

GAC in Fluidized Bed - Process Evaluation at the WWTP Delémont and Surroundings



Client:

VSA-Plattform – Verfahrenstechnik
Mikroverunreinigungen
c/o Eawag, Überlandstrasse 133
8600 Dübendorf

Project Partner²:

SEDE, Syndicat pour l'assainissement des eaux
de Delémont et environs
Bois du Treuil 4, 2805 Soyhières

Contractor¹:

Fachhochschule Nordwestschweiz¹ (FHNW)
Hochschule für Life Sciences
Hofackerstrasse 30
4132 Muttenz

Project Partner³:

Eawag
Überlandstrasse 133
8600 Dübendorf

Authors: Luca Loreggian¹, Bartosz Kawecki¹, Michael Thomann¹, Nora Corvini¹, Benjamin Gyax¹,
Michael Pulfer¹, Caroline Baillat², Pierre-Michel Seuret², Marc Böhler³

Muttenz, 18. März 2026

Table of Contents

1	Introduction.....	4
2	Material and Methods	7
2.1	WWTP Delémont	7
2.2	Wastewater Sampling	10
2.3	Measurement of Organic Micropollutants (OMPs).....	10
2.4	Measurement of μ GAC Loss	11
2.5	Measurement of Sum Parameters	12
3	Results and Discussion.....	13
3.1	Standard Parameters	13
3.2	Influent Flowrate to WWTP Delémont	14
3.3	Fluidized Bed Behavior	14
3.4	Micropollutant Concentrations.....	16
3.5	Micropollutant Removal	16
3.6	Micropollutant Removal at different μ GAC injection rates	19
3.7	Micropollutant Removal during Rain Events.....	21
3.8	Activated Carbon Loss	24
3.9	Diclofenac Effluent Concentrations	27
4	Conclusions	28
5	References	30

Summary

This report evaluates the full-scale performance of the GAC in fluidized bed (Carboplus) for micropollutant elimination at the Wastewater Treatment Plant (WWTP) in Delémont. Implemented to comply with the Swiss Water Protection Ordinance, the system utilizes micro-granular activated carbon (GAC) in fluidized bed reactors. The study monitored the system for approximately one year between late 2023 and late 2024, analyzing organic micropollutant removal (OMPs), sum parameters, activated carbon retention, and operational behavior under varying weather conditions. The system comprises three fluidized beds (CBP1, CBP2, CBP3) operated in parallel. Performance was benchmarked against regulatory targets and compared with a similar installation at WWTP Penthaz. Key findings are:

Micropollutant Removal Efficiency:

- **Dry Weather:** The process reliably achieved the regulatory target of >80% removal for indicator substances. Diclofenac concentrations are estimated to remain below the Swiss regulatory limit in the receiving river after dilution.
- **Rain Events:** Removal efficiency declined during rain events. This drop correlated with upflow velocities, likely due to reduced contact time and wastewater dilution.
- **Injection Rates:** Varying the GAC injection rate (approx. range 10.5–15 mg/L) showed no immediate correlation with removal efficiency possibly due to the long solids retention times (>200 days), which might buffer short-term dosing changes.

Activated Carbon Retention:

- **Retention:** The system demonstrated high retention of GAC (94–100%), on average meeting the new VSA recommended threshold of 96%. The mean effluent carbon concentration was 0.26 mg/L.
- **Impact of Flow:** Retention remained robust even during high flow velocities associated with rain events.

Operational Behavior:

- **Bed Dynamics:** Bed heights fluctuated, often increasing after rain due to the accumulation of total suspended solids (TSS), necessitating regular backwashing and particularly after strong rain events.

Practical recommendations:

Based on the project findings and on-site operational experience, the following parameters are recommended to consistently achieve a micropollutant removal efficiency of 80%, ensure sufficient Diclofenac elimination, and maintain adequate activated carbon retention (particularly during commissioning):

- **Dosing:** Maintain a dosage of at least 1.8 mg GAC per mg DOC (approx. 12–13 mg/L at typical DOC levels) to provide a safety margin for consistent removal.

- Hydraulics: Limiting hydraulic filter velocities to a maximum of 11–12 m/h seems to ensure sufficient contact time (approx. 6–8 min EBCT).
- Bed Management: Target a resting bed height of 1.6-1.8 m (expanded 2.0-2.7 m).

Conclusions The process is a mature technology capable of meeting regulatory standards. However, performance decreases during high-flow events. Small short-term dosing adjustments are ineffective for immediate process control likely due to system inertia. Future optimization could explore two-stage removal strategies, such as dosing grinded GAC into the biological treatment, further testing is needed to explore this possibility.

1 Introduction

Organic micropollutants (OMPs) such as pharmaceuticals, pesticides and industrial chemicals are often not fully removed in conventional municipal wastewater treatment plants (WWTPs), leading to their release into natural water bodies. On January 1, 2016, an amendment to the Swiss Water Protection Ordinance came into force, which requires certain wastewater treatment plants, based on the number of connected inhabitants and the characteristics of the receiving water body, to implement an additional stage for the elimination of micropollutants (GSchV Annex 3.1). The WWTPs concerned must demonstrate that at least six out of twelve defined indicator substances are eliminated by at least 80%.

Since the amendment came into force many Swiss municipal wastewater treatment plants have been upgraded with ozonation, activated carbon adsorption or a combination of both. In recent years, the Carboplus® process has emerged for the removal of micropollutants from wastewater and has been implemented in multiple Swiss wastewater treatment plants (WWTP). The Carboplus® process utilizes a granular activated carbon up-flow fluidized bed and is typically installed after biological treatment (for example after secondary clarification). The activated carbon used has a particle size between 0.2 and 0.9 mm and is commonly referred to as micro-GAC (μGAC). The fluidized bed is regularly injected with fresh μGAC while spent μGAC is extracted. Spent μGAC is extracted based on the bed height at rest as this is interpreted as an indicator for the total amount of μGAC in the bed. The bed height is monitored continuously to manage μGAC extractions and to prevent loss of activated carbon through the effluent.

The most important design parameters are bed height at rest, upflow velocity and μGAC injection rate. Based on experience from WWTP Penthaz a bed height at rest of 1.5-1.7 m, an upflow velocity of 7-16 m/h and a μGAC injection rate of 13 $\text{mg}_{\mu\text{GAC}}/\text{l}$ (approx. 2 $\text{g}_{\mu\text{GAC}}/\text{g}_{\text{DOC}}$) appear to be adequate to comply with the Swiss Water Protection Ordinance (Albers et al., 2022; Grelot et al., 2021). The empty bed contact time (EBCT) calculated using the bed height at rest lies in the range of 5-15 min and is

significantly shorter than in traditional GAC filtration. It is assumed that the injection of fresh activated carbon and fast adsorption kinetics due to the small particle size of μ GAC compensate for the shorter EBCT. The height of the expanded bed lies typically in the range of 2.0-2.6 m (Albers et al., 2022). However, bed expansion can vary depending on the particle size distribution, density of the μ GAC used and water velocity. Based on data from pilot tests, more than 95% of the activated carbon is retained in the fluidized bed (VSA-Plattform Verfahrenstechnik Mikroverunreinigungen, 2019).

The implementation of the Carboplus® process is planned in many more Swiss WWTPs. Despite the process being considered mature, little operational data is available and some knowledge gaps remain especially regarding the loss of μ GAC in the effluent, the required μ GAC injection rate and the elimination of organic micropollutants during rain events. This study aims to close some of the knowledge gaps by answering the following research questions:

Activated carbon retention: How high is the activated carbon retention under different operating conditions? Can backwashing increase retention? Is an additional filter needed after the fluidized beds?

μ GAC injection rate: What is the ideal μ GAC injection rate to achieve 80% removal of indicator substances? What is the optimal height of the carbon bed? How much carbon is in the system and how long does it stay in the system?

Operation with rain: How does the Carboplus system respond in the short and medium term to increased inflows (reduced contact time, solid retention, etc.)? Can operational measures potentially mitigate the effect of diluted wastewater matrices and increased flows?

Dosing strategies: Which control/regulation strategy has proven effective for ensuring the quality target is met, especially during rain events? Can an optimized dosing strategy or GAC batch dosing improve the elimination of micropollutants?

Design: What is the maximum filter speed that still allows sufficiently high contact times? Is a sufficient contact time maintained at a rate of 15 m/h? How does an optimized filtering regime look like when using multiple reactors?

WWTP Delémont which implemented the Carboplus® process in April 2022 offers an opportunity to gather more information on the process. To answer the research questions above the Carboplus® process at the WWTP Delémont was monitored for about a year at dry weather and rain weather conditions and at various μ GAC injection rates. Wastewater samples were collected on a regular basis and analyzed for organic micropollutant concentrations, μ GAC loss in the effluent and sum parameters such as total suspended solids (TSS), turbidity, spectral absorption coefficient at 254 nm (SAC254) and

dissolved organic carbon (DOC). Operational data such as flow velocities, bed heights during operation, bed heights at rest and so on were provided by the wastewater treatment plant operator (SEDE). The combined data was analyzed and used to answer the above-mentioned research questions. This study closes some of the knowledge gaps regarding the design and operation of the Carboplus® process and provides valuable information for engineers and WWTP operators.

2 Material and Methods

2.1 WWTP Delémont

The WWTP Delémont, also known as SEDE (Syndicat pour l'assainissement des eaux usées de Delémont et environs), is a modern wastewater treatment facility engineered to serve a population equivalent of 50'000. It employs multiple processes to transform raw domestic and industrial wastewater into clean water that can be safely discharged into the Birs river.

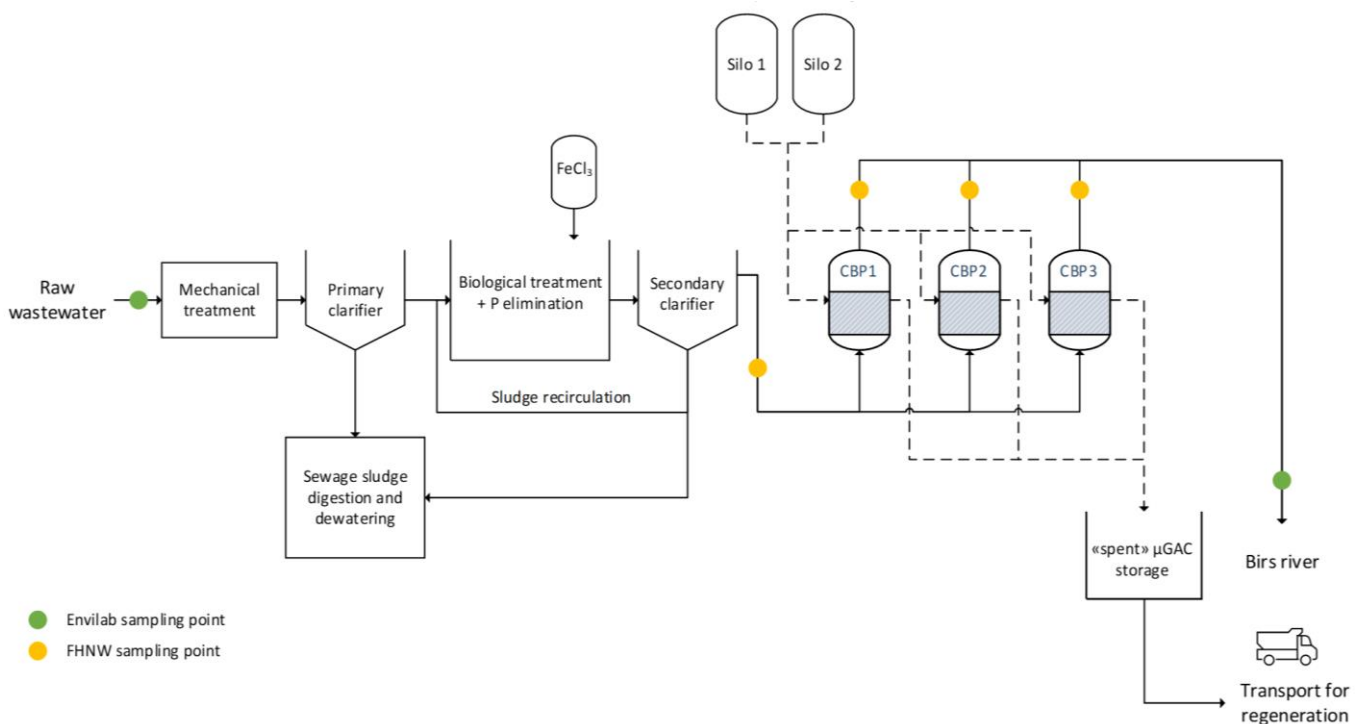


Figure 1: Simplified diagram of the WWTP Delémont, including the OMPs elimination stage with three Carbopulus® reactors in parallel (CBP1, CBP2, and CBP3) and sampling points for micropollutant analysis.

