

Combined Sewer Overflow Treatment: Removal of oxygen-depleting parameters through Retention Soil Filters

Traitement aux déversoirs d'orage : rendements sur les paramètres responsables de la déperdition d'oxygène via la rétention et l'infiltration dans le sol

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RÉSUMÉ

Les filtres de rétention au sol permettent d'atténuer la pollution des eaux de surface provoquée par les rejets unitaires de temps de pluie. A l'origine, les filtres de rétention au sol avaient été conçus pour retenir les matières en suspension, mais la recherche a également démontré leur capacité à retenir l'ammonium dans une certaine mesure. Pendant les phases sèches entre les événements, l'ammonium adsorbé dans le lit bactérien est nitrifié et donc l'impact sur les milieux récepteurs est atténué. En Rhénanie du Nord-Westphalie, plusieurs de ces filtres ont été construits et installés au cours de la dernière décennie. Ils sont en fonctionnement depuis près de dix ans. Dans ce projet de recherche, des filtres de rétention au sol à grande échelle qui fonctionnent depuis plus de cinq ans ont été évalués pour étudier la façon dont ils retiennent plusieurs paramètres. Une attention particulière a été accordée aux paramètres responsables de la déperdition d'oxygène, à l'ammonium et à la demande chimique en oxygène qui jouent un rôle important dans le bon état chimique tel que défini par la Directive-Cadre sur l'Eau de l'UE. La rétention de l'ammonium et sa transformation en nitrate ont été mesurées par des électrodes incorporées, mesures suivies d'analyses en laboratoire pour plusieurs paramètres. Même après plusieurs années de fonctionnement, nous avons pu prouver que la rétention et la transformation de l'ammonium fonctionnent bien. Le facteur d'efficacité de rétention pour l'ammonium se situait entre 60 et 86 %, et entre 67 et 87 % pour la demande chimique en oxygène. La concentration en nitrate dans l'écoulement est en corrélation avec la période sèche depuis le dernier événement. Ceci démontre des processus d'ammonification dans le filtre.

ABSTRACT

Retention soil filters help to mitigate the pollution of surface waters caused by combined sewer overflows. Originally, retention soil filters were designed to retain total suspended solids, but research has shown that they also retain ammonium to a certain extent. In the dry phases between events, adsorbed ammonium in the filter bed is nitrified and, thus, the impact on the receiving waters mitigated. In North Rhine-Westphalia, several of these filters have been built and installed in the last decade. They have been in operation for up to ten years now. In this research project, large scale retention soil filters in operation for more than five years were evaluated as to how well they retained several parameters. One focus was set on the oxygen depleting parameters ammonium and chemical oxygen demand that play an important role for the good chemical status in the EU Water Framework Directive. The retention of ammonium and its transformation to nitrate were monitored with online electrodes accompanied by laboratory analyses for several parameters. Even after several years of operation, we could prove that the retention and transformation of ammonium works well. The retention efficiency factor for ammonium was between 60 and 86%, for chemical oxygen demand between 67 and 87%. The concentration of nitrate in the outflow correlates with the dry period since the last event. This indicates ammonification processes in the filter.

KEYWORDS

Ammonification, Combined sewer overflow, Constructed wetlands, Nitrification, Retention soil filters

1 INTRODUCTION

The overflow from combined sewer systems contains an enormous load of critical substances, even if pre-treated in a stormwater tank (Brombach et al., 2005; Welker, 2007; Gasperi et al., 2011, Passerat et al., 2011). To minimise the impact on the surface waters, retention soil filters (RSFs) have played an increasingly important role in cleaning this overflow in the last 20 years. This special type of constructed wetland is described in detail in Uhl and Dittmer (2005) and Frechen et al. (2006). Several research projects in Europe work on the adaptation of RSFs to their local combined sewer system (Meyer et al., 2013).

In North Rhine-Westphalia, most of the 120 sites in combined sewer systems were built and started operation in the last decade (MUNLV, 2003; MKULNV, 2010). Research results for the retention of several substances, for example ammonium, chemical oxygen demand (COD), total suspended solids (TSS), phosphate and heavy metals have already been investigated in the last 20 years in different application areas as the treatment of the overflow of stormwater tanks in combined sewer systems, rainwater in separate sewer systems and highway-runoffs (Dittmer, 2006; Woźniak, 2008; Holthuis et al., 2012).

