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EVALUATION OF THE TREATMENT PERFORMANCE OF SMALL WASTEWATER TREATMENT PLANTS IN UPPER AUSTRIA

Master thesis

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Diplomingenieur

submitted by:

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Abstract

The first aim of this master thesis was to determine the number of small wastewater treatment plants (WWTPs) in Upper Austria and to assign the different technologies. Currently, there are 2'526 small WWTPs in operation in Upper Austria. With 873 treatment plants, Sequencing Batch Reactors (SBR) are most widely used, followed by 646 conventional activated sludge (CAS) plants and 475 vertical flow wetlands (VFWs).

In a second step, the treatment performance of the different technologies, using the external monitoring reports provided by the Upper Austrian government, was evaluated. For this purpose, different statistical parameters of the NH_4-N, BOD_5 and COD effluent concentrations were calculated. The comparison of the median values and the number of measurements above the respective threshold shows that VFWs as well as SBR plants with a vertical flow (VF) bed and CAS plants with a VF bed have the lowest median values and the lowest number of values above the threshold.

The third aim was to analyse if a change of the treatment performance over the operation time of the small WWTPs can be observed. Overall, a significant improvement or deterioration of the treatment performance of any technology could not be verified. However, VFWs and treatment plants with a VF bed show lower median effluent concentrations and lower fluctuations in following years than purely technical treatment plants. Furthermore, the Mann-Kendall trend test was conducted with all treatment plants where more than four NH_4-N measurements were available. A trend occurs in 8.5% of these treatment plants and a deterioration of the treatment performance can be detected in only half of these small WWTPs.

The evaluation of the external monitoring reports of small WWTPs showed that all technologies can comply with the required threshold values. Additionally, for all technologies a stable treatment performance could be found, only few plants showed a deterioration of the treatment performance over time.

Kurzfassung

Das erste Ziel dieser Arbeit ist es, die Anzahl der Kleinkläranlagen (KKA) in Oberösterreich zu erfassen und sie den verschiedenen Reinigungstechnologien zuzuordnen. Derzeit sind in Oberösterreich 2‘526 KKA in Betrieb. Belebungsanlagen im Aufstaubetrieb (SBR) sind mit 873 Anlagen am häufigsten vertreten, gefolgt von 646 Belebungsanlagen im Durchlaufbetrieb und 475 Pflanzenkläranlagen (PKA).

Als zweiter Schritt wurde die Reinigungsleistung der einzelnen Technologien, anhand der von der OÖ Landesregierung zur Verfügung gestellten Fremdüberwachungsberichte, beurteilt. Dazu wurden verschiedene statistische Parameter der NH_4-N, BSB_5 und CSB Ablaufkonzentrationen berechnet. Beim Vergleich der Medianwerte und der Anzahl der Messwerte über dem jeweiligen Grenzwert stellte sich heraus, dass sowohl PKA als auch Anlagen mit nachgeschaltetem bepflanztem Bodenfilter die niedrigsten Medianwerte und die geringste Anzahl an Grenzwertüberschreitungen aufweisen.

Das dritte Ziel war es zu ermitteln, ob sich die Reinigungsleistung über die Betriebsdauer der KKA verändert. Dabei ergab sich bei keiner Technologie eine signifikante Verbesserung oder Verschlechterung der Reinigungsleistung. Jedoch konnte bei PKA und bei Anlagen mit nachgeschaltetem bepflanztem Bodenfilter eine geringere Schwankung der Medianwerte der Ablaufkonzentrationen in den Folgejahren bei größerem Alter der KKA festgestellt werden als bei rein technischen KKA.

Durch den Mann-Kendall Trend Test, von Anlagen mit mehr als vier NH_4-N Messwerten, konnte gezeigt werden, dass ein Trend in 8,5% dieser KKA auftritt. Eine Verschlechterung der Reinigungsleistung trat nur bei der Hälfte dieser Anlagen ein.

Die Evaluierung der Fremdüberwachungsberichte der KKA zeigte, dass alle Technologien die Grenzwerte einhalten können. Zusätzlich konnte für alle Technologien eine stabile Reinigungsleistung nachgewiesen werden und nur bei wenigen Anlagen verschlechterte sich die Reinigungsleitung über die Zeit.

Abbreviations

AOX	Adsorbable Organic Halides
BOD_5	Biochemical Oxygen Demand in 5 days
CAS	Conventional activated sludge
COD	Chemical Oxygen Demand
MBR	Membrane bioreactor
NH_4-N	Ammonium-Nitrogen
NO_2-N	Nitrite-Nitrogen
PE	Population Equivalent
RBC	Rotating biological contactor
SBR	Sequencing Batch Reactor
TOC	Total organic carbon
VF	Vertical Flow
VFW	Vertical Flow Wetland
WWTP	Wastewater Treatment Plant

1. Introduction

Wastewater treatment is crucial to protect the quality of all water bodies. In Austria 95.2% of all households are connected to public sewer systems and therefore municipal WWTPs. To ensure the appropriate wastewater treatment of the remaining 4.8% in decentralized areas small WWTPs with a design size ≤50 PE and cesspools are used (BMNT, 2018). Small WWTPs are technical/biological wastewater treatment systems, which treat domestic wastewater up to 50 PE. In general, small WWTPs have a mechanical pre-treatment as well as a biological treatment stage and an outlet into a receiving water. It is obligatory, that the treated wastewater complies with the given threshold values before being discharged into a receiving water. Under specific circumstances infiltration can also be an option (LAND SALZBURG, 2011).

However, the general aim of wastewater management in Austria is to treat wastewater out of coherent residential areas in municipal WWTPs. Over the past few years the public sewer systems and the respective WWTPs were consistently expanded, but due to the rather dispersed settlement pattern in Austria, it will not be possible in the future to treat all wastewater without decentralized systems (BMNT, 2018).

Between 1993 and 2014 about 13'800 small WWTPs received federal funding and were newly licensed (BMNT, 2018). The total number of small WWTPs was analyzed in 2016, with the result that there are about 27'500 small WWTPs operating in Austria. They were furthermore grouped according to their treatment technology, so that an overview is available. The highest number of small WWTPs can be found in Styria, Carinthia, Lower Austria and Upper Austria (LANGERGRABER et. al, 2018).

To ensure high water quality the member states of the European Union are according to 91/271/EEC obliged to report the state and development of wastewater treatment to the commission every two years. Austria is able to comply with the legal specifications according the treatment performance given in article 4 and 5 of 91/271/EEC (BMNT, 2018). In this report, the treatment performance of municipal WWTPs > 50 PE is analysed. Due to the comparably low cumulative design size of smaller WWTPs, there is almost no data about their treatment performance available.

The only Austrian study is from Salzburg in 2008, where SCHABER et. al. conducted an analysis with 40 small WWTPs. Aim of the study was to analyse if the four most popular technologies used in the federal state of Salzburg can comply with the effluent threshold values of 10 mg/l NH_4-N, 25 mg/l BSB_5 and 90 mg/l CSB. The investigated technologies are CAS, SBR, trickling filters and vertical flow wetlands. All investigated treatment plants were able treat the wastewater properly.

Since in this study only 10 small WWTPs of each technology were inspected, there is no detailed data about the wastewater treatment performance of the different technologies used in small WWTPs available. External monitoring of small WWTPs is compulsory and the data is collected by the federal states of Austria. In Upper Austria, for example, the data is entered into a computer system, however the data is not analysed in detail.

2. Objectives

In the last few years DOPPLINGER (2016), FEIGL (2018) and GERSTORFER (2018) summarized the number of small WWTPs in Austria for every federal state. As further research it is the objective of this Master's Thesis to show the development of the number of small WWTPs in general and of the different treatment technologies in particular in Upper Austria from 2016 to 2019.

Furthermore, an analysis is conducted to determine the treatment performance of the different technologies and the development of the performance over the operation time. To analyse the treatment performance of the different technologies it is necessary to additionally assign the different types of treatment plants according to their secondary treatment. This results in nine types of small WWTPs which are considered in the statistical evaluation. The statistic software R-Studio is used to carry out the statistical analysis.

The three specific objectives of the thesis are:

1. Assignment of the data to the different treatment technologies and compilation of a comparison with the data collected in 2016
2. Evaluation of the treatment performance of each treatment technology
3. Evaluation of the treatment performance of each treatment technology over the operation time and a trend analysis of the NH_4-N effluent concentrations

Structure of the thesis

In **chapter 3**, the basics of wastewater treatment, the legal requirements and the most frequently used technologies in decentralized wastewater treatment in Upper Austria are shortly described. In **chapter 4** material and methods are explained. **Chapter 5** shows the results of the main questions of this thesis as well as a discussion. **Chapter 6** provides an overview of the results and an outlook on further research activities and **chapter 7** contains a summary of the thesis.

3. Fundamentals

3.1 Legal situation in Austria

3.1.1 Definition Wastewater

According to BGBl. Nr. 186/1996 §1 wastewater is water with changed characteristics due to its usage. Wastewater can no longer be discharged into receiving waters without compromising its quality. There are different kinds of wastewater, like industrial or domestic wastewater (AAEV, 1996). Before it can be discharged into a receiving water or infiltrated it has to be treated in a wastewater treatment plant to remove nutrients and other possibly harmful substances. The composition as well as the amount of wastewater depends on its origin. To discharge wastewater a permit according to WRG 1959 is necessary in any case. The thresholds described in the emission-ordinance define the amount of substances which can remain in the treated wastewater and therefore discharged (BMLRT, 2019).

3.1.2 European and Austrian law

Wastewater treatment in Austria is, on the one hand, regulated by laws from the European Union and, on the other hand, by national law.

On a European level the **Water Framework Directive** (WFD, 2000/60/EC) as well as the **Urban Waste Water Treatment Directive** (UWWTD 91/271/EEC) are crucial to protect and enhance water quality (EUROPEAN COMMISSION, 2019). The European norm **EN 12566** has 6 different parts to regulate small wastewater treatment plants. According to EU regulations it shall be given the status of a national standard by publication of the text in a national context (EN 12566, 2016).

The **Austrian Water Act** came into force in 1959 and is, including its amendments, relevant for the permission of WWTPs. According to Article 32 discharging treated wastewater as well as infiltration are subject to permission. In Article 33g legal regulations according permits for small WWTPs with less or equal to 50 PE can be found (AMT DER OÖ LANDESREGIERUNG, 2006). Regulations compromising general water management requirements concerning wastewater treatment can be found in the **Wastewater Emission Ordinance** (Allgemeine Abwasseremissionsverordnung – AAEV, BGBl. Nr. 186/1996) (AAEV, 1996). The **1st Wastewater Emission Ordinance for municipal wastewater** includes regulations according the discharge of wastewater from WWTPs with PE > 50 in settlement areas (1. AEVkA, 1996). Regulations for wastewater treatment in extreme locations can be found in the **3rd Wastewater Ordinance for municipal wastewater** (3. AEVkA, 2006).

3.2 Wastewater treatment regulations for small WWTPs in Upper Austria

3.2.1 Requirements, design, permission

Households within a radius of 50m to a public sewer are in general obliged to connect to this system, however some exceptions are possible, for example for agricultural objects. In Upper Austria the regulations according the obligation to connect to a public sewer system and the other possibilities to treat wastewater (e.g. small WWTP, cesspool) can be found in the **Upper Austrian wastewater regulation** (Oberösterreichisches Abwasserentsorgungsgesetz). The disposal of the arising wastewater on a municipal level is regulated by the **Wastewater disposal concept** (Abwasserentsorgungskonzept) of the respective municipality (AMT DER OÖ LANDESREGIERUNG, 2006).

In case a small WWTP is authorized the following standards, published by the Austrian Standards Institute, are relevant:

- ÖNORM EN 12566-3 (2016) „Small wastewater treatment systems for up to 50 PT“
- ÖNORM B 2500 (2015), Waste water management – Formation and disposal of waste water – Terms and definitions and symbols – National supplements to ÖNORM EN 16323
- ÖNORM B 2502-1 (2012), Domestic sewage treatment plants for buildings up to 50 inhabitants and population equivalents (PT) – Installations produced on site – Application, dimensioning, construction and operation
- ÖNORM B 2505 (2009), Wastewater treatment plants – Intermittently loaded effluent filtration systems (Constructed Wetlands) – Application dimensioning, installation, operation, service and inspection

For sampling techniques at WWTPs the following ÖNORM includes relevant regulations:

- ÖNORM M 6258 (1992), Water analysis – Guidance on sampling technique – Sampling of waste water

The certification norm EN 12566-3 (2016) only requires testing for organic matter and is therefore not implemented in Austria due to the requirement of nitrification also for small WWTPs. In most other European countries nitrification is not mandatory for small WWTPs. Moreover, it only requires the evaluation of the treatment performance in percent and not, like in Austria, in effluent concentrations. The permission for small WWTPs is therefore simplified by applying ÖNORM B 2502-1 (2012) and ÖNORM B 2505 (2009) because they take the legal requirement for nitrification into account (LANGERGRABER et. al., 2018).

Permissions for small WWTPs are in Upper Austria limited to an operation time of 15 years. Furthermore, it has to be ensured that the sewage sludge is properly disposed, respective regulations can be found in the **Upper Austrian Soil Protection Act** (Oberösterreichisches

Bodenschutzgesetz) (AMT DER OÖ LANDESREGIERUNG, 2006). In general, the following possibilities to dispose or utilize the sludge are allowed:

- Agricultural usage
- Composting
- Humification
- Transport to a municipal WWTP

3.2.2 Monitoring of small WWTPs

To ensure appropriate wastewater treatment all WWTPs have to be regularly monitored. The operator of the small WWTP is obliged to visually inspect the outlet of the plant and to determine the NH_4-N content with a test strip in the effluent once a month. Furthermore, he or she has to commission an independent and officially recognized body (e.g. civil engineers, maintenance company...) to perform the external monitoring at least once a year. In the course of this monitoring, it should be verified that the WWTPs are able to comply with given threshold values (ÖNORM B 2502-1, 2012). The monitoring interval of small WWTPs in Austria is different in the nine federal states. In Upper Austria it is required to execute the external monitoring, additional to the steady monitoring by the owner, once a year in case the owner has absolved the required training course for operators carried out by the ÖWAV.

In the course of the yearly monitoring, the following thresholds included in the 1st Wastewater emission ordinance for municipal wastewater (1. AEVkA, 1996) should be complied with. The ordinance includes the effluent threshold values for different design sizes. In Austria the following four design size classes are defined:

I 51-500 PE_{60}

II 501- 5’000 PE_{60}

III 5’001-50’000 PE_{60}

IV >50’000 $PE6_{0}$

Since there are no special threshold values for small WWTPs, the values of class I are considered to be relevant. The thresholds can be seen in Table 1 and the ones considered as relevant for small WWTPs are indicated in bold.

Table 1: Threshold values of different design size classes according to 1. AEVkA (1996)

	I	II	III	IV
BOD_5	**25**	20	20	15
COD	**90**	75	75	75
TOC	**30**	25	25	25
NH_4-N*	**10**	5	5	5
Total P	**-**	2	1	1

* class I & II: threshold has to be complied with when the effluent temperature is > 12°C, class III & IV: > 8°C

P removal is in Austria required for WWTPs with a design size > 1’000 PE_{60} and the effluent concentrations are only to be complied with when the temperature is > 12°C (1. AEVkA, 1996). More threshold values are presented in the 3rd Wastewater Ordinance for municipal wastewater (3. AEVkA, 2006), but they mostly do not apply for small WWTPs in Upper Austria because the status of an extreme location is not given.

3.2.3 Wastewater discharge

Treated wastewater should be discharged in a receiving water with sufficient water supply of at least 10 l/s. In exceptional situations irrigation can be an option, however in this case secondary treatment is required. Biological small wastewater treatment plants with a vertical flow bed are eligible for infiltration. In general, whenever possible an irrigation has to be avoided and it is only allowed if the site meets the hydrogeological requirements to avoid potential hazards to the groundwater body or to springs in the catchment area. Furthermore, wastewater of not more than four properties or 20 PE is allowed to be infiltrated (AMT DER OÖ LANDESREGIERUNG, 2006).

3.3 Wastewater treatment in Austria

Austria counts 8’858’775 inhabitants, an area of 83.879 km^2 and currently 2’095 municipalities in nine federal states (STATISTIK AUSTRIA, 2019). All over Austria, for every household or municipality appropriate wastewater treatment is ensured, either with WWTPs > 50 PE, with small WWTPs ≤ 50 PE or with cesspools. 95.2% of all Austrian households are connected to public sewer systems and therefore to WWTPs > 50 PE. Even though during the last years the connection rate to public sewer systems has increased, it is not realistic to connect every household due to the topography and the settlement structure of Austria (BMNT, 2018).

Currently, there are 1’927 WWTPs > 50 PE operating in Austria with a cumulative design size of 21.47 million PE (Table 2).

Table 2: Number of WWTPs > 50 PE and cumulative design size according to ÖWAV (2019)

Design size	**Number of WWTPs**		**Cumulative design size**	
	Total	%	PE in million	%
51 - 500	1’040	54	0.18	1
501- 5’000	505	26	1.13	5
5’001 - 50’000	316	16	6.10	28
> 50’000	66	4	14.06	66
Total	**1’972**	**100**	**21.47**	**100**

The number of WWTPs decreases with increasing design size, which is the exact converse of the cumulative design size. Remarkably the 66 WWTPs with a design size > 50’000 PE are responsible for 14.06 million PE (ÖWAV, 2019).

3.3.1 Decentralized wastewater treatment

About 4.8% or 419’000 inhabitants of Austria are not connected to a public sewer system. However appropriate WW treatment is guaranteed with small WWTPs and cesspools. Between 1993 and 2014 about 13’800 small WWTPs were newly implemented. Despite the high number of small WWTPs they play a minor role regarding the cumulative design size with less than 1% (BMNT, 2018). Additional to the WWTPs > 50 PE, summarized in Table 2, there are about 27’500 small WWTPs ≤ 50 PE in Austria with a cumulative design size of only 260’500 PE (Table 3). Most small WWTPs are located in Styria (10’665) followed by Carinthia (6’961), Lower Austria (4’541) and Upper Austria (2’389). Almost no small WWTPs can be found in Burgenland (20) and Vienna (13) (LANGERGRABER et. al., 2018).

Table 3: Overview of small WWTPs in Austria and cumulative design size per federal state (LANGERGRABER et. al., 2018)

Federal state	**Number of WWTPs**	**Cumulative design size**
Burgenland	20	198
Carinthia	6’961	62’459
Lower Austria	4’515	50’655
Upper Austria	2’398	29’412
Salzburg	1’655	20’924
Styria	10’665	85’726
Tirol	1’096	9’508
Vorarlberg	129	1’331
Wien	13	280
Total	**27’452**	**260’493**

However, the share of the cumulative design size is very small compared to WWTPs > 50 PE, small WWTPs are still important to ensure the high quality of the receiving waters.

The highest number of small WWTPs, pictured in Figure 1 in dark brown, occurs in districts in Styria, Carinthia and Lower Austria (LANGERGRABER et. al., 2018). Due to the topographical conditions in Styria, Carinthia and western Lower Austria decentralized solutions are more frequently used. Free flow channels are in these areas often not feasible and pressurized systems are much more expensive. The geographical distribution per district also indicates that in northern Lower Austria as well as in Burgenland the topology and settlement structure make it easier to build centralized solutions. In Vorarlberg and Tirol long collection sewers along the valley bottom and a WWTP at the end of the valley were built frequently to implement centralized systems and therefore the density of small WWTPs per district is rather low (BMNT, 2018).

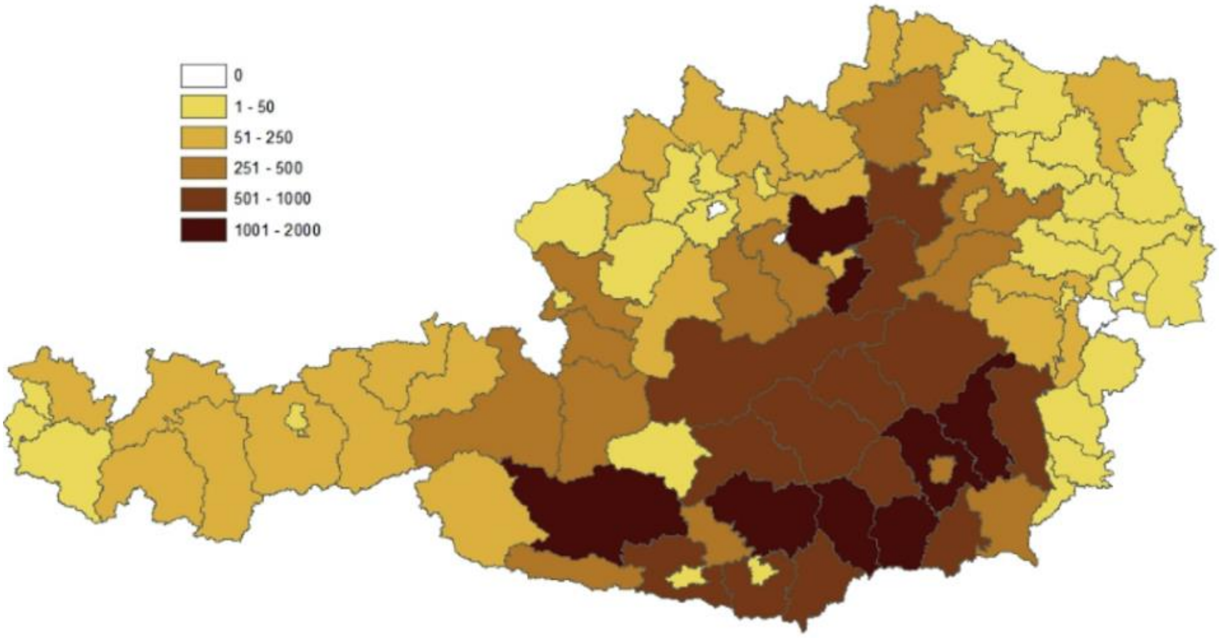

Figure 1: Small WWTPs per district in Austria (LAGERGRABER et. al., 2018)

3.3.2 Decentralized wastewater treatment in Upper Austria

The federal state of Upper Austria has a population of 1’482’095, an area of 11’982 km^2 and a population density of 124 inhabitants per km^2. It is divided into 18 political districts with 438 municipalities (AMT DER OÖ LANDESREGIERUNG, 2020). As already mentioned above, households are obliged to connect to a public sewer if they are located within a radius of 50m. The remaining households are treating the arising wastewater with small WWTPs or with cesspools.

In 2016 2’398 small WWTPs were operating in Upper Austria with a cumulative design size of 29’412 PE (Table 3). Figure 1 shows that there are two districts without small WWTPs in Upper Austria, Steyr-Stadt and Wels-Stadt. The analysis also shows which technologies are represented in small WWTPs in Austria. To gain an overview about the situation in Upper Austria, the following table (Table 4) shows the number of small WWTPs grouped according to their technology (LANGERGRABER et. al., 2018).

Table 4: Wastewater treatment technologies represented in small WWTPs in Upper Austria (LANGERGRABER et. al., 2018)

Technology	Number of WWTPs	Percentage per technology
SBR	702	29.3%
Conventional activated sludge (CAS)	646	26.9%
Vertical flow wetland (VFW)	475	19.8%
Primary treatment only	381	15.9%
Trickling filter	100	4.2%
Rotating biological contactor (RBC)	37	1.5%
MBR	26	1.2%
Filtration	27	1.1%
Unknown	4	0.2%
Total	**2’398**	**100%**

The most frequently used technology in small WWTPs are SBR treatment plants with a share of 29.3% and CAS treatment plants with 26.9%. Furthermore, 475 (19.8%) VFWs are located in Upper Austria.

3.4 Wastewater treatment technologies for small WWTPs

In general, the technologies used for small WWTPs are not different from other design sizes, however the most important ones are shortly described.

Mechanical wastewater treatment with 3-chamber septic tanks is not state of the art anymore, but in the past, they were often used as a complete treatment plant. Nowadays their usage is restricted as a primary treatment stage in biological treatment plants. Septic tanks are used for solids separation and the system is based on sedimentation or floating on the surface of the solid substances after a corresponding retention time (AMT DER OÖ LANDESREGIERUNG, 2006). The remaining WWTPs with primary treatment only can be still in operation because of old contracts, permitted before 1991 were nitrification was not yet required, without an expiration date (LANERGRABER et. al., 2018).

Most commonly used as a secondary treatment are activated sludge treatment plants and vertical flow wetlands. Activated sludge treatment plants can be technically designed with or without pre-treatment, as **conventional activated sludge treatment plants** (separated in space), as **Sequencing Batch Reactors** (separated in time, in the same tank) or as combined systems. The process principle is based on aeration to build biomass which digests organic matter (AMT DER OÖ LANDESREGIERUNG, 2006).

