Mičaník, T., Sýkora, F., Chrastina, D., Kristová, A. (2026). Changes in partial parameters of surface water quality in the context of climate changes in the Sitka catchment. In: Tolasz, R. (Ed.), Proceedings of the 2nd PERUN Project Conference (TA ČR, SS02030040). CHMI, Praha, s. 124–134, ISBN 978-80-7653-095-9. https://doi.org/10.59984/978-80-7653-095-9.16

Changes in partial parameters of surface water quality in the context of climate changes in the Sitka catchment

(Změny dílčích parametrů jakosti povrchových vod v kontextu změny klimatu v povodí Sitky)

Mičaník, T., Sýkora, F., Chrastina, D., Kristová, A.

https://doi.org/10.59984/978-80-7653-095-9.16

Tomáš Mičaník, T. G. Masaryk Water Research Instit, tomas.micanik@vuv.cz

František Sýkora, T. G. Masaryk Water Research Instit, frantisek.sykora@vuv.cz

David Chrastina, T. G. Masaryk Water Research Instit, david.chrastina@vuv.cz

Alena Kristová, T. G. Masaryk Water Research Instit, alena.kristova@vuv.cz

Abstract: Climate change, accompanied by a rise in air temperature across the entire territory of the Czech Republic, is causing an increase in the frequency of hydrological extremes, which affect the quality of surface water. In our study, we focused on changes in surface water quality caused by hydrological drought, when the dilution factor of wastewater in the receiving water body is lower than during normal or increased flows. The objective was to determine the impact of low pollution dilution in surface waters on downstream water quality, depending on climatic and hydrological conditions. It was found that flows below Q_{355} – which define hydrological drought– have been more frequent in most rivers over the past two decades than in previous decades. The research was conducted on the Sitka River downstream of the town Šternberk in the Morava River basin during the period 2024–2026.

The results of pollution attenuation downstream of the Šternberk WWTP during the summer months at low flow rates confirmed a significant reduction in total nitrogen, with denitrification processes occurring at a high rate. When the surface water temperature drops to 10 °C, denitrification practically ceases. It was confirmed that under oxic conditions and at normal flow rates, ammonia was not detected downstream of the Šternberk WWTP. However, at low flow rates, it was always present without any apparent attenuation; as the concentration of dissolved oxygen decreased, reduction processes took place, accompanied by an increase ammonia concentration in the stream. Attenuation of phosphorus was confirmed only in a section of the stream approximately 4 km downstream from the Šternberk WWTP; thereafter, it ceased, and in the lower reaches of Sitka River, concentrations of phosphorus and phosphates rose again. This development will require further research, particularly verification of phosphorus concentrations in nearby watercourses running along the Sitka River. Organic pollution, as characterized by the COD_{Cr} indicator, showed a slight downward trend only under normal flow conditions; during periods of low flow in the summer, the opposite trend was true. Pharmaceuticals were detected in the effluent from the Šternberk WWTP; the most abundant included telmisartan (9,870 $ng \cdot l^{-1}$), carbamazepine (840 $ng \cdot l^{-1}$), and diclofenac (810 $ng \cdot l^{-1}$), with other pharmaceuticals present at concentrations below 355 $ng \cdot l^{-1}$. The reduction in their concentrations in the studied section of the Sitka River averaged 20%, with the exception of citalopram (over 50%).

Keywords: hydrological drought – surface water – changes in water quality – nutrients – pharmaceuticals

Abstrakt: Změna klimatu provázená v České republice nárůstem teploty vzduchu na celém jeho území je příčinou vyšší četnosti hydrologických extrémů, které ovlivňují jakost povrchových vod. V naší práci jsme se zaměřili na změny jakosti povrchové vody vlivem hydrologického sucha, kdy je faktor ředění odpadních vod v recipientu nižší než při běžných nebo zvýšených průtocích. Cílem bylo zjistit, jaký dopad má nízké ředění znečištění v povrchových vodách na jakost vody směrem po proudu v závislosti na klimatických a hydrologických podmínkách. Bylo zjištěno, že průtoky pod Q_{355}, které hydrologické sucho definují, jsou ve většině toků v posledních dvou dekádách četnější než v předchozích desetiletích. Výzkum probíhal na dolním úseku řeky Sitka pod městem Šternberk v povodí řeky Moravy v období 2024–2026.

