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Occurrence and fate of drug residues and related polar contaminants during bank filtration and artificial recharge

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List of Abbreviations

2,4-D	2,4-dichlorophenoxy acetic acid
AMDOPH	1-acetyl-1-methyl-2-dimethyl-oxamoyl-2-phenylhydrazide
BEE	Beelitzhof (designation of the water works located at lake Wannsee)
BWB	Berlin Water Company
GWA	ground water replenishment site
LOQ	limit of quantitation
MCPA	4-chloro-2-methylphenoxy acetic acid
MID	multiple ion detection
n.d.	not detected
NPS	N-(phenylsulfonyl)-sarcosine
o,p'-DDA	2-(2-chlorophenyl)-2-(4-chlorophenyl) acetic acid
OWA	surface water purification plant
p,p'-DDA	2,2-bis(4-chlorophenyl)acetic acid
PhaC's	pharmaceutically active compound
SIM	selected ion monitoring
SPE	solid phase extraction
STP	sewage treatment plant
TEG	Tegel (designation of the water works located at lake Tegel)
TS	transect

1 Pharmaceutically active compounds

1.1 Introduction

This part of the NASRI project provided a quantitative data basis for a better understanding and improvement of the removal of pharmaceutically active compounds (PhAC's) and related polar compounds during groundwater recharge by conducting detailed process studies. Residues of drugs (parent compounds or drug metabolites) originating from therapeutical use in human medical care are excreted unchanged or as water-soluble conjugates via faces and/or urine. Conjugates are easily cleaved in the municipal sewers and/or the receiving sewage treatment plants (STPs). Some of these compounds are not or only partially removed in the municipal STPs and have thus been detected in several samples of surface, ground and drinking waters (Heberer et. al., 2004b). For the investigations within the NASRI project, two highly sensitive analytical methods have been applied to water samples collected monthly from the transects at the lakes Tegel and Wannsee. Using these methods, eight drug residues were identified in the surface water of both lakes and were thus recognized as being important for bank filtration at the investigated field sites. The PhAC's occurring at both field sites included the analgesic/anticonvulsant drugs diclofenac, indometacine and propyphenazone, the antiepileptic drugs carbamazepine and primidone, the blood lipid regulating drug bezafibrate and the two drug metabolites AMDOPH (1-acetyl-1-methyl-2-dimethyl-oxamoyl-2-phenylhydrazide) and clofibric acid. Together with these residues, the herbicides bentazone and mecoprop, NPS (N-(phenylsulfonyl)-sarcosine), a metabolite of a corrosion inhibitor, as well as the herbicide metabolites p,p'-DDA (2,2-bis(4-chlorophenyl)acetic acid) and its isomer o,p'-DDA (2-(2-chlorophenyl)-2-(4-chlorophenyl)acetic acid) were also detected in several samples during these investigations. The observed PhAC's were also subject of further detailed studies. The investigations of their behaviour during bank filtration were accompanied by batch experiments, column studies, slow sand filter and enclosure experiments. Additionally, the ground water replenishment site located at lake Tegel and the surface water purification plant (OWA) Tegel were investigated to get more information about the behaviour of the drug residues during aerobic infiltration and during phosphate elimination treatment, respectively. Besides the monthly sampling at the transects, the distributions of the observed compounds within lake Wannsee as well as the occurrence of these substances in further adjacent surface waters (the river Unterhavel, lake Kleiner Wannsee, and the Teltowkanal) were determined. The results of these investigations are described in detail in this report.

1.2 Methods

The analysis of the collected samples was carried out by solid-phase extraction (SPE), derivatization and detection applying gas chromatography-mass spectrometry (GC-MS) with selected ion monitoring (SIM). As shown in Table 1, a total of twenty pharmaceuticals and seven related polar contaminants, most of them pesticides, were detectable and quantifiable down to the low ng/L range in surface and ground water samples.

Table 1. Detectable compounds, their affiliation and the individual limits of quantification

Compound	Affiliation	LOQ (ng/L)
1-acetyl-1-methyl-2-dimethyl-oxamoyl-2-phenylhydrazide (AMDOPH)	metabolite analgesic	5
2-(2-chlorophenyl)-2-(4-chlorophenyl) acetic acid (o,p'-DDA)	metabolite of an insecticide	10
2,2-bis(4-chlorophenyl)acetic acid (p,p'-DDA)	metabolite of an insecticide	10
2,4-dichlorophenoxyacetic acid (2,4-D)	herbicide	5
4-chloro-2-methylphenoxy acetic acid (MCPA)	herbicide	5
bentazone	herbicide	5
bezafibrate	blood lipid regulator	50
carbamazepine	antiepileptic	5
clofibric acid	metabolite of blood lipid regulator	10
dichlorprop	herbicide	5
diclofenac	analgesic / anticonvulsants	5
fenofibrate	blood lipid regulator	20
fenoprofen	analgesic	5
gemfibrozil	blood lipid regulator	5
ibuprofen	analgesic / anticonvulsants	5
indometacine	analgesic / anticonvulsants	30
ketoprofen	analgesic / anticonvulsants	20
meclofenamic acid	analgesic / anticonvulsants	5
mecoprop	herbicide	5
mefenamic acid	analgesic / anticonvulsants	5
N-(phenylsulfonyl)-sarcosine (NPS)	metabolite of a corrosion inhibitor	30
naproxen	analgesic / anticonvulsants	5
oxazepam	vasodilator	20
pentoxifylline	vasodilator	30
phenacetin	analgesic / anticonvulsants	40
primidone	analgesic / anticonvulsants	5
propyphenazone	analgesic / anticonvulsants	10
tolfenamic acid	analgesic / anticonvulsants	5

1.2.1 Sample preparation procedure

During the sampling 2 liters of water were collected for PhAC analysis. The samples were acidified (<pH 2) with hydrochloric acid and then stored in brown flask at a temperature below 4℃. For each method 500 to 1000 mL of the sample were spiked with 100 ng of the surrogate standards (dehydrocarbamazepine, 4-chlorophenoxybutyric acid) and then directed to SPE (Figure 1). SPE cartridges were dried over night (~ 12 hours) under a gentle stream of nitrogen and then eluated with methanol.

Figure 1. Picture shows the build up of a solid phase extraction

After adding 100 ng of an internal standard (2-(m-chlorophenoxy)propionic acid) to control the derivatization process, the sample was dried again using a gentle stream of nitrogen and derivatized with pentafluorobenzylbromide (PFBBr) or N-(tert.-butyldimethylsilyl)-N-methyl-trifluoroacetamide (MTBSTFA), respectively. Both methods have been elaborated, validated and published. More information on sample preparation, conditions for derivatization, MS conditions, reproducibility and limits of detection and quantitation are also available from Reddersen and Heberer (2003).

1.3 Laboratory & semi technical investigations

1.3.1 Batch experiments

1.3.1.1 Introduction

During the investigations at the transects lake Tegel and lake Wannsee, clofibric acid, metabolite of three different blood lipid regulators, and the antiepileptic drug carbamazepine occurred among other drug residues in surface water and groundwater monitoring wells. At the investigated field sites clofibric acid concentrations were observed with attenuation rates between 43% and 89% during the first meters of infiltration induced by bank filtration (chapter 1.4.4 & chapter 1.4.6) or by artificial groundwater replenishment (chapter 1.4.3). Opposite to this, carbamazepine concentrations at the shallow monitoring wells near the bank were observed to be stable within the measurement accuracy of 20 %. Both substances and ibuprofen which is known to be easily biodegradable [Buser et al, 1999; Stumpf et al., 1998; Winkler et al., 2001] were investigated in two batch experiments with mixtures dissolved in de-ionized water and surface water from lake Wannsee using two different types of Wannsee sediment. Experiments were accomplished in cooperation with the hydrogeology group of the Free University of Berlin. Three different experiments were conducted. In the first approach, only the solvent was spiked. In the second experiment, the spiked solvents were mixed with Wannsee sediment type 2 (WS2, soil from different parts of the aquifer at transect Wannsee) and in the third experiment, spiked solvents were mixed with Wannsee sediment type 3 (WS3, from the colmation layer (the first 10 cm the bottom of lake Wannsee) and sampled over a period of 26 days.

1.3.1.2 Carbamazepine

In the experiments with de-ionized water as solvent (Figure 2, left), carbamazepine concentrations were stable with around 100 % recovery after a period of 26 days.

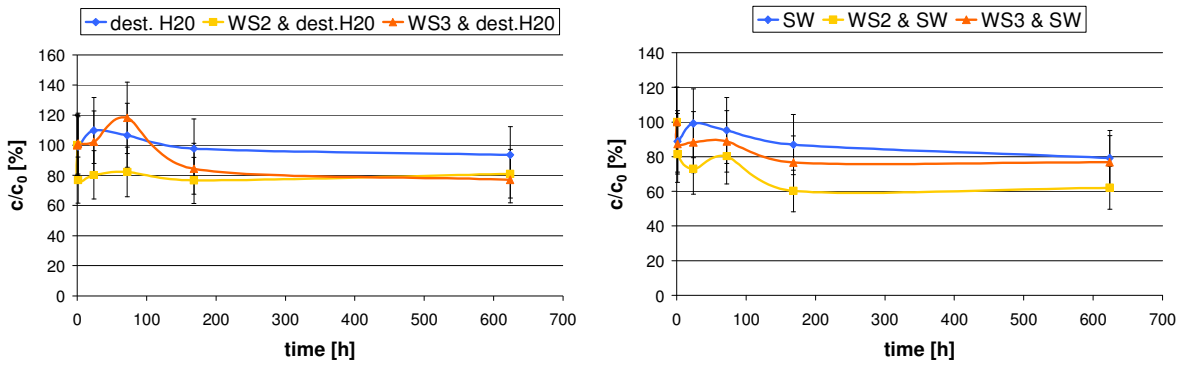


Figure 2. Concentrations of carbamazepine during the batch experiments and a sampling period of 26 days (left: de-ionized water; right: surface water from lake Wannsee)

In the experiments with de-ionized water and Wannsee sediments no.2 or no. 3, the carbamazepine concentrations show a slight decrease down to 80 % of the initial concentration. However, this concentration change is within the measurement accuracy of the analytical method of 20 %. Thus, this obvious decrease is no final proof for the occurrence of effects of sorption or even degradation. As presented in Figure 2 (right), the experiments with surface water showed only one difference, in the mixture with WS2 carbamazepine concentrations decreased to a recovery of 60 % after a contact time of 7 days.

1.3.1.3 Clofibric acid

As illustrated in Figure 3, the observed concentrations of clofibric acid in the batch experiments varied between 85 % and 130 % in de-ionized water and in the mixture with WS2. The experiments with surface water in a mixture with WS2 showed recoveries between 85 % and 110 %. Thus, no significantly attenuation could be recognized for these experiments. In contrary to this, during the experiments with sediment WS3 added to the mixture, a decrease down below the LOD was noticed.

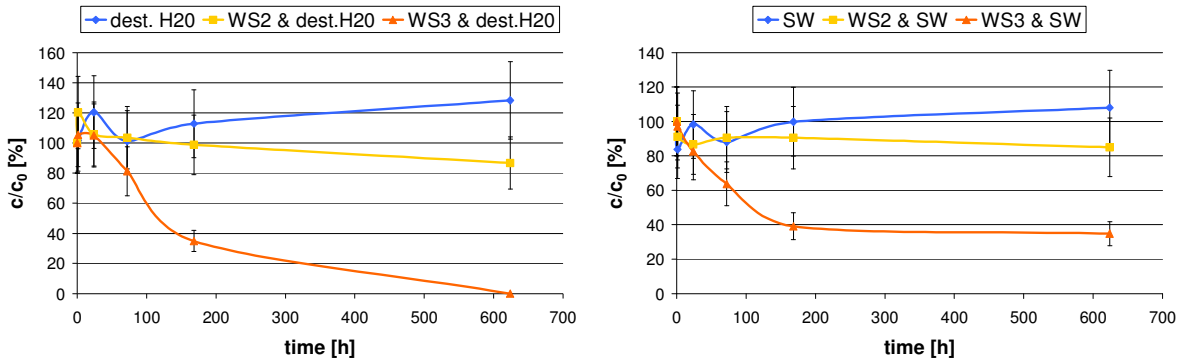


Figure 3. Concentrations of clofibric acid during the batch experiments and a sampling period of 26 days (left: de-ionized water; right: surface water from lake Wannsee)

1.3.1.4 Ibuprofen

After a period of 7 days, ibuprofen concentrations in spiked de-ionized water decreased by 34 % and in spiked surface water by 79 %, as Figure 4 shows. The experiments with added sediments lead to a complete attenuation of ibuprofen. Comparing the different sediment types, the approach with surface water showed a faster attenuation of ibuprofen down to concentrations below the LOD after 7 days.

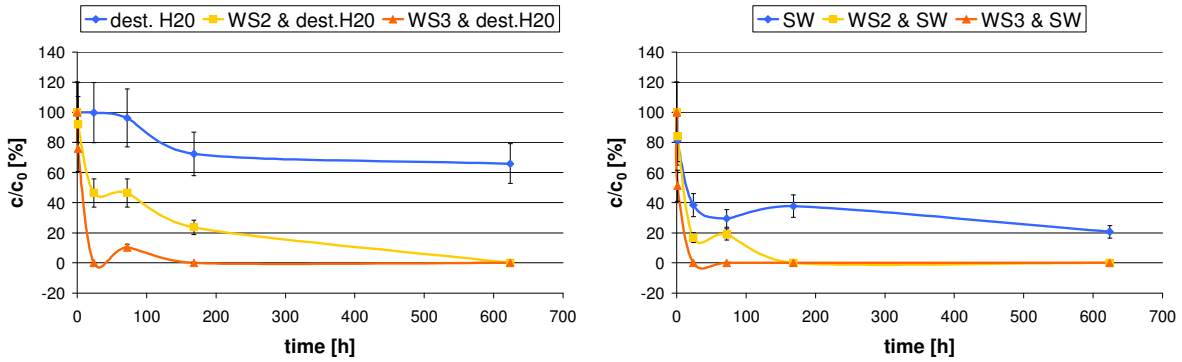


Figure 4. Concentrations of ibuprofen during the batch experiments and a sampling period of 26 days (left: de-ionized water; right: surface water from lake Wannsee)

1.3.1.5 Conclusions

During these experiments it was noticed that carbamazepine showed no (within the analytical measurement accuracy of 20%) attenuation when dissolved in de-ionized water or additionally mixed with WS2 and WS3. However, when using surface water and surface water with added Wannsee sediments a slightly attenuation between 20% and 40 % was recognized. No tendencies for decrease were observed for dissolved clofibric acid or with the added soil material from the aquifer (WS2) at transect Wannsee. Opposite to this behaviour, added sediments from the colmation layer (WS3) lead to attenuations within a range of

concentrations below the LOD up to 40 % of initial concentrations. As expected from other studies [Buser et al. 1999; Stumpf et al. Winkler, 2001, Zwiener et al., 2000], ibuprofen only dissolved in de-ionized water was easily removed with an attenuation rate of 35 % and rapidly when using surface water instead of de-ionized water. Dissolved in both kinds of water and in contact with Wannsee sediments WS2 and WS3, a complete degradation was observed after period of 26 days.

1.3.2 Sand filtration experiments

1.3.2.1 Introduction

In this part of the NASRI project, the fate of four selected pharmaceuticals during sand filtration was investigated. Four experiments were carried out at the test-field site of the *Umweltbundesamt* (UBA, German Federal Environmental Agency) in Berlin-Marienfelde. Enclosure No. 3, which was used in the experiments presented here. Additional informations are available.

Contaminant-free groundwater from the area underneath this filed-site was used to fill the storage pond and to carry out the experiments at the sand filtration facility. Some parameters measured for this water are shown in Table 2.

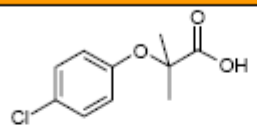
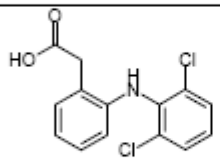
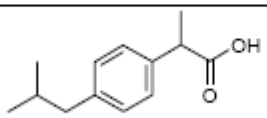
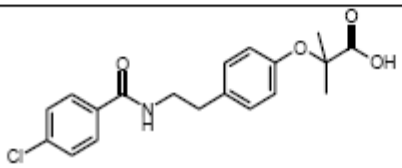
Table 2. Physical-chemical parameters measured of the groundwater used for the experiments

Cations			
Na^+	K^+	Ca^{2+}	Mg^{2+}
46,4	4,3	125	17,7
Anions			
SO_4^{2-}	NO_3^-	PO_4^{3-}	SO_4^{2-}
236	0,3	<0,1	236
Other parameters			
DOC^2	pH	conductivity	
5,5 mg/L	7,8	963 µS/cm	

Four pharmaceuticals, namely clofibric acid, diclofenac, ibuprofen, and bezafibrate were chosen for this study. All four substances have already been found in the aquatic environment and have been selected as model-substances due to their different physical-

chemical properties and their expected or reported different behaviour during groundwater recharge.

Table 3. Selected pharmaceuticals

Name	Structure	Molecular weight totals formula	Group of prescription/use
Clofibric acid		296,2 $C_{14}H_{11}Cl_2NO_2$	blood lipid lowering agent (metabolite)
Diclofenac		214,7 $C_{10}H_{11}ClO_3$	non-steroidal antiphlogistic
Ibuprofen		203,3 $C_{13}H_{18}O_2$	non-steroidal antiphlogistic
Bezafibrate		361,8 $C_{19}H_{20}ClNO_4$	blood lipid lowering agent

1.3.2.2 Slow sand filter experiment no. SSF3

A first experiment (slow sand filter experiment SSF3) with clofibric acid and diclofenac was carried out with one of the slow sand filters, where only samples from surface water and outlet could be taken. Results are shown in Figure 5

Tabelle 1. Experimental conditions of enclosure experiment #1

Slow sand filter experiment #1 (SSF3)		
Date	23.– 25.04.2003	
Flow rate	6.4 m^3/h	
Filtration velocity	2.1 m/d	
Initial concentration of pharmaceuticals	clofibric acid	diclofenac
	1µg/L	1µg/l
Condition of the sediment surface	large algae growth	

In addition, sodium chloride was added as a tracer and conductivity was measured by the working group of Dr. Chorus from the Federal Environmental Agency (UBA). The results from this experiment are shown in Figure 5.

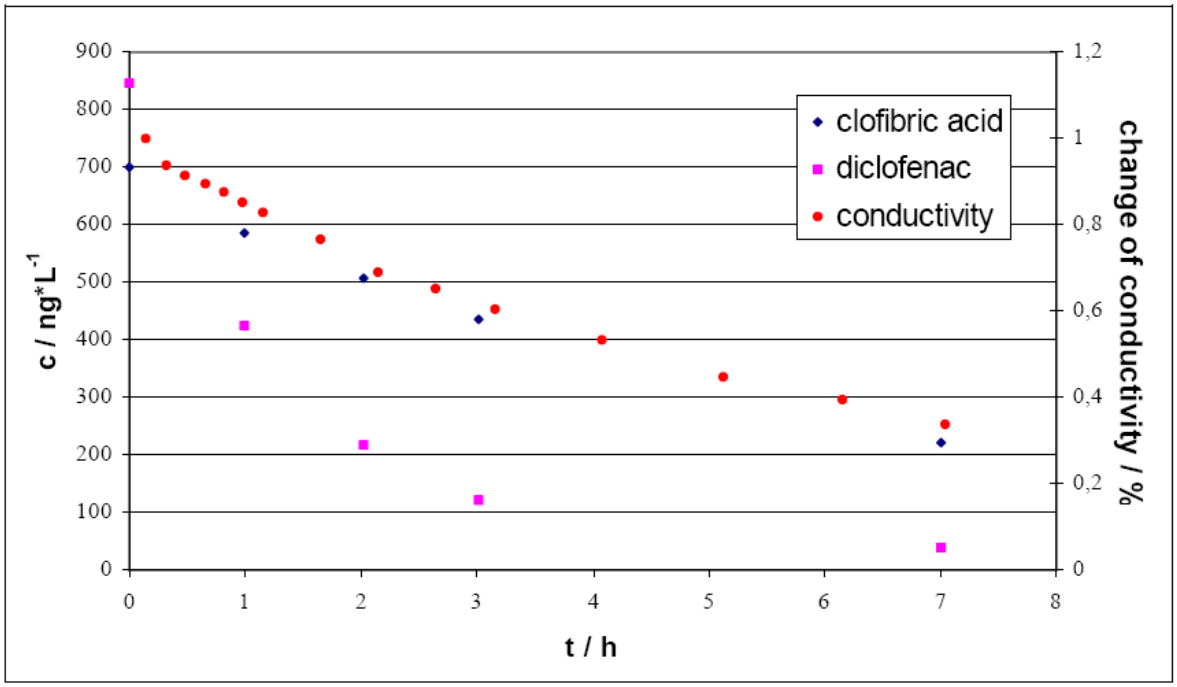


Figure 5. Concentrations of pharmaceuticals and temporal change of conductivity measured in spiked surface water during slow sand filter experiment #1 (23.-25.04.2003).

As can be seen from the results of this experiment presented in Figure 6, the concentration of clofibric acid changed similar to the concentration of sodium chloride that was observed by measuring the conductivity. Thus, clofibric acid showed the tracer-like behavior that has already been described for this substance in various references for this substance (e.g. Mersmann et al., 2002; Verstraeten et al., 2002). In contrast to that, there is a distinct decrease of the diclofenac concentration was observed in the surface water and it was assumed that this was caused by photolytical degradation, which has previously been reported for diclofenac in the literature (Buser et al., 1998, Tixier et. al., 2003).

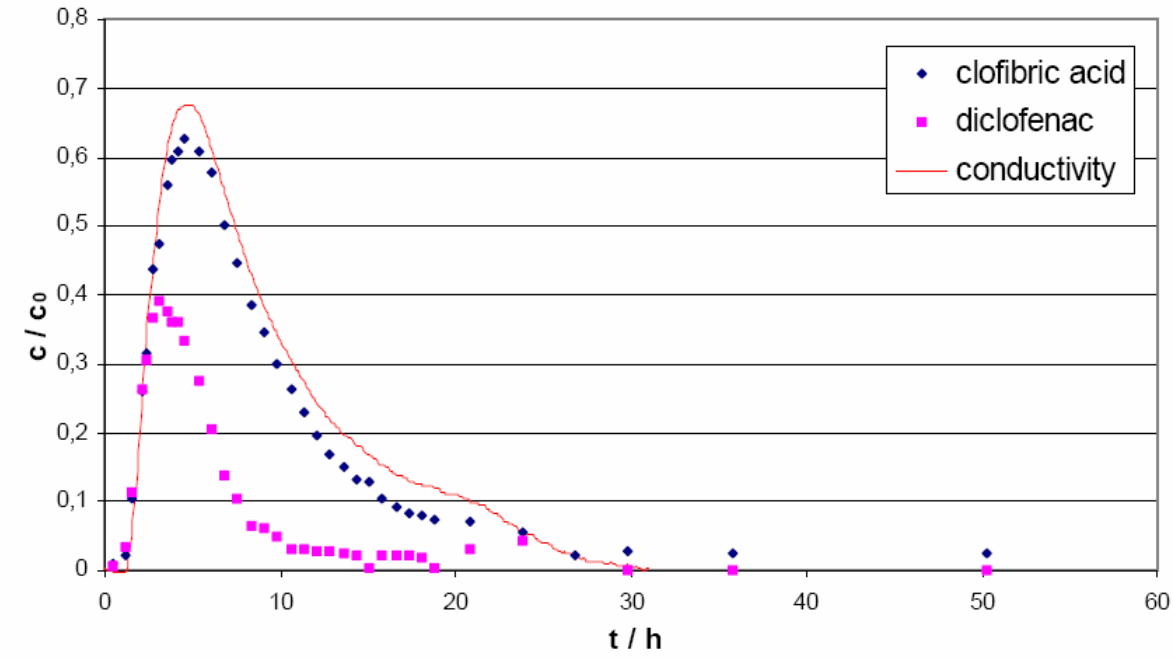


Figure 6. Proportions (c/c_0) of pharmaceuticals and temporal change of conductivity measured at the outlet of slow sand filter during slow sand filter experiment #1 (23.-25.04.2003).

A mass balance was calculated which showed that 70% of the infiltrated amount of clofibric acid was detected at the outlet, while only 30% of the spiked amount of diclofenac was recovered (for diclofenac photolytical degradation has to be taken into account resulting in an unknown amount of diclofenac that was removed from the surface water without being infiltrated into the sand filter).

1.3.2.3 Slow sand filter experiment no. SSF5

The experiment was repeated two month later (slow sand filter experiment #2) under different conditions and with all four substances to a test mixture (clofibric acid, diclofenac, ibuprofen, bezafibrate) applied to the slow sand filters. Again sodium chloride was used as a tracer. Additionally, microcystines (algae toxins) and bacteriophages (viruses) were added by the two working groups from the UBA (Chorus/Lopez-Pila).

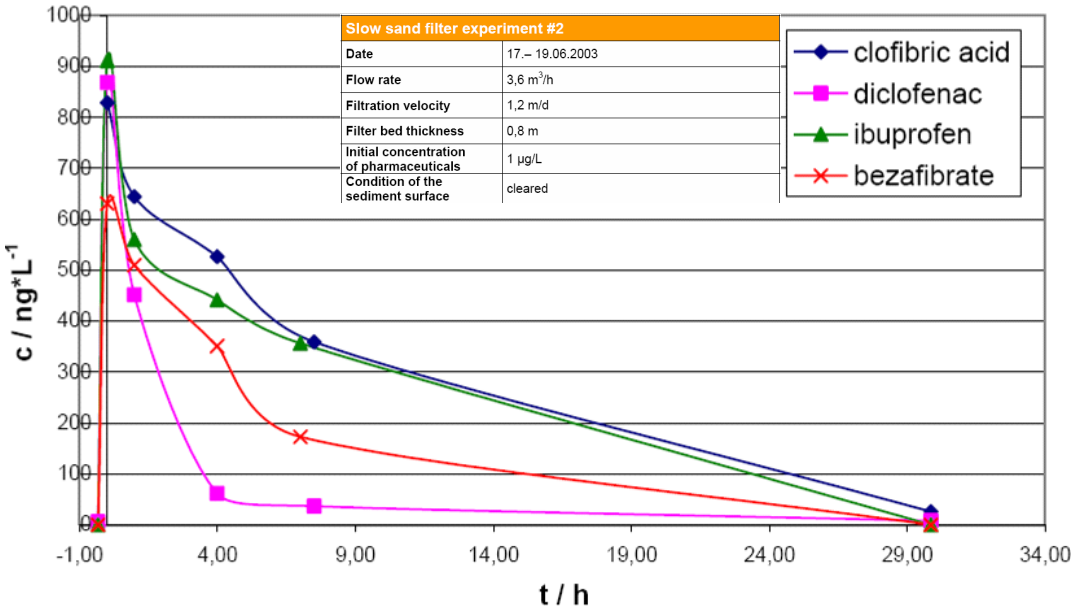


Figure 7. Concentrations of pharmaceuticals and temporal change of conductivity measured in the spiked surface water during slow sand filter experiment #2 (17.-19.06.2003). Additionally experiment parameters are shown.

The results for clofibric acid and diclofenac shown in Figure 7 were comparable to those of slow sand filter experiment #1. The calculated mass balance showed that in this experiment 85% (70% SSF3) of the infiltrated amount of clofibric acid and 30% (30% SSF3) of the initial amount of diclofenac could be recovered in the outlet as presented in Figure 8.

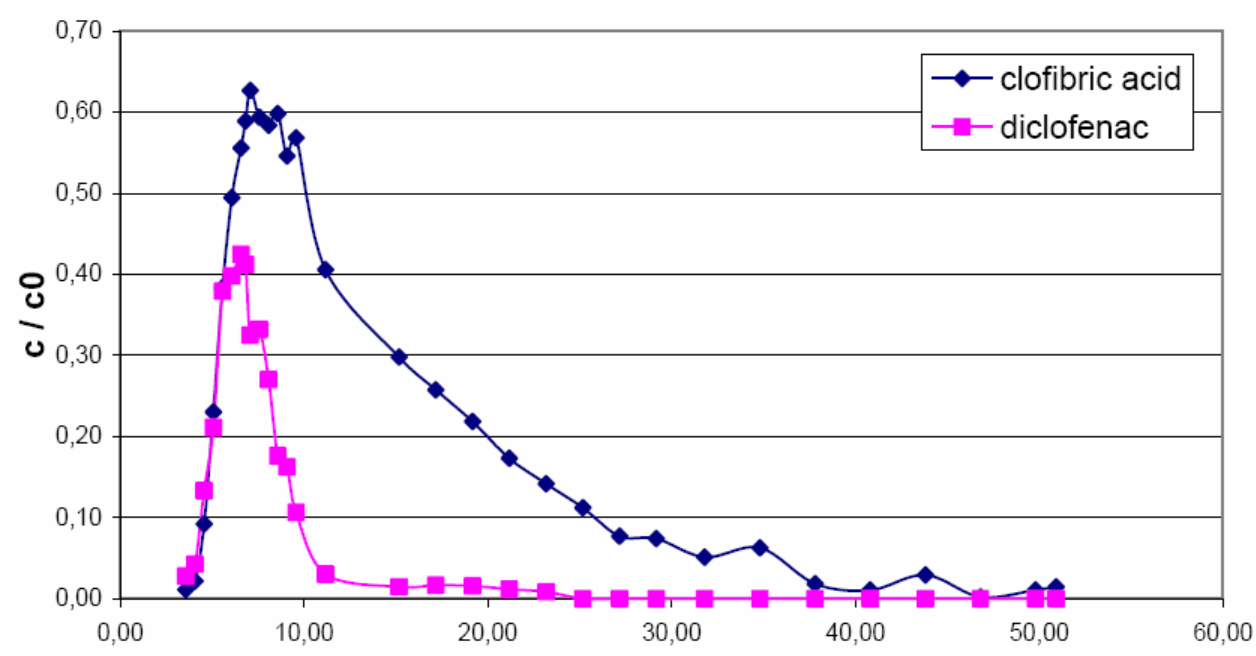


Figure 8. Proportions (c/c0) of pharmaceuticals and temporal change of conductivity measured at the outlet of slow sand filter during slow sand filter experiment #2 (17.-19.06.2003).

The two additional substances ibuprofen and bezafibrate were fully attenuated during slow sand filtration and could not be detected in the outlet.