This research project, funded by the Ministry for Climate Protection, Environment, Agriculture, Nature Conservation and Consumer Protection of the German Federal State of North Rhine-Westphalia, focused on evaluating the cleaning capacity of RSFs after several years of operation. One assumption was that first flush effects in the inflow and outflow could be detected. The results should lead to suggestions on how to improve RSFs according to construction and operation.

One of the parameters investigated was ammonium. Several recent research projects have proved that the RSFs retain ammonium up to more than 95% in bench scale, and in some cases this could be confirmed on large scale plants (Dittmer, 2006; Woźniak et al., 2007).

An RSF is only loaded during heavy rainfalls and retains several sewage pollutants due to physical and biochemical processes (Uhl and Dittmer, 2005). Between events, the filter bed is aerated through the drainage pipes. Thus, adsorbed ammonium is nitrified and nitrate released into the surface waters with the first flush of the next heavy rainfall event. Due to this, the filter's capacity to absorb ammonium is regenerated (Dittmer, 2006). The processes in the filter rely on the duration of the dry period between two events. In the first days of the dry period, the adsorbed ammonium is nitrified. After a phase which Dittmer (2006) evaluates to be five days, the ammonification of the retained organic compounds in the filter starts. Dittmer (2006) observed a direct nitrification of the generated ammonium into nitrate. Most likely the nitrification also takes place in the retention phase during events and as infiltrated water passes through the filter (Woźniak et al., 2007).

Since oxygen-depleting parameters such as COD and ammonium are crucial parameters with regard to the good chemical status of surface water bodies as defined in the EU Water Framework Directive (2000/60/EG), the conditions of its retention and nitrification should be optimised. For COD, the retention was given between 66 and 85% depending on the filter material and the filtration velocity (Woźniak, 2008).

In this research project, three sites were picked out of practical reasons providing that one filter represents a filter with low batch rates, one with batch rates as suggested to be optimal in the German construction recommendations (MUNLV, 2003; DWA, 2005) and an overloaded one. It was expected to find a correlation between dry phases and retention efficiency. The results should lead to an optimisation of design, construction and operation of existing plants and new construction advice. For several reasons within the project and very few analysed events for all filters, only the results for the filter selected as heavily loaded are presented in this paper. A schematic flow scheme of the plant is given in Figure 1. The first flush of a heavy rainfall event from the combined sewer overflow is stored in stormwater tank (Figure 1, No. 1). If its capacity is insufficient for the inflow, the overflow is retained in the second stormwater tank (Figure 1, No. 2) with another overflow into the RSF. A diving structure between the stormwater tank and filter bed (Filter 1, No. 3) discharges the overflow into the receiving water if the retention volume (Figure 1, No. 4) of the filter is completely filled. The filter bed has a total surface area of 2,200 m² and a retention volume of approximately 4,200 m³.

The retained water runs through the sand layer (0.75 m, carbonated technical filter sand 0/2 mm), which is planted with reed, and into the drainage pipes that are arranged in a gravel bed (0.3 m, 2/8 mm) underneath the sand layer. The outflow is pumped through the outflow buildings (Figure 1, No. 5) into the receiving waters.

The RSF outflow quantities were measured after the outflow buildings (Figure 1, e). The discharged water into RSF 1 is measured with an ultrasonic flow meter (Nivumaster NM3111 P-06, accuracy 0.25% of the measured range according to producer) at the weir sill of the separation construction. There was no further data available on validation during operation.

The outflow of the filter bed is divided into two streams because the filter drainage is separated into two filter beds, one near the inflow and one behind the first bed. In the outflow and the overflow, two magnetic flow meters are placed in each drainage stream.