Výsledky atenuace znečištění pod ČOV Šternberk v letním období při nízkých průtocích potvrdily významný úbytek celkového dusíku, kdy procesy denitrifikace probíhají s vysokou intenzitou. Při poklesu teploty povrchové vody k 10 °C denitrifikace prakticky neprobíhá. Bylo potvrzeno, že v toxických podmínkách a při normálních průtocích nebyl amoniak pod ČOV Šternberk detekován. Při nízkých průtokových stavech byl však vždy přítomen bez zjevné atenuace; s poklesem koncentrace rozpuštěného kyslíku se uplatnily redukční pochody provázené vzestupem jeho koncentrace v toku. Atenuace fosforu směrem po proudu byla potvrzena pouze v cca 4 km úseku toku pod zdrojem znečištění, poté se zastavila a v dolní části koncentrace fosforu a fosforečnanů opět vzrostla. Tento vývoj bude potřebovat další výzkum, především ověření koncentrace fosforu v blízkých vodotečích probíhajících podél toku Sitky. Organické znečištění charakterizované ukazatelem CHSKCr vykazovalo mírně klesající trend pouze za normálních průtokových stavů, v době nízkých průtoků v letním období tomu bylo opačně. V odpadní vodě z ČOV Šternberk byla potvrzena farmaka, mezi nejvíce zastoupená náleží telmisartan (9 870 $ng \cdot l^{-1}$), karbamazepin (840 $ng \cdot l^{-1}$) a diklofenak (810 $ng \cdot l^{-1}$), další farmaka pod 355 $ng \cdot l^{-1}$. Snížení jejich koncentrace ve studovaném úseku Sitky činila v průměru 20 % vyjma citalopramu (přes 50 %).

Klíčová slova: hydrologické sucho – povrchová voda – změny jakosti vod – nutrienty – farmaka

Introduction

Changing climatic conditions affect not only the timing and intensity of precipitation, but also – with a certain time lag – the seasonal variation of surface and groundwater amounts. As average air temperatures rise, precipitation extremes increase in terms of both abundance and scarcity. Drought can be defined in various ways; a detailed explanation is provided, for example, by Hisdal (2000). In general, a drought is primarily defined as a shortage of water to meet certain needs at a given place and time. Along with floods, droughts can be considered the most significant natural disaster in the Czech Republic (Vlnas 2010). Hydrological drought is associated with a decrease in streamflow and, at the same time, a drop in groundwater levels. It develops gradually; outflow from watercourses is replenished by outflow from groundwater reserves. Hydrological drought is most commonly encountered during the summer, but it can also occur in winter or spring as a result of insufficient snowfall. In the Czech Republic, hydrological drought is defined as the 355-day flow (Q_{355}), which is exceeded or reached on 355 days of the year. Because hydrological conditions change every year, the Q_{355} flow rate is calculated from a long-term hydrological series of daily average flow rates (currently 1991–2020).

Pollution that enters rivers during periods of hydrological drought are less diluted; consequently, water quality during such periods should naturally be poorer than during periods of higher flow. However, this may not always be the case, because – especially during the summer – other factors come into play that can contribute to the pollutions' faster breakdown. These factors include higher temperature, higher light intensity, and longer exposure time (photodegradation), as well as lower water flow velocity – and thus a longer period during which the bottom substrate interacts with the water column and the pollution. For example, in the case of the Metuje River (at the Metuje-Krčín profile), the CIT model determined that when the water level drops by 14 cm (from 34 to 20 cm), the volume of water per unit area of the

riverbed decreases by 41%, and the reaction time increases by 30% due to the lower flow velocity. Sunlight causes the water column to warm up more quickly and accelerates biological and photodegradation processes.

The nutrients nitrogen and phosphorus are a significant source of surface water pollution, causing eutrophication. Nitrogen is present in significant quantities in wastewater from municipal and industrial sources; inputs from diffuse sources and non-point source pollution in agricultural landscapes are also substantial (García 2021). Inputs from agricultural activities occur through surface runoff and groundwater percolation. It occurs in several forms, such as nitrate and ammonia nitrogen, which contribute most significantly to water quality problems. It is also present in complex organic compounds, such as amino acids, and in organic matter, including detritus (Rabalais et al. 1996). A less significant source of nitrogen is atmospheric deposition and the fixation of gaseous nitrogen from the air (N_2) into biologically available forms (Vitousek 1997). In the case of nitrogen, the process involves both nitrification under oxic conditions – during which ammonia nitrogen is oxidized to nitrates – and, simultaneously, denitrification, in which nitrates are reduced to gaseous nitrogen (N_2), which escapes into the atmosphere. Microbial denitrification is a way to mitigate the harmful effects of eutrophication, as it removes reactive nitrogen from the aquatic environment (Seitzinger 2006). Through the decomposition of organic matter, organic nitrogen is converted into ammoniacal nitrogen, which is more readily available to nitrifying bacteria than oxygenated forms of nitrogen (Sheibley et al. 2016).

The most significant source of phosphorus is wastewater from point sources of pollution, including both municipal sources and selected industrial sectors, because it is predominantly present in the dissolved form of phosphates. Most of the phosphorus in soils is insoluble, adsorbed onto charged particles, particularly clays, so eroded phosphorus is less readily available for eutrophication (Hendricks 2000). Atmospheric deposition of phosphorus is lower than that of nitrogen (Allan 2007). The dissolved form of phosphorus is readily available to phytoplankton, macrophytes, and benthic organisms. It also readily binds to particles and is deposited in river sediment, from where it can be remobilized into the water column depending on hydrological conditions and the geomorphological characteristics of the river channel (Sheibley 2016).

Method

To study the attenuation of pollutants along the longitudinal profile of a watercourse during a hydrological drought, a total of 4 sites were selected in various parts of the Czech Republic with significant sources of municipal wastewater, where a low dilution factor with surface water is expected during a hydrological drought. At the same time, there are no other significant point sources of pollution in the monitored section, allowing for the observation of any attenuation of the substances of interest. An overview of these sites is provided in Tab. 1.