1.3.2.4 Enclosure experiments E2o, E3d, E4d & E5d

Behavior of clofibric acid, diclofenac, bezafibrate and ibuprofen during experiment no. E2o

The first enclosure experiment (E2o) was carried out in August 2003. The joined experiments were carried out together with several other groups of the NASRI project. Besides PhAC's some other compounds (microcystines, viruses, Gadolinium and again sodium chloride as a tracer) were also spiked to the feed water of the enclosures. Therefore, and a minor sample-volume of only 25ml/min could be collected at the four sampling-points the initial concentrations of our pharmaceuticals had to be increased. The enclosure was covered to protect the UV-sensitive bacteriophages and to avoid photochemical reactions. Table 4 shows the experimental parameters during enclosure experiment no. 1.

Table 4. Experimental conditions of enclosure experiment #1

Enclosure experiment #1 (E2o)		
Date	05.– 06.08.2003	
Flow rate	0,05 m^3/h	
Filtration velocity	1,3 m/d	
Initial concentration of pharmaceuticals	clofibric acid diclofenac	ibuprofen bezafibrate
	2µg/L	5µg/l
Condition of the sediment surface	cleared	

Figure 9 shows the temporal changes of concentrations for the four spiked pharmaceuticals in the supernatant water layer. Apart from their different initial concentrations, the change of concentration was quite similar for all four substances. The rapid decrease of the diclofenac concentration that was observed in the first slow sand filter experiments did not occur because the enclosure was covered. This result also confirmed the assumption of a photolytical degradation of diclofenac in the supernatant water layer in both experiments with slow sand filtration. Therefore, adsorption at the top of the sand filtration facilities can be excluded being an important cause for the decrease of the diclofenac concentration. The results measured for all four pharmaceuticals in the column of the enclosure at a depth of 20cm are presented in Figure 9.

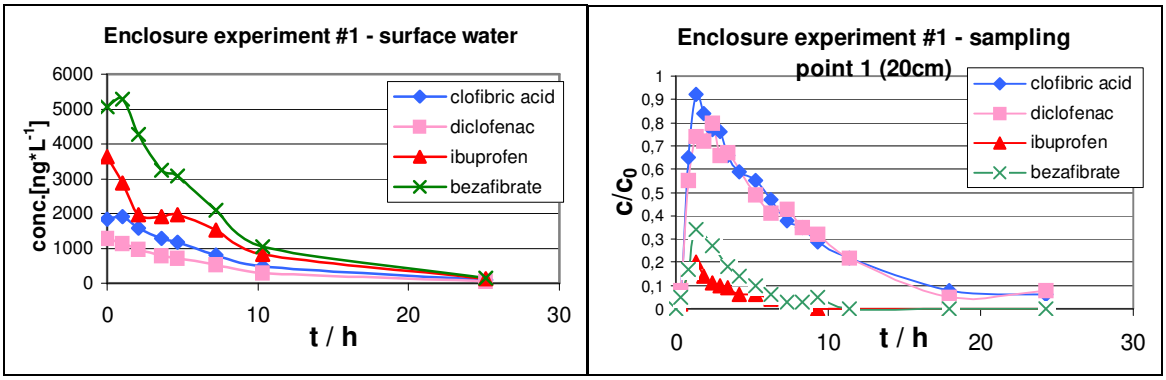


Figure 9. Concentrations of pharmaceuticals measured in the spiked surface water and breakthrough curves at a depth of 20cm during enclosure experiment #1 (E2o)

Ibuprofen and bezafibrate were already strongly attenuated resulting in rather low maximum c/c_0 values of <0.4 and <0.2 respectively. From the mass balance it was calculated that only 10% and 20% of the infiltrated amount of ibuprofen and bezafibrate were found at sampling-point #1, respectively. In contrast to that clofibric acid was found at about 80% and diclofenac at about 85% of the initial amount.

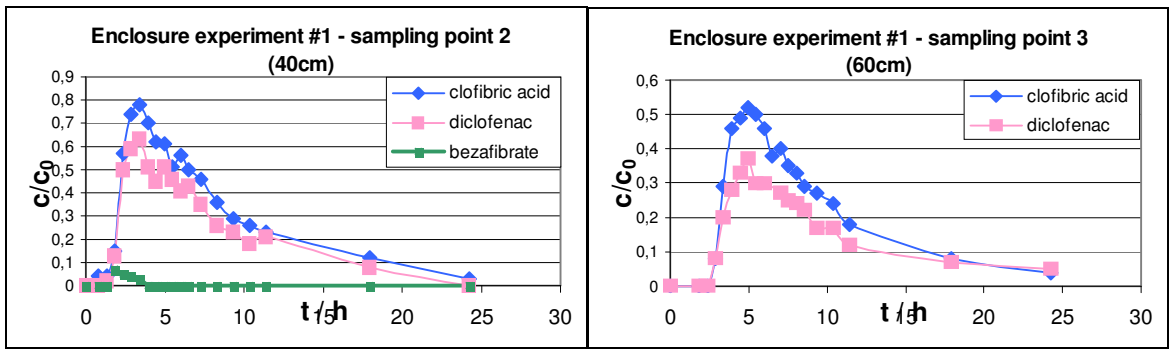


Figure 10. Breakthrough curves of pharmaceuticals measured at a depth of 40cm and 60cm in the enclosure during enclosure experiment #1 (E2o)

As shown in Figure 10 ibuprofen was not detected any longer after a passage of 40cm. Only about 2% of the initial quantity of bezafibrate was recovered at sampling-point #2, while the mass balance resulted in 70% and 65% of the initial amount for clofibric acid and diclofenac, respectively. The decrease of the recovered quantities continued at sampling-point #3 (60cm). 50% and 40% of the initial amounts of clofibric acid and diclofenac were found here, respectively. Bezafibrate was not detected in any sample from this sampling-point.

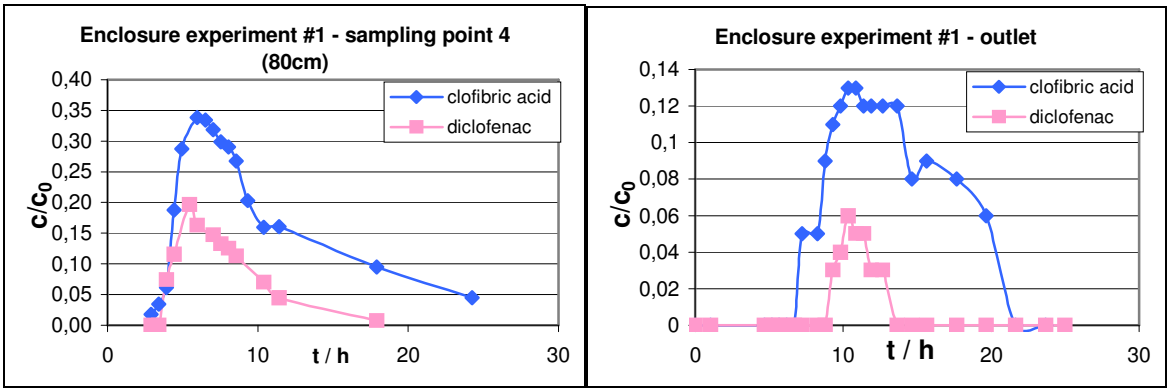


Figure 11. Breakthrough curves of pharmaceuticals measured at a depth of 80cm and enclosure outlet during enclosure experiment #1 (E2o)

Figure 11 shows the breakthrough curves for clofibric acid and diclofenac after 80cm (sampling-point #4), which is comparable to the thickness of the filter bed of the slow sand filtration units, described before. In contrast to both experiments at the slow sand filter, a significant decrease of the clofibric acid concentration was observed in enclosure experiment #1. After 80cm only 35% of the initial amount was detected. Finally in the outlet (Figure 11) there were only 15% and 5% of clofibric acid and diclofenac found, respectively.

Results for clofibric acid and diclofenac are summarised in Figure 12. Similarly, the amount of diclofenac recovered at enclosure outlet were also much lower (15%) than in the slow sand filtration experiments (~30%), although photolytic degradation was inhibited by covering the enclosures.

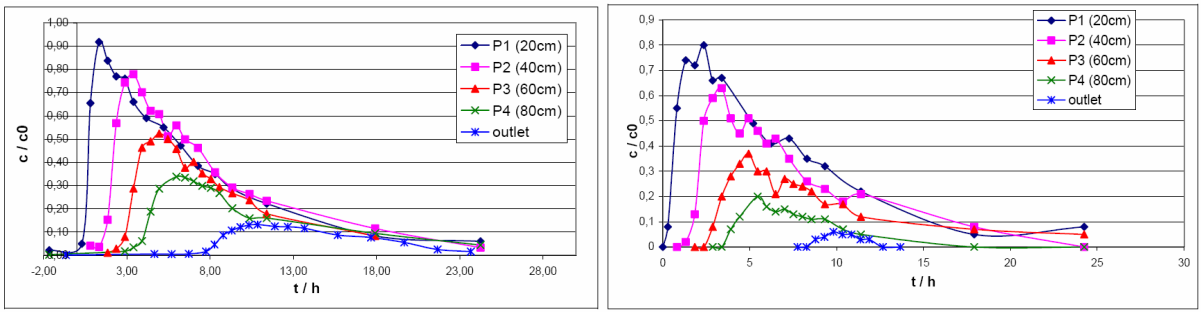


Figure 12. Breakthrough curves of clofibric acid and diclofenac measured during enclosure experiment #1 (E2o)

In contrast to that, the data of the conductivity measurement was nearly identical to those of the first two slow sand filtration experiments resulting in the breakthrough curves shown in Figure 13.

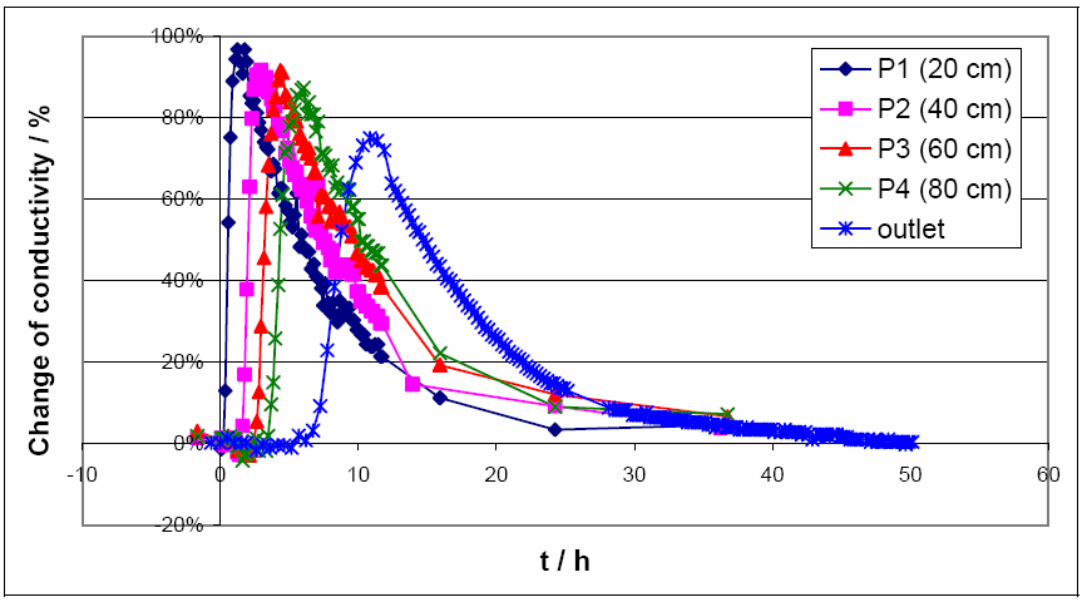


Figure 13. Temporal change of conductivity measured during enclosure experiment #1 (E2o)

These curves showed only the typical decrease of the maximum conductivity after breakthrough caused by dispersion. Thus, a distinct difference between the conductivity data and the results for clofibric acid was observed in this experiment.

Behavior of clofibric acid, diclofenac, bezafibrate and ibuprofen during experiment no. E3d

The second experiment (E3d) at the enclosures was carried out one month later. Table 5 shows the experimental parameters during enclosure experiment no. 1.

Table 5. Experimental conditions of enclosure experiment #2

Enclosure experiment #2 (E3d)		
Date	09.– 10.09.2003	
Flow rate	0,05 m^3/h	
Filtration velocity	1,1 m/d	
Initial concentration of pharmaceuticals	clofibric acid diclofenac	ibuprofen bezafibrate
	2µg/L	5µg/l
Condition of the sediment surface	slightly developed clogging layer	

For ibuprofen and bezafibrate the results of the first enclosure experiment were also confirmed in this experiment. However, both substances appeared to be removed even more efficiently in this experiment with a slightly developed clogging layer. After 20cm (Figure 14) only about 3% of bezafibrate and 1% of ibuprofen were recovered, respectively. However, about 85 % of the infiltrated amount of Clofibric acid could be recovered. For diclofenac the calculated mass balance resulted 115%, obviously caused by unavoidable mistakes of the used analytical and mathematical methods.

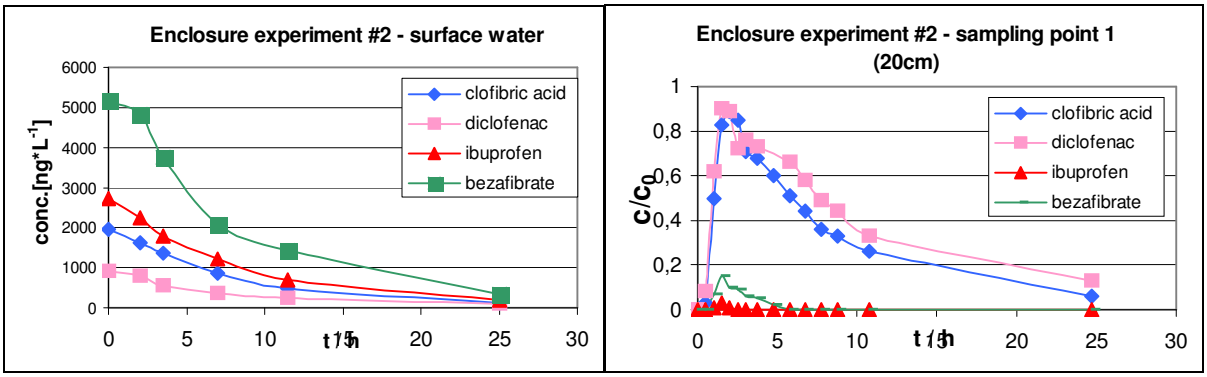


Figure 14. Concentrations of pharmaceuticals measured in the spiked surface water during enclosure experiment #2 (E3d)

As shown in Figure 15, ibuprofen could not be observed after 40 cm (sampling point 2). Bezafibrate is recovered at about 1 %, while clofibric acid and diclofenac were found at levels of 80 % and 110 % of the initial amounts, respectively.

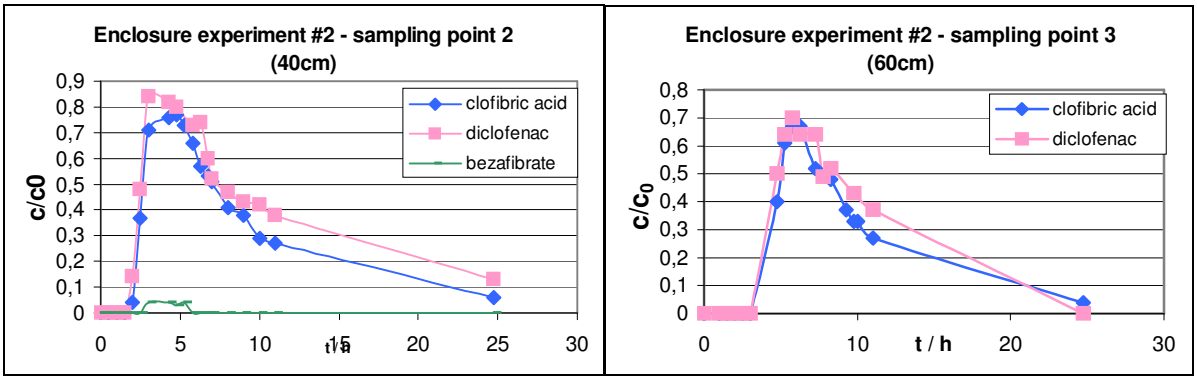


Figure 15. Breakthrough curves of pharmaceuticals measured at a depth of 40cm and 60cm in the enclosure during enclosure experiment #2 (E3d)

Clofibric acid and diclofenac were found at 65 % and 80 % of the infiltrated quantity after 60 cm (sampling point 3), respectively.

At sampling-point #4 (80cm depth) shown in Figure 16, the mass balance resulted in a recovery of 60% of the initial amount of diclofenac. For clofibric acid the results of enclosure experiment #2 did not confirm those of experiment #1. 55% of the initial quantity of clofibric acid was detected at sampling-point 4.

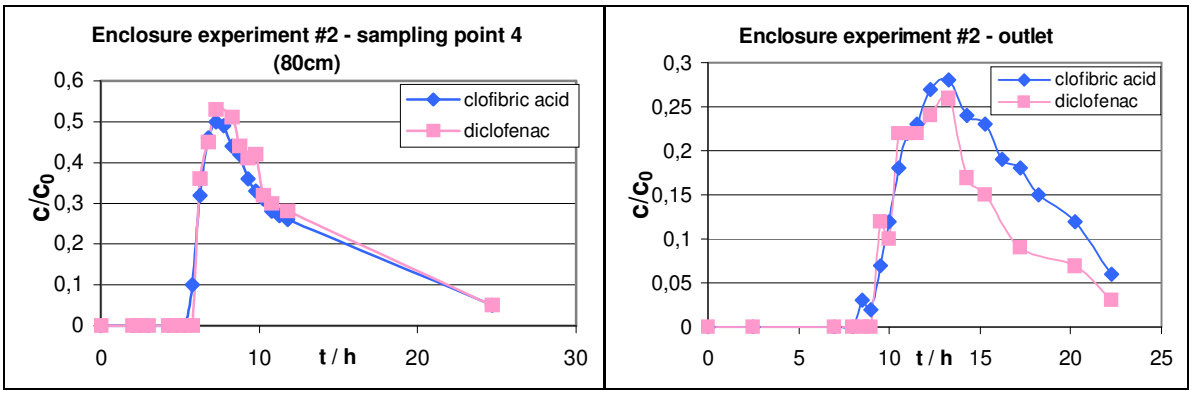


Figure 16. Breakthrough curves of pharmaceuticals measured at a depth of 80cm and enclosure outlet during enclosure experiment #2 (E3d)

This is still less than the amount that was recovered in the first two slow sand filtration experiments, but the dramatic decrease of the total amount of clofibric acid that was observed in the first enclosure experiment (35%) was not observed again.

Behavior of carbamazepine, clofibric acid, diclofenac, ibuprofen and primidone during experiment no. E4d

The third and fourth enclosure experiments were carried out during November 11th - November 12th and during November 25th - 26th. Opposite to enclosure experiment no. E2o and E3d, added target compounds were varied. Additionally to clofibric acid, diclofenac and ibuprofen, the antiepileptic drugs carbamazepine and primidone were spiked to the feed water of the enclosure. The parameters of the enclosure experiment E4d are shown in Table 6.

Table 6. Experimental conditions of enclosure experiment #3

Enclosure experiment #3 (E4d)		
Date	11.– 12.11.2003	
Flow rate	0,05 m^3/h	
Filtration velocity	1,2 m/d	
Initial concentration of pharmaceuticals	carbamazepine diclofenac ibuprofen	clofibric acid primidone
	2 - 3 µg/L	4 µg/L
Condition of the sediment surface	cleared	

Over a period of 50 hours during experiment no. 3, samples were collected at two different depths of 40 cm and 80 cm. After 2.6 hours all compounds excluding ibuprofen could be observed at maximum relative concentrations between 74 % and 96 % at the first sampling point (40 cm) as shown in Figure 17. Ibuprofen was only detected at a maximum relative concentration of 20 %.

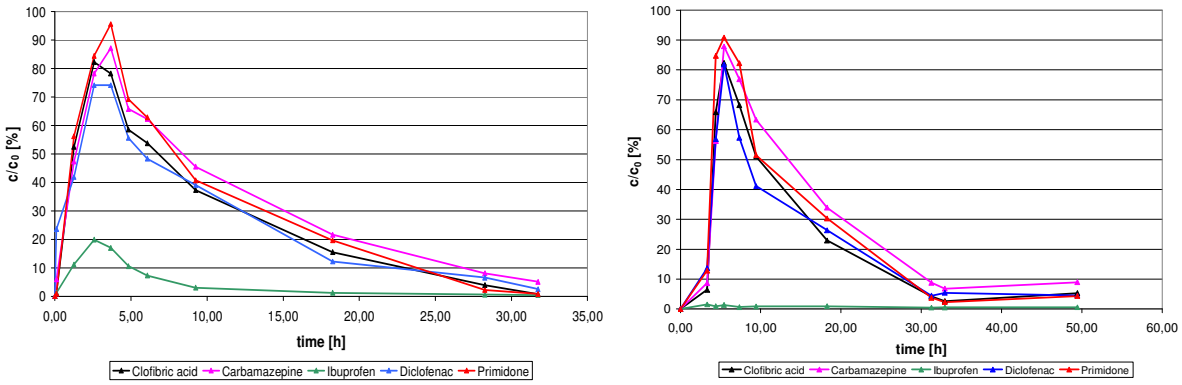


Figure 17. Breakthrough curves of pharmaceuticals measured at two different depths (40cm & 80cm) during enclosure experiment #3 (E4d).

At the second sampling point (80cm), ibuprofen concentrations were below the limit of quantification. The other compounds show maximum recoveries between 80 and 90 %.

Behavior of carbamazepine, clofibric acid, diclofenac, ibuprofen and primidone during experiment no. E5d

The fourth enclosure experiment was carried out during the 25. & 26.11.2003 and was a repeat of experiment E4d. The spectrum of spiked compounds and other experiment

parameters like flow rate etc. were unchanged and are shown in Table 7. Only the initial concentration of ibuprofen was increased to 4 - 5 µg/L to obtain concentrations above limit of quantification at the second sampling point (80 cm). Sediment surface was not cleared before the experiment.

Table 7. Experimental conditions of enclosure experiment #4

Enclosure experiment E5d		
Date	25.– 26.11.2003	
Flow rate	0,05 m^3/h	
Filtration velocity	1,2 m/d	
Initial concentration of pharmaceuticals	carbamazepine diclofenac	clofibric acid ibuprofen primidone
	2 - 3 µg/L	4 - 5 µg/L
Condition of the sediment surface	slightly developed clogging layer	

The results for the fourth enclosure experiment (E5d) were absolutely comparable to the former experiment E4d and are shown in Figure 18 . Carbamazepine, clofibric acid, diclofenac and primidone were observed with recoveries between 84 % and 96 % of initial concentrations after a passage of 40 cm at sampling point 1. In spite of the increased initial concentration, ibuprofen was again observed with a recovery around 20 %. That is very similar to the result of the former experiment. After a passage of 80 cm (sampling point 2) ibuprofen was below limit of quantification. The other substances show recoveries from 74 % to 84 %.

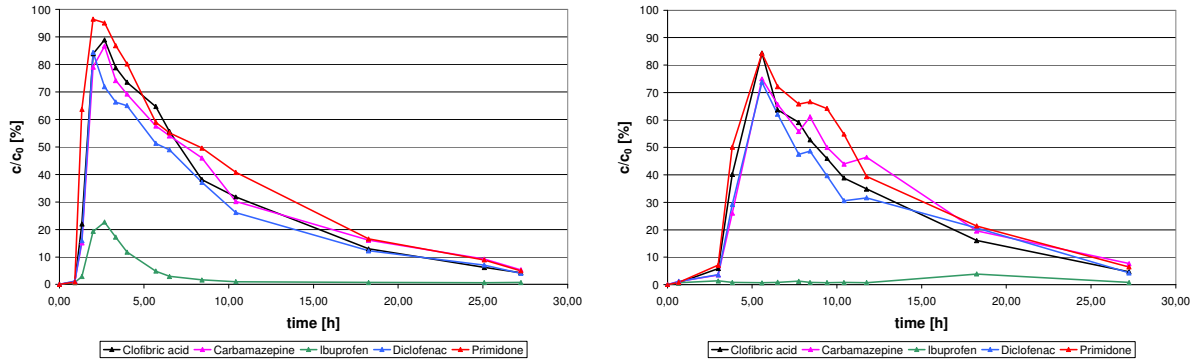


Figure 18. Breakthrough curves of pharmaceuticals measured at two different depths (40cm & 80cm) during enclosure experiment #4 (E5d).

Using the added tracer (sodium chloride) the experiment parameters like filtration and distance velocity etc. were determined by using Visual CXTFIT and are shown in Table 8.

Table 8. Calculated experiment parameters using Visual CXTFIT

Experiment no.	E4d		E5d	
Sampling point	40 cm	80 cm	40 cm	80 cm
Condition of sediment surface	cleared	cleared	not cleared	not cleared
Filtration velocity vf [m/h]	0.051	0.051	0.045	0.045
Distance velocity va [m/h]	0.38	0.32	0.5	0.35
Dispersion coefficient D [-]	0.008	0.02	0.04	0.08
Dispersion length αL [cm]	2.11	6.3	8.00	22. 9
Effective pore volume nf [%]	13.4	15.9	9.00	12. 9

The retardation coefficients and the attenuation coefficients of the investigated substances were calculated using the experiment parameters in Table 8. Results of Visual CXTFIT for the spiked drug residues are presented in Table 9.

All compounds showed retardation during the soil passage. Only minor attenuation coefficients ($\mu < 0.1\ h^{-1}$) caused by adsorption or metabolism were observed for all tested compounds excluding ibuprofen. For ibuprofen a higher attenuation coefficient of 1.6 up to 2.0 h^{-1} was calculated. The condition of sediments surface did not have any significantly effect on the attenuation and the retardation coefficients of the compounds carbamazepine, clofibric acid, diclofenac and primidone. In contrast, for ibuprofen the retardation coefficient increased from 1.5 up to 2.9 after 80 cm of soil passage.

Table 9. Calculated attenuation and retardation coefficients using Virtual CXTFIT

Compound	Parameter	40 cm [cleared]	80 cm [cleared]	40 cm [not cleared]	80 cm [not cleared]
Clofibric acid	retardation coefficient R	1.4	1.5	1.2	1.5
	attenuation coefficient μ [h^{-1}]	0.00	0.05	0.00	0.00
Carbamazepine	retardation coefficient R	1.5	1.7	1.3	1.5
	attenuation coefficient μ [h^{-1}]	0.00	0.04	0.00	0.00
Diclofenac	retardation coefficient R	1.4	1.6	1.6	1.5
	attenuation coefficient μ [h^{-1}]	0.09	0.10	0.00	0.03
Ibuprofen	retardation coefficient R	1.6	1.5	2.0	2.9
	attenuation coefficient μ [h^{-1}]	1.6	2.0	2.0	2.0
Primidone	retardation coefficient R	1.0	1.5	1.0	1.3
	attenuation coefficient μ [h^{-1}]	0.00	0.00	0.00	0.00

1.3.2.5 Conclusions for the slow sand filter experiments and enclosure experiments

The results from the experiments at the UBA facilities show that sand filtration is an efficient method to remove several selected residues of pharmaceuticals such as ibuprofen and bezafibrate. This was confirmed by the slow sand filter experiments where both substances were not detected in the outlet. This result was also confirmed in enclosure experiments E2o & E3d where the calculated mass balance showed that both substances are already significantly attenuated in the first cm of the sand passage. Additionally, in enclosure experiments E4d (just cleared surface) and E5d (slightly developed colmation layer) ibuprofen has also been removed about 80 % after 40 cm soil passage. In enclosure experiment E3d, with a slightly developed clogging layer, the removal seemed to be even more efficient. This may indicate that ibuprofen and bezafibrate are subject to a microbial degradation and that their removal is not only a result of an adsorption to the sediment. This is also in line with results from other studies investigating these substances, which describe

bezafibrate as a substance with sorption properties (Ternes et al., 2002) and ibuprofen to be well degradable by microorganisms under aerobic conditions (Zwiener et al., 2000). For diclofenac the enclosure experiments approved the assumption of a photolytic degradation reported by Buser et al. (1998). Thus, the rapid decrease of the diclofenac concentration that was observed in the first two experiments with slow sand filtration did not occur in the covered enclosure experiments carried out in the dark. Enclosure experiments E2o and E3d show that diclofenac can be significantly attenuated but not completely removed by sand filtration. Contrary to this, attenuation rates of diclofenac observed during the enclosure experiments E4d and E5d were negligible. Clofibric acid showed a different and varying attenuation behavior in these experiments. Especially, the results of enclosure experiment E2o and enclosure experiments E4d and E5d as well as the first two experiments with slow sand filtration (SSF3 & SSF5) are contradictory. A recovered amount of only 35 % of the initial quantity after 80 cm sand passage in enclosure experiment (E2o) was not expected for this substance, which has been described as being rather persistent (Zwiener et al., 2000; Ternes et al., 2002, Andreozzi et al., 2003) and mobile (Mersmann et al., 2002) during groundwater recharge. As described above the first two experiments SSF3 & SSF5 seemed to confirm this behavior during sand filtration, too. Nevertheless, it was also reported that sand filtration has a certain ability to remove clofibric acid (Sacher et al., 2000; Preuß et al., 2001). Several suggestions were considered about the differences between the experiments that could possibly give an explanation for the observed differences. For example, it was suggested that there was an increased microbial activity caused by the high temperatures during enclosure experiment E2o in August 2003. On the other hand, results of the first two experiments were comparable, although data showed that at least air temperatures varied stronger between these experiments than for example between slow sand filter experiment SSF5 and enclosure experiment E2o. Other considerations were made concerning a possible adaption of microorganisms at the filtration facility after the first two experiments or experimental errors like the usage of methanol helping to dissolve the pharmaceuticals for the experiments at the slow sand filter. But finally the observed differences could not be explained satisfactorily. For the antiepileptic drugs carbamazepine and primidone no significant removals were observable during enclosure experiments E4d & E5d.

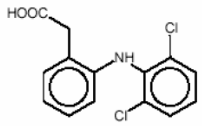
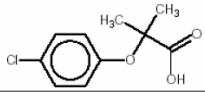
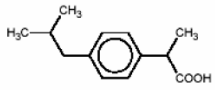
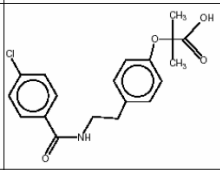
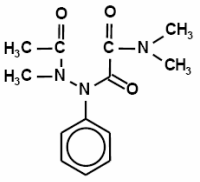
1.3.3 Column experiments

1.3.3.1 Long column experiments

Behavior of AMDOPH, bezafibrate, clofibric acid, diclofenac, and ibuprofen during long column experiments

The study investigating the mobility of pharmaceutical residues in the long column studies was divided into two experiments. At first, the selected compounds shown in Table 10 were added for two weeks (May 12th – May 26th) at a concentration of around 1.5 µg/l. Samples were only taken at the end of the soil column using an auto sampler for 13 weeks (until August 11th).

