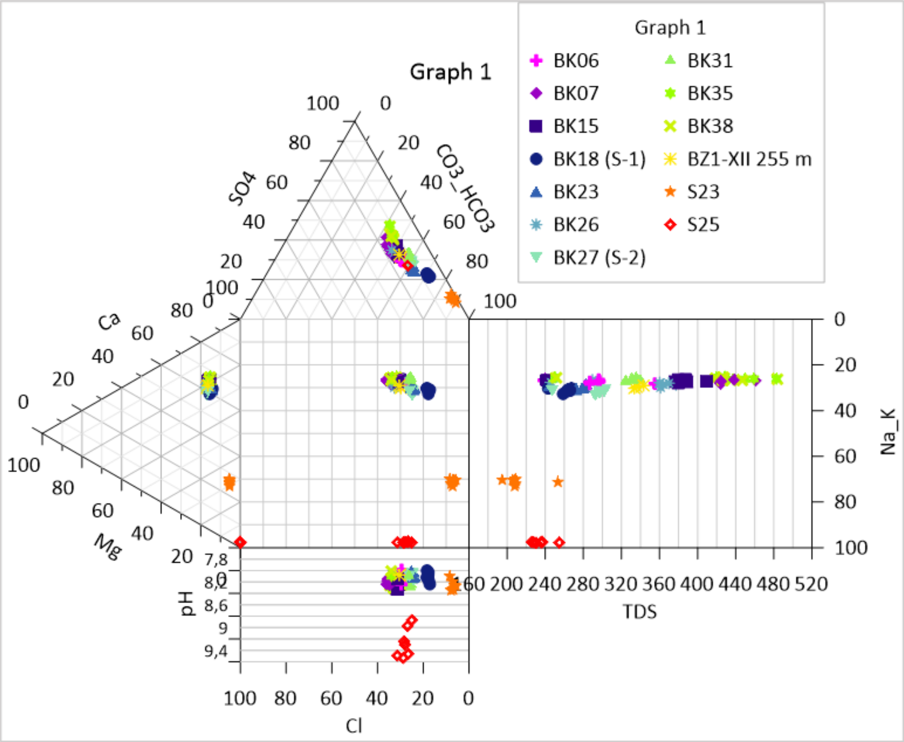


Figure 20 Durov diagram of the chemical composition of inflows in the area of Bukov URF I in the period 2023-2024

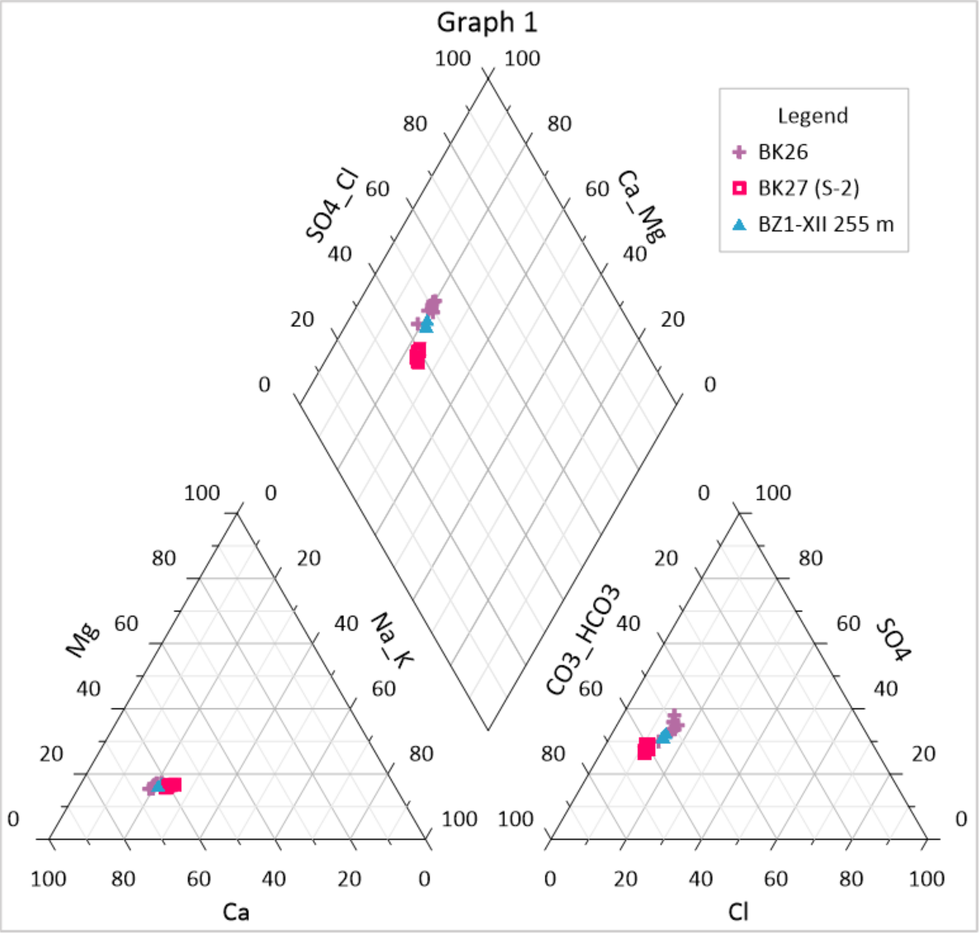


Figure 21 Piper diagram of the detail of the chemical composition of inflows 296HGM0018 (BK26), 296HGM0019 (BK27(S-2)) and 296HGM0052 at BZ1-XIIJ 255 m

Development of the chemical composition of groundwater – selected anions and cations

Selected monitored parameters of the chemical composition of groundwater inflows to the area of Bukov URF I for the period 2023-2024 are included in the appendixes (Appendixes 5-10).

The development of selected parameters (Ca, Mg, Na, sulphates, bicarbonates, chlorides, nitrates) of the chemical composition of groundwater inflows to the area of Bukov URF I for the period 2018-2023 is shown in graphs (Appendix 9). The report presents graphs of three inflows BK18 (S-1) and boreholes S-23 and S-25 as examples (Figures 23-25).

Compared to groundwater from springs on the surface of Bukov URF I, the development of the monitored parameters in the area of Bukov URF was relatively stable. As can be seen from the graphs (Appendixes 6 and 9), in the groundwater of the inflows to Bukov URF I in the period 2023-2024, HCO_3 and Ca predominated (inflows “BK”), and in the inflows from boreholes S-23 and S-25, HCO_3 and Na predominated (Figures 23-25).