Table 1. List and characteristics of sites for the study of pollution elimination in the longitudinal profile of the river.

River	River km	Q_{355} $m^3 \cdot s^{-1}$	WWTP	$Q_{ww.}$ $m^3 \cdot s^{-1}$	Dilution Factor
Bílovka	0.3 až 5.3	0.018	Velké Albrechtice	0.020	0.9
Metuje	22.2 až 31.5	1.070	Náchod	0.143	7.5
Rakovnický potok	0.2 až 17.9	0.124	Rakovník	0.054	2.3
Sitka	0.2 až 12.0	0.024	Šternberk	0.048	0.5

The dilution factor was calculated based on the average annual wastewater discharge (for 2024) and the flow rate in the receiving water body at Q_{355}. Precipitation and flow rate data for the above-mentioned locations were recorded daily from online monitoring stations; flow rates were recorded at hourly intervals, and the average daily flow rate was calculated.

We focused on the following nutrients: total nitrogen, nitrate nitrogen, ammonia nitrogen, total phosphorus, filtered total phosphorus, phosphate phosphorus, undissolved matter (at 105 °C), and

pharmaceuticals. Water sampling was conducted at flow rates close to hydrological drought conditions, as well as under standard hydrological conditions at various times of the year (spring, autumn). Sampling profiles were selected as follows: upstream of the point source of pollution, at the outflow from the point source of pollution, and several downstream profiles located 1 to 3 km downstream of the pollution source. Water samples were kept cool during transport and analyzed in accordance with standard operating procedures. The following text presents the results from the Sitka River.

Characteristics of the Sitka River

The Sitka River (also known as the Hůzovka) originates in the Sovinecko Nature Park in the southwestern part of the Nízký Jeseník Mountains on the slopes of Stránský Hill (725 m above sea level). Its total length is 36.6 km. More than half of its course flows through a mountainous area dominated by forests and scattered settlements. On the slopes of the Nízký Jeseník Mountains, it flows into the town of Šternberk (population 13 239), which is the largest settlement in its catchment. The landscape changes abruptly to a flat, intensively farmed area. The differences in land use are clearly evident in Tab. 2. The narrow, elongated Sitka River catchment ends at its confluence with the Oskava River, which in turn flows into the Morava River just 750 m downstream (Fig. 1).

Table 2. Sitka Land Use in the Sitka River Basin.

Land Use	Entire catchment		Lower section of the catchment	
	Area [km^2]	[%]	Area [km^2]	[%]
Arable land	11.5	13.9	6.2	81.6
Forest stand	33.8	40.8	0	0
Shrubby vegetation	4.2	5.1	<0.1	<0.1
Built-up area, road network	4.2	5.0	1.0	13.6
Meadows and Pastures	24.9	30.1	0	0
Diverse Agricultural Lands	4.2	5.0	0.4	4.8
Water areas	0.1	0.1	<0.1	<0.1

The Šternberk Municipal Wastewater Treatment Plant (WWTP) is the sole and, at the same time, the most significant source of pollution in the lower reaches of the Sitka River. The other smaller municipalities located in this area are connected to the Štěpánov WWTP, which is situated in a different catchment (Oskava). Another reason for this arrangement is that the lower Sitka catchment is a site of significant groundwater abstraction, with designated water source protection zones. Therefore, this area was selected as suitable for studying pollution degradation. A total of 8 sampling profiles, P1 through P8, were selected, with P1 located upstream of pollution source P2 (the Šternberk WWTP). (Fig. 2) The list of profiles is provided in Tab. 3.

Table 3. List of sampling sites on the lower section of the Sitka River.

Site No.	Site name	River kilometer
P1	Sitka-above WWTP Šternberk	12.0
P2 WWTP	WWTP Šternberk	10.95
P3	Sitka-Lužice	10.05
P4	Sitka-Stádlo	8.6
P5	Sitka-Moravská Huzová above	6.9
P6	Sitka-Moravská Huzová below	5.9
P7	Sitka-Benátky	4.2
P8	Sitka-above Grygava stream estuary	2.1