The treatment processes are the following:

- **Grit and Grease Removal:** The screened wastewater then passes into a grit and grease chamber. The flow of the water is slowed down significantly, allowing heavy but fine inorganic materials like sand and gravel to settle at the bottom for removal. This is vital as grit is highly abrasive and can cause wear on pumps and pipes. Simultaneously, lighter materials like fats and oils float to the surface, where they are skimmed off.
- **Primary Clarification:** The water proceeds to primary clarifiers operating in parallel. These are large basins where the water remains for several hours. Through simple gravity sedimentation, a significant portion of the suspended organic solids settle to the bottom to form primary sludge. The primary

purpose of this step is to reduce the concentration of organic matter, which lessens the load on the subsequent biological treatment phase, making it more efficient and cost-effective.

- **Biological Treatment:** This stage uses natural biological processes to remove dissolved organic matter and nutrients. The core of this phase is the activated sludge process. The water from the primary clarifiers enters a large basin containing a high concentration of microorganisms known as activated sludge. **Nitrification (Aerobic Zone):** Air is bubbled through this zone to create an oxygen-rich environment. Here, aerobic bacteria consume the dissolved organic pollutants as food. In this same process, they convert toxic ammonia (NH_4^+) into nitrate (NO_3^-).
- **Phosphorus Removal:** To remove phosphorus, FeCl_3 is added to the water. This chemical acts as a coagulant, reacting with dissolved phosphate to form stable, insoluble solid particles. These solids then precipitate out of the water and are removed along with the excess sludge. Removing phosphorus is essential to prevent eutrophication (algal blooms) in the receiving river.
- **Carboplus®:** The Carboplus® process was implemented in 2022 and consists of three fluidized beds (CBP1, CBP2 and CBP3). At dry weather conditions, two of the fluidized beds are operated in parallel, while the third rests. During rain events, all three fluidized beds are operated in parallel. The operation of the beds is rotated, to avoid excessive bed compaction due to prolonged resting. The beds are also regularly flushed to remove activated sludge particles which might have accumulated. During extreme rain events, a fraction of wastewater bypasses the fluidized beds and is discharged directly into the Birs River. The beds have a surface area of 42.9 m² each and a total column height of 4.35 m. The target value for the bed height at rest is 1.55 – 1.65 m. The beds are operated at an upflow velocity of 7-15 m/h which results in a bed height of up to 3.5 m. Since commissioning the beds have been mostly operated at a μGAC injection rate in the range of 10.5-15 mg/l (Table 1). Injections of μGAC take place in intervals every 8'500 m³ of treated wastewater. The μGAC injection rate was changed over time as the WWTP operators were trying to optimize the process. Some of the changes such as setting different μGAC injection rates in the timeframe 15.02.2024 - 12.05.2024 were made specifically for this study (see table below).

Table 1: μ GAC injection rates in the Carboplus® beds CBP1, CBP2 and CBP3.

Timespan	CBP1 (mg μ GAC/l)	CBP2 (mg μ GAC/l)	CBP3 (mg μ GAC/l)
24.03.2022 - 11.05.2022	15.0	15.0	15.0
11.05.2022 - 23.08.2022	20.0	20.0	20.0
23.08.2022 - 30.11.2022	15.0	15.0	15.0
30.11.2022 - 21.02.2023	14.0	14.0	14.0
21.02.2023 - 03.04.2023	13.0	13.0	13.0
03.04.2023 - 12.06.2023	14.0	14.0	14.0
12.06.2023 - 10.07.2023	12.8	12.8	12.8
10.07.2023 - 30.07.2023	12.5	12.5	12.5
30.07.2023 - 08.09.2023	12.3	12.3	12.3
08.09.2023 - 21.11.2023	12.0	12.0	12.0
21.11.2023 - 21.12.2023	11.5	11.5	11.5
21.12.2023 - 28.12.2023	13.5	13.5	13.5
28.12.2023 - 16.01.2024	14.5	14.5	14.5
16.01.2024 - 15.02.2024	14.0	14.0	14.0
15.02.2024 - 12.05.2024	14.0	12.5	11.5
12.05.2024 - 06.06.2024	13.5	13.5	13.5
06.06.2024 - 16.06.2024	10.5	10.5	10.5
16.06.2024 - 06.07.2024	12.0	12.0	12.0
06.07.2024 - 25.09.2024	13.5	13.5	13.5

The average residence time of the activated carbon in the beds lies around 212 - 277 d. Depending on the bed height at rest, the μ GAC injection rate and other factors the residence time might vary. At the time of this study, the Carboplus® process at Delémont had been in operation for 570 days, and the carbon in the beds had been replaced around 2 - 2.5 times (first full replacement around January 2023). It should be noted that during the start-up phase all the carbon is new, resulting in high micropollutant adsorption performance. The process configurations at the WWTP Delémont and WWTP Penthaz which has also implemented the Carboplus process are quite similar (Table 2). However, the Carboplus process at WWTP Penthaz operates with a slightly lower bed height at rest and a slightly higher maximum upflow velocity, resulting in a lower EBCT (Table 2). A notable difference between the processes at the two WWTPs is that the secondary effluent at WWTP Penthaz undergoes prefiltration using a disc filter, whereas no such filtration is performed at WWTP Delémont. In the publication by Mailler et al. (2016) μ GAC dosage rate was identified as a crucial parameter that greatly influences performance. For example, the average removal of 13 key pharmaceuticals reached 78 - 89% at a dose of 20 g/m³ but dropped to 57 - 68% at 10 g/m³ (Mailler et al., 2016). The study suggests that to achieve an average

removal of 80% for these compounds, operating at 20 g/m³ is necessary. In terms of how long the carbon remains active in the system, an optimal Solids Retention Time (SRT) of 90 - 100 days was determined for μ GAC, which is the point where pollutant removal efficiency reached a maximum and stabilized (Mailler et al., 2016). This is significantly longer than the 5 - 7-day SRT typical for powdered activated carbon (PAC). This long residence time for μ GAC also allowed for the formation of a biofilm in the reactor, which contributed to biological activity (Mailler et al., 2016). It is important to distinguish the carbon's SRT from the water's contact time, which was estimated to be much shorter at 10 to 20 minutes.

Table 2: Comparison of Carboplus® installation at WWTP Penthaz and WWTP Delémont (Grelot et al., 2021; VSA, 2021), and pilot experiment at WWTP Seine Centre (Paris) ((Mailler et al., 2016)).

Process parameters	WWTP Penthaz	WWTP Delémont	Mailler et al. (2016)
Scale	Full scale	Full scale	Pilot scale
μ GAC-Type	Cyclecarb 305 (Chemviron)	Cyclecarb 305 (Chemviron)	Cyclecarb 305 (Chemviron)
Bed surface	2 x 12.25 m ²	3 x 42.9 m ²	4 m ²
Bed height at rest (targeted)	1.5 m	1.55 m	1.5 - 2 m
Bed height expanded	1.6 - 2.8 m	1.8 - 3.5 m	NA
Upflow velocity	5.4 - 6.8 m/h	7 - 15 m/h	15 m/h
EBCT	4.5 - 13 min	6 - 15 min	10 - 20 min
μ GAC injection rate	12.5 -16.4 mg/l	11 - 15 mg/l	10 – 20
μ GAC age	≈ 350 d	212 – 277 d	90 - 100

NA: Data are not available.

2.2 Wastewater Sampling

Within this study the effluent from the secondary clarifier and the effluent from each fluidized bed were sampled for micropollutant analysis, determination of μ GAC loss and analysis of sum parameters (48 hours composite samples, 5 L per sample). Samples were taken in the timespans 21.10.2023 - 11.12.2023, 13.02.2024 - 24.03.2024 and 24.07.2024 - 25.09.2024.

2.3 Measurement of Organic Micropollutants (OMPs)

Samples were prepared for organic micropollutants analysis by filtration using glass fiber filters 0.4 μ m (Macherey-Nagel, Germany). The concentrations of the twelve indicator substances were determined by direct injection in liquid chromatography coupled to tandem mass spectrometry (HPLC-MS/MS, Agilent Technologies, Germany) without any pre-concentration. To separate the substance mixtures, a gradient HPLC (water/acetonitrile, 0.1% formic acid) was combined with a ACQUITY HSS T3 UPLC

column (1.8 μm , 3.0 x 100 mm, Waters, Switzerland). Apart from hydrochlorothiazide and Acesulfam, the detection and quantification of the indicator substances was carried out in positive MS mode based on suitable fragment ions. 4- and 5-Methylbenzotriazole could not be quantified independently of each other using this method, which is why the concentrations determined apply equally to both substances. In addition, internal standards were added to all samples and used to correct matrix- and measurement-related fluctuations in the determination of concentration.

Table 3: Quotients of the initial or fragment ions, as well as detection and determination limits (LOD or LOQ) of the indicator substances in LC-MS/MS measurement. Category according to UVEK (2016).

Substance	Category	Rt [min]	MS1 <i>m/z</i>	MS2 <i>m/z</i>	LOD [$\mu\text{g/L}$]	LOQ [$\mu\text{g/L}$]
Acesulfam	-	2.3	162.0	82	0.010	0.05
Gabapentin	-	5.8	172.1	154.1	0.015	0.05
Amisulprid	1	6.6	370.2	242.1	0.010	0.05
Carbamazepin	1	8.5	237.0	194.0	0.005	0.05
Citalopram	1	7.9	325.2	109.2	0.015	0.05
Metoprolol	1	7.0	268.2	72.1	0.010	0.05
Venlafaxin	1	7.5	278.0	58.2	0.005	0.05
Clarithromycin	1	8.6	748.4	158.2	0.015	0.05
Diclofenac	1	10.3	296.0	214.0	0.005	0.05
Hydrochlorothiazid	1	6.1	296.0	268.9	0.015	0.05
Irbesartan	2	8.7	429.3	207.2	0.005	0.05
Benzotriazol	2	6.6	120.0	65	0.001	0.05
Candesartan	2	8.9	440.9	262.9	0.005	0.05
4- and 5-Methylbenzotriazol	2	7.4	134.1	77.2	0.005	0.05

To broaden the existing data set, Acesulfam and Gabapentin, although they are not amongst the twelve indicator substances, were also measured and its removal efficiency was evaluated. Simultaneously with the measurements carried out in this project, the monitoring campaign for the elimination of OMPs continued. Envilab was chosen as the analytical laboratory for this purpose. The results were provided for direct comparison with the concentrations measured by FHNW.