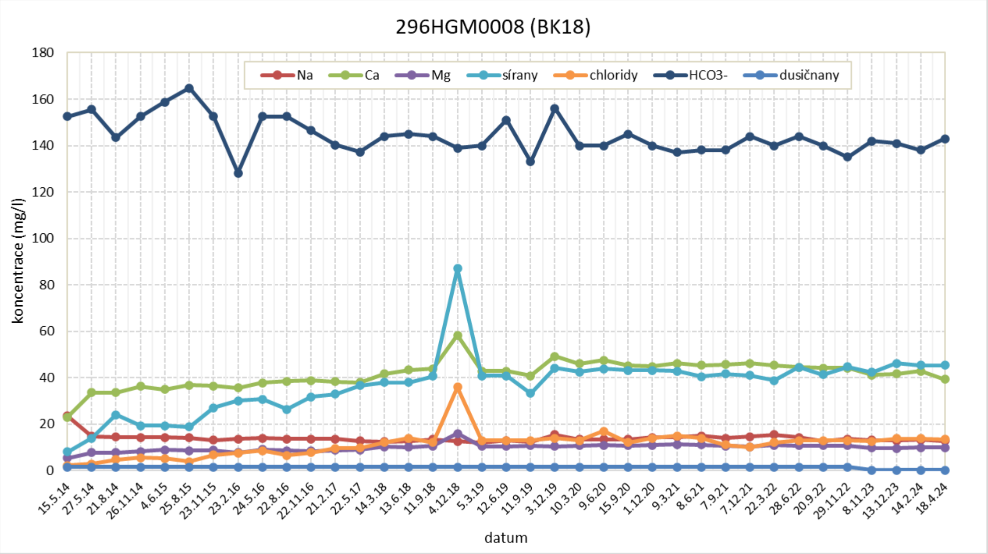


Figure 22 Evolution of the composition of the groundwater of inflow 296HGM0008

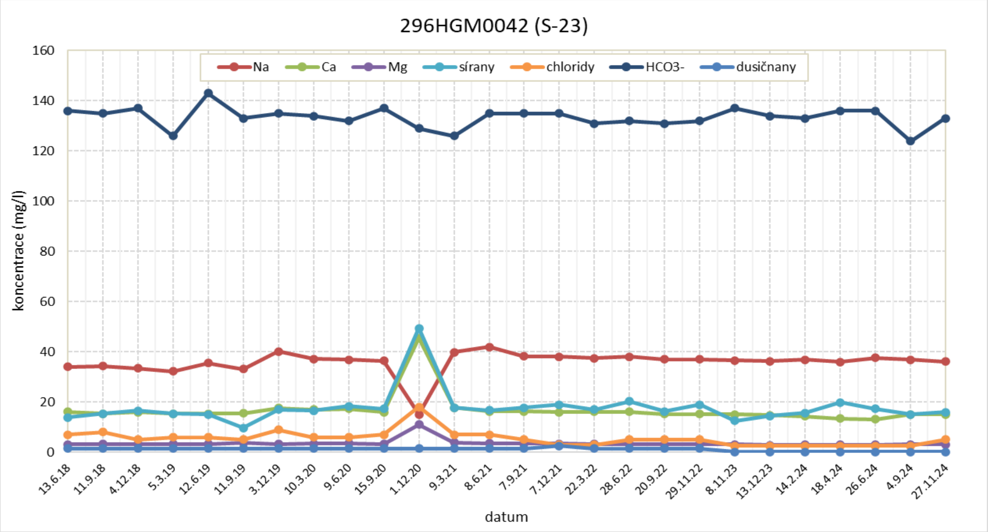


Figure 23 Evolution of the composition of the groundwater of inflow 296HGM0042

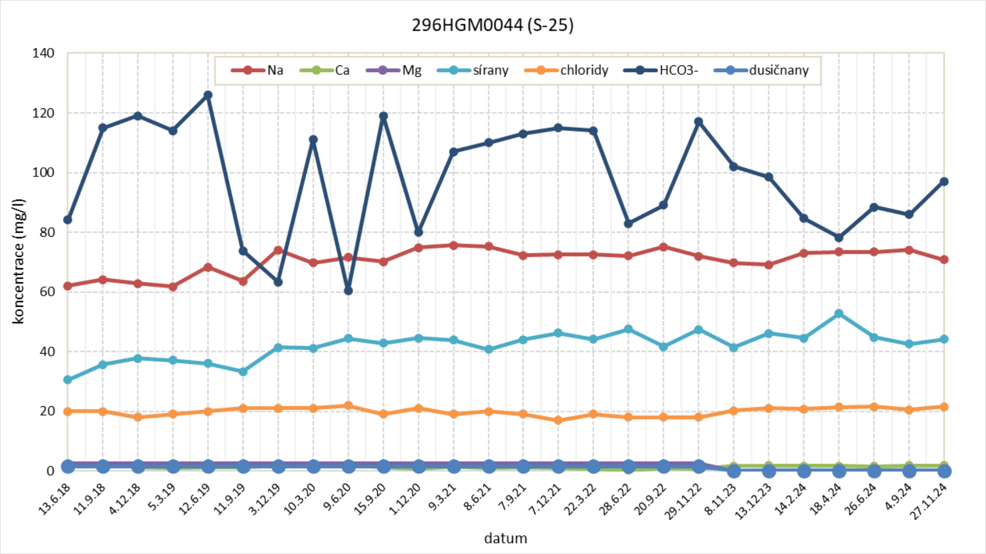


Figure 24 Evolution of the composition of the groundwater of inflow 296HGM0044

The temporal development of groundwater chemistry over time was graphically expressed using Piper and Durov diagrams (Appendix 6). Figure 26 (Zeman 2025) shows as an example the temporal development of groundwater chemistry at inflow 296HGM0008 (BK18 (S-1)) in the period 2014-2018. The graphical representation (Figure 22) showed an increasing proportion of Ca, chlorides, increasing total mineralisation and decreasing pH (in the direction of the red arrow).

The temporal development of groundwater chemistry at the same inflow in the subsequent period 2019-2024 (Figure 27) shows a noticeable difference in the development of chemistry after 2014-2018 (for pH and total mineralization. The trends of changes highlighted in Figure 26 by the red arrow were no longer so noticeable. Changes in chemistry may be related to the mine flooding that has been ongoing since 2021.

For a comparison, the report included other graphs with the time evolution of the chemistry of the inflow from borehole 296HGM0044 (S-25) with a different chemical composition, a predominance of Na^+ and HCO_3^- (Figure 28).

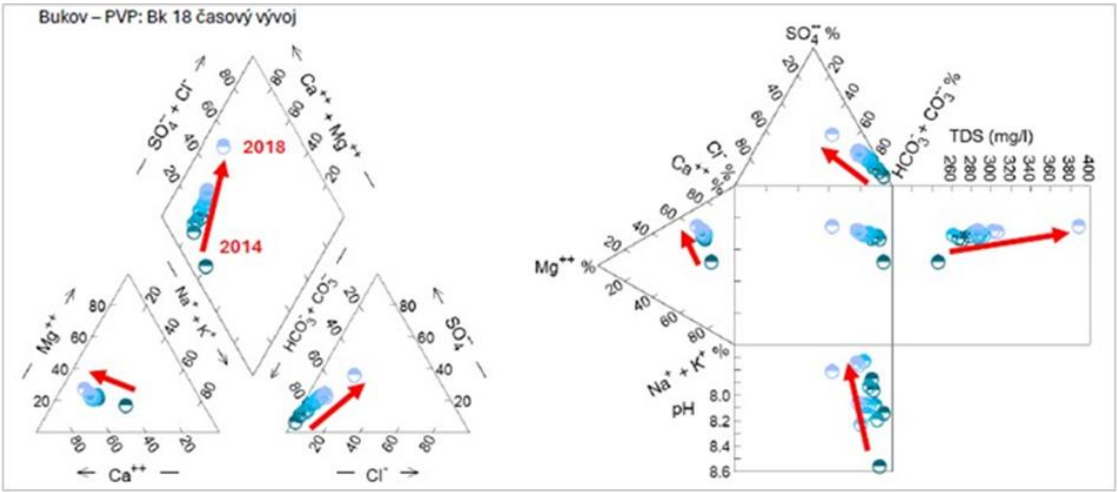


Figure 25 Temporal development of the chemistry of inflow 296HGM0008 (BK18 (S-1)) in the period 2014-2018 (adapted from the presentation Zeman 2025)

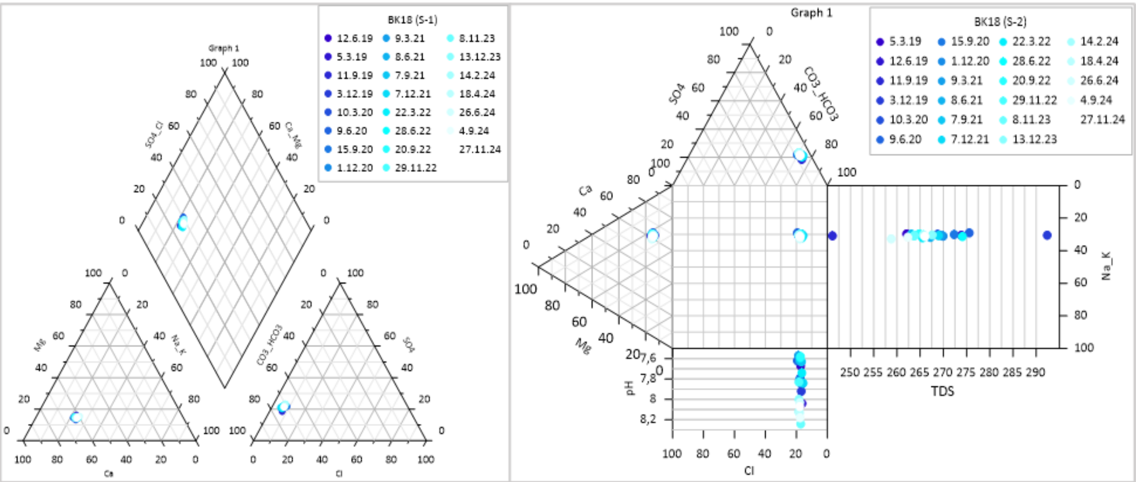


Figure 26 Temporal development of the chemistry of inflow 296HGM0008 (BK18 (S-1)) in the period 2019-2024

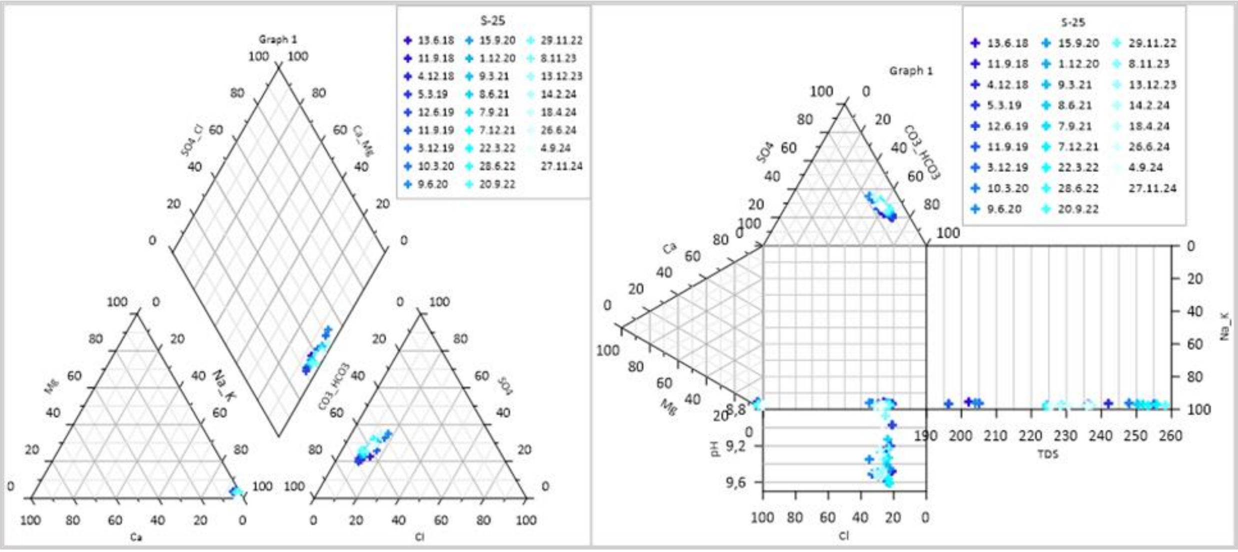


Figure 27 Temporal development of the chemistry of inflow 296HGM0044 (S-25) in the period 2018-2024

4.2.3 Direct measurements of the physical and chemical parameters of groundwater of inflows in the area of Bukov URF I

An overview of the minimum, maximum and average values of the monitored physical and chemical parameters (pH, conductivity, water temperature, dissolved oxygen, oxidation-reduction potential) in the period 2023-2024 for inflows to the area of Bukov URF I on level 12 of the mine (Table 13) is as follows:

- pH between 7.67 (BK06) and 10.37 (S-25), except for boreholes, highest 8.99 at BK15; slightly alkaline to alkaline water;
- Conductivity between 253 uS/cm (S-23) and 712 uS/cm (BK23); in BK inflows (except for boreholes S-23, S-25) highest 345 uS/cm at BK18,
- ORP (oxidation-reduction potential) between -127 mV (S-25) and 157 mV (S-25); except for boreholes, lowest -14 mV at BK27;
- Dissolved O_2 between 0.15 mg/l (BK18(S-1) to 14.84 mg/l (BK15);
- Water temperature between 12.9 °C (BK15) to 17.0 °C (BK18(S-1)), relatively stable, minimal fluctuations

Their development over time is shown in graphs (Appendix 8), where long-term fluctuations in all parameters have been evident for most of the inflows since 2018. The greatest fluctuation in values was for dissolved oxygen, while the development of pH and water temperature was relatively stable.

The report provides as an example graphs of inflow BK18 (S-1) with relatively stable development of parameters and the inflows from boreholes S-23 and S25 (Figures 29-31) with less stable development.