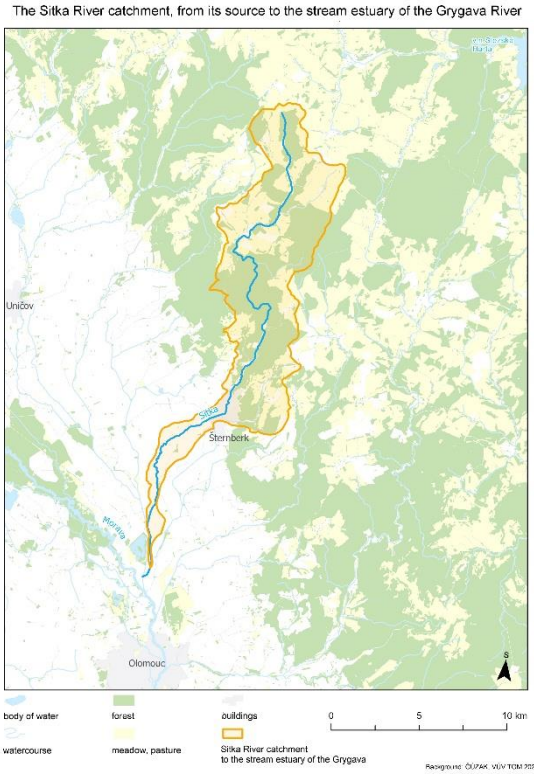


Fig. 1. Sitka River catchment

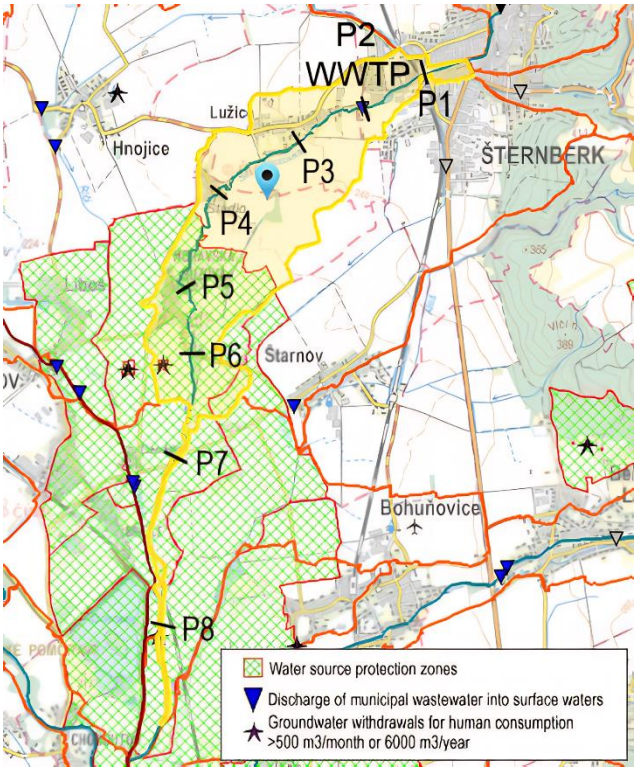


Fig. 2. Sampling sites on the lower section of the Sitka River

Results

Hydrological Drought

First, an analysis was conducted of hydrological data from the CHMI Sitka-Šternberk gauging station (QD_364000) for the period from 1980 to 2024. The number of days in a given year with a flow rate characteristic of hydrological drought Q_{355}, which is 0.024 m³/year, was evaluated. Although a slight upward trend in the frequency of days of hydrological drought is evident, it is not as pronounced as in other locations. The Hrubý and Nízký Jeseník mountain have a beneficial effect here, as they receive more precipitation compared to other regions of the Czech Republic. Fig. 3 clearly shows that drier periods occurred in two intervals: 1992–1997 and 2013–2018. The year 2015 had the highest number of days of hydrological drought, significantly exceeding other dry periods in the given hydrological series. It is interesting to assess during which periods of the year hydrological drought occurs. It is not necessarily limited to the summer months, when evaporation is at its highest. This is illustrated by Fig. 4, which shows that hydrological drought can also occur during the winter months. In 2015, however, it was exclusively during the summer months that hydrological drought was most pronounced, particularly in September following the previous two months, during which the number of days of hydrological drought had already been predominant. Although a brief downpour may temporarily increase stream flows, the water quickly drains from the catchment, and flows can soon return to hydrological drought levels during the summer months.

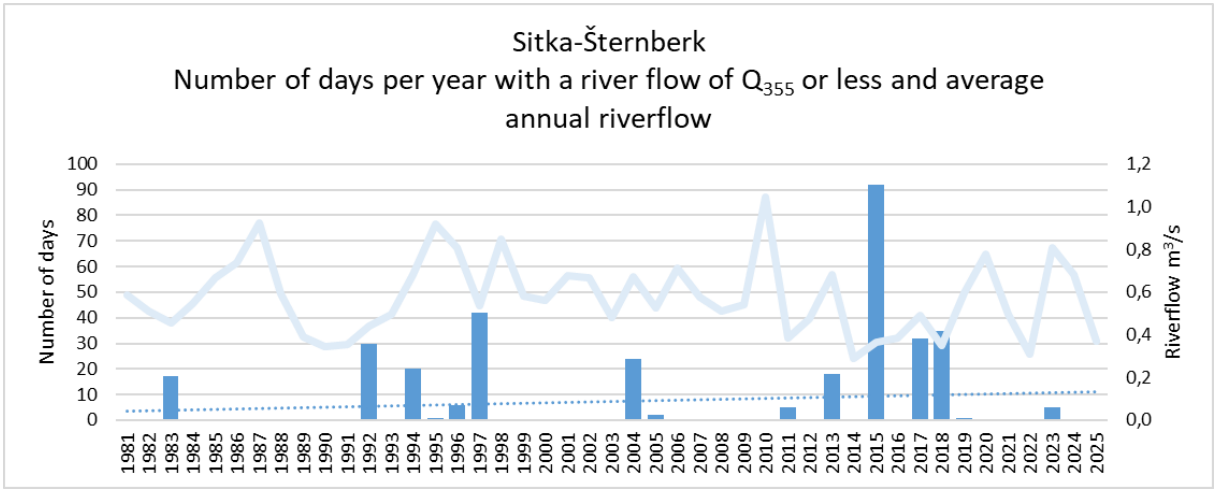


Fig. 3. Sitka-Šternberk – Number of days per year with a river flow of Q_{355} or less during the period 1980–2024