Table 10. Selected pharmaceuticals and some chemical properties

Compound	Structure	Mol. weight and formula	Log K_{ow}	solubility	Indication group
Diclofenac		296.2 $C_{14}H_{11}Cl_2NO_2$	4.51	2.37 mg/l	Antiphlogistic/ Antirheumatic
Clofibric Acid		214.7 $C_{10}H_{11}ClO_3$	2.57	582.5 mg/l	Blood lipid regulator (Metabolite)
Ibuprofen		203.3 $C_{13}H_{18}O_2$	3.97	21.0 mg/l	Antiphlogistic/ Antirheumatic
Bezafibrate		361.8 $C_{19}H_{20}ClNO_4$	4.25	k.A.	Blood lipid regulator
AMDOPH		263.2 $C_{13}H_{17}N_3O_3$	k.A.	k.A.	Metabolite of the antiphlogistic Dimethylamino-phenazone (no longer produced since 1978)

In addition, samples from sampling point 1-0 were taken twice to measure the actual influent/feed concentration of the pharmaceuticals. In the second experiment, the inflow/feed water was spiked at the same concentration for one week (June 23rd – June 30th) to investigate the behavior of the added compounds within the first few decimeters of the

column. Assuming that degradation and adsorption take place especially in the first meter of the column, samples have been taken manually once a day at sampling points 1-1 (21 cm), 1-3 (84 cm) and 1-4 (166 cm). A list of all collected samples is shown in table 11.

Table 11 Overview of all samples collected during this study.

Description	Volume*	Dates of Sampling	Details
Lake Tegel	100 ml	May: 12., 23.; June: 3., 12., 24. July: 7., 21.; August: 4.	Taken from the storage tank after each filling
Col 1-0 (ColIn)	50 ml	May: 12., 23.; June: 26., 30.	
Col 1-1 (21 cm)	50 ml	June: 20., 23.-30. July: 1.-5., 7., 8.	No samples on 21./22. 6. and 6.7. (weekend)
Col 1-3 (84 cm)	50 ml	June: 20., 23.-30. July: 1.-5., 7., 8.	No samples on 21./22. 6. and 6.7. (weekend)
Col 1-4 (166 cm)	50 ml	June: 20., 23.-30. July: 1.-5., 7., 8.	No samples on 21./22. 6. and 6.7. (weekend)
Col6Out (column outlet)	100 ml	May: 16.-26. June: 3.-30. July: 1.-31. August: 1.-11.	

* volume used for one analysis

Influent concentrations of added pharmaceuticals

The target influent concentrations of all four added compounds were 2 µg/l, respectively. To achieve this concentration, a stock solution (10 mg/l) was prepared using S0-solutions (1 mg/ml in ethyl acetate). The stock solution was used for both experiments. The determined concentration at the influent are shown in Table 12

Table 12. Measured concentrations of the pharmaceuticals at sample point 1-0 (influent)

Sample name	Diclofenac [µg/l]	Clofibric acid [µg/l]	Ibuprofen [µg/l]	Bezafibrate [µg/l]
Col 1-0 13.5.	1.4	1.2	1.3	2.1
Col 1-0 23.5.	1.3	1.6	1.0	1.9

To avoid an increase of the natural DOC in the influent water, organic solvents had to be evaporated and compounds were then re-dissolved in purified water. Analysis of the influent/feed water from Lake Tegel revealed the presence of AMDOPH at concentrations between 430 and 530 ng/l (median value: 500 ng/l – see also box plot in Figure 19).

Background concentrations of the four added compounds have usually been below limits of determination.

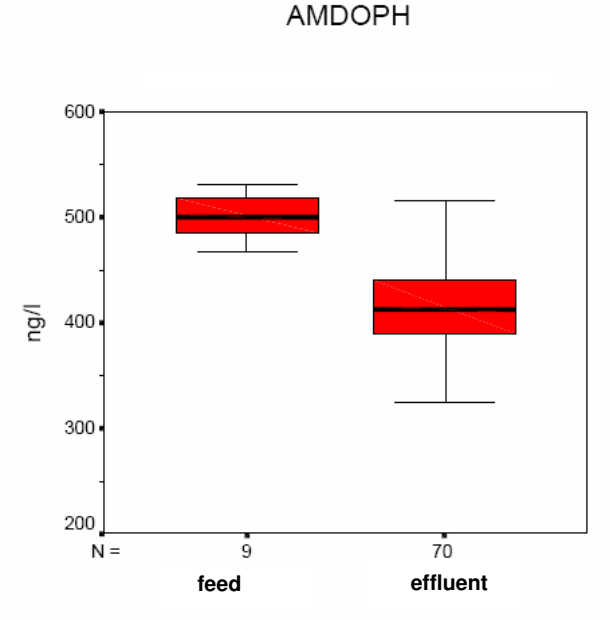


Figure 19. Distribution of AMDOPH concentrations before (feed water) and after soil passage (column effluent).

First experiment

During the first experiment (influent spiked from 5/12/03 to 5/26/03), only the effluent concentrations of the pharmaceutical residues have been measured (Col 6.21). It has been expected that at least clofibric acid (that has been characterized in the literature as hardly degradable and very mobile) can be measured at the end of the column. Instead, the effluent concentrations of all four added compounds (clofibric acid, diclofenac, ibuprofen and bezafibrate) were below limit of detection. Only AMDOPH which was already detected in the surface water from Lake Tegel was also detected in the effluent of the column. Statistical calculations show a little decrease – median concentrations were decreased from 500 ng/l to 420 ng/l (16 %) (see box plot in Figure 19).

Second experiment

During the second experiment (pharmaceuticals added from 23rd to 30th of June), samples were taken only from the first few sampling points to investigate if the elimination process

taking place within the first decimeters of the soil column. Samples were taken daily (see Table) from sample points Col 1.1 (21 cm), Col 1.3 (84 cm), and Col 1.4 (166 cm). The breakthrough curves are compared with a modeled tracer breakthrough curve that was generated using the parameters gained from a Gd-tracer experiment (Table 13). The modeled curve simulates the behavior of the Gd-tracer added together with the pharmaceuticals over the same time period.

Table 13. Parameters of the soil column derived from a Gd-tracer experiment

Mean velocity	0.91 m/d
Porosity	31.9 %
Dispersion	0.04 m
Dispersion coefficient	0.036 m²/d
Average residence time	33 days

Breakthrough curves of the four added pharmaceutical residues at the three analyzed sampling points are shown in Figure 20 - Figure 22.

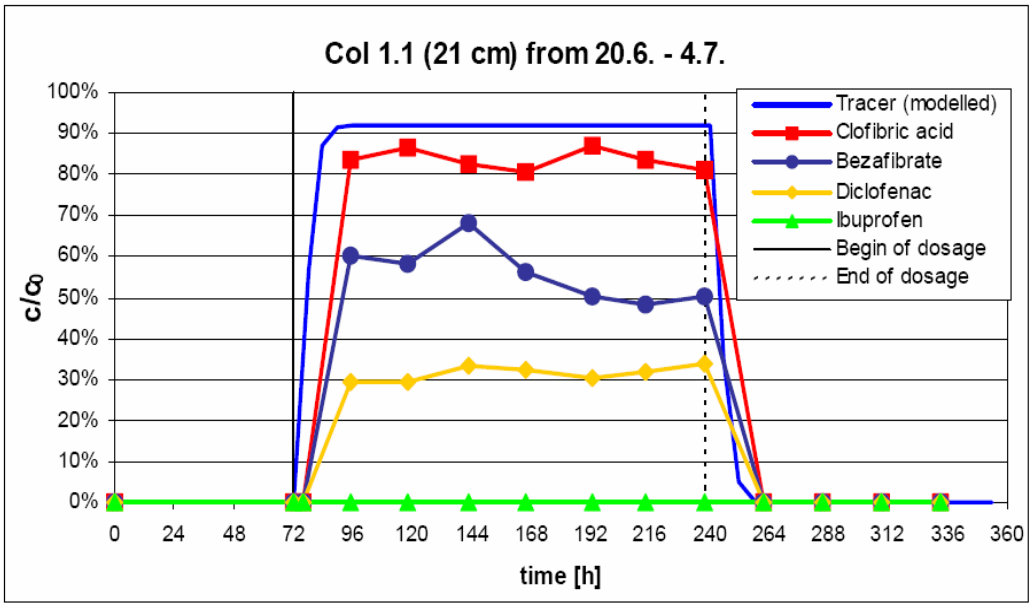


Figure 20. Breakthrough curves for the spiked pharmaceuticals at Col 1.1 (21 cm)

As shown in Figure 20, the concentrations of the four added pharmaceuticals considerably changed already after a soil passage of only 21 cm. The concentration of ibuprofen was already below the detection limit of 20 ng/l.

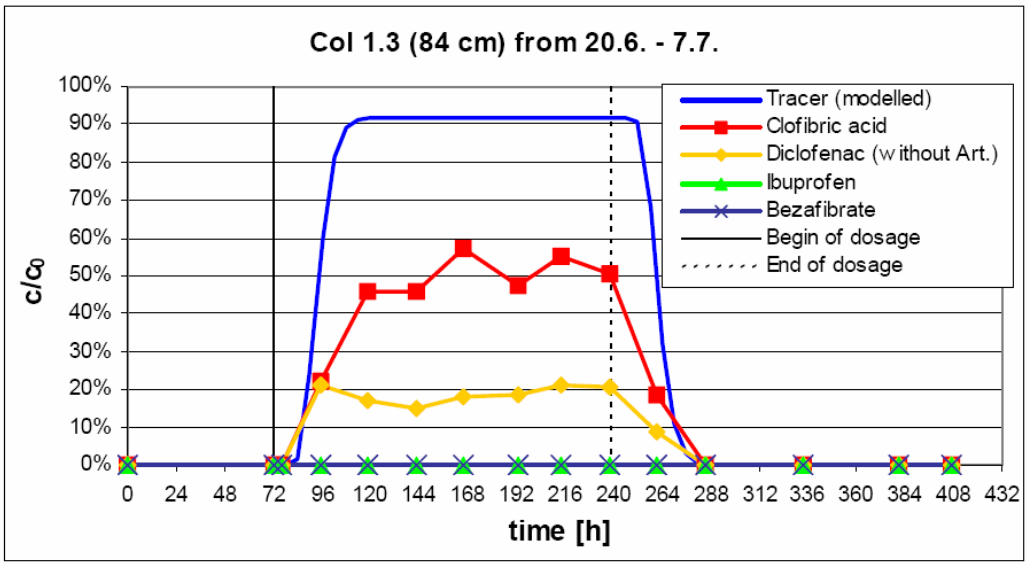


Figure 21. Breakthrough curves for the spiked pharmaceuticals at Col 1.3 (84 cm)

After 84 cm (Col 1.3) presented in Figure 21, bezafibrate was also not detectable any longer. The concentration of clofibric acid had also decreased to approximately 50% of the initial concentration.

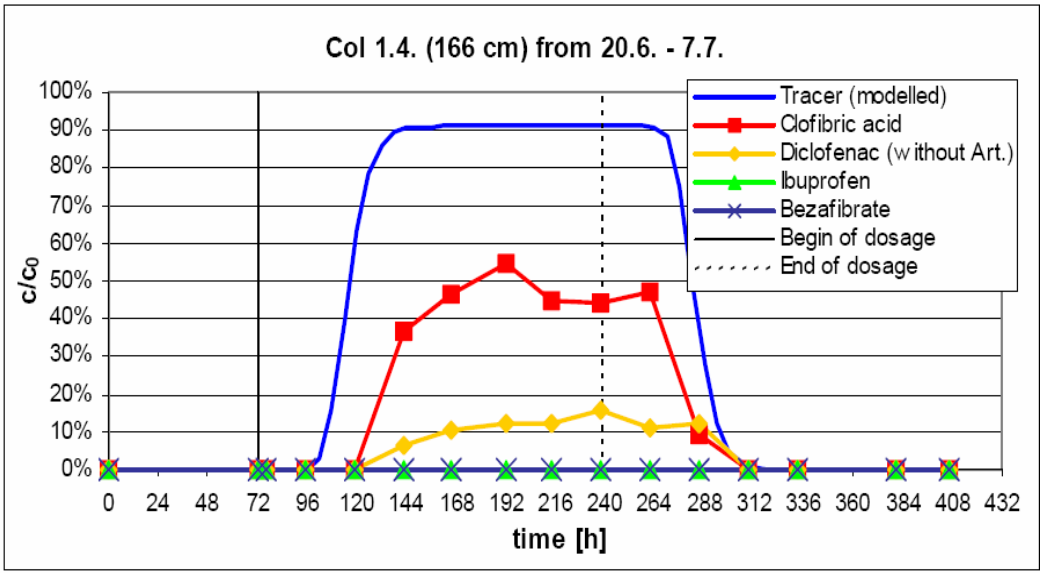


Figure 22. Breakthrough curves for the spiked pharmaceuticals at Col 1.4 (166 cm)

As shown in Figure 12 the concentrations of the remaining two compounds (clofibric acid and diclofenac) only decreased slightly at 166 cm (Col 1.4), compared to sample point Col 1.3. It has to be considered that due to the low resolution in time (one sample per day), the real start or ending of a peak may differ by several hours.

1.3.3.2 Summary of the results

Comparing the results of the sample points Col 1.0 (influent), Col 1.1, Col 1.3, Col 1.4 und Col 6.21 (effluent), the following points can be summarized:

- all four compounds (clofibric acid, diclofenac, ibuprofen, bezafibrate) added to the feed water were removed within the soil column system,
- the concentration of AMDOPH was reduced by 15-20%,
- ibuprofen was eliminated within the first 21 cm of the soil column,
- bezafibrate was eliminated within the first 84 cm of the soil column
- the concentration of diclofenac was reduced by around 70% within the first 21 cm, and thereafter it continued to decrease slowly,
- the concentration of clofibric acid was reduced by approximately 50% within the first 84 cm, and thereafter it continued to decrease slowly.

It can be seen that the largest decrease in concentrations takes place within the first decimeters of the soil column. This zone is also characterized by an extended microbial degradation, as confirmed by the elimination of the DOC.

1.3.3.3 Conclusions

The experiments at the soil column system in Marienfelde revealed some unexpected results. A complete removal of clofibric acid has not been reported in the literature until now. In fact, some studies even described clofibric acid as an almost persistent and tracer-like compound (Heberer, 2002; Mersmann, 2002,Ternes et al., 2002;Winkler et al., 2001, Zwiener et al. , 2001;Zwiener et al., 2002). Only Preuß et al., 2001 reported a decrease of clofibric acid concentrations by 40-60% in a soil column experiment. The concentration of diclofenac was reduced comparably quickly. Already at the first sampling point (after 21 cm), only 30% of the initial concentration could be measured. Reported degradation of diclofenac in batch experiments ranged from only a few percent, to a maximum of 50% (Möhle et. al, 1999; Zwiener et al., 2002). In a soil column experiment conducted by Mersmann et al.,

2002), no removal of diclofenac could be observed after passage through a 35 cm long column. On the contrary, Preuß et al., 2001 reported a reduction of diclofenac concentrations by 60-80% after 80 cm. The easy degradability of ibuprofen, as described in the literature (Buser et al., 1999; Stumpf et al., 1998; Winkler et al., 2001; Zwiener et al., 2000) completely removed (concentration below limit of detection).

1.3.3.4 Small columns

The aim of these investigations was to examine the behavior of selected drug residues in short retention columns at different redox conditions. Altogether the behavior of nine pharmaceutically active compounds including AMDOPH, bezafibrate, carbamazepine, clofibric acid, diclofenac, indometacine, primidone and propyphenazone was examined. The influences and efficiency of attenuation during the infiltration process should be clearifieed and assigned to definite parameters which are hardly to be precisely recognized at the field sites. The experiments were carried out in cooperation with the organics group of the Technical University Berlin.

Three experiments were carried out using eight columns with various conditions. Apart of columns no. 7 & 8 which were filled with real bank material and aquifer material, all other columns were filled with technical sand. The columns had a length of 1 m with a diameter of 0.14 m. Each column was charged daily with 800 mL of lake Tegel surface water and spiked during the three experiments with different concentrations of selected drug residues. The flow of 0.8 L/d leads to a retention time around 6 days. Columns no. 4, 5 and 6 were charged with anoxic water and should be used for comparisons with oxic water charged columns. The effluent of column no. 2 charged column no. 5, so that means apllied compounds passaging 2 meters of technical sand under anoxic conditions. The influent of column no. 0 was additionally spiked with sodiumazide to achieve abiotic conditions. At columns no. 3 & 6, starch, an easily degradable substance, was added to the influent to get anaerobic conditions during column passage. The influent of column no. 4 was spiked with nitrate to promote denitrification. Table 14 shows parameters and conditions of the investigated columns.

Table 14. Column conditions including filling material, lenght, type of charging water, added compounds and the individual redox condition trend.

column no.	0	1	3	4	5	6	7	8
Material	tech. sand	tech. sand	tech. sand	tech. sand	tech. sand	tech. sand	bank	aquifer
length [m]	1	1	1	1	2	1	1	1
type of charging water	oxic	oxic	oxic	anoxic	anoxic	anoxic	oxic	oxic
added substances	10 g/L NaN3	-	3 mg/L starch	5 mg/L NO3-N		3 mg/L starch		
redox condition trend	oxic (abiotic)	oxic	oxic anoxic anaerobic	anoxic (denitri-fication)	anoxic	anoxic anaerobic	oxic anoxic anaerob	oxic

Each experiment was carried out within four weeks and was started with an equilibration time of three weeks. The initial concentrations of the investigated compounds were selected at concentrations of 10 µg/L, 5 µg/L and 1.3 µg/L, during the experiments A, B and C. The oxic and anoxic influents were sampled during week three and four and the individual effluents were sampled three times during the fourth week. Caused by a power failure during the first experiment, the pump that mixed surface water with investigated compounds was out of order and the gained data of the column effluents were unusable. Additionally, some unexplainable effects (like higher effluent concentrations than influent ones etc.) lead to data that were hard to interpret and so the results could only be considered as tendencies for the behavior of the investigated compounds.

1.3.3.5 Results

Generally higher attenuation rates were observed at the columns fed with oxic surface water as shown in Table 15. Surprisingly, almost all applied drug residues showed removal rates between 23 % and more than 95 % at the abiotic column no. 0 where only sorption effects should take affect. Using the individual logP_{OW} the behaviour of bezafibrate (log P_{OW} 4.2) and indometacine (log P_{OW} 4.27) could be explained by their high sorption potential. However, diclofenac was also attenuated about 61 %, despite of the reported low log P_{OW} of 1.13. The low observed sorption between 0 % and 50 % of AMDOPH (log P_{OW} unknown), carbamazepine (log P_{OW} 2.45), clofibric acid (log P_{OW} 3.1), ibuprofen (log P_{OW} 3,97) and primidone (log P_{OW} 0.91) seem to be relatively independent from the individual log P_{OW}. Propyphenazone (log P_{OW} 3.1) did not show any significant sorption rate at the abiotic column no.0.

Table 15. Attenuation tendencies of the investigated drug residues

	Effluent column no. 0	Effluent column no. 1	Effluent column no. 3	Effluent column no. 7	Effluent column no. 8	Effluent column no. 4	Effluent column no. 5	Effluent column no. 6
AMDOPH	-	-	-	-	-	-	-	-
Bezafibrate	+	++	++	++	++	++	++	-
Carbamazepine	-	-	-	-	-	-	-	-
Clofibric acid	-	+	+	-	-	+	+	-
Diclofenac	+	-	+	-	++	-	+	-
Ibuprofen	+	++	++	++	++	++	++	++
Indometacine	++	-	++	++	++	-	++	-
Primidone	-	-	-	-	-	-	-	-
Propyphenazone	-	+	+	+	+	-	+	-

- low attenuation < 45 %
+ medium attenuation between 46 % and 95 %
++ high attenuation between >95 %

At column no. 1 (aerobic) AMDOPH, carbamazepine, diclofenac and primidone showed low attenuation rates up to 45 %. Despite of the behaviour at column no. 0 indometacine observed attenuation rates were lower than 30 %. Bezafibrate and ibuprofen were observed with high attenuation rates over 95 %. Medium removal rates (46 - 95 %) were recognized for propyphenazone and for clofibric acid that has previously been reported as a highly persistent compound and tracer like compound (Mersmann et al. Heberer, Ternes et al. 2002, Winkler et al. 2001, Zwiener 2000a&b).

The fate of the applied compounds at column no. 3 with successive conditions inside (aerobic, anoxic, anaerobic) was comparable to their behaviour at column no. 1. However, diclofenac and propyphenazone were observed with a medium attenuation rate. The determined removal of clofibric acid was lower (63 %) than at column no. 1.

The column no. 4 fed with anoxic water and added nitrate to increase denitrification was sustainable (> 95 %) for the removal of bezafibrate and ibuprofen. AMDOPH, carbamazepine, indometacine and primidone only show insignificant attenuation rates around 20 %. Clofibric acid, diclofenac and propyphenazone were observed with a medium attenuation rate 34 % and 49 %.

At column no. 5 with anoxic conditions and a length of 2 meters equal attenuation tendencies to column no. 3 (suksessive conditions) were recognized. AMDOPH, carbamazepine and primidone showed low attenuation. Clofibric acid and diclofenac were observed with a medium attenuation rate of 52 % at the effluent. Highest attenuations (more than 95 % %) were determined for bezafibrate, ibuprofen, indometacine and propyphenazone.

Column no. 6 shows only for diclofenac low attenuation rates of 30 % and complete removal of ibuprofen. The concentrations of the other compounds were not obviously decreased during soil passage under anaerobic conditions.

At column no. 7 filled with real bank material, high attenuation rates (> 95 %) were observed for bezafibrate, ibuprofen and indometacine. Propyphenazone was removed about 83 % and clofibric acid was only slightly attenuated around 37 % %. No significant attenuations were observed for AMDOPH, carbamazepine and primidone.

During the passage of real aquifer material at column no. 8 with oxic conditions, only AMDOPH, carbamazepine, clofibric acid and primidone showed no significant attenuation rates. The remained compounds were efficiently attenuated (> 95 %).

1.3.3.6 Conclusions

AMDOPH (log POW unknown), carbamazepine (log POW 2.45) and primidone (log POW 0.91)

- showed only low sorption under abiotic conditions (column no. 0)
- concentrations were only partly decreased (up to 40 %) in almost all of the oxic charged columns (column no. 1 & 3)
- under anoxic or anaerobic conditions no significant removal was observed (column no. 4, 5 & 6)
- similar behaviour at the columns filled with real field site material and with successive redox conditions (columns no. 7) or exclusive oxic conditions (column 8)
- transport is comparable to results at the field sites GWA & TS Tegel and TS Wannsee (chapters 1.4.3, 1.4.4 & 1.4.6).

Bezafibrate (log POW 4.2)

- a sorption of 69 % under abiotic conditions (column no. 0) was observed
- passing technical sand under oxic or successive redox conditions (columns no. 1 & 3) initial concentration were also reduced by more than 97 %
- high attenuation rates (>97 %) were noticed under anoxic - denitrifying and exclusively anoxic conditions (columns no. 4 & 5)

- real bank and aquifer materials (columns no. 7 & 8) lead to high removal (>97 %). This behaviour is comparable to the fate of bezafibrate at field sites lake Tegel and lake Wannsee (chapters 1.4.3, 1.4.4 & 1.4.6).

Clofibric acid (log POW 3.1)

- under abiotic conditions (column no. 0) low attenuation (43 %) was found
- observed low and medium attenuations were between no obvious removal and 63 % removal in almost all other columns
- under oxic conditions (column no. 1), a decrease of 87 % was noticed and during the passage of column no. 5 (filled with technical sand and anoxic conditions), an attenuation of 52 % was observed
- low attenuation rates of 37 % and 42 % were determined in the columns filled with real field site materials. This result is similar to the observations at transects Tegel and Wannsee (chapters 1.4.3, 1.4.4 & 1.4.6).

Diclofenac (log POW 1.13)

- abiotic conditions (column no. 0) lead to a medium removal rate of 61 %
- medium attenuation rate of 52 % and of 57 % were observed under long anoxic passage (column no. 5) and during passage oxic - anoxic conditions (column no. 3), respectively
- low attenuation (45 %) were observed under exclusive oxic (column no. 1) or (in column no. 6) exclusive anoxic conditions (decrease of about 30 %)
- the noticed medium attenuation rate of 39 % in column no. 7 filled with bank material is comparable to the field sites investigations but in column no. 8 filled with aquifer material a high removal (> 95 %) was observed.

Ibuprofen (log POW 2.45)

- a sorption of 49 % was noticed under abiotic conditions (column no.0)
- high removal rates (> 95 %) were determined in the oxic and anoxic charged columns
- passage of bank material (column no. 7) and aquifer material (column no. 8) under oxic anoxic conditions leads to a high removal (> 95 %)

Indometacine (log POW 4.27)

- under abiotic conditions (column no. 0) a sorption rate of > 95 % was determined
- surprisingly only low removal / sorption was observed under oxic (column no. 1) conditions
- In columns under oxic - anoxic (column no. 3) and anoxic - anaerobic (column no. 6) conditions high attenuation rates (> 95 %) were observed
- passing bank or aquifer material (columns no. 7 & 8) leads to high attenuation rates (> 95 %) comparable to the behaviour at the field sites (chapters 1.4.3, 1.4.4 & 1.4.6).

Propyphenazone (log POW 3.1)

- showed low sorption (23 %) under abiotic conditions (column no. 0)
- low attenuation of about 39 % were observed under anoxic – denitrifying conditions (column no. 4)
- medium removal rates between 66 % and 86 %) could be noticed under oxic conditions (column no. 1), successive redox conditions (column no. 3) and in column no. 5 with a 2 meter soil passage under anoxic conditions
- passing real bank / aquifer material leads to medium removal rates of 83 % (columns no. 7) and 89 % (column no. 8), respectively. This behavior was comparable to the fate at the investigated field sites (chapters 1.4.3, 1.4.4 & 1.4.6).

Generally, aquifer material with an oxic redox regime seems to have the highest potential for the removal of the investigated compounds. Oxic charged column with successive redox conditions (column no. 3) and anoxic conditions and greater passage time at column no. 5 leads to comparable attenuations for all investigated drug residues. Easily degradable dissolved organic carbon (e.g. starch) under anoxic conditions (column no. 6) seems to reduce the removal potential for the applied compounds. In opposite to this, added starch under successive redox conditions (column no.3) did not show this inhibiting effect. Surprising results in the abiotic column no. 0 may be explainable by high sodium azide concentration (10 g/L) of the charging surface water. This properly lead to a displacement of balance of applied compounds between charging water and soil.

1.4 Field site investigations

1.4.1 Surface water preparation plant Tegel

The OWA Tegel located north of lake Tegel is used for mechanical purification and phosphate elimination of surface water influxing lake Tegel (influxes from the Nordgraben receiving the effluents from the STP Schönerlinde and from the Tegeler Fließ). Additionally, water can be pumped bidirectionally through a six kilometres long pipeline between river Havel and lake Tegel. Corresponding to the influxes and depending on the amounts of rain in summer or winter it is necessary to guarantee a relative constant discharge of 3 m^3/s *phosphate reduced water* to be discharged into lake Tegel. Table 16 shows the amount from the influxes and the amounts pumped through the lake pipeline into lake Tegel or respectively the river Havel.

The OWA Tegel was sampled monthly starting in January 2004 and was accomplished in July 2004. Additionally, in 2004 two weeks with daily sampling were included. The first one during winter from January 27th until February 1st, the second one from July 25th till July 31$^{st.}$. The lake pipeline was sampled monthly at the same days of the influent and effluent sampling.

Table 16. Total discharge into Lake Tegel from the influxes Nordgraben & Tegeler Fließ. The direction and amounts of water pumped through the lake pipeline.

	Amounts of water [m_3]			
Sampling date	**Nordgraben**	**Tegeler Fließ**	**Lake pipeline to the OWA Tegel**	**Lake pipeline to Havel**
19.01.2004	121.000	64.000	0	27.500
16.02.2004	104.500	60.500	0	26.500
15.03.2004	115.000	31.000	101.000	0
19.04.2004	113.500	26.000	153.000	0
24.05.2004	99.000	23.500	70.000	0
21.06.2004	84.500	24.000	106.000	0
26.07.2004	124.000	23.500	155.000	0

During this investigation eight drug residues were observed and quantified up to the µg/L range, as reported in Table 17.

Table 17. Drug residues with positive findings and their minimum, median and maximum concentrations [ng/L]

	Influent			Effluent			Lake pipeline		
	n=20			n=20			n=7		
	min	median	max	min	median	max	min	median	max
AMDOPH	126	307	419	146	323	475	133	362	930
Bezafibrate	35	159	453	< LOQ*	173	277	< LOQ*	< LOQ*	< LOQ*
Carbamazepine	675	1359	3452	866	1410	3023	171	344	651
Clofibric acid	52	85	141	40	83	123	< LOQ	19	28
Diclofenac	438	976	1522	478	1033	1583	35	68	263
Primidone	172	474	770	167	492	730	30	74	170
Propyphenazone	49	90	137	10	57	122	42	117	172
Indometacine	< LOQ*	97	514	21	110	417	< LOQ*	< LOQ*	189

*LOQ limit of quantification

1.4.1.1 AMDOPH

As shown in Figure 23, AMDOPH was detected at concentrations of 120 ng/L up to 460 ng/L in influent and effluent samples. Concentrations in the lake pipeline vary between 130 ng/L and 930 ng/L. The high concentrations of AMDOPH in the lake pipeline between March and July 2004 are from the sampling location of the lake pipeline near the river Oberhavel. Comparing the median concentrations of 307 ng/L in influent water and 323 ng/L in effluent water, the values are within the analytical measurement accuracy for AMDOPH.

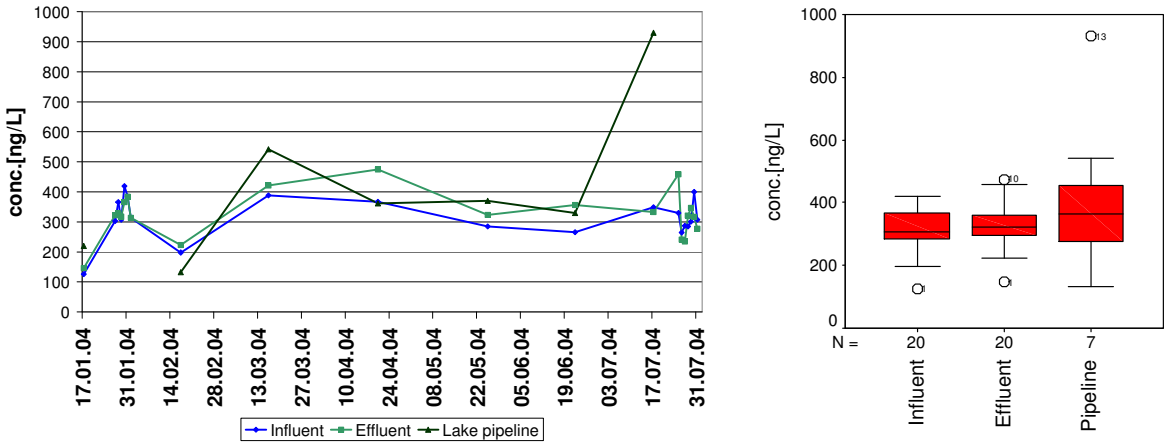


Figure 23. Fate of AMDOPH during the passage of the OWA Tegel. (a: time series, b: box plots)

1.4.1.2 Bezafibrate

As illustrated in Figure 24, bezafibrate concentrations between the limit of quantification of 50 ng/L and 453 ng/L for bezafibrate in surface water were detected in the three compartments of the OWA Tegel. Similar to AMDOPH, the median concentrations of the influent (159 ng/L) and the effluent (173 ng/L) showed no great difference. The observed concentrations in the lake pipeline were below the limit of quantification.