Vertical flow wetlands are systems which use natural processes where the wastewater is led through a sandy-gravelly soil to treat it with the help of soil, vegetation and microorganisms. Mechanical pre-treatment is obligatory as well as an effective wetland area of $4m^2$ per person connected. Furthermore, constructed wetlands are suitable as an additional treatment after an activated sludge treatment plant. There are horizontal as well as vertical flow wetlands (AMT DER OÖ LANDESREGIERUNG, 2006), but since the 1990s in Austria only vertical flow wetlands can be implemented due to legal requirements. Thus, it can be assumed that only a small number of horizontal flow wetlands with older permissions are left in Austria (LANGERGRABER and WEISSENBACHER, 2017).

According to LANGERGRABER et. al. (2018) the treatment technologies **membrane bioreactor, trickling filter, rotating biological contactor and soil filter** are, additionally to the already described ones, represented in Upper Austria. Fixed bed reactors cannot be found in Upper Austria, but in the other federal states.

4. Material and methods

4.1 Material

To conduct the analysis two datasets are provided by the Upper Austrian government:

1. In the first dataset all small WWTPs currently operating in Upper Austria can be found. It includes for example information about the location, the technology, the date of implementation and the PE as well as the identification number of the small WWTP.
2. The second dataset includes the identification number of the WWTP and measurement values of different parameters as well as the date of the measurement.

4.2 Methods

The analysis is conducted with MS Excel and the statistic software R studio. As a first step, MS Excel is used to assign the treatment plants to their technology. Then the treatment performance analysis is conducted with R studio. The tables and diagrams are made within the two programmes depending on their complexity.

4.2.1 Categories

The treatment plants were allocated to different categories, according to their primary treatment technology. In Upper Austria the following technologies can be found:

- Conventional Activated Sludge (CAS)
- Sequencing Batch Reactor (SBR)
- Vertical flow wetlands (VFW)
- Primary treatment only
- Trickling filter
- Rotating biological contactor (RBC)
- Membrane bioreactor (MBR)
- Filtration

The most important technologies are explained in chapter 3.3. After the assignment to the primary treatment technology, the plants are assigned also according to their secondary treatment, which results in two more categories:

- CAS with VF bed
- SBR with VF bed

The division into treatment plants with and without a VF bed as a secondary treatment performance is required to analyse the treatment performance.

4.2.2 Assignment to technologies

To assign the treatment plants to the technologies, the data, provided by the Upper Austrian government, is analysed. Information about the treatment technology is given in different columns in the dataset with general information about all small WWTPs currently operating in Upper Austria.

The relevant columns for the assignment can be seen in Figure 2, which shows an extract of the applied dataset. In the first column the identification number of the treatment plant is available, in the columns B to G information about the district, the names of the owners as well as the date of commissioning and the state of operation can be found.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	BUNDESNU				EW 60	INBETR	Realisier	VERFAHRE	RE	C	N	N-	P-		FABRIKATTYPE	ABLEITUNG	KO
2	40101205	Lin	ÖB	Ö	30	01.04.00	in Betrieb	Belebtschlam	n	j	j	n	n	<N	<NULL>	Einleitung in (	
3	40101206	Lin	Vla	Vl	7	24.10.06	in Betrieb	Belebtschlam	n	j	j	n	n	<N	<NULL>	Einleitung in (	
4	40301201	We	Scl	Sc	5	01.01.16	in Betrieb	<NULL>	n	j	j	n	n		KHM Umwelttechnik	Einleitung in (	3
5	40401202	Bra	Pri	Pr	8	01.04.13	in Betrieb	bepflanzte Bo	j	j	n	n	n		3-Kammer PE-Absetzzschacht DN 1700 mit ein	Einleitung in \	
6	40402200	Bra	Jui	Ju	8	1993	in Betrieb	Tropfkörper	j	j	j	n	n		PIMA-3 Kammer-Kläranlage (V=3,4m³) als Vork	Einleitung in (	
7	40402201	Bra	Zie	Zi	3	01.01.97	in Betrieb	Belebtschlam	n	j	j	n	n		Einbeckenanlage mit Rührwerk	Einleitung in (	
8	40402203	Bra	Ro	Rc	50	01.08.98	in Betrieb	Belebtschlam	j	j	j	n	n	<N	Aqua Comp + Schönungsteich; Bio	Einleitung in (	
10	40402205	Bra	Ho	H	12	25.03.08	in Betrieb	Belebtschlam	j	j	j	n	n	<N	<NULL>	Einleitung in (	
11	40402206	Bra	Dö	D	16	12.11.08	in Betrieb	Belebtschlam	j	j	j	n	n	<N	<NULL>	Einleitung in (	
12	40402207	Bra	Pie	Pi	4	01.07.09	in Betrieb	Tauchkörper	j	j	j	n	n	<N	Georg Huber;	Einleitung in (	
13	40402210	Bra	Hä	Hä	5	01.01.15	in Betrieb	bepflanzte Bo	j	j	j	n	n	ÖN	Liquis-Naturkläranlage, 2 Rottekammern, Mult	Einleitung in (	
14	40404201	Bra	Sta	St	20	01.09.08	in Betrieb	Belebtschlam	j	j	j	n	n	<N	Aqua Komp. 20; Schlammspeicher / Grobfang I	Einleitung in (	

Figure 2: Screenshot showing a part of the dataset including all small WWTPs in Upper Austria.

Column H provides relevant information for the assignment to the above mentioned categories, with the treatment technology. It can be seen in row 4, that there are plants without a treatment technology in this column. In these cases, the information in column O is considered, it presents more detailed information about the technology for some treatment plants. Sometimes the information in column H and O is not the same, in these cases the technology described in column O is considered as relevant, because it includes a more detailed description. Another option, before calling a plant unknown, is to check the record in the so called WIS (water information system) Upper Austria, where the permits can be found. In Upper Austria the WIS is integrated in the GIS application DORIS, it is available via the following link: http://doris.ooe.gv.at/viewer/(S(w40ydk2gh2yffg2zwvi1a3bd))/init.aspx?karte=wage.

The last possibility to gain information about the treatment technology is to contact the company that built the plant. However, this was only possible for one treatment plant, which is shown in row 4.

Column E, which contains information about the design size of the treatment plant, is filtered because the dataset includes some plans with more than 50 PE, and they should not be considered in this analysis.

After the treatment plants were assigned according to the described process, they were copied into another MS-Excel file, which is then used to conduct the analysis. An example of the assignment can be seen in Figure 3 with the assigned CAS plants. Treatment plants highlighted in orange are categorized according the information in column O because the particular make is mentioned there, and it is therefore considered as a CAS plant.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	BUNDESN				EW (	INBETRIE		Realisie	VERFAHRENSART BIOLOGIE						GRI	FABRIKATTYPE	ABLEITUN(
562	41746201	Vöc	L	Lo	4	15.12.00		in Betrieb	Belebtschlammverfahren	n	j	j	n	n		Aqua Komp. 3, GFK-Rundbecken DNi 1800, S	Einleitung in (
563	41746202	Vöc	M	M:	8	29.07.09		in Betrieb	Belebtschlammverfahren	j	j	j	n	n	Die An	INOWA BIOTEC 8 KS für 8 EGW	Einleitung in (
564	41752202	Vöc	W	W	30	01.01.02		in Betrieb	Belebtschlammverfahren	n	j	j	n	n		Aqua Komp. 30, Rundbecken-Beton DNi 250	Einleitung in (
565	41803202	We	S	Scl	12	01.09.04		in Betrieb	Belebtschlammverfahren	j	j	j	n	n	<NULL	<NULL>	Einleitung in (
566	41803203	We	K	Kr	25	12.12.06		in Betrieb	Belebtschlammverfahren	j	j	j	n	n	<NULL	<NULL>	Einleitung in (
567	41805202	We	R	Rü	6	19.03.09		in Betrieb	Belebtschlammverfahren	n	j	j	n	n		KKA-6.9SP mit Schlammspeicher KS-15	Einleitung in (
568	41823201	We	H	He	6	01.06.06		in Betrieb	Belebtschlammverfahren	n	j	j	n	n	<NULL	<NULL>	Einleitung in (
569	41824202	We	M	Mi	12	09.04.04		in Betrieb	Belebtschlammverfahren	n	j	j	n	n	<NULL	<NULL>	Einleitung in (
570	41507010	Ste	G	Gr	50	01.05.98		in Betrieb	Belebtschlammverfahren, Tauc	j	j	j	j	n	ÖNORI	AQUA-COMP 50; DN 2500, Vorklärung/Schla	Einleitung in (
571	40707199	Gm	A	W	43	01.08.99		in Betrieb	Belebtschlammverfahren, sons	j	j	j	n	n	<NULL	<NULL>	Einleitung in \
572	40604202	Frei	N	Na	6	16.01.07		in Betrieb	Belebtschlamm - Aufstauverfah	j	j	j	n	n	<NULL	Europhat - Anlage, Type U-20/6; Durchlaufve	Einleitung in (
573	40611212	Frei	S	Sti	8	20.08.12		in Betrieb	Belebtschlamm - Aufstauverfah	j	j	n	n	n		Meisl MK 8 Durchlaufanlage, Belebungsbeck	Einleitung in (

Figure 3: Screenshot showing an extract of the file including assigned CAS treatment plants

4.2.3 Treatment performance

A second dataset with the measurement values assigned to the identification number of the treatment plant is provided. An extract of the first part is presented in Figure 4. It includes some more information about the sampling (e. g. measuring point, date, time) and the executive company as well as the laboratory. In column O it is described if external influences, like a cooled or frozen sample, are present. Figure 5 shows an extract of the second part of the dataset with all available measurement values.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	EW-BSB$_5$	Realisierungsstatus	Aktenzahl	GTW-Zahl	Inbetriebnahme	bewilligt bis	Bundesnr.	Messpunkt	Beginn Datum	Beginn Uhrzeit	Probenbearbeitungsdatum	Art der Probenahme	Datenwerber	Labor Nr.	Äußere Einflüsse
2			2015-55152				40301201		15.09.17	12:30	18.09.17	Stichprobe	KHM Umwelttechnik	AgroLab	
3		1. Bef.	2015-59508				40401202	Ablauf	23.05.13	15:00	24.05.13	Stichprobe	Aqua-Sys	RHV Polling	gekühlt
4		in Betrieb	2015-59508				40401202	Ablauf	23.04.14	14:15	24.04.14	Stichprobe	Aqua-Sys	RHV Polling	gekühlt
5		in Betrieb	2015-59508				40401202	Ablauf	20.08.15	13:20	21.08.15	Stichprobe	Aqua-Sys	RHV Polling	gekühlt
6		in Betrieb	2015-59508				40401202	Ablauf	05.09.16	13:15	06.09.16	Stichprobe	Aqua-Sys	RHV Polling	gekühlt
7		in Betrieb	2015-59508				40401202	Ablauf	28.06.17	08:00	29.06.17	Stichprobe	Aqua-Sys	RHV Polling	gekühlt
8		in Betrieb	2015-59508				40401202	Ablauf	29.08.18	10:45	30.07.18	Stichprobe	Aqua-Sys	RHV Polling	gekühlt
9		1. Bef.	2015-58928				40402200	Ablauf	12.09.11	15:30	12.09.11	Stichprobe	Betreiber	KA Aspach	gekühlt
10		in Betrieb	2015-58928				40402200	Ablauf	06.03.13	10:30	06.03.13	Stichprobe	Betreiber	KA Aspach	gekühlt
11		in Betrieb	2015-58928				40402200		11.09.13	12:40	11.09.13	Stichprobe	Feichtenschlager Fran:	KA Aspach	gekühlt
12		in Betrieb	2015-58928				40402200	Ablauf	09.09.14	12:55	09.09.14	Stichprobe	Betreiber	KA Aspach	gekühlt
13		in Betrieb	2015-58928				40402200	Ablauf	17.09.15	09:45	18.09.15	Stichprobe	Betreiber	KA Aspach	gekühlt
14		in Betrieb	2015-58928				40402200	Ablauf	26.09.16	15:00	26.09.16	Stichprobe	Feichtenschlager Fran:	KA Aspach	gekühlt
15		in Betrieb	2015-58928				40402200	Ablauf	25.09.17	09:40	25.09.17	Stichprobe	Feichtenschlager Fran:	KA Aspach	gekühlt

Figure 4: Screenshot showing an extract of the second dataset provided by the Upper Austrian government including additional information about the sampling

	A	B	C	D	E	F	G	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
1	EW-BSB$_5$	Realisierungsstatus	Aktenzahl	GTW-Zahl	Inbetriebnahme	bewilligt bis	Bundesnr.	Anmerkungen	Abs St ml/l	BSB$_5$	CSB mg/l	Probe Temperatur °C	NH_4-N (T>12°C) mg/l	NH_4-N (T> 8°C) mg/	NH_4-N mg/l	NO_3-N mg/l	NO_2-N mg/l	Pges mg/l	pH Wert	Summe Kohlenwasserstoffe m	TOC mg/l	AOX mg/l
2			2015-55152				40301201		0.1	3	76	17	0.16		0.16							
3		1. Bef.	2015-59508				40401202		0.1	3	15	6.8	0.28		0.28							
4		in Betrieb	2015-59508				40401202		0.1	3	15	9	2		2							
5		in Betrieb	2015-59508				40401202		0.1	3	15	20.99	2		2							
6		in Betrieb	2015-59508				40401202		0.1	3	15	18.5	1		1							
7		in Betrieb	2015-59508				40401202		0.1	3	19.1	19	1		1							
8		in Betrieb	2015-59508				40401202		0.1	4	30.8	19.5	1		1							
9		1. Bef.	2015-58928				40402200		0	13	60	19.2	8.5		8.5				7.8			
10		in Betrieb	2015-58928				40402200		0	24	66	9.5	9.4		9.4				7.6			
11		in Betrieb	2015-58928				40402200		0	10	46	16.3	3		3				7.6			
12		in Betrieb	2015-58928				40402200		0	9	43.9	18.1	3.1		3.1				7.1			
13		in Betrieb	2015-58928				40402200		0	5	26.3	14.4	4.2		4.2				7.4			
14		in Betrieb	2015-58928				40402200		0.2	24	86.8	15.6	9.6		9.6				7.6			
15		in Betrieb	2015-58928				40402200		0.1	12	68.9	13.3	9.6		9.6				7.5			

Figure 5: Screenshot showing an extract of the second dataset provided by the Upper Austrian government including the measurement values

To conduct the analysis of the treatment performance a table with the technology and the measured parameters is required. For the assignment of the identification number and the measurement values to the treatment technology, the MS Excel command “VLOOKUP” is used. As a result, a table like the extract in Figure 6 is produced, including the technology and the respective measurement values.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Bundesnur	Verfahren	Beginn Da	Abs St r	BSB_5	CSB r	Temperat	NH_4-N	NH_4-N	NH_4-N mg	NO_3-N r	NO_2-N	Pges	pH Wert	Summe K	TOC mg/l	AOX mg/l	Inbetri	ahme
2	40402201	Belebtschlammv	11.12.09	0,1	6	34	17,3	0,27		0,27				7,4				01.01.97	12
3	40402201	Belebtschlammv	14.12.10	0,1	20	73	16	0,09		0,09				7,6				01.01.97	13
4	40402201	Belebtschlammv	01.12.11	0,1	3	30	21,4	0,3		0,3				7				01.01.97	14
5	40402201	Belebtschlammv	04.12.12	0,1	3	48	22,3	0,61		0,61				6,8				01.01.97	15
6	40402201	Belebtschlammv	09.12.13	0,1	9	53	21,3	0,44		0,44				7,7				01.01.97	16
7	40402201	Belebtschlammv	03.11.14	0,1	8	58	23,6	0,38		0,38				7,1				01.01.97	17
8	40402201	Belebtschlammv	14.12.15	0,1	7	32,6	22,5	0,14		0,14				7,2				01.01.97	18
9	40402201	Belebtschlammv	15.12.16	0,1	10	32,8	14	0,91		0,91				7,9				01.01.97	19
10	40402201	Belebtschlammv	06.12.17	0,1	8	30,2	14,2	0,44		0,44				8,1				01.01.97	20
11	40402206	Belebtschlammv	21.02.11	0,3	47	123	7,8	6,4		6,4								12.11.08	2
12	40402206	Belebtschlammv	19.07.11	0,3	3	52	19,1	2,8		2,8								12.11.08	2
13	40402206	Belebtschlammv	12.06.12	0,3	6	60	17	2,6		2,6								12.11.08	3
14	40402206	Belebtschlammv	25.06.13	0,1	9	50	17,8	2,6		2,6								12.11.08	4
15	40404202	Belebtschlammv	21.09.10	0,05	8,2	41,2	17,3	0,23		0,23				7,4				01.07.10	0
16	40404202	Belebtschlammv	04.08.11	0,1	7	31,3	18,2	0,1		0,1				6,9				01.07.10	1
17	40404202	Belebtschlammv	17.07.12	0,1	5,5	31,7	18,5	0,1		0,1				7,4				01.07.10	2

Figure 6: Part of the table with assigned treatment technology and measured values

The table contains numerous measurement values for BOD_5, COD, NH_4-N, the temperature and the pH-value. There are also columns for NO_2-N, P, total hydrocarbons, TOC and AOX. Due to the fact that not enough measured values are available, these columns are not considered in the data analysis. In Column R the date of commissioning can be seen and in column S the difference in years between the date of the measurement and the commissioning of the WWTP is shown. To calculate this difference the Excel function DATEDIF was used. Due to the fact, that in the data of some treatment plants the date of commissioning is after the first measurement some errors in the results occur. The respective values are considered as year zero and were manually corrected in the table. This column is relevant, to analyse the treatment performance over the operation time of small WWTPs.

4.3 Statistical analysis

To gain an overview and some general knowledge about the dataset, and therefore the treatment performance, descriptive statistics was applied and the used terms are shortly described in the following chapter.

The arithmetic **mean** is the most common measure of location and it is calculated by dividing the sum of all values by the number of values. It is sensitive against extreme values or outliers and this may be problematic. A robust measure of location is the **median value**, this means that it is not sensitive to outlier values. The median value is the value placed in the middle of the dataset, that implies that 50% of the measured values are higher or equal to the median value and 50% are lower or equal.

Additional to the median value, the quartiles show more information about the data distribution. 25% of all values are smaller than the **lower quartile ($x_{0.25}$)** and 25% of all values are higher than the **upper quartile ($x_{0.75}$)**. In between these two quartiles are 50% of all values and the distance between them is the so-called interquartile range (d_Q). If the quartiles have about the same distance to the median value, the distribution is symmetrical. If the distance of $x_{0.75}$ to the median value is higher than the distance from the median value to $x_{0.25}$, the distribution is skewed to the right. The same applies conversely. The median value equals the 50% quartile.

One of the most frequently used statistical estimator to describe the scattering of a dataset is the **standard deviation** and its square the **variance**. A high standard deviation means that the data are widely spread around the mean while a low standard deviation indicates that the data are distributed closer to the mean. They are both not robust against outlier values.

To illustrate the data boxplots and violin plots are used. As it can be seen in Figure 7 the **boxplot** contains a box with the $x_{0.25}$ as the lower end and $x_{0.75}$ as the upper limit of the box. The line in the box shows the location of the median value. Values outside the upper and lower quartiles are indicated with the extending lines, called whiskers. They are restricted by the maximum and minimum value without outliers (FAHRMEIER et. al., 2016). The points indicate the outlier values.

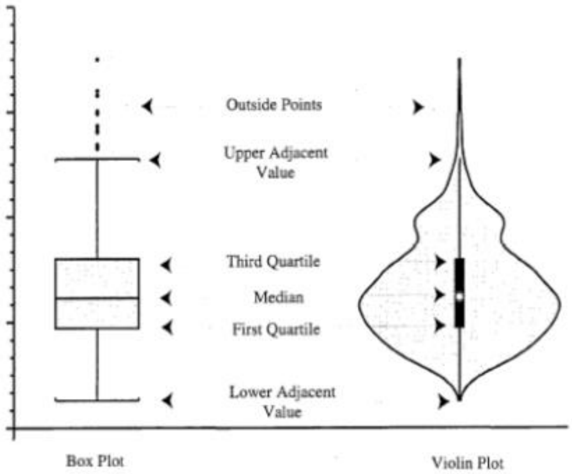

Figure 7: Boxplot and violin plot (HINTZE & NELSON, 1998)

Violin plots show more information about the distribution of the data (Figure 7). It is a combination of the estimators illustrated in a traditional boxplot and the density shape in a single plot, which is then useful for further data exploration. The boxplot is combined with symmetrically, to the left and to the right, plotted density traces. Due to the symmetry it is easier to gain a quick overview and a comparison between different distributions. Peaks, valleys and bumps of the distribution are not visible in boxplots, but they are in violin plots. In Figure 8 the difference between boxplots and violin plots is illustrated. The three different distributions show no difference in the location and scale characteristics (median value, quartiles). Violin plots reveal the shape of the distribution. If a bimodal distribution underlies the data, the two bumps can only be seen in a violin plot. In a boxplot the bimodal and the uniform distribution look exactly the same, only the normal distribution can be distinguished (HINTZE & NELSON, 1998).

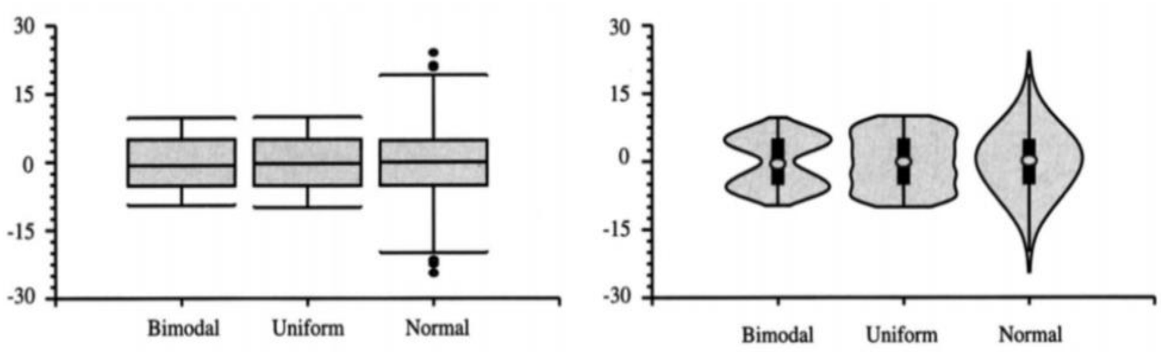

Figure 8: Boxplots (left) and violin plots (right) from three different known distributions (HINTZE & NELSON, 1998)

4.3.1 Treatment performance over the operation time

The treatment performance over the operation time of small WWTPs is at first analysed per technology. Therefore, the measured effluent concentrations of the three parameters NH_4-N, BOD_5 and COD are assigned to the years after commissioning of the treatment plants. The median value of all values for every year is then calculated to figure out if an improvement or a deterioration of the treatment performance can be seen.

To analyse the treatment performance over the operation time of every single treatment plant, with more than or equal to five years of measured values, they are inspected if a trend of the NH_4-N effluent concentration occurs.

The non-parametric Mann-Kendall trend test with a 95% significance level is performed in R-studio within the package 'trend'. This test is commonly used to detect monotonic trends in environmental, climate or hydrological data. The function 'mk.test' is used with an alternative hypothesis H_A, stating that the effluent concentrations follow a monotonic trend. If a statistically significant trend can be detected, meaning that the p-value is smaller than 0.05, the Sen's slope is calculated as a robust estimate of the slope (magnitude) of a trend. The R code 'sens.slope', also found in the package 'trend', is used to compute the slope, in other words: the linear rate of change, according to Sen's method where the slope is calculated as the median value of all slopes (CRAN, 2020).

5. Results and discussion

5.1 Number of small WWTPs in Upper Austria

5.1.1 Evaluation of small WWTPs since 2016

As it can be seen in Table 5 and Figure 9 the number of small WWTPs in Upper Austria has changed in the past three years. According to LANGERGRABER et. al (2018) the total number of small treatment plants in Upper Austria in 2016 was 2’398, compared to a total number of 2’526 in 2019. The biggest difference can be seen in the alteration of the number of SBR plants, in 2019 there are 171 more treatment plants operating than three years before. Another significant change occurs in the difference of the number of VF wetlands. Currently there are 60 treatment plants more with this technology than in 2016.

Old treatment plants, which provide only mechanical treatment, are mainly conventional 3-chamber septic tanks which are not state-of-the-art anymore but are still allowed to operate because of permissions granted before 1992 without expiration date. Before the requirement of nitrification has been introduced in 1990 for all sizes of treatment plants it was legal to discharge only mechanically treated wastewater from small WWTPs (LANGERGRABER et. al, 2018). The number of these treatment plants decreased by 79 over the last three years.

After the requirement for nitrification was introduced mainly CAS treatment plants have been implemented. Currently the number of newly implemented CAS plants is decreasing slightly while other technologies like SBRs and VFWs gain popularity (LANGERGRABER et. al, 2018). This development can also be seen in Upper Austria.