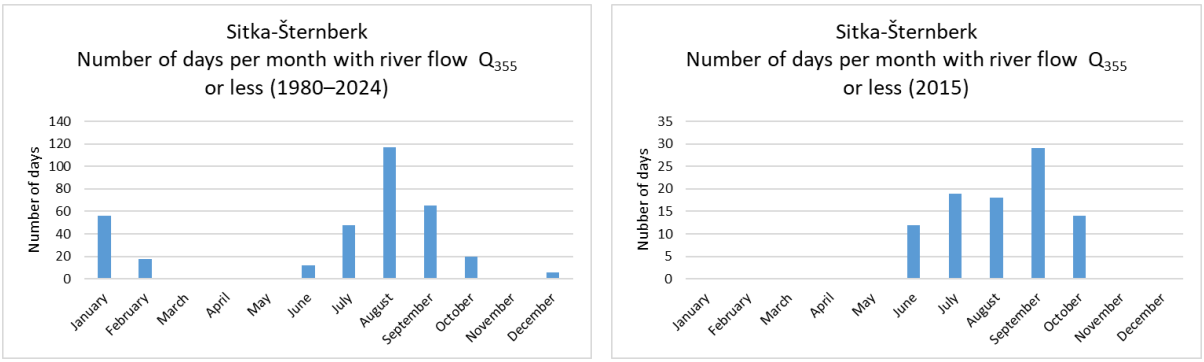


Fig. 4. Sitka-Šternberk – Number of days per month with a river flow of Q_{355} or less during the period 1980–2024 and 2015 separately

Nitrogen Compounds

In the wastewater from the Šternberk WWTP and in the upper reaches of the Sitka River downstream of the discharge point, nitrates account from 72 to 78% of total nitrogen (Fig. 5a). The ammonia content in the wastewater from the WWTP was a maximum of 5.5% of total nitrogen. The remainder consists of organic nitrogen. Under standard flow conditions, no ammonia concentrations were detected in the stream, even during the colder half of the year when nitrification – involving the oxidation of ammonia to nitrites and subsequently to nitrates – does not occur. The dilution effect of wastewater in the receiving water body under standard flow conditions is sufficient. This does not apply during low flows approaching hydrological drought conditions (Fig. 5e, 5f).

Ammonia was detectable up to 6 km downstream from the WWTP outfall, even though oxygen levels were sufficient for the nitrification process. The significant increase in ammonia concentration in the downstream profiles P7 and P8 has other causes. In this section of the river, the continuity of the flow was likely disrupted due to groundwater abstraction and the resulting elimination of base flow. Surface water samples were collected from pools where the dissolved oxygen concentration had dropped to as low as 2.3 $mg \cdot l^{-1}$, corresponding to 20% oxygen saturation. This created conditions conducive to reduction processes, and the reverse conversion of nitrates to ammonia predominated.