In the period 2023-2024, the most stable inflow in terms of the development of the physical and chemical parameters was 296HGM0008 (BK18 (S-1)). In most inflows, pH in 2024 decreased slightly, conductivity in most inflows stagnated or fluctuated very slightly with the exception of 296HGM0002 (BK23 in 09/2024), ORP increased slightly except for 296HGM0017 (BK38) and except for boreholes 296HGM0042 (S-23) and 296HGM0044 (S-25).

Table 13 Direct measurements of the physical and chemical parameters of inflows in the area of Bukov URF I (2023-2024)

2023-24		**T oC**	**pH**	**Vodivost uS/cm**	**O rozp. mg/l**	**ORP mV**
Objekt	jedn.	°C		µS/cm	mg/l	mV
BK06	min	*12,9*	*7,67*	415	11,78	15
	max	16,2	8,75	431	14,77	125
	prum.	14,4	8,21	421	12,96	68
BK07	min	13,9	7,95	614	11,55	25
	max	15,8	8,81	629	14,07	113
	prum.	14,6	8,30	625	12,72	68
BK15	min	13,3	8,10	543	11,93	28
	max	16,5	8,99	559	**14,84**	121
	prum.	14,4	8,43	550	13,13	72
BK18	min	15,4	7,80	*345*	*0,15*	19
	max	16,3	8,66	356	1,59	97
	prum.	15,7	8,26	348	0,85	52
BK23	min	13,1	7,88	381	8,84	-8
	max	16,0	8,72	712	14,35	132
	prum.	14,4	8,12	433	11,18	69
BK26	min	14,2	7,85	516	10,74	21
	max	16,7	8,87	546	13,90	95
	prum.	14,7	8,32	526	12,71	59
BK27	min	14,8	7,84	409	1,80	*-14*
	max	15,5	8,67	422	5,45	71
	prum.	15,1	8,25	413	4,44	22
BK31	min	14,2	8,05	449	11,56	27
	max	15,8	8,94	466	14,52	114
	prum.	14,8	8,40	456	13,03	73
BK35	min	14,2	8,06	621	11,62	35
	max	17,0	8,95	635	14,42	110
	prum.	15,1	8,46	628	12,92	73
BK38	min	14,5	8,06	608	11,26	27
	max	16,7	8,94	638	13,76	98
	prum.	15,4	8,45	624	12,24	59
S23	min	13,7	8,37	*253*	0,93	2
	max	15,8	9,16	265	6,55	88
	prum.	14,8	8,70	258	3,40	35
S25	min	14,0	9,50	349	1,22	-127
	max	16,9	**10,37**	369	7,50	**157**
	prum.	14,7	9,85	358	3,02	-39
BZ1-XII 255 m	min	14,5	7,83	477	10,78	3
	max	15,3	8,75	493	11,47	83
	prum.	14,9	8,27	485	11,19	41
BK	*min*	*12,9*	*7,67*	*345*	*0,15*	*-14*
	max	17,0	8,99	712	14,84	132
BK + S23,25	min	*12,9*	*7,67*	*253*	*0,15*	*-127*
	max	**17,0**	**10,37**	**712**	**14,84**	**157**
všechny objekty	min	12,9	7,67	253	0,15	-127
	max	**17,0**	**10,37**	**712**	**14,84**	**157**

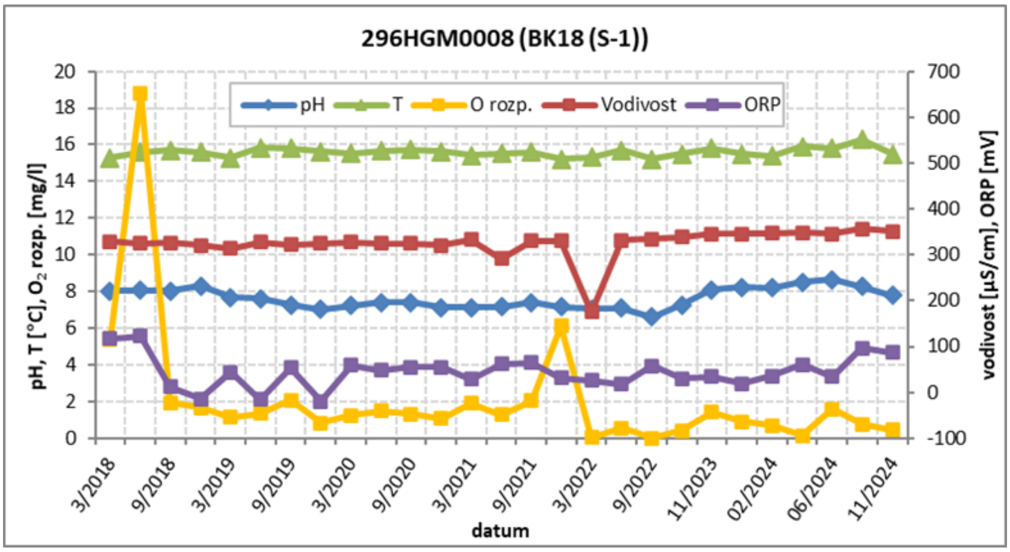


Figure 28 Development of physical and chemical parameters of inflow 296HGM0008

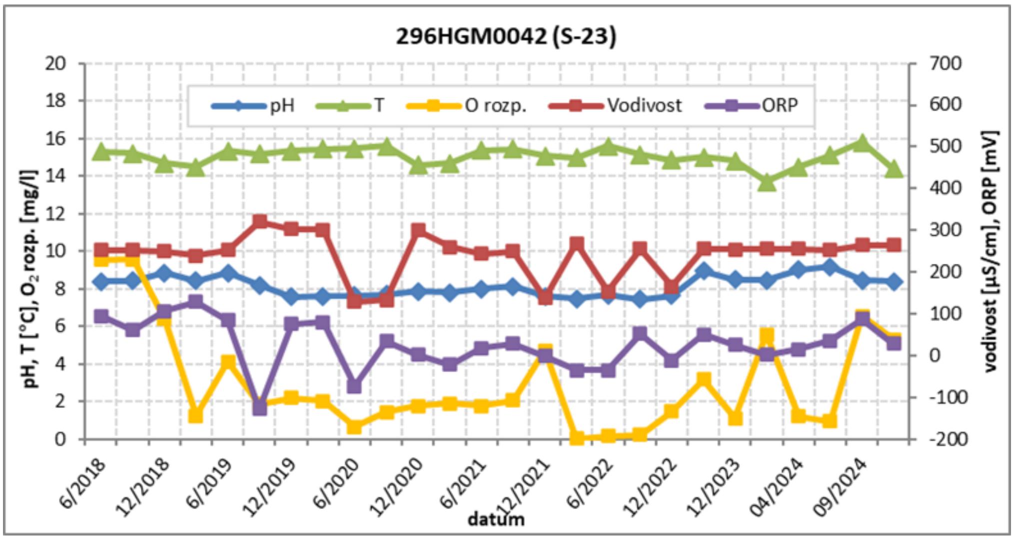


Figure 29 Development of physical and chemical parameters of inflow 296HGM0042

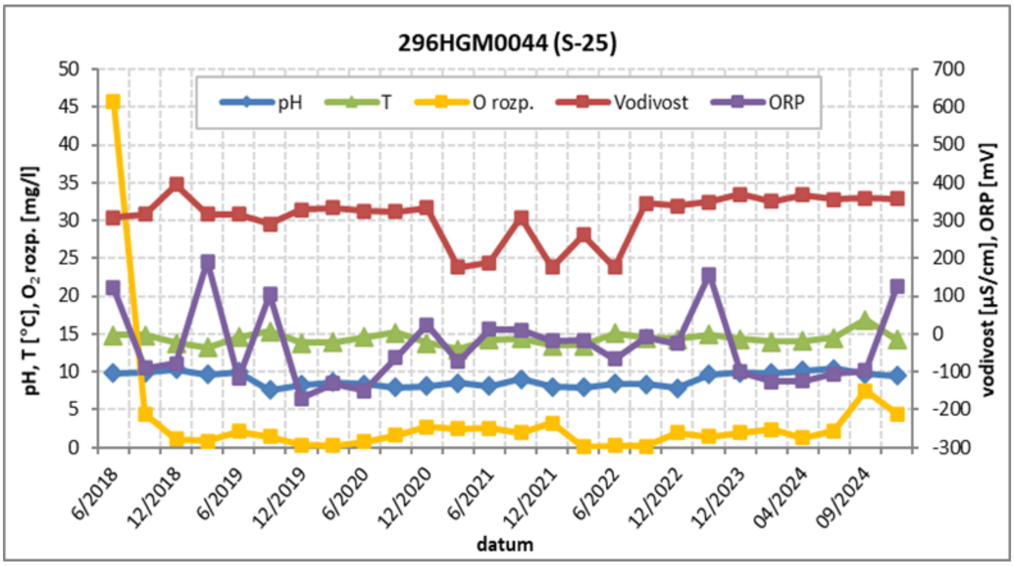


Figure 30 Development of physical and chemical parameters of inflow 296HGM0044

4.2.4 Radiology

Samples for the determination of radioactive substances were taken in the period 2023-2024 in the area of Bukov URF I in 04/2024 and in 11/2024 from 7 inflows (Table 14).