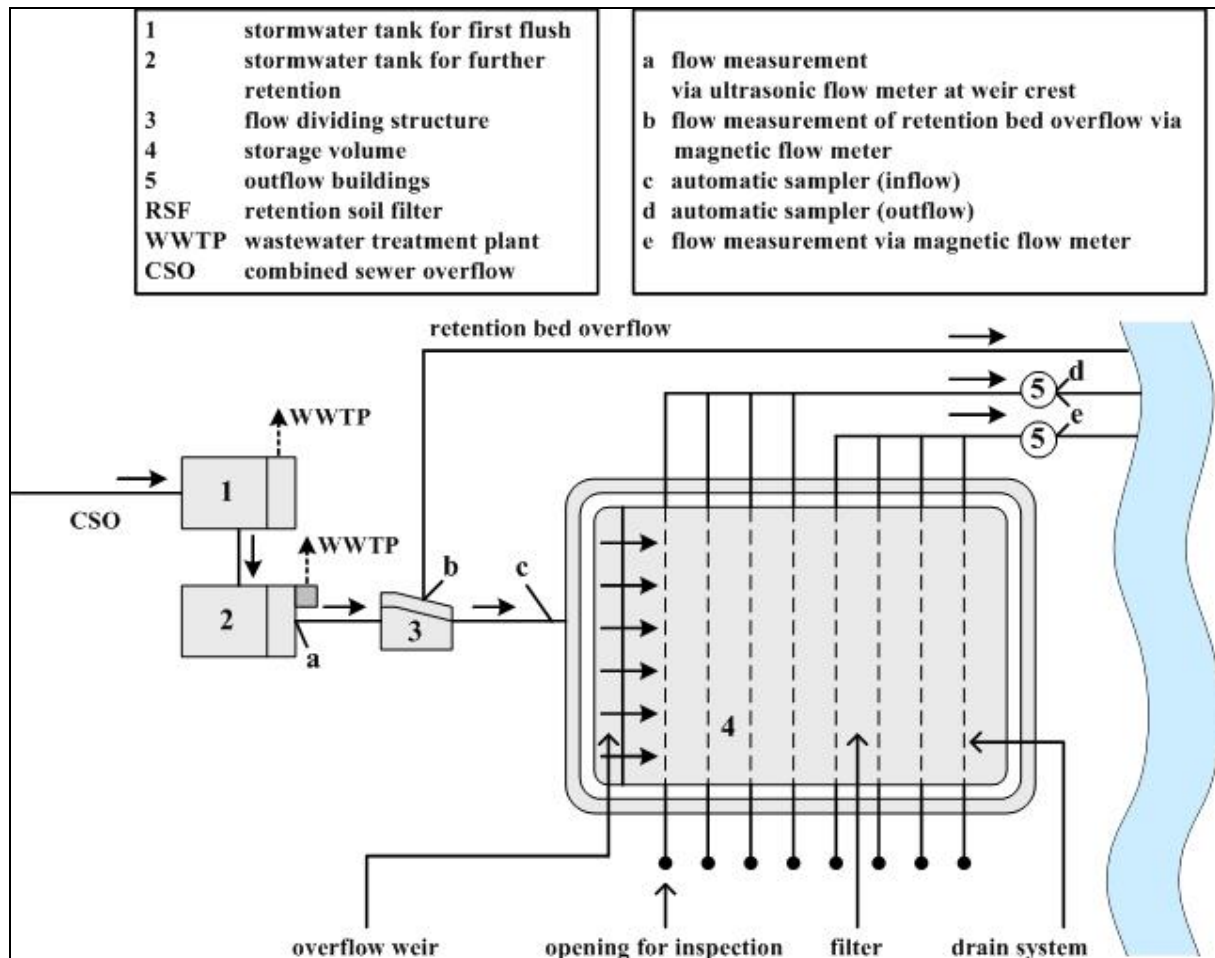


Figure 1: Flow scheme of the examined retention soil filter (RSF).

2 METHODS

Online electrodes for the measurement of ammonium and nitrate (Hach-Lange AN-ISE) were installed in the inflow and the outflow construction of the filter. These electrodes record nitrate, ammonium and other complementary parameters in adjustable intervals. Predominantly, they are used in aeration tanks of wastewater treatment plants. The electrodes have to be submerged at all times. Thus they were installed at a level in the inflow and outflow construction of the RSF which guarantees a certain water level throughout the whole year. From time to time, the electrodes were recalibrated with cuvette tests to the levels of nitrate and ammonium in their residence medium. The interval was not recorded. During the project, the cartridges with the electrodes had to be changed once after five months of operation because this special application led to a faster aging of the electrodes than expected.