Table 5: Difference in the number of small WWTPs from 2016 (LANGERGRABER et.al, 2018) to 2019

Technology	Number 2016	Number 2019	Difference
SBR	702	873	171
Conventional activated sludge (CAS)	646	628	-18
Vertical flow wetland (VFW)	475	535	60
Primary treatment only	381	302	-79
Trickling filter	100	97	-3
Rotating biological contactor (RBC)	37	37	0
MBR	26	26	0
Filtration	27	27	0
Unknown	4	1	-3
Total	**2’398**	**2’526**	**128**

It is illustrated in Figure 9 that the most popular technology in Upper Austria is SBR. There are currently 873 treatment plants with this technology. Also, a high number of treatment plants with CAS technology (628) can be found as well as VFWs (535). Even though the number of old 3-chamber treatment plants decreased, the remaining treatment plants which can only provide mechanical treatment is still considerable with 302 WWTPs. Furthermore, there are 97 trickling filters, 37 RBC treatment plants, 26 MBR and 27 filtration treatment plants. The technology of 1 treatment plants remains unknown.

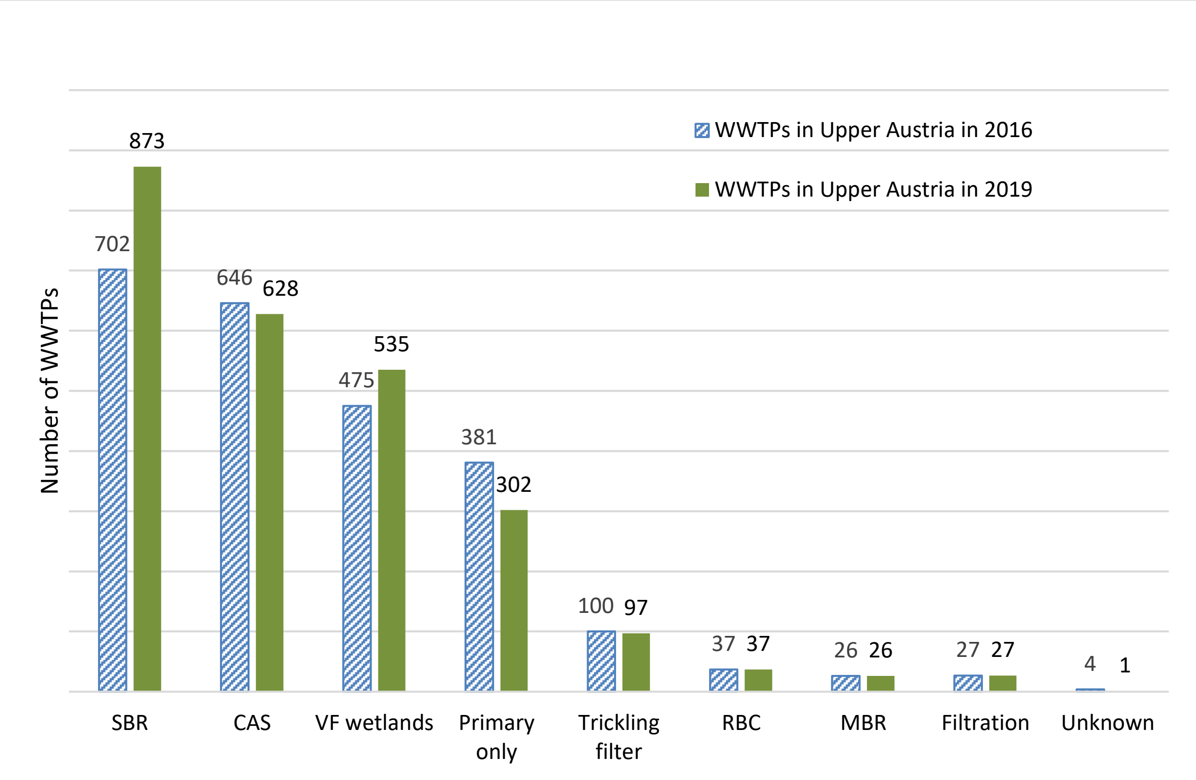

Figure 9: Development of the number of small WWTPs in Upper Austria

5.1.2 Comparison of shares of technologies in Upper Austria and Austria

The analysis conducted by LANGERGRABER et. al. (2018) summarizes the total amount of small WWTPs in all federal states. In Austria there are overall about 27'500 small WWTPs currently operating. Figure 10 shows a comparison of the shares of the different technologies in Austria in 2016, in Upper Austria in 2016 as well as in 2019 according to the obtained data.

It has to be mentioned that there is no data for all over Austria in 2019 available yet. A comparison with the Upper Austrian data is useful anyways to get an overview of the shares of the technologies and to figure out if there is a special situation in Upper Austria.

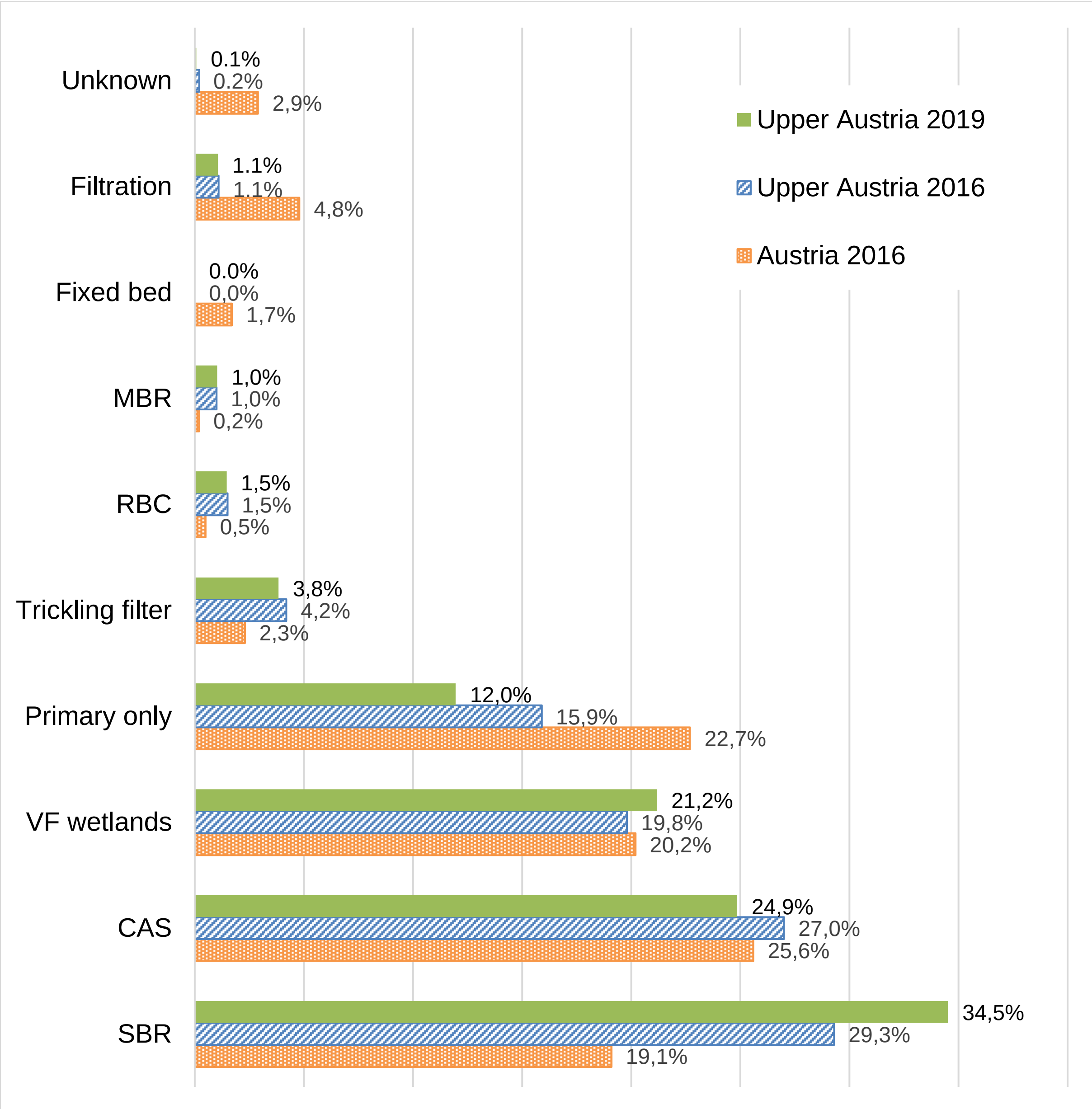

Figure 10: Share of technologies in Austria compared to Upper Austria

In Upper Austria the share of SBR plants is with about 34.5% significantly higher than all over Austria and there is, as mentioned before, a substantial increase over the past three years. Compared with this, the percentage of CAS treatment plants was in 2016 in Upper Austria higher than in the Austrian average and decreased to 24.9% in 2019.

There are no fixed bed treatment plants in Upper Austria while the percentage all over Austria is 1.7%. Furthermore, the number of filtration treatment plants is comparably low in Upper Austria, the same applies for WWTPs with primary treatment only. The shares of MBRs, RBCs, trickling filters and VFWs is slightly higher than in the Austrian average.

The number of treatment plants with an unknown technology in Upper Austria is very low. In 2016 there were 4 treatment plants with unknown technology (0.2%), this number can be reduced to 1 in 2019. For this particular treatment plant neither information is available in the provided data nor can be found in WIS, so it remains unknown. Due to the fact that only one treatment plant has an unknown technology, it can be assumed that the data basis in Upper Austria is quite good. All over Austria the technologies of 2.9% of the operating treatment plants in 2016 are unknown, compared to Upper Austria with only 0.1% (status as of 2019).

5.1.3 Number of treatment plants with a VF bed

To conduct the statistical analysis about the treatment performance of each technology it is necessary to separate the technologies with a vertical flow bed as an additional treatment from the treatment plants without one. SBR as well as CAS treatment plants occur with such a VF bed.

In Upper Austria currently 33% of all SBR treatment plants have a secondary treatment and 9% of CAS treatment plants. As it can be seen in Figure 11 this equals 290 SBR and 54 CAS treatment plants.

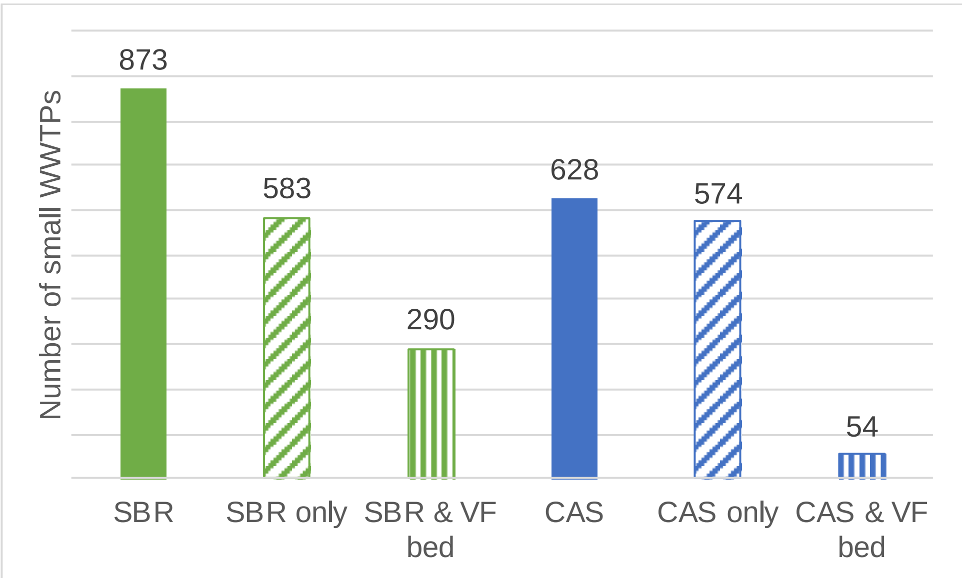

Figure 11: Number of WWTPs with a downstream vertical flow bed

5.2 Treatment performance

The treatment performance of the different technologies used for small WWTPs is analysed in three different steps. In the beginning all available measurement values are inspected. As a second step in the analysis the same statistical parameters as before with all values will be calculated with the median values of the individual treatment plants. In the end only the WWTPs with more than five available measurements are considered in the analysis. Old treatment plants with mechanical treatment only are not included in the analysis because no measurements are available.

5.2.1 Analysis with all measurement values

To evaluate if in general all treatment technologies are able to meet the requirements an analysis with all available values is conducted in R-studio.

In Table 6 the results of the statistical analysis with all measured **NH_4-N** outflow concentrations are presented and therefore a general overview about the data is given. It can be seen that overall 14'100 measured NH_4-N values of 1'975 treatment plants are available. Most values are available for SBRs, CAS treatment plants and VF wetlands.

Table 6: Statistical information about the NH_4-N effluent concentrations

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	493	252	539	52	486	85	36	25	7	1975
Number of values	3347	1566	4382	418	3178	689	282	184	54	14100
Median [mg/l]	**1.00**	**0.68**	**1.09**	**0.24**	**0.37**	**2.20**	**1.20**	**1.78**	**2.66**	**0.98**
Mean [mg/l]	2.43	1.14	2.95	1.54	1.43	4.21	3.48	2.52	4.23	2.31
Standard dev. [mg/l]	5.08	2.35	5.85	4.19	2.91	6.18	6.17	3.99	4.69	4.84
Lower quartile [mg/l]	0.20	0.16	0.38	0.06	0.10	0.56	0.33	0.67	0.53	0.20
Upper quartile [mg/l]	2.90	1.07	3.50	1.18	1.30	6.30	4.28	2.96	6.45	2.42
Maximum value [mg/l]	137	45.5	92.	51.6	41.7	61.7	64	38.3	22.1	137
Minimum value [mg/l]	0*	0*	0.01	0.01	0*	0.01	0.03	0.02	0.10	0*
95 percentile [mg/l]	8.79	3.65	9.00	8.12	6.89	10.90	12.16	6.80	12.34	8.72
85 percentile [mg/l]	4.93	2.00	6.21	2.29	2.48	8.39	7.39	3.98	9.02	4.50
values above threshold	72	13	137	9	48	42	17	6	6	350
[%]	2.2	0.8	3.1	2.2	1.5	6.1	6.0	3.2	11.1	2.5

* the value 0 was included in the database, the correct value would be below the limit of detection

It is obvious that the lowest median values occur at CAS treatment plants with secondary treatment (0.24 mg/l), VF wetlands (0.37 mg/l) and SBRs with secondary treatment (0.68 mg/l).

These technologies also show the lowest shares of values above the threshold of 10 mg/l. For SBR treatment plants with a downstream VF bed only 13 values above the threshold where measured, this equals 0.8%. VF wetlands show 48 values above the threshold, this means 1.5%. Compared to the low median value for CAS treatment plants with downstream planted soil filters the share of values above the threshold with 2.2% is higher than in SBRs and VF wetlands. The standard deviation of CAS & VF bed measurements is also significantly higher (4.19 mg/l), than of SBR & VF bed (2.35 mg/l) and VF wetlands (2.91 mg/l). With 11.1% most values above the threshold occur in the measurements of filtration treatment plants, whereas trickling filters show the highest standard deviation with 6.18 mg/l.

On the first sight all treatment technologies are able to meet the required NH_4-N threshold values. To gain more information about the distribution of the data violin plots are created. In Figure 12 the violin plots of all technologies are illustrated. The y-axis shows the NH_4-N measurements in mg/l in a logarithmic scale and the different technologies can be found on the x-axis. The dashed red line indicates the threshold value of 10 mg/l.

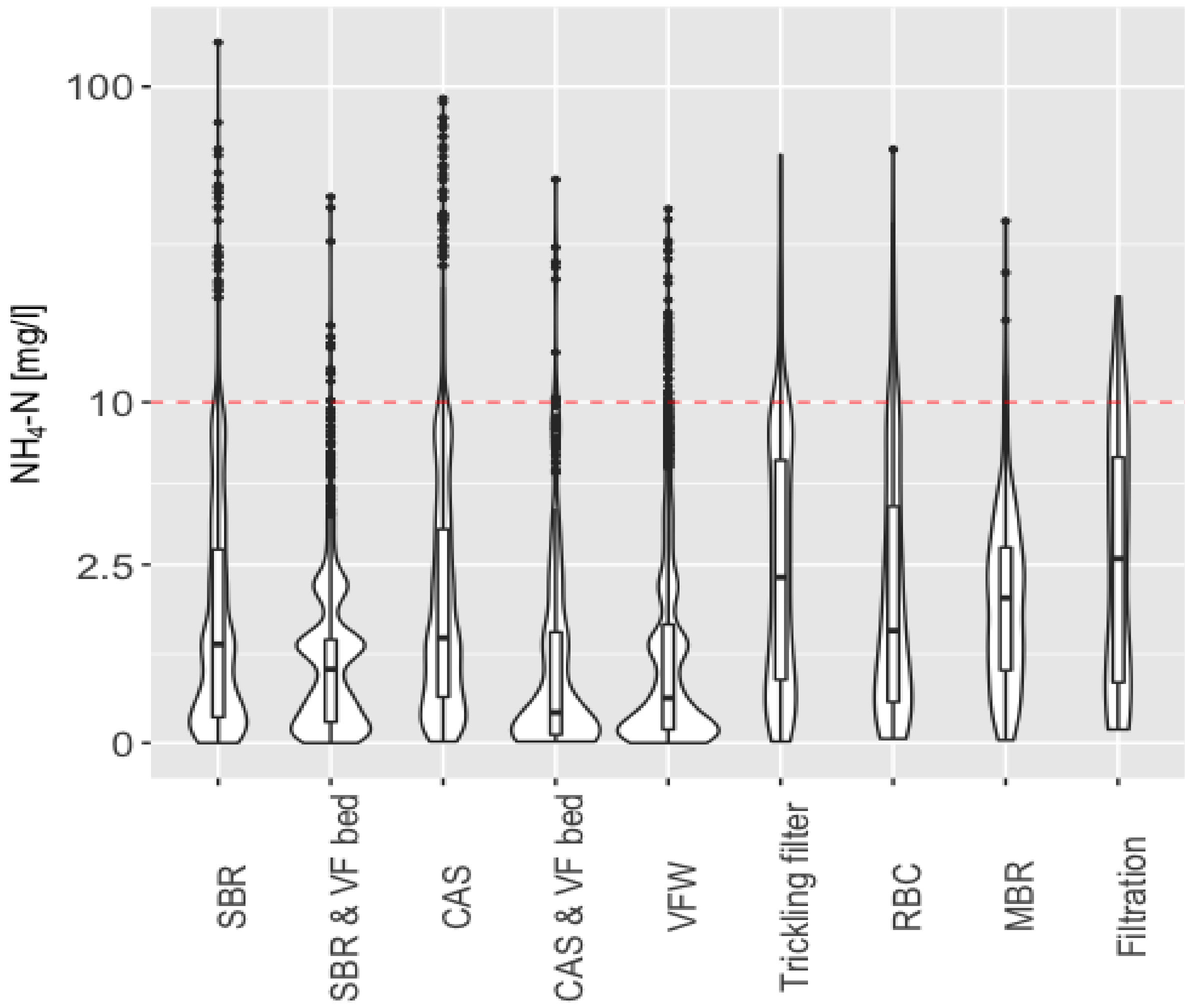

Figure 12: Violin plots of NH_4-N effluent concentrations for all technologies

A lot of values close to zero occur especially in VFWs and CAS treatment plants with VF beds as well as in SBR plants with VF beds. These are also the three technologies with the lowest median values and the lowest lower quartiles. Most values measured for these technologies are accumulated below 2.5 mg/l. The reason for the higher median value of SBRs & VF bed plants appears in the violin plot as the second bump in the density shape around the upper quartile. The data distribution of trickling filters and filtration treatment plants is quite evenly between 0.01 mg/l (trickling filter) or 0.10 mg/l (filtration) and the threshold. The highest upper quartiles occur in these two technologies with 6.30 mg/l and 6.45 mg/l.

The median values of all technologies are far below the threshold value of the NH_4-N effluent concentration and overall only 2.5% of all measurements exceed the threshold. It is therefore reasonable to assume that all technologies are in general able to treat the wastewater sufficient according to the legal requirements regarding NH_4-N.

There are slightly more **BOD_5** measurements available than NH_4-N because there is one CAS treatment plant more which can provide BOD_5 values and five VFWs. The calculated statistical parameters of all available BOD_5 effluent measurements are listed in Table 7.

Table 7: Statistical information about the BOD_5 effluent concentrations

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	493	252	540	52	491	85	36	25	7	1981
Number of values	3358	1563	4402	422	3223	700	279	185	54	14186
Median [mg/l]	**5**	**3**	**5**	**3**	**3**	**8**	**7**	**4**	**6**	**5**
Mean [mg/l]	7	5	7	5	5	9	9	5	8	6
Standard dev. [mg/l]	7	3	8	4	3	6	7	5	5	7
Lower quartile [mg/l]	5	3	3	3	3	4	4	3	4	3
Upper quartile [mg/l]	9	5	9	6	5	12	14	5	8	8
Maximum value [mg/l]	242	45	230	47	40	51	36	46	23	242
Minimum value [mg/l]	0*	0*	0*	0*	0*	1	1	2	0*	0*
85 percentile [mg/l]	12	7	12	7	7	15	18	8	12	10
95 percentile [mg/l]	17	11	18	12	11	20	22	13	20	16
values above threshold	27	3	55	3	4	6	5	1	0	104
[%]	0.8	0.2	1.3	0.7	0.1	0.9	1.8	0.5	0.0	0.7

* the value 0 was included in the database, the correct value would be below the limit of detection

The median values of all measurements are close together, more precisely between 3 mg/l and 8 mg/l. SBR and CAS treatment plants with VF beds as well as VFWs show the lowest median values, in contrast to this the highest median value occurs at trickling filters.

104 measurements, that equals a share of 0.7%, are higher than the BOD_5 threshold of 25 mg/l. The highest measurements can be found in the data of SBR and CAS treatment plants with 242 mg/l and 230 mg/l. Due to the fact that these are only single measurements they should not be overrated. In percentages most values above the threshold can be found in the measurements of RBC treatment plants (1.8%) and CAS treatment plants (1.3%). It is noteworthy, that there is no measurement value of filtration treatment plants above the BOD_5 threshold, whereas 11.1% of the NH_4-N are above the associated threshold.

The BOD_5 threshold level at 25 mg/l is illustrated in Figure 13 as the dashed red line on the logarithmic y-axis. In this plot it gets more obvious that the number of measurements above the threshold of all technologies is significantly lower compared to the NH_4-N measurements.

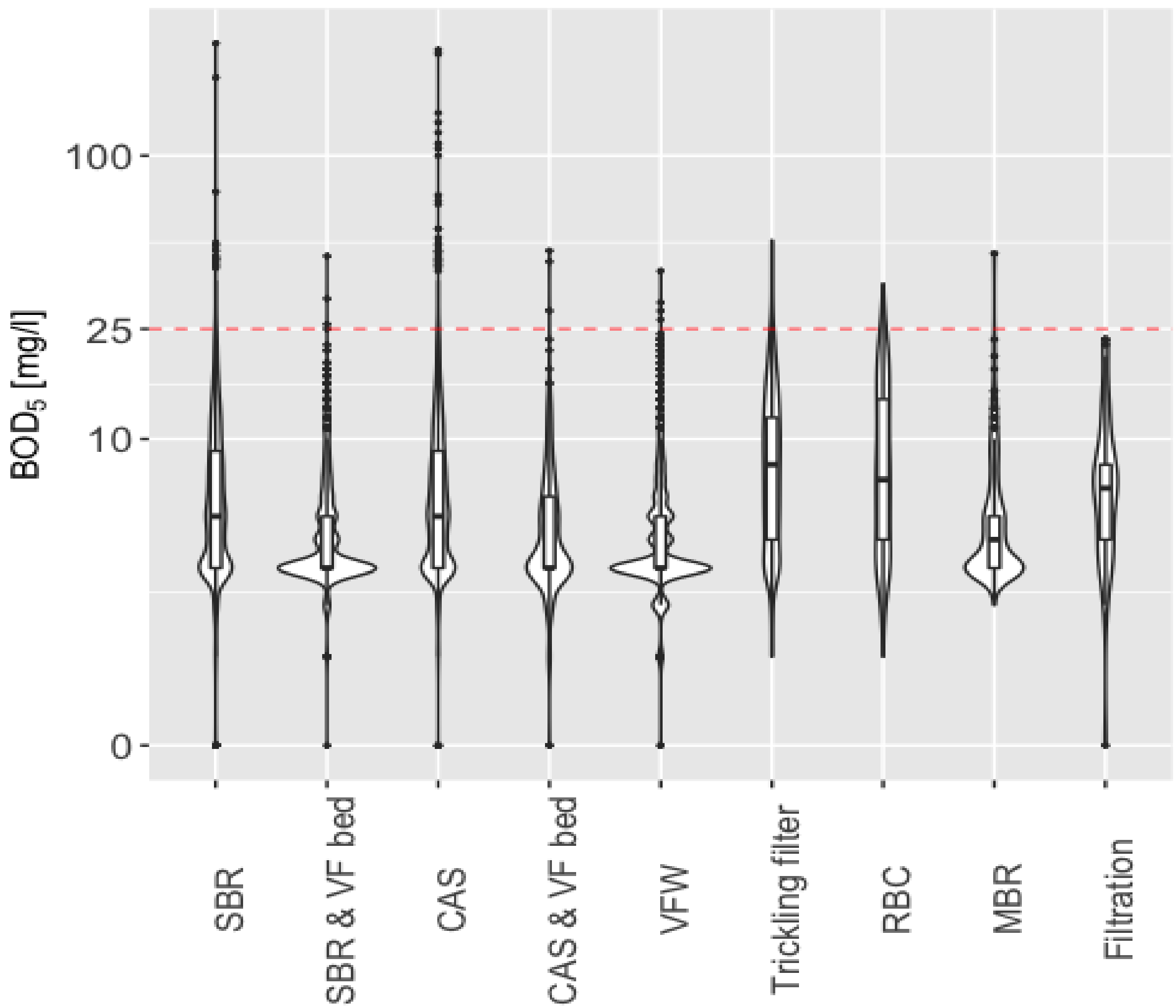

Figure 13: Violin plots of BOD_5 effluent concentrations for all technologies

There are six technologies with a minimum value of 0 mg/l, the minimum values of trickling filters and RBC treatment plants are 1 mg/l and the lowest measured value in the data for MBR is 2 mg/l. SBR and CAS treatment plants with a VF bed as a secondary treatment as well as

VFWs have a median value of 3 mg/l which equals the respective lower quartile. The shape of the violin plots illustrates that the measurements accumulate around 3 mg/l, this also accounts for MBR treatment plants but there the median value is higher with 4 mg/l. Almost evenly distributed are the measurements of trickling filter, RBC and filtration treatment plants. However, a slight accumulation can be seen around the upper quartile (8 mg/l) of filtration WWTPs.