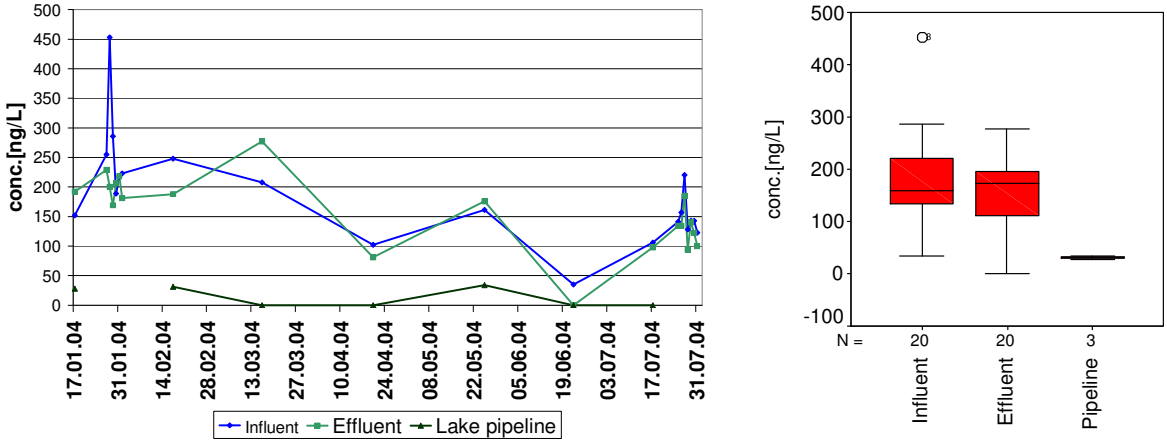


Figure 24. Fate of bezafibrate during the passage of the OWA Tegel. (a: time series, b: box plots)

1.4.1.3 Carbamazepine

Carbamazepine was detected in influent and effluent water at concentrations between 675 ng/L and 3450 ng/L, as shown in Figure 25. No significant discrepancy of the median concentrations of 1359 ng/L (influent) and 1410 ng/L (effluent) were recognized. At the lake pipeline minor concentrations around a median of 344 ng/L were measured.

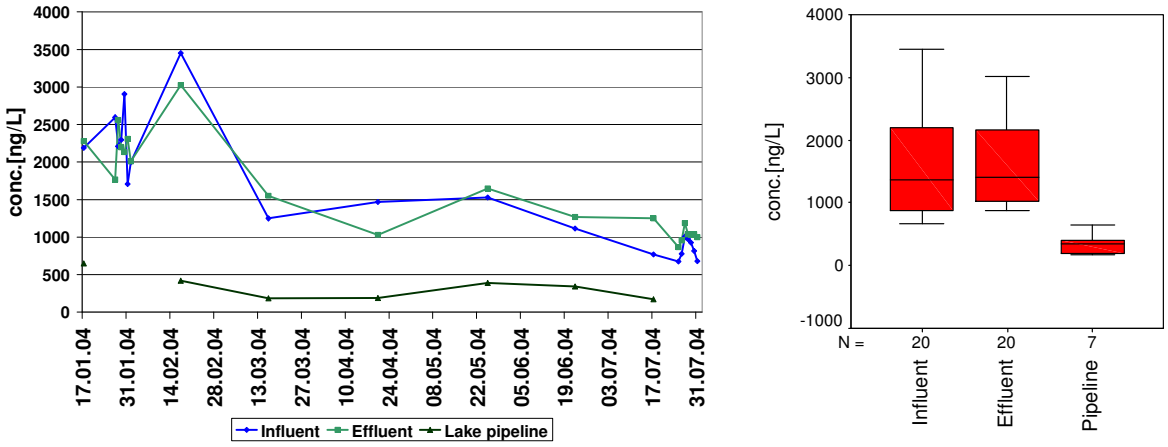


Figure 25. Fate of carbamazepine during the passage of the OWA Tegel.
(a: time series, b: box plots)

1.4.1.4 Clofibric acid

As shown in Figure 26, clofibric acid was observed at concentrations between 40 ng/L and 141 ng/L at the influent and effluent sampling locations. The median concentrations of 85 ng/L (influent) and 83 ng/L (effluent) were similar. In the lake pipeline, clofibric acid concentrations lower than the limit of quantification and concentrations up to 28 ng/L were found.

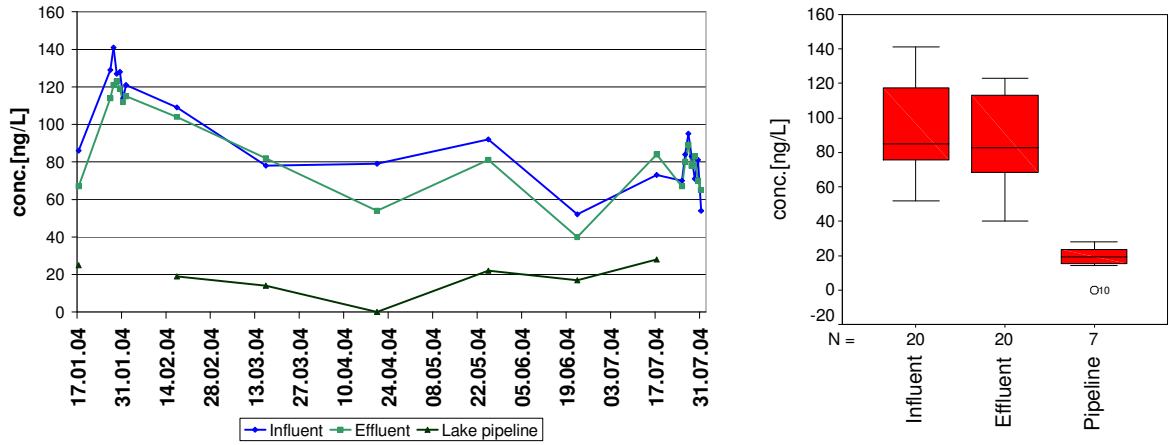


Figure 26. Fate of clofibric acid during the passage of the OWA Tegel.
(a: time series, b: box plots)

1.4.1.5 Diclofenac

The antiphlogistic / antirheumatic drug diclofenac was detected in influent water and effluent water in a concentration range starting at 438 ng/L up to 1583 ng/L as presented in Figure 27. Similar to the previous described compounds, the comparison between the median concentrations of 976 ng/L in influent and 1033 ng/L effluent water showed no clear difference. Concentrations in the pipeline varied between 35 ng/L and 263 ng/L with a median value of 68 ng/L.

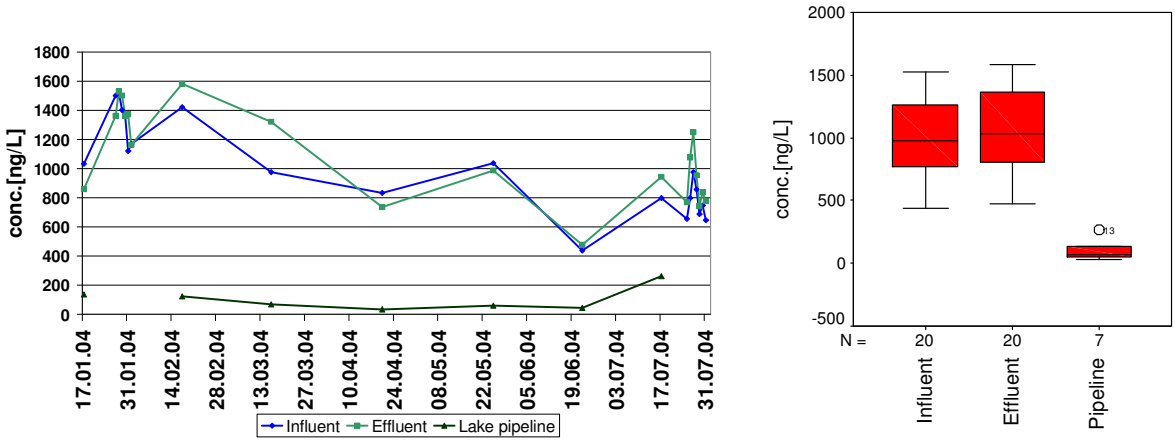


Figure 27. Fate of diclofenac during the passage of the OWA Tegel.
(a: time series, b: box plots)

1.4.1.6 Indometacine

Indometacine, a pharmaceutical with antiphlogistic / antirheumatic features, was observed with concentrations (displayed in Figure 28) between the limit of quantification and 137 ng/L in influent and effluent water. During the investigation, detected concentrations unexpectedly started to increase in March 2004 from around 90 ng/L to a maximum of 514 ng/L at July 27th. The median concentrations at both compartments were very comparable with amounts of 97 ng/L and 110 ng/L. At lake pipeline a minimum below the limit of quantification and 189 ng/L were recognized.

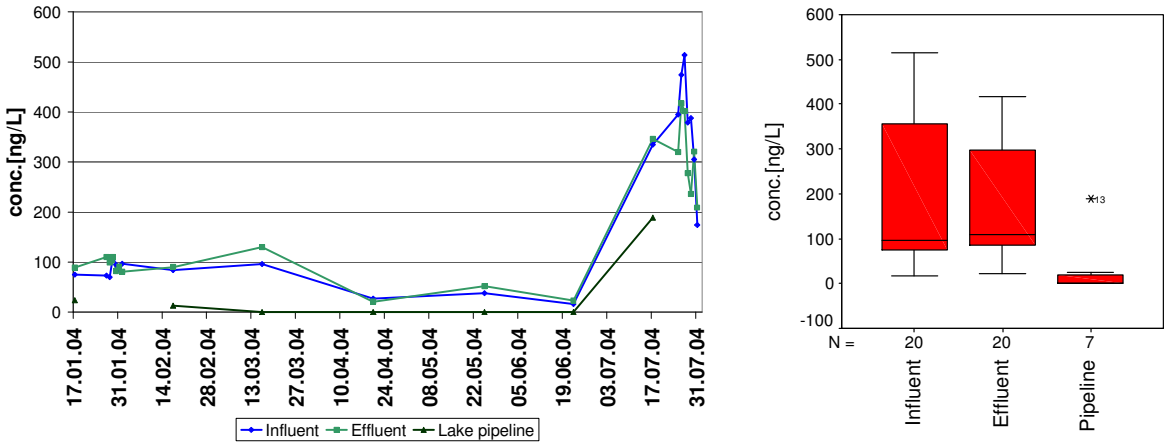


Figure 28. Fate of indometacine during the passage of the OWA Tegel.
(a: time series, b: box plots)

1.4.1.7 Primidone

As presented in Figure 29, primidone concentrations between 167 ng/L and 770 ng/L were found in the influent and the effluent water. The antiepileptic drug was observed with median concentrations of 474 ng/L (influent) and 492 ng/L (effluent). Thus, a significant removal during passage the treatment processes of the facility was not noticed. Concentrations of 35 ng/L up to 263 ng/L and a median value of 68 ng/L were detected.

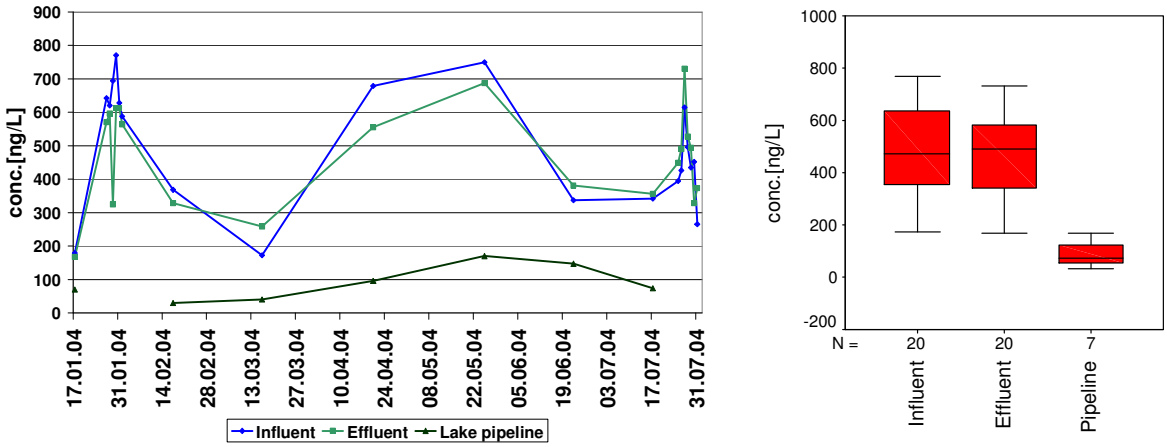


Figure 29. Fate of primidone during the passage of the OWA Tegel.
(a: time series, b: box plots)

1.4.1.8 Propyphenazone

Propyphenazone concentrations between 10 ng/L and 137 ng/L were detected in influent and effluent water, as also shown in Figure 30. The median concentrations of 90 ng/L (influent) and 57 ng/L (effluent) reveal an attenuation rate of 36 % during the passage. The observed concentrations in pipeline water range from 42 ng/L up to 172 ng/L and a median value of 117 ng/L, are comparable to the concentrations found in the influent water. This effect can be explained because propyphenazone is discharging from the same superfund site as AMDOPH and is additionally in steady use as an antiphlogistic / antirheumatic drug.

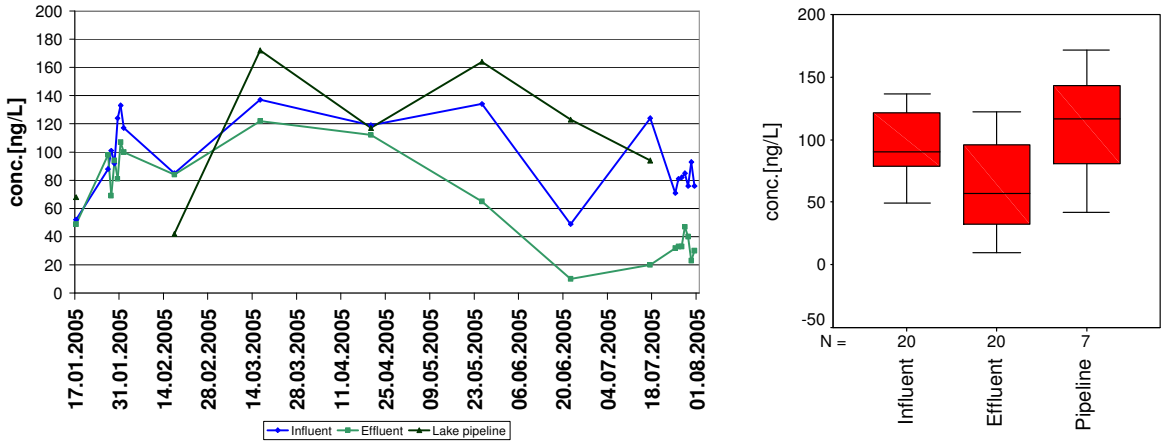


Figure 30. Fate of propyphenazone during the passage of the OWA Tegel. (a: time series, b: box plots)

1.4.2 Conclusions

During the investigation at the OWA Tegel, eight different PhAC's were observed. As expected these compounds are the same as those detected in surface water of transect Tegel, namely AMDOPH, bezafibrate, carbamazepine, clofibric acid, diclofenac, primidone, propyphenazone, and indometacine. Comparing the detected influent and effluent median concentrations, no significant attenuation rates were observed. The individual case of propyphenazone showed an attenuation rate of 36 % during April and July 2004. Maybe this could be interpreted by a better removal behavior during warmer parts of the year. Detected concentrations at sampling location of the pipeline water were negligible for all compounds except for AMDOPH and propyphenazone. These two phenazone-type derivatives were discharged into the environment by spills from a pharmaceutical plant located north-west of Berlin and are transported to the city via the river Oberhavel. Because of the short sampling period of only six month a seasonal effects or variations of the concentrations of the drug residues could not be observed.

1.4.3 Groundwater replenishment site Tegel (GWA)

The measurements at the GWA Tegel started in July 2002 and were carried out over a 12 months period. Sampling points TEG366 and TEG365 and the water supply well 20 were sampled for 12 months, whereas sampling points TEG247, TEG248 and TEG342 were monitored for 8 months (July 2002 to February 2003) and sampling points TEG368, TEG369OP, TEG369UP, TEG370OP und TEG370 UP for 6 months (January 2003 to June 2003).

1.4.3.1 Results from the GWA investigations (July 2002 to June 2003)

In the monthly measurements at the transect GWA-Tegel 8 PhAC's and 5 other contaminants were detected. The drug residues were bezafibrate, carbamazepine, diclofenac, indometacine, primidone, propyphenazone and the drug metabolites clofibric acid and AMDOPH. Furthermore, the pesticides 2,4-D, dichlorprop, MCPA and mecoprop as well as NPS (metabolite of a corrosion inhibitor) were also found in these samples. Figure 31 shows a MID-chromatogramm of the PFBBr-derivatized extract of sample RP 3 collected in November 2002. The antiepileptic drugs carbamazepine and primidone were only analyzed with the MTBSTFA method and do therefore not appear in this chromatogramm.

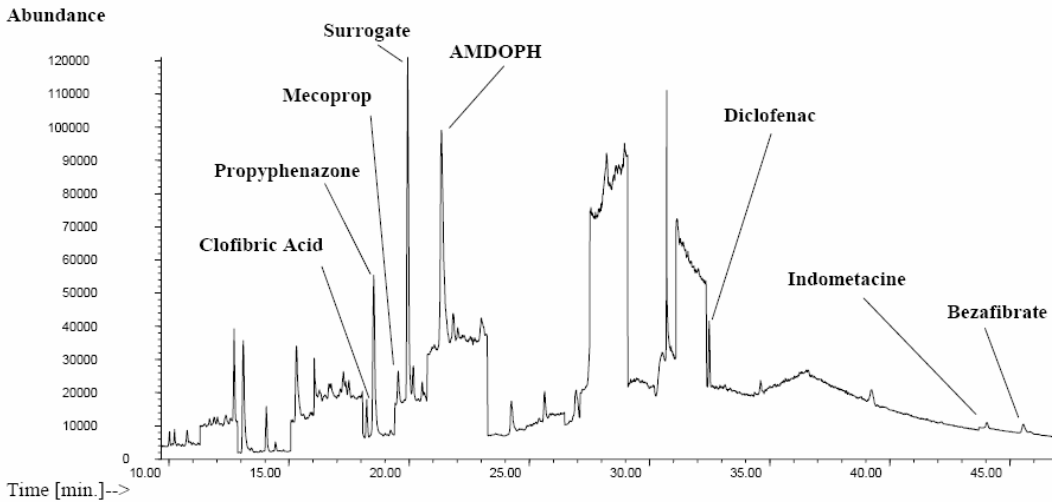


Figure 31. MID-chromatogram of the derivatized extract of sample RP 3 collected in November 2002

A summary of all results is shown in Table 18. It compiles the mean concentrations (n=12/8/6) of drugs and drug metabolites detected at the individual sampling points

throughout the entire sampling period. The individual PhAC's show a very different removal behaviour on their way on the soil passage to water-supply well 20.

Table 18. Mean concentrations [ng/l] of observed PhAC's throughout July 2002 to June 2003

	RP 3	TEG366	TEG365	TEG247	TEG368	TEG248	TEG369 OP	TEG369 UP	Well 20	TEG370OP	TEG370 UP	TEG342
	n=12	n=12	n=12	n=8	n=6	n=8	n=6	n=6	n=11	n=6	n=6	n=8
Flowdirection:	→	→	→	→	→	→	→	→		←	←	←
AMDOPH	455	440	395	425	390	315	300	330	1570	1085	3915	160
Bezafibrate	30	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Carbamazepine	470	545	430	385	460	430	220	230	210	20	20	15
Clofibric Acid	20	5	5	10	10	5	5	5	5	15	n.d.	10
Diclofenac	135	15	45	5	15	10	< LOQ	< LOQ	10	n.d.	n.d.	n.d.
Indometacine	< LOQ	< LOQ	< LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Primidone	135	140	125	115	170	95	80	90	100	30	70	15
Propyphenazone	120	20	20	30	15	20	10	10	40	10	55	20

n.d. not detected

<LOQ. < limit of quantitation

1.4.3.2 Annual variations of the concentrations of the target PhAC's

AMDOPH

As illustrated in Figure 32, AMDOPH was detected at relatively constant concentrations in the surface water and in all wells that were only influenced by recharge with recent surface water. In contrast to well 20 and the landward sampling wells, they are not affected by contaminated landward groundwater as they are containing AMDOPH only at concentrations "lower" concentrations of between 225 and 570 ng/l. On the other hand, concentrations between 350 and 5845 ng/l of AMDOPH were found in the landward wells. The strong fluctuations of the concentrations in the monitoring wells TEG370OP and TEG370UP have to be attributed to not yet completely clarified hydraulic conditions in the deeper groundwater aquifer.

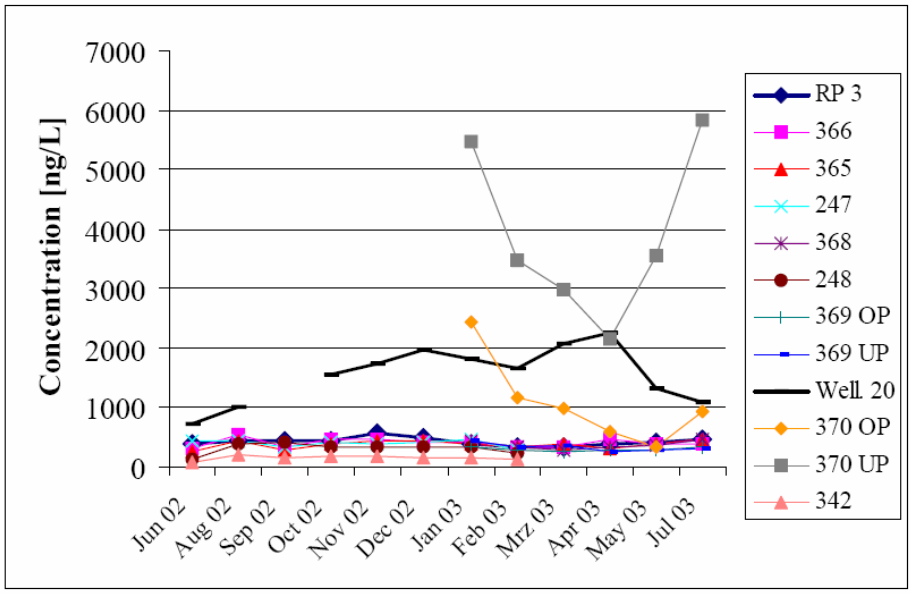


Figure 32. Concentration profiles of AMDOPH at the sampling points/wells (July 02 - June 03)

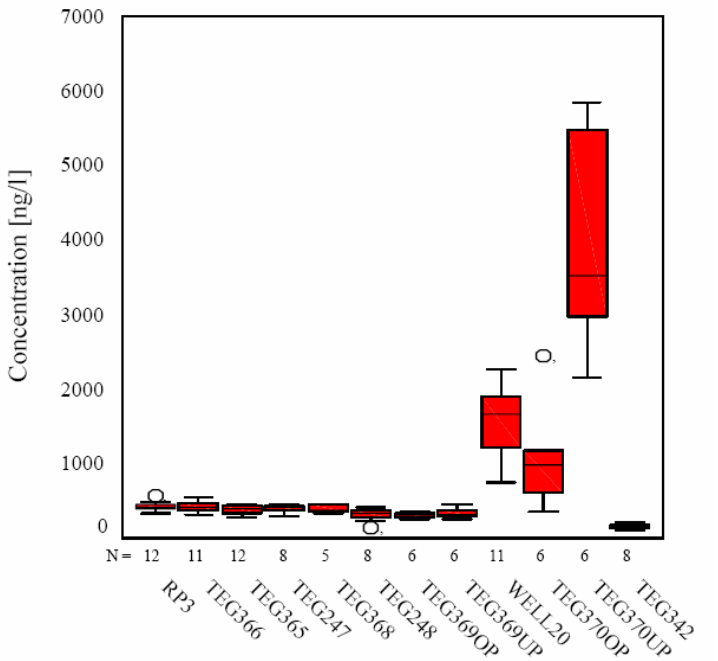


Figure 33. Box plots of AMDOPH concentrations [ng/l] at the individual monitoring wells and the receiving water-supply well 20

For the complete clarification of the hydraulic conditions in the deeper groundwater aquifers further hydro geological investigations will be required. During the soil passage a mean removal rate for AMDOPH of 28 % (compared to the surface water concentration) was observed. This implies that under the prevailing recharge conditions, the majority of the AMDOPH residues (approx. 70%) was not adsorbed at soil particles or biodegraded by the microbial soil flora and reached almost unaffected the groundwater aquifer. Thus, the GWA

is less suitable for the removal of AMDOPH from surface water. Figure 33 shows a statistical evaluation of the AMDOPH concentrations at the individual sampling points as box plot graphs. This figure also demonstrates the high mobility of AMDOPH as well as the low removal during the infiltration process. In addition, it shows the high load of AMDOPH in the landward monitoring wells TEG370OP and TEG370UP and in water-supply well 20.

Carbamazepine

Carbamazepine was found with very variable concentrations in the surface water (RP 3) and in all wells except for the landward monitoring wells (Figure 34).

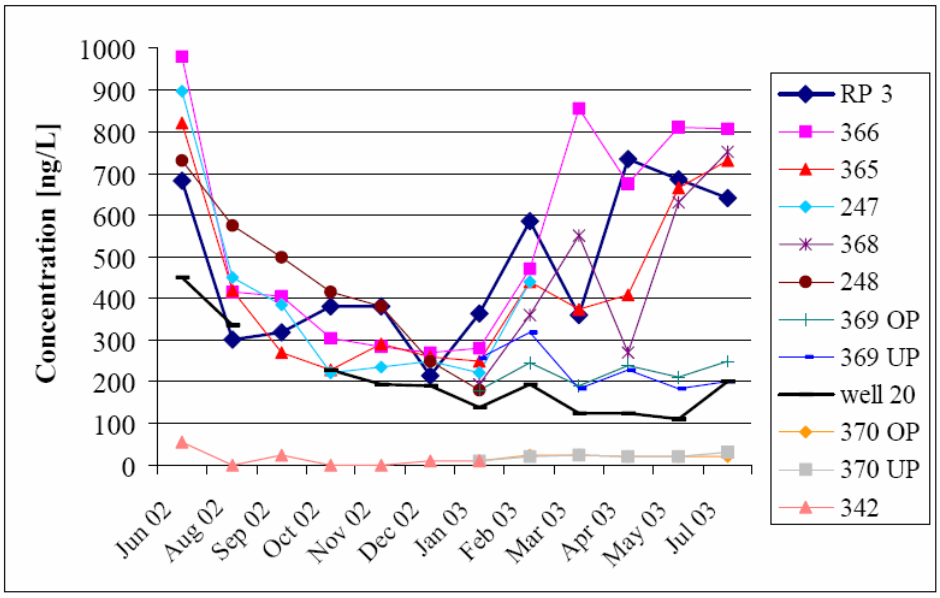


Figure 34. Concentration profiles of carbamazepine at the sampling points/wells (July 02 - June 03)

It was detected in the surface water at concentrations up to 1 µg/l. The strong increase of the concentrations of carbamazepine starting in March 2003 might be explained by the phasing out of the sewage water treatment plant in Falkenberg located in the east districts of Berlin. Since March 27, 2003 its waste water was directed to the sewage water treatment plant in Waßmannsdorf (2/3) located in the south of Berlin and to the sewage water treatment plant in Schönerlinde (1/3) north of Berlin.

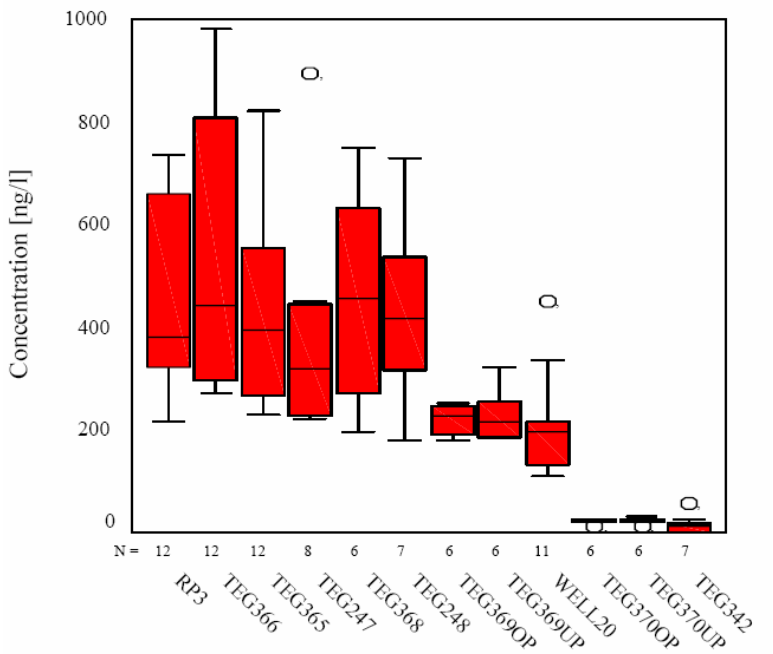


Figure 35. Box plots for the carbamazepine concentrations [ng/l] measured at the individual sampling wells

The treated waste water from the STP in Schönerlinde is discharged into the Nordgraben, which flows into Lake Tegel and causes an increase of the drug concentrations in the surface water. In tendency, the concentration profiles at the monitoring wells up to the water-supply well 20 follow the temporal changes of the concentration measured in the surface water. There is no significant removal of carbamazepine along the transect. Thus, up to monitoring well TEG248, a mean removal rate of only 9 % was observed for carbamazepine. Similar to AMDOPH, carbamazepine represents a very mobile drug residue, only attenuated to a small degree under the prevailing recharge conditions. Thus, the GWA is less suitable for the removal of carbamazepine from surface water. Figure 35 shows a statistical evaluation of the carbamazepine concentrations detected in the individual monitoring wells and in water-supply well 20. It shows the high mobility of carbamazepine as well as the small removal during the infiltration process.