The operational data for each site were recorded in intervals of 15 minutes. These data were analysed to identify the beginning, duration and end of an event as well as the amount of inflow and outflow streams. Because of problems determining the inflow rates, the loads of the polluting parameters cannot be calculated. Therefore, only concentrations are used to evaluate the efficiency factor in the following. In the outflow, two magnetic flow meters record the outflow rates. In combination with the concentration for nitrate monitored with the online electrodes, the total nitrate load into the receiving water can be calculated.

Portable samplers (MAXX[®] TP1) on-site took samples of inlet and outlet during a rainfall event that led to an overflow. The samples were taken into cylinders (first stainless steel, in 2012 replaced with glass). When the water level exceeded 0.15 m above the filter bed, the inflow and outflow samplers received a signal to start sampling:

- every minute 0.2 L of the inflow were captured for three samples of 4 L each,
- inflow-sampling ended after one hour (sample volume in total 12 L),
- every two minutes 0.18 L of the outflow were captured for three samples of 4 L each and
- outflow-sampling ended after three hours (sample volume in total 12 L).

In 2012, the inflow was set to 3 hours of sampling (single sample after 60 minutes). Unfortunately, problems with the portable sampler allowed only one mixed sample to be taken for both inflow and outflow at the event on 2012-06-20.

After each event, the samples were cooled down to 5°C and analysed in a laboratory. They were analysed as to their physical-chemical parameters, nutrients, heavy metals, micropollutants and bacteria. Results for micropollutants, bacteria and TSS are presented in Tondera et al. (2013).

3 RESULTS AND DISCUSSION

During 11 events between October 2011 and July 2012, the electrodes recorded data in five-minute intervals. For the evaluation, the data of three events were not considered because implausible results were caused by out-dated cartridges or technical problems. In the laboratory, samples of ten events between July 2011 and July 2012 were analysed as to nitrate and ammonium amongst other parameters. Three other events cannot be compared because of technical problems with the sampler or the outflow pumps. For one event, there is both data from the online electrodes as well as results from the laboratory analysis.

Figure 2 shows the results of a single event on October 12-13, 2011. The beginning of the inflow (first dashed vertical line) is followed by a delayed rise of the ammonium inflow as well as of the nitrate outflow. The delay is about half an hour for all evaluated events. There might be two explanations for this: The starting point of an event in the filter had to be estimated from the recorded data of the RSF. This was correlated with parameters as an overflow in the stormwater tank combined with the pumps in the RSF outflow (Figure 1, No. 5) beginning to dewater. There could be an inaccuracy in the determination of this starting point. Another explanation is that the online electrodes need to adapt to the change in the medium from the supernatant of the last event to the inflowing and filtered mixed water from the stormwater tank.

The laboratory results for nitrate and ammonium during the same event are also given as the arithmetic mean for all samples in Figure 2. The “inflow concentration” indicates the arithmetic mean of the first hour of the event: The “outflow concentration” represents the first three hours of the event. The difference between the laboratory result and the values from the online electrode can be explained by the fact that the samples in the sampler were stored several hours at 5°C and had to be transported to a laboratory for the analysis. A shift of the parameters is possible. As the electrodes have to be recalibrated from time to time, a shift in the electrode values could also give an explanation. However, the results are still within the range of the online curve and thus plausible. Figure 3 displays the laboratory results of all sampled events for ammonium.

The rise of the nitrate outflow itself is expected as can be seen in the literature review (Dittmer, 2006): In the preceding event, ammonium is adsorbed in the filter material. During the dry phase of the filter (at 2011-10-12, about three days), the ammonium is nitrified. The resulting nitrate is flushed out at the beginning of the event.

The concentration of ammonium in the outflow also shows the predicted adsorption effects during the event. As it is not possible to determine the loads into the filter, it is unclear if nitrification also happens during the event and not only between events.

At all events, the concentration of ammonium first sinks to a lower level which proves that the filter adsorbs effectively. After a time span of four to nine hours the ammonium concentration rises visibly. It indicates that the adsorption capacity of the filter is reached.

