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Moisture regime in *Alnus incana* alluvial forest Javorová valley, Tatra Mountains, the West Carpathians

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Abstract. This study deals with factors adversly influencing the moisture regime of *Alnus incana* at the Javorová valley sampling site. Research was conducted between November 2016 and November 2018. Meteorological variables were evaluated along with measurements taken by a weighable lysimeter and soil probes distributed in the alder stand. Soil moisture was measured using soil probes and a lysimeter at depths of 40 cm, 80 cm and 120 cm. Soil solution samples were taken from the same soil depths as the water well samples from the lysimetric cylinder. From the collected data, five basic factors that influence the moisture regime were determined. We evaluated the changes in the average and monthly values of soil moisture, the monthly and yearly meteorological characteristics, and the seasonal characteristics of the chemical soil solution. The results of the work show that the impact of each individual factor is influenced by the seasonality of the period. At the same time, however, the impact of climate change on individual factors shows their character in the long term. The most important factor influencing the moisture regime is the evapotranspiration of vegetation

Key words: *Alnus incana,* humidity regime, Javorová valley, X-ray, evapotranspiration, lysimeter

Introduction

Water is important for the existence of all living organisms on Earth and exists in all three states - solid, liquid and gaseous. We classify water as a renewable natural resource, but to some extent its circulation is also influenced by humans. The destruction of tropical forests, acid rain, ozone disruption, high usage, melioration and changes in the water regime of soil all disrupt the hydrological cycle. The retention potential of landscapes, ecosystems, or small landscaped areas is of great importance in maintaining biological processes of ecosystems, maintaining biodiversity, and mitigating the effects on human and animal populations (Loreau *et al.* 2001). Significant consequences of climate change are becoming more prevalent. Extreme weather fluctuations have become common; the amount of rain that falls is concentrated in short intervals, and ecosystem stability is at risk due to potential erosion as a result of storm rainfall and flooding, which may also cause extensive property damage (Milly *et al.* 2008). Considering the increasing risk of drought due to global warming, Boczoń *et al.* (2016) examined the direct impacts on the forest ecosystem.

The evolution of forest ecosystems is influenced by multiple factors, whether they are positive or negative phenomena. Climate is the most important factor that significantly affects the development of forest stands. The most significant negative factor affecting the production and growth of tree stands is drought, or water stress. During dry periods, the demand for adaptability increases and may result in native species beginning to grow in new habitats. The consequences of increasing environmental adaptability can be observed today including changes in tree composition or disappearance of some species due to water stress.

Alnus incana (L.) Moench is a species of alder with a wide area of distribution in the cooler areas of the northern hemisphere. It is a relatively short-lived deciduous tree that grows to a height of 15 to 20 m. It is characterized by a shallow root system, a good stump, and root fineness. *Alnus incana* in Slovakia ranges from lowlands to higher mountain locations and has a high demand for sunlight and soil moisture (Bugala and Migas 2011). According to Pagan (1996), it requires habitats with flowing and oxygenated water, and aerated soil such as those a high occurrence of stones. The lifespan of *Alnus incana* has an effect on the developmental cycle of the natural forest. Thanks to the rapid decomposition of fallen leaves with high nitrogen content, alder belongs to the group of meliorating, soil-improving woody plants and also has an irreplaceable function in the biological treatment of watercourses, thanks to its vegetative reproduction, which represents the most economical and appropriate protection (Lukáčik and Bugala 2007).

Kontriš *et al.* (2005) investigated phytocoenoses of marsh-willow shrubs, floodplain forests and slopes of alder in Pieniny National Park, where mountain alder was found predominantly on the alluvium in the mouth of the Dunajec. The relief was irregular and wavy. *Alnus incana* dominated the tree floor, and willows were subdominant. *Sambucus nigra* (L.), *Cornus sanguinea* (L.) and *Lonicera* *xylosteum* (L.) were the most common speciea in the scrub floor. Furthermore, Kontris *et al.* (2005) reported the occurrence of a slope of alder of small size, which were found in the erosion grooves and the slope slides. The tree floor was comprised mostly of *Alnus incana* with minimal *Abies alba* Mill., *Picea abies* (L.) Karst, *Fraxinus excelsior* (L.), *Ulmus laevis* Pallas, *Acer pseudoplatanus* (L.). The scrub floor consisted of species characteristic of field shrub communities, such as *Corylus avellana* (L.), *Prunus spinosa* (L.), *Rubus hirtus* Waldst. & Kit, *Crataegus monogyna* Jacq. The results show that mountain alder along with willows are found on alluvial terraces (Kontris *et al.* 2005). Lukáčik and Bugala (2007), in their analysis of qualitative signs of trunks, crowns and health status of gray alder (*Alnus incana*) and sticky alder (*Alnus glutinosa* (L.) Moench.) in the Laborecká vrchovina state, found that these species are capable of forming natural homogeneous stands. The findings from this analysis pointed to differences within the taxon between individual locations, but also to differences between examined taxons. Growing characteristics natural to the gray alder population (*Alnus incana*) show that production potential of this species is not comparable to other farm trees (Bugala and Parobeková 2016). Producion potential also depends on increasing altitude, where the optimum altitude is 370-400 m a.s.l. (Bugala and Parobeková 2016).

The original alder stands have been significantly influenced by human activities. They have been converted into agricultural land or removed as a result of watercourse modifications. The biological balance and the aesthetic value of watercourses were disturbed by the elimination of alder stands. Shore erosion, loss of wood production, devastation of shoreline vegetation, and other damage to crops were triggered by removal of these trees. According to Lukáčik and Bugala (2009), the proper management of alder forests could contribute to the protection of natural environments and increase the biological value of the landscape.

Stradiot *et al.* (2014) evaluated the spatial variability of retention properties of selected soils in the Borská lowlands. Stradiot *et al.* (2014) state that the granular composition of the soil, the mineralogy of the clay fraction, the properties of organic matter, soil structures and so on, affect the relationship of soil water and soil moisture. The variability of the soil structure affects the water content in the soil and its ability to retain this moisture (Rehák *et al.* 2006). According to Rehák (2006), the size and shape of pores are particularly important for soil and water dynamics. The organic content of soil, soil species, structure and genetic soil horizon all determine pore distribution in the soil profile. Based on the above stated characteristics and the proportion of clay, dust, and sand in the soil, soils are classified into soil species. The basic soil species include gravel soils, stony soils, boulder soils, light soils (sandy, loamy-sandy), medium-heavy soils (sandy-loamy, loamy, loamy-loamy) and heavy soils (clay soils). Stradiot *et al.* (2014) state that "the group of medium-heavy soils shows a relatively smooth course of the drainage branch of retention curve, while in the group of the light soils there is a rapid decrease in moisture".