Primidone

Exactly as carbamazepine, primidone was detected with variable concentrations in the surface water and in all monitoring wells, as shown in Figure 36. Starting in March 2003, the increase of the concentrations, due to the enhanced discharges from the STP Schönerlinde caused by the phasing out of the STP in Falkenberg, could been recognized. In tendency, the concentration profiles of the monitoring wells up to the water-supply well 20 follow the temporal changes of the concentrations measured in the surface water. There is no significant removal of primidone along the transect. Thus, up to monitoring well TEG248, a

mean removal rate of 30 % was observed for primidone. The removal rate of primidone up to well 20 is not substantially improved (26 %), because primidone was also detected in the landward sampling points at average concentrations of 70 ng/l.

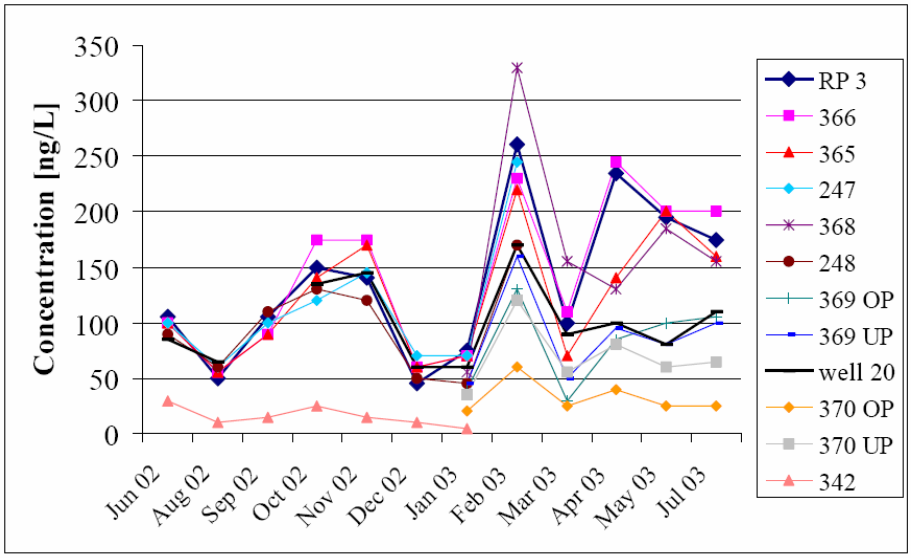


Figure 36. Concentration profiles of primidone at the sampling points/wells (July 02 - June 03)

Primidone, similar to AMDOPH and carbamazepine, is characterized by its very high mobility, and is only attenuated to small degree under the prevailing recharge conditions. Figure 37 shows a statistical evaluation of the primidone concentrations at the individual sampling points as box plots graph. This figure also demonstrates the high mobility of primidone as well as the low removal during the infiltration process.

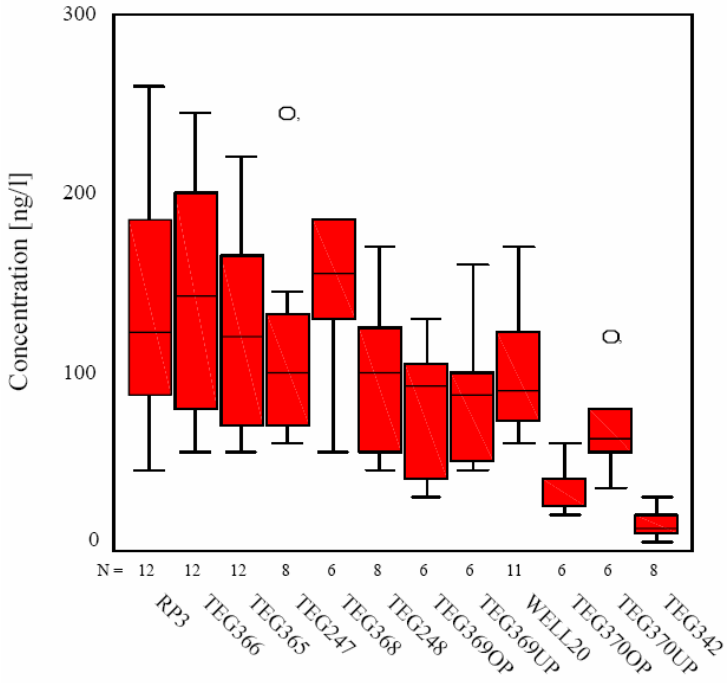


Figure 37. Box plots for the primidone concentrations [ng/l] measured at the individual sampling wells

Propyphenazone

Propyphenazone was detected with relatively constant concentrations in the surface water (Figure 38). The enhanced discharges from the STP Schönerlinde starting in March 2003 did not cause a significant increase of propyphenazone concentration in the surface water of Lake Tegel. The main source for propyphenazone in the surface water of Lake Tegel are residues from the Havel river, which is contaminated by production spills of a former pharmaceutical production plant [Reddersen et al., 2002]. In contrast to the group 1 PhAC's, a much higher removal rate is observed for propyphenazone.

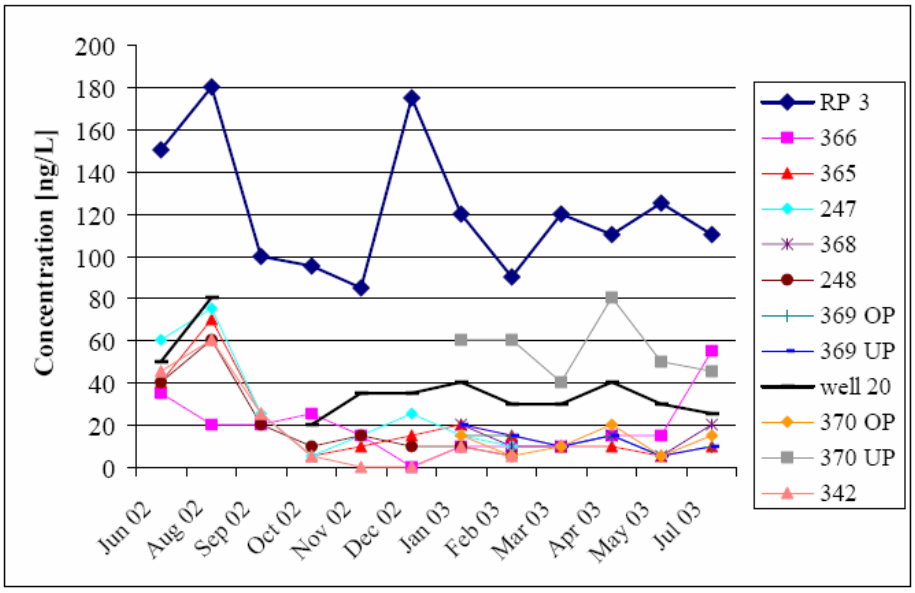


Figure 38. Concentration profiles of propyphenazone at the sampling points/wells (July 02 - June 03)

A removal rate of 83 % was observed up to the monitoring well TEG248. Propyphenazone loaded landward groundwater (TEG370UP) caused an alleged lowering of the removal rate to 67 % at well 20. In general, the GWA is suitable for the pre-treatment of propyphenazone loaded surface water lowering its concentrations. Figure 39 shows a statistical evaluation of the propyphenazone concentrations at the individual sampling points as box plots graph. This figure also demonstrates the attenuation of propyphenazone during the soil passage.

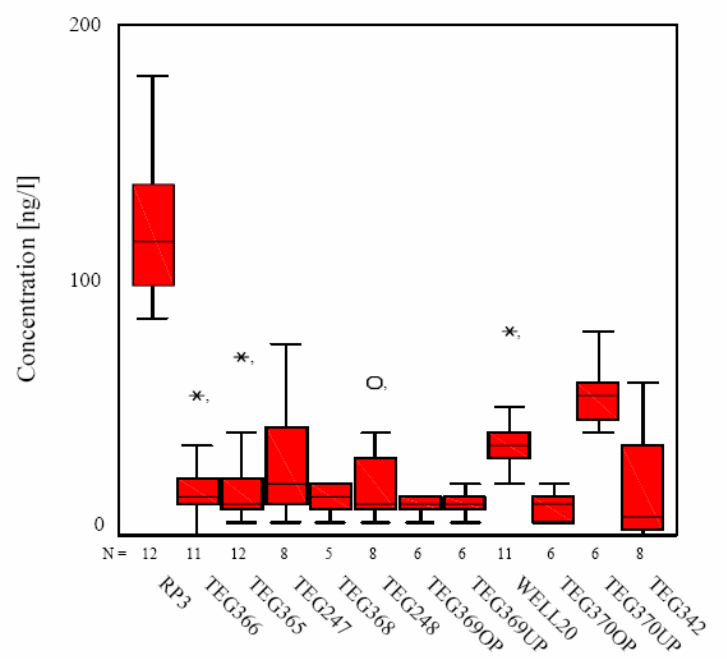


Figure 39. Box plots for the propyphenazone concentrations [ng/l] measured at the individual sampling wells

Diclofenac

The concentration profile of diclofenac in surface water shows pronounced temporal variations (Figure 40). Higher concentrations between 65 and 435 ng/l during the winter and spring months decreased to values below 50 ng/l in the summer months. This is most likely caused by the photochemical degradation of diclofenac, as already described by Buser et al. (1998) and Tixier et al. (2003).

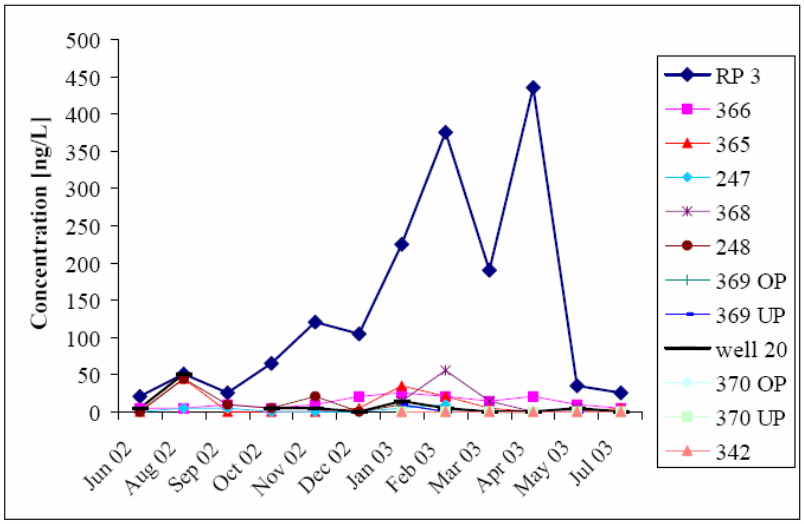


Figure 40. Concentration profiles of diclofenac at the sampling points/wells (July 02 - June 03)

Diclofenac was measured at relatively constant concentrations clearly below 50 ng/l in all monitoring wells up to water-supply well 20. This also demonstrates the ability of the GWA for the attenuation of diclofenac even with high concentrations in the winter months. At monitoring well TEG248 and at water-supply well 20 a mean removal rate of 93% was determined.

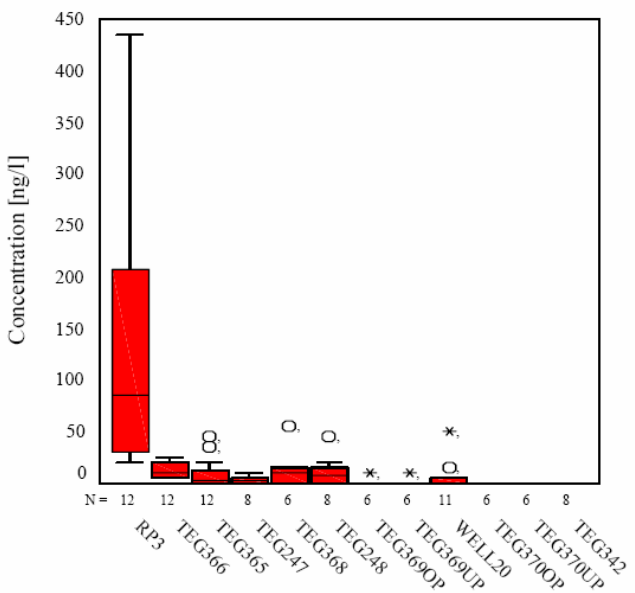


Figure 41. Box plots for the diclofenac concentrations [ng/l] measured at the individual sampling wells

Thus, the GWA was found as being suitable for the pre-treatment of diclofenac loaded surface water. Nevertheless, the removal is not complete and still small loads of diclofenac infiltrate into the groundwater aquifer and reach water supply well 20. Figure 41 shows a statistical evaluation of diclofenac concentrations at the individual sampling points as box plots graph. This figure also demonstrates the attenuation of diclofenac during the soil passage.

Clofibric acid

The drug metabolite clofibric acid was found with relatively constant concentrations in the surface water and in all monitoring wells as shown in Figure 42. It was detected in the surface water at concentrations between 10 and 30 ng/l. Up to both sampling points TEG248 and water supply well 20 an average removal rate of 75 % was observed. The clofibric acid based active substances were used more frequently in the past decades, thus, this persistent metabolite could infiltrate into and adsorb to the soil particles of the groundwater aquifer.

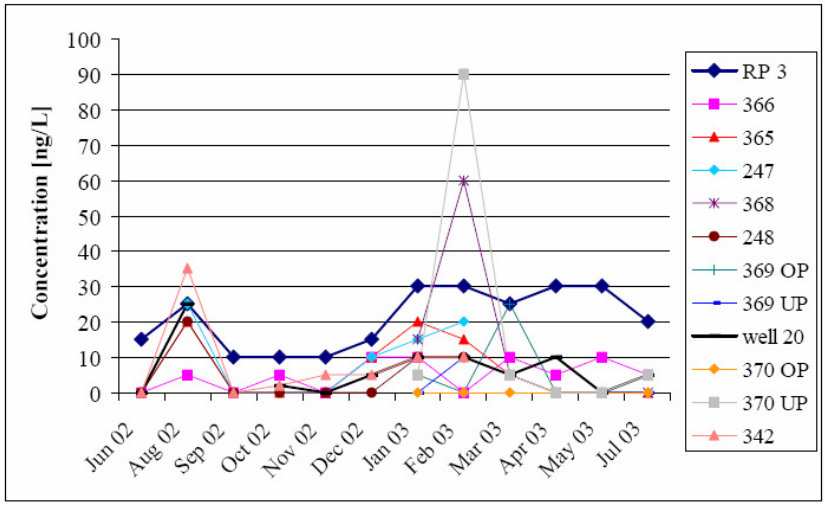


Figure 42. Concentration profiles of clofibric acid at the sampling points/wells (July 02 - June 03)

The decreasing administration trend of medication containing the precursor derivatives of clofibric acid is illustrated by the small concentrations in the surface water. However, thereby the high persistence of the clofibric acid is also demonstrated. Nevertheless, a significant decrease of the concentrations was observed. Thus, the GWA was found as being suitable for the pre-treatment of clofibric acid loaded surface water.

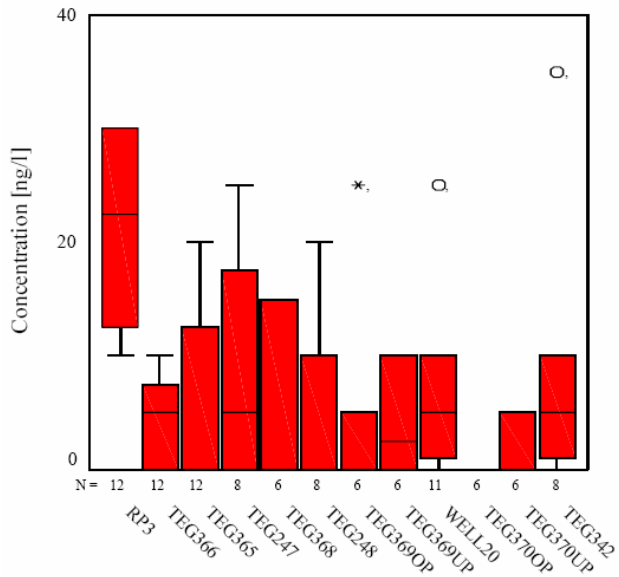


Figure 43. Box plots for the clofibric acid concentrations [ng/l] measured at the individual sampling wells

Figure 43 shows a statistical evaluation of clofibric acid concentrations at the individual sampling points as boxplots graph. This figure also demonstrates the attenuation of clofibric acid during the soil passage.

Bezafibrate and indometacine

Bezafibrate and indometacine only occur at very small concentrations close to the limit of determination in the surface water. The remaining residues of both compounds were completely attenuated during ground water recharge, which was also observed and described by Brauch et al. (2000) and Heberer et al. (2002).

1.4.3.3 Conclusions

On the basis of PhAC's removal rates calculated between RP 3 and shallow monitoring well TEG248, the drug residues could been classified into three groups as described in Table 19 and also reported earlier by Heberer and Adam (2004).

Table 19. Classification of target PhAC's according to their removal rates

Group	Compound	Median rate of attenuation at TEG248	Median rate of attenuation at WSW 20	
1 low removal rates 0-50 %	AMDOPH	31%	-245%	(exceptional case)
	Carbamazepine	9%	55%	
	Primidone	30%	26%	
2 medium removal rates 51-95 %	Clofibric acid	75%	75%	(exceptional case)
	Diclofenac	93%	93%	
	Propyphenazone	85%	67%	(exceptional case)
3 high removal rates > 95 %	Bezafibrate	> 97 %	> 97 %	
	Indometacine	> 95 %	> 95 %	

- Group 1 includes AMDOPH, carbamazepine and primidone and is characterized by modest removal rates of ≤ 30 % up to well 20. The higher removal rate (55%) for carbamazepine observed in well 20 is mainly caused by dilution with landward groundwater (TEG370OP to TEG342), which shows only very low concentrations of carbamazepine. This assumption is also supported by the results obtained for sampling point TEG248, which almost exclusively consists of water recharged from RP 3. In this case only a minor removal rate of 9 % was observed for carbamazepine. The drug metabolite AMDOPH represents an

exceptional case. AMDOPH was detected in ground water samples from well 20 at average concentrations 240 % higher, than those in RP 3. This observation can be explained by the production spills of a former pharmaceutical production plant north of Berlin, which led to high concentrations of AMDOPH and the original drug dimethylaminophenazone in the Havel river and in the groundwater of north-western districts of Berlin (Reddersen et al., 2002). For sampling point TEG248, only influenced by the surface water of RP 3, a mean removal rate of 28 % was observed for AMDOPH.

- Group 2 includes clofibric acid, diclofenac and propyphenazone. These drugs are characterized by high removal rates of more than 70%. The elevated concentrations of propyphenazone in well 20 can be explained by the shares of contaminated landward groundwater (TEG370UP). Despite their good removal rates, portions of all three drugs arrived in the water of well 20.

- Group 3 includes bezafibrate and indometacine. These drugs were removed completely during the soil passage and could not even be quantified at sampling point TEG366 (underneath RP 3) and near the bank at sampling point TEG365.

The results of this investigations show that there is a breakthrough of six of the eight detected drug residues during the artificial groundwater recharge into the water supply well 20. The behaviour of the observed compounds could be classified into three groups with different removal rates. Thus, the GWA may serve at best for the pre-treatment of contaminated surface water but is not sufficient for the complete removal of these residues.

1.4.4 Transect Tegel

Starting in May 2002, the surface water, the shallow monitoring wells (3311, 3310, 3308 and 3305), the deep monitoring wells (3301, 3302, 3303, 3304), and water supply well no. 13 of the transect located at lake Tegel were sampled monthly until August 2004. Due to a low ground water levels in summer the shallow wells 3311, 3310 and 3308 could not be sampled during June and September. The multi-level well TEG371OP/UP and the shallow monitoring well TEG372 have been included in the investigations since January 2003. Additionally, the deep monitoring well TEG374 was drilled and sampled since January 2004. Table 20 shows that altogether eight pharmaceutical residues were quantified up to the µg/L level in the surface water from lake Tegel. These compounds are: AMDOPH (1-acetyl-1-methyl-2-dimethyl-oxamoyl-2-phenyl-hydrazide), bezafibrate, carbamazepine, clofibric acid, diclofenac, indometacine, primidone and propyphenazone. Furthermore, two herbicides namely bentazone and mecoprop, a metabolite of an insecticide (p,p'-DDA), and N-Phenylsulfonylsarcosin (NPS) another metabolite of a corrosion inhibitor were detected in the surface water.

The analgesic drug diclofenac, the antiepileptic drugs carbamazepine and primidone, the two drug metabolites AMDOPH and clofibric acid and the analgesic propyphenazone were detectable in the shallow monitoring wells (3311, 3310, 3308), the multi level well (TEG371UP/OP) and the deep monitoring wells (3301, 3302, 3303). Except for AMDOPH and propyphenazone, the other PhACs occur in low concentrations at the water supply well 13. AMDOPH and clofibric acid were observed in obliviously higher concentrations in the deepest monitoring well TEG374 (e.g., up to 8,3 µg/L for AMDOPH) Up to 1,8 µg/L of AMDOPH were found in the receiving water supply well 13. Bezafibrate (a blood lipid regulator) and indometacine (an antiphlogistic drug) were detectable up to 100 ng/L in the surface water, but they are efficiently removed during the infiltration process and were not detectable behind the first two monitoring wells as shown in Table 20 and Table 21.

Table 20. Compounds with positive findings and their concentration range [ng/L] at the shallow monitoring wells and the multi level well of transect lake Tegel

ng/L	Surface water (n=26)		3311 (n=16)		3310 (n=12)		3308 (n=16)		TEG371OP (n=18)		TEG371UP (n=18)		TEG372 (n=18)		well 13 (n=22)		3305 (n=6)	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
AMDOPH	175	605	145	605	120	545	55	345	165	510	160	1215	80	525	260	1755	65	90
carbamazepine	180	1170	210	1240	210	1100	255	1100	90	620	50	310	140	745	30	185	n.d.	20
clofibric acid	<LOQ	125	<LOQ	55	<LOQ	70	<LOQ	65	<LOQ	75	<LOQ	55	<LOQ	35	10	65	n.d.	<LOQ
diclofenac	5	375	5	130	5	165	5	65	5	100	5	95	5	105	5	60	n.d.	<LOQ
primidone	30	480	30	370	25	440	20	270	45	475	65	365	25	265	30	190	5	10
Propyphena-zone	35	385	5	195	15	60	5	175	10	220	15	1075	5	70	60	280	n.d.	50
indometacine	<LOQ	55	<LOQ	40	<LOQ	45	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
bezafibrate	<LOQ	140	<LOQ	<LOQ	<LOQ	35	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
bentazone	n.d.	30	n.d.	25	n.d.	35	n.d.	30	n.d.	20	n.d.	25	n.d.	30	n.d.	15	n.d.	n.d.
mecoprop	n.d.	45	n.d.	40	n.d.	45	n.d.	45	n.d.	60	n.d.	40	n.d.	50	n.d.	35	n.d.	n.d.
NPS	n.d.	55	n.d.	30	n.d.	30	n.d.	30	n.d.	95	n.d.	60	n.d.	215	15	145	n.d.	n.d.
p,p'-DDA	n.d.	20	n.d.	5	n.d.	n.d.	n.d.	5	n.d.	5	n.d.	15	n.d.	5	n.d.	10	n.d.	n.d.
o,p'-DDA	n.d.	5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5	n.d.	n.d.	n.d.	5	n.d.	n.d.

n.d. not detected

<LOQ. < limit of quantitation

Table 21. Compounds with positive findings and their concentration range [ng/L] at the deeper monitoring wells of transect Tegel

ng/L	Surface water (n=26)		3301 (n=26)		3302 (n=26)		3303 (n=21)		TEG374 (n=8)		Well 13 (n=22)		3304 (n=26)	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max
AMDOPH	175	605	165	915	160	935	150	770	4150	8320	260	1755	85	835
carbamazepine	180	1170	100	360	100	480	165	545	n.d.	10	30	185	n.d.	145
clofibric acid	<LOQ	125	<LOQ	80	<LOQ	35	<LOQ	20	115	235	10	65	<LOQ	45
diclofenac	<LOQ	375	5	100	5	75	5	95	n.d.	n.d.	n.d.	60	n.d.	55
primidone	30	480	40	385	35	365	30	315	45	185	30	190	5	55
propyphenazone	n.d.	385	40	875	5	1020	5	215	15	115	60	280	n.d.	160
indometacine	<LOQ	<LOQ	35	35	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
bezafibrate	<LOQ	140	<LOQ	50	<LOQ	<LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
bentazone	n.d.	30	n.d.	25	n.d.	25	n.d.	10	n.d.	n.d.	n.d.	15	n.d.	5
mecoprop	5	45	n.d.	40	n.d.	25	n.d.	10	n.d.	15	n.d.	35	n.d.	30
NPS	n.d.	55	n.d.	310	n.d.	105	5	30	n.d.	95	15	145	25	610
p,p'-DDA	10	20	n.d.	30	n.d.	10	n.d.	10	n.d.	5	n.d.	10	n.d.	5
o,p'-DDA	5	10	n.d.	10	n.d.	5	n.d.	5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d. not detected

<LOQ. < limit of quantitation

1.4.4.1 AMDOPH and propyphenazone at transect Tegel

AMDOPH was observed in surface water of lake Tegel at concentrations between 175 ng/L and 605 ng/L. Propyphenazone concentrations varies from not detectable up to 385 ng/L in lake Tegel.

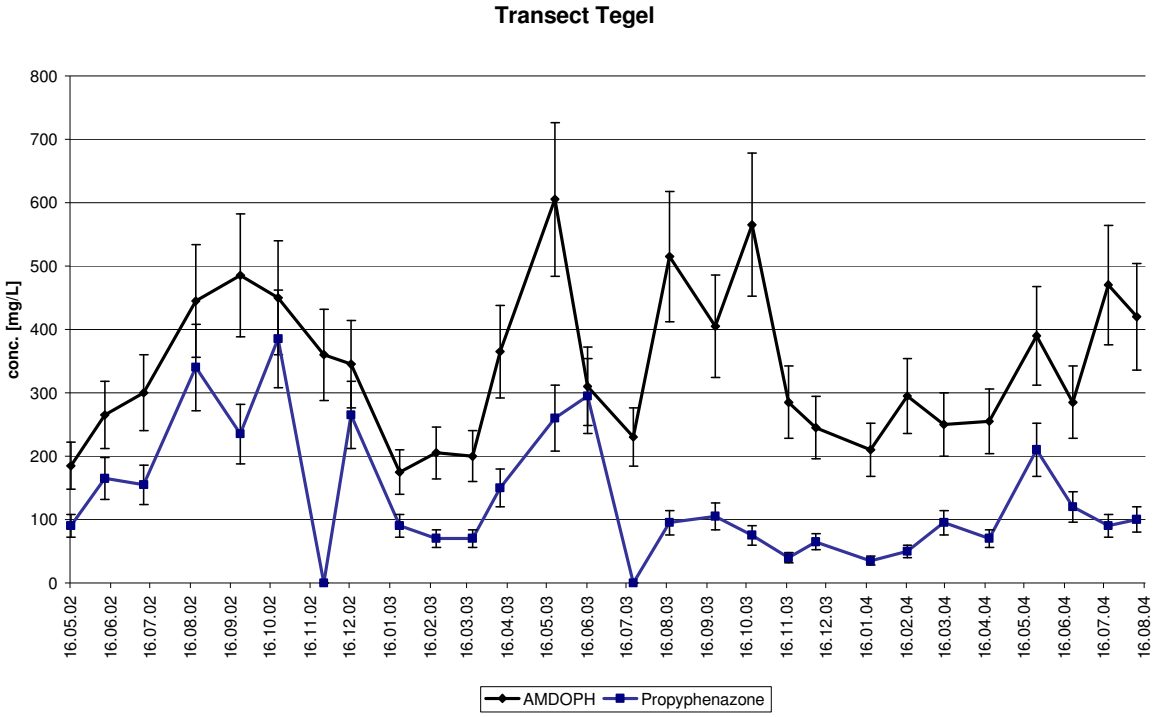


Figure 44. AMDOPH and propyphenazone concentrations at lake Tegel surface water

As shown in Figure 44, concentration trends for AMDOPH and propyphenazone were very similar and seemed to depend on the proportion of Havel water discharged into lake Tegel via the OWA Tegel as illustrated in Figure 45. The visuability of this dependence is explainable by an old environmental damage caused by a leakage at a pharmaceutical plant located in Oranienburg, where different phenazone derivates were produced (Reddersen et. al, 2002).

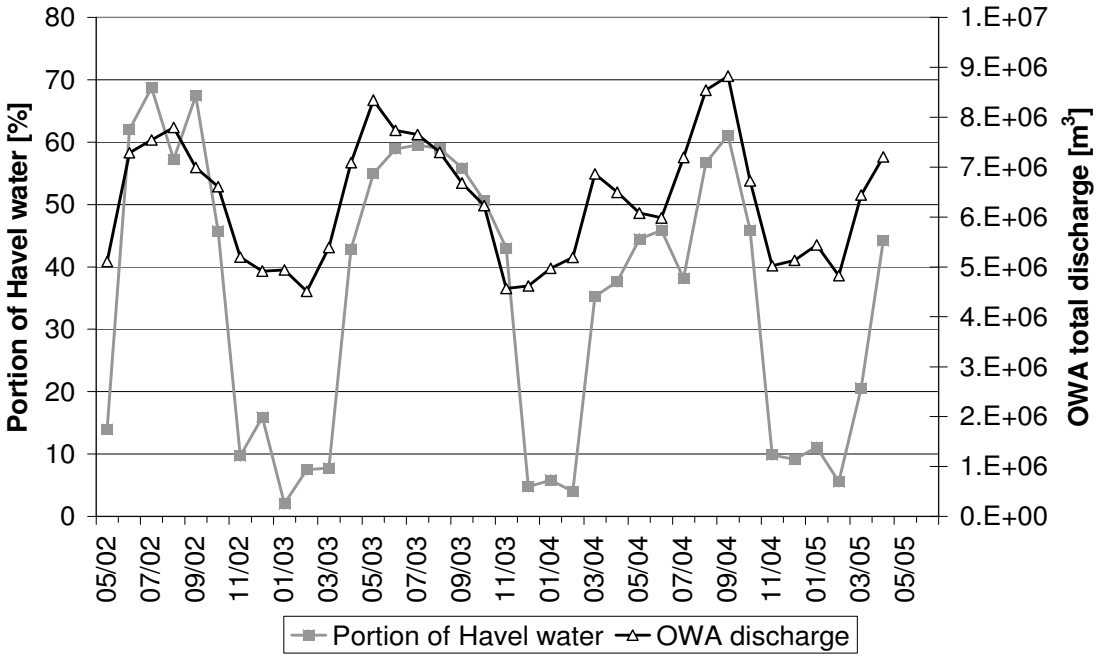


Figure 45. Total discharge into Lake Tegel and the portion of water from the Havel lake pipeline (data BWB)

1.4.4.2 AMDOPH

Median concentrations of 328 ng/L down to 170 ng/L were observed in surface water and in ground water from the shallow monitoring wells 3311, 3310, 3308 and TEG372. As presented in Figure 46 the median concentrations of AMDOPH are decreasing slightly with distance and depth from the infiltration area.