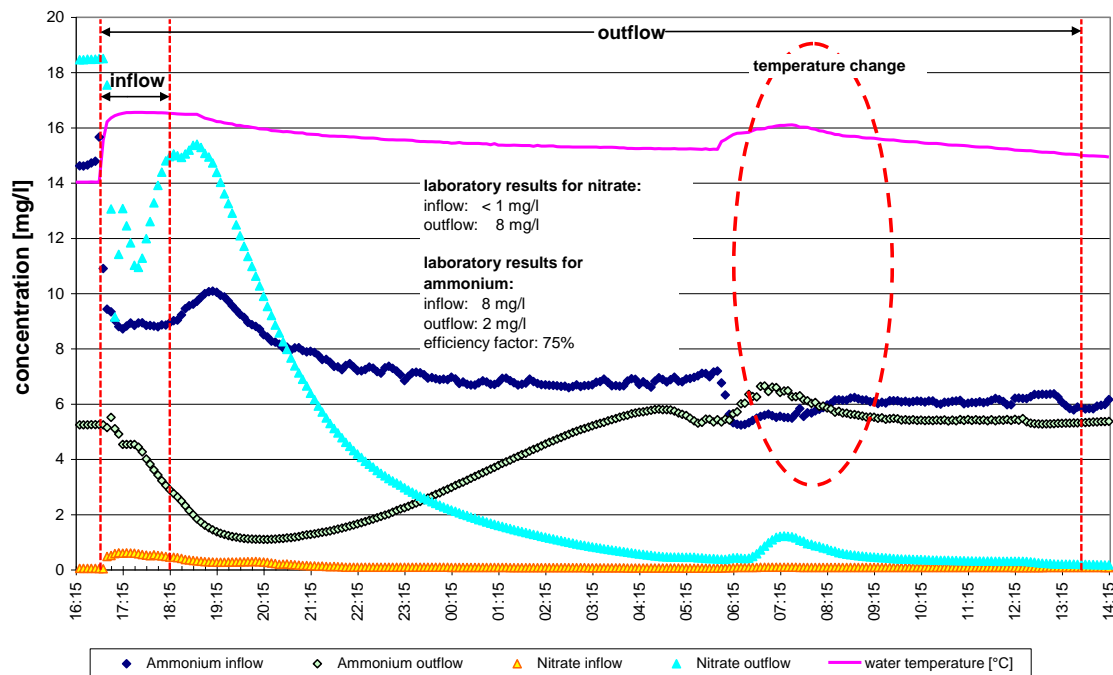


Figure 2: Recorded data for the event of October 12-13, 2011 in five-minute intervals

Table 1: Loads of nitrate into the receiving waters.

Event [year-month-day]	2011-10-12	2011-12-16	2011-12-20	2011-12-22	2011-12-30	2012-01-02	2012-01-05	2012-06-20
Nitrate load into receiving waters [kg]	17	25	17	16	21	16	22	13
Outflow volume [m ³]	3,090	3,350	2,046	2,919	3,376	3,817	2,843	1,221

At six events, the outflow concentration of nitrate increases after several hours and often falls again after a short time while the ammonium concentrations of both inflow and outflow also show declining and rising effects. At most of these events, there is also a change in the water temperature measured around this time. It is yet unclear if these phenomena that are marked with the ellipse in Figure 2 rely on operating conditions of the filter construction.

The concentration-based efficiency factor over all events can be given as 83% for ammonium. This is within the range of the literature research (Uhl and Dittmer, 2005; Woźniak 2008) and proves that even after several years of operation, the filter's capacity to adsorb ammonium still regenerates after each event. The result from June 20th, 2012 relies on only one mixed sample each because the sampler malfunctioned during these events. Only a few bottles were filled. Because of this, this result has not been considered in search of correlations.

Figure 4 gives the correlation between the dry period since the end of the last event and the nitrate concentration in the outflow which presents as nitrified ammonium from last event. The ammonification followed by a direct nitrification observed by Dittmer (2006) explains the indication of a correlation. Unfortunately, the area between 20 days of dry period and 50 days of dry period could not be investigated because of a lack of analysed events. This would have to be subject of further research activities.

In Table 1, the total loads of nitrate into the receiving waters in the filter outlet during the analysed events are given. An evaluation of the impact on the receiving waters would only be possible on an immission-based reflection which was not part of this research project. It is as well connected to the chemical status of the receiving waters.