Table 14 Radiological analysis – area of Bukov URF I in the period 2018-2024

Documentation point	Original name	Sample date	Gross alpha activity	Gross beta activity	Radon (Rn 222)	Dissolved uranium
SÚRAO		**Unit**	**Bq/l**	**Bq/l**	**Bq/l**	**µg/l**
296HGM0002	BK23	9/2018	0.16	<0.10	22.8	2.03
	BK23	9/2019	0.32	0.12	16.8	1.63
	BK23	9/2020	0.05	0.16	29.7	1.58
	BK23	9/2021	<0.04	<0.10	31.4	2.71
	BK23	9/2022	0.08	0.12	38.1	1.8
	BK23	4/2024	0.07	<0.10	13	1.5
	BK23	11/2024	0.07	<0.10	12.2	1.47
296HGM0003	BK06	9/2018	0.22	0.1	17.5	2.48
	BK06	9/2019	0.13	0.13	10.7	1.8
	BK06	9/2020	0.08	0.13	<7.10	1.86
	BK06	9/2021	0.09	0.11	9.9	3.04
	BK06	9/2022	0.13	0.17	8.8	2.32
	BK06	4/2024	<0.04	<0.10	<5.0	1.64
	BK06	11/2024	0.08	<0.10	5.3	1.65
296HGM0019	BK27 (S-2)	9/2018	0.11	<0.10	184	<1
	BK27 (S-2)	9/2019	0.18	0.12	110	8.49
	BK27 (S-2)	9/2020	<0.04	0.24	108	0.62
	BK27 (S-2)	9/2021	0.05	0.12	127	0.65
	BK27 (S-2)	9/2022	0.08	<0.10	129	0.53
	BK27 (S-2)	4/2024	0.07	0.12	83.9	0.43
	BK27 (S-2)	11/2024	0.06	<0.10	107	0.42
296HGM0018	BK26	9/2018	0.3	<0.10	3.7	8.95
	BK26	9/2019	0.22	0.13	<5.0	8.36
	BK26	9/2020	0.11	0.15	<8.10	8.9
	BK26	9/2021	0.14	<0.10	15.9	9.27
	BK26	9/2022	0.11	<0.10	5.9	4.19
	BK26	4/2024	0.06	0.11	5.2	3.48
	BK26	11/2024	0.04	0.12	6.8	2.91
296HGM0013	BK35	9/2018	0.07	0.13	-	<1
	BK35	9/2019	0.62	0.13	<5.0	0.72
	BK35	9/2020	<0.05	0.14	<8.2	0.95
	BK35	9/2021	<0.07	0.13	<5.0	1.09
	BK35	9/2022	0.15	0.23	9.8	1.18
	BK35	4/2024	0.05	<0.10	<5.0	1.86
	BK35	11/2024	0.08	0.12	<5.0	1.91
296HGM0044	S25	9/2019	0.24	<0.10	52.6	<0.15
	S25	9/2020	<0.04	0.18	87.2	<0.15
	S25	9/2021	<0.04	<0.10	53	<0.15
	S25	9/2022	<0.04	<0.10	72.8	<0.15
	S25	4/2024	<0.04	<0.10	30.8	<0.10
	S25	11/2024	<0.04	<0.10	49.4	<0.10
296HGM0052	BZ1-XII 255 m	11/2024	0.04	<0.10	36.7	1.7
Decree 422/2016 Coll.			0,2	0.5	100	15

The measured values of the monitored radioactive substances were compared with the limits of Decree 422/2016 Coll. on radiation protection and security of radionuclide sources. Their comparison with the legislative limits (investigation level for total volumetric activity α 0.2 Bq/l and for total volumetric activity β 0.5 Bq/l and for reference values ^{222}Rn 100 Bq/l and dissolved U 15 ug/l) are shown in Table 14.

4.2.5 Older waters

Groundwater samples from inflow 296HGM0008 (BK18 (S-1)) were analysed using the isotopic methods in the Testing Laboratory of the VÚV, T.G.M., v.v.i. in Prague (method 3H) and in the laboratory of the AGH University of Kraków, Faculty of Physics and Applied Computer Science (Marek Dulinski, Ph.D.) using the radiocarbon method (14C). From the results of the analyses (Tables 17 and 18) it is possible to conclude that this is water whose age corresponds to the waters before the nuclear tests prior to 1950. The contribution of seepage of current surface and rainwater is very small. The assessment from 2024 was compared with archival analyses from 2014 and 2018 (Tables 15 and 16).

Table 15 Estimation of residence time in the rock environment using the tritium method

SURAO No.	**Orig. name**	**Sample sate**	**Tritium (Bq/l)**	**AP**	**Comment**
296HGM0008	BK18(S-1)	11/09/2018	0.171	± 0.045	V.Ú.V., T.G.M., v.v.i.
296HGM0008	**BK18 (S-1)**	**17/04/2024**	**0.131**	**± 0.040**	**V.Ú.V., T.G.M., v.v.i.**
^{3}H to 1950	***Rainwater***		***0.5-0.9***		***Natural level see El. Appendix 5***
	groundwater		***0.094 – 0.472***		***El. Appendix 5***

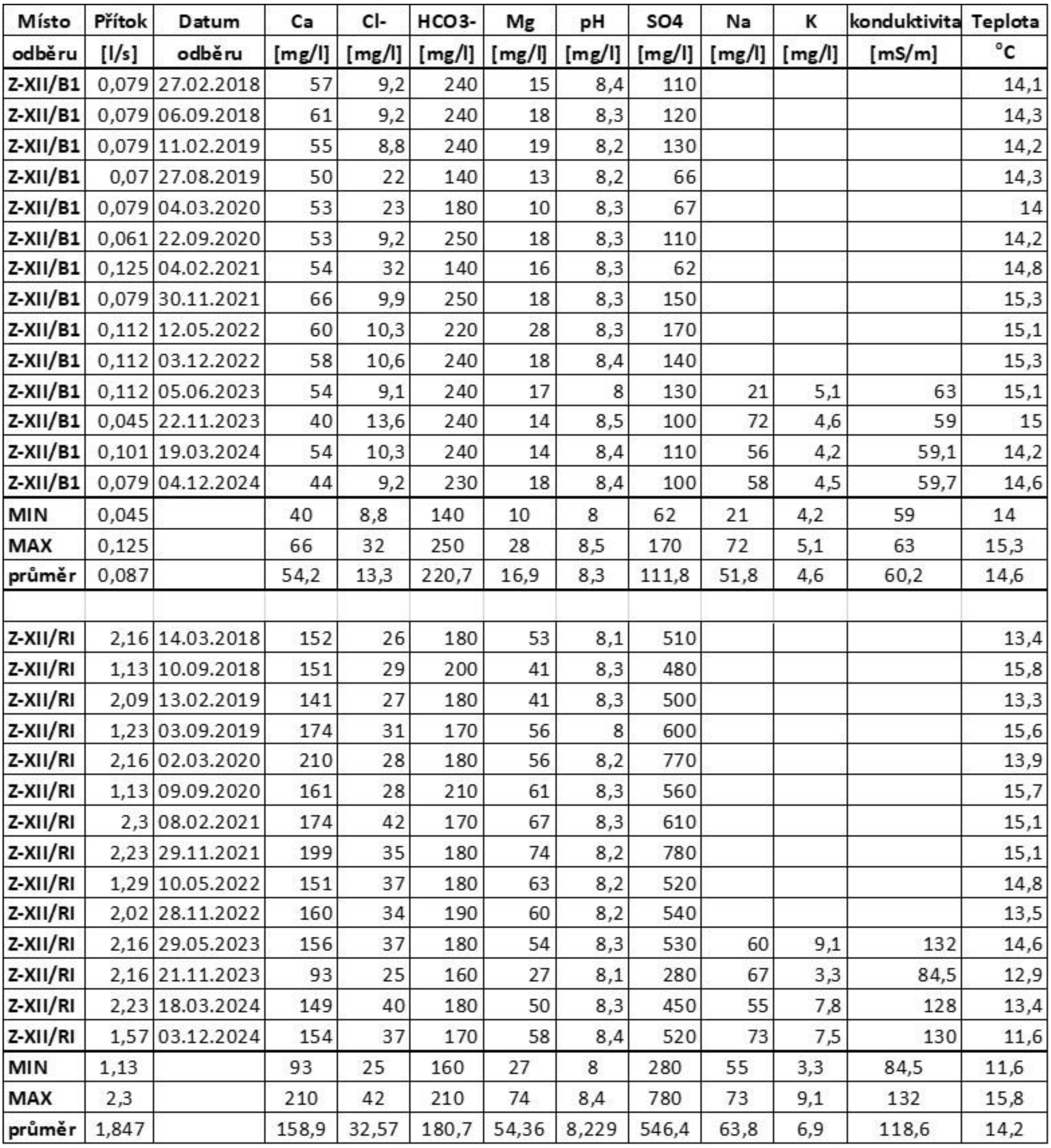
Table 16 Estimation of residence time in the rock environment using the radiocarbon method

SURAO No.	**Orig. name**	**^{14}C residence time (years))**	**Comment**
296HGM0003	BK06	6 530 ± 40	Lab. Poznaň 2014 (prof. T. Goslar)
296HGM0008	**BK18 (S-1)**	**7 100 ± 50**	**Lab. Poznaň 2014 (prof. T. Goslar)**
296HGM0019	BK27	6 410 ± 40	Lab. Poznaň 2014 (prof. T. Goslar)
296HGM0010	BK31	6 500 ± 40	Lab. Poznaň 2014 (prof. T. Goslar)
296HGM0018	BK26	4 895	Lab. Poznaň 2018 (prof. T. Goslar)
296HGM0008	**BK18(S-1)**	**4 900 – 5 200 ± 500**	**Lab. Kraków 2024 (prof. M. Dulinski)**

4.2.6 Mine waters

Pre-treated mine water discharged into Bukovský Stream from the Bukov mine decontamination station met the reference level for uranium (0.100 mg/l) and the investigation level for ^{226}Ra (0.400 Bq/l), i.e., levels set in the SÚJB Decision. From a radiological point of view, it should not affect Bukovský Stream. Based on selected parameters (Table 17) from regular control sampling of mine water on level 12 of the mine, 550 m below ground level from sampling points Z-XII/B1 and Z-XII/R1, it became clear that since 2018, in the mine water in shaft B1, HCO_3^- prevailed over SO_4^{2-} and Ca+ over Mg+ and in shaft R1, SO_4^{2-} over HCO_3^- and Ca^+ over Mg^+ and Na^+ and had a higher total mineralisation.