2.4 Measurement of μGAC Loss

Activated carbon concentration in the effluent of the fluidized μGAC beds was measured by mathematical image processing analysis of activated carbon (MIPA2C) according to (Pulfer et al., 2024). Triplicate measurements were performed using 0.5 L sample volume per measurement. For quality control, samples were spiked with 0.1 mg PAC/L also in triplicate. Samples were prepared by filtration through 0.45 μm cellulose nitrate filters (Whatman NC45, 50 mm diameter, Sigma-Aldrich, USA). Filters were dried

at 105°C for at least 4 hours and scanned (EPSON Perfection V600 scanner at 2400 dpi). The activated carbon concentration was calculated by determining RGB values using a multiple polynomial regression model. For triplicates LOD and LOQ were 0.051 mg/L and 0.102 mg/L respectively.

2.5 Measurement of Sum Parameters

Wastewater samples taken from the secondary clarifier effluent and the effluent of the Carbopius beds were analyzed for TSS (SN EN 872:2005), SAC254 (DIN EN ISO 10523:2012-04+) and DOC (DIN EN 1484:2019-04+).

3 Results and Discussion

3.1 Standard Parameters

Ammonia, nitrite and nitrate concentrations in the effluent of the WWTP Delémont show that stable nitrification is achieved (see Figure below). TSS, COD and DOC concentrations in the secondary clarifier also lie in a typical range (see Figure below). COD concentrations sometimes appear relatively low compared to DOC and TSS concentrations, which might be attributed to measurement uncertainty.

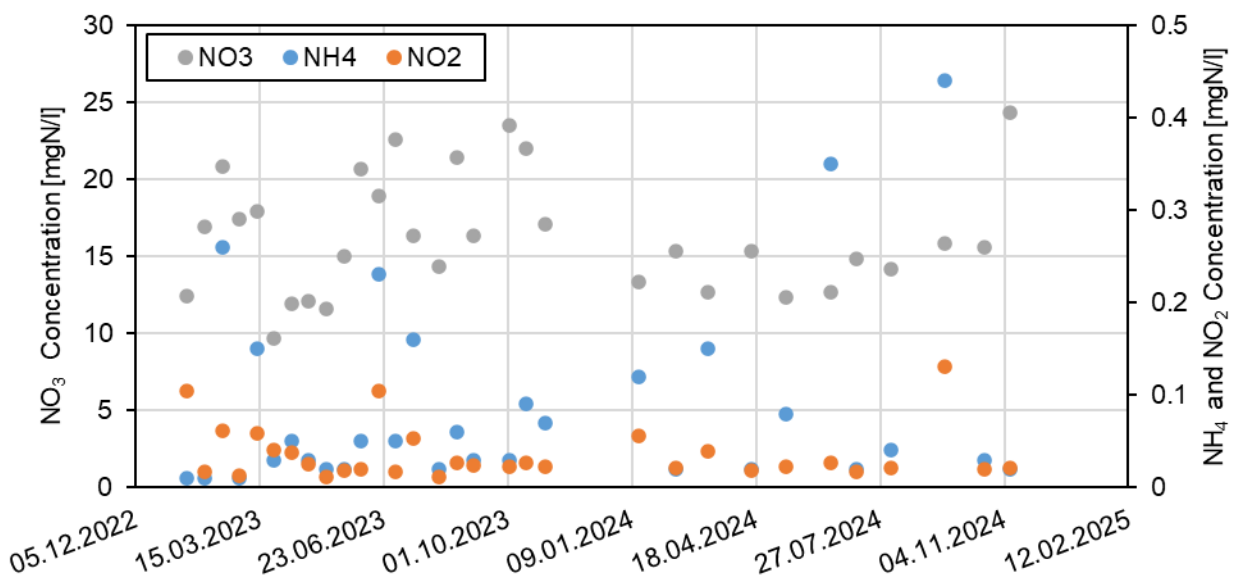


Figure 2: Ammonia, nitrite and nitrate concentrations in the effluent of the WWTP Delémont.

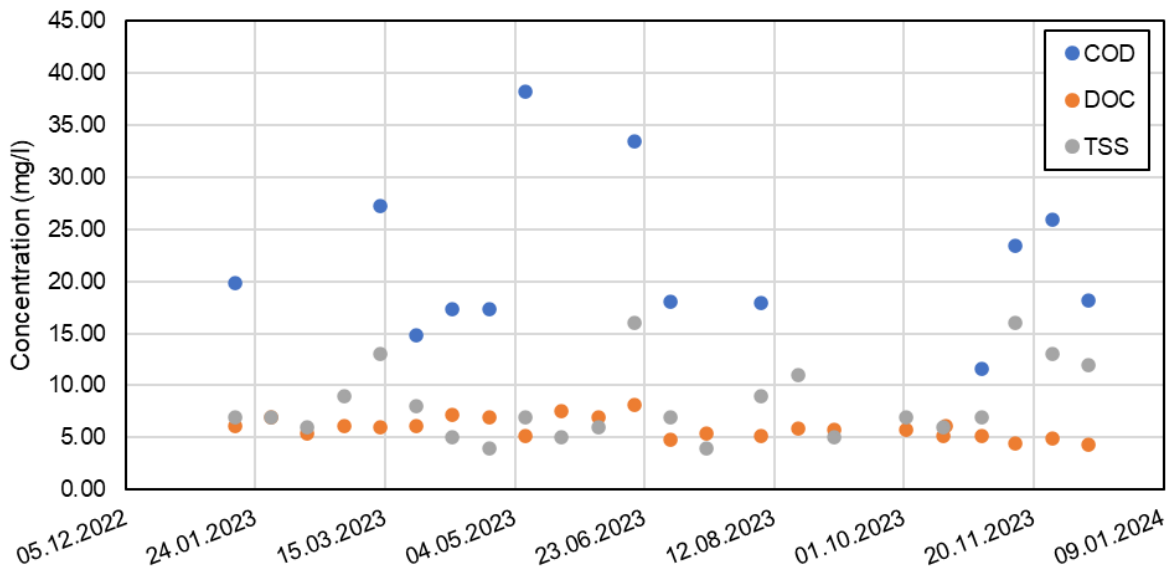
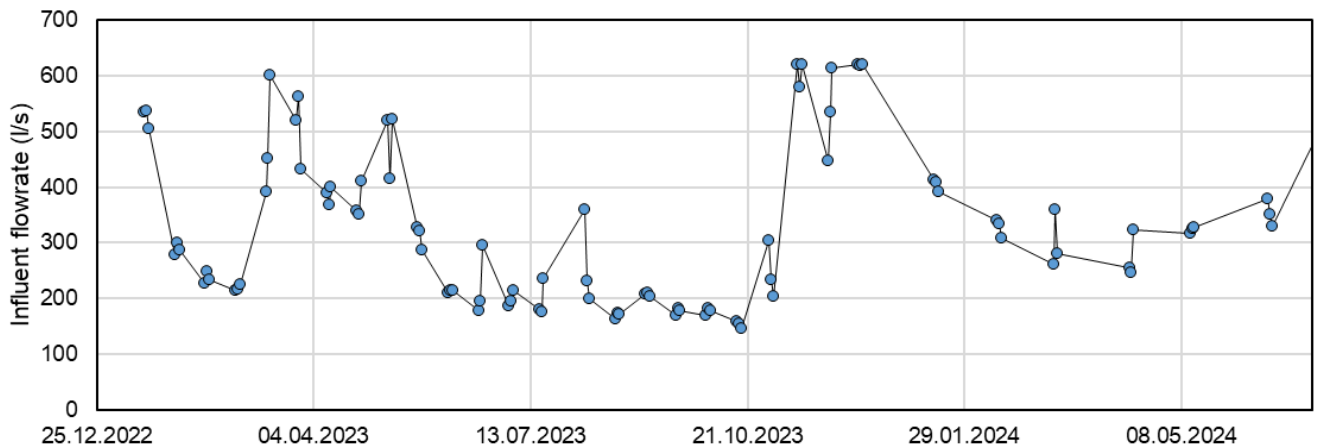


Figure 3: COD, DOC and TSS concentrations in the secondary clarifier effluent of the WWTP Delémont.

3.2 Influent Flowrate to WWTP Delémont

Influent flowrate data from the WWTP Delémont shows that during the study period multiple rain periods occurred (see Figure below).



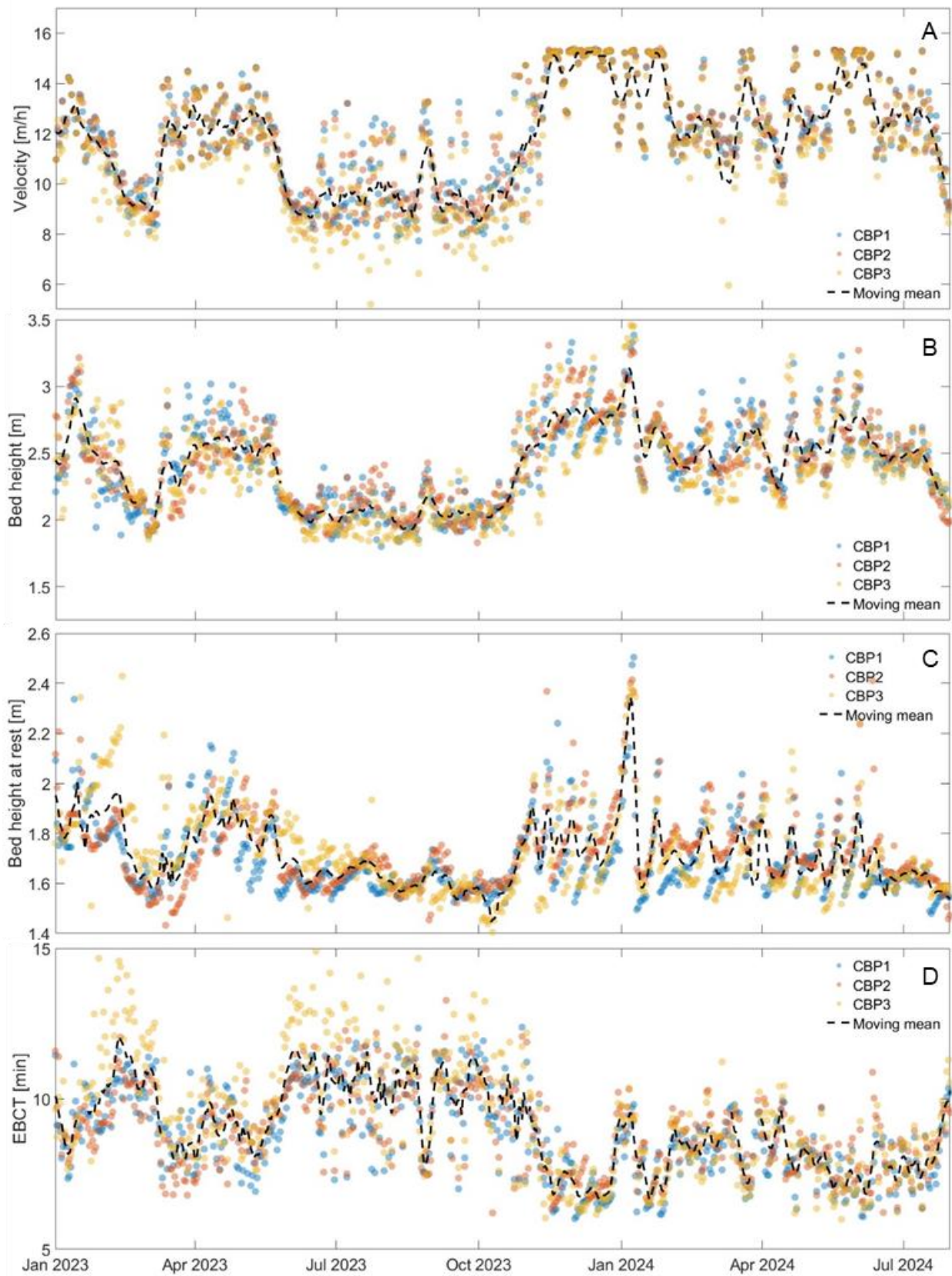


Figure 5: Operational data from the fluidized beds (CBP1, CBP2, CBP3) at the WWTP Delémont.