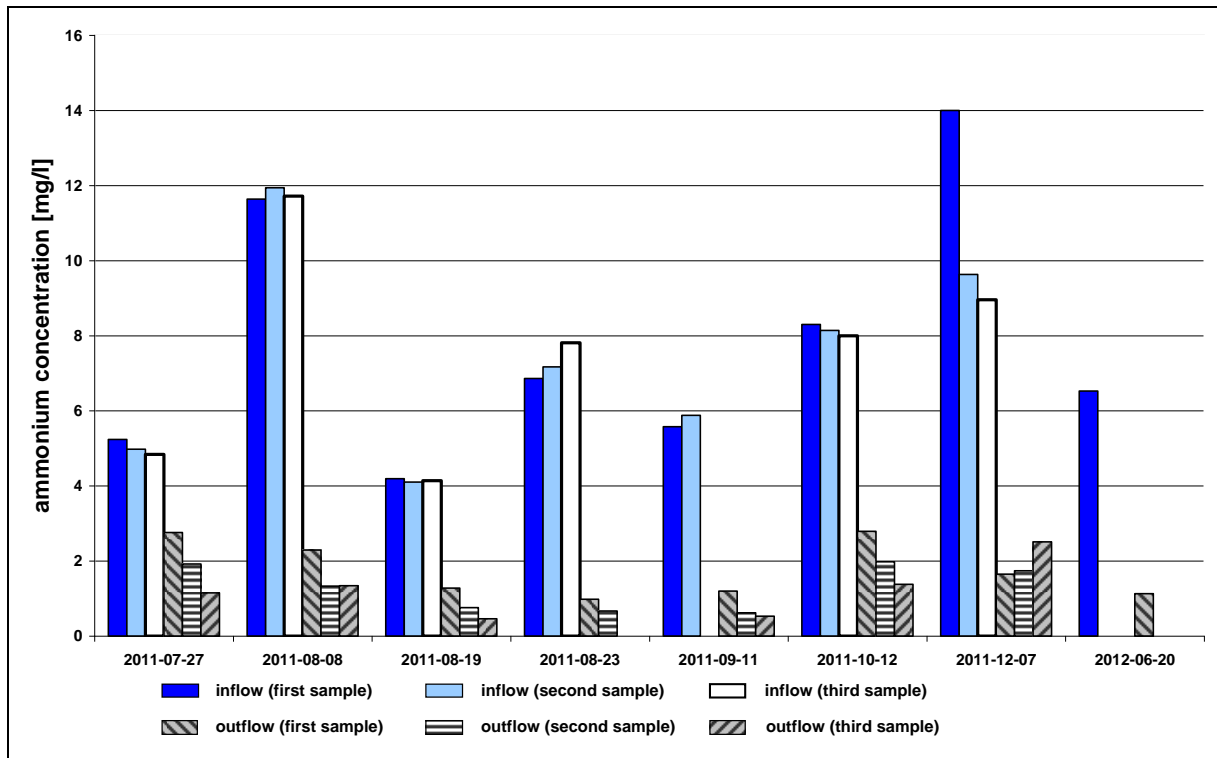


Figure 3: Laboratory results for ammonium.