Overall, it can be determined that all technologies are able to meet the legal requirements according the BOD_5 effluent concentrations. The median values as well as the upper quartiles of all technologies are far below the threshold level. Furthermore, only 0.7% of all available measurement values exceed the threshold of 25 mg/l.

To conduct the analysis of the **COD** effluent concentrations the measurement values of 1’981 small WWTPs are available. The results of the statistical calculations are presented in Table 8.

Table 8: Statistical information about the COD effluent concentrations

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	493	252	540	52	491	85	36	25	7	1981
Number of values	3365	1568	4406	422	3233	703	283	185	54	14219
Median [mg/l]	**37**	**24**	**35**	**24**	**21**	**44**	**43**	**27**	**33**	**31**
Mean [mg/l]	42	28	41	40	25	47	47	31	34	36
Standard dev. [mg/l]	25	16	38	249	14	22	21	15	14	51
Lower quartile [mg/l]	25	16	25	17	15	31	32	18	23	20
Upper quartile [mg/l]	55	35	50	35	30	61	59	41	44	46
Maximum value [mg/l]	670	179	1824	5136	136	183	193	89	68	5136
Minimum value [mg/l]	2	0*	0*	3	1	5	10	15	0*	0*
85 percentile [mg/l]	66	43	60	43,01	37	69	69	49	48	57
95 percentile [mg/l]	81	58	75	57,97	54	85	80	59	56	74
values above threshold	48	7	53	1	4	11	4	0	0	128
[%]	1.4	0.5	1.2	0.2	0.1	1.6	1.4	0.0	0.0	0.9

* the value 0 was included in the database, the correct value would be below the limit of detection

VFWs show the lowest median value of all technologies with 21 mg/l. Only slightly above that SBR and CAS treatment plants, both with a VF bed, have a median value of 24 mg/l and the median value of MBRs is 27 mg/l. The calculated median value of all other technologies is over 30 mg/l. The highest median value occurs in trickling filters with 44 mg/l. The number of measured values above the threshold is in general very low. MBR and filtration treatment plants have no value above the threshold of 90 mg/l, though the maximum occurring measurement value of MBR WWTPs is 89 mg/l which is close to the threshold.

The violin plots in Figure 14 illustrate that there is a higher density of values around the lower quartile of SBR treatment plants with a VF bed (16 mg/l) and VFWs (15 mg/l). Furthermore, it becomes obvious that SBR and CAS treatment plant have the highest number of outlier values and therefore values above the threshold, however the percentage is low with 1.4% and 1.2% because these are the technologies with the most available measurements.

The highest measured concentration can be found in the values of CAS & VF bed treatment plants with 5136 mg/l. It is the only value above 90 mg/l, an extreme outlier value and it is shown in Figure 14. This value occurs in the measurements of a treatment plant where all the other measurements comply with the respective threshold values. The possibility of a mistake in the data transfer seems possible. If this extreme value is neglected the highest value of all CAS treatment plant measurements is 88 mg/l, what seems more reasonable.

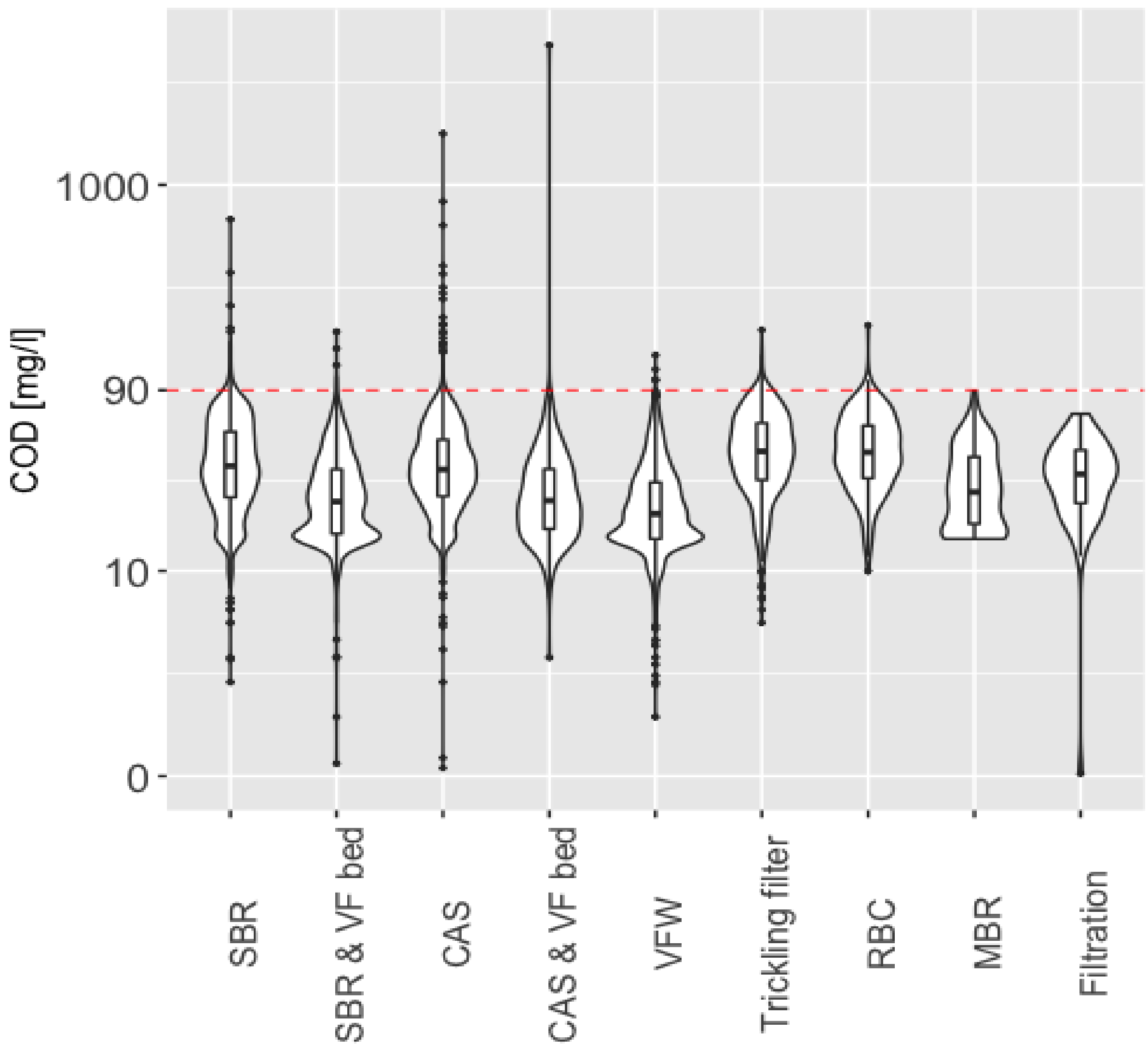

Figure 14: Violin plots of COD effluent concentrations for all technologies

Overall the analysis with all measurements shows that all technologies are able to comply with the given threshold values. In Table 7 and 8 it can be seen that the number of values above the threshold level is significantly lower for BOD_5 and COD effluent concentrations than for NH_4-N concentrations. Only 0.7% of all measured BSB_5 values are higher than the threshold of 25 mg/l and only 0.9% of all COD measurements are higher than 90 mg/l. This clarifies that nitrification is the most sensitive process in wastewater treatment with 2.5% of measurements above the respective threshold of 10 mg/l.

5.2.2 Analysis with median values of individual small WWTPs

To exclude outlier values and to focus more on the individual WWTPs, an analysis with the median values of the measurements of every treatment plant is conducted and a general overview about the results of the statistical analysis is presented in the Tables 9 - 12. In these tables all median values of treatment plants, no matter how many measurement values are available, are included. This means, if only one measurement of a treatment plant is available this value is included in the analysis as well.

In Table 9 the **NH_4-N** results are listed. The lowest median values occur again at the same technologies than in the analysis with all values (SBR & soil filter, CAS & soil filter, VFW). Only nine treatment plants show a median value above the threshold of 10mg/l, this means that at least 50% of the measurements of the respective treatment plants exceed the threshold limit.

Table 9: Statistical information about the NH_4-N effluent concentrations with median values of individual WWTPs

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	493	252	539	52	486	85	36	25	7	1975
Median [mg/l]	**1.00**	**0.84**	**1.17**	**0.12**	**0.47**	**2.60**	**1.16**	**1.36**	**3.21**	**1.00**
Mean [mg/l]	1.86	0.76	1.88	0.98	0.99	3.63	2.37	1.89	3.74	1.58
Standard dev. [mg/l]	6.43	0.71	2.02	1.94	1.54	3.48	2.63	1.88	4.12	3.65
Lower quartile [mg/l]	0.21	0.12	0.55	0.05	0.10	0.73	0.60	0.92	1.00	0.21
Upper quartile [mg/l]	2.00	1.00	2.46	1.00	1.00	6.55	2.66	2.20	4.28	1.85
Maximum value [mg/l]	137	5.60	17.0	8.69	12.0	15.8	9.70	9.70	12.3	137
Minimum value [mg/l]	0.04	0.02	0.05	0.02	0.01	0.03	0.06	0.24	0.20	0.01
85 percentile [mg/l]	3.14	1.00	3.68	1.48	1.62	7.72	5.23	2.82	5.75	2.88
95 percentile [mg/l]	6.49	1.75	6.27	5.46	3.77	9.03	8.10	3.62	10.1	6.21
medians above threshold	2	0	1	0	3	2	0	0	1	9
[%]	0.4	0.0	0.2	0.0	0.6	2.4	0.0	0.0	14.3	0.5

Exactly the same median value than in the analysis with all individual measurements is calculated for SBR treatment plants with 1.00 mg/l. SBR WWTPs with a vertical flow bed have now a median value of 0.84 mg/l compared to 0.68 mg/l with all measurements, the median value of CAS treatment plants is also slightly higher with 1.17 mg/l (compared to 1.09 mg/l before). There are only two median values that are lower in this second part of the analysis. These are CAS treatment plants with a VF bed and RBCs. All the other median values are higher but still remain significantly lower than the threshold.

It is also noteworthy that all upper quartiles are lower in this part of the analysis than with all measurements. The only exception are trickling filters where the upper quartile rises from 6.30 mg/l to 6.55 mg/l. The minimum values of 0.00 mg/l seen before are in this part of the analysis between 0.01 mg/l (VFWs) and 0.24 mg/l (MBRs).

There are some treatment plants of various technologies with a median value which is higher than the threshold of 10 mg/l. In the following part a detailed look into this treatment plants is provided.

Two **SBR** treatment plants show median values above the threshold. For one of these treatment plants, only one measurement in 2009 is available. At this time the treatment plant is 4 years old and all measured parameters are above the threshold values (BOD_5=242, COD=670, NH_4-N=137). At the time of the measurement the pH-value was 7.55 and the temperature 12.7°C. For this treatment plant, no measurements are available in the following years, but in the dataset, it still has the status: in operation. The second treatment plant with a NH_4-N median value above the threshold is a plant built in 2012 and there are 5 measurements available, three of them are higher than 10 mg/l. A value of 48.6mg/l in the last year with an available measurement (2017), is the highest. For all five measurements the temperature is above 12°C and the pH-values are between 7.2 and 8.0.

The **CAS** treatment plant with a median value above the threshold is one with measurement values between 2011 and 2017. Five out of the seven available measurements are above 10 mg/l and the highest occurring value is 74.6 mg/l. The treatment plant was built in 2010 and therefore it is not very old. The pH-values are in a normal range between 7.0 and 7.5, as well as the temperatures, which are all between 13°C and 20°C.

Three **VF** wetlands show median values above 10 mg/l. One of these treatment plants has only one measured value of 12 mg/l at a temperature of 5°C. The second treatment plant has two measurements and the temperature was for both measurements under 8.5°C. Therefore, the significance of these measurements is limited. The third treatment plant has three years of measurements and the temperatures are between 15.7 and 17°C, it is a relatively new treatment plant built in 2015.

Two **trickling filter** treatment plants show median values above the threshold. The first treatment plant has two measurements and the second one three. Furthermore, both treatment plants are quite old and built in 1997 and 1998. The temperatures are above 12° C for three values and below for three others, however the highest as well as the lowest measurement occurs at a temperature below 12°C. The highest value of more than 60 mg/l was measured at a temperature of 10° C and the lowest with 0,35 mg/l at 9,2° C.

The **filtration** treatment plant with a median value above 10 mg/l was built in 2001 and six years of measurements are available. It can be seen that the lowest measured value is 10 mg/l and the highest is 22.1 mg/l. It can be concluded that this particular treatment plant is not able to meet the required threshold value for NH_4-N. Since the last available measurement took place in 2014 it could be assumed that this plant is shut down but according to the list of treatment plants currently operating in Upper Austria it is still in operation.

To get a closer look on the density shape of the data, in Figure 15 the violin plots are presented. On the logarithmic y-axis the threshold level of 10 mg/l is indicated with a red dashed line and it can be seen that the number of outliers and values above this threshold is now comparably low. This is obvious because only the median values of the individual WWTPs are plotted and therefore the amount of individual values is lower than before because it equals the amount of WWTPs of each technology.

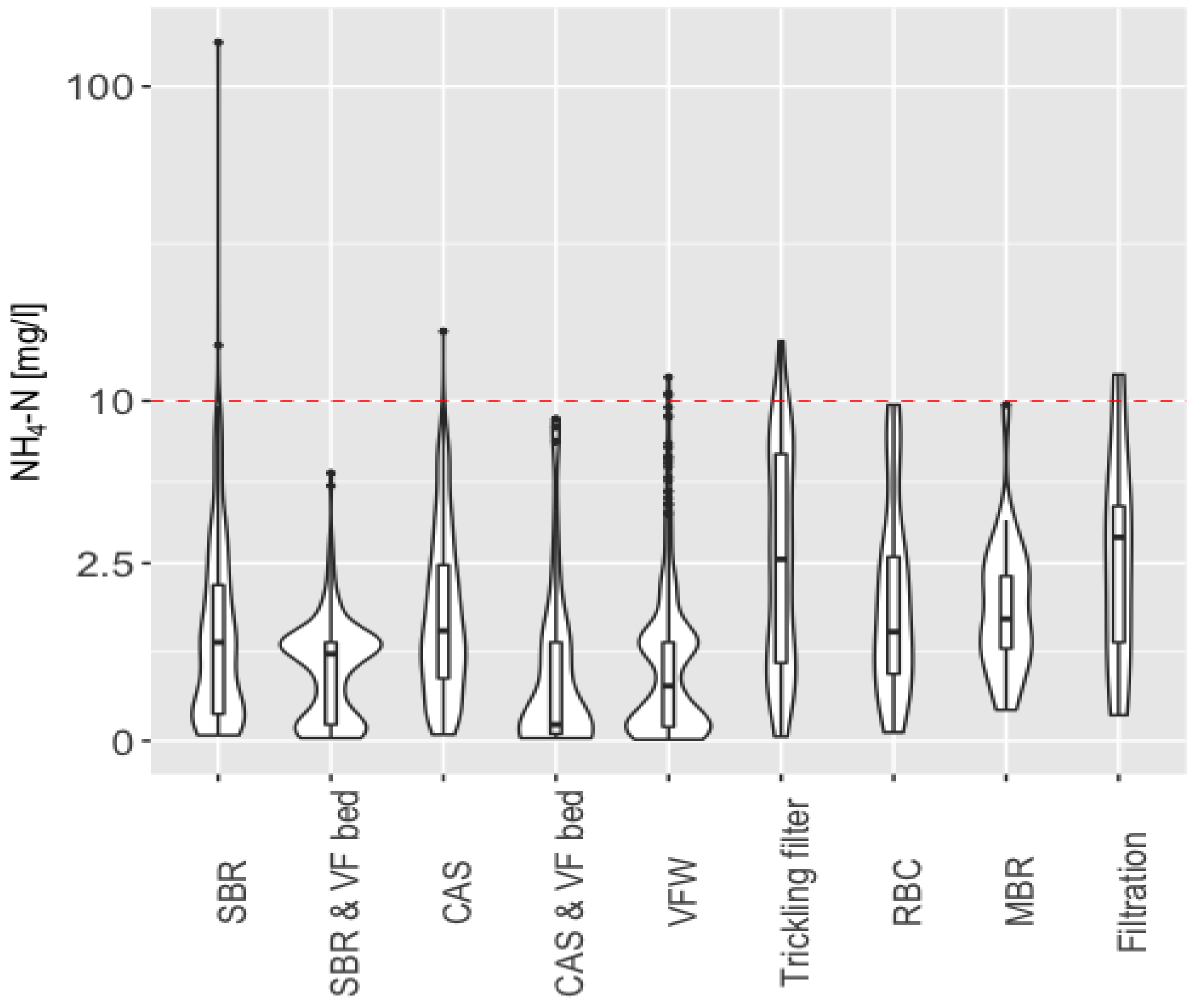

Figure 15: Violin plots of NH_4-N effluent concentrations with median values of individual WWTPs

The density shapes of the technologies do not change significantly. The biggest differences can be seen in SBRs with a VF bed and in VFWs. They both show a higher density around the upper quartile than in the analysis with all individual values.

In this part of the analysis the data of five more treatment plants is available with measurements of the **BOD_5** effluent concentration than for the before presented NH_4-N concentration. The median BOD_5 effluent concentrations of 1'980 small WWTPs are analyzed in the following part and the summary of the statistical analysis is presented in Table 10.

Table 10: Statistical information about the BOD_5 effluent concentrations with median values of individual WWTPs

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	492	252	540	52	491	85	36	25	7	1980
Median [mg/l]	**5**	**3**	**5**	**3**	**3**	**8**	**7**	**4**	**6**	**4**
Mean [mg/l]	6	4	6	4	4	8	8	5	6	6
Standard dev. [mg/l]	11	2	4	2	2	4	5	3	2	6
Lower quartile [mg/l]	4	3	4	3	3	6	5	3	4	3
Upper quartile [mg/l]	7	4	8	5	4	11	11	5	7	6
Maximum value [mg/l]	242	24	33	12	15	21	18	13	9	242
Minimum value [mg/l]	2	2	2	1	2	3	2	3	4	1
85 percentile [mg/l]	9	5	10	7	5	12	14	7	7	8
95 percentile [mg/l]	12	8	12	10	7	15	17	11	8	12
medians above threshold	1	0	1	0	0	0	0	0	0	2
[%]	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1

The median values of the different technologies calculated with the median values of the individual treatment plants is the same than in the analysis with all values. If the mean values are considered, it can be seen that they are lower for all technologies except MBRs, where it remains the same than with all values. The same accounts for the upper quartile. The calculated percentiles are all lower than in the analysis with all values.

There are some treatment plants with a median value which is higher than the threshold. Only two treatment plants show median values above the BSB_5 threshold of 25 mg/l. One of these WWTPs is the **SBR** treatment plant mentioned before where only one year of measurement is available, and all parameters are above the respective threshold. The second treatment plant is a **CAS** plant which was built in 2005 and eight different measurements between 2010 and 2017 are available. In 2014 there are two different measurements available. The first measurement took place in February and all parameters where too high. At the second measurement in August all parameters where below the respective threshold value. Nevertheless, the highest BOD_5 value measured at this treatment plant is 120 mg/l and five out of eight measurements exceed the threshold. It can be concluded that this particular treatment plant is not able to meet the requirements according BOD_5.

The violin plots in Figure 16 reveal that the density shape is, compared to the ones with all values, mostly the same. The outlier values are again missing and the shape of the MBR violin plot has changed. In the analysis with all values there was a notable bump around the lower quartile, which is now almost completely missing. The underlying boxplots clarify that for most technologies the upper and lower quartiles are closer together and therefore more values are accumulated in this area. All upper quartiles are significantly below the threshold value.

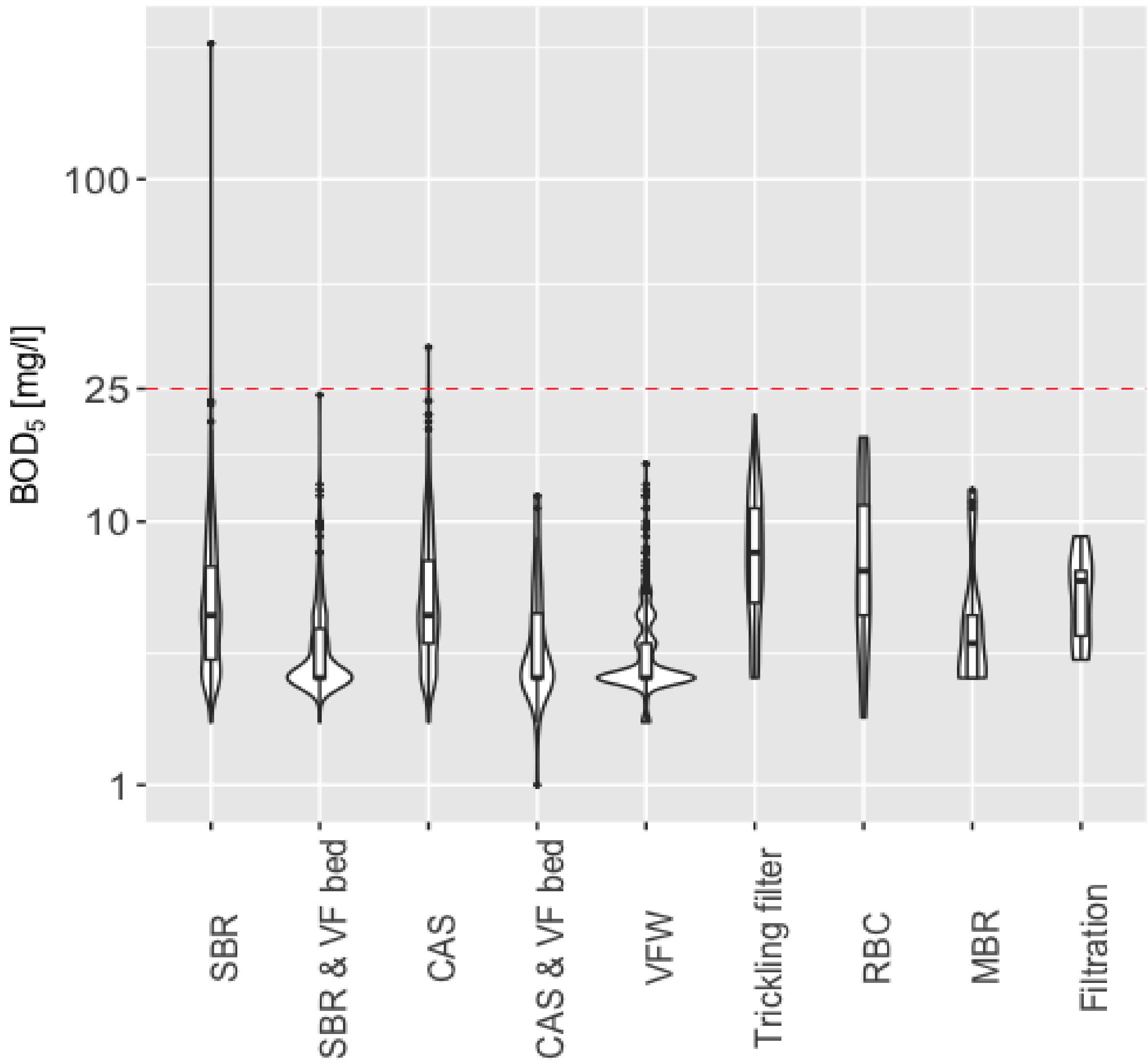

Figure 16: Violin plots of BOD_5 effluent concentrations with median values of individual WWTPs

The median **COD** effluent concentrations of 1’980 small WWTPs are used to calculate the statistical parameters listed in Table 11.