3.4 Micropollutant Concentrations

The figure below compares micropollutant concentrations in the secondary clarifier effluent from the WWTP Delémont and WWTP Penthaz. Effluent from WWTP Penthaz shows higher concentrations of certain micropollutants. Potential reasons for this discrepancy include regional differences in pharmaceutical use, industrial activity, or the composition of infiltration water. Overall, the observed concentrations are typical for wastewater treatment plants in western Switzerland (Kanton Waadt, 2019).

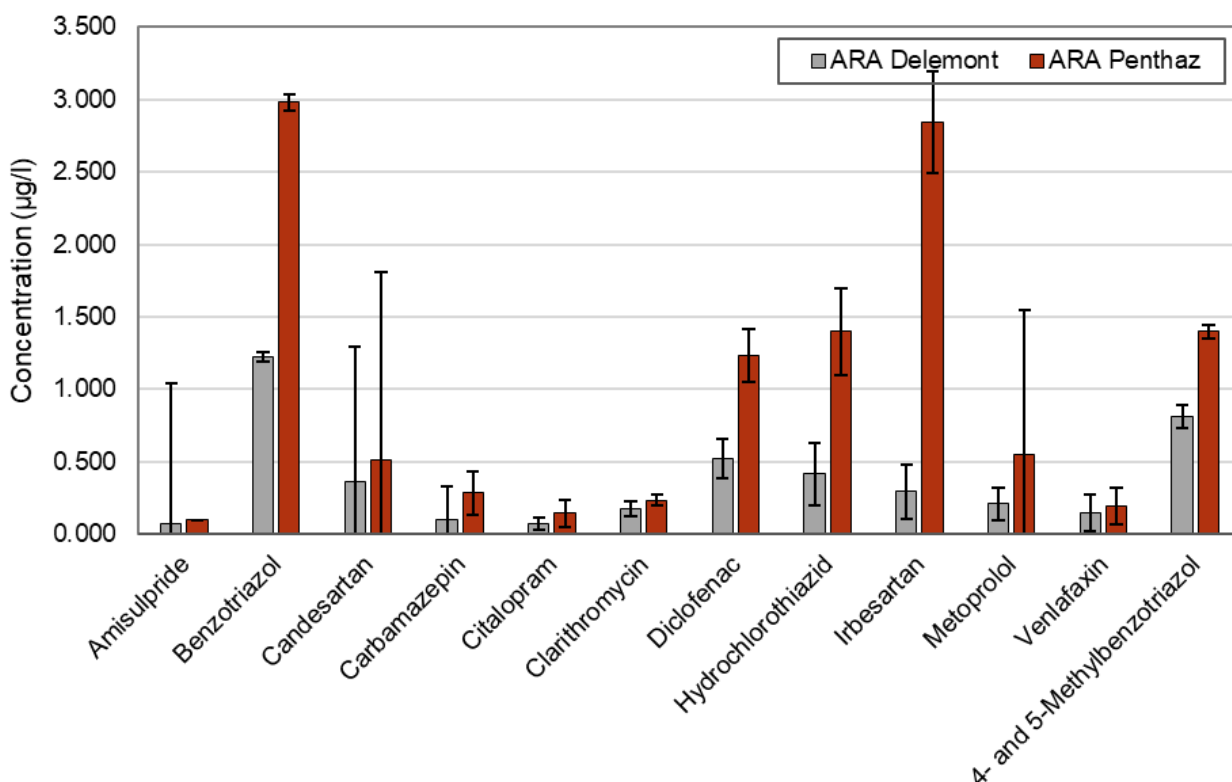


Figure 6: Concentrations of micropollutants in the secondary clarifier effluent of the WWTP Delémont and ARA Penthaz.

3.5 Micropollutant Removal

Since the implementation of the Carbopulus Process at the WWTP Delémont category 1 and category 2 micropollutants were frequently removed by an average of more than 80% with a few exceptions in March 2023, May 2023, and November 2023 (Figure 7). According to Swiss legislation, the removal rate of the marker substances must be above 80%. However, it should be noted that not all twelve substances must necessarily be used for the assessment. The cantons are free to select at least six substances from these twelve. Their average is calculated in a ratio of 2:1 for the categories 1 and 2.

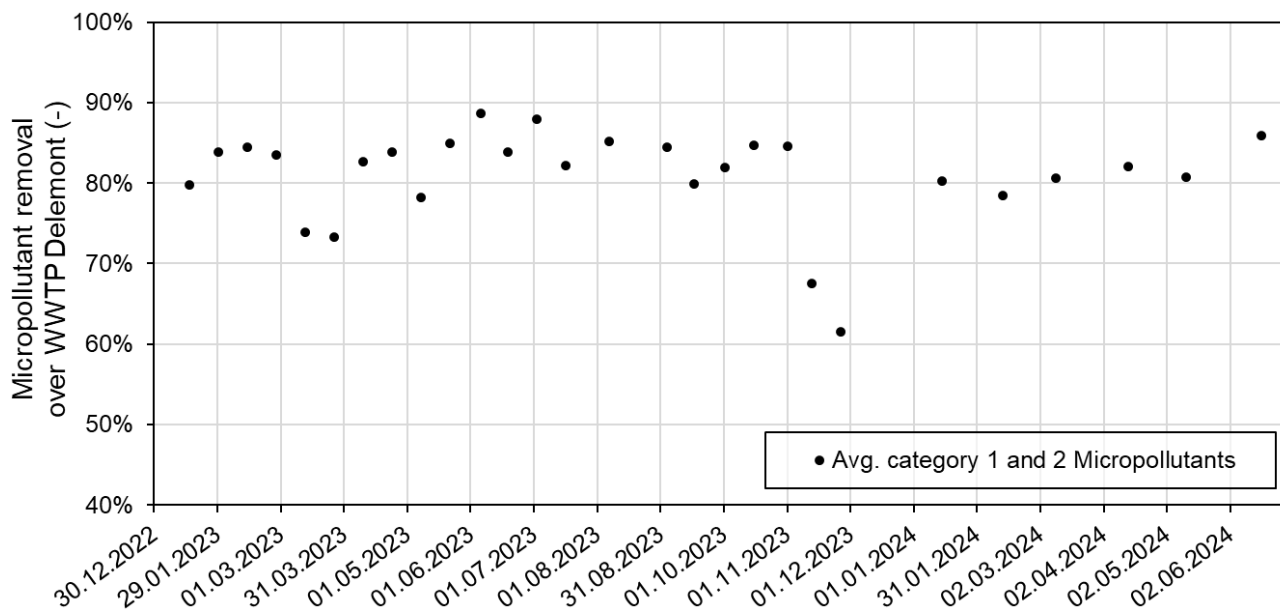


Figure 7: Removal of category 1 and category 2 micropollutants at ARA Delémont measured by Envilab.

Micropollutant removal rates measured at WWTP Penthaz are on average slightly higher than measured at WWTP Delémont (Figure 8). The average removal of all 12 micropollutants was 85% for WWTP Penthaz and 81% for WWTP Delémont. Metoprolol, Benzotriazole and 4- and 5-methylbenzotriazole, well adsorbable molecules, are well removed in both plants (i.e., $\Delta > 95\%$). Carbamazepine and Hydrochlorothiazide are adsorbed to a similar extent. The Caboplus® process at the WWTP Penthaz is operated at a slightly higher carbon dose than at the WWTP Delémont. This may have resulted in a slightly better performance. Mailler et al. (2016) observed for a dosage of 10 mgGAC/L a mean Diclofenac elimination of about 65% and for a dosage of 20 mgGAC/L a mean Diclofenac elimination of about 80%. The mean of the Diclofenac elimination of about 72% for a dosage of 11 - 15 mgGAK/L (WWTP Delémont) and the mean of about 85% for a dosage of 12.5 - 16.4 mgGAK/L (WWTP Penthaz) are showing a slightly better Diclofenac adsorption. When it comes to Carbamazepine Mailler et al. (2016) have observed removal rates in the range of 80-95% which are slightly higher than removal rates observed for WWTP Penthaz and WWTP Delémont.

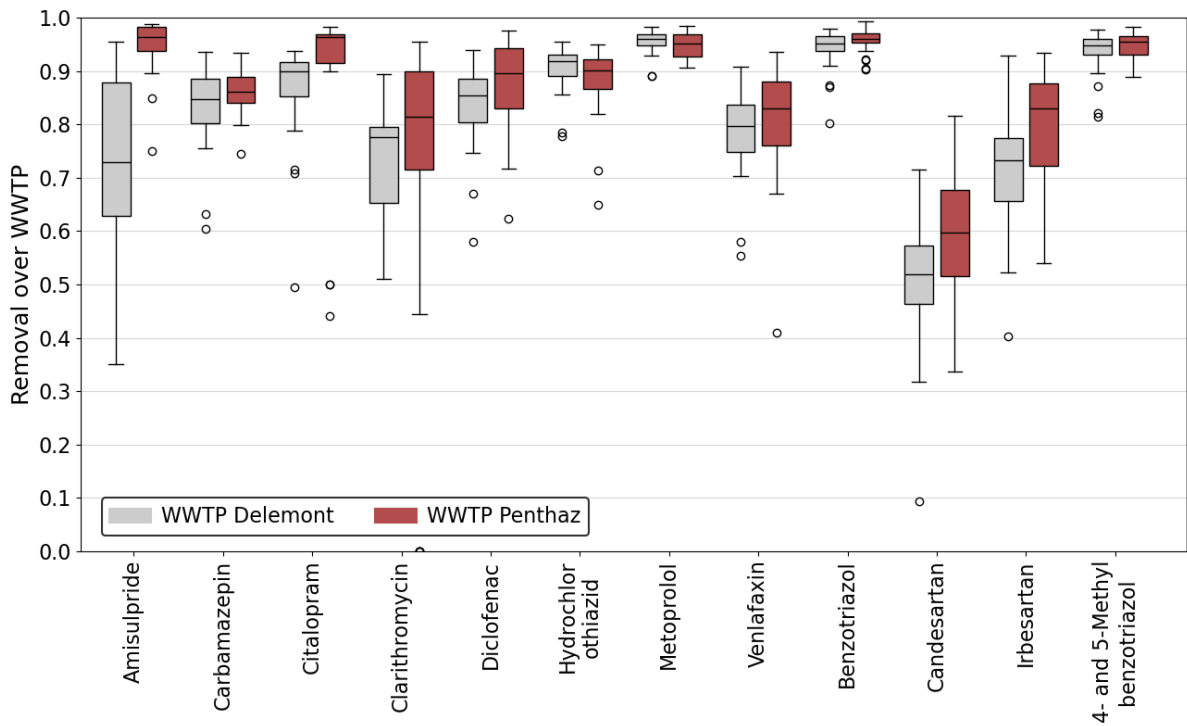


Figure 8: Micropollutant removal over WWTP Delémont and over WWTP Penthaz (2019-2023).