With regard to the analytical measurement accuracy, no significant removal was noticed at the first monitoring wells 3310 & 3311. The attenuation rate between surface water and the bank filtrate at sampling point 3308 was about 44 %. At monitoring well TEG371UP the concentrations are slightly increased in comparison to TEG371OP which can be explained by a mixture of young bank filtrate with formerly infiltrated water at times when AMDOPH surface water concentrations were much higher. The deeper monitoring wells and the water supply well no.13 show much higher concentrations of AMDOPH. The median concentrations at the monitoring wells are increasing by depth and at the deepest monitoring well TEG374, a maximum around 6 µg/L was observed. At the landsite monitoring wells, the detected median concentrations are increasing by depth from 78 ng/L up to 220 ng/L. The

water supply well no.13 represents a mixing of older bank filtrate / groundwater from deeper layers (TEG374), landsite groundwater (3304) and young bank filtrate from the lake Tegel.

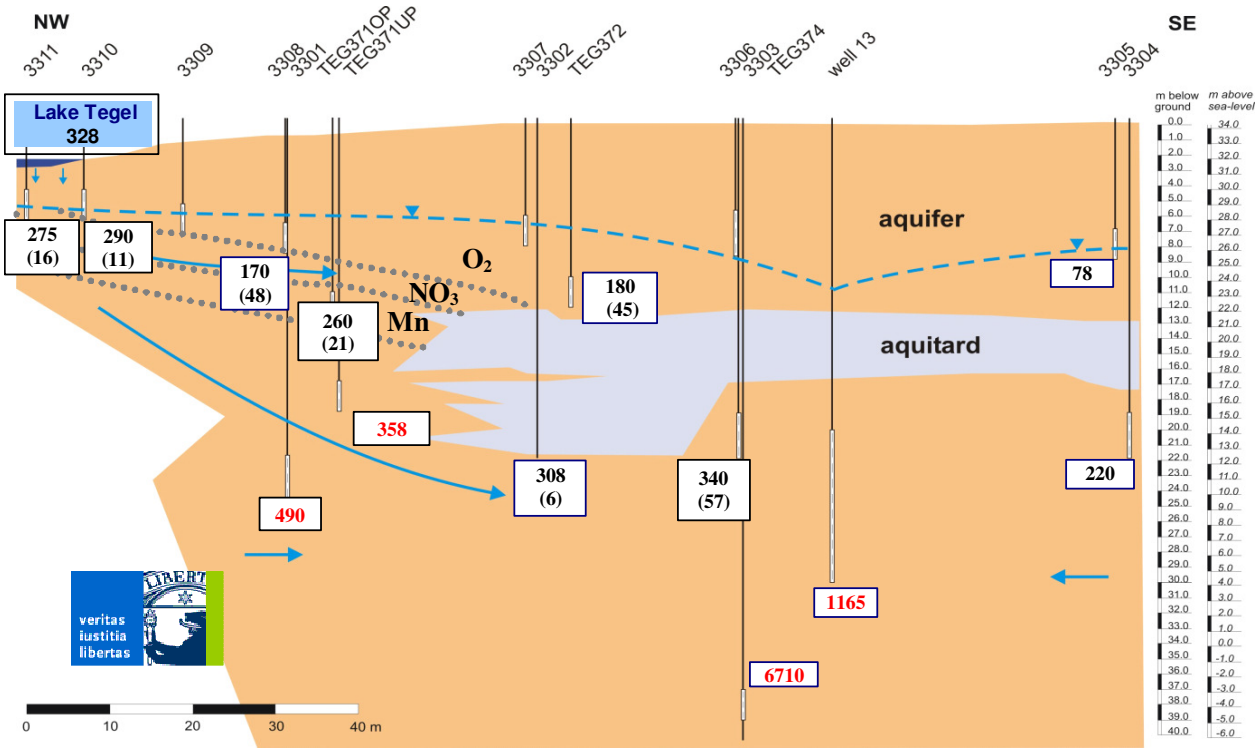


Figure 46. Transect Tegel - median concentrations of AMDOPH at the different monitoring wells and the water supply well 13. Values in brackets show the calculated attenuation rates in percent.

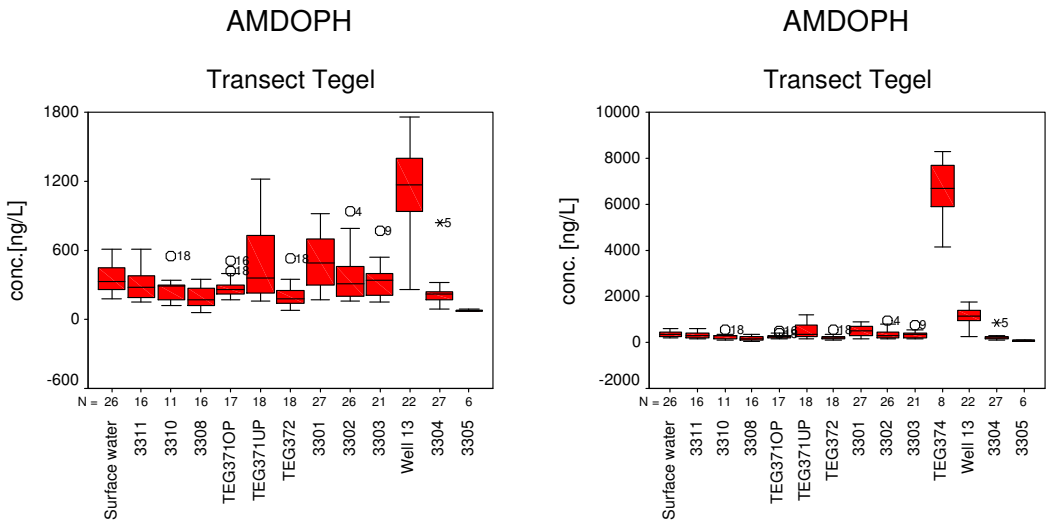


Figure 47. Distribution of AMDOPH concentrations at transect lake Tegel. In the first box plot monitoring well TEG374 is excluded for better resolution. Second box plot show the concentrations at TEG374 in comparison with the other monitoring wells.

The distribution of AMDOPH concentrations shown in Figure 47 are comparable with the distribution of ammonium concentrations (Figure 48) determined by the BWB. Like AMDOPH, the ammonium concentrations at the shallow monitoring wells are decreasing from surface water to TEG372, but show higher values at TEG371UP than in surface water and the other deeper monitoring wells (3301-3304). At monitoring well TEG374 AMDOPH and ammonium concentrations show their maximum.

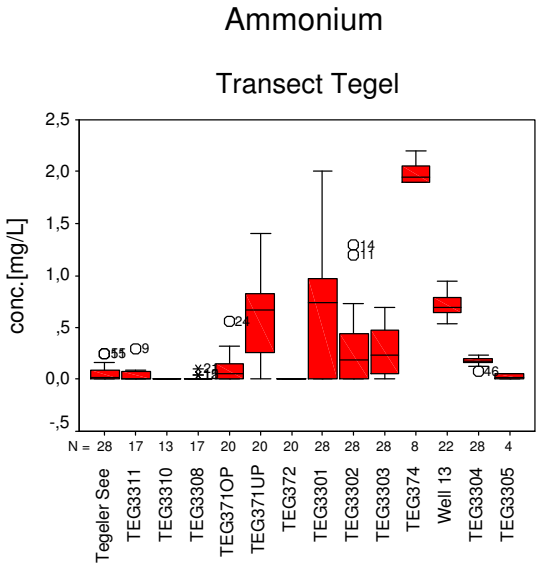


Figure 48. Distribution of ammonium concentrations at the transect Tegel

1.4.4.3 Propyphenazone

The median concentrations of propyphenazone from surface water to the first shallow monitoring wells 3308, 3310 and 3311 are significantly decreased and an attenuation rate around 85 % was observed at 3308 as shown in Figure 49 . At the deep monitoring well 3301 a higher median concentrations (300 ng/L) than in surface water (98 ng/L) was measured. Additionally, at the deeper screens of the multi-level well TEG371 an increased median concentration of 190 ng/L was detected and support the assumption that during the infiltration older bank filtrate formerly higher amounts of phenazone-type compounds from the before mentioned superfund site are mixed with younger bank filtrate. At TEG374, the deepest monitoring well, a median concentration of 60 ng/L was observed. The water supply well with a median concentration of 135 ng/L represents a mixture of younger and older bank filtrate. The monitoring wells behind water supply well no.13 in the south east only showed traces of propyphenazone below the limit of quantification (10 ng/L).

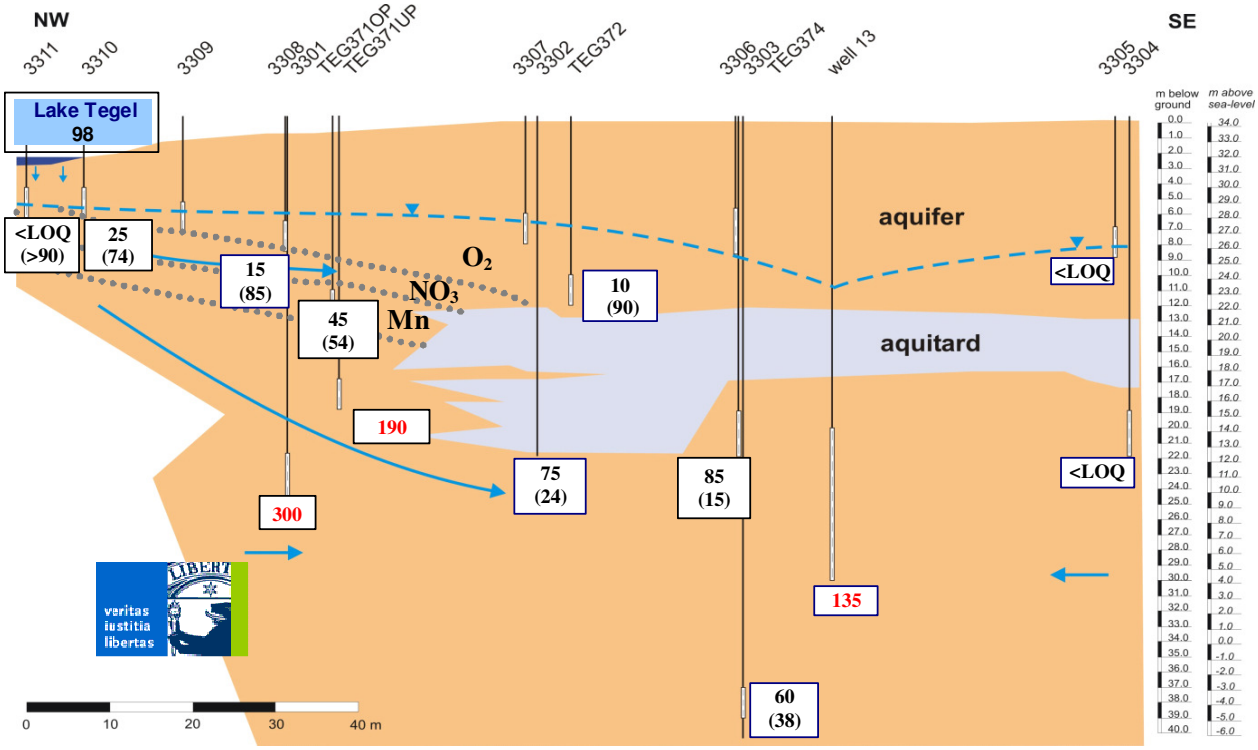


Figure 49. Transect Tegel - median concentrations of propyphenazone at the different monitoring wells and the water supply well 13. Values in brackets show the calculated attenuation rates in percent.

As illustrated in Figure 50 , the distribution of propyphenazone concentrations at TEG371UP and monitoring well 3301 show concentration tendencies with higher values than in surface water and e.g. TEG372. This seems to be similar to the distributions observed for AMDOPH (Figure 47) and ammonium (Figure 48).

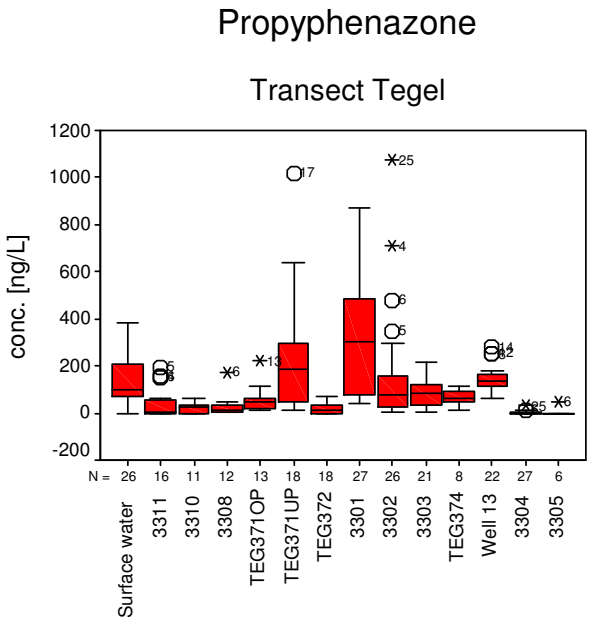


Figure 50. Distribution of propyphenazone concentrations at transect Tegel

1.4.4.4 Clofibric acid

The median concentrations at almost all sampling locations were detected in a concentration range from the limit of quantification up to 35 ng/L, as presented in Figure 51.

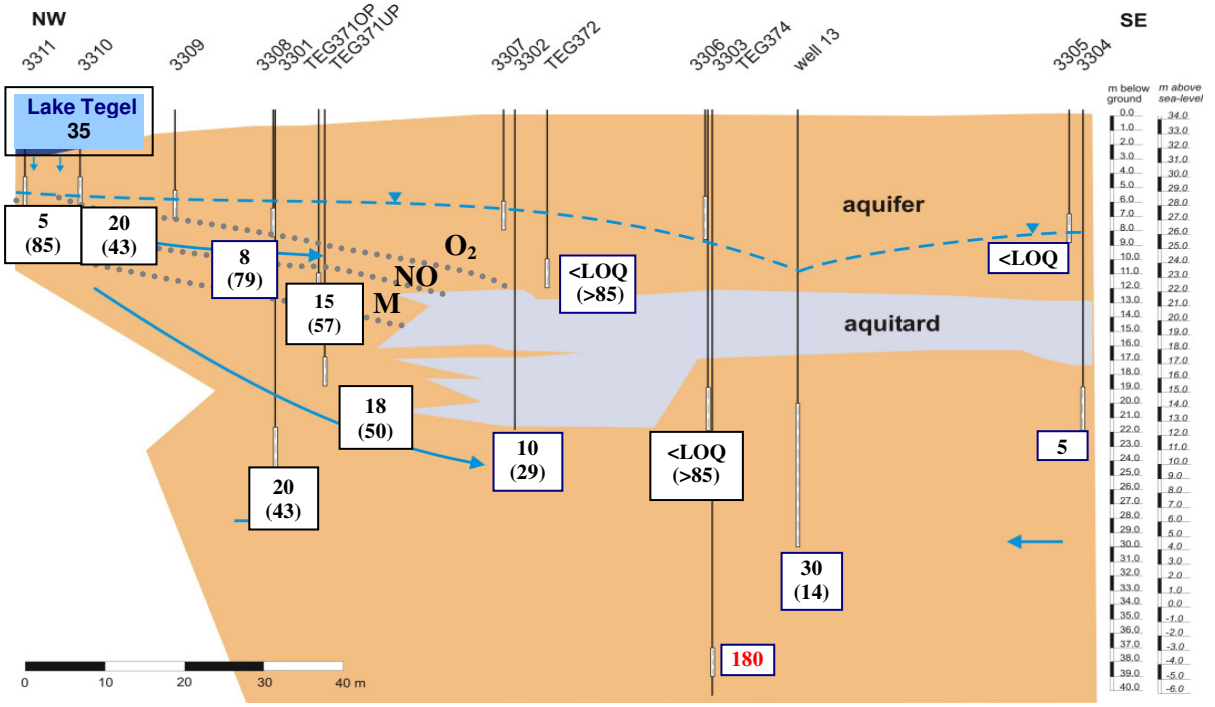


Figure 51. Transect Tegel - median concentrations of clofibric acid at the different monitoring wells and the water supply well 13. Values in brackets show the calculated attenuation rates in percent.

Depending on the low observed concentrations clofibric acid showed no significantly attenuation during infiltration. In opposite to the others, the deepest monitoring well TEG374 show a median concentration of 180 ng/L as illustrated in Figure 52. This median concentration of clofibric acid is probably caused by formerly infiltrated water when the precursor pharmaceutical compounds clofibrate ethyl, etofibrate and etofyllinclofibrate were applicated at higher amounts. The persistence of clofibric acid was already reported in literature [Zwiener, 2000; Winkler, 2001; Preuß, 2001 and Scheytt, 2001].

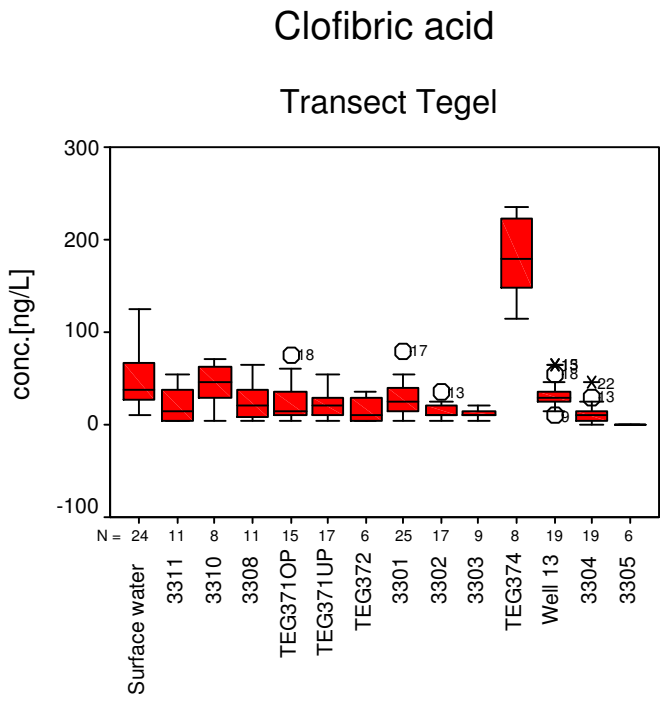


Figure 52. Distribution of clofibric acid concentrations at transect Tegel

At the deeper landsite monitoring well 3304 only traces of clofibric acid were observed.

1.4.4.5 Diclofenac

As Figure 53 shows, a median concentration of 103 ng/L was detected in surface water. Attenuation rates between 74 % and 85 % were observed at the shallow monitoring wells 3311, 3308, TEG371OP and TEG372 and in the deep monitoring well 3303 in front of water supply well no.13. However, the shallow monitoring well 3310 located close to the bank only shows an attenuation rate of 41 %. In deeper monitoring wells 3301 and TEG371UP an attenuation rate of about 64 % was observed. At the shallow landsite monitoring well 3305 no diclofenac was found. In the deeper landsite monitoring well 3304 a median concentration of 13 ng/L was observed.

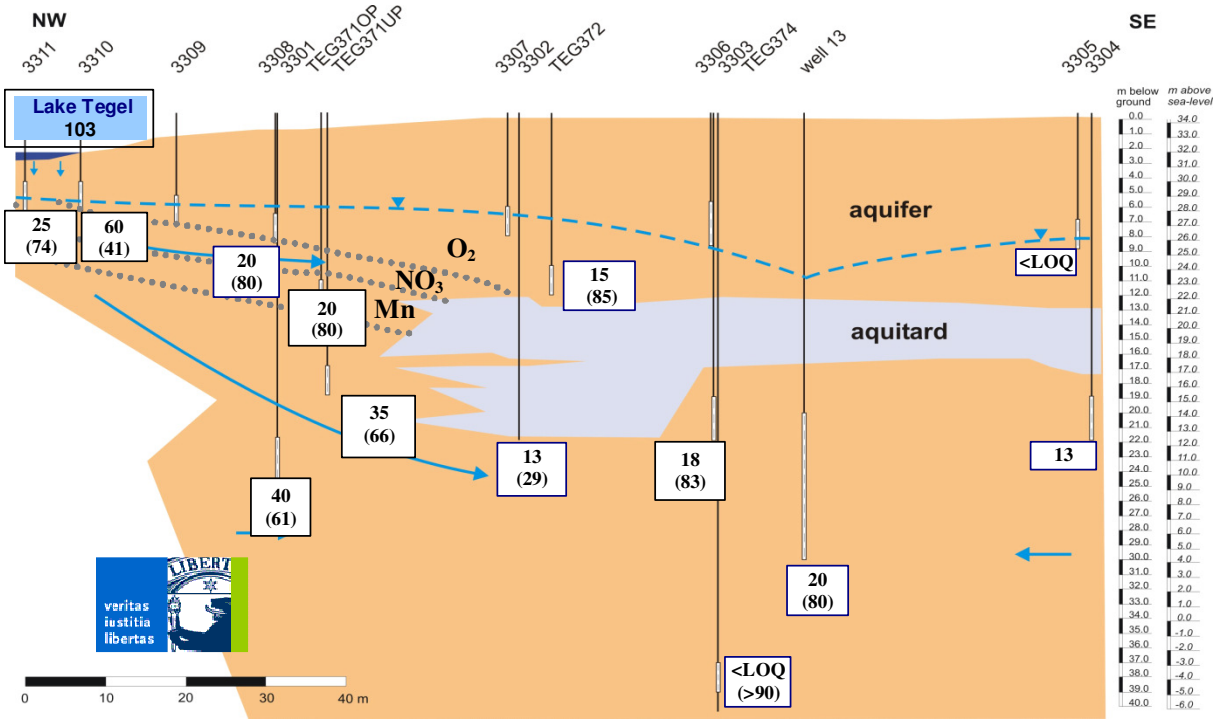


Figure 53. Transect Tegel - median concentrations of diclofenac at the different monitoring wells and the water supply well 13. Values in brackets show the calculated attenuation rates in percent.

In contrast to the results for AMDOPH, propyphenazone and clofibric acid, no diclofenac was found in the deep monitoring well TEG374. The Figure 54 shows a statistical evaluation of the observed concentrations.

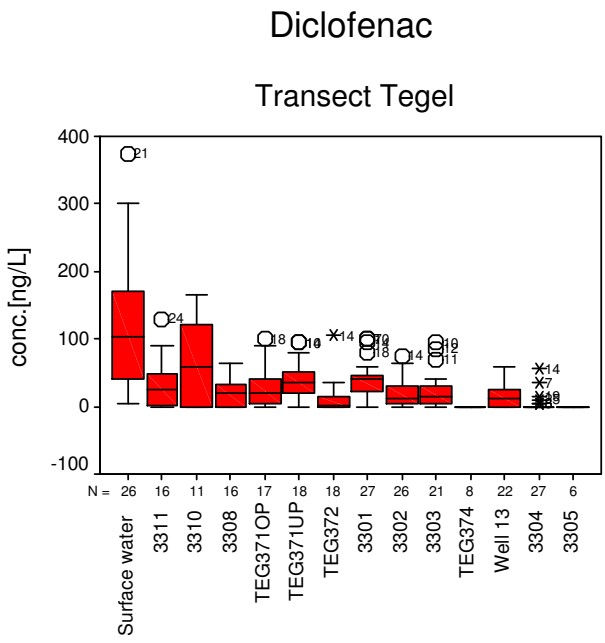


Figure 54. Distribution of diclofenac concentrations at transect Tegel

1.4.4.6 Primidone

Concentrations around 140 ng/L were detected at the surface water and the shallow monitoring well 3310. At monitoring well 3311 a minor attenuation rate of 26 % was noticed.

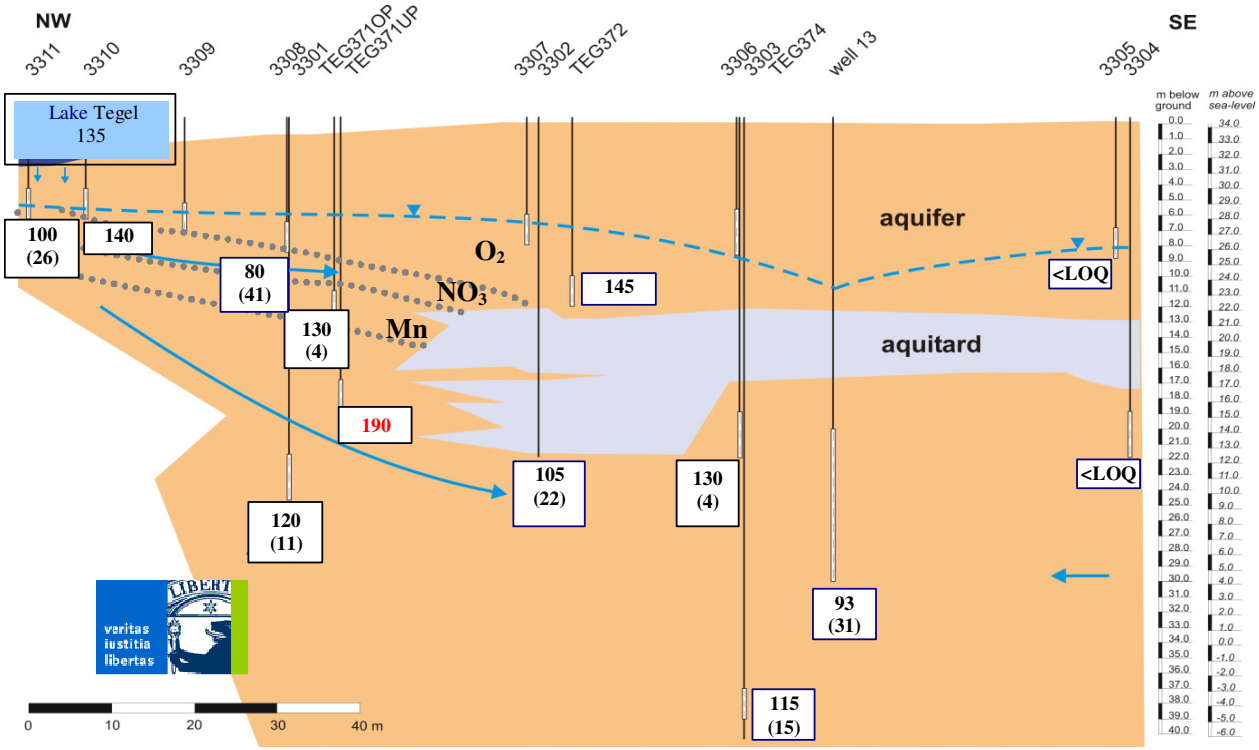


Figure 55. Transect Tegel - median concentrations of primidone at the different monitoring wells and the water supply well 13. Values in brackets show the calculated attenuation rates in percent.

Maximum attenuation rate of 41 % was observed at the shallow well 3308. Similar to the previously described compounds attenuation rates of primidone at the monitoring wells 3301, 3302 were slightly decreased or respectively higher median concentrations than in surface water were noticed. At the deep monitoring wells 3303 and TEG374 equal median concentrations as observed in surface water were observed. The landsite monitoring wells behind the water supply well only showed traces of primidone below the limit of quantification.

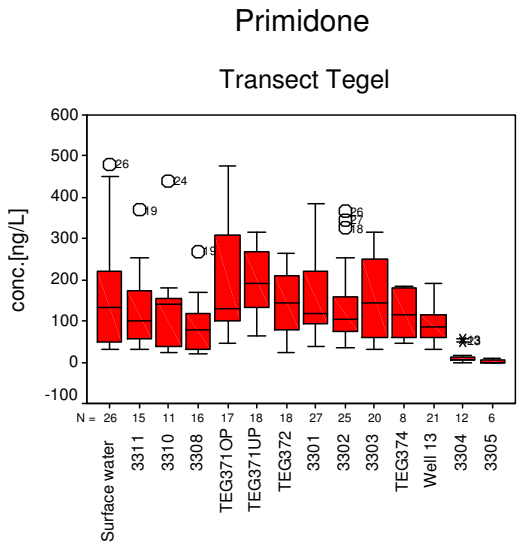


Figure 56. Distribution of primidone concentrations at transect Tegel.

As Figure 56 illustrates, the values of detected primidone concentrations are decreasing during infiltration starting from surface water along the shallow monitoring wells 3311 to 3308.

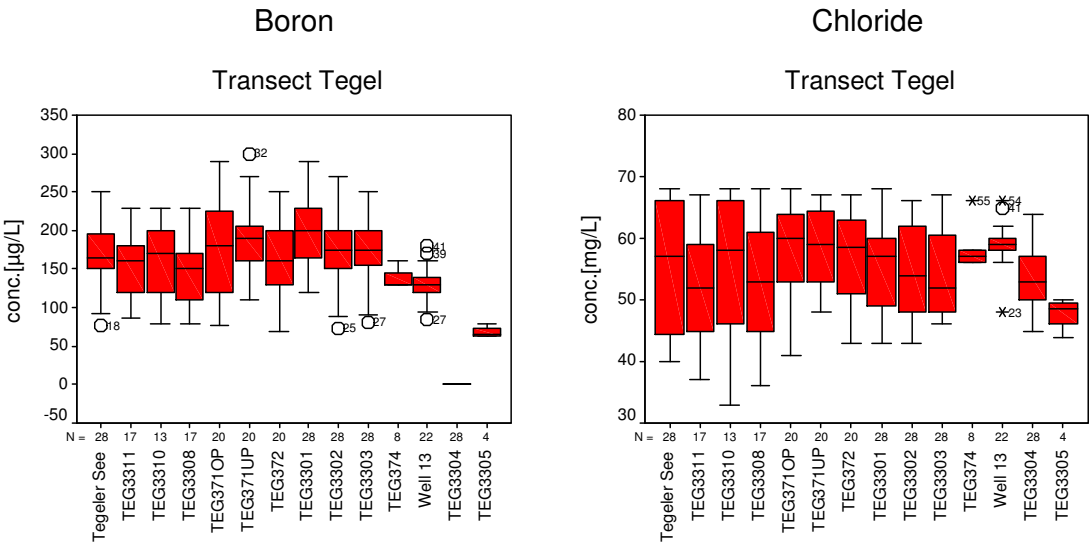


Figure 57. Distribution of boron and chloride concentrations at transect Tegel (data by BWB)

Contrary to these investigations, median concentrations of primidone were increased in the multi-level well TEG371 up to 190 ng/L at its deeper screens. Along the track to the water supply well no.13, no significant attenuation was observed within the analytical measurement accuracy of 20 %. The distribution of primidone concentrations at the monitoring wells in front of water supply well no. 13 were comparable to the distributions of the conservative tracer

boron and chloride which were analysed by the BWB as displayed in Figure 57. A median concentration of 93 ng/L was detected at the supply well no. 13.