Table 11: Statistical information about the COD effluent concentrations with median values of individual WWTPs

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	492	252	540	52	491	85	36	25	7	1980
Median [mg/l]	**37**	**24**	**36**	**24**	**21**	**43**	**43**	**28**	**32**	**30**
Mean [mg/l]	41	27	38	26	23	45	44	32	31	34
Standard dev. [mg/l]	32	12	14	10	10	16	15	12	8	21
Lower quartile [mg/l]	29	18	28	18	16	34	32	24	28	22
Upper quartile [mg/l]	50	31	46	30	27	54	54	38	36	41
Maximum value [mg/l]	670	76	129	62	82	88	74	61	42	670
Minimum value [mg/l]	12	12	10	13	7	13	19	15	18	7
85 percentile [mg/l]	57	37	53	35	31	63	59	44	37	50
95 percentile [mg/l]	69	51	64	46	41	73	73	56	40	63
medians above threshold	2	0	2	0	0	0	0	0	0	4
[%]	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2

The median values are compared to the analysis with all values not significantly different. SBR, SBR & VF bed, CAS & VF bed, VFW and RBC treatment plants show the same median value. The CAS median value is with 36 mg/l higher than with all measurements (35 mg/l) as well as the MBR median value with 28 mg/l compared to 27 mg/l in the calculation before. The median value of trickling filter and soil filter is by 1 mg/l lower than with all measurements. Calculated means are lower for all technologies except MBR plants where it is with 32 mg/l by 1 mg/l higher. The interquartile ranges are smaller for all technologies.

In total four median values above the threshold occur in four treatment plants in two different technologies (SBR and CAS). Additional to the above mentioned **SBR** treatment plant with values above the threshold of 90 mg/l there is a second one. This treatment plant was built in 2017 and due to that only one measurement is available. The measured COD value is 113 mg/l, however, the other parameters are below the respective threshold.

There are two **CAS** treatment plants with median values above the threshold, which equals 0.37% of all CAS plants. For one of these plants two measurements are available in 2014 and 2015, at this time the treatment plant is 14 and 15 years old. The COD values are 81 and 177 and the other parameters are below the particular limit value. The other treatment plant (identification number: 41423213) with a COD median above 90 mg/l was built in 2007. There is one measurement, which took place between 2012 and 2014, where no measurement date is available, and the only recorded parameter is COD (149 mg/l). However, this is not an outlier value in the measurements of this treatment plant. Five out of nine values are higher than the threshold value and the highest is 195 mg/l. Neither a BOD_5 nor a NH_4-N measurement exceeds the respective threshold. It has to be assumed that this particular treatment plant is not able to comply with the legal requirements regarding COD.

The density shapes illustrated in the violin plots in Figure 17 are now with almost no outlier values compared to the analysis with all values. On the first sight the shape of the technology filtration changed the most, this should not be overrated because only 7 values took place in this analysis and the density around the median value remains the highest.

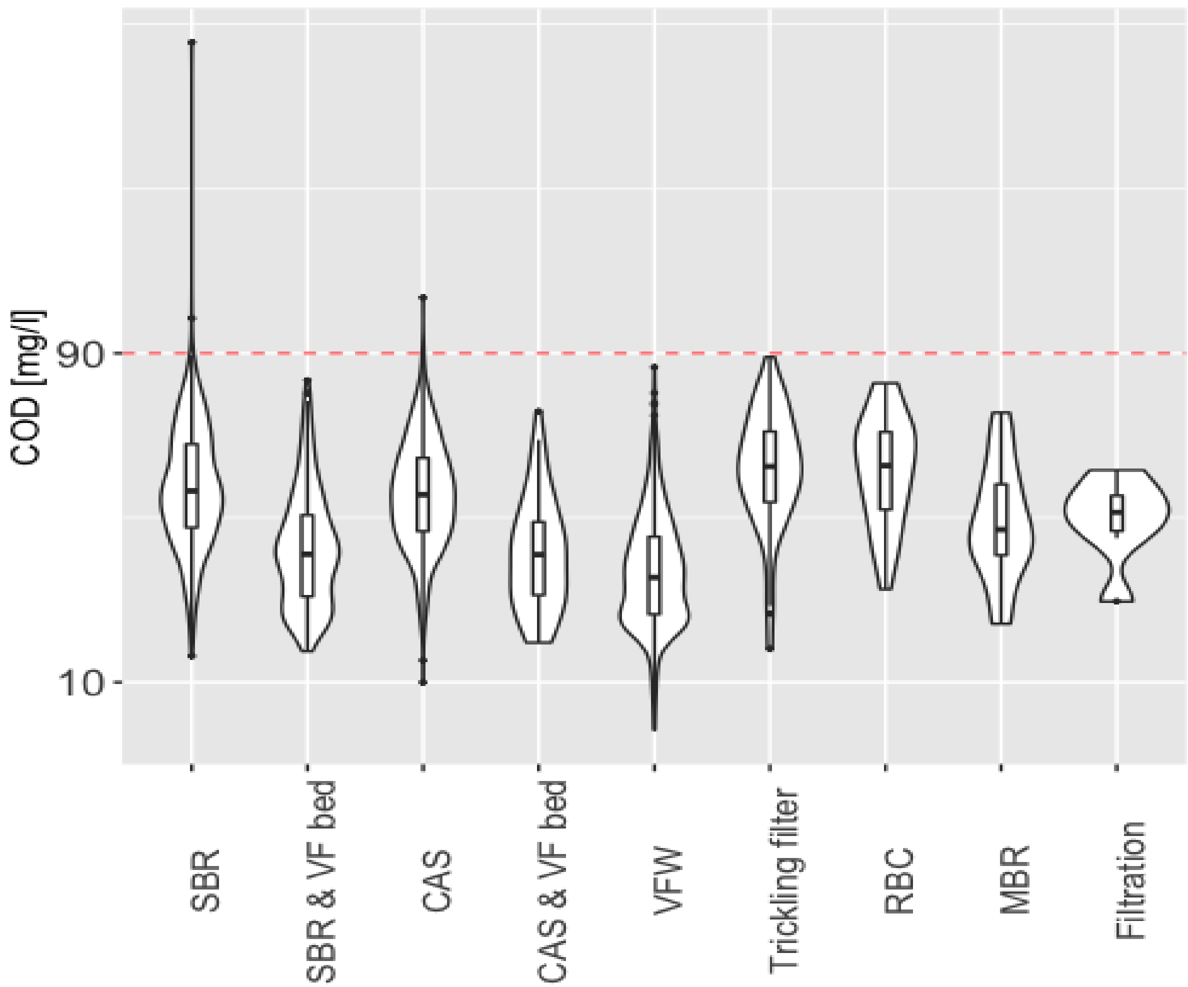

Figure 17: Violin plots of COD effluent concentrations with median values of individual WWTPs

5.2.3 Analysis with individual WWTPs with more than five measurements

To handle the problem with treatment plants where only a few measurements are available, an analysis with median effluent concentrations of WWTPs where more than five measurements are available is conducted. This is done to reduce the impact of outlies even more. It can be seen on the first sight that the number of treatment plants in the analysis is notably reduced.

The results of the statistical calculations are listed in Table 12. **NH_4-N** effluent concentration measurements of 1’443 small WWTPs are observed in this part of the analysis.

Table 12: Statistical information about the NH_4-N effluent concentrations with median values of individual WWTPs with more than five measurements

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	339	148	467	44	317	73	30	19	6	1443
Median [mg/l]	**1.00**	**0.88**	**1.17**	**0.22**	**0.35**	**2.25**	**1.16**	**2.00**	**3.37**	**1.00**
Mean [mg/l]	1.52	0.84	1.90	1.12	0.81	3.38	2.21	2.17	4.20	1.53
Standard dev. [mg/l]	1.77	0.79	2.02	2.07	1.25	3.08	2.38	2.06	4.32	1.93
Lower quartile [mg/l]	0.30	0.24	0.57	0.07	0.10	0.59	0.64	1.00	1.55	0.27
Upper quartile [mg/l]	2.00	1.00	2.49	1.00	1.00	6.60	2.57	2.56	4.65	2.00
Maximum value [mg/l]	9.30	5.60	17.00	8.69	9.50	9.48	8.10	9.67	12.25	17.00
Minimum value [mg/l]	0.05	0.03	0.05	0.02	0.01	0.03	0.20	0.24	0.20	0.01
85 percentile [mg/l]	3.01	1.00	3.69	1.64	1.22	7.70	3.24	3.01	6.83	2.93
95 percentile [mg/l]	5.51	2.07	6.40	6.76	2.84	8.73	7.79	4.33	10.44	6.13
medians above threshold	0	0	1	0	0	0	0	0	1	2
[%]	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	16.7	0.1

Compared to the analysis in chapter 5.2.2 the SBR, CAS and RBC median value is exactly the same. The median value of all technologies is with 1.0 mg/l also the same than if all median values of the WWTPs are considered. The median value of the SBR treatment plants with a VF bed is 0.04 mg/l higher and therefore the highest median value of this technology of all three parts of the analysis. CAS treatment plants with a VF bed show a median value which is 0.10 mg/l higher than if all WWTPs are considered. This could indicate that there are a lot of newly implemented treatment plants with less than five measurements with low measurement values. There are eight CAS treatment plants with a VF bed not included in the analysis because they cannot provide more than five measurements. All of them were built in the years 2013, 2014 and 2015. SBR treatment plants with downstream planted soil filters have 104 treatment plants with less or equal to five measurements, 90 of them where built between 2013 and 2017. The median value for VF wetlands and trickling filters with more than five measurements is lower than with all WWTPs considered, for MBR and Filtration it is the other way around.

It can be seen that there are only two treatment plants (0.1%) which cannot meet the threshold value compared to nine, when all WWTPs are considered. This clarifies that in the long term all technologies are able to comply with the threshold level and that the median values above the threshold are mostly extreme values which do not represent the overall treatment performance.

In Figure 18 the violin plots illustrate that there are only two technologies with a small WWTP which exceeds the threshold value, CAS and filtration. However, it is in each case only a single treatment plant and therefore not representative for the treatment performance of the technology. A change in the density shape cannot be seen compared to the analysis with median values of all individual small WWTPs.

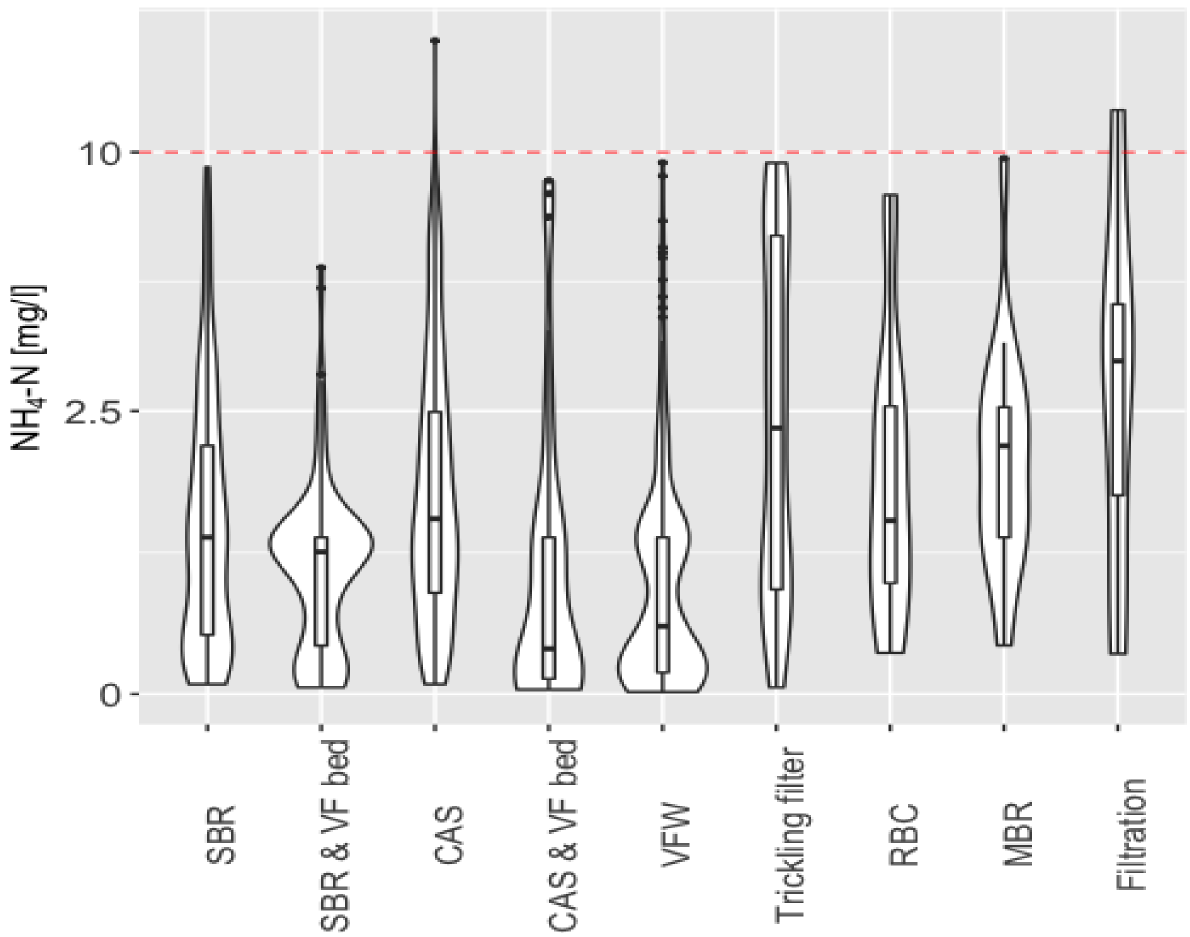

Figure 18: Violin plots of NH_4-N effluent concentrations with median values of individual WWTPs with more than five measurements

For the analysis with the **BOD_5** effluent there are five more treatment plants available for the analysis. The calculated statistical parameters are listed in Table 13.

Table 13: Statistical information about the BOD_5 effluent concentrations with median values of individual WWTPs with more than five measurements

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	339	148	468	44	321	73	30	19	6	1448
Median [mg/l]	**5**	**3**	**5**	**3**	**3**	**8**	**7**	**4**	**7**	**4**
Mean [mg/l]	6	4	6	4	4	8	9	5	6	5
Standard dev. [mg/l]	3	2	3	2	2	4	5	3	2	3
Lower quartile [mg/l]	4	3	4	3	3	6	5	3	5	3
Upper quartile [mg/l]	7	4	7	5	4	10	14	5	7	6
Maximum value [mg/l]	23	12	33	12	15	17	18	13	9	33
Minimum value [mg/l]	2	2	2	1	2	3	2	3	4	1
85 percentile [mg/l]	9	5	9	7	5	12	15	6	8	8
95 percentile [mg/l]	12	6	12	9	7	14	17	12	8	12
medians above threshold	0	0	1	0	0	0	0	0	0	1
[%]	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1

A change in the calculated median value can only be found in filtration treatment plants, where the median value is 7 mg/l and therefore 1 mg/l higher than in the analysis before. One treatment plant less is included in this part of the analysis because there are only two different measurements available. The measurements took place in 2017 and 2018. It is unclear why in the other years no data is available since the plant was already built in 1990. A median value of 4.5 mg/l in the data of this particular plant is responsible for the lower values before. This treatment plant is the oldest of all filtration treatment plants is still able to comply with the threshold values.

The number of WWTPs with a median value above the threshold limit is reduced to the one single CAS treatment plant which is already described above in the second part of the treatment performance analysis.

In the violin plots in Figure 19 it can be seen that the density shapes do not change compared to the analysis with all individual WWTPs. SBR and CAS treatment plants with a VF bed as well as VFWs have a median value which equals the lower quartile. In the density shapes of SBRs with a VF bed and VFWs a clear bump in the density shape can be found in this area, which means an accumulation of values there.

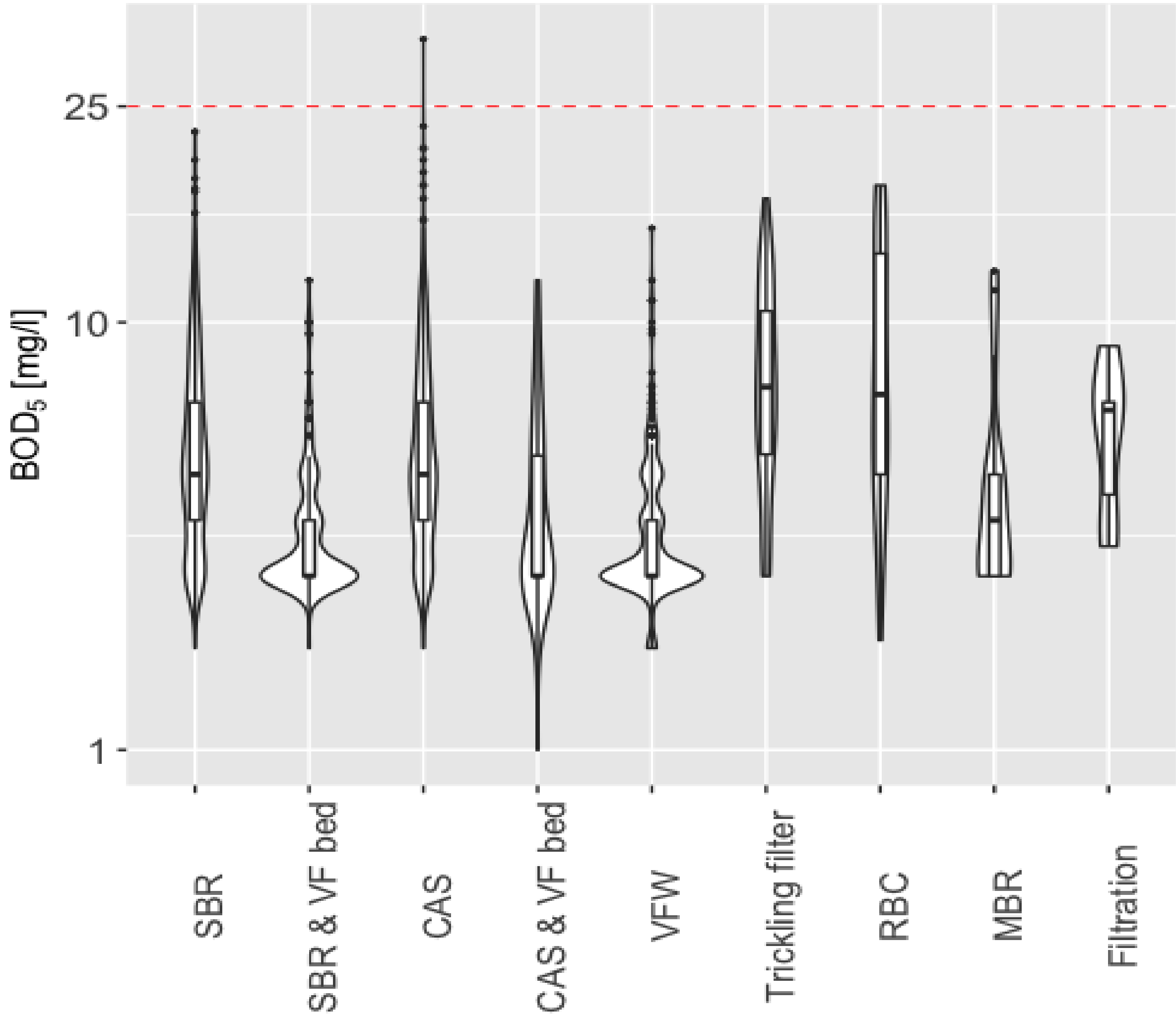

Figure 19: Violin plots of BOD_5 effluent concentrations with median values of individual WWTPs with more than five measurements

Table 14 shows the results of the statistical analysis with COD effluent concentrations. The median values of treatment plants with VF beds and VFWs are between 20 mg/l and 25 mg/l, the highest median value can be seen in RBC treatment plants with 46 mg/l.

Table 14: Statistical information about the COD effluent concentrations with median values of individual WWTPs with more than five measurements

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Number of WWTPs	339	148	468	44	321	73	30	19	6	1448
Median [mg/l]	**36**	**23**	**35**	**25**	**20**	**43**	**46**	**26**	**32**	**30**
Mean [mg/l]	39	25	37	26	22	44	45	30	31	33
Standard dev. [mg/l]	14	10	12	11	9	15	15	11	9	14
Lower quartile [mg/l]	29	18	28	18	16	34	33	23	27	23
Upper quartile [mg/l]	49	29	44	31	26	54	54	36	36	41
Maximum value [mg/l]	85	64	92	62	70	78	74	57	42	92
Minimum value [mg/l]	15	12	10	13	9	13	19	15	18	9
85 percentile [mg/l]	55	34	51	36	30	63	59	38	38	49
95 percentile [mg/l]	65	44	61	46	39	71	73	52	41	62
medians above threshold	0	0	1	0	0	0	0	0	0	1
[%]	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1

The CAS treatment plant with the identification number 41423213 is exceeding the threshold level. It is again the same treatment plant than described above, however the value is with 92 mg/l only slightly above the threshold. The lowest median values and quartiles can be found in the same technologies than before.

The results of the analysis with COD effluent concentrations are illustrated in the violin plots in Figure 20.

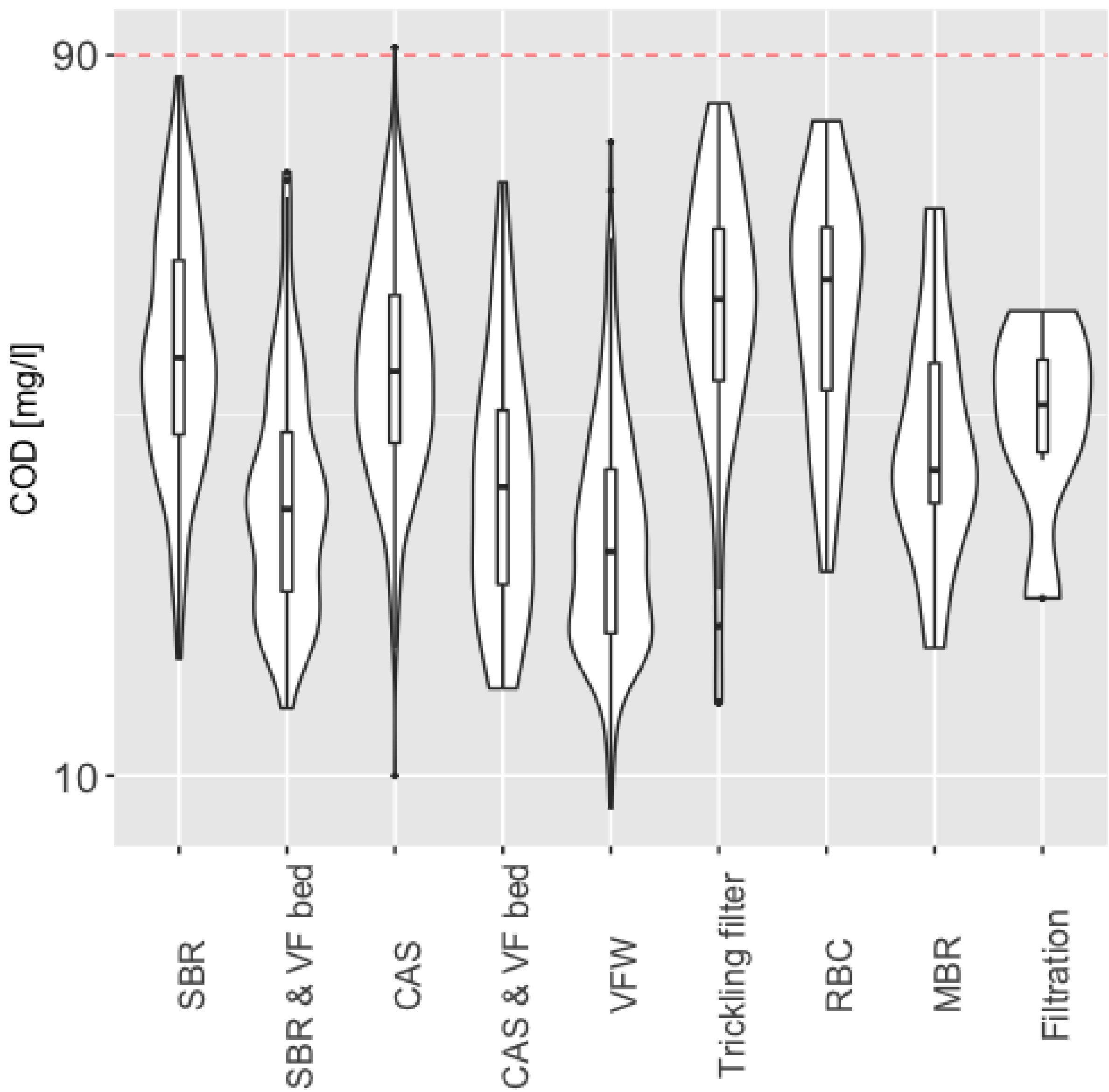

Figure 20: Violin plots of COD effluent concentrations with median values of individual WWTPs with more than five measurements

It can be seen that there is for BOD_5, COD and for NH_4-N one treatment plant that shows a median value above the threshold. Here it has to be mentioned that it is another treatment plant in each case, and it cannot be concluded that there is one small WWTP which does not treat the wastewater properly. Overall the treatment plants comply with the respective threshold values.