Table 17 Rožná mine water on level 12 of the mine (Z-XII/B1, Z-XII/R1) - selected parameters in the period 2018-2024



Místo odběru	Přítok [l/s]	Datum odběru	Ca [mg/l]	Cl- [mg/l]	HCO3- [mg/l]	Mg [mg/l]	pH [mg/l]	SO4 [mg/l]	Na [mg/l]	K [mg/l]	konduktivita [mS/m]	Teplota °C
Z-XII/B1	0,079	27.02.2018	57	9,2	240	15	8,4	110				14,1
Z-XII/B1	0,079	06.09.2018	61	9,2	240	18	8,3	120				14,3
Z-XII/B1	0,079	11.02.2019	55	8,8	240	19	8,2	130				14,2
Z-XII/B1	0,07	27.08.2019	50	22	140	13	8,2	66				14,3
Z-XII/B1	0,079	04.03.2020	53	23	180	10	8,3	67				14
Z-XII/B1	0,061	22.09.2020	53	9,2	250	18	8,3	110				14,2
Z-XII/B1	0,125	04.02.2021	54	32	140	16	8,3	62				14,8
Z-XII/B1	0,079	30.11.2021	66	9,9	250	18	8,3	150				15,3
Z-XII/B1	0,112	12.05.2022	60	10,3	220	28	8,3	170				15,1
Z-XII/B1	0,112	03.12.2022	58	10,6	240	18	8,4	140				15,3
Z-XII/B1	0,112	05.06.2023	54	9,1	240	17	8	130	21	5,1	63	15,1
Z-XII/B1	0,045	22.11.2023	40	13,6	240	14	8,5	100	72	4,6	59	15
Z-XII/B1	0,101	19.03.2024	54	10,3	240	14	8,4	110	56	4,2	59,1	14,2
Z-XII/B1	0,079	04.12.2024	44	9,2	230	18	8,4	100	58	4,5	59,7	14,6
MIN	0,045		40	8,8	140	10	8	62	21	4,2	59	14
MAX	0,125		66	32	250	28	8,5	170	72	5,1	63	15,3
průměr	0,087		54,2	13,3	220,7	16,9	8,3	111,8	51,8	4,6	60,2	14,6
Z-XII/RI	2,16	14.03.2018	152	26	180	53	8,1	510				13,4
Z-XII/RI	1,13	10.09.2018	151	29	200	41	8,3	480				15,8
Z-XII/RI	2,09	13.02.2019	141	27	180	41	8,3	500				13,3
Z-XII/RI	1,23	03.09.2019	174	31	170	56	8	600				15,6
Z-XII/RI	2,16	02.03.2020	210	28	180	56	8,2	770				13,9
Z-XII/RI	1,13	09.09.2020	161	28	210	61	8,3	560				15,7
Z-XII/RI	2,3	08.02.2021	174	42	170	67	8,3	610				15,1
Z-XII/RI	2,23	29.11.2021	199	35	180	74	8,2	780				15,1
Z-XII/RI	1,29	10.05.2022	151	37	180	63	8,2	520				14,8
Z-XII/RI	2,02	28.11.2022	160	34	190	60	8,2	540				13,5
Z-XII/RI	2,16	29.05.2023	156	37	180	54	8,3	530	60	9,1	132	14,6
Z-XII/RI	2,16	21.11.2023	93	25	160	27	8,1	280	67	3,3	84,5	12,9
Z-XII/RI	2,23	18.03.2024	149	40	180	50	8,3	450	55	7,8	128	13,4
Z-XII/RI	1,57	03.12.2024	154	37	170	58	8,4	520	73	7,5	130	11,6
MIN	1,13		93	25	160	27	8	280	55	3,3	84,5	11,6
MAX	2,3		210	42	210	74	8,4	780	73	9,1	132	15,8
průměr	1,847		158,9	32,57	180,7	54,36	8,229	546,4	63,8	6,9	118,6	14,2

4.3 Quantitative monitoring in the area of Bukov URF I

4.3.1 Direct measurements in the monitored area on level 12 of the mine

In the area of Bukov URF I on level 12 of the Rožná mine, quantitative monitoring was performed in 11, 12/2023 and in 02, 04/2024 at 19 documentation points and in 06, 09, 11/2024 at 20 documentation points (Table 10, Figures 17 and 18).

Table 20 shows the minimum, maximum and average values up until 2022 and in the period 2023-2024. The development of the measured yields of the inflows in the period 2023-2024 is shown in the graph (Figure 32). The yields from direct measurements, including graphs, are included in the appendixes (Appendixes 3, 8, 10).

The inflow rates in the period 2023-2024 can be divided according to the average measured values (Table 18) into five categories as follows:

- < 0.001 l/s (lowest values) for 1 inflow 296HGM0017 (BK38),
- 0.001-0.01 l/s for 8 inflows (296HGM0007, 296HGM0002, 296HGM0013, 296HGM0006, 296HGM0011, 296HGM0012, 296HGM15 and 296HGM0016),
- 0.01-0.1 l/s for 5 inflows (296HGM0003, 296HGM0005, 296HGM0010, 296HGM0042, 296HGM0044),
- 0.1-1.0 l/s for 4 inflows (296HGM0008, 296HGM0018, 296HGM0019, 296HGM0004),
- > 1 l/s (highest values) for 2 inflows (296HGM0001 and 296HGM0052).

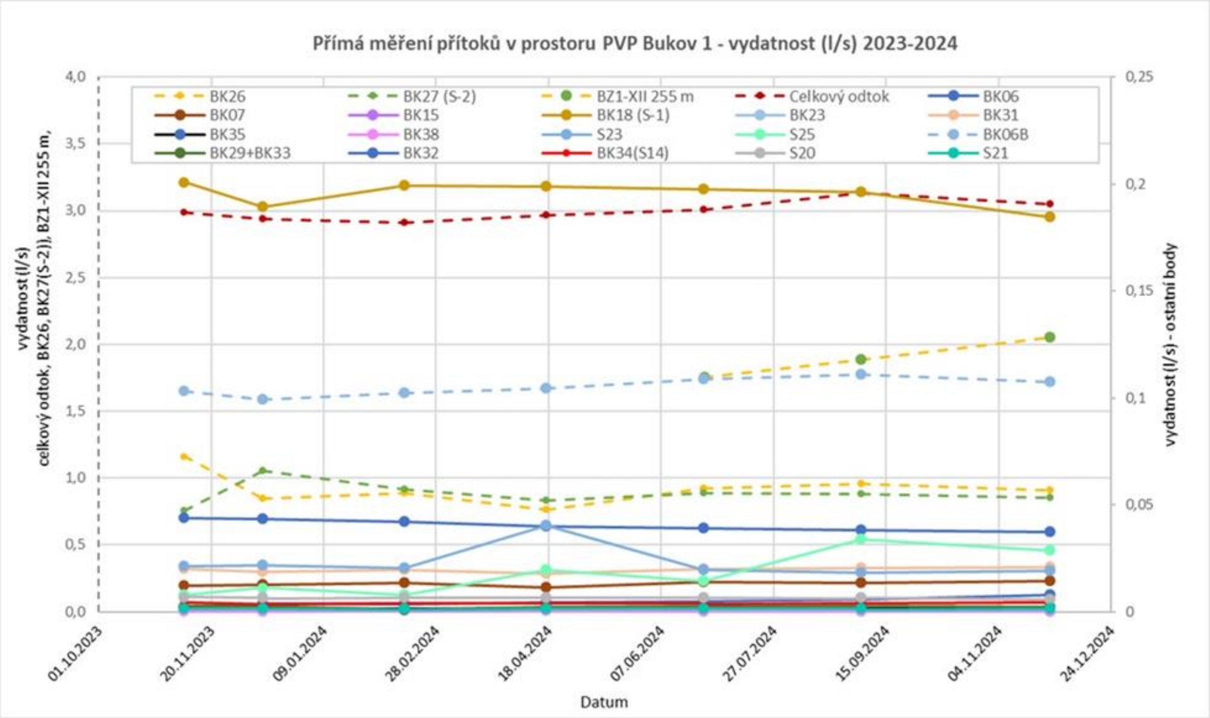


Figure 31 Direct measurements - development of inflow yields in the area of Bukov URF I in the period 2023-2024

Table 18 Direct measurements – manual measurement of the flow rate into the monitoring area on level 12 of the mine

Point name original /SÚRAO		Yield (l/s) 2023-24	Date	Yield (l/s) to 2022	Date	Comparison/ trend	Comment
BK06	min.	0.03734	XI.24	0.0466	XII.22	↓	
296HGM0003	max.	0.04380	XI.23	0.1510	VI.18	↓	
	Average	0.04052		0.0854		↓	
BK07	min.	0.01130	IV.24	0.0060	III.19	↑	
296HGM0005	max.	0.01429	XI.24	0.0230	VI.18	↓	
	Average	0.01303		0.0104		↑	
BK15	min.	0.00120	XII.23, IV.24	0.0007	III.19	↑	
296HGM0007	max.	0.00160	XI.24	0.0019	III.22	↓	
	Average	0.00133		0.0012		↑	
BK18 (S-1)	min.	0.18468	XII.23	0.1100	XII.18	↑	
296HGM0008	max.	0.20080	XI.23	0.2930	III.18	↓	
	Average	0.19517		0.2100		↓	
BK23	min.	0.00017	XI.24	drips	III,VI.22	↓	0.0007 l/s (VI.20)
296HGM0002	max.	0.00190	XI.23, XII.23	0.0600	III.19	↓	
	Average	0.00102		0.0059		↓	
BK26	min.	0.76140	IV.24	0.4500	IX.19	↑	
296HGM0018	max.	1.16100	XI.23	0.9000	VI.19	↑	
	Average	0.92027		0.6100		↑	
BK27 (S-2)	min.	0.75600	XI.23	0.8740	VI.20	↓	
296HGM0019	max.	1.05170	XII.23	0.9370	III.21	↑	
	Average	0.88129		0.9032		↓	
BK31	min.	0.01800	IV.24	0.0100	IX,XII.20	↑	
296HGM0010	max.	0.02070	XI.23	0.0420	III.18	↓	
	Average	0.01959		0.0189		↑	
BK35	min.	0.00160	VI.24	0.0030	IX.19	↓	
296HGM0013	max.	0.00200	XI.23	0.0070	II,VI,XII.18	↓	
	Average	0.00170		0.0057		↓	
BK38	min.	0.00020	XI-XII.23	dry	XII.22	↓	0.0008 l/s (III.21)
296HGM0017	max.	0.00030	VI-XI.24	0.0030	II,VI,XII.18	↓	
	Average	0.00022		0.0016		↓	
S23	min.	0.01820	IX.24	0.0100	IX.19	↑	
296HGM0042	max.	0.04030	IV.24	0.0230	II.22	↑	
	Average	0.02291		0.0199		↑	
S25	min.	0.00800	II.24	0.0070	VI, IX.18	↑	
296HGM0044	max.	0.03370	IX.24	0.1200	III.19	↓	
	Average	0.01762		0.0168		↑	
BZ1-XIIJ 255 m	min.	1.75400	VI.24				
296HGM0052	max.	2.05000	XI.24				
	Average	1.89633					
Total outflow	min.	2.91200	II.24				
296HGM0001	max.	3.13010	IX.24				

Point name original /SÚRAO		Yield (l/s) 2023-24	Date	Yield (l/s) to 2022	Date	Comparison/ trend	Comment
	Average	2.99826					
BK06B	min	0.09909	XII.23				
296HGM0004	max	0.11070	IX.24				
	Average	0.10508					
BK29+BK33	min.	0.00080	II.24				
296HGM0006	max.	0.00280	IX.24				
	Average	0.00232					
BK32	min.	0.00360	XII.23				
296HGM0011	max.	0.00887	XI.24				
	Average	0.00555					
BK34(S14)	min.	0.00360	XII.23				
296HGM0012	max.	0.00440	XI.23				
	Average	0.00405					
S20	min.	0.00586	XI.24				
296HGM0020	max.	0.00690	XI.23				
	Average	0.00654					
S21	min.	0.00130	II.24				
296HGM0016	max.	0.00142	XI,XII.23; IV,VI,IX,XII.24				
	Average	0.00139					

A comparison of the results of direct measurements, or average yield values in the period up to 2022 and in the period 2023-2024 (Table 20) showed that yields in the inflows BK06, BK18 (S-1), BK23, BK27 (S-2), BK35 and BK38 decreased, and conversely increased in the inflows BK07, BK15, BK26 and BK31. The graphic representation of the development of chemistry and yield of inflows (Figures 33-35) shows the relative stability of chemical parameters in the inflows with different chemistry BK18 (S-1) and S-23 and S-25.