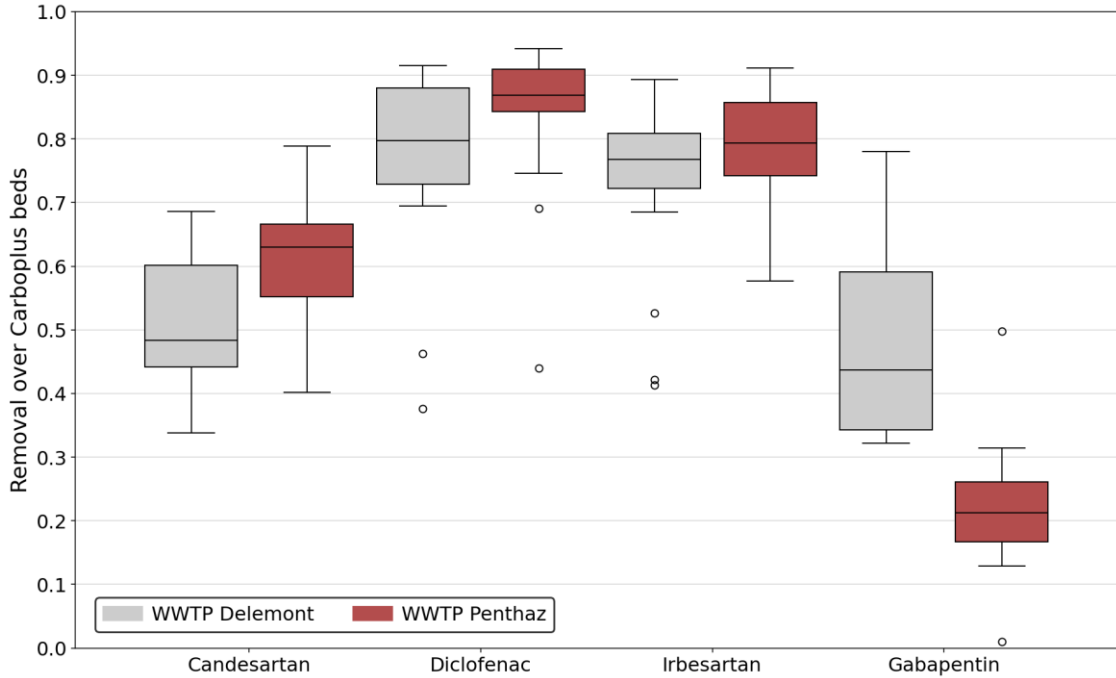


Figure 9: Micropollutant removal over Carbopulus beds at WWTP Delémont measured by FHNW during dry weather and removal over Carbopulus beds at WWTP Penthaz (2019-2020).

3.6 Micropollutant Removal at different μ GAC injection rates

Micropollutant removal rates measured over WWTP Delémont do not correlate with the applied μ GAC injection rates, even when normalized for the DOC concentration in the secondary clarifier effluent (Figure 10). The lack of a correlation between micropollutant removal and μ GAC injection rate could potentially be attributed to μ GAC injection rates being changed frequently and never maintained for long periods of time. Due to the long residence time of carbon in the bed of around 212 - 277 d short-term changes to μ GAC injection rates might not significantly affect the overall adsorption capacity of carbon present in the bed. Furthermore, other factors, such as fluctuations in bed height at rest and rain events, could be masking the impact of the μ GAC injection rate on removal efficiency.

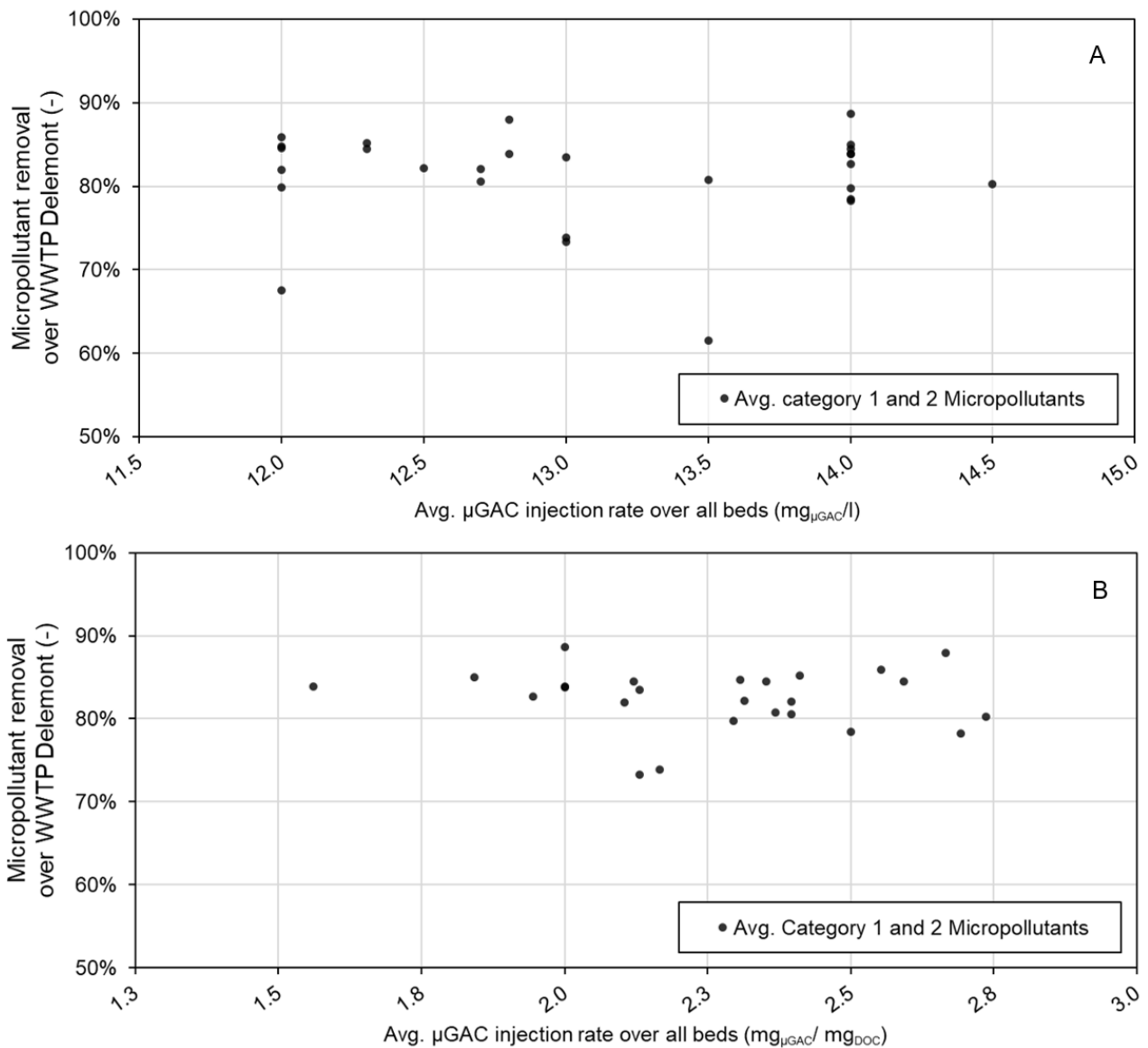


Figure 10: Micropollutant removal measured by Envilab over WWTP Delémont vs. applied μ GAC injection rate per liter of wastewater (A) and per mg of dissolved organic carbon (DOC) (B).

Micropollutant removal rates measured over WWTP Penthaz do also not correlate with applied μGAC injection rates (Figure 11) possibly due to the same reasons as discussed above.

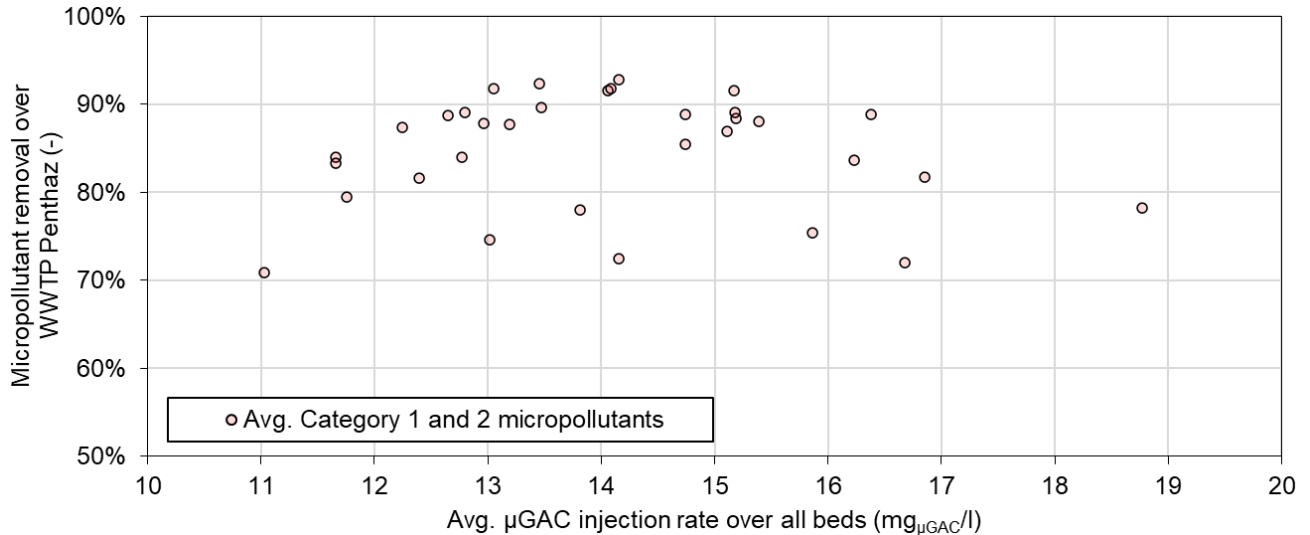


Figure 11: Micropollutant removal measured over WWTP Penthaz vs. applied μGAC injection rate per liter of wastewater.

In the time period of 02.2024 - 03.2024 during which different μGAC injection rates were applied to CBP1, CBP2 and CBP3, micropollutant removal measured over the μGAC beds does not correlate with μGAC injection rate (Figure 12). Slightly higher removal was only observed for Acesulfam (Figure 12).