1.4.4.7 Carbamazepine

During infiltration from surface water along the shallow monitoring wells 3311, 3310 and 3308, carbamazepine median concentrations around 527 ng/L were detected as Figure 58 shows.

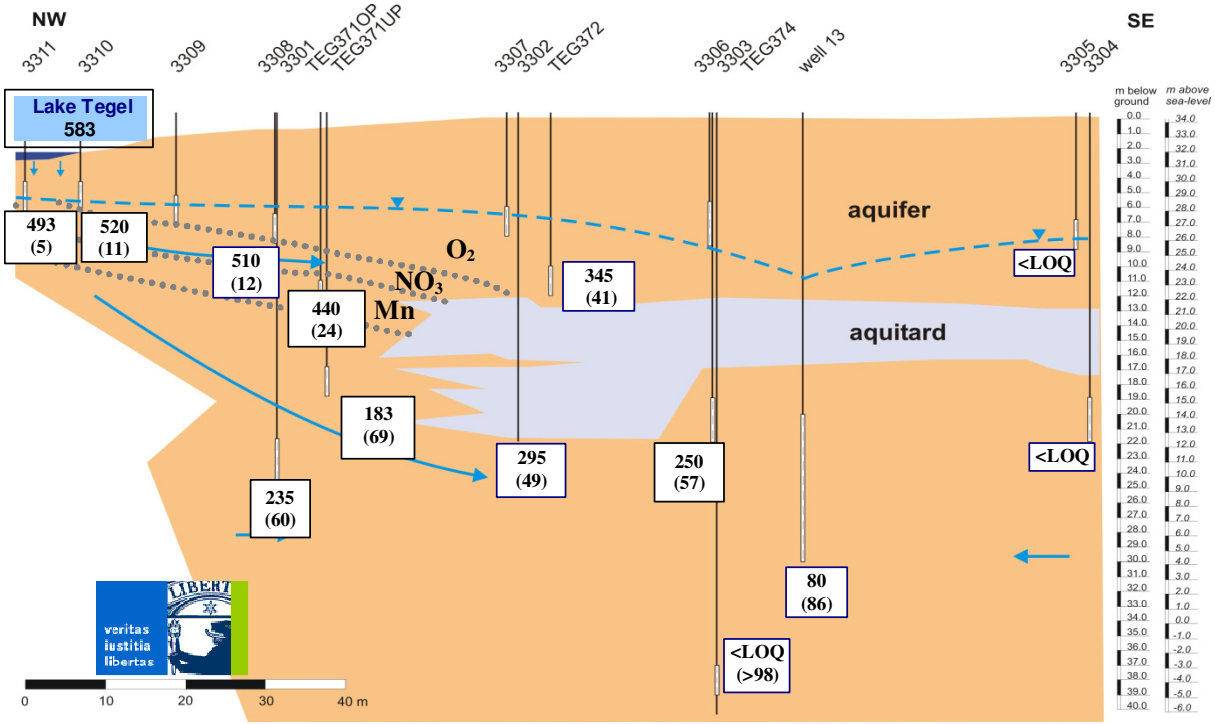


Figure 58. Transect Tegel - median concentrations of carbamazepine at the different monitoring wells and the water supply well 13. Values in brackets show the calculated attenuation rates in percent.

However, these concentrations were within the measurement accuracy of 20 % and thus no significant attenuation was recognized. At monitoring well TEG371OP a slight attenuation of 24 % was noticed. In the deeper screened monitoring wells TEG371UP and 3301 attenuation rates around 65 % were observed. Surprisingly, minor attenuation rates between 49 and 57% were obtained at the monitoring wells 3302 and 3303. The deepest monitoring well TEG374 only show traces of carbamazepine at a median concentration below the limit of quantification. At the water supply well 80 ng/L (median concentration) of carbamazepine was detected that corresponds to an attenuation rate of 86 %. As Figure 59 shows carbamazepine concentrations of the surface water increased since march 2003 up to a maximum of 1170 ng/L. This increase could be explained by the higher amounts of purified

effluents of the STP Schönerlinde reaching lake Tegel and also leads to higher concentrations of indicators of sewage prone waters like boron, chloride and sodium.

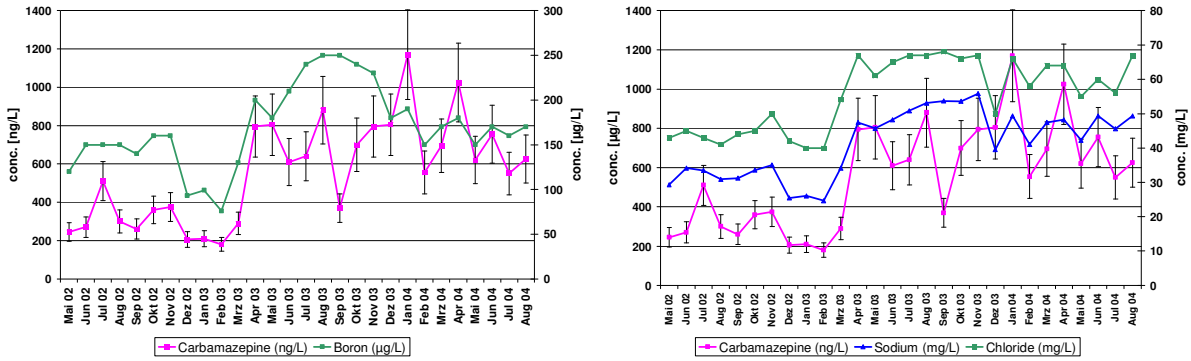


Figure 59. Comparison of concentration trends of carbamazepine and other sewage prone ions (data BWB)

Comparing surface water concentrations of carbamazepine with observed concentrations in monitoring wells 3301, 3302, 3303 and in water supply well 13 (Figure 60), observed concentrations in the bank filtrate / groundwater did not show any significant changes within the analytical measurement accuracy. Due to this no time shift was recognizable.

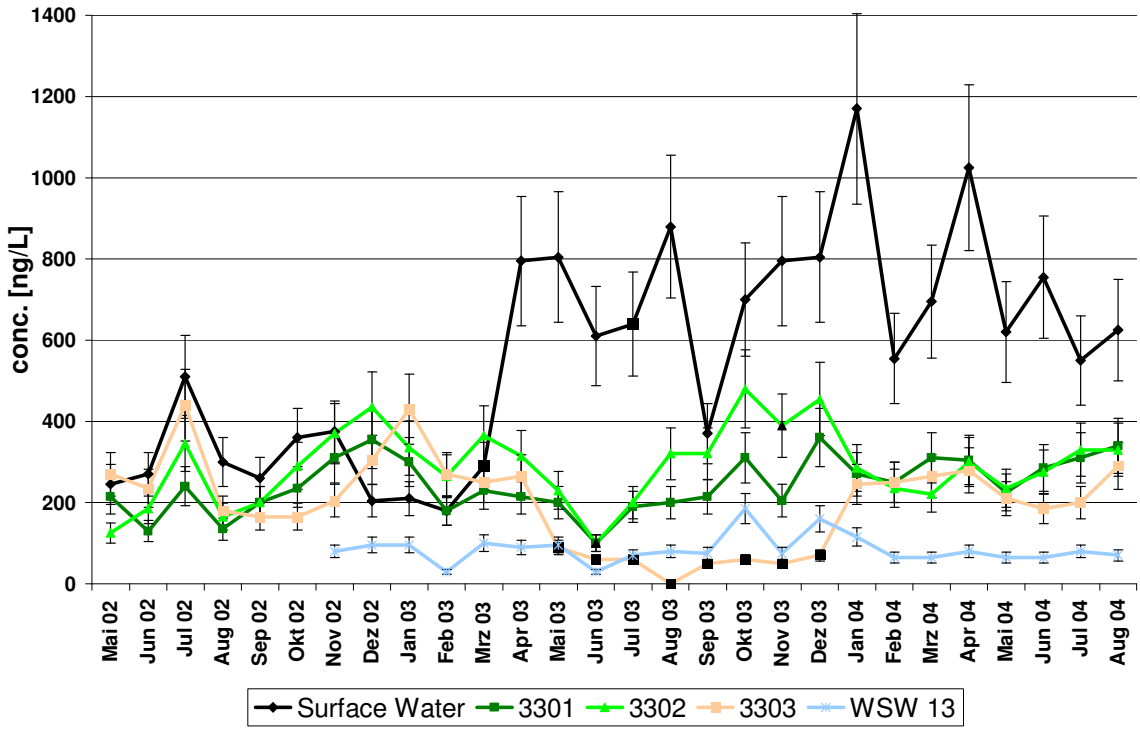


Figure 60. Transect Tegel - Concentrations of carbamazepine in lake Tegel and at the deep monitoring wells and the water supply well 13. (Black marked concentrations data by BWB)

As Figure 63 illustrates, distribution of carbamazepine concentrations seem to have a relation with the determined redox potential. Distributions of carbamazepine concentrations

at surface water and the shallow monitoring wells 3311, 3310 and 3308 were observed at a similar level like the distribution of the redox potential at these monitoring wells.

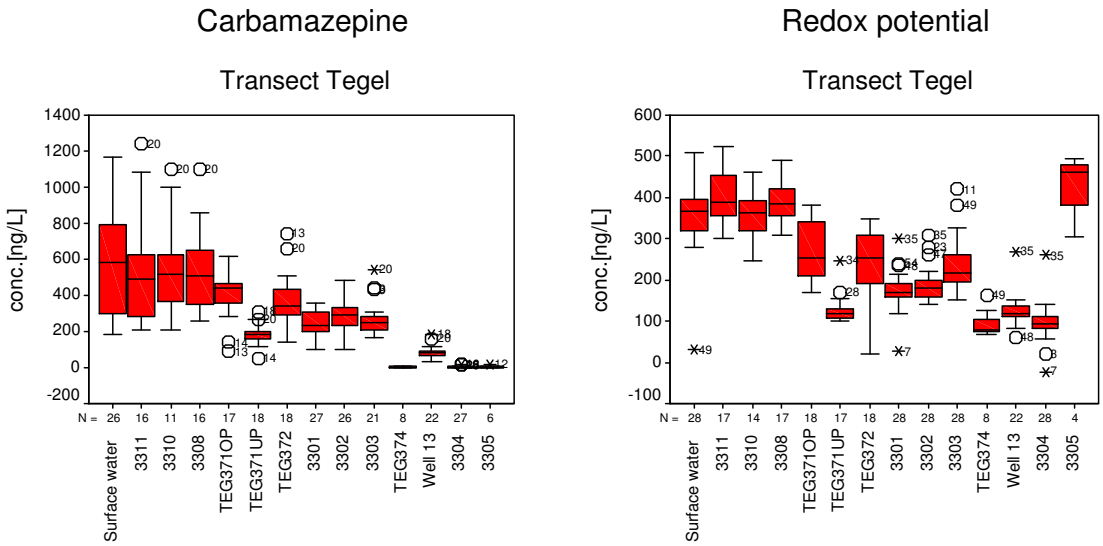


Figure 61. Distribution of carbamazepine concentrations and the determined redox potential (data by BWB) at transect Tegel

1.4.4.8 Other observed polar residues

Additional to the investigated drug residues two pesticides namely bentazone and mecoprop, 2,2-bis(4-chlorophenyl)acetic acid (p,p'-DDA) and its isomer 2-(2-chlorophenyl)-2-(4-chlorophenyl)-acetic acid could be detected in traces just around limit of quantification along the infiltration path at all monitoring wells and the water supply well no. 13. N-(phenylsulfonyl)-sarcosine (NPS) a metabolite of a corrosion inhibitor also was observed with low concentrations (< 20 ng/L) in surface water and at the shallow monitoring wells. Similar to AMDOPH, clofibric acid and propyphenazone increasing median concentrations of 55 ng/L at monitoring well TEG374 and about 85 ng/L at 3304 a deep land site monitoring well were noticed. Due to this a median concentration around 65 ng/L at the receiving water supply well 13 was detected.

1.4.4.9 Conclusions

Eight drug residues were detected in the surface water of lake Tegel. Six of them were identified as being relevant for drinking water production because they were transported along the infiltration path and found in water supply well 13. The analgesic drug indometacine and the blood regulating pharmaceutical bezafibrate were determined in very low concentrations in the surface water of lake Tegel and were sustainably removed with attenuation rates higher than 95 % during first meters of infiltration at TEG372, a shallow

monitoring well in front of the water supply well 13. Clofibric acid, the pharmacologically active metabolite of three blood regulating drugs, and the analgesics diclofenac and propyphenazone showed medium removal rates up to the shallow monitoring well TEG372. Only low attenuations were observed for AMDOPH the metabolite of dimethylaminophenazone (analgesic) and the antiepileptic drugs carbamazepine and primidone.

Table 22. Classification of target compounds according to their rates of attenuation

Group	Compound	Median rate of attenuation at TEG372	Median rate of attenuation at WSW 13	
1 low removal rates 0-45 %	AMDOPH	45 %	- 256 %	(exceptional case)
	Carbamazepine	41 %	86 %	
	Primidone	0 %	31 %	
2 medium removal rates 46-95 %	Clofibric acid	90 %	14 %	(exceptional case)
	Diclofenac	85 %	80 %	
	Propyphenazone	90 %	- 38 %	(exceptional case)
3 high removal rates > 95 %	Bezafibrate	> 95 %	> 95 %	
	Indometacine	> 97 %	> 97 %	

At water supply well 13, where infiltrated surface water is mixed with land sited groundwater and old groundwater from the deep aquifer, carbamazepine and diclofenac were attenuated by 80 % and 86 %, respectively. A low attenuation rate of around 14 % was observed for clofibric acid at the water supply well 13 resulting from mixture of young bank filtrate and older bank filtrate / groundwater with higher amounts of this compound. The observed clofibric acid median concentration of 180 ng/L at TEG374 also were higher than the concentrations noticed at surface water and could be explained by a formerly higher application of the precursor compounds clofibrate ethyl, etofibrate and etofyllinclofibrate. AMDOPH and propyphenazone represent exceptional cases with detected concentrations that were partly higher (up to 200 %) in water supply well 13 than those observed in the surface water. The explanation of this behavior for AMDOPH and propyphenazone is a formerly production spill of a pharmaceutical plant in the city Oranienburg located upstream from the north-western districts of Berlin (Reddersen, 2002). Additionally, very high AMDOPH concentrations (around a median of 6.2 µg/L) were detected at TEG374. T/He effective age dating yielded an age of 25 years for the groundwater at TEG374 [NASRI Report 1, Chapter 1.4.5.] which supported the hypothesis of the mixing with older groundwater contaminated with higher concentrations of phenazone-type residues..

1.4.5 Wannsee surface water

Former investigations by the hydro geologic group reported the distribution of anthropogenic tracer compounds in Lake Wannsee such as boron and EDTA [NASRI Report 1, Chapter 1.5.]. To get an idea of the distribution of the drug residues across Lake Wannsee in front of transect Wannsee I and Wannsee II, the lake was sampled two times in March 2004 and July 2004. As Figure 62 shows, nineteen different locations were chosen and sampled in cooperation with the algae group [NASRI Report 5, Chapter 3]. Additionally sampling point 9 was sampled during both campaigns at the surface and at the different depths of 2, 4, 6 and 7 meters.

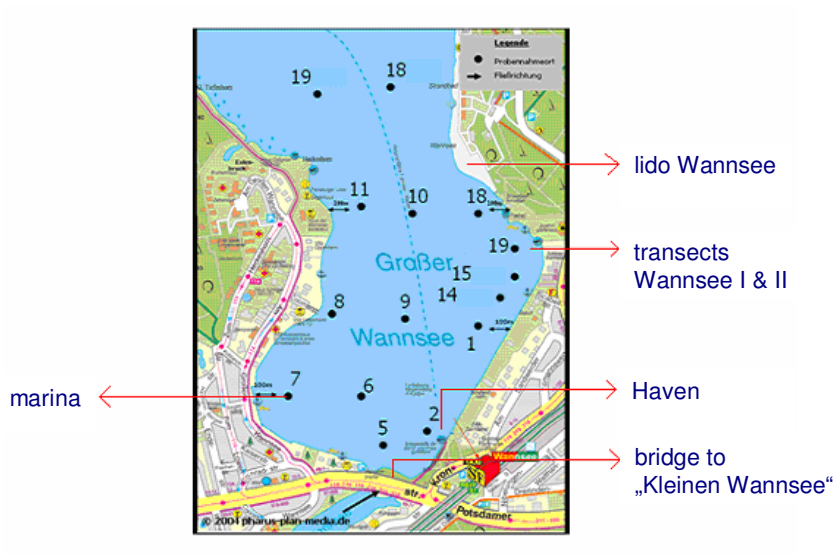


Figure 62. Sampling locations across lake Wannsee

Because the Teltowkanal is seasonally loaded with the effluents from up to three STP and partially flows into the south of lake Wannsee, the channel affects the concentrations of drug residues within this lake. Therefore, four different locations along the channel, one near the influx to lake Wannsee and another one in front of transect Wannsee were sampled in September 2004, as shown in Figure 63.

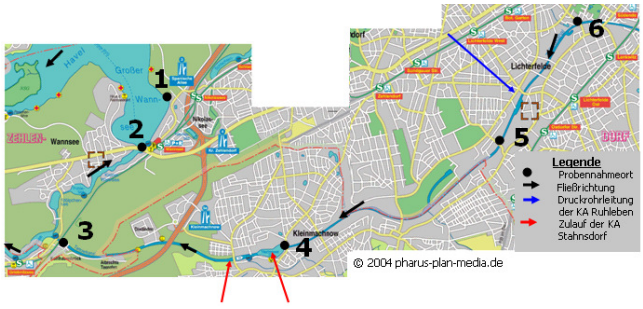


Figure 63. Sampling locations along the Teltowkanal

Table 23 gives an overview of the six sampling locations of the third sampling event.

Table 23. Investigated locations along Teltow channel at lake Wannsee.

Nr.	Location
1	Steg beim Jugendgästehaus (in front of transect Wannsee)
2	Wannsee bridge (connection between kleiner Wannsee and lake Wannsee)
3	Nathanbrücke (end of Teltowkanal)
4	Friedensbrücke; Zehlendorfer Damm
5	Eugen-Kleine-Brücke; Wismarer Straße
6	Prinzregent-Ludwig-Brücke;Birkbuschstr.

During this investigation seven pharmaceutical residues were detected, namely AMDOPH, bezafibrate, carbamazepine, clofibric acid, naproxen, primidone and propyphenazone. Table 24 shows concentration range and mean concentrations of the observed compounds.

Table 24. Concentration (ng/L) range of pharmaceutically active compounds with positive findings in lake Wannsee.

	March 2004 (n=15)			July 2004 (n=15)		
	min [ng/L]	max [ng/L]	mean concentration [ng/L]	min [ng/L]	max [ng/L]	Mean concentration [ng/L]
AMDOPH	110	170	129	200	250	228
Bezafibrate	50	220	93	10	40	25
Carbamazepine	440	1050	611	200	470	367
Clofibric acid	30	100	53	20	40	31
Diclofenac	150	830	298	60	170	83
Naproxen	20	70	29	30	30	30
Primidone	190	560	294	190	320	241
Prophyphenazone	50	70	60	120	140	129

Results of the sampling at different depths are presented in Table 25 and show no significant distribution between different layers in the surface water within the analytical measurement inaccuracy. Only in July 2004, surface water concentrations for diclofenac show a clear decrease of 100 ng/L by depth. This behaviour is unexpected because diclofenac is known to be eliminated by photo chemical reactions (Buser, 1998) and if a depth distribution would be presumed then a concentration increase with the depth would be expected.

Table 25. Results of different depth sampling in March and July 2004

Date	March 2004						July 2004				
Sampling point	FU 9						FU 9				
Depth	Surface	2m	4m	6m	7m		Surface	2m	4m	6m	7m
	[ng/L]						[ng/L]				
AMDOPH	150	140	130	120	130		250	270	240	230	230
Bezafibrate	50	70	70	50	60		10	20	20	20	30
Carbamazepine	470	430	440	480	560		410	380	460	470	370
Clofibric acid	40	40	40	40	40		30	30	30	30	30
Diclofenac	210	210	260	230	200		170	100	70	70	80
Naproxen	20	20	20	20	20		30	30	30	30	30
Primidone	350	230	290	280	330		240	170	220	240	250
Prophyphenazone	60	50	50	50	50		130	130	130	130	130

The results for the third sampling campaign at Teltowkanal and two sampling points in September 2004 are presented in Figure 64.

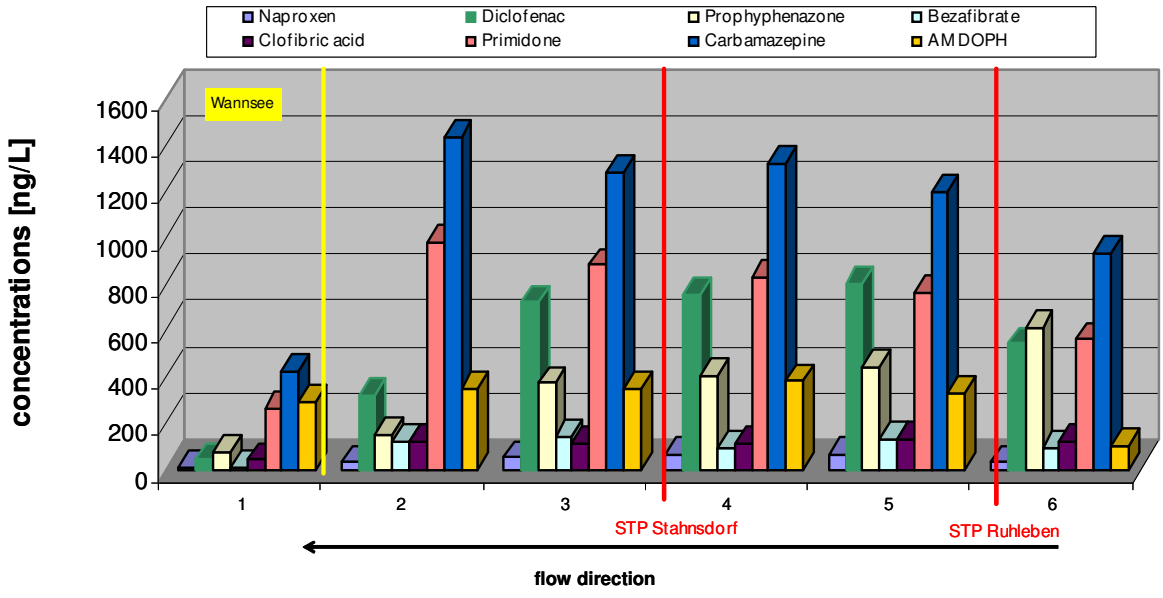


Figure 64. Concentrations of the observed compounds at the Teltowkanal

1.4.5.1 AMDOPH

The observed concentrations of AMDOPH were very similar across lake Wannsee in March 2004. Concentrations between 110 ng/L - 170 ng/L with a mean concentration of 129 ng/L were found during the first sampling. Opposite to this, the concentrations during the second sampling event are higher and vary between 200 ng/L - 250 ng/L with a mean concentration of 228 ng/L.

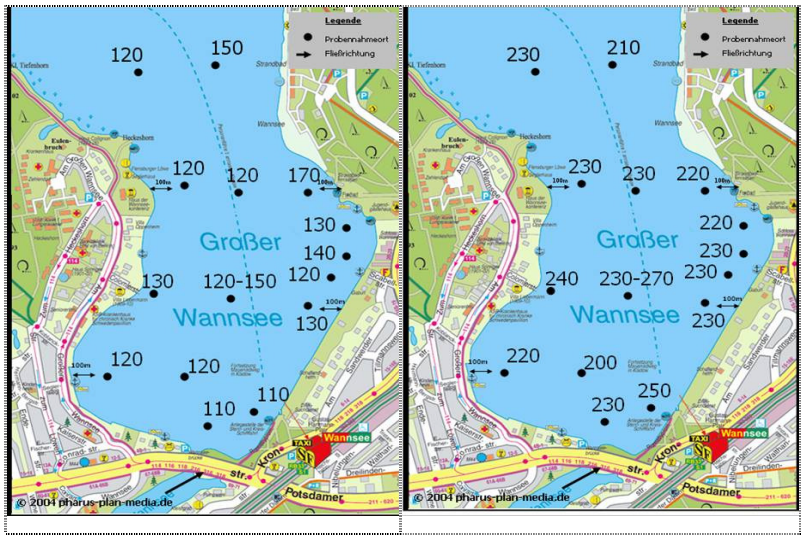


Figure 65. AMDOPH concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

During third sampling event in September 2004 at the Teltowkanal and the two other sampling locations, AMDOPH concentrations between 100 ng/L and 380 ng/L were observed as Figure 67 presents. A concentration of 100 ng/L was detected at sampling point upstream the pipeline from the sewage water treatment plant Ruhleben. After the passage of the pipeline effluent from STP Ruhleben, concentration increased up to 380 ng/L. At the location in front of transect Wannsee 290 ng/L of AMDOPH were detected.

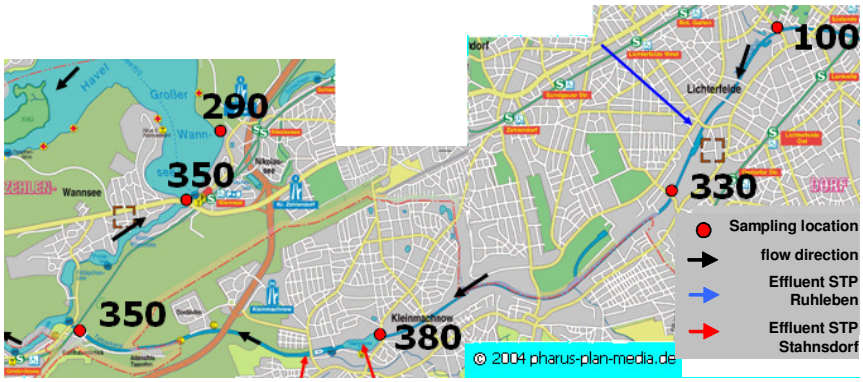


Figure 66. AMDOPH concentrations [ng/L] along the Teltowkanal and lake Wannsee in September 2004

1.4.5.2 Propyphenazone

In March 2004 the concentrations of propyphenazone across lake Wannsee were between the measurement inaccuracy of 20 %, concentrations around 60 ng/L were detected. Samples in July 2004 were increased in comparison to first sampling event around a concentration of 130 ng/L. Similar to results of AMDOPH no significant distribution differences could be observed in lake Wannsee during both campaigns.

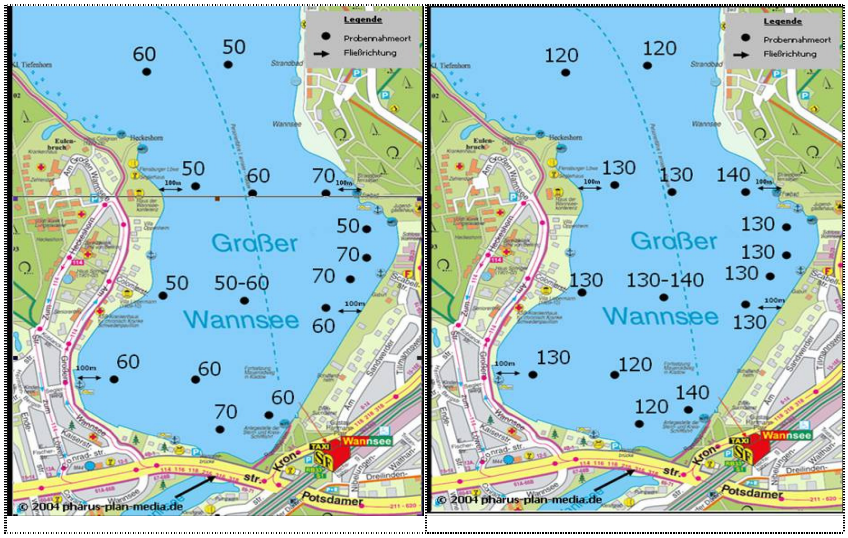


Figure 67. Propyphenazone concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

Figure 68 shows detected concentrations at Teltowkanal that are slightly decreasing with a maximum of 610 ng/L at upstream sampling point no. 6 (see Figure 63) in the east a minimum of 70 ng/L in surface water in front of transect Wannsee. The effluents of the sewage water treatment plants Ruhleben and Stahnsdorf show no obvious effect on the concentration of Propyphenazone along the Teltowkanal.

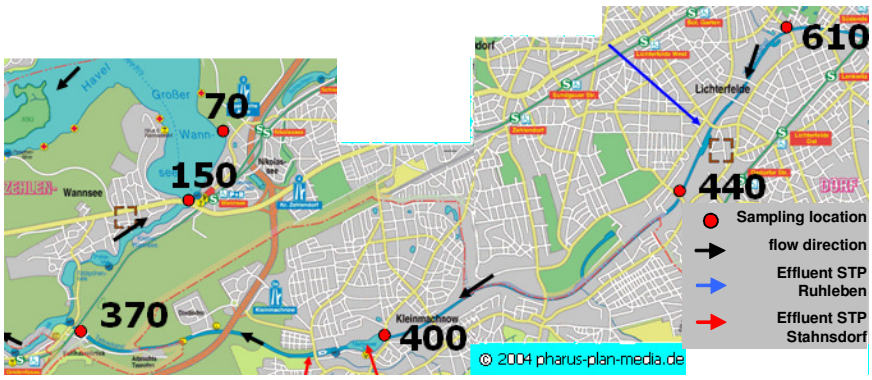


Figure 68. Propyphenazone concentrations [ng/L] along Teltowkanal and lake Wannsee in September 2004

1.4.5.3 Bezafibrate

In Figure 69 bezafibrate concentrations in March 2004 are presented for the different sampling points in lake Wannsee. They were between a minimum of 60 ng/L and increasing up to 220 ng/L in the south near bridge Wannsee. During investigations in July 2004 very low concentrations under the limit of quantification of this compound (LOQ < 50 ng/L) were observed.