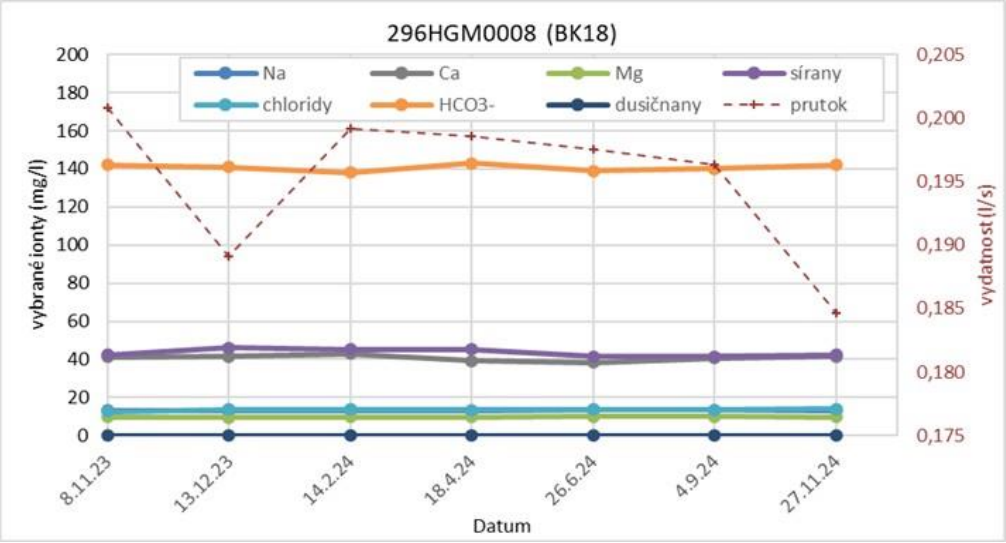


Figure 32 Development of groundwater chemistry and inflow yield in the period 2023-2024 - 296HGM0008

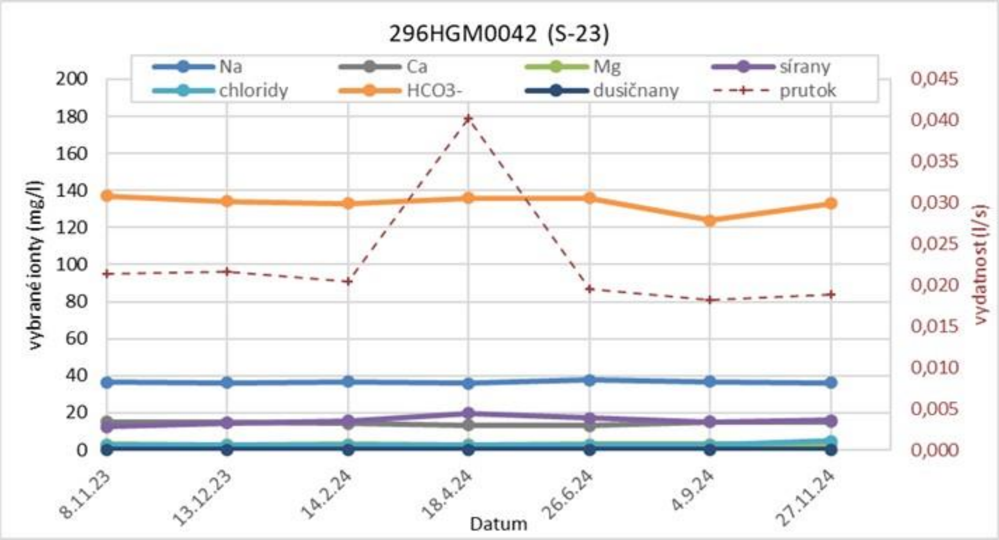


Figure 33 Development of groundwater chemistry and inflow yield in the period 2023-2024 - 296HGM0042

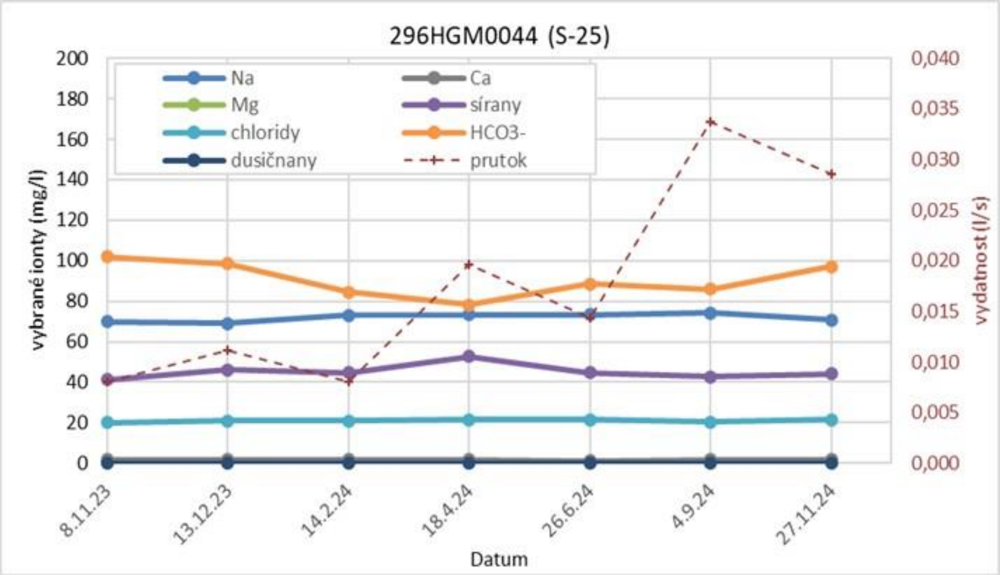


Figure 34 Development of groundwater chemistry and inflow yield in the period 2023-2024 - 296HGM0044

4.4 Automatic Measuring Stations

4.4.1 Bukovský Stream hydrological station

The flow of Bukovský Stream was significantly affected by the discharge of mine water (Figure 35). The long-term average daily flow of the discharged mine water for the period 2019-2024 was 9.1 l/s. The average daily flow of Bukovský Stream for the same period in the measurement profile was 32.9 l/s (Figure 36 - Q Bukovský confluence). The discharge of mine water for the period 2019-2024 represents 28% of the total outflow.

The average daily flow of the discharged mine water for the period 2023-2024 was 8.2 l/s. The average daily flow of Bukovský Stream for this period in the measurement profile was 33.9 l/s. The discharge of mine water in the period 2023-2024 constituted 24% of the total outflow.

The discharge of mine water occurs intermittently, with a relatively small dispersion of values in daily averages (the typical dispersion of average discharge flows of mine water was 7-11 l/s).

The flow of Bukovský Stream, as with most surface watercourses, fluctuated considerably depending on atmospheric precipitation and snowmelt in the winter and spring periods (Figure 35), e.g., in September 2024 (Figure 36).

On the contrary, during periods of drought, the discharge of mine water may exceed the flow of Bukovský Stream and constitute the majority of the total outflow, e.g., in September 2021, the discharge represented approximately 90% of the total outflow.

Dry periods, when the discharge of mine water represents 50-70% of the total outflow, are common.

4.4.2 Weather station

Meteorological data provide supporting information for the hydrological and hydrogeological assessment of the area. The trends of average daily air temperatures, daily precipitation totals and soil moisture for the period 2019-2024 are graphically depicted (Figure 36).

The average annual precipitation total for the period 2019-2024 was 576.7 mm. The years 2019 (553.1 mm), 2021 (464.1 mm), and 2022 (511.9 mm) were below average in terms of precipitation, the year 2023 (561.0 mm) almost reached the average, and the years 2020 (694.3 mm) and 2024 (680.5 mm) were above average in terms of precipitation.

The evaluation of basic meteorological parameters in terms of air temperatures (number of ice, frost, summer and tropical days, number of tropical nights) showed a clear warming trend even in the relatively short period of 2019-2023.