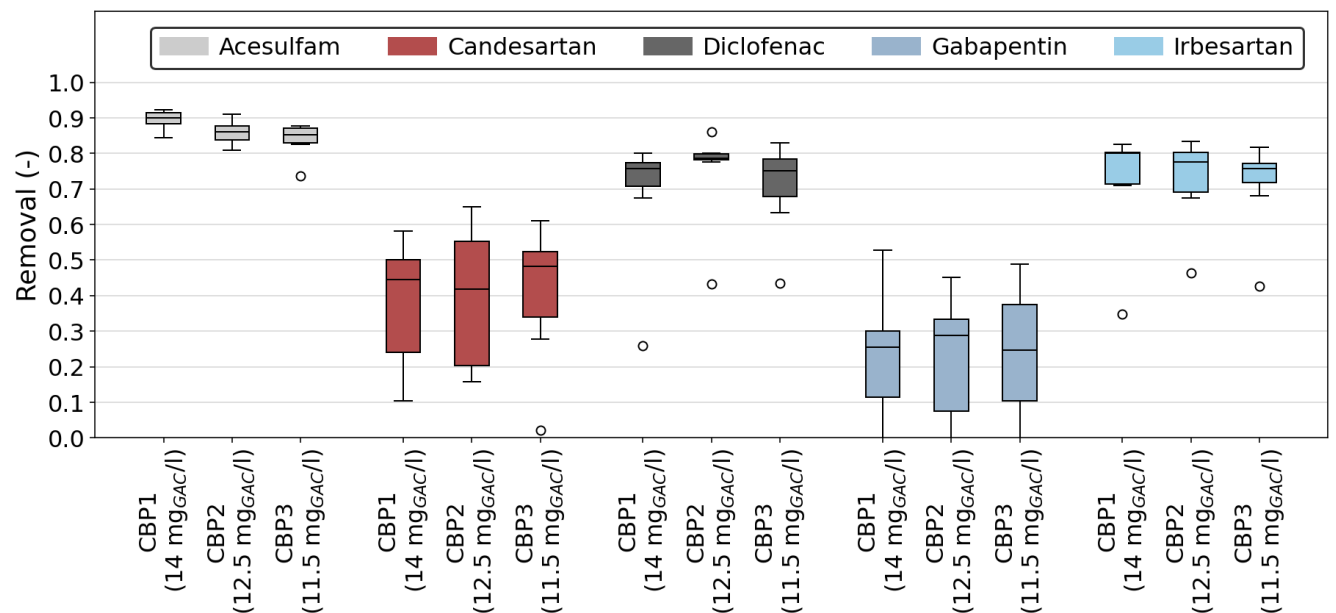


Figure 12: Micropollutant removal over Carbopulus beds measured by FHNW in the time frame 02.2024 - 03.2024 during which the beds were operated at different μGAC injection rates.

Micropollutant removal rates could not be accurately determined for Hydrochlorothiazid, Benzotriazol, Amisulpride, Carbamazepin, Citalopram, Clarithromycin, Metoprolol, Venlafaxin and 4- and 5-

Methylbenzotriazol as effluent concentrations were measured mostly below LOQ. Over the period of this study, the average concentration of Amisulpride in the influent to the WWTP (measured by Envilab) was $0.074 \pm 0.032 \mu\text{g/l}$ while its concentration in the secondary clarifier effluent (measured by FHNW) was $0.068 \pm 0.031 \mu\text{g/l}$. The effluent concentration was always found below LOQ. Similarly to Amisulpride, Carbamazepine, citalopram, Clarythomycin, metoprolol, venlafaxine and 4- an 5- Methylbenzotriazole were also found below LOQ in the effluent of the Carboplus® stage.

3.7 Micropollutant Removal during Rain Events

Micropollutant concentrations measured by Envilab indicate poor removal of micropollutants across WWTP Delémont during rain events, represented by high upflow velocity (Figure 13). The following mechanisms are expected to affect the elimination during rain events:

- (1) reduced micropollutant removal in biological treatment due to shorter hydraulic residence time
- (2) reduced micropollutant removal in the Carboplus process due to shorter contact time
- (3) poor adsorption caused by dilution of wastewater
- (4) desorption caused by dilution of wastewater

Given the data set of this study and the fact that all these mechanisms occur simultaneously, the contribution of each of them to the overall elimination cannot be resolved and should be determined in further experiments. To distinguish between the effect of shorter contact time and wastewater dilution, removal rates were also plotted for high flows in a narrow range (see Annex). The dataset from WWTP Delémont and Penthaz are substantially in agreement when velocity ranges between 4 and 10 m/h. At WWTP Delémont, during heavy rain events, velocities faster than 11 m/h were recorded. At these conditions, the average elimination of several OMPs (see Annex) was negatively affected. To draw definitive conclusions on the effect of velocity, dedicated pilot studies should be carried out. Special attention should be given to the effect of dilution, so that the two mechanisms can be isolated.

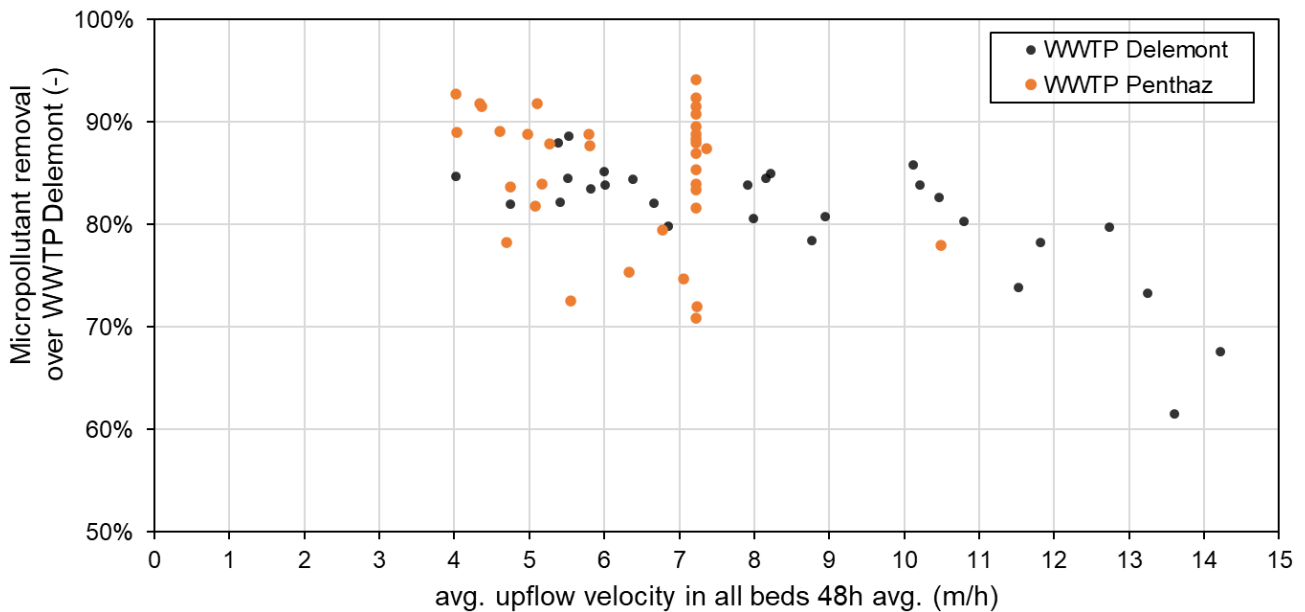


Figure 13: Micropollutant removal in WWTP Delémont vs. average upflow velocity in Carboplus beds.

Micropollutant removal rates measured over the Carboplus beds alone show a similar picture with lower elimination rates at low inlet concentrations, however the effect of rain is not strongly pronounced across all micropollutants (Figure 14 & Figure 15). Amisulpride, Carbamazepine, Citalopram, Clarithromycin, Metoprolol, Venlafaxine and 4- and 5-Methylbenzotriazol are well eliminated by activated carbon (Kanton Waadt, 2019). The removal of these compounds is not as strongly affected by lower contact times and changes in influent concentration as for compounds which are more poorly adsorbed (e.g. Candesartan, Diclofenac, Irbesartan and Gabapentin).

One potential measure to increase micropollutant removal during rain events could be to temporarily strongly increase the μ GAC injection rate. However, as discussed in the previous chapter it is unclear if the effect would be noticeable due to the long residence time of carbon in the beds. Recirculating spent μ GAC (possibly grinding necessary to avoid sedimentation and abrasion) to the biology could also be explored as two stage activated carbon processes are more efficient than single stage ones (Zwick-empflug et al., 2010). However, the recirculated carbon could then not be used for regeneration, which would be a drawback. But this optimization of the adsorption process is strongly recommended to be analyzed in future experiments.

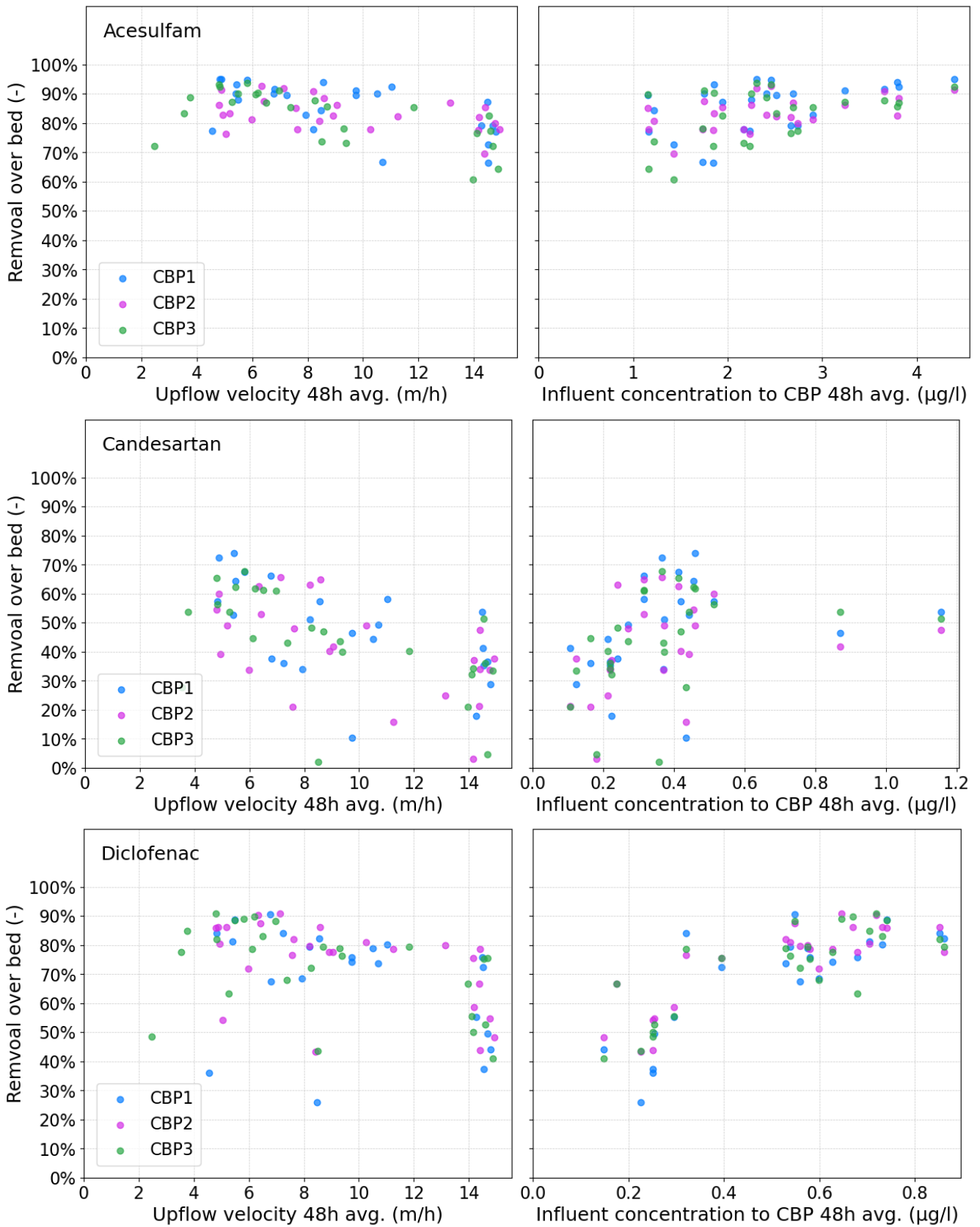


Figure 14: Micropollutant removal in Carbopius beds vs. upflow velocity and influent concentration.