We describe water balance in forest ecosystems using the quatitative state of the water regime during a period of time in the forest stand. The result is a correlation between the incoming and outgoing water in the environment, which determines the water balance. Changes in hydrological conditions of an environment are manifested as an imbalance between the gain and loss of water in the soil - plant - atmosphere system (Minďáš *et al.* 2010; Střelcová *et al.* 2011). Water balance is determined by the flow of water in and out of the soil. Using soil water balance we can set determine values including transpiration, evapotranspiration, and soil vapor. In cases of excellent structure and abundant overgrowth of roots, forest soils can accumulate up to 200 liters of water per square meter per month, which flows slowly and evenly.

Factors including climatic conditions, altitude, terrain slope, exposure, stand structure, woody composition, age, stifling and canopy affect the water balance (Tužinský 2007; Vida *et al.* 2012). Atmospheric precipitation in all forms, including dew, is the main source of water for forest ecosystems. Depending on volume, frequency and timing during the growing season, rainfall events will affect water balance differently. Horizontal precipitation, particularly fog, has an exceptional significance in terms of water gain in forest ecosystems at higher altitudes. Significant precipitation differentiation occurs when rainfall flows into the forest ecosystem, and when this precipitation comes into contact with vegetation. Interception occurs when rainfall is trapped in trees, shrubs, and herbaceous vegetation. Some rainfall runs down the trunks of trees, and some penetrates the soil's surface (Penka 1985; Tužinský 2007).

Variability in the distribution of rainfall in forest ecosystems is most affected by the tree crowns. Precipitation trapped in varying amounts on the surface of the arboreal, shrubbery, and herbaceous vegetation subsequently evaporates into the air. This process is called interception. From a hydrological point of view, interception is considered part of water loss (when considering total vapor), and is a non-reproductive component of evapotranspiration (Tužinský 2007).

Forest stands can hold between 10-50% of atmospheric precipitation, depending on their composition and stand structure, the developmental stage of the vegetation, the growing season, weather conditions and other factors. The correlation between crown density and interception means that beech and spruce stands (30-50%) retain more rainfall than pine trees (15-30 %) (Krečmer 1962; Tužinský 2007). Drain represents an important income component of water balance for these stands, and smooth-bark vegetation tend to exhibit higher water content along their trunk. Kantor (1983) mentions for that in beech stands, water collected along the trunk can account for 19.9% of free area rainfall, while this value for spruce trees is only 1.4%.

Water transpiration in plants takes place through vents. Transpiration is a physico-biological process and is an important component of water balance expenditure (Penka 1985; Novák 1995). Evapotranspiration is an ongoing process in the environment. Evapotranspiration is the evaporation of water that is consumed by plant transpiration and is increased by the amount of water that evaporates through interception and from soil under tree stands. The forest eliminates wind speed, and shade undergrowth and increases the relative humidity of the air, causing vapor reduction. Forest stands reduce the annual evaporation by half compared to the free surfaces. In the summer months evaporation in the forest is reduced by 70-90% compared to unforested areas.

The aim of this work was to determine factors affecting the moisture regime in the alluvial forest of *Alnus incana* at the selected site of Javorová valley. Partial objectives were:

- evaluation of moisture conditions during the experiment
- evaluation of meteorological characteristics during the experiment
- evaluation of chemical elements of soil solution

Material and Methods

Study area

The study area was located very close to the Institute of High Mountain Biology, which is situated in the village of Tatranská Javorina (N: 49° 16´ 5”, E: 20° 8´ 29”). Tatranská Javorina falls into a buffer zone of the Tatra National Park. From a geological point of view, the study area is located on fluvial sediments of mountain streams. Thus, we find a diversity of surface geography, as fluvial sediments in the mouth of the Javorova valley are carbonate (Belianske Tatras) and granite (High Tatras) from the Tatra mountains (Vološčuk *et al.* 1994). Lithium, ranker, podzol, cambis, rendzina, and fluvi type soils have been formed. The whole territory encompassing the Tatras is characterised by typical features of the alpine climate. It is divided into three circuits (subdivisions) according to the average July temperature, between 10° - 12° C. The relative air humidity of mountain areas varies, but temperature inversions (increases in air temperature with altitude) are characteristic of mountainous areas (Smolen and Ostrozlik 1994).

Equipment

We used two weather stations to measure and obtain meteorological data. The first meteorological station - Vantage Pro2 (Davis Instruments, USA) - was located in an open area. The second meteorological station with a weight lysimeter from Umwelt-Geräte-Technik GmbH (Germany) was located at the edge of an alder stand. Both meteorological stations and the lysimeter transmit data using the internet to a central server at the Institute of High Mountain Biology. Data was measured continuously and recorded in 15 minute intervals (mean or sum value of 15 minute intervals). Additionaly, we used soil probes from UGT-Umwelt-Geräte-Technik GmbH (Germany) for monitoring soil temperature and moisture within the alder stand. Leaf moisture sensors from Davis Instruments (USA) were used to monitor the level of surface moisture on foliage. Using the lysimeter, we measured soil temperature (° C), moisture (%) and tension (hPa) at depths of 40 cm, 80 cm and 120 cm, as well as run off (mm), drain off (mm) and weight (kg) of the lysimeter. In the alder stand, we measured soil temperature (° C) and moisture (%) using soil probes, which were placed at the same depths (40 cm, 80 cm and 120 cm) under the root systems in two locations in the middle of the stand. The meteorological stations measured air temperature (° C), humidity (%), pressure (hPa), solar radiation (watt), precipitation (mm), wind speed ($m.s^{-1}$) and wind direction.

Evapotranspiration modeling

Based on measured meteorological variables (air temperature, humidity, pressure, wind speed and radiation) we calculated potential evapotranspiration (PET). We used the FAO Penman-Monteith ET_0 (Allen *et al.* 1998).