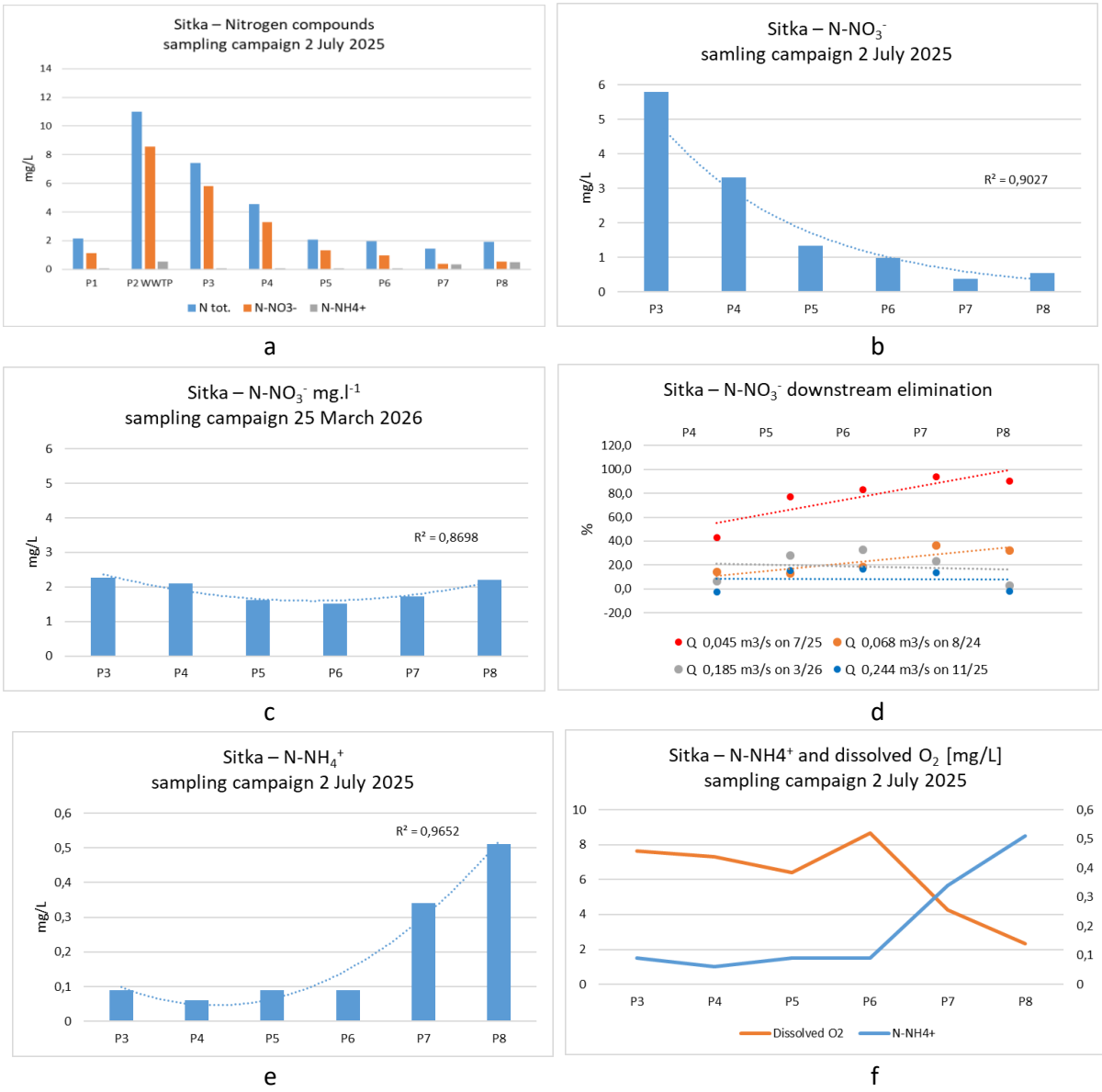


Fig. 5. Concentrations of nitrogen compounds in the Sitka River downstream of the WWTP Šternberk to the Grygava stream estuary

The rate of denitrification (conversion to gaseous nitrogen) is strongly influenced by temperature. Our findings confirm this. Low water levels intensify this phenomenon because the water column warms up more easily. Results from July 2, 2025, show a significant decrease in nitrate levels (Fig. 5b, 5d – red line), when the surface water temperature ranged from 18.3 to 22.4 °C. At a slightly higher flow rate and a similar surface water temperature of 19.4 to 20.5 °C, denitrification was twice as slow. This is somewhat surprising, given that the conditions were similar. Denitrification is influenced by a complex set of other factors, as noted, for example, by Velthuis (2022). At a water temperature of around 10 °C, the decrease in nitrate concentration in the stream was minimal, and as the water temperature dropped further, nitrogen removal ceased entirely (Fig. 5c, 5d – gray and blue lines).

Phosphorus Compounds

As is the case with nitrogen, the Šternberk WWTP is also a significant source of phosphorus for surface waters (Fig. 6a). Phosphates, an easily available form, predominate in the discharged wastewater (over 90% of total phosphorus). The proportion of phosphates in surface water downstream was slightly lower in the spring and during periods of hydrological drought in the summer – around 80% of total phosphorus – in contrast to conditions in the autumn, when it was around 90%. A certain decrease in phosphate

concentrations in the stream during spring and summer under normal or low flow conditions – when no input of particulate phosphorus via erosion is expected – can be explained by its assimilation into the cells of phytoplankton, macrophytes, and benthic algae. Physicochemical processes, such as sorption onto fine river sediment particles and complexation with metal oxides and hydroxides under aerobic conditions, also contribute to phosphorus loss. We are somewhat unable to explain the slight increase in phosphorus concentrations in the downstream profiles P7 and P8 of the Sitka Stream (Figures 6b, c, d). In this section, the Sitka watershed is very narrow, and the Oskava and Grygava streams are located nearby, which may "communicate" with the Sitka Stream via baseflow. Phosphorus removal in the Sitka River downstream of the Šterberk WWTP is much lower than that of nitrogen (Fig. 6e). Phosphorus concentrations in this catchment increase significantly as the flow rate in the receiving water body decreases, confirming the significant influence of a point source of pollution (Fig. 6f).

Pharmaceuticals

Municipal wastewater is a significant source of pharmaceuticals and their metabolites. Their behavior in the aquatic environment and biodegradability depend on their chemical structure and physical properties. One of their fundamental properties is their lipophilicity or hydrophilicity – that is, their affinity for nonpolar or polar environments. This is expressed as the decimal logarithm of the partition coefficient in the octanol-water liquid system ($logK_{ow}$). If $logK_{ow}<3$, the substance preferentially remains in the water column; if $logK_{ow}>5$, the substance preferentially binds to fine river sediment particles. At $\log K_{ow}$ values between 3 and 5, the substance binds to suspended matter floating in the river current.