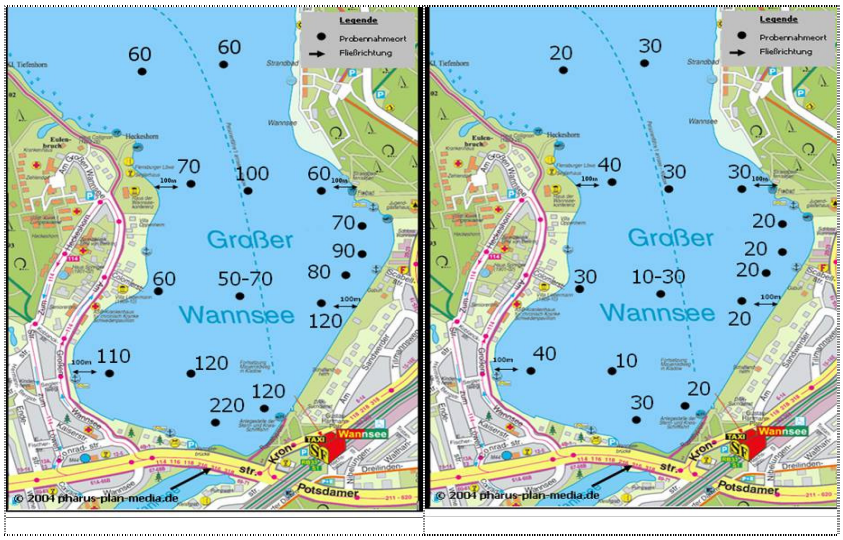


Figure 69. Bezafibrate concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

Teltow channel sampling in September 2004 show bezafibrate concentrations between 90 ng/L and 130 ng/L, as represented in Figure 69. The sampling points before the effluents of STP Ruhleben and Stahnsdorf reaching the channel, show concentrations of 90 ng/L. After these effluents reached the channel concentrations are increased up to 130 ng/L respective 140 ng/L. At the sampling location in front of transect Wannsee only a trace (10ng/L) of bezafibrate could be identified in September 2004.

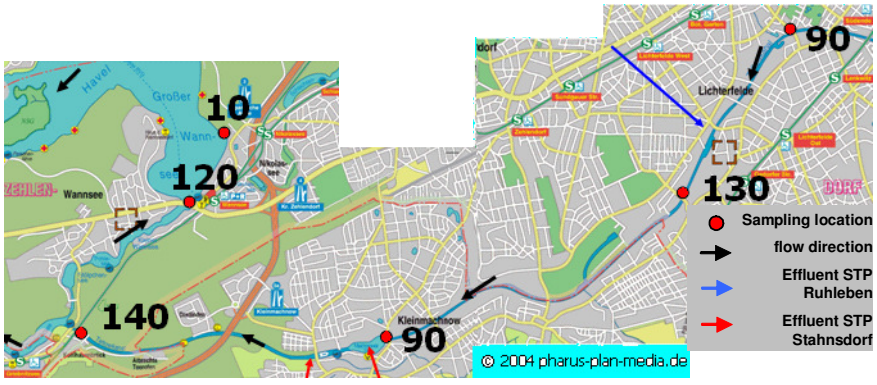


Figure 70. Bezafibrate concentrations [ng/L] along the Teltowkanal and lake Wannsee in September 2004

1.4.5.4 Carbamazepine

As shown in Figure 71, carbamazepine concentrations in March 2004 were detected with a maximum of 1050 ng/L at sampling point near the Wannsee bridge in the south of the lake. Minimum concentrations of 440 ng/L were measured at sampling point 10 (see Figure 62) in the north of the lake. High concentrations between 720 ng/L and 800 ng/L were observed at the eastern bank of lake Wannsee. In summer the concentrations of carbamazepine were significantly lower than during the first sampling event.

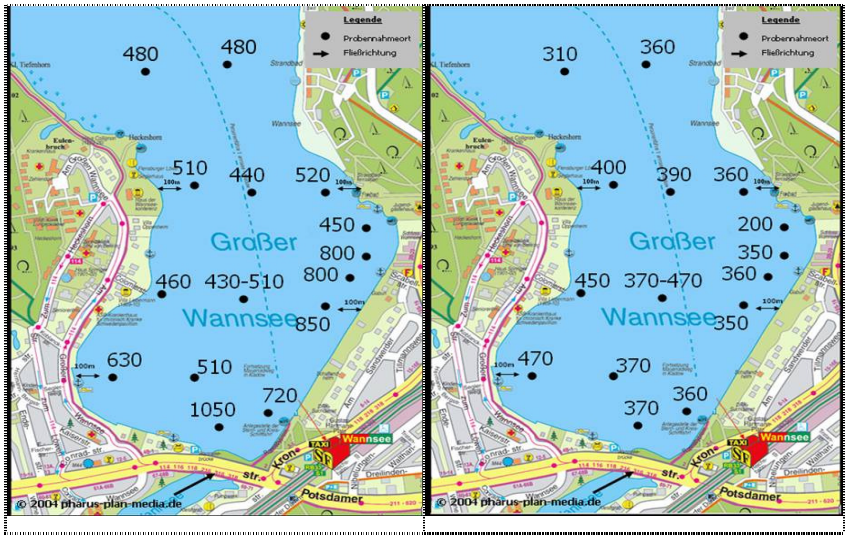


Figure 71. Carbamazepine concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

During investigations at the Teltowkanal, carbamazepine concentrations of 930 ng/L were observed upstream the effluent of STP Ruhleben as illustrated in Figure 72. Behind that effluent increased concentrations from 1200 ng/L to 1430 ng/L were founded. The effluent of STP Stahnsdorf has no clear effect on carbamazepine concentrations, this is very similar to the behaviour of AMDOPH concentrations. In front of transect Wannsee only 420 ng/L were detected.

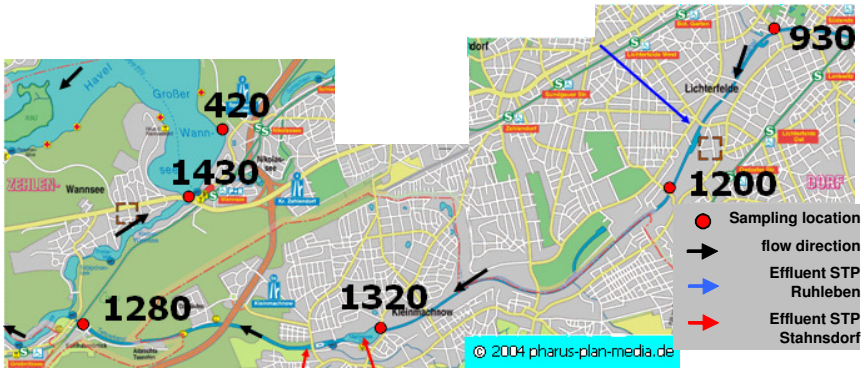


Figure 72. Carbamazepine concentrations [ng/L] along the Teltowkanal and lake Wannsee in September 2004

1.4.5.5 Clofibric acid

In March 2004, clofibric acid concentrations around a mean concentration of 53 ng/L were observed and no obviously distribution could be concluded as displayed in Figure 73. In spite of this sampling point no.5 (see Figure 62) that is nearly the connection of the Teltow channel and lake Wannsee, showed a concentration of 100 ng/L. During second sampling period a little lower mean concentration of 31 ng/L was determined across the lake. In contrast to March sampling, concentration near the Wannsee bridge show an amount like the other sampling locations.

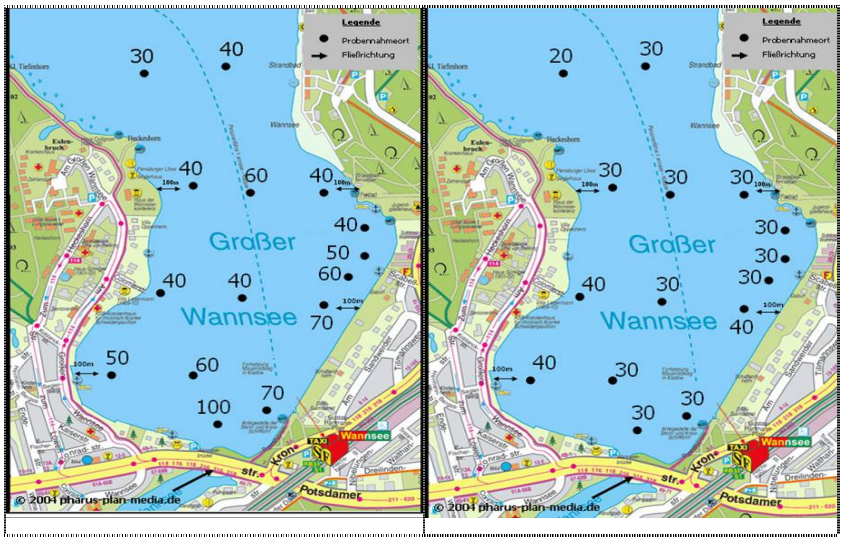


Figure 73. Clofibric acid concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

The investigations at Teltowkanal show constant concentrations around a mean of 120 ng/L, as presented in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The effluents of the two sewage water treatment plants have no obvious effect on clofibric acid concentrations. At the sampling location in front of transect Wannsee a significantly decreased concentration of 40 ng/L was detected.

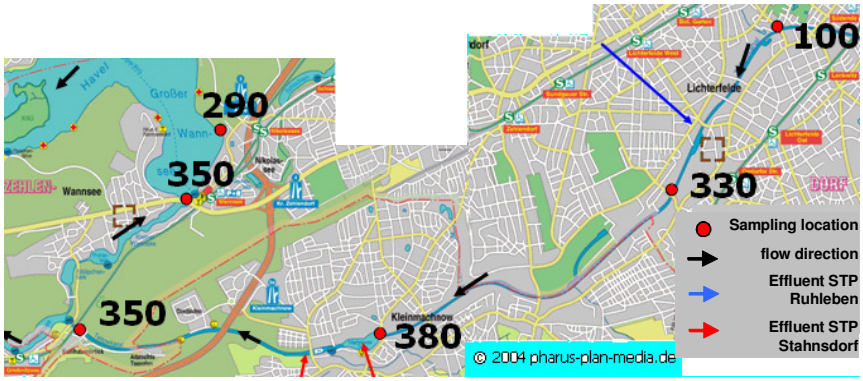


Figure 74: Clofibric acid concentrations [ng/L] along the Teltowkanal and lake Wannsee

1.4.5.6 Diclofenac

Diclofenac concentrations with a minimum of 150 ng/L in the north of the lake and a maximum of 830 ng/L in the south near Wannsee bridge were observed during sampling in March 2004. A mean concentration of 298 ng/L was detected. Like the distribution of carbamazepine, the concentrations at the south-eastern bank were higher than at the western bank as Figure 75 shows. In July 2004, the mean concentration of only 83 ng/L was determined. A clear distribution as shown during the first sampling was not observed.

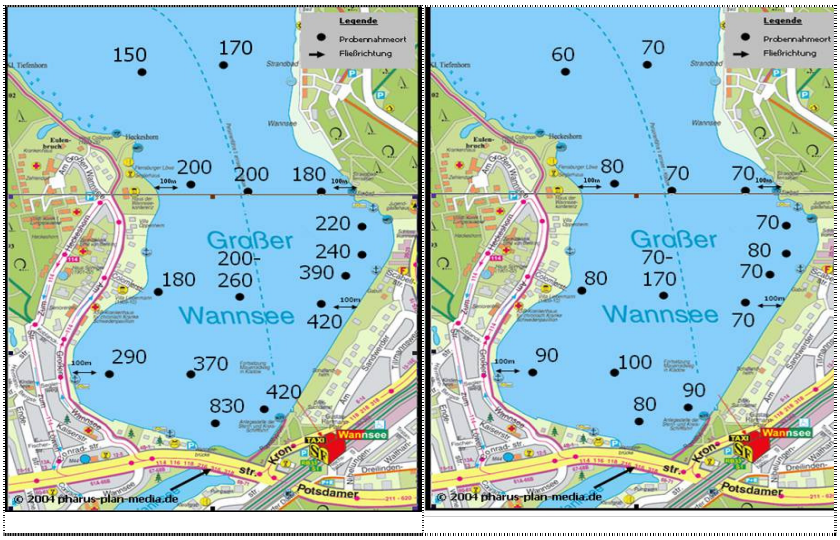


Figure 75. Diclofenac concentrations [ng/L] across lake Wannsee in March (left) and July (right) 20042004

The diclofenac concentrations investigated at Teltowkanal were detected between 540 ng/L and 720 ng/L as shown in Figure 76. At the additional sampling locations at the Wannsee

bridge and in front of transect Wannsee concentrations of 320 ng/L respective only 40 ng/L were observed. Concentrations along the channel are increased behind the effluent of STP Ruhleben but were not affected behind effluent of STP Stahnsdorf. This effect is very similar to the behaviour of AMDOPH and carbamazepine.

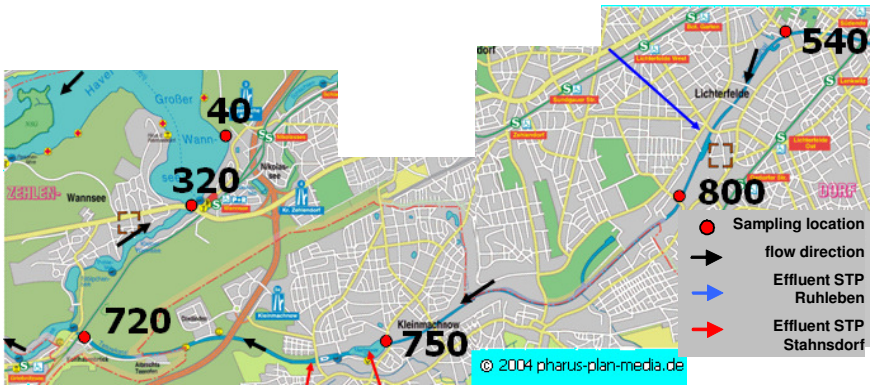


Figure 76. Diclofenac concentrations [ng/L] along the Teltowkanal and lake Wannsee in September 2004

1.4.5.7 Primidone

Concentrations of primidone in March 2004 were detected between 190 ng/L up to 560 ng/L with a mean of 294 ng/L, as illustrated in Figure 77. The concentrations show a distribution with minor concentrations in the north and higher concentrations in the south. A significant distribution among the western and eastern bank were not observed. In July 2004, a mean concentration of 241 ng/L was detected within a range of 190 ng/L to 320 ng/L. A clear distribution between north and south respectively west and east was not observed.

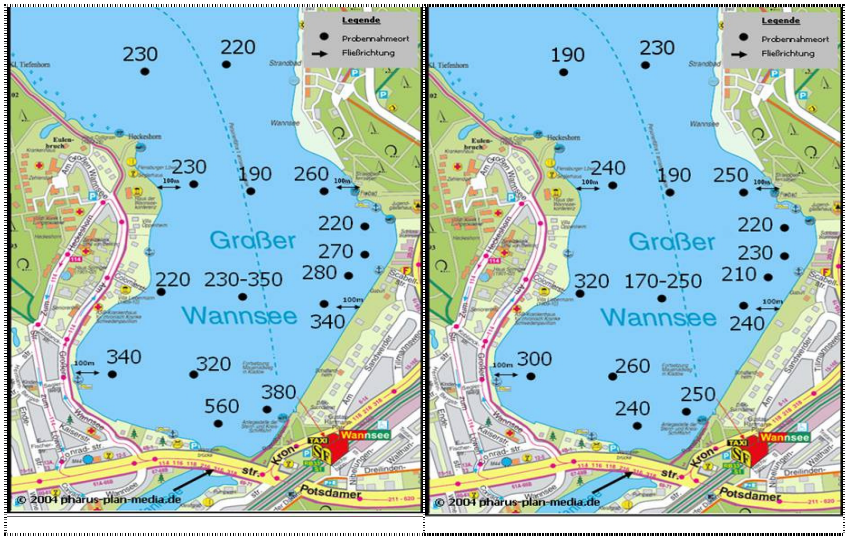


Figure 77. Primidone concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

As shown in Figure 78, primidone concentrations from 560 ng/L up to 880 ng/L along the Teltowkanal were detected. Behind the effluents of the STP Ruhleben a concentration

increase of 200 ng/L was observed. Effluent of Stahnsdorf leads to no significantly increase within the measurement inaccuracy of around 20 % at the sampling locations behind it. At the sampling location near Wannsee bridge a maximum concentration of 980 ng/L was observed. In front of transect Wannsee a significant concentration decrease around 500 ng/L was recognizable.

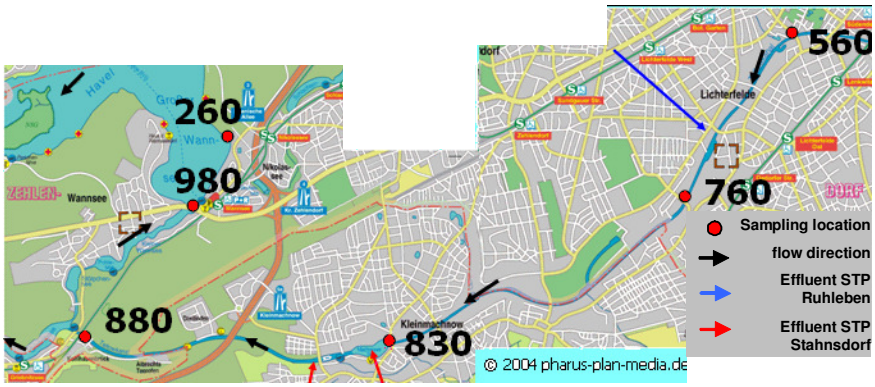


Figure 78. Primidone concentrations [ng/L] along the Teltowkanal and lake Wannsee in September 2004

1.4.5.8 Naproxen

Naproxen concentrations across lake Wannsee in sampling campaigns March and July 2004 presented in Figure 79 show an approximate similar concentration level around a mean concentration around 30 ng/L. A distribution of the naproxen concentrations in lake Wannsee was not observable.

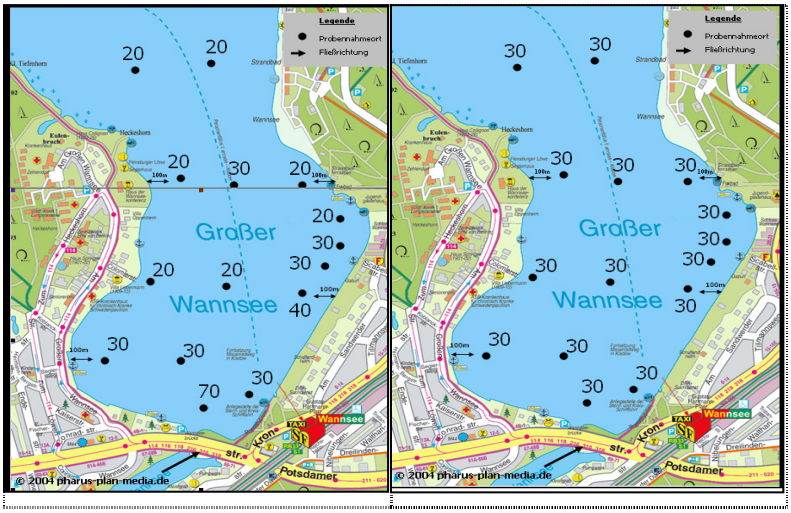


Figure 79. Naproxen concentrations [ng/L] across lake Wannsee in March (left) and July (right) 2004

Concentrations of naproxen along the Teltowkanal were detected at a mean of 50 ng/L. At sampling location no.6 (see Figure 63) before the effluent of STP Ruhleben reached the channel, a naproxen concentration of 30 ng/L was detected. Behind the effluent the measured concentrations were increased up to 60 ng/L. Near Wannsee bridge only 30 ng/L were observed and in front of transect Wannsee only a trace (4 ng/L) of naproxen was identified.

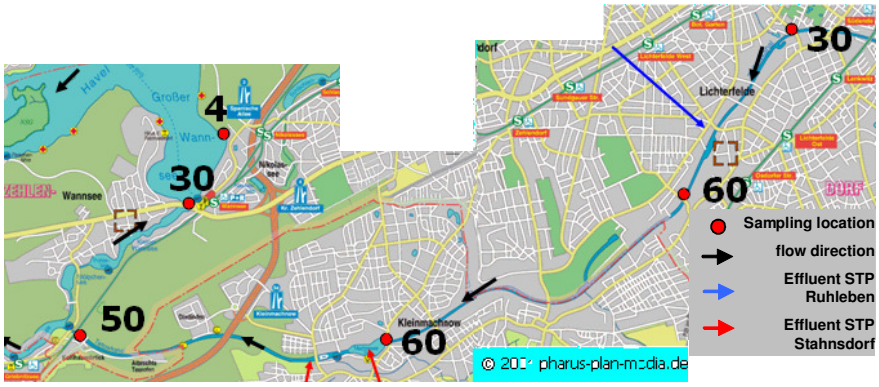


Figure 80. Naproxen concentrations [ng/L] along the Teltowkanal and lake Wannsee in September 2004

1.4.5.9 Conclusions about the occurrence of PhAC's in surface water

Up to eight PhAC's were observed in surface water of lake Wannsee. The metabolite of dimethylaminophenazone AMDOPH, the antiepileptic drugs carbamazepine and primidone, the antirheumatic / antiphlogistic drugs indomethacine, naproxen and propyphenazone, the blood lipid regulator bezafibrate and the metabolite of different blood lipid regulators clofibric acid were identified and quantified in the lake water. In March 2004 a tendency of distribution

of higher concentrations at the eastern bank was observed for carbamazepine, clofibric acid, diclofenac and bezafibrate at lake Wannsee. In July 2004, the distribution tendency for bezafibrate, carbamazepine and primidone was observed in the reverse direction. This may be explainable with the western located marina that is especially used in summer and where toilette reservoirs partly excreted untreated in the lake. The other compounds did not show any western / eastern distribution. A north / south distribution was established for all compounds (except for AMDOPH and propyphenazone) with higher concentrations in the south most likely caused by influents from the Teltowkanal which is loaded during summer with effluents of three sewage water treatment plants. AMDOPH and propyphenazone did not show the behaviour caused by the main origin of these two compounds from a superfund site at a pharmaceutical plant located in the city of Oranienburg north-west of Berlin.

1.4.6 Transects Wannsee 1 & Wannsee 2

From the beginning of the NASRI project in May 2002 the surface water, the shallow wells (3338, 3337, 3335) and the water supply well no. 4 at transect Wannsee 1 were sampled monthly until April 2004. The multi-level well BEE201UP/OP was sampled since January 2003. The monitoring well 3338 could only be sampled in 2002 and three times in 2003 and 2004 because the ground water level was beyond the screen of the well. The deep monitoring wells 3332, 3334 and 3336 have only been sampled one time in March 2003. Since the completion in January 2004 the transect Wannsee 2 was sampled monthly until August 2004. Differences in the sample numbers (n) shown in the Table 26 and Table 27 depend on an intensive sampling period during September and October 2003 and an effort to reduce the number of samples at monitoring wells delivering unnecessary data.

The results show that similar to the transect Tegel the already named compounds have been detected in the surface water in front of transects Wannsee 1 and 2. The pharmaceuticals carbamazepine, diclofenac and primidone could be observed in the shallow monitoring wells and the multi-level wells at the transect Wannsee 1 and Wannsee 2 as shown in Table 26. They also occur in low concentrations at the water supply wells 3 and 4.

The metabolites AMDOPH, clofibric acid and the analgesic drug propyphenazone could be detected in the shallow wells and appeared in significantly higher concentrations in the multi-level wells in front of the water supply wells at both transects at lake Wannsee.

Table 26. Compounds with positive findings and their concentration range [ng/L] at transect Wannsee 1

ng/L	Surface Water (n=28)		3338 (n=11)		3337 (n=27)		BEE201OP (n=18)		BEE201UP (n=14)		3335 (n=12)		Well 4 (n=23)	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Diclofenac	10	265	15	80	n.d.	85	n.d.	65	5	85	n.d.	50	n.d.	55
Clofibric acid	<LOQ	120	n.d.	70	n.d.	60	15	270	n.d.	240	n.d.	15	40	245
Propyphenazone	20	350	45	180	n.d.	280	105	565	55	505	n.d.	125	n.d.	90
AMDOPH	45	365	55	295	70	425	130	1790	425	1770	65	430	100	615
Carbamazepine	185	760	180	620	185	610	30	275	15	105	205	565	n.d.	60
Primidone	20	245	20	190	n.d.	280	95	235	90	220	20	305	n.d.	100
Indometacine	n.d.	85	n.d.	<LOQ	n.d.	<LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bezafibrate	n.d.	105	n.d.	<LOQ	n.d.	<LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bentazone	n.d.	50	n.d.	65	n.d.	55	n.d.	30	n.d.	30	n.d.	45	n.d.	40
Mecoprop	n.d.	50	n.d.	60	n.d.	30	n.d.	45	n.d.	55	n.d.	60	n.d.	40
NPS	n.d.	55	n.d.	60	n.d.	75	20	925	30	600	n.d.	25	25	130
p,p'-DDA	n.d.	50	5	55	n.d.	50	10	60	n.d.	55	n.d.	45	n.d.	35
o,p'-DDA	n.d.	15	n.d.	20	n.d.	15	5	20	n.d.	20	n.d.	15	n.d.	10

n.d. not detected

<LOQ. < limit of quantitation

Table 27. Compounds with positive findings and their concentration range [ng/L] at transect Wannsee 2

ng/L	Surface water (n=24)		BEE 205 (n=22)		BEE 206 (n=23)		BEE 202OP (n=23)		BEE 202MP1 (n=18)		BEE 202MP2 (n=16)		BEE 202UP (n=20)		BEE 203 (n=24)		well 3 (n=20)		BEE 204UP (n=17)		BEE 204OP (n=14)	
	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Diclofenac	n.d.	175	n.d.	150	n.d.	70	n.d.	65	n.d.	80	5	75	n.d.	90	n.d.	40	n.d.	65	n.d.	40	n.d.	45
Clofibric acid	10	120	n.d.	45	n.d.	40	n.d.	55	n.d.	70	n.d.	385	10	340	n.d.	40	25	160	n.d.	100	n.d.	35
Propy-phenazone	20	215	10	175	n.d.	85	n.d.	55	5	565	235	635	150	650	n.d.	370	25	200	n.d.	60	n.d.	40
AMDOPH	45	365	75	305	80	270	45	220	85	1725	270	1845	385	1660	60	1120	245	905	25	895	5	345
Carbamazepine	185	760	145	775	135	875	150	470	65	265	n.d.	110	n.d.	65	80	620	n.d.	110	n.d.	50	n.d.	30
Primidone	20	270	40	285	45	305	n.d.	200	30	215	n.d.	190	40	245	25	275	35	140	n.d.	25	n.d.	20
Indometacine	n.d.	85	n.d.	25	n.d.	25	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	25	n.d.	n.d.	n.d.	n.d.
Bezafibrate	n.d.	105	n.d.	25	n.d.	25	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Bentazone	n.d.	45	n.d.	25	n.d.	30	n.d.	20	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Mecoprop	n.d.	50	n.d.	65	n.d.	25	n.d.	10	n.d.	30	n.d.	35	n.d.	35	n.d.	15	n.d.	25	n.d.	20	n.d.	15

n.d. not detected

<LOQ. < limit of quantitation

Bezafibrate and indometacine could not be detected behind the shallow wells 3338 and 3337 at transect Wannsee 1 and at BEE205 and BEE206 of transect Wannsee 2. At the deeper wells 3332, 3334 and 3336 only traces (< 20 ng/L) of AMDOPH, clofibric acid and primidone were observable.

1.4.6.1 AMDOPH

As presented in Figure 81, the median concentration of AMDOPH detected in the surface water in front of the transects Wannsee was around 185 ng/L. The attenuation rates at the shallow monitoring wells BEE205 and BEE206 were between 20 % and 28 % and show only a slightly removal of AMDOPH still within or slightly higher than the analytical measurement accuracy of 20 %. At BEE202OP and BEE203 attenuation of around 47 % were obtained. However, as it was noticed in the deeper screens of the multi-level well BEE202, AMDOPH concentrations are increasing by depth and showed a maximum median concentration of 870 ng/L in BEE202MP2. This behaviour is caused by the origin of AMDOPH and is confirmed by age dating investigations that show in the share of young bank filtrate decreases by depth of the multi-level well BEE202. [B.Fritz: Bitte Verweis auf Hydrogelogen Teil]. Same behaviour was recognized at the landsite multi-level monitoring well with concentrations of 15 ng/L at BEE204OP and 220 ng/L at BEE204UP. Water supply well no. 3 with 375 ng/L is a mixture of older and landward groundwater and recently infiltrated surface water.

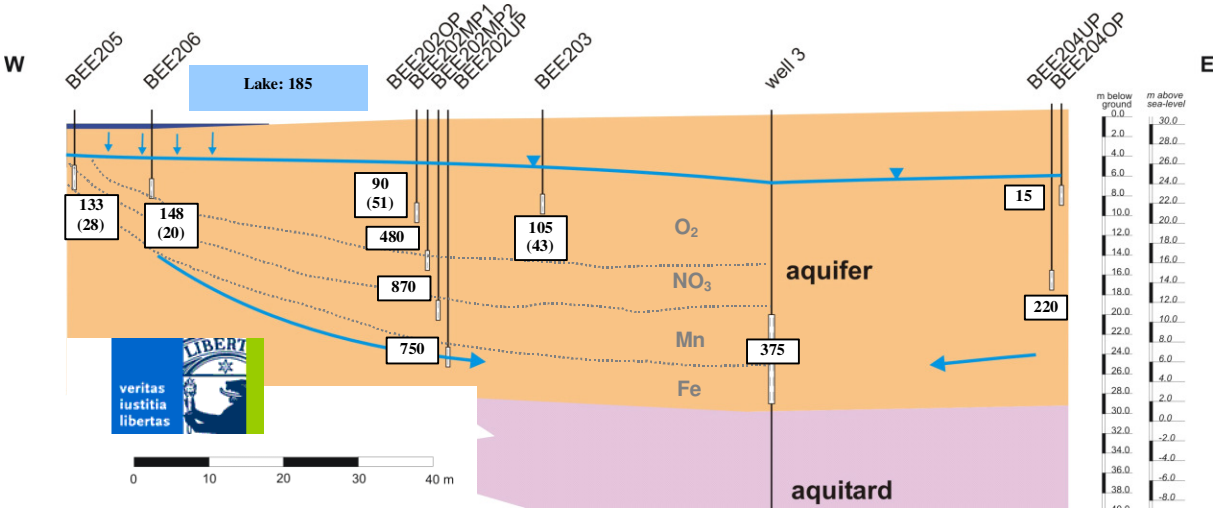


Figure 81. Transect Wannsee 2 - median concentrations of AMDOPH at the different monitoring wells and the water supply well 3. Attenuation rates in percent are given in brackets.

Similar to the observations at lake Tegel, the distribution of AMDOPH concentrations was comparable to the distribution of ammonium concentrations as illustrated in Figure 82.