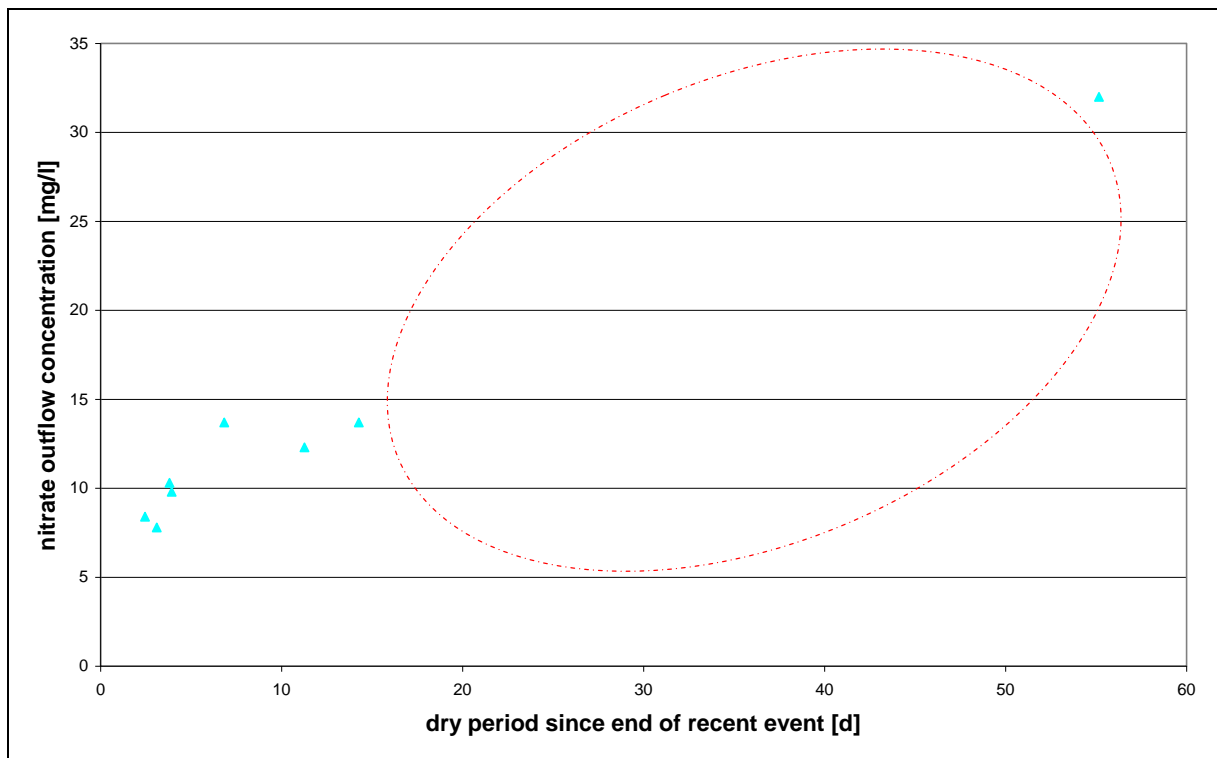


Figure 4: Nitrate concentration correlated with dry period since recent event. (The dashed ellipse gives the area that still needs to be investigated to confirm a correlation.)

Since it is impossible to analyse the filter material in a filter of this size in operation, which material is ammonificated cannot be evaluated. A part of this material should be the retained organic compounds of the last event. Figure 5 shows the inflow and outflow concentrations of COD during the project phase. As can be seen for COD in Figure 5 and ammonium in Figure 3, no clear first flush effects can be proved with this sampling method. However, the curves of the online electrodes describe a sloping curve in a way that it might be worthwhile to look for this effect with other online electrodes suitable for

further parameters as COD etc.

Unfortunately, there was no clear correlation between the retention efficiency and the dry phase for ammonium or COD. It seems, however, that a very short dry period of less than three days has a negative impact on the retention capacity since the filter might not be aerated long enough (Figure 4). This assumption will have to be proved through further research since in this project only one event with such a brief time period to the last event was sampled.

The efficiency factor for COD varies between 67 to 87% as presented in Table 2 and is, therefore, within the range that Woźniak (2008) evaluated on bench scale, as well as ammonium (between 60 and 86%).

Table 2: Efficiency factor of COD and ammonium and dry period since last event for the sampled events.

Event [year-month-day]		2011-07-27	2011-08-08	2011-08-19	2011-08-23	2011-09-11	2011-10-12	2011-12-07	2012-06-20
Efficiency factor [%]	COD	67	83	67	70	83	84	87	84
	Ammonium	60	83	75	86	83	75	82	86
Dry period since last event [d]		2.5	11.3	3.9	3.8	14.3	3.1	55.2	7.8