The most significant detections of pharmaceuticals in treated wastewater from the Šternberk WWTP and in profiles downstream of the outfall are shown in Fig. 7. Among the most significant are telmisartan (antihypertensive, $logK_{ow}=6.13$), carbamazepine (an antiepileptic, $logK_{ow}=2.45$), and diclofenac (an analgesic, $logK_{ow}=4.51$). Telmisartan is not easily degraded in water; its downstream attenuation can be explained by its gradual binding to river sediment due to its lipophilicity. Carbamazepine and oxcarbazepine also exhibit low biodegradability; hydrolysis and biodegradation are not significant in the aquatic environment, and they are resistant to photodegradation by sunlight (Kunkel 2012). Diclofenac is somewhat more degradable in aquatic environments, though still insufficiently so. It tends to accumulate in aquatic organisms at all trophic levels (Wojcieszyńska 2023).

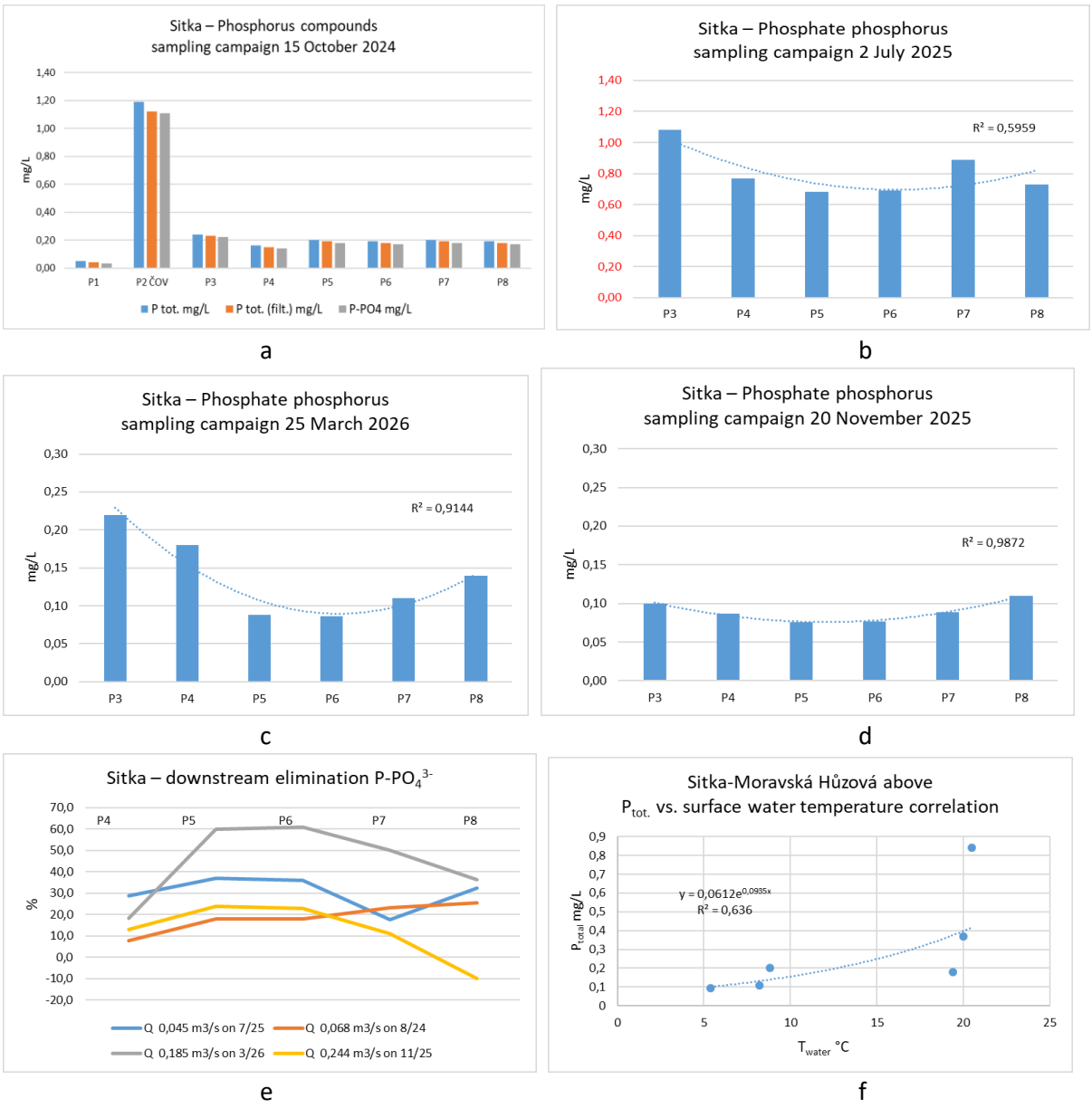


Fig. 6. Concentrations of phosphorus compounds in the Sitka River downstream of the WWTP Šternberk to the Grygava stream estuary.