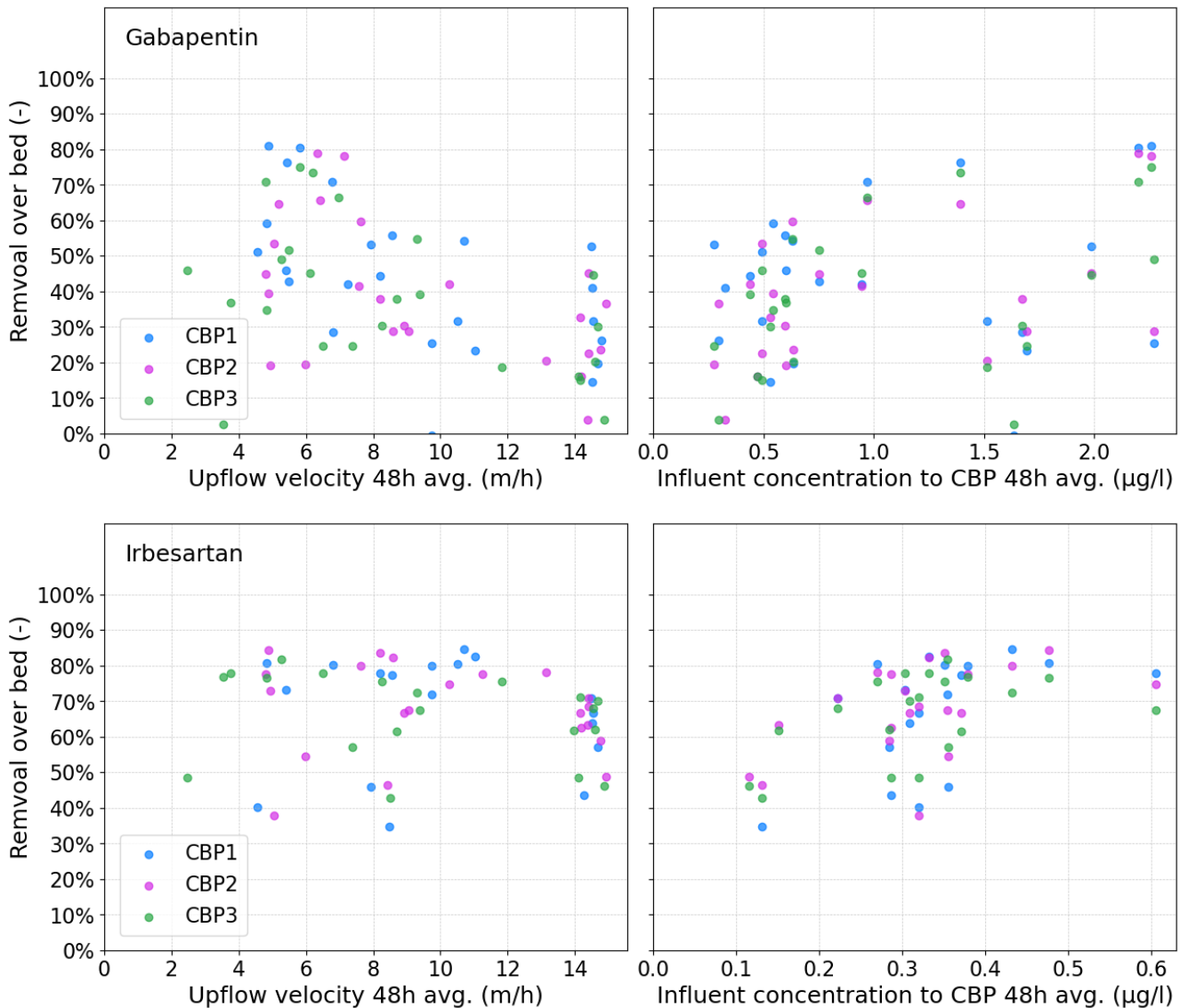


Figure 15: Micropollutant removal in Carboplus beds vs. upflow velocity and influent concentration.

3.8 Activated Carbon Loss

The μ GAC retention in the Carboplus beds was measured in the range of 94–100% (Figure 16). Fewer than 10% of the measurements fell below the new VSA-recommended threshold of 96% (VSA-Plattform Verfahrenstechnik Mikroverunreinigungen, 2025). When μ GAC retention was plotted against upflow velocity, no apparent correlation was observed (Figure 16). The mean carbon concentration in the effluent was 0.26 mg/L. Considering that state-of-the-art systems typically achieve mean concentrations of approximately 0.4 mg/L or lower, the Carboplus process can be regarded as satisfactory in terms of limiting carbon loss to the effluent. Carboplus appears to perform less well than the other existing PAC processes in Switzerland. Activated carbon concentrations and loss of activated carbon has been measured

to be slightly higher in WWTP Penthaz than in WWTP Delémont (Figure 17). However, the activated carbon retention in both cases is mostly above the new threshold of 96% suggested by the VSA. In comparison, to other Swiss WWTPs which use powdered activated carbon retention is in a similar range.

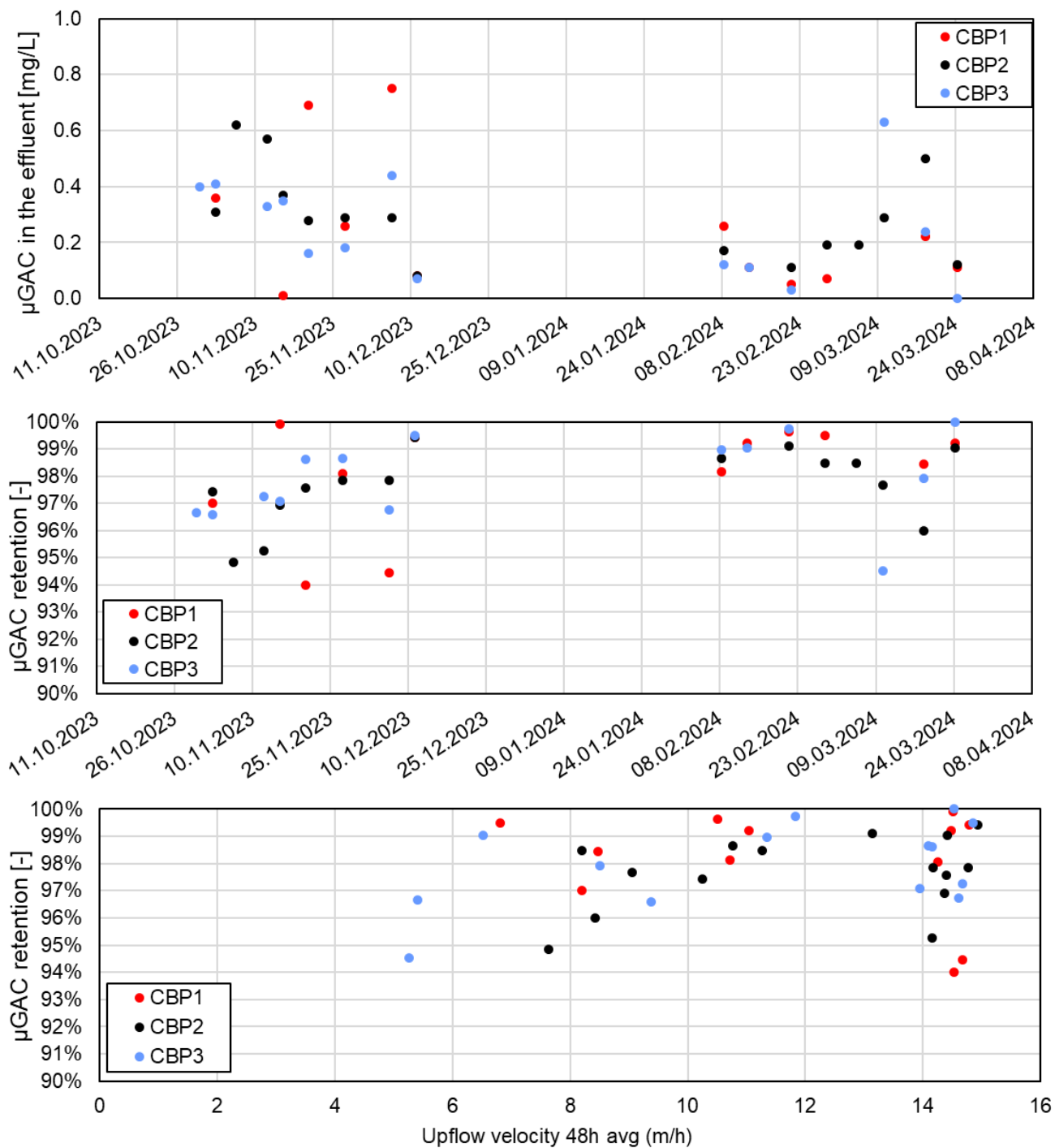


Figure 16: μGAC concentration in the effluent of the WWTP over time (top), μGAC retention in the CarboPlus beds over time (mid) and vs. upflow velocity (bottom) and μGAC concentration

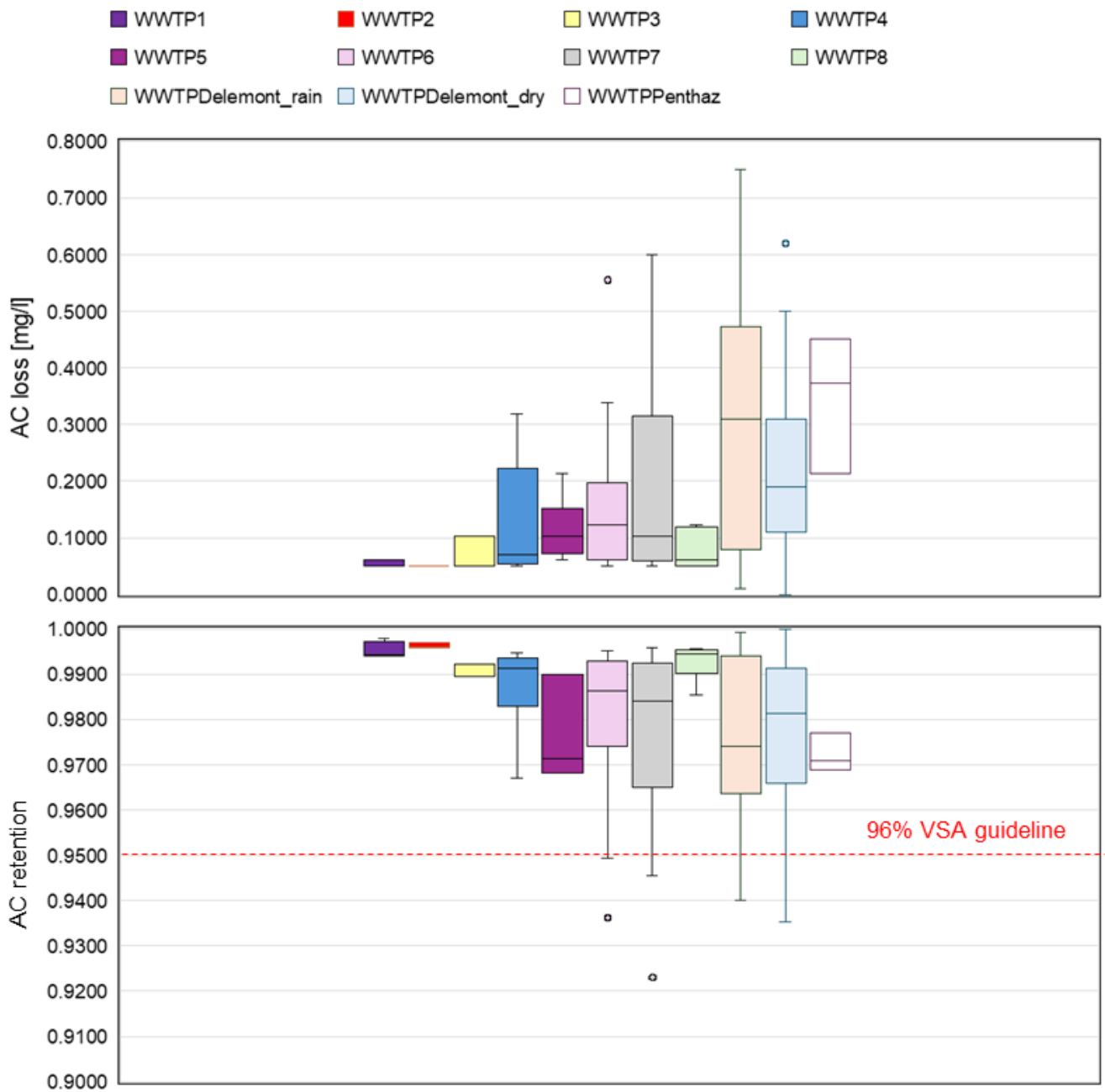


Figure 17: Activated carbon concentrations and activated carbon retention in WWTP Delémont, WWTP Penthaz and other swiss wastewater treatment plants utilizing powdered activated carbon.