Actual evaporation (AET) is determined by the difference in the daily changes of the lysimetric cylinder weights where precipitation and water seepage enter the formula:

$$AET = (W_{i-1} + p_{i-1} - s_{i-1}) - (W_i + p_i - s_i)$$

W	weight of lysymeter	[kg]
P	precipitation	[mm^{-1} $hour^{-1}$]
S	seepage water	[mm^{-1} $hour^{-1}$]
i	date of day	

Water sample collection and determination of chemical elements

Water samples were gathered using tensiometer probes (at 40 cm, 80 cm, 120 cm) to collect run off as well as drain off, and a well sample that should represent the groundwater source at that location. The samples were collected every fourteen days, or twich per month.

Chemical elements were determined and measured by an ED-XRF Spectrometer DELTA (Bas, Rudice, CZECH). Measurement of water samples was carried out in the closed protective box of the ED-XRF Spectrometer DELTA. Water samples were analysed in a special plastic vial and every sample was measured using the same duration of X-ray beam (80 sec.). In the process of sample X-raying, we used the multiple-beam measurement mode calibrated by “Reference Material for Elements in Surface Water - SPS-SW2 Batch 127” (Spectrapure Standards, Norway).

Statistical analysis

A matrix was created in Microsoft Excel for all the data files, with 15 minute intervals. The data matrix was processed in STATISTICA 8.0 (StatSoft Inc., 2008). Data from the lysimeter, soil probe and meteorological stations were analysed using principal component analysis (PCA), with determination of cross-correlation, based on factor scores. For analysis of differences between groups of parameters, ANOVA one-way analysis of variance was used. Values of $p \leq 0.05$ were considered to be statistically significant. Daily inputs of meteorological values were evaluated by ANOVA (one-way analysis of variance) on the base of data with 15 minute intervals.

Results

In tables 1 and 2 we summarize the monthly and yearly rainfall as well as the average air temperatures, soil temperature in at 5 cm, relative air humidity, wind speed, air pressure and solar radiation.

The coldest month of 2017 was January and the hottest month was August. In 2017, the highest average daily air temperature was recorded as 21.37° C on 1.8.2017. The lowest average daily air temperature was recorded as -22.28° C on 7.1.2017. When compared to the long-term average, the yearly air temperature increased by 1.32° C. September was characterized by the largest amount of rainfall (246 mm) and January was characterized by the smallest amount of rainfall. The biggest rainfall events in 2017 occurred on 23.7.2017 (60.00 mm) and 21.9.2017 (60.20 mm), respectively. Overall yearly rainfall was consistent with the long-term average, but in September we recorded an abnormal occurrence of rainfall, when rainfall exceeded the long-term average.

The coldest month of 2018 was February and the warmest month of the year was August (Table 2). The highest average air temperature was 19.25° C and was recorded on 9.8.2018, while the lowest average air temperature recorded was -20.04° C on 28.2.2018. Measurements in 2018 were completed on 28.11.2018, and excluded the month of December, so we were unable to compare these values with the long-term average for the year. June (244 mm) and July (349 mm) were characterized by the highest amount of rainfall. January, along with Feb-

Month	Rain open space	Rain in forest	Air temperature	Soil temperature in 5 cm	Humidity	Wind speed	Pressure	Radiation
1	5.00	24.10	-8.74	-0.11	79.62	0.97	1020.29	37.07
2	24.20	25.20	-0.78	0.18	79.38	0.89	1017.67	56.36
3	43.20	39.60	2.59	2.79	76.08	1.10	1016.55	77.97
4	143.40	119.80	3.37	3.80	81.51	1.07	1016.14	86.18
5	145.20	90.00	10.04	10.03	82.49	0.97	1018.72	109.87
6	135.60	62.10	14.32	12.76	73.85	1.06	1018.00	100.60
7	151.40	64.20	14.08	12.96	82.40	0.74	1018.29	71.54
8	119.00	99.20	15.40	14.09	79.75	0.64	1022.11	88.28
9	246.00	210.20	9.53	9.65	87.56	0.53	1017.26	53.59
10	117.60	109.60	5.69	6.16	82.46	0.72	1019.37	39.93
11	65.40	107.70	0.19	1.63	89.23	0.40	1015.10	28.73
12	32.60	121.80	-2.09	0.22	84.38	0.75	1014.08	12.09
Year	1228.60	1073.5	5.32	6.22	81.55	0.82	1017.79	63.59

Table 1. . Monthly and yearly meteorological characteristics of 2017 (rain – mm; temperature - ° C; humidity - %; wind speed – m/s; pressure – hPa; radiation – W/m).

Month	Rain open space	Rain in forest	Air temperature	Soil temperature in 5 cm	Humidity	Wind speed	Pressure	Radiation
1	4.80	17.10	-2.16	-0.93	85.18	0.59	1015.73	28.42
2	4.40	43.70	-5.40	-0.22	89.68	0.30	1013.77	21.18
3	25.80	25.50	-2.88	-0.62	79.65	0.57	1007.41	78.07
4	47.60	41.50	10.06	8.94	65.56	1.08	1017.38	135.19
5	96.40	62.40	11.84	11.04	78.14	0.94	1018.92	87.08
6	244.00	179.80	12.91	12.20	88.67	0.48	1017.57	44.30
7	349.00	307.50	14.60	13.37	84.90	0.51	1017.39	49.91
8	162.60	119.80	15.61	14.50	83.49	0.51	1021.50	70.00
9	97.20	71.50	11.29	10.81	84.25	0.50	1022.94	56.23
10	80.80	65.10	7.66	7.45	80.93	0.70	1020.54	46.28
11	16.80	24.10	3.17	4.58	83.30	0.37	1021.27	39.53
Year	1129.40	958.00	7.30	7.56	81.87	0.60	1017.71	61.10

Table 2. Monthly and yearly meteorological characteristics of 2018 (rain – mm; temperature - ° C; humidity - %; wind speed – m/s; pressure – hPa; radiation – W/m)).

ruary, were characterized by the smallest amount of rainfall. The biggest rainfall events in 2018 were recorded in July; 18.7.2018 (88.40 mm) and 22.7.2018 (69.80 mm). Compared to the long-term average, the months of June and July had an excess of precipitation, where several times more precipitation than the long-term average fell. The evaluation of the yearly total rainfall was not evaluated due to the missing data from December 2018.

Evaluation of soil moisture regime of monitored locations

Changes in values of average monthly soil moisture (Lys H) are consistent in the long term (Fig. 1a). The most significant oscillations are at 40 cm and 80 cm deep. The lowest soil moisture at 40 cm occurred during August. The month of August is also significant in terms of the average monthly temperature since it was the hottest month in both cases during 2017 and 2018.