5.2.4 Comparison of analysis methods

In Table 15 an overview of the three different analysis methods using the NH_4-N effluent concentrations is presented. It includes the median values, the mean values as well as the standard deviations and the number of values above the threshold value. The last column, including all values, shows that the median value, which is robust against outliers, does not change a lot. Differences can be seen in the mean value as well as in the standard deviation, which are both lowest in the analysis using median values of individual WWTPs with more than five measurements.

Table 15: Comparison of the different analysis methods for NH_4-N effluent concentrations

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Using all measurements										
Number of WWTPs	493	252	539	52	486	85	36	25	7	1975
Number of values	3347	1566	4382	418	3178	689	282	184	54	14100
Median [mg/l]	**1.00**	**0.68**	**1.09**	**0.24**	**0.37**	**2.20**	**1.20**	**1.78**	**2.66**	**0.98**
Mean [mg/l]	2.43	1.14	2.95	1.54	1.43	4.21	3.48	2.52	4.23	2.31
Standard dev. [mg/l]	5.08	2.35	5.85	4.19	2.91	6.18	6.17	3.99	4.69	4.84
values above threshold	72	13	137	9	48	42	17	6	6	350
[%]	2.2	0.8	3.1	2.2	1.5	6.1	6.0	3.2	11.1	2.5
Using median values of individual WWTPs										
Number of WWTPs	493	252	539	52	486	85	36	25	7	1975
Median [mg/l]	**1.00**	**0.84**	**1.17**	**0.12**	**0.47**	**2.60**	**1.16**	**1.36**	**3.21**	**1.00**
Mean [mg/l]	1.86	0.76	1.88	0.98	0.99	3.63	2.37	1.89	3.74	1.58
Standard dev. [mg/l]	6.43	0.71	2.02	1.94	1.54	3.48	2.63	1.88	4.12	3.65
values above threshold	2	0	1	0	3	2	0	0	1	9
[%]	0.4	0.0	0.2	0.0	0.6	2.4	0.0	0.0	14.3	0.5
Using median values of individual WWTPs with more than five measurements										
Number of WWTPs	339	148	467	44	317	73	30	19	6	1443
Median [mg/l]	**1.00**	**0.88**	**1.17**	**0.22**	**0.35**	**2.25**	**1.16**	**2.00**	**3.37**	**1.00**
Mean [mg/l]	1.52	0.84	1.90	1.12	0.81	3.38	2.21	2.17	4.20	1.53
Standard dev. [mg/l]	1.77	0.79	2.02	2.07	1.25	3.08	2.38	2.06	4.32	1.93
values above threshold	0	0	1	0	0	0	0	0	1	2
[%]	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	16.7	0.1

A comparison of the three different applied analysis methods for BOD_5 effluent concentrations is shown in Table 16. There is almost no difference between the median values calculated in the three analysis methods, the only exception are filtration treatment plants. However, the amount of treatment plants is limited.

Table 16: Comparison of the different analysis methods for BOD_5 effluent concentrations

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Using all measurements										
Number of WWTPs	493	252	540	52	491	85	36	25	7	1981
Number of values	3358	1563	4402	422	3223	700	279	185	54	14186
Median [mg/l]	**5**	**3**	**5**	**3**	**3**	**8**	**7**	**4**	**6**	**5**
Mean [mg/l]	7	5	7	5	5	9	9	5	8	6
Standard dev. [mg/l]	7	3	8	4	3	6	7	5	5	7
values above threshold	27	3	55	3	4	6	5	1	0	104
[%]	0.8	0.2	1.3	0.7	0.1	0.9	1.8	0.5	0.0	0.7
Using median values of individual WWTPs										
Number of WWTPs	492	252	540	52	491	85	36	25	7	1980
Median [mg/l]	**5**	**3**	**5**	**3**	**3**	**8**	**7**	**4**	**6**	**4**
Mean [mg/l]	6	4	6	4	4	8	8	5	6	6
Standard dev. [mg/l]	11	2	4	2	2	4	5	3	2	6
values above threshold	1	0	1	0	0	0	0	0	0	2
[%]	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Using median values of individual WWTPs with more than five measurements										
Number of WWTPs	339	148	468	44	321	73	30	19	6	1448
Median [mg/l]	**5**	**3**	**5**	**3**	**3**	**8**	**7**	**4**	**7**	**4**
Mean [mg/l]	6	4	6	4	4	8	9	5	6	5
Standard dev. [mg/l]	3	2	3	2	2	4	5	3	2	3
values above threshold	0	0	1	0	0	0	0	0	0	1
[%]	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1

In Table 17 a comparison of the different methods, to analyse the treatment performance for COD effluent concentrations, is shown. The values above the threshold are reduced from 128 in the analysis using all measurements to 2 in the analysis using the median values of individual WWTPs with more than five measurements. A very high standard deviation can be seen in the analysis using all measurement values for CAS & VF bed treatment plants with 249 mg/l. This is due to an extreme outlier value which is then excluded in the other analysis methods. This example shows that the median value is not influenced by this value, however, the mean value (changes from 40 mg/l to 26 mg/l) as well as the standard deviation are.

Table 17: Comparison of the different analysis methods for COD effluent concentrations

	SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
Using all measurements										
Number of WWTPs	493	252	540	52	491	85	36	25	7	1981
Number of values	3365	1568	4406	422	3233	703	283	185	54	14219
Median [mg/l]	**37**	**24**	**35**	**24**	**21**	**44**	**43**	**27**	**33**	**31**
Mean [mg/l]	42	28	41	40	25	47	47	31	34	36
Standard dev. [mg/l]	25	16	38	249	14	22	21	15	14	51
values above threshold	48	7	53	1	4	11	4	0	0	128
[%]	1.4	0.5	1.2	0.2	0.1	1.6	1.4	0.0	0.0	0.9
Using median values of individual WWTPs										
Number of WWTPs	492	252	540	52	491	85	36	25	7	1980
Median [mg/l]	**37**	**24**	**36**	**24**	**21**	**43**	**43**	**28**	**32**	**30**
Mean [mg/l]	41	27	38	26	23	45	44	32	31	34
Standard dev. [mg/l]	32	12	14	10	10	16	15	12	8	21
values above threshold	2	0	2	0	0	0	0	0	0	4
[%]	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Using median values of individual WWTPs with more than five measurements										
Number of WWTPs	339	148	468	44	321	73	30	19	6	1448
Median [mg/l]	**36**	**23**	**35**	**25**	**20**	**43**	**46**	**26**	**32**	**30**
Mean [mg/l]	39	25	37	26	22	44	45	30	31	33
Standard dev. [mg/l]	14	10	12	11	9	15	15	11	9	14
values above threshold	0	0	1	0	0	0	0	0	0	2
[%]	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.1

On the first sight the results of all three methods are in the same range. However, most outlier values with an influence on the mean values as well as on the standard deviation are included in the first analysis (using all measurements). Therefore, also most values above the threshold occur in this part and logically the lowest amount occurs in the third analysis method (using median values of individual WWTPs with more than five measurements).

All three methods have different advantages and disadvantages. The first applied method, using all values, shows the results independent of the individual WWTPs and most individual values are used in the statistical analysis. However, the influence of the outlier values cannot be denied. Using only the median values of individual WWTPs in the analysis has the advantage that some outlier values are excluded, and the measurement values of newly implemented treatment plants remain in the analysis. On the other hand, individual measurements of plants with only a few measurements may distort the result. The analysis method using median values of individual WWTPs with more than five measurements is the most reliable regarding the exclusion of outlier values. However, newly implemented treatment plants are excluded as well.

5.3 Treatment performance over the operation time

To analyse the possibility of increasing or decreasing measurement values and therefore an improving or deteriorating treatment performance over the lifetime of the WWTPs, an evaluation with all available values is conducted. In the following tables the number of measurement values (No.) for every year after the commissioning (Years) of the respective small WWTP as well as the median value (Med.) of all these measurements can be seen.

The oldest treatment plant with measurement values in Upper Austria is a trickling filter with 29 years. In the past few years only a minor amount of plants with this technology were built and therefore not a lot of values are available of young treatment plants. Most trickling filters in Upper Austria are between 10 and 25 years old. By contrast, the number of newly licensed SBR plants, with as well as without a VF bed, was high over the past few years. This also applies to VFWs where most measurements are available of treatment plants younger than 10 years. CAS treatment plants, with or without a VF bed, are also rather young as well as MBR plants. In contrast RBC and filtration treatment plants are older.

In the following figures only years with more than five available measurement values are taken into account to reduce the impact of outlier values. However, for an overview the values are still listed in the tables. Especially for filtration treatment plants a conclusive analysis is not possible because not enough measurements per year are available and therefore, they are not illustrated in the following figures. The other technologies can at least provide nine years with more than five values and are represented in the figures.

In Table 18 the median **NH_4-N** effluent concentrations for every technology depending on the operation time of the small WWTPs are shown. The values marked with a * are not considered in the following figures.

Table 18: Median NH_4-N effluent concentrations over the lifetime of WWTPs (median values in bold are used in the following figures)

Years	SBR		SBR & VF bed		CAS		CAS & VF bed		VFW		Trickling filter		RBC		MBR		Filtration	
	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.
0	348	**1.00**	226	**0.53**	99	**0.85**	16	**0.08**	392	**1.00**	3	2.00*	2	2.77*	15	**1.23**	-	-
1	343	**0.80**	191	**0.38**	136	**1.16**	28	**0.11**	333	**0.47**	2	1.50*	5	2.20*	16	**1.47**	-	-
2	343	**0.79**	179	**0.38**	195	**1.04**	28	**0.05**	344	**0.38**	4	2.31*	8	**1.98**	21	**1.02**	-	-
3	334	**0.96**	177	**0.47**	236	**1.22**	35	**0.07**	322	**0.39**	4	4.35*	9	**2.60**	23	**2.08**	-	-
4	334	**1.00**	152	**0.58**	261	**1.10**	33	**0.17**	280	**0.50**	5	1.15*	9	**1.47**	18	**1.58**	1	0.19*
5	308	**1.00**	153	**0.54**	302	**1.10**	30	**0.10**	253	**0.30**	4	1.54*	13	**2.15**	19	**2.00**	1	0.53*
6	296	**1.00**	129	**1.00**	324	**1.06**	32	**0.24**	209	**0.29**	8	**1.74**	13	**2.40**	14	**2.00**	1	0.12*
7	241	**1.00**	107	**1.00**	342	**1.19**	26	**0.20**	174	**0.20**	5	1.08*	17	**2.10**	18	**2.00**	1	0.66*
8	198	**1.00**	86	**1.00**	338	**1.34**	28	**0.70**	156	**0.16**	8	**1.64**	20	**1.77**	11	**1.00**	2	7.10*
9	141	**1.00**	60	**1.00**	349	**1.00**	27	**0.78**	124	**0.20**	9	**2.80**	19	**0.82**	9	**2.41**	2	6.25*
10	98	**1.00**	26	**1.00**	327	**1.00**	23	**1.00**	95	**0.20**	10	**0.63**	21	**0.40**	2	2.60*	2	5.28*
11	62	**0.90**	12	**1.00**	297	**1.10**	20	**0.55**	75	**0.20**	19	**1.69**	21	**1.10**	-	-	2	6.20*
12	51	**0.72**	9	**1.00**	281	**1.40**	24	**1.03**	67	**0.17**	16	**1.55**	19	**1.30**	-	-	3	1.00*
13	44	**0.85**	8	**0.86**	217	**1.00**	15	**0.94**	67	**0.20**	29	**2.13**	21	**1.16**	-	-	3	1.00*
14	32	**0.80**	7	**1.00**	197	**1.17**	15	**1.00**	52	**0.30**	32	**1.18**	20	**1.24**	1	0.90*	1	0.52*
15	29	**0.61**	4	2.76*	139	**1.00**	9	**1.09**	46	**0.14**	35	**2.87**	15	**0.40**	1	2.70*	2	4.92*
16	27	**0.30**	6	**1.09**	105	**1.00**	7	**0.24**	35	**0.25**	50	**1.92**	11	**0.90**	1	4.60*	2	3.75*
17	22	**0.17**	6	**0.57**	71	**1.00**	6	**1.28**	31	**0.20**	56	**2.30**	8	**1.76**	2	15.95*	3	0.15*
18	22	**0.31**	6	**0.53**	55	**0.90**	7	**0.65**	29	**0.20**	64	**2.45**	6	**1.31**	2	20.06*	3	6.40*
19	20	**1.00**	4	0.50*	45	**1.74**	3	1.42*	22	**0.30**	67	**3.50**	8	**3.99**	1	7.85*	5	2.86*
20	16	**1.12**	5	0.20*	22	**1.50**	2	2.21*	20	**0.86**	57	**1.21**	10	**1.22**	2	5.59*	3	1.74*
21	13	**0.50**	3	1.00*	17	**0.90**	1	27.30*	15	**0.30**	50	**3.55**	4	2.65*	2	4.40*	4	2.19*
22	10	**1.99**	3	1.00*	9	**4.20**	1	25.10*	12	**1.01**	45	**2.25**	2	6.38*	1	0.14*	5	5.45*
23	5	0.90*	2	0.30*	6	**0.90**	-	-	5	0.47*	42	**1.82**	1	8.90*	1	18.50*	2	5.00*
24	5	0.84*	2	0.40*	5	0.30*	-	-	7	**0.77**	24	**2.60**	-	-	-	-	2	5.00*
25	3	2.83*	2	0.65*	2	1.24*	-	-	6	**0.17**	22	**5.93**	-	-	1	0.06*	3	3.55*
26	3	1.00*	-	-	1	2.10*	-	-	4	0.67*	9	**4.91**	-	-	1	0.77*	1	3.41*
27	-	-	-	-	1	1.90*	-	-	-	-	5	1.36*	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	3	4.79*	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	1	0.10*	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Figure 21 shows the median NH_4-N concentrations on the y-axis and the years of operation on the x-Axis of various technologies. In the year of commissioning CAS treatment plants have the lowest median value with 0.85 mg/l, slightly above that SBR plants and VFWs can be found with 1.00 mg/l.

The median values of VFWs are constantly decreasing over the first eight years and then remain more or less on the level of about 0.20 mg/l, only in the last years fluctuations can be seen. This may be caused by lower amount of available measurement values.

SBR and CAS plants show median values around 1.00 mg/l. Trickling filters, RBC and MBR plants have in general less measurement values available and there are more years which are not included in the figure because of that. The median values of this technologies are higher in most years of operation and higher fluctuations in the following years are occurring even for younger treatment plants.

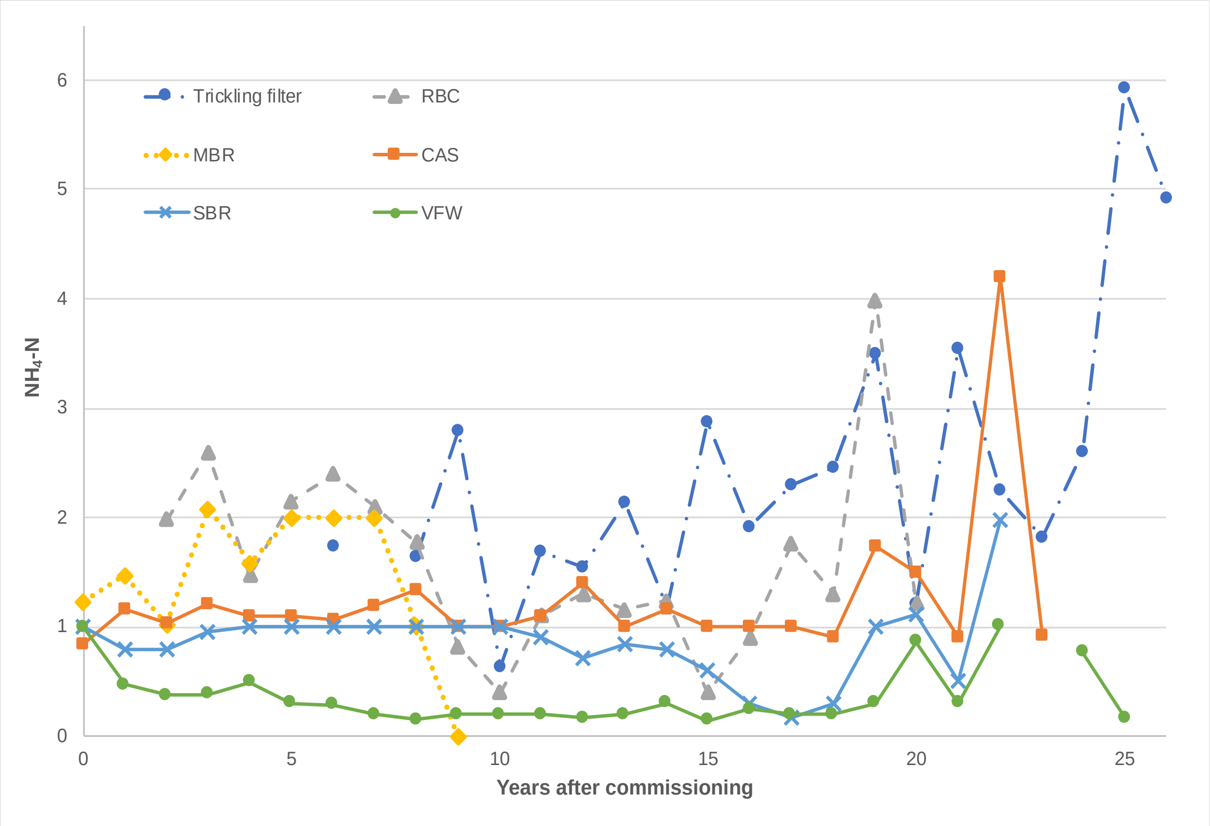

Figure 21: Median NH_4-N effluent concentrations in mg/l of treatment plants depending on the age of the WWTPs

In Figure 22 treatment plants with a VF bed as well as CAS and SBR plants are illustrated. It shows that in the year of the commissioning of the treatment plants all median effluent concentrations are at 1.00 mg/l of below that.

CAS treatment plants with a VF bed have the lowest median values in the first six years and they remain quite constant over this time. In the seventh year of operation the median effluent concentration is with 0.20 mg/l exactly the same than the one of VFWs in this year after commissioning of the treatment plants. After that the median value increased to 1.00 mg/l in the tenth year and then shows quite high fluctuations in the following years.

Technologies with a VF bed show in the first years a lower median effluent concentration than treatment plants without a VF bed. After then years the median effluent concentrations of treatment plants with a VF bed sometimes exceed the median values of the same technologies without a VF bed, but it has to be mentioned that the number of available measurements is comparably low and therefore the significance is limited.

In general, higher fluctuations to following years occur in technical treatment plants than in VFWs. This indicates that VFWs are robust regarding the process of nitrification.

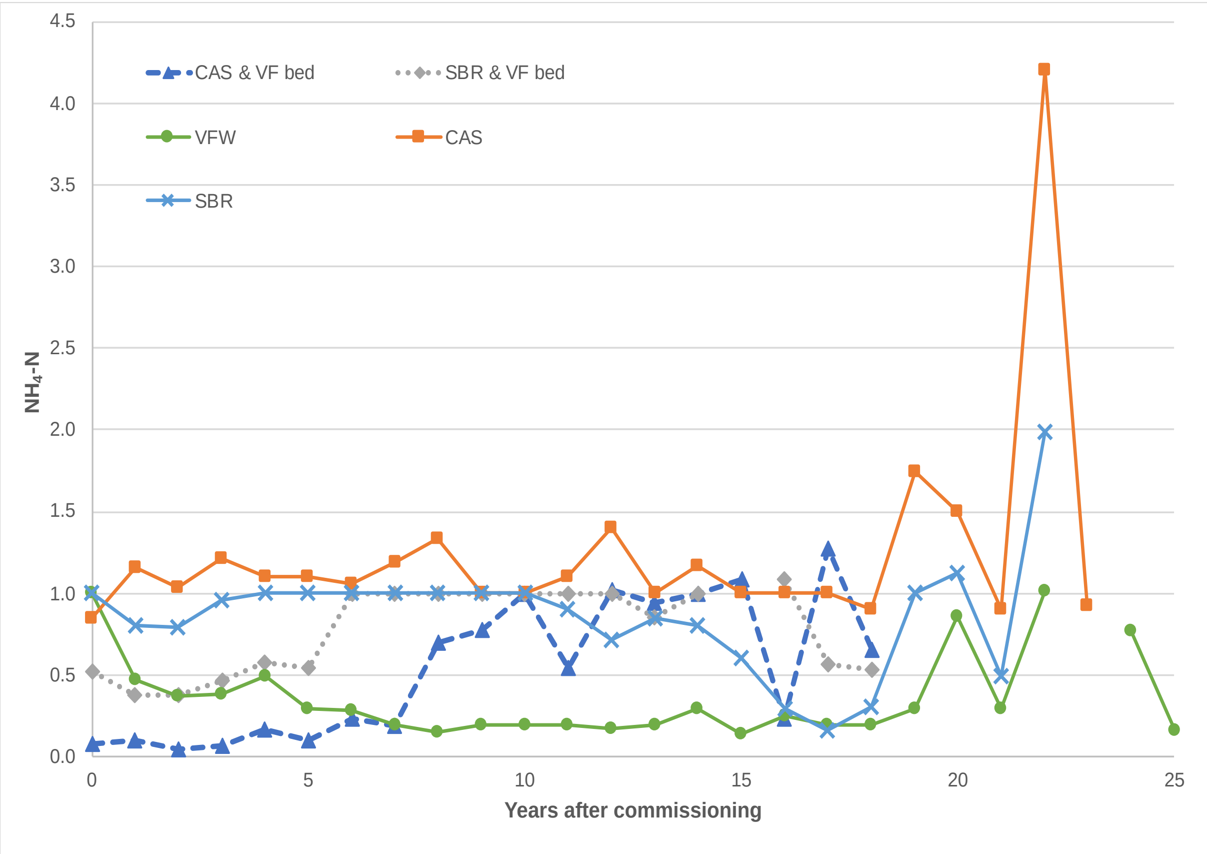

Figure 22: Median NH_4-N effluent concentrations in mg/l of WWTPs with VF beds depending on their age

The next analysed parameter is **BOD_5**. Like in the analysis of the treatment performance in chapter 5.2 slightly more measurements are available than for NH_4-N.

Table 19: Median BOD_5 effluent concentrations over the lifetime of WWTPs (median values in bold are used in the following figures)

Years	SBR		SBR & VF bed		CAS		CAS & VF bed		VFW		Trickling filter		RBC		MBR		Filtration	
	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.
0	350	**5**	227	**3**	99	**7**	16	**3**	393	**3**	5	3*	2	10*	15	**3**	-	-
1	344	**5**	190	**3**	138	**6**	28	**4**	336	**3**	3	3*	4	7*	17	**4**	-	-
2	347	**6**	177	**3**	196	**6**	28	**3**	347	**3**	4	4*	8	**4**	21	**4**	-	-
3	334	**5**	178	**3**	235	**6**	35	**3**	324	**3**	4	8*	9	**8**	23	**4**	-	-
4	336	**5**	151	**3**	264	**6**	33	**3**	284	**3**	5	7*	10	**7**	18	**4**	1	8*
5	309	**5**	153	**3**	302	**5**	30	**3**	258	**3**	4	8*	13	**5**	19	**3**	1	5*
6	296	**5**	129	**3**	325	**5**	32	**3**	213	**3**	8	**6**	13	**5**	14	**4**	1	6*
7	243	**5**	107	**3**	341	**5**	27	**3**	178	**3**	5	8*	16	**10**	18	**3**	1	20*
8	199	**5**	86	**3**	339	**5**	30	**3**	160	**3**	8	**8**	19	**7**	11	**3**	2	7*
9	141	**5**	60	**3**	350	**5**	27	**4**	127	**3**	8	**6**	19	**6**	9	**5**	2	6*
10	98	**6**	26	**3**	327	**5**	23	**3**	98	**3**	10	**6**	20	**8**	2	4*	2	5*
11	62	**6**	12	**3**	299	**5**	20	**5**	75	**4**	19	**10**	21	**8**	-	-	2	5*
12	51	**6**	9	**3**	281	**5**	23	**5**	67	**4**	17	**8**	19	**6**	-	-	3	4*
13	44	**6**	8	**5**	217	**5**	16	**4**	67	**5**	28	**9**	21	**7**	-	-	3	6*
14	32	**6**	7	**4**	197	**5**	15	**5**	52	**4**	32	**9**	20	**9**	1	15*	1	6*
15	29	**5**	4	5*	139	**5**	9	**7**	44	**4**	35	**9**	15	**8**	1	20*	2	10*
16	28	**6**	6	**3**	106	**5**	8	**6**	35	**4**	50	**9**	11	**15**	1	13*	2	4*
17	23	**5**	6	**4**	73	**5**	6	**6**	31	**4**	56	**8**	8	**13**	2	17*	3	8*
18	22	**4**	6	**4**	56	**5**	7	**3**	30	**5**	65	**8**	6	**8**	2	11*	3	14*
19	19	**6**	4	4*	46	**6**	3	7*	22	**6**	69	**9**	8	**10**	1	13*	5	10*
20	15	**5**	6	**3**	24	**5**	2	7*	20	**5**	58	**6**	10	**8**	2	9*	3	9*
21	12	**5**	3	3*	18	**4**	1	15*	15	**5**	52	**9**	4	8*	2	10*	4	5*
22	9	**7**	3	4*	10	**5**	1	8*	12	**4**	46	**7**	2	12*	1	4*	5	3*
23	5	6*	2	8*	7	**8**	-	-	6	**4**	43	**9**	1	3*	1	18*	2	4*
24	5	4*	2	4*	6	**5**	-	-	7	**5**	25	**8**	-	-	-	-	2	5*
25	3	9*	2	5*	2	10*	-	-	6	**4**	22	**8**	-	-	1	6*	3	4*
26	3	14*	-	-	1	4*	-	-	4	5*	9	**4**	-	-	1	3*	1	7*
27	-	-	-	-	1	7*	-	-	-	-	5	5*	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	3	4*	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	1	7*	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

In Figure 23 the median effluent concentrations of various technologies over the operation time of the small WWTPs are illustrated. The highest fluctuations in the measurements of young treatment plants occur in RBC plants. Enough measurements are at first available in the third year of operation and the starting value is 4 mg/l. The highest median value can be seen in the 16th year after commissioning with 15 mg/l. it is also the highest overall median effluent concentration per year.