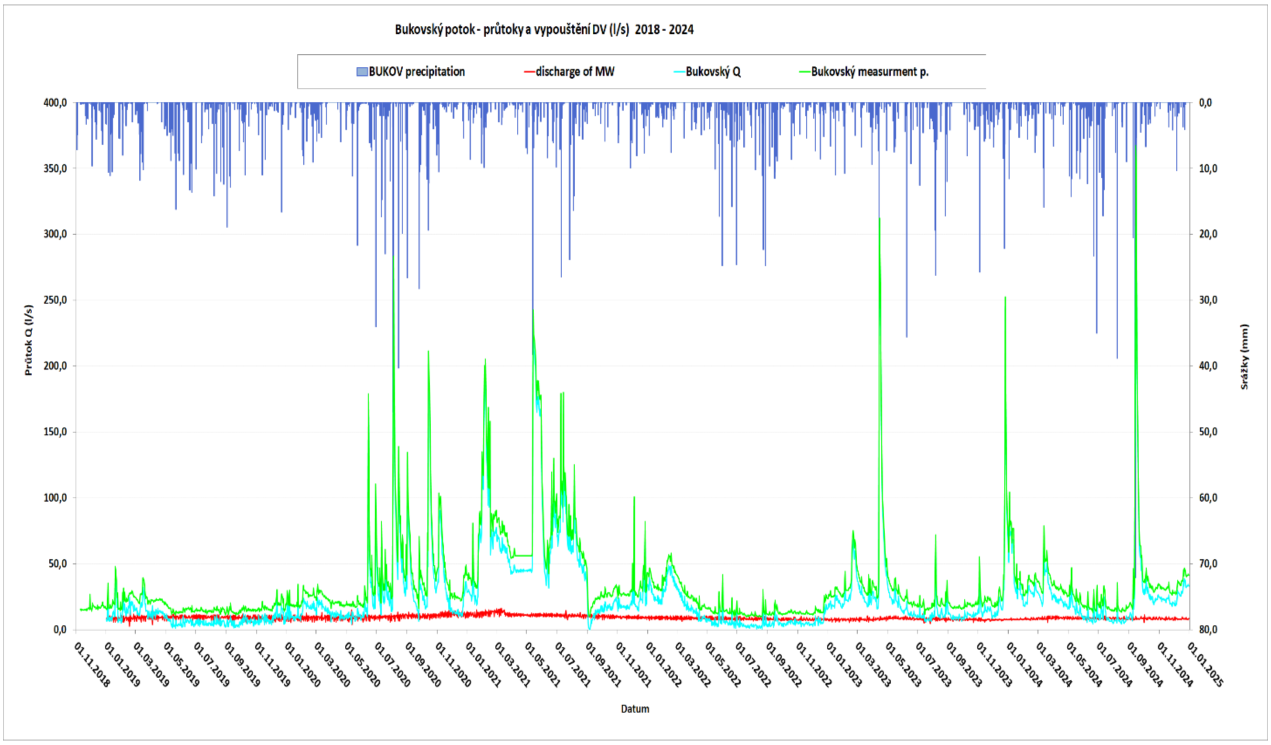


Figure 35 Flow at the Bukovský Stream AMS and discharge of mine waters during the period 2019-2024

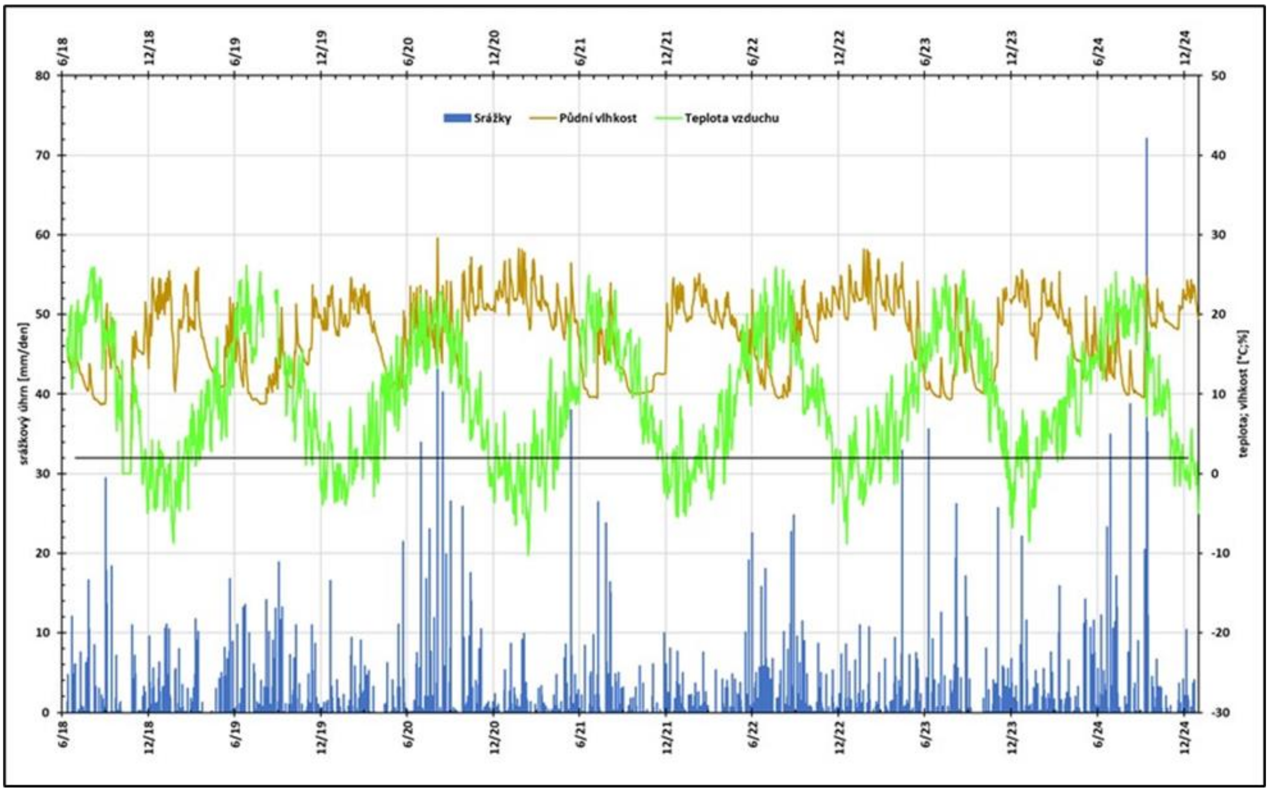


Figure 36 Bukov weather station – daily precipitation totals, average air temperatures and soil moisture for the period 2019-2024

4.4.3 Automatic measuring stations in the monitored area of Bukov URF I

Measurements in the monitored area of Bukov URF I were provided by three strategically located AMS. Table 19 shows the long-term trends in the yields/flows (Q) of inflows to the monitored area of Bukov URF I with AMS (Figure 18).

In the monitoring period 2023-2024, the largest changes (the most significant decrease) were shown in point 296HGM0002 (BK23).

The highest yields/flow rates in 2024, ranging between 0.9 and 3.0 l/s, were recorded for the total outflow (296HGM0001) of approximately 3 l/s (=sum of outflow values from all documentation points), and further for points 296HGM0018 (BK26) of approximately 1.1 l/s (significant increase in flow in 2021, variable development until 2024) and for 296HGM0019 (BK27 (S-2)) of approximately 0.9 l/s (stable development).

In 2023, the share of points BK26 and BK27 (S-2) in the total outflow was up to 65%. Other points with lower yields accounted for approximately 35% of the total outflow; unknown sources accounted for approximately 21%. The new point 296HGM0052, which improved the measurement of drips and seepage between points BK26 and BK27 (S-2), reduced the share *of* unknown sources by approximately 2% (6 months) in 2024. The development and share of these inflows in the monitored area of Bukov URF I in the period 2019-2024 is graphically shown in Figure 37. The lowest yields/flows with values < 0.01 l/s were recorded for 11 inflows (Table 19).

Table 19 Trends in the yield of inflows with AMS in the area of Bukov URF I

Original name	Documentation point SÚRAO	Part of mine workings DIAMO	Yield trend (flow rate)	Yield to 2024 (l/s)
Total runoff	296HGM0001	BZ-XIIJ	Decrease – Figure 37	3.00
BK23	296HGM0002	BZ-XIIJ	Decrease	< 0.01
BK06	296HGM0003	BZ-XIIJ	Decrease	< 0.01
BK06B	296HGM0004	BZ-XIIJ	Decrease	Approx. 0.01
BK07	296HGM0005	BZ-XIIJ	Increase	0.143
BK29+BK33	296HGM0006	BZ-XIIJ	Constant	< 0.01
BK15	296HGM0007	BZ-XIIJ	Increase	< 0.01
BK18(S1)	296HGM0008	VrK-1	Decrease	0.193
BK31	296HGM0010	BZ1-XII	Constant	< 0.01
BK32	296HGM0011	BZ1-XII	Increase	< 0.01
BK34(S14)	296HGM0012	BZ1-XII	Constant	< 0.01
BK35	296HGM0013	BZ1-XII	Cannot be determined	< 0.01
S20	296HGM0015	ZK-3S	Decrease	< 0.01
BK38	296HGM0017	ZK-3S	Decrease	< 0.01
S21	296HGM0016	ZK-3S	Increase	< 0.01
BK26	296HGM0018	BZ1-XII	Variable – Figure 37	1.10
BK27 (S2)	296HGM0019	BZ1-XII	Constant – Figure 37	0.90
BZ1-XIIJ 255 m	296HGM0052	BZ1-XII	From 6/2024	Approx.1.00

Control flow measurements were performed by hydrometry using the velocity field method (Figure 38).

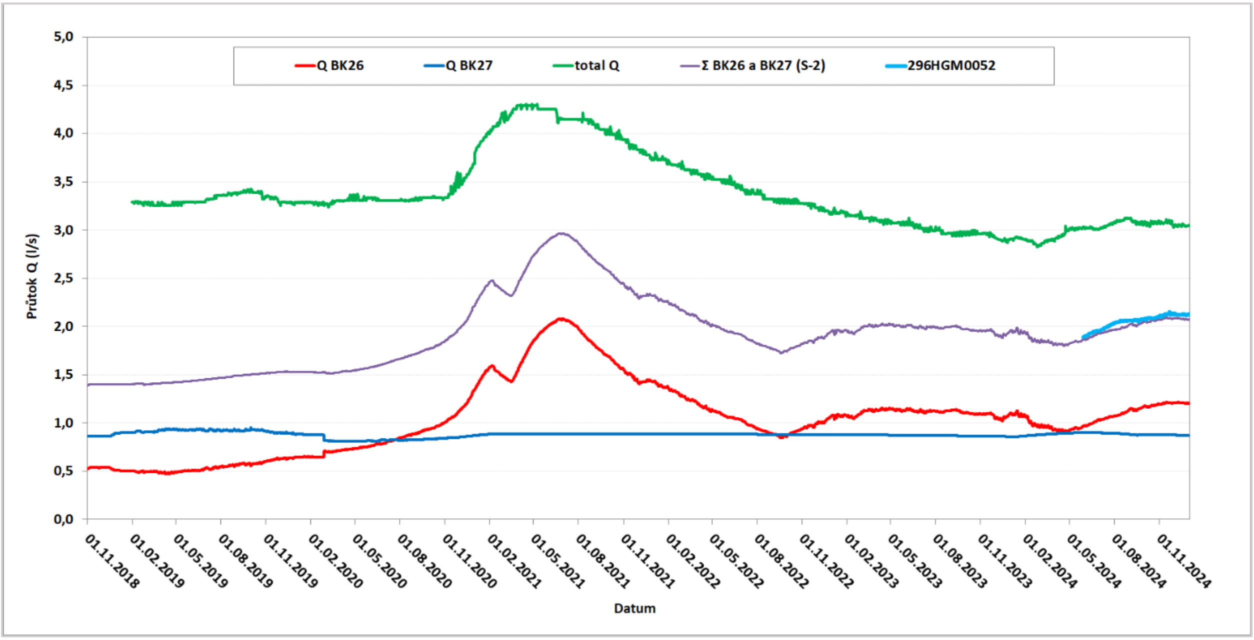


Figure 37 AMS flows in the monitored area of Bukov URF I (BK26, BK27 (S-2), total outflow,296HGM00525)