More significant changes in the average monthly values of soil moisture during the year can be seen in the alder forest in locality 1 (Loc1 H, Fig. 1b). The most significant decrease in moisture occurs at the beginning of the calendar year between January and February, with the subsequent March increase in moisture at the upper soil horizons. Between March and May, the soil moisture decreases very slightly again. From May to July, atmospheric precipitation in the form of rain, which in turn affects and increases soil moisture, occurs increasingly in the stand, particularly in the upper soil horizons. From July to the end of the calendar year, soil moisture is higher than in the spring months, and is relatively constant. At the end of the year moisture starts to increase, which is probably caused by winter snowfall in the form of snow. Lower soil horizons were also affected by rainfall activity in May and June. The highest moisture value at 120 cm was measured in June. Later in the year, the moisture in the lower soil horizons decreased, balancing out by the end of the calendar year. Figure 1b also shows that the month of February and May yielded the lowest levels of groundwater. Medium soil horizons at 80 cm oscillate slightly throughout the year and show no major deviations. A slight decrease in soil moisture occurred simultaneously with a decrease in moisture in the upper soil horizons.

Moisture characteristics at locality 2 in the alder forest (Loc2 H) differed from those in locality 1 (Fig. 2a). Moisture decline in the upper horizon early in the calendar year extended into March, whereas moisture decline only extended into February at locality 1. From May to the end of the calendar year, soil moisture recorded at locality 2 is similar to that of locality 1, but with more significant oscillations and a more significant decline in soil moisture in August. Measurements from the middle soil horizons are missing, which makes it impossible to evaluate them. The most significant changes compared to locality 1 occur at the lower soil horizons (Fig. 2b). The soil moisture profile from both localities is most significant for its oscillations. A decline in moisture occurs in February, May and August. The greatest differences in soil moisture occur between February and March, and the highest moisture values during the year occur in June, July and

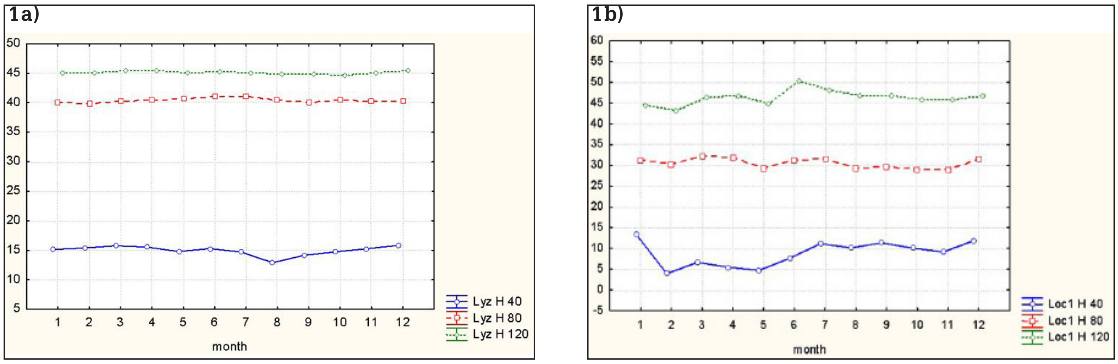

Fig. 1a) Changes in average monthly values of soil moisture in lysimeter during the reference period. **b)** Changes in average monthly values of soil moisture in stand of alder in locality 1 during the reference period.

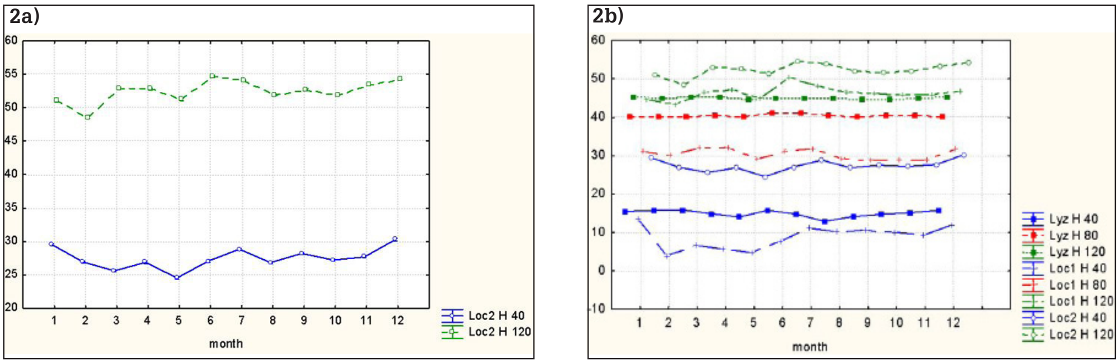

Fig. 2a) Changes in average monthly values of soil moisture in stand of alder in locality 2 during the reference period. **b)** Comparison of changes in average monthly values of soil moisture in the monitored locations during the reference period.

December. The characteristics of each locality is different, so it follows that soil moisture measurements over the course of the year should differ as well. Locality 2 is characterized by the highest soil moisture in both upper soil horizons and lower soil horizons. Locality 1 has the lowest soil moisture in the upper horizons. At the lower soil horizons, locality 1 is slightly drier at the beginning of the calendar year, but soil moisture is shown to increase in March. Moisture levels in the middle layers of soil horizons (80 cm) were lowest at locality 1.