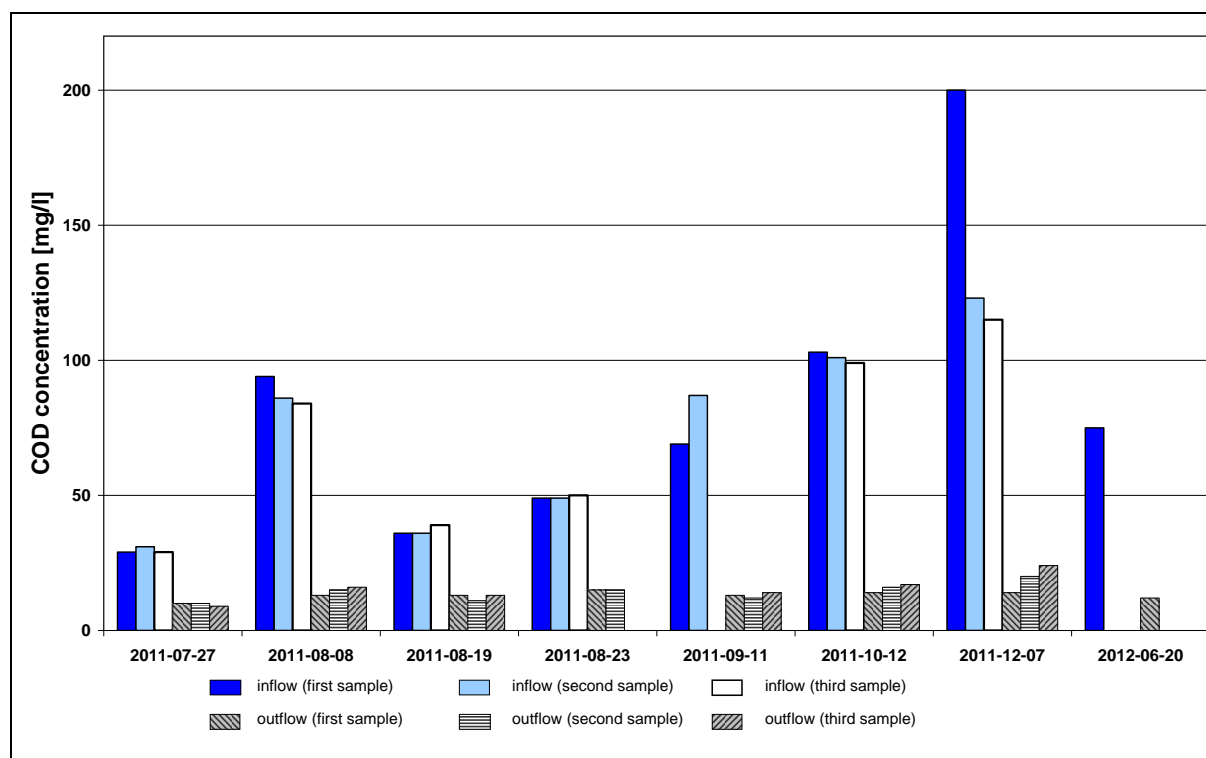


Figure 5: Laboratory results for COD.

4 CONCLUSIONS AND OUTLOOK

Retention soil filters help to effectively mitigate the impact of combined sewer overflow on surface waters. Even after several years of operation, the observed filter in this project retained ammonium and COD efficiently: ammonium between 60 and 86%, COD between 67 and 87% of the inflow concentrations. It proves that RSFs are able to regenerate their capacity to adsorb ammonium even on a large scale. Fewer events than expected in the sampling phase led to the fact that a correlation between a dry period since the last event and the retention of ammonium could not be proved. It seems, however, that a dry period of less than three days weakens the regeneration of the retention capacity for ammonium.

First flush effects were monitored for ammonium in the inflow and nitrate in the outflow by the online electrodes, but could not generally be confirmed for the analysed parameters by the laboratory results. Further investigations with other online electrodes for COD and other parameters would be necessary.

With the help of online electrodes we could also prove that the nitrification of the adsorbed ammonium in the dry period between events mitigate the oxygen depleting effect of CSO on the receiving waters. After several days, ammonification leads to a conversion of organic compounds to ammonium, which is nitrified immediately (Dittmer, 2006). This could be shown by an increase in the nitrate concentration in the outflow after several days: The concentration in the project phase rises with the dry period since the end of the last event. This assumption will have to be proved through further research. To evaluate the impact of the total nitrate load on the receiving waters, an immission-based reflection would be necessary. The impact also depends on the chemical conditions of the receiving waters. If critical loads were reached, an optimisation according to the reduction of nitrate in the outlet would be necessary.

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