The development of the median values of VFWs, CAS and SBR treatment plants is quite constant at a low level between 3 mg/l and 6 mg/l. Only CAS treatment plants show a median value of 7 mg/l in the first year and 8 mg/l in the 24th year, however this should not be overrated because there are only seven measurements available. The same applies for last median value of SBR treatment plants with 7 mg/l and only nine measurements.

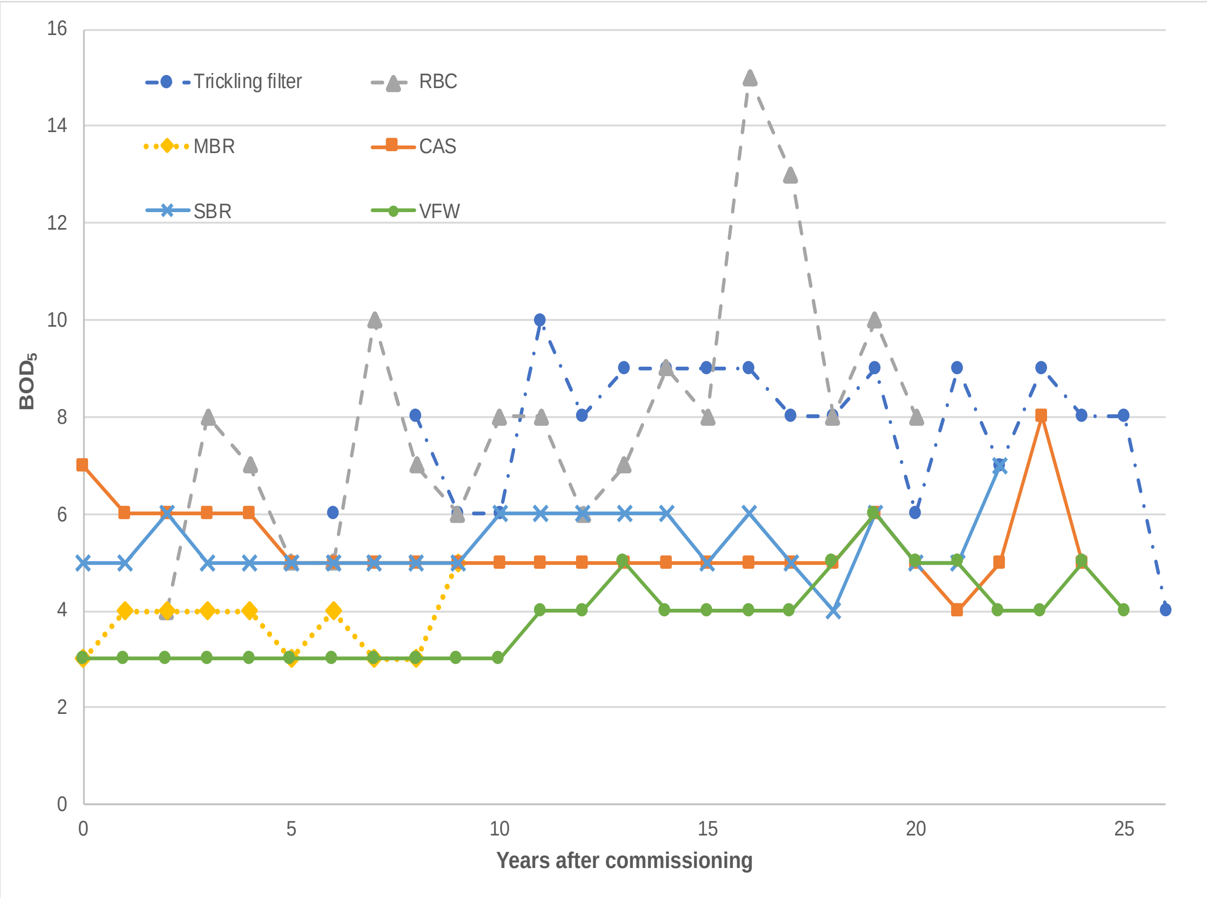

Figure 23: Median BOD_5 effluent concentrations in mg/l of WWTPs depending on their age

Median BOD_5 effluent concentrations of treatment plants with a VF bed as well as SBR and CAS plants are illustrated in Figure 24. The lowest median effluent concentrations occur like in the analysis before at treatment plants with VF beds. Higher fluctuations after ten years may be caused by the decreasing amount of available measurements.

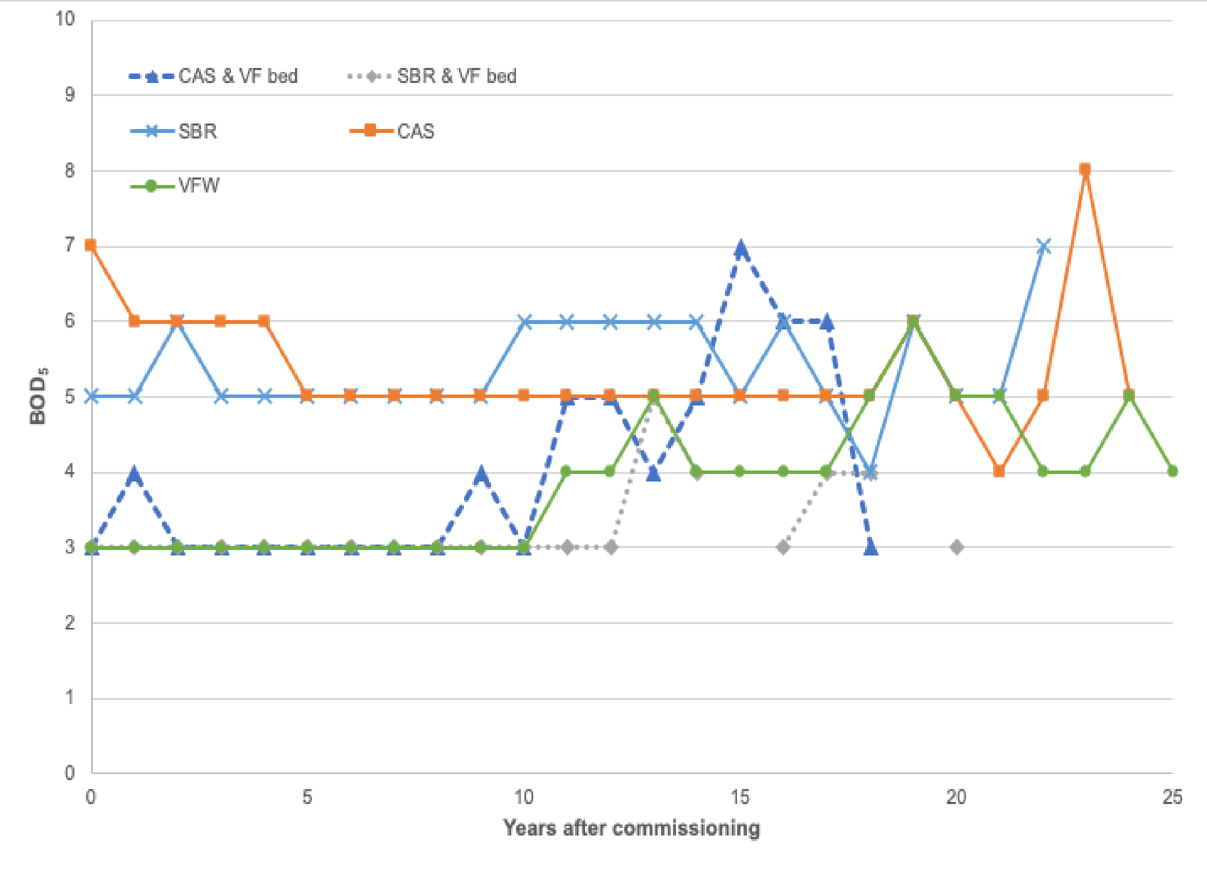

Figure 24: Median BOD_5 effluent concentrations of treatment plants with VF beds depending on the age of the WWTPs

To conclude the analysis of the treatment performance over the operation time of small WWTPs the median **COD** effluent concentrations of all technologies represented in Upper Austria are listed in Table 17.

Table 20: Median COD effluent concentrations over the lifetime of WWTPs (median values in bold are used in the following figures)

Years	**SBR**		**SBR & VF bed**		**CAS**		**CAS & VF bed**		**VFW**		**Trickling filter**		**RBC**		**MBR**		**Filtration**	
	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.	No.	Med.
0	350	**40**	228	**26**	99	**41**	16	**28**	394	**20**	5	19*	2	44*	15	**29**	-	-
1	347	**37**	190	**24**	138	**38**	28	**27**	337	**21**	3	15*	5	49*	17	**30**	-	-
2	347	**39**	178	**23**	196	**41**	28	**21**	349	**21**	4	29*	8	**38**	21	**26**	-	-
3	335	**36**	177	**24**	235	**37**	35	**20**	326	**19**	4	33*	9	**34**	23	**21**	-	-
4	335	**37**	152	**24**	264	**40**	33	**22**	285	**20**	5	49*	10	**36**	18	**22**	1	36*
5	310	**36**	154	**20**	304	**38**	30	**21**	258	**20**	4	32*	13	**39**	19	**26**	1	45*
6	297	**34**	129	**24**	325	**35**	32	**23**	213	**21**	8	**38**	13	**34**	14	**26**	1	24*
7	242	**36**	107	**21**	343	**35**	27	**23**	179	**18**	5	67*	17	**47**	18	**16**	1	46*
8	198	**35**	86	**23**	339	**34**	30	**21**	160	**19**	8	**32**	20	**38**	11	**18**	2	28*
9	142	**34**	60	**28**	350	**33**	27	**24**	127	**20**	9	**64**	19	**35**	9	**38**	2	36*
10	98	**39**	26	**26**	328	**32**	23	**23**	98	**22**	10	**38**	21	**44**	2	32*	2	29*
11	62	**39**	12	**24**	299	**35**	20	**30**	75	**24**	19	**47**	21	**46**	-	-	2	28*
12	51	**39**	9	**30**	281	**33**	23	**27**	67	**22**	17	**44**	19	**44**	-	-	3	16*
13	44	**36**	8	**41**	217	**35**	16	**27**	67	**22**	29	**51**	21	**50**	-	-	3	34*
14	32	**38**	7	**33**	197	**33**	15	**29**	52	**23**	32	**49**	20	**43**	1	48*	1	31*
15	29	**33**	4	**25**	139	**34**	9	**43**	46	**22**	35	**48**	15	**39**	1	82*	2	34*
16	27	**35**	6	**18**	106	**30**	8	**27**	35	**20**	50	**45**	11	**62**	1	49*	2	20*
17	23	**37**	6	**24**	73	**36**	6	**38**	31	**19**	57	**44**	8	**72**	2	75*	3	32*
18	22	**30**	6	**27**	56	**37**	7	**28**	30	**27**	65	**40**	6	**58**	2	57*	3	55*
19	20	**33**	4	25*	45	**43**	3	38*	22	**24**	69	**42**	8	**54**	1	55*	5	33*
20	16	**26**	6	**22**	24	**39**	2	67*	20	**25**	58	**45**	10	**40**	2	47*	3	37*
21	13	**28**	3	20*	18	**32**	1	71*	15	**20**	52	**42**	4	49*	2	50*	4	28*
22	10	**34**	3	35*	10	**40**	1	46*	12	**26**	46	**42**	2	57*	1	69*	5	24*
23	5	28*	2	26*	7	**33**	-	-	6	**20**	43	**45**	1	53*	1	69*	2	27*
24	5	32*	2	18*	6	**24**	-	-	7	**19**	25	**46**	-	-	-	-	2	40*
25	3	37*	2	40*	2	42*	-	-	6	**26**	22	**62**	-	-	1	18*	3	34*
26	3	49*	-	-	1	77*	-	-	4	25*	9	**63**	-	-	1	51*	1	43*
27	-	-	-	-	1	71*	-	-	-	-	5	59*	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	3	68*	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	1	29*	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

SBR and CAS treatment plants show very similar median effluent concentrations in the course of the operation time, as it can be seen in Figure 25. Higher median values as well as higher fluctuations occur in trickling filters and RBC plants. The median effluent concentrations of MBR treatment plants are below the before mentioned technologies, however fluctuations are high. Significance may be limited because MBR as well as RBC plants have the lowest amount of available measurements. The lowest effluent concentrations as well as the fewest fluctuations occur in VFWs.

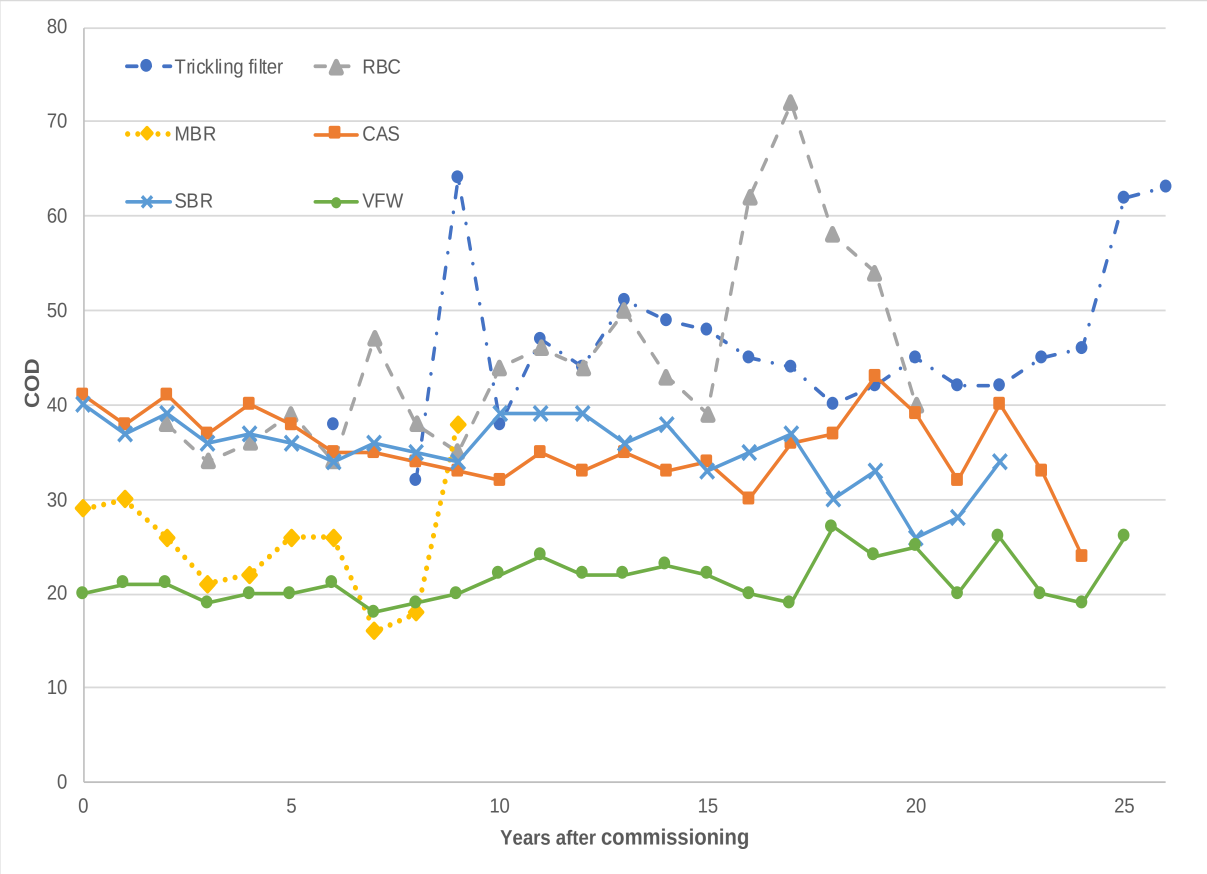

Figure 25: Median COD effluent concentrations in mg/l of WWTPs depending on their age

In Figure 26 the comparison of treatment plants with and without VF beds is illustrated again. Over the first ten years of the operation time the median COD effluent concentrations of all technologies with a VF bed are similar and significantly lower than in purely technical treatment plants.

After ten years the fluctuations of SBR treatment plants with a VF bed increase, but there are less than 12 measurements available respectively. Compared to that, VFWs can provide more than 12 measurements till the 22nd year of operation time.

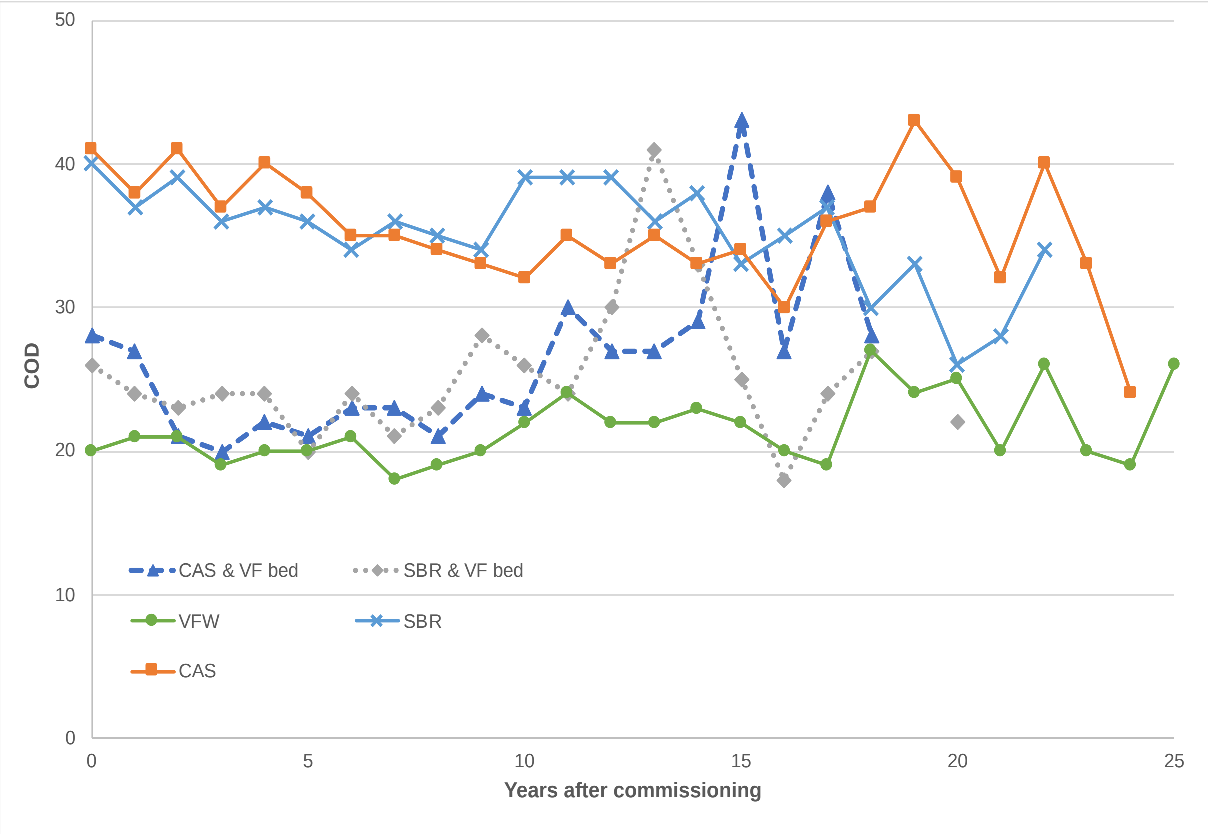

Figure 26: Median COD effluent concentrations of treatment plants with VF beds depending on the age of the WWTPs

Overall a significant improvement or deterioration of the treatment performance of any technology is, in this part of the analysis, unverifiable. However, VFWs show the lowest median effluent concentrations for all analysed parameters and the fluctuations are as well lower. SBR and CAS treatment plants with a VF bed can provide similar results to VFWs, however the biggest differences occur in median NH_4-N effluent concentrations.

5.4 Trend analysis of individual WWTPs

5.4.1 Trend analysis for SBR plants

Wastewater treatment plants with more or equal to five years of measurements are analyzed if a trend in the **NH_4-N effluent concentration** occurs. The before described Kendall trend test at a 5% significance level and the Sen's slope are used to identify trends and the associated slope (incl. confidence interval). There are also treatment plants with five measurements included and not as before only WWTPs with more than five measurements. This is done to include even more treatment plants in the analysis and the Kendall trend analysis can be conducted with few measurements.

The rows in the tables with the results of the Mann-Kendall Trend analysis show the treatment plants where the H_0 is rejected (p.value < 0.05) and therefore a monotonic trend can be detected. A positive slope indicates increasing effluent concentrations and therefore a deterioration of the treatment performance while a negative slope indicates decreasing measurement values and an improvement of the performance. Treatment plants with a negative trend are highlighted in light grey in the following tables. The number of available measurements can be seen in the second column, called "n", next to the identification number of the treatment plant and the third column, named "Age", shows the age of the treatment plant when the first available measurement took place.

In Table 21 the results of the Mann-Kendall trend analysis for **SBR** plants are presented. 11 out of 25 treatment plants, where a trend can be detected, show a negative trend and therefore an improving treatment performance. It is noteworthy that treatment plants with the first available measurement in the year of commissioning of the treatment plant as well as the oldest treatment plants show decreasing measurement values (i. e. improving treatment performance) over the operation time. The oldest SBR treatment plant with a trend was already 14 years in operation when the first measurement, available in the dataset, took place. These results substantiate the statement that a deterioration of the treatment performance with increasing operation time cannot be demonstrated.

Table 21: Results of the Mann-Kendall test for SBR WWTPs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence intervals	
40614216	6	0	0.03538	-2.104	-0.828	-0.060	-0.375	0.000
40627211	9	2	0.01187	2.516	0.704	0.150	0.035	0.845
40701223	9	1	0.04760	1.981	0.556	0.565	0.025	1.168
40718203	9	0	0.02857	-2.189	-0.611	-0.120	-0.360	-0.007
40902229	5	1	0.04326	2.021	0.949	0.035	0.000	0.350
40907207	9	4	0.02686	2.214	0.629	0.062	0.012	0.463
40909211	9	5	0.03334	-2.128	-0.609	-0.043	-0.140	0.000
40913203	8	12	0.01265	-2.494	-0.764	-1.093	-1.733	-0.700
40913214	6	2	0.02417	2.254	0.867	0.513	0.130	1.750
40922204	8	7	0.03545	-2.103	-0.643	-1.091	-2.600	-0.100
41104205	9	2	0.02686	-2.214	-0.629	-0.070	-0.700	-0.010
41115207	9	0	0.00386	2.889	0.825	0.100	0.050	0.200
41322207	10	0	0.00729	2.683	0.689	0.340	0.120	0.528
41402217	9	0	0.01924	2.341	0.667	0.669	0.003	1.195
41403202	11	5	0.02354	2.265	0.550	0.770	0.083	1.416
41409208	10	0	0.04910	1.968	0.511	1.170	0.042	2.463
41508223	10	0	0.01532	-2.425	-0.629	-0.370	-0.565	-0.037
41508224	9	1	0.04760	1.981	0.556	0.421	0.037	0.865
41510210	5	1	0.04326	2.021	0.949	0.053	0.000	2.170
41510211	12	2	0.00749	2.674	0.606	0.113	0.032	0.280
41510218	9	0	0.02036	-2.320	-0.700	-0.025	-0.140	0.000
41512203	9	14	0.04728	-1.984	-0.588	-0.058	-0.193	0.000
41512214	9	8	0.04258	-2.028	-0.645	0.000	-0.033	0.000
41513208	10	1	0.03182	2.147	0.556	0.280	0.020	1.345
41604211	5	1	0.02749	-2.205	-1.000	-0.113	-4.590	-0.030

It can be seen in Table 22, that there are overall 493 SBR treatment plants with NH_4-N measurements and 369 of them can provide more than or exactly five years of measurements. A trend occurs at 6.8% of the treatment plants. In 56.0% of these treatment plants a positive trend occurs and 44.0% show a negative trend and therefore decreasing measurement values.