Principle component analysis

The collected data was evaluated using principle component analysis based on determination of factor coordinates, in order to understand the relationships between individual measured characteristics. The most significant were the first five factors (Table 3). The results of the analysis show individual relationships and their seasonal patterns during the year. The first factor with a variance of 34.145% is the most significant. This phenomenon

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**
Lyz T 40	**0.981**	0.077	-0.074	0.045	-0.021
Lyz T 80	**0.981**	0.083	-0.039	0.129	-0.005
Lyz T 120	**0.974**	0.087	-0.019	0.170	0.010
Lyz H 40	**-0.526**	**0.529**	**-0.301**	0.047	**-0.287**
Lyz H 80	0.197	**0.620**	**-0.464**	0.075	**-0.321**
Lyz H 120	-0.344	**0.688**	**-0.520**	0.034	-0.048
Lyz tens 120	0.243	**-0.717**	**0.510**	-0.097	**0.205**
Lyz drain sum	0.038	**0.761**	-0.081	-0.130	**0.355**
Lyz Weight	**-0.767**	0.259	-0.118	0.028	-0.182
T 2m	**0.889**	-0.004	-0.242	-0.160	-0.023
H 2m	-0.056	**0.563**	**0.472**	**0.496**	-0.190
Pressure 2m	0.480	-0.287	0.036	0.223	0.186
Radiation 2m	**0.563**	-0.337	**-0.504**	**-0.367**	0.022
rain forest sum	0.133	**0.732**	0.261	-0.297	**0.310**
T soil 5cm	**0.935**	0.000	-0.171	-0.111	-0.021
Lyz H % listy	0.174	**0.703**	**0.400**	-0.136	-0.111
Loc1 T 120	**0.900**	0.100	0.047	**0.320**	0.051
Loc1 T 80	**0.965**	0.092	-0.003	0.200	0.020
Loc1 T 40	**0.984**	0.072	-0.065	0.060	-0.011
Loc1 H 120	0.031	**0.710**	**-0.450**	0.102	-0.185
Loc1 H 80	-0.215	**0.770**	**-0.301**	-0.084	**0.235**
Loc1 H 40	0.000	**0.540**	-0.108	0.163	**0.573**
Loc2 T 120	**0.896**	0.096	0.058	**0.324**	0.035
Loc2 T 40	**0.982**	0.074	-0.045	0.099	-0.009
Loc2 H 120	-0.102	**0.611**	**-0.467**	0.158	-0.102
Loc2 H 40	-0.168	**0.787**	-0.137	0.069	**0.390**
Loc2 H % listy	0.089	**0.651**	**0.479**	-0.057	-0.143
rain building sum	0.247	**0.758**	**0.348**	**-0.378**	0.116
wind Speed	0.057	-0.115	**-0.418**	**-0.548**	0.050
I forest mean	0.288	0.216	0.254	-0.233	**-0.381**
Rain/Drain	0.328	0.388	**0.594**	**-0.434**	-0.170
Weght change	-0.031	**0.480**	**0.492**	-0.058	0.100
AET	**-0.533**	-0.312	-0.197	**0.343**	0.222
ETo	-0.495	-0.397	0.023	-0.025	0.223
ETsum	**0.611**	-0.342	**-0.523**	**-0.395**	0.046
Total variance %	34.145	23.119	10.595	5.602	4.222
Cumulative variance %	34.145	57.264	67.859	73.461	77.683

Table 3. Principle component analysis with first five factor coordinates.

presents the contrast in evapotranspiration during summer and winter. The increase in air temperature, soil temperatures and radiation allow for the spring onset of vegetation and water consumption for plant development and photosynthesis. The most significant manifestation of this factor occurs between May and September. While vegetation is small, evaporation from the soil prevails, but as vegetation grows over time, the volume of water lot is offset by evaporation and plant transpiration. If the vegetation is well developed and the stand is well connected with the treetops, transpiration represents the majority of water lost by the stand (Fig. 3) and the importance of vapor from the soil decreases. The opposite occurs from November to April when the loss of water from stands is the most significant through evaporation from the soil. Transpiration is affected by radiation and temperature. The first factor indicates that the function of evapotranspiration of the forest in Javorová valley is the most significant between May and October.

The second factor, with a variance of 23.119% is an important phenomenon in terms of water balance of the stand. The increase in soil moisture, air humidity and bottom runoff causes an increase in atmospheric precipitation. The increase in atmospheric precipitation is reflected in the change in lysimetric cylinder weight. The most significant second-factor relationships include growing rainfall, growing soil moisture at the 80 cm and 120 cm depths, and decreasing tension at the 120 cm depth. These relationships correlate to water balance in the soil and soil saturation with water. Figure 4 expresses the manifestation of summer rainfall in June and July. The impact of rainfall was also significant in March and September, suggesting their consistency in the form of rain. Precipitation events also increases air humidity. The second factor describes the impact of the precipitation profile and water on the soil. Summer atmospheric rainfall in June and July plays an important role in restoring groundwater reserves for the summer. Summer rainfall during this period is reflected by storm events. The most significant storm events occurred on 23.7.2017 (60.00 mm), 21.9.2017 (60.20 mm), 18.7.2018 (88.40 mm) and 22.7.2018 (69.80 mm).

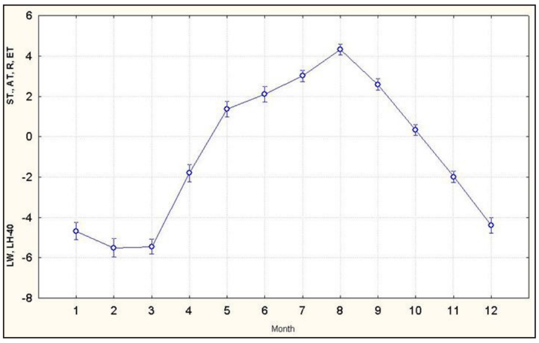

Fig. 3. Factor 1 (F(11,460)=428.55; p=0.0000); LW - lysimeter weight; LH-40 - lysimeter soil humidity in 40 cm; ST - soil temperature (all location); AT - air temperature; R - radiation; ET - evaporation measured by vantage pro 2.

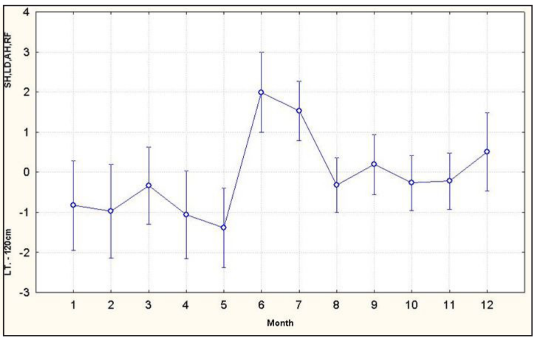

Fig. 4. Factor 2 (F(11.460)=4.6853; p=.00000) LT–120 cm - lysimeter tension in 120 cm; SH - soil humidity (all location); LD - lysimeter drain; AH - air humidity; RF - rain forest (precipitation in forest).