3.9 Diclofenac Effluent Concentrations

According to the Swiss Water Protection Ordinance Diclofenac concentrations in surface waters should not exceed 0.05 µg/l averaged over a period of two weeks. Diclofenac concentrations in the effluent of the WWTP Delémont were measured mostly in the range of 0.05 – 0.20 µg/l (Figure 18). At WWTP Delémont the mean daily wastewater flow during dry weather lies around 250 L/s. The waterflow in the Birs River below WWTP Delémont lies around 1'500 - 2'000 L/s during prolonged dry weather periods (Figure 19).

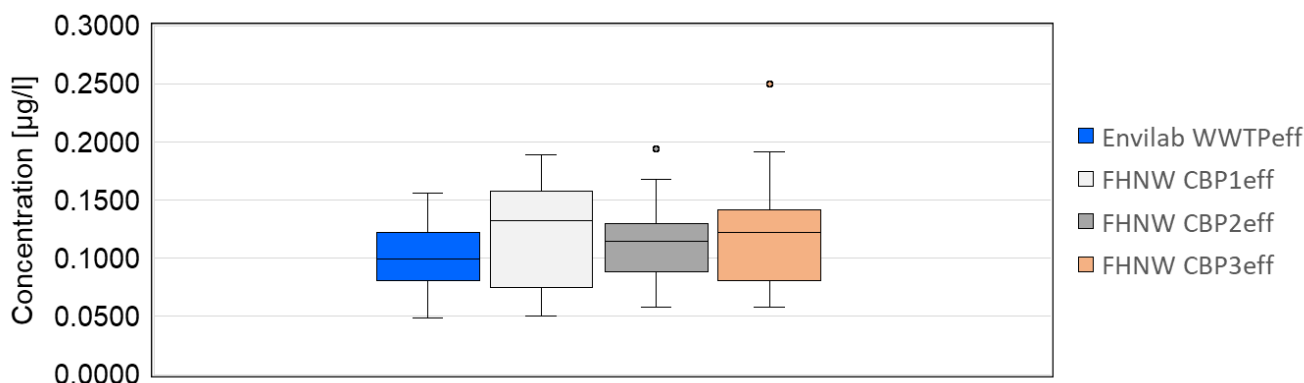


Figure 18: Diclofenac concentration in the effluent of the WWTP Delémont measured by Envilab and FHNW.

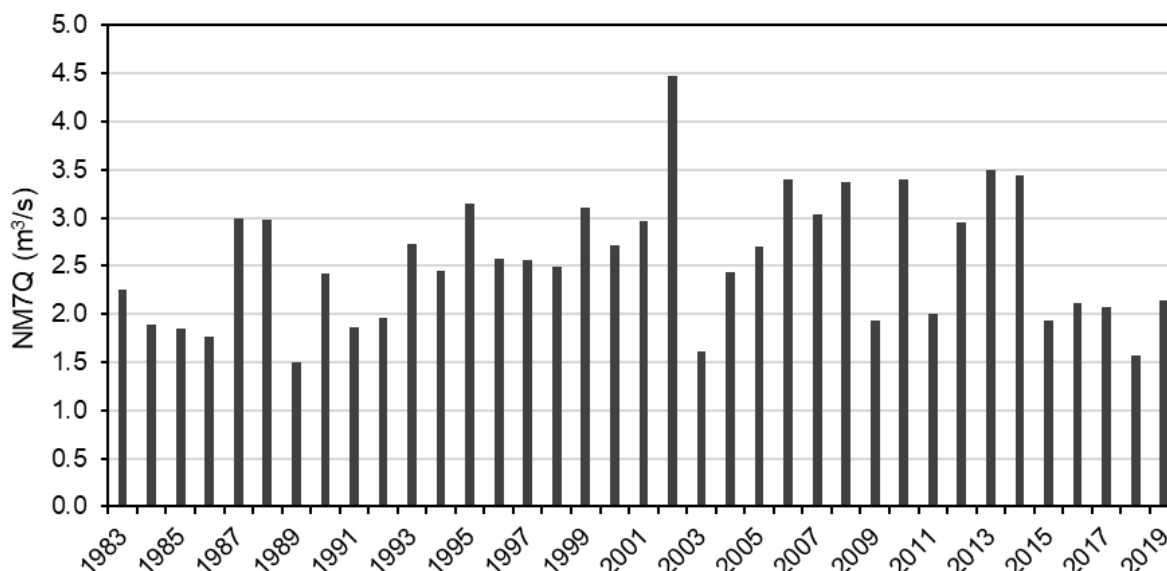


Figure 19: NM7Q (lowest average flow rate over 7 consecutive days during a year) in the Birs River at Soyhières, Bois du Treuil in the time period 1983-2019 (Federal Office for the Environment FOEN, 2025).

When considering the worst-case scenario, 0.25 µg/L Diclofenac concentration is used as the highest measured concentration by both FHNW and Envilab AG. Assuming 0.25 µg/L concentration in the WWTPs effluent, and a dilution factor of six times in the Birs river during prolonged dry weather, it is

estimated to be a final concentration of 0.042 µg/L in the river after dilution. This is below the threshold of the Swiss water protection ordinance of 0.05 µg/L. However, if wastewater from other WWTP along the Birs River is considered the cumulative wastewater content might lead to higher Diclofenac concentrations.

4 Conclusions

This study examined the full-scale CarboPlus® process at the WWTP Delémont, focusing on fluidized bed behavior, micropollutant removal, and the retention of both activated carbon and total suspended solids. The key findings are as follows:

Micropollutant (MP) Removal Efficiency

- **Effective Under Dry Conditions:** The CarboPlus® process successfully removes micropollutants during dry weather, achieving compliance with Swiss regulatory standards.
- **Reduced Rain Weather Performance:** Removal efficiency decreases during rain events, likely due to a combination of shorter water-carbon contact times and wastewater dilution. The exact contribution of each factor remains to be determined.
- **Insensitivity to Minor Adjustments:** Short-term changes to the micro-granular activated carbon (µGAC) injection rate did not significantly alter MP removal. This is likely because the daily dose is small compared to the large volume of carbon already present in the bed, which has a residence time of nearly a year.

Activated Carbon (µGAC) and Solids Retention

- **High Carbon Retention:** The system retains activated carbon very effectively, with retention rates consistently above 96%, meeting the thresholds suggested by the Swiss Water Association (VSA). This performance was not negatively impacted by increased hydraulic loads during rain events.
- **Variable TSS Retention:** The retention of Total Suspended Solids (TSS) from the secondary clarifier was inconsistent, averaging around 50%. This sometimes led to TSS accumulation within the carbon beds, causing an increase in bed height.

Potential Improvement Strategies & Comparisons

- **Enhancing Rain Weather Performance:** A potential strategy was identified to boost MP removal: Dosing µGAC into the main biological treatment stage to create a two-stage removal effect.

Note: Grinding of the μ GAC to achieve a lower particle size might be necessary to avoid sedimentation in activated sludge tanks. The viability of this strategy would require pilot testing.

- Comparative Analysis: The CarboPlus® process at WWTP Delémont showed slightly lower MP removal efficiency compared to a similar installation at WWTP Penthaz. The underlying reasons for this difference could not be identified within the scope of this study.

Overall Significance

- This study provides valuable insights into the full-scale operational dynamics of the CarboPlus® process, addressing key knowledge gaps for engineers and plant operators regarding bed behavior, retention rates, and performance under varying conditions

5 References

- Albers, S., Baggenstos, M., Casazza, R., Le Goaziou, Y., Horisberger, M., Lambert, M., Margot, J., Rieck, T., Schneider, L., Fleiner, J., Morgado, A., Zöllig, H., Joss, A., Thomann, M., Liebich, C., Brander, A., Eugster, F., Tama, N., 2022. Faktenblatt - Aktueller Stand GAK im Schwebbett.
- Federal Office for the Environment FOEN, 2025. Birse - Soyhières, Bois du Treuil [WWW Document]. URL <https://www.hydrodaten.admin.ch/en/seen-und-fluesse/stations/2478> (accessed 4.28.25).
- Grelot, J., Horisberger, M., Casazza, R., 2021. Elimination des micropolluants par CAG en lit fluidisé. Aqua & Gas.
- Kanton Waadt, 2019. Micropolluants dans les stations d'épuration vaudoises.
- Mailler, R., Gasperi, J., Coquet, Y., Buleté, A., Vulliet, E., Deshayes, S., Zedek, S., Mirande-Bret, C., Eudes, V., Bressy, A., Caupos, E., Moilleron, R., Chebbo, G., Rocher, V., 2016. Removal of a wide range of emerging pollutants from wastewater treatment plant discharges by micro-grain activated carbon in fluidized bed as tertiary treatment at large pilot scale. *Science of The Total Environment* 542, 983–996. <https://doi.org/10.1016/j.scitotenv.2015.10.153>
- Pulfer, M., Obrecht, J., Lutz, J.S., Tobias, B., Corvini, N., Hochstrat, R., Thomann, M., 2024. Mathematical image processing analysis of activated carbon (MIPA2C) in wastewater treatment plant effluents.
- UVEK, 2016. Verordnung des UVEK [WWW Document]. URL <https://www.fedlex.admin.ch/eli/cc/2016/671/de> (accessed 1.17.25).
- VSA, 2021. CAG en lit fluidisé a la STEP de Penthaz.
- VSA-Plattform Verfahrenstechnik Mikroverunreinigungen, 2025. Aktivkohle-Schlupf [WWW Document]. VSA Micropoll. URL <https://micropoll.ch/verfahren/aktivkohle/aktivkohle-schlupf/> (accessed 3.4.25).
- VSA-Plattform Verfahrenstechnik Mikroverunreinigungen, 2019. Aktueller Stand Beurteilung Aktivkohle Rückhalt.
- Zwickenpflug, B., Böhler, M., Sterkele, B., Joss, A., Siegrist, H., Traber, J., Gujer, W., Behl, M., Dorush, F., Hollender, J., Ternes, T., Fink, G., 2010. Einsatz von Pulveraktivkohle zur Elimination von Mikroverunreinigungen aus kommunalem Abwasser.