Figure 38 Control flow measurement by hydrometry using the velocity field method

5 Conclusion, Recommendations

Qualitative monitoring

In the monitored area of Bukov URF I on level 12 of the mine, monitoring in the period 2023-2024 confirmed the occurrence of groundwater of the hydrochemical type (>20% meq.) with a predominance of Ca, Mg and HCO_3, SO_4(Cl) to SO_4HCO_3 in the “BK” inflows: HCO_3, SO_4(Cl) type in inflows BK06, BK07, BK18 (S-1), BK26, CaMg-HCO_3SO_4 type in inflows BK18, BK23, BK27 (S-2), BK31 and CaMg-SO_4HCO_3 type in inflows BK35 and BK38. The predominant bicarbonates (HCO_3^-) were replaced by sulphates and also chlorides with increasing mineralisation. In well 296HGM0042 (S-23) and 296HGM0044 (S-25) on level 12 of the mine in shaft B1, the groundwater in the period 2023-2024 corresponded to NaCa-HCO_3^- in S-23 to Na-HCO_3SO_4(Cl) in S-25.

From the graphic representation of the time evolution of the chemistry of the inflows in the period 2014-2018 and 2019-2024 and their comparison, e.g., inflow 296HGM0008 (BK18 (S-1)), it can be stated that the most significant changes in chemistry (increasing representation of Ca, sulphates and chlorides, increasing total mineralization, decreasing pH) occurred in the year 2018. Changes in chemistry were evident in all inflows and are most likely related to the flooding of the lower levels of the mine, which has been ongoing since 2021.

In terms of the occurrence of trace elements in the period 2023-2024, the most frequent occurrences of Mn above 0.05 mg/l were found in inflows at points 296HGM0003 (BK06), 296HGM0008 (BK18 (S-2)), 296HGM0002 (BK23), 296HGM0019 (BK27), 296HGM0017 (BK38), at Fe above 0.2 mg/l at points 296HGM0005 (BK07), 296HGM0007 (BK15), 296HGM0002 (BK23) and occasionally at Al above 0.2 mg/l together with Fe and Mn at point 296HGM0007 (BK15).

The age of the water determined by 2 independent methods of isotopic analysis of groundwater from the inflow 296HGM0008 (BK18 (S-2)) corresponded approximately to the age of the water determined from previous research. From the measurable tritium concentration of 0.131 ± 0.040 Bq/l, it can be judged that the water was old prior to the nuclear tests before 1950 with a very small contribution from the seepage of current surface water and precipitation. The radiocarbon method determined the residence time to be 4900-5200 ± 500 years, with the water sample containing an admixture of current infiltration water, i.e., water containing tritium that penetrated after the nuclear weapons tests that began in 1952.

In most springs on the surface of Bukov URF I, the groundwater in the period 2023-2024 corresponded in chemical composition (20% meq.) to hydrochemical types with a predominance of Ca^+ and Mg^+, and Na^+, and SO_4HCO_3 to $SO_4^{2-}(Cl^-)$: CaMg-SO_4HCO_3 type in 296HGM0034 (BP008), CaMg(Na)-SO_4HCO_3 type in 296HGM0032 (BP001), Ca(Na)Mg-SO_4HCO_3 to CaMg-SO_4Cl in BP005, CaMg-SO_4(Cl) to CaMg-SO_4HCO_3 in 296HGM0035 (BP019). In spring 296HGM0036 (BP021), the groundwater, with its different chemical composition of MgCa-HCO_3SO_4, resembled groundwater of deeper circulation.

The groundwater of springs 296HGM0055 (BP027) and 296HGM0037 (BP022) with a higher proportion of Na+ and Cl- differed in chemical composition. In the spring of Bukovský Stream BP022, the chemical composition was unstable due to its influence by the Bukov landfill and the discharged mine waters from the decontamination station.

Groundwater from spring 296HGM0055 (BP027) with a higher proportion of Na^+ and a predominance of Cl^- over HCO_3^- also corresponded to anthropogenic pollution, probably from winter maintenance of the adjacent road and from agricultural activities on adjacent land (nitrates 16.8-63.2 mg/l, chlorides, highest concentration 105-166 mg/l in the period 2023-2024).

The highest (123 mg/l) and lowest (8.9 mg/l) nitrate values in the period 2023-2024 were found in the spring of Bukovský Stream 296HGM0037 (BP022). In spring 296HGM0036 (BP021), nitrates ranged between 13.9 and 15.7 mg/l and, except for the minimum of 8.9 mg/l in BP022, they were the lowest.

Trace elements were recorded in all springs in values that are orders of magnitude higher than in inflows (up to units of mg/l). The most frequent occurrences of Mn, Fe, Al were in spring 296HGM0055 (BP027) and in Bukovský Stream 296HGM0038 (anomalous values were observed in the case of Ba, Sr, Li, and Rb).

Quantitative monitoring

Regular service activities were conducted throughout the monitoring period of 2023-2024. Under the conditions of the mine workings, there were problems with the mechanical parts of the gauges (clogging of the bearings and other parts of the equipment with sediments). During the monitoring, the flow profile of the springs and Bukovský Stream changed due to overgrowing of the banks with bushes during the growing season or a temporary increase in flow rates due to extreme situations (higher precipitation totals, strong winds).

The groundwater levels in shallow hydrogeological wells 296HGM029 (PV-5), 296HGM0030 (PV-6), 296HGM0031 (PV-8) monitoring the Bukov landfill ranged between 6.23 and 13.31 m below ground level in the period 2023-2024, depending on the location of the well and the season, as well as the precipitation totals in the monitored area of Bukov URF I.

The total average annual precipitation for the period 2019-2024 was 576.7 mm. The years 2019, 2021 and 2022 were below average in terms of precipitation, the year 2023 almost reached the average, and the years 2020 and 2024 were above average.

During the monitoring in the period 2023-2024, changes in the hydrogeological conditions manifested by a decrease or loss of spring yield and flow in streams were evident in the spring of Bukovský Stream 296HGM0037, which was dry in 11/2023 and in the period 06-11/2024; its yield is directly dependent on atmospheric precipitation and the discharge of pre-treated mine water from the Rožná mine. During the direct measurements, a decrease in the average yield was recorded at the spring 296HGM0034 (BP008).

Based on the evaluation of long-term continuous AMS measurements, the yields of inflows to the monitored area of Bukov URF I were unchanged in most cases. In terms of the long-term trend, the yields of inflows decreased by 2024 in 7 inflows (out of 18 inflows with AMS); in addition, 4 inflows recorded an increase, 4 inflows recorded a constant development, 1 inflow recorded a variable development and for 2 inflows the trend was not determined. The highest yields were recorded by the total outflow 296HGM0001 (3.0 l/s) and inflows 296HGM0018 (BK26 – 1.1 l/s) and 296HGM0019 (BK27 (S-2) – 0.9 l/s); The yields of the other points were all approximately 1 l/s. The lowest yields below 0.01 l/s were recorded at 11 points.

More significant changes were recorded at point 296HGM0002 (BK23 - decrease) and at point 296HGM0018 BK26 - variable). Another change was the construction of a new point 296HGM0052, which significantly improves the accuracy of the measurement of drips and seepage between BK26 and BK27 (S-2). The results of direct measurements were in accordance with the results of the AMS measurements.

In wells 296HGM0042 (S-23) and 296HGM0044 (S-25), an increase was recorded at S-23 based on direct measurements; for S-25, the trend cannot be clearly determined.

Recommendations

Measuring profile 296HGM0039 Bukov Stream – 1. Continue with continuous water level measurement and flow evaluation, further eliminate the risks of influencing regime measurements by clogging the profile with sediments during increased flow rates in the basin, overgrowth in the profile during the vegetation period or damaging the profile under extreme weather conditions. 2. Continue updating the measuring profile based on direct flow measurements by hydrometry. 3. Consider the possible construction of a permanent measuring profile in the profile above the ford.

Wells 296HGM029 (PV-5), 296HGM0030 (PV-6), 296HGM0031 (PV-8) – end the monitoring of three wells in the Bukov landfill for the purposes of hydrogeological monitoring of groundwater, surface and mine waters in the Bukov landfill. The results of groundwater level measurements in shallow boreholes drilled for the purposes of monitoring the Bukov landfill provided indicative data on the groundwater regime in the shallow aquifer; these are not representative data for the purposes of hydrogeological and hydrological assessment of the area of Bukov URF I.

Springs – install measuring stations on springs with and initiate continuous monitoring to increase the representativeness of flow regime measurements in the given sub-basin, at least for springs 296HGM0036 (BP021), possibly also 296HGM0033 (BP005), which appeared to be the most stable in the period 2023-2024 from both a qualitative and quantitative monitoring point of view.

Spring 296HGM0055 (BP027) Střítež u Bukova – change the location of groundwater measurement and sampling or cancel the point. The highest concentrations of chlorides and sodium were detected at the spring in the monitoring period 2023-2024, regardless of the season. Based on these results and from the point position, it can be concluded that the water chemistry is influenced by substances contained in settled runoff from adjacent roads and agricultural lands.

In the monitored area of Bukov URF I - ensure the replacement of worn sensors, perform technical modifications to some objects, e.g., 296HGM0003 (BK06), 296HGM0004 (BK06B).

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Methodological guideline SÚRAO MP.23

Appendixes

SÚRAO

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