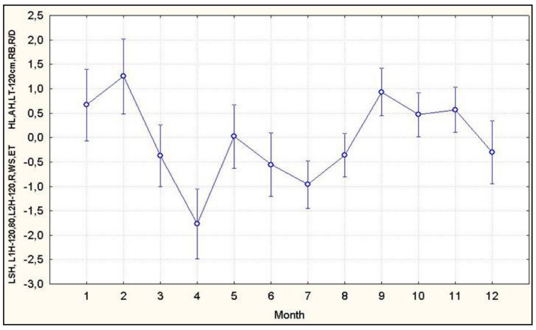

Fig. 5. Factor 3 (F(11.460)=7.5974; p=.00000) LSH - lysimeter soil humidity; L1H-120,80 - locality 1 soil humidity in 120 and 80 cm; L2H - locality 2 soil humidity in 120 cm; R - radiation; WD - wind speed; ET - evaporation measured by vantage pro 2; HL humidity leaf; AH - air humidity; LT-120 - lysimeter tension in 120 cm; RB - rain building (precipitation); R/D – rain/drain.

The third factor, with a variance of 10.595%, is the phenomenon of seasonal contrast of the water cycle in air and soil (Fig. 5). In the winter and autumn months, the air humidity is relatively higher, which in autumn is reflected in the moisture of the leaves along with the occurrence of atmospheric precipitation. The peculiarity of this cycle is the decrease in soil moisture despite the occurrence of atmospheric precipitation. In the winter, precipitation occurs in the form of snow (though in relatively high volumes); soil moisture decreases significantly and the importance of evapotranspiration diminished during this season. The opposite course occurs in April when the spring period begins; hours of daylight increase, wind speed increases, and snow melts. Snow melting increases soil moisture and the change in the phenological phase of plant development causes growth and increase in the importance of evapotranspiration in April. In May, the air humidity increases, resulting in storms and associated rainfall. Plants cease to transpire, but the importance of interception increases due to the phenological phase of the stand and a small amount of rainfall in the stand, resulting in leaf moisture and soil moisture reduction. Evapotranspiration was likely suppressed due to low rainfall in the stand, causing vegetation to close off vents, while aerial parts of the plants trapped precipitation that evaporated from their surface. In 2017 and 2018, this interception was measured at 38% and 32.8% respectively. In the period between April and August, the Javorová valley forest played a significant role in capturing water, depending on the phenological phase of the stand.

The fourth factor -spring rains- represented a variance of 5.602%. This phenomenon has the most significant effect between March and May (Fig. 6). During this period, the occurrence of spring rains is increased by spring winds. The change in the phenological phase of vegetation in this period, together with spring atmospheric precipitation, changed the character of water vapor to air. In the autumn and winter, evaporation of water into the air is carried out by evaporation, whereas in the spring it is mainly a by product of the transpiration ability of vegetation. Transpiration by vegetation is weak or non-existent during winter and autumn. The spring is characterized by high consumption of atmospheric precipitation by vegetation. The increase in water consumption is due to a change in the phenological phase and the onset of photosynthesis. The progression of this phenomenon is the most significant for coastal growth due to the ability to transpire water in the spring. Long term, these phenomenon and their impacts may be influenced by climate change.

The fifth factor represents a variance of 4.222% and relates to the phenomenon of physical forest interception and the moisture of upper soil horizons. The stand captures the most atmospheric precipitation in June (Fig. 7). At the same time, the soil moisture is comparatively lower in the upper horizons at this time. However, the opposite is true in lysimeter. This can be caused by the relatively small and closed space of the cylinder in the lysimeter, along with the location of the lysimeter next to the stand. In June a lesser amount of rainfall reaches the forest floor due to tree crows. The importance of evaporation from the soil, and water leakage through the soil profile were reduced and the tension of the soil at a depth of 120 cm increased. April, August, September and October measurements showed higher soil moisture, water leakage through the soil horizon, increased evaporation and an increase in the amount of rainfall penetrating through the crown floor. The end of summer through autumn is characterized by lower interception, higher water leakage in the soil and greater environmental evaporation. The summer months, and most significantly the month of June, are characterized by the interception ability of the stand and the decrease in surface moisture.

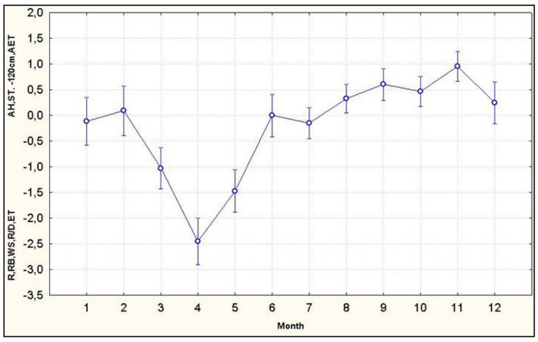

Fig. 6. Factor 4 (F(11.460)=23.741; p=0.0000) R - radiation; RB - rain building (precipitation); WS - wind speed; R/D - rain/drain; ET - evaporation measured by vantage pro 2; AH - air humidity; ST-120 - soil temperature in 120 cm (locality 1 and 2); AET - actual evaporation calculated from lysimeter weight.

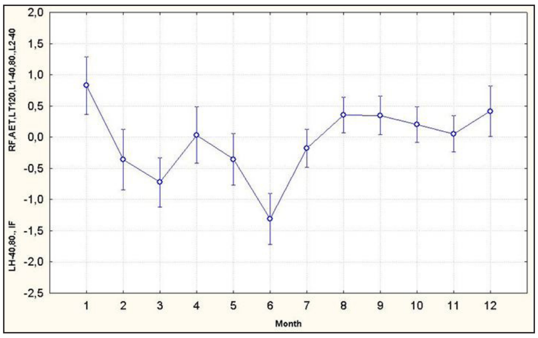

Fig. 7. Factor 5 (F(11.460)=8.0009; p=.00000) LH-40,80 - lysimeter soil humidity in 40 and 80 cm; IF - interception forest; RF - rain forest (precipitation in forest); AET - actual evaporation calculated from lysimeter weight; LT-120 - lysimeter tension in 120 cm; L1 -40,80 - Locality 1 soil humidity in 40 and 80 cm; L2-40 - locality 2 soil humidity in 40 cm.

Course of chemical components in the season

The variability of sulfur values throughout the year is very high. In January, February and March, sulfur levels are below the detection limit, with an occasional exception for water samples from 120 cm, 40 cm, and wells. Between April and August, sulfur levels were at their highest concentration. From September to December, sulfur values were often below the detection limit in well water samples. It follows that the highest values during the season were measured in June, July, August and the lowest values occurred in spring, autumn and winter (Fig. 8a). The most stable pattern occurred in a well water control sample where the water level was less than 120 cm during the year.