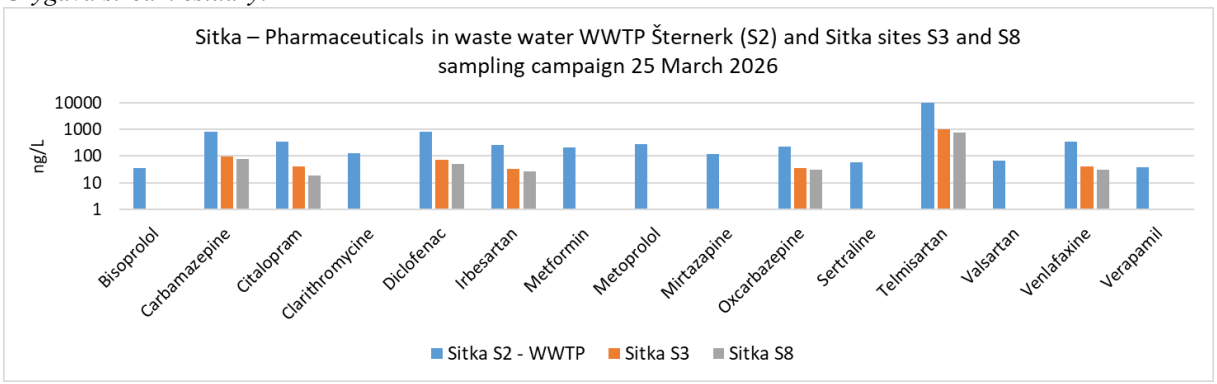


Fig. 7. Concentrations of selected pharmaceuticals in wastewater at the Šternberk WWTP, at Sitka downstream of the Šternberk WWTP (S3), and at the end site (S8).

Conclusions

The number of days per year with a flow rate characteristic of hydrological drought or lower has shown a slight upward trend in the Sitka River catchment since 1980. The driest year was 2015, with 92 days of average daily flow Q_{355} or lower (Q_{355}=0.024 m³/s). The volume of wastewater discharged from the Šternberk WWTP is, on average, twice as high. This has a significant impact on surface water quality in the lower reaches of the Sitka River. The behavior of pollution from this point source during periods of low flow is therefore a pressing concern.

This paper presents the results of a study on the attenuation of nutrient pollution, organic pollution, and pharmaceuticals in the lower Sitka River basin (Olomouc Region, Moravia, Czech Republic) downstream of the Šternberk wastewater treatment plant under various hydrological conditions throughout the year from 2024 to 2026. Nutrients in surface waters are responsible for eutrophication. It was confirmed that during the summer, at times of low flows approaching hydrological drought, when the surface water temperature reaches values around 20 °C, an intensive process of nitrate denitrification occurs, accompanied by a significant decrease in their concentration downstream. In the spring and fall, this process is significantly slowed down or does not occur at all. At average flow rates, wastewater is sufficiently diluted with surface water, and ammonia nitrogen is not detected in the stream, likely due to easy oxidation under oxic conditions. However, this is not the case at low flow rates; under conditions approaching anoxia, reduction processes take place, during which nitrates are reduced while ammonia concentrations increase.

In wastewater and surface water, phosphorus was predominantly present in its most readily available form – phosphates. Particulate phosphorus was minor under normal flow conditions and during periods of hydrological drought. Downstream phosphorus removal was not significant, with the highest rates occurring in the spring and summer months. This can be explained by its assimilation into the cells of phytoplankton, macrophytes, and benthic algae. Phosphorus loss is also contributed to by sorption onto fine river sediment particles and complexation with metal oxides and hydroxides. The increase in phosphorus concentration in the terminal profiles of the Sitka River catchment will need to be verified, as the Sitka River basin is very narrow due to other nearby watercourses, and we assume that interactions via baseflow are influencing this. The process of phosphorus being re-released from the sediment into the water column cannot be ruled out either.

Organic pollution, as measured by the COD_{Cr} parameter, showed a slight downward trend only under normal flow conditions. During periods of low flow in the summer, the opposite was true. Degradation did not occur or was masked by the decomposition of organic matter. The improvement is therefore more likely due to dilution or increased baseflow under favorable hydrological conditions.

The behavior of pharmaceuticals in surface water depends on their physicochemical properties. With a few exceptions, they are not completely degradable during wastewater treatment, and both the parent compounds and their metabolites enter surface waters in significant quantities. Their attenuation in the Sitka River during the spring months was not significant, amounting to about 20%, except for citalopram, where it was higher (over 50%). We assume that the reduction in their concentrations downstream is due to binding to fine particles of river sediment or suspended matter (pharmaceuticals with a higher *logKow* value), uptake by aquatic organisms, and dilution by base flow.

Acknowledgments

This research was conducted with the support of the PERUN project – Prediction, Evaluation and Research for Understanding National sensitivity and impacts of drought and climate change for Czechia (grant no. SS02030040), funded by Technology Agency of the Czech Republic.

We would like to thank Povodí Moravy, a state enterprise, for providing surface water quality monitoring data for the Sitka-Benátky profile (PMO_XPPSK017) for the period from 2022 to 2024.

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