Table 22: Overview of results of the Mann-Kendall trend test for SBR treatment plants

Number of SBR WWTPs	493	
Number of WWTPs with at least 5 years of measurements	369	74.8%
Number of WWTPs where a trend occurs	25	6.8%
Positive slope	14	56.0%
Negative slope	11	44.0%

Table 23 shows the results of the trend analysis for **SBR treatment plants with a VF bed**. Out of 18 treatment plants with a monotonic trend in the NH_4-N effluent concentrations, 7 show a negative trend and are highlighted in light grey. Newly implemented treatment plants, with the first available measurement in the year of the commissioning of the plant, show positive as well as negative trends. The oldest treatment plant, with an age of 16 years at the first available measurement, has according to these results still an improving treatment performance. Therefore, it cannot be concluded that the age of the treatment plant is significant for the treatment performance.

Table 23: Results of the Mann-Kendall test for SBR WWTPs with a VF bed

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
40611206	10	5	0.03046	-2.164	-0.568	-0.004	-0.137	0.000
40612202	9	2	0.03401	2.120	0.609	0.140	0.000	0.336
40617208	6	0	0.03538	-2.104	-0.828	-0.233	-0.585	0.000
40625206	16	0	0.00019	3.737	0.700	0.031	0.093	1.029
40701198	7	0	0.01626	-2.403	-0.810	-1.613	-3.093	-0.590
40701219	9	2	0.03334	2.128	0.609	0.109	0.000	0.173
41124203	9	1	0.02859	-2.189	-0.654	-0.100	-0.571	0.000
41221203	6	1	0.03538	2.104	0.828	0.150	0.000	0.525
41231222	10	1	0.02476	2.245	0.584	0.125	0.025	0.421
41322205	10	2	0.00847	2.633	0.690	0.119	0.027	0.218
41332203	10	1	0.02323	2.270	0.598	0.106	0.020	0.197
41338213	9	1	0.03334	2.128	0.609	0.102	0.000	0.240
41430206	10	0	0.03679	2.088	0.552	0.084	0.000	0.170
41506220	10	1	0.02323	2.270	0.598	0.103	0.030	0.203
41507232	16	1	0.00187	3.110	0.609	0.035	0.003	0.440
41507253	10	0	0.02323	-2.270	-0.598	-0.051	-0.085	-0.005
41517255	9	0	0.01219	-2.507	-0.764	-0.029	-0.750	0.000
41742202	8	16	0.04606	-1.995	-0.618	-0.242	-0.987	0.000

An overview of the results of the Mann-Kendall trend test is presented in Table 24. 164 out of the 252 SBR & VF bed treatment plants can provide more or exactly five measurements. A trend occurs at 18 of these treatment plants, that equals 10.1%. A positive trend can be found for 18 WWTPs or 61.1%, a negative slope can be seen in 38.9% of the treatment plants.

Table 24: Overview of the results of the Mann-Kendall test for SBR WWTPs with a VF bed

Number of SBR WWTPs with a VF bed	252	
Number of WWTPs with at least 5 years of measurements	164	65.1%
Number of WWTPs where a trend occurs	18	11.0%
Positive slope	11	61.1%
Negative slope	7	38.9%

5.4.2 Trend analysis for CAS plants

The results of the Mann-Kendall trend analysis for **CAS** treatment plants are shown in Table 25. A negative trend, and therefore decreasing NH_4-N measured effluent concentrations, occur in 15 treatment plants, while 24 small WWTPs show a deteriorating treatment performance over the operation time. An influence of the age of the treatment plants on the treatment performance cannot be proven, like for SBR plants, because old as well as young treatment plants show positive as well as negative trends.

In general n, which is the number of available measurements, is not higher than 10 because the dataset includes yearly measurements between 2008 and 2018. The only exception is the treatment plant with the identification number 41119208. It shows an unusual high amount of measurements with 16. The first measurement took place in 2010 and from 2012 on there where 2 measurements per year, the reason for that is not obvious.

Table 25: Results of the Mann-Kendall test for CAS WWTPs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
40609206	8	3	0.04606	1.995	0.618	0.941	0.000	2.150
40615203	9	5	0.04760	-1.981	-0.556	-0.131	-0.195	-0.020
40620207	9	2	0.02857	2.189	0.611	0.685	0.087	1.560
40624201	10	12	0.01906	-2.344	-0.614	-0.325	-0.600	-0.010
40902212	9	0	0.02857	2.189	0.611	0.681	0.262	6.569
40907206	10	3	0.00421	2.862	0.733	0.942	0.370	1.317
40909203	8	12	0.02190	-2.292	-0.718	-0.014	-0.128	0.000
40916205	8	6	0.04606	-1.995	-0.618	-0.471	-1.567	0.000
40918205	10	7	0.03888	2.065	0.539	0.400	0.050	0.900
40920208	9	2	0.02142	-2.300	-0.669	-0.189	-0.317	0.000
40921203	10	11	0.02868	-2.188	-0.582	-0.080	-0.120	0.000
40922205	9	7	0.02857	-2.189	-0.611	-0.428	-1.390	-0.098
40922206	9	4	0.04520	-2.003	-0.572	-0.142	-11.650	0.000
41002205	10	2	0.03182	2.147	0.556	0.055	0.040	1.107
41101205	9	5	0.02142	2.300	0.669	0.042	0.000	0.828
41104207	9	0	0.00642	2.726	0.761	0.251	0.097	0.400
41119208	16	0	0.04737	-1.983	-0.377	-0.171	-0.587	0.000
41119215	7	0	0.04829	1.975	0.683	0.062	0.000	0.270
41125207	9	3	0.03603	-2.097	-0.592	-0.221	-0.600	-0.093
41125224	5	1	0.02749	2.205	1.000	1.015	0.020	3.120
41220204	10	1	0.03679	2.088	0.552	0.100	0.000	0.227
41308201	10	10	0.03182	-2.147	-0.556	-0.790	-1.947	-0.224
41316003	9	4	0.00747	2.675	0.766	0.010	0.003	0.020
41323202	10	3	0.04491	2.006	0.535	0.105	0.000	0.227
41332202	8	3	0.00443	-2.846	-0.857	-0.140	-0.456	-0.045
41338203	10	5	0.03182	2.147	0.556	0.867	0.170	1.523
41407207	9	1	0.03603	2.097	0.592	0.145	0.052	0.863
41420204	9	6	0.04760	1.981	0.556	0.487	0.022	1.655
41423211	10	2	0.00729	-2.683	-0.689	-0.515	-1.754	-0.102
41430202	10	8	0.02004	2.326	0.600	0.134	0.033	0.360
41505208	9	5	0.00488	2.815	0.778	0.259	0.080	0.435
41506214	9	4	0.02857	2.189	0.611	1.010	0.063	1.813
41513203	10	6	0.01778	2.370	0.629	0.088	0.007	0.155
41513207	9	3	0.04760	-1.981	-0.556	-0.302	-0.700	-0.004
41517222	10	7	0.03182	2.147	0.556	0.533	0.035	0.996
41518203	10	9	0.04729	1.984	0.523	0.280	0.000	0.499
41617202	9	14	0.00915	2.606	0.722	0.844	0.470	1.458
41752202	9	7	0.04760	-1.981	-0.556	-0.870	-1.344	-0.040
41823201	8	3	0.00937	2.598	0.786	3.080	0.550	14.900

Table 26 shows that about 90% of the plants with this technology are used for the analysis because more than five values are available. A trend occurs in 8.1% and 38.5% of them show a negative trend and slope.

Table 26: Overview of the results of the Mann-Kendall test for CAS WWTPs

Number of **conventional activated sludge** WWTPs	539	
Number of WWTPs with at least 5 years of measurements	484	89.8%
Number of WWTPs where a trend occurs	39	8.1%
positive slope	24	61.5%
negative slope	15	38.5%

In Table 27 the results of the Mann-Kendall trend analysis for **CAS & VF bed** treatment plants can be seen. As mentioned before there are only 52 treatment plants with this technology, but slightly over 90% of these WWTPs can provide more than or equal to five years of measurements.

Table 27: Results of the Mann-Kendall test for CAS WWTPs with a VF bed

Identification number	**n**	**Age**	**p.value**	**Statistic z**	**tau**	**Sen's slope**	**95 confidence interval**	
41126202	8	4	0.01265	2.493	0.764	0.129	0.038	0.210
41316202	9	7	0.01649	2.398	0.667	0.600	0.163	3.505
41418201	9	7	0.01815	2.363	0.730	0.008	0.000	0.013
41507216	10	6	0.00541	-2.781	-0.740	-0.167	-0.445	-0.018
41615206	9	6	0.01649	2.398	0.667	0.138	0.030	0.638

It is summarized in Table 28 that a trend occurs in five treatment plants, that is a share of about 10.6%, four of them have a positive trend (80.0%) and one a negative (20.0%).

Table 28: Overview of the results of the Mann-Kendall test for CAS WWTPs with a VF bed

Number of CAS WWTPs with a VF bed	52	
Number of WWTPs with at least 5 years of measurements	47	90.4%
Number of WWTPs where a trend occurs	5	10.6%
positive slope	4	80.0%
negative slope	1	20.0%

5.4.3 Trend analysis for VFWs

Table 29 shows the results of the trend analysis for **VF wetlands**. The highest number of treatment plants with a negative trend, and therefore decreasing measurement values, can be seen in this technology. 24 out of 35 VFWs with a monotonic trend show a negative trend.

Table 29: Results of the Mann-Kendall test for VFWs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
40438204	9	3	0.02819	-2.195	-0.707	-0.019	-0.060	0.000
40603206	10	1	0.00128	-3.220	-0.822	-0.220	-0.820	-0.220
40605205	10	1	0.04491	2.006	0.535	0.119	0.000	0.192
40606204	5	0	0.04326	-2.021	-0.949	-1.008	-1.910	0.000
40615206	10	0	0.04138	-2.040	-0.549	-0.035	-0.190	0.000
40615207	9	0	0.00333	-2.935	-0.817	-0.923	-1.256	-0.360
40621216	8	0	0.02393	-2.258	-0.725	-0.123	-5.929	0.000
40625213	7	0	0.01866	-2.352	-0.823	-0.072	-0.123	0.000
40701205	9	10	0.03334	-2.128	-0.609	-0.176	-0.326	0.000
40701229	6	0	0.02417	2.254	0.867	0.760	0.070	2.450
40710210	9	0	0.00488	-2.815	-0.778	-0.429	-1.280	-0.153
40720204	5	0	0.04326	-2.021	-0.949	-0.313	-2.030	0.000
40904214	6	0	0.02417	-2.254	-0.867	-1.507	-3.705	-0.420
40906210	9	0	0.04760	-1.981	-0.556	-0.275	-1.834	-0.020
40906214	9	0	0.02110	-2.306	-0.648	-0.408	-1.475	-0.037
40906216	10	0	0.04729	-1.984	-0.523	-0.063	-0.569	0.000
40909216	10	3	0.02868	-2.188	-0.582	-0.023	-0.073	0.000
40914202	10	9	0.01532	2.425	0.629	1.337	0.100	3.700
41020204	9	2	0.04760	1.981	0.556	0.023	0.005	0.165
41101212	10	0	0.04138	-2.040	-0.549	-0.030	-0.250	0.000
41119216	7	0	0.04149	2.039	0.720	0.006	0.000	0.018
41323201	10	6	0.01193	2.514	0.677	0.010	0.000	0.073
41328203	9	3	0.00915	2.606	0.722	0.022	0.009	0.036
41331209	8	0	0.02482	2.244	0.691	0.222	0.067	0.652
41336202	10	5	0.00865	2.626	0.690	0.073	0.012	0.139
41337205	8	0	0.04606	1.995	0.618	0.393	0.000	2.098
41337210	6	0	0.02677	-2.215	-0.894	-1.758	-2.650	0.000
41411206	9	1	0.03603	2.097	0.592	0.139	0.005	0.394
41505222	8	1	0.01874	-2.351	-0.714	-0.243	-1.389	-0.006
41507240	9	0	0.04520	2.003	0.572	0.116	0.000	0.430
41510216	8	0	0.04852	-1.973	-0.681	0.000	-0.200	0.000
41517234	9	6	0.04258	-2.028	-0.645	0.000	-0.200	0.000
41519208	9	2	0.00915	-2.606	-0.722	-0.227	-0.756	-0.030
41521201	9	18	0.00642	-2.726	-0.761	-1.226	-2.107	-0.300
41521206	10	6	0.02607	-2.225	-0.597	-0.333	-0.588	0.000
41604207	8	0	0.02482	-2.244	-0.691	-0.038	-0.573	-0.005

The oldest VFW with 18 years at the time of the first available measurement has a negative trend as well as treatment plants with the first measurement in the years of the commissioning. It appears, that the age of the treatment plants is not restrictive for an improving treatment performance.

A summary of the results for VFWs is presented in Table 30. Data of 484 VFWs is available and 357 of them can provide at least five measurements. A trend occurs at 10.1%. 66.7% of them show a negative slope and 33.3% a positive and therefore a deterioration of the treatment performance over the operation time.

Table 30: Overview of the results of the Mann-Kendall test for VFWs

Number of VFW WWTPs	484	
Number of WWTPs with at least 5 years of measurements	357	73.8%
Number of WWTPs where a trend occurs	36	10.1%
Positive slope	12	33.3%
Negative slope	24	66.7%

5.4.4 Trend analysis for trickling filter plants

The results of the Mann-Kendall trend test for trickling filter treatment plants are presented in Table 31. It can be seen that all detected trends are negative, and therefore the treatment performance is improving.

Table 31: Results of the Mann-Kendall test for trickling filter WWTPs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
40425202	8	17	0.02482	-2.244	-0.691	-1.733	-2.650	-0.650
41222201	10	15	0.04910	-1.968	-0.511	-0.511	-1.130	-0.015
41231205	10	14	0.04910	-1.968	-0.511	-0.519	-1.070	-0.048
41318202	10	14	0.01227	-2.504	-0.644	-0.081	-0.221	-0.019
41507204	11	14	0.00628	-2.733	-0.661	-0.410	-0.763	-0.010

It is shown in Table 32 that 77 trickling filter treatment plants have at least five measurements available. A trend occurs at 6.5% of these WWTPs and all of them show a negative slope.

Table 32: Overview of the results of the Mann-Kendall test for trickling filter WWTPs

Number of trickling filter WWTPs	85	
Number of WWTPs with at least 5 years of measurements	77	90.6%
Number of WWTPs where a trend occurs	5	6.5%
Positive slope	0	0.0%
Negative slope	5	100.0%

5.4.5 Trend analysis for RBC plants

Table 33 presents the results of the trend test for RBC treatment plants. Both detected trends are negative.

Table 33: Results of the Mann-Kendall test for RBC WWTPs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
41406201	7	14	0.01626	-2.403	-0.810	-1.083	-15.385	-0.080
41601205	9	8	0.03334	-2.128	-0.609	-0.217	-1.117	0.000

Table 34 shows that 88.9% of all **RBC** treatment plants can provide more than or exactly five years of measurements. Only two of them show a trend detectable at a significance level of 95%. Both trends show a negative slope and therefore decreasing NH_4-N effluent concentrations.

Table 34: Overview of the results of the Mann-Kendall test for RBC WWTPs

Number of RBC WWTPs	36	
Number of WWTPs with at least 5 years of measurements	32	88.9%
Number of WWTPs where a trend occurs	2	6.3%
Positive slope	0	0.0%
Negative slope	2	100.0%

5.4.6 Trend analysis for MBR plants

The results of the Mann-Kendall trend for MBR plants are listed in Table 35. Only one treatment plant shows a positive trend.

Table 35: Results of the Mann-Kendall test for MBR WWTPs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
41514228	10	0	0.04909	1.968	0.511	0.344	0.003	0.787

There are 25 **MBR** treatment plants with measured values and 21 of them can provide at least five measurements (Table 36). A trend occurs at only one treatment plant and it shows a positive slope.

Table 36: Overview of the results of the Mann-Kendall test for MBR WWTPs

Number of MBR WWTPs	25	
Number of WWTPs with at least 5 years of measurements	21	84.0%
Number of WWTPs where a trend occurs	1	4.8%
Positive slope	1	100.0%
Negative slope	0	0.0%

5.4.7 Trend analysis for filtration plants

The trend test results for filtration treatment plants are presented in Table 37.

Table 37: Results of the Mann-Kendall test for filtration WWTPs

Identification number	n	Age	p.value	Statistic z	tau	Sen's slope	95 confidence interval	
41514204	8	17	0.00937	2.598	0.786	1.212	0.352	1.945

It is shown in Table 38 that six out of seven **filtration** treatment plants have more than or exactly five years with measurements. A trend with a positive slope occurs at only one treatment plant, however this equals 16.7%.

Table 38: Overview of the results of the Mann-Kendall test for filtration WWTPs

Number of filtration WWTPs	7	
Number of WWTPs with at least 5 years of measurements	6	85.7%
Number of WWTPs where a trend occurs	1	16.7%
Positive slope	1	100.0%
Negative slope	0	0.0%

5.4.8 Summary of the trend analysis

Overall a trend can be detected in a minor amount of small WWTPs. The highest percentage of 16.7% occurs in filtration treatment plants, however this equals only one WWTP with a deteriorating treatment performance. Slightly more positive than negative trends occur according to the results of the Mann-Kendall trend test, summarized in Table 39. Four technologies show only positive or negative trends (trickling filter, MBR, RBC, filtration), however the number of available treatment plants of these technologies is limited.

The other technologies include treatment plants with positive and negative trends. The biggest difference occurs in CAS treatment plants with a VF bed where 80.0% show an increasing trend and 20.0% a decreasing trend, however the total number of treatment plants with a trend is again limited. Most negative trends, and therefore decreasing effluent concentrations occur in VFWs with 66.7%.

Table 39: Summary of the results of the Mann-Kendall trend test for all technologies

Technology	**WWTPs with trend**		**Number of positive trends, i.e. treatment performance deteriorates over time**		**Number of negative trends, i.e. treatment performance improves over time**	
SBR	25	6.8%	14	56.0%	11	44.0%
SBR & VF bed	18	11.0%	11	61.1%	7	38.9%
CAS	39	8.1%	24	61.5%	15	38.5%
CAS & VF bed	5	10.6%	4	80.0%	1	20.0%
VFW	36	10.1%	12	33.3%	24	66.7%
Trickling filter	5	6.5%	0	0.0%	5	100.0%
RBC	2	6.3%	0	0.0%	2	100.0%
MBR	1	4.8%	1	100.0%	0	0.0%
Filtration	1	16.7%	1	100.0%	0	0.0%

6. Conclusion and outlook

The aim of this Master's thesis was to compile an overview about the number of small WWTPs in Upper Austria and to analyse their treatment performance. From the results of the analysis the following conclusions can be drawn:

1. Number of small WWTPs in Upper Austria

- Overall the number of small WWTPs in Upper has raised from 2'398 in 2016 to 2'526 with the biggest alteration of +171 in SBR treatment plants. The number of old treatment plants, with mechanical treatment only, dropped by 79 to 302.
- Compared to other federal states of Austria the data basis in Upper Austria is good with only 1 operating small WWTP with an unknown technology.

2. Treatment performance of small WWTPs

- All technologies are able to comply with the legal requirements and therefore the respective NH_4-N, BOD_5 and COD threshold values. However, VFWs and technical treatment plants with a VF bed show lower median values and less individual measurements exceeding the threshold.
- In the analysis with median effluent concentrations values of individual treatment plants similar results occur. Outlier values are excluded and only a minor amount of individual WWTPs show a median value higher than threshold. Therefore at least half of the measurements of almost all treatment plants are below the respective threshold.
- The number of measurement values above the respective threshold is significantly lower for BOD_5 and COD than for NH_4-N. Nitrification is the most sensitive process in wastewater treatment.
- A significant improvement or deterioration of the treatment performance cannot be detected for any technology in the analysis with median effluent concentrations. However, technical small WWTPs without a VF bed show higher fluctuations of the effluent concentration with increasing years of operation. VFWs have less fluctuations and lower median effluent concentrations. This indicates a very robust treatment performance.
- Of all treatment plants with more than four years of measurements a trend in the effluent concentrations occurs in 8.5% of these WWTPs. Therefore, a significant statement about the improvement or deterioration of the treatment performance according to the results of the Mann-Kendall trend test with a 95% significance level cannot be made.

Further research can be conducted regarding the current status of small WWTPs in Austria since the last analysis took place in 2016 and only in the federal state of Upper Austria the number has changed by 128 treatment plants over a time period of 3 years. To make conclusive statements about the treatment performance further research is necessary since in this analysis only data from Upper Austria is used.

7. Summary

According to the aim of this Master thesis, described in chapter 2, the results of the three research questions will be summarized in this chapter.

To address the first objective, the **number of treatment plants** currently operating in Upper Austria was determined and categorized according their treatment technology. In 2019 2’526 small WWTPs are in use in Upper Austria. The number of treatment plants according their technology is listed in the following table.

Table 40: Summary of represented treatment technologies in Upper Austria

Technology	Number	Percentage
SBR	873	34.6%
Conventional activated sludge	628	24.9%
Primary treatment only	302	12.0%
Trickling filter	97	3.8%
Rotating biological contactor	37	1.5%
MBR	26	1.0%
Filtration	27	1.1%
Unknown	1	0.0%
Total	**2’526**	**100%**

CAS and SBR treatment plants occur with a VF bed. The breakdown into WWTPs with and without a VF bed results in 583 SBR treatment plants and 290 SBR treatment plants with a VF bed as well as 574 CAS plants and 54 CAS treatment plants with a VF bed.

The second objective was to analyse the **treatment performance** of the represented technologies. Descriptive statistical parameters were calculated with the yearly measured NH_4-N, BOD_5 and COD effluent concentrations. An overview of the results of the analysis using all measurements is listed in Table 41. VFWs and technical treatment plants with a VF bed show lower median values and less measurements above the respective threshold. Overall more NH_4-N measurements exceed the threshold than BOD_5 and COD values. However, all technologies are able to comply with the respective threshold values. This is specified in the analysis with median values of the individual treatment where only a minor amount of WWTPs cannot meet the legal requirements.

Table 41: Overview of median values of the effluent concentrations and values above the respective threshold using all measurement values (the three lowest values for each parameter are bold).

		SBR	SBR & VF bed	CAS	CAS & VF bed	VFW	Trickling filter	RBC	MBR	Filtration	all values
NH_4-N	**Median [mg/l]**	1.00	**0.68**	1.09	**0.24**	**0.37**	2.20	1.2	1.78	2.66	0.98
	values above threshold	72	13	137	9	48	42	17	6	6	350
	[%]	2.2	0.8	3.1	2.2	1.5	6.1	6.0	3.2	11.1	2.5
BOD_5	**Median [mg/l]**	5	**3**	5	**3**	**3**	8	7	4	6	5
	values above threshold	27	3	55	3	4	6	5	1	0	104
	[%]	0.8	0.2	1.3	0.7	0.1	0.9	1.8	0.5	0.0	0.7
COD	**Median [mg/l]**	37	**24**	35	**24**	**21**	44	43	27	33	31
	values above threshold	48	7	53	1	4	11	4	0	0	128
	[%]	1.4	0.5	1.2	0.2	0.1	1.6	1.4	0.0	0.0	0.9

To address the third objective of this Master thesis, an **analysis over the operation time** of the treatment plants with median values per year as well as a Mann-Kendall trend analysis was conducted. A possible improvement or deterioration of the treatment performance over the time of operation cannot be detected in any technology. The yearly median effluent concentrations of VFWs and technical treatment plants with a VF bed are below purely technical treatment plants and show in general lower fluctuations in following years.

The Mann-Kendall trend test detects a trend in 8.5% of treatment plants with more or equal to five measurements. A positive trend, that means a deterioration of the treatment performance can be detected in 51.5% of these WWTPs. 48.5% show a negative trend and therefore an improvement of the treatment performance.

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I certify, that the master thesis was written by me, not using sources and tools other than quoted and without use of any other illegitimate support.

Furthermore, I confirm that I have not submitted this master thesis either nationally or internationally in any form.

Nüziders, 27.05.2020 *Eva Engstler*