The seasonal profile of potassium in the soil monolith, along with the well water control sample and drainage water, followed the same pattern of variance (Fig. 8b). The lowest measured values occurred in the months of November, December, January and February. The highest values were measured during March and October, with the exception of July. The cycle of potassium values oscillated during the year, depending on seasonal changes.

Rubidium distribution was not significantly dependent on the season, although in some cases (for example March - Rb 80, Rb 120, Rb well) it appeared to be affected by seasonal characteristics (Fig. 8c). The upper part of the soil monolith (Rb 40) exhibited relatively similar rubidium concentrations from January to May with a deviation from this standard occurring in February. Increased values persisted until the end of the year with oscillations to lower values in August and November. The middle part of the soil monolith (Rb 80) exhibited a significantly different rubidium profile when compared to the upper soil monolith. Lower values were measured early in the year (January, February) as well as at the end of the calendar year (November, December) as well as in May. Between March and August, there were changes rubidium concentration (Fig. 8c) with the highest values occurring in March and July. September and October were characterized by moderation and stabilization of changes in values. Lower parts of the soil monolith (Rb 120) had the most significant increase of values in March. Prior

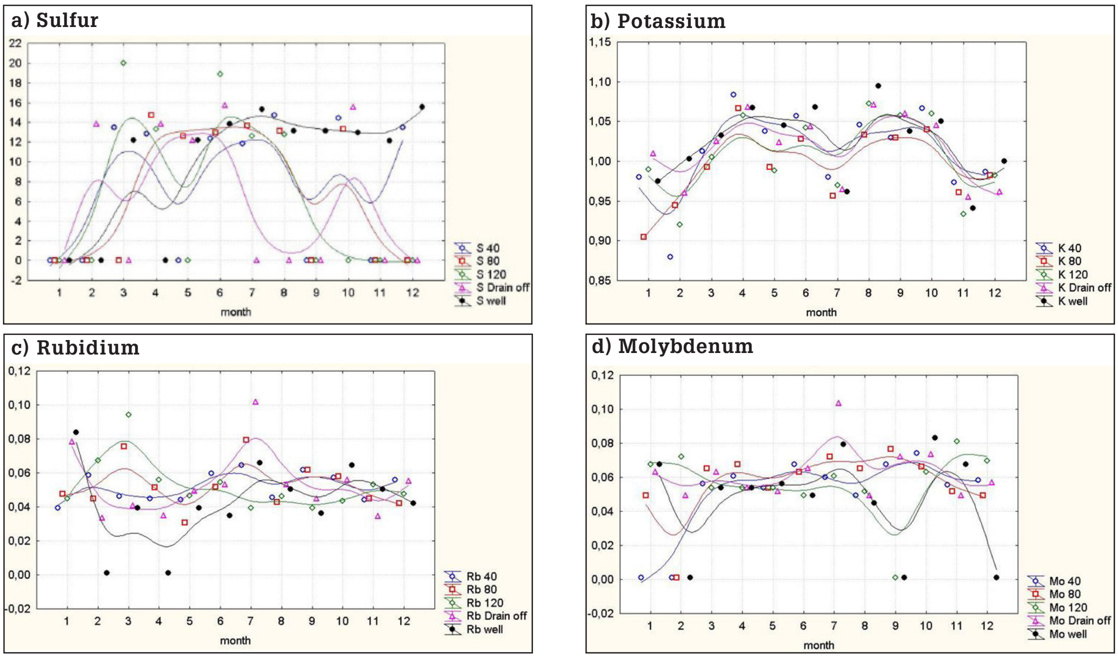

Fig. 8. Profile of chemical components throughout the year.

to March, concentrations of rubidium generally declined, and then increased again near year-end. The values of rubidium in drainage and well water followed the same pattern. The highest measured value of rubidium was taken in the month of June in a water sample from drain-off.

Molybdenum (Fig. 8d) concentrations show a period of high variability of values between September and February; a period of low variability between March and May; and a period of increased variability and increase in values between June and August. The high variability period (September to February) occurs due to low concentrations of molybdenum in September and again in February. In March, molybdenum levels stabilized and subsequent homogeneity of values persisted until May. In May, values of molybdenum were relatively equal in all monitored locations. In June, variability increased again particularly in the upper (40 cm) and middle layers (80 cm) as well as in the lysimeter reading. The opposite pattern emerged for the upper layers (120 cm) and for well samples. In July, there was an increase in molybdenum content in almost every monitored location with the exception of the upper soil monolith, where the value decreased. In August, there was a decrease in molybdenum concentrations across all locations.

Discussion

Antal *et al.* (2003) consider soil moisture to be a fundamental characteristic of water content in soil. Water in soil is the most important factor affecting the water cycle regime (Tužinský 1993). Soil moisture at individual locations during the monitoring period varied depending on the season. An exception occurred in the lysimeter measurements when the soil moisture was relatively constant. We can infer that this occurred as a result of the design of the lysimeter system as it creates a closed soil system that prevents the natural distribution of water in the soil when compared to the forest ecosystem. The highest variability was recorded from soil probes at site 1 and 2. We anticipated that the highest soil water content would occur during snow melt, when groundwater reserves are replenished. Tužinský (1993) predicted a favorable soil moisture content by June, assuming sufficient precipitation in winter and spring. However, in the spring, the soil moisture values were at their lowest levels, which did not confirm the Tužinský supposition. Lapin *et al.* (1990) predicted an increase in potential evapotranspiration of 7-14% by the year 2000, and an increase up to 18% by the year 2020, which would have the effect of drastically reducing runoff and increasing water deficiency. Tužinský (1993) hypothesized that evapotranspiration would consume the winter water supply in early spring and subsequent evapotranspiration would be forced from May to September. Consumption of winter water supply by transpiration (Tužinský 1993) was confirmed.

The principal component analysis was used to evaluate the factors influencing the soil moisture regime of the monitored stand. The first factor presented the contrast in evapotranspiration in summer and winter. The effect of evapotranspiration in Javorová valley was the most significant from May to October. Tužinský (1993) predicted the onset of forced evapotranspiration for the period between May and September, based on a change in soil moisture caused by climate change. The most significant manifestation of a evapotranspiration event in the period from May to August confirmed this hypothesis. Šiška *et al.* (2005) evaluated the changes in total potential and actual evapotranspiration as well as the evapotranspiration deficit in Slovakia's elevation profile from the perspective of possible climate development. The results suggest an increase in potential evapotranspiration of 9% by

2010, 15% by 2030; and 25% by 2075 for northern parts of Slovakia (Šiška *et al.* 2005). Changes are also expected to be 6% in 2010, 9% in 2030, 13% in 2075, while the evapotranspiration deficiency could increase by up to 32% by 2010, 54% by 2030 and 111% by 2075 (Šiška *et al.* 2005). Evapotranspiration is considered to be an important component of the water balance and its expected increase due to climate change suggests an increase in longer-term drought, as well as greater and faster evapotranspiration in the future.

The fourth factor showed the impact of spring rain on the vegetation under investigation. We can infer that the of spring rain (from March to May) was probably influenced by the phenological phase of the stand. Škvareninová (2009) reported a period of budding of needles (*Picea abies*) for stands above 950 meters in the second half of April.

In forest ecosystems, loss of water balance through interception is influenced by stagnation, canopy, woody composition and age of vegetation (Tužinský 2004). The impact of physical forest interception on the moisture content of top soil horizons was most significant in June. In in June of 2017, interception accounted for 73.5 mm or 54.2% of rainfall out of a total 135.6 mm that fell in the open area. In 2018, precipitation was significant in June, and 244 mm rainfall fell in the open area. During this time period, interception captured 64.2 mm or 26.3%. According to Tužinský (1997), the process begins with the penetration of rainfall through the crown floor from ≥1.0 mm. The percentage of rainfall penetration varies depending on the foliage stage. Results show that the amount of water trapped by interception depends on the amount of precipitation.

The second factor measured was important in terms of water balance components and describes the profile of rainfall, water and soil impact. The most significant relationship occurred between rainfall and soil moisture. Impact collisions during storm events occurred in June and July. At higher altitudes and areas predisposed to fog, horizontal rainfall (Fojt and Krečmer 1975) contributes significantly to water totals. The effect of horizontal rainfall on the water balance of the stand is an increase in the amount of water leaked through the soil monolith, and increase in soil and air humidity. These effects were most significant in June and July. Rainfall during this period was high in volume and intensity, but there was a prolonged time period between rainfall events. When the stand had sufficient water content, these rainfall events replenished the groundwater levers. Forest stands play an important role in the hydric function of the ecosystem (Lepeška 2008).

The third factor for analysis is the effect of seasonal changes and characteristics on water balance. Holko *et al.* (2011) lists specific characteristics of the hydrological cycle in mountain environments, including: distribution of basic climatic elements, vegetation, height differences and the impact of complex landscape morphology. The water cycle influences the soil moisture regime. In the winter, the surface of soil freezes, snowfall increases air humidity, and soil moisture decreases. Change in moisture conditions correlate with the change of season and the phenological phase of the stand. Tužinský (2006) reports solar radiation as the most important factor affecting phenological phenomena. The peculiarity of this cycle was the decrease of soil moisture despite the occurrence of atmospheric precipitation. From a hydropedological point of view, a significant factor is the depth of the soil to which the roots reach, which, through deduction, affects the water supply in the soil (Tužinský 2006). These factors, along with the climatic elements, landscape morphology, phenological phase of the stand and the depth of the soil, influence the soil moisture regime.

Measurements of element concentrations showed high sulfur variability during the year as it undergoes various photochemical, oxidative, catalytic and other reactions. Sulphur is one of the most common air contaminants, entering the environment through the burning of fossil fuels, volcanic activity, as well as though the biological processes of soil microorganisms (Prousek 1991). Variation in sulphur concentrations in Javorová valley depend both on climatic conditions and the chemical composition of precipitation. Changes to the chemical composition of precipitation is more likely to occur in June, July, and August when sulfur levels are highest. Soil acidification by sulfur was the most significant in the upper soil layers and in the well water control sample. We observed that acidic deposition by rainfall has the greatest impact on groundwater reserves.

The seasonal cycle of potassium exhibited the same type of variation in all the monitored components. The lowest values were recorded in November, December, January, and February and highest values were observed between March and October. In July potassium levels was significantly lower, comparable to winter values. Acid rain in mountain environments leaches calcium, magnesium, potassium and sodium from the soil (Hruška *et al.* 2009). From the measurements, we assume that the lower potassium content in the soil components is due to the higher sulfur content. Potassium belongs to the biogenic elements and its concentration in cellular fluids plays an important role in healthy organism development. Its function is partly the regulation of the plant's water regime. Because it is significantly osmotic, potassium increases the hydrophilicity of the protoplasm, increases osmotic pressure, and reduces evaporation. According to Ložek (2000), potassium content in soil is primarily inorganic potassium with a small proportion of organic potassium biologically absorbed from dead plant tissues and soil microflora. It is likely that potassium activates enzymes that cause protein synthesis (Procházka and Macháčková 1998). Potassium plays a major role in plant health. Potassium leaching is a negative effect of long-term soil acidification. According to Michalík (2001), potassium deficiency causes anion and carbohydrate accumulation in plant tissues, decreases the intensity of biochemical processes, putrescine formation, chlorosis, necrosis and leaf wilt. Potassium deficiency could cause a number of problems in the future, and its deficit will contribute to disrupting the ecological stability of ecosystems.

Rubidium concentration was not significantly dependent on the season, although in some cases it could be affected by seasonal characteristics. In nature, free rubidium does not occur, except in compounds in which the oxidation stage I exits as a Rb cation. Kabata-Pendias (2000) included rubidium in a group of elements with a low degree of potential threat. The values of this element were balanced over the course of the year. Minerals containing rubidium may cause a higher concentration of this element in water. Some plants respond to potassium deficiency by starting to absorb rubidium. One or more of these reasons may have caused this element to decline or increase. Although we are not aware of a biological imperative for this element, we know that it has a stimulating effect on metabolism, similar to potassium.

We classified the seasonal variability of molybdenum into three periods depending on the nature of element variability. Molybdenum is an oft forgotten microelement, but it is a significant microbiogenic element (Marschner 2002). It is part of more than sixty enzymes catalyzing various oxidation-reduction reactions (Mendel and Schwarz 1991). Molybdenum occurs in natural water in trace amounts, usually below 1 $\mu g.dm^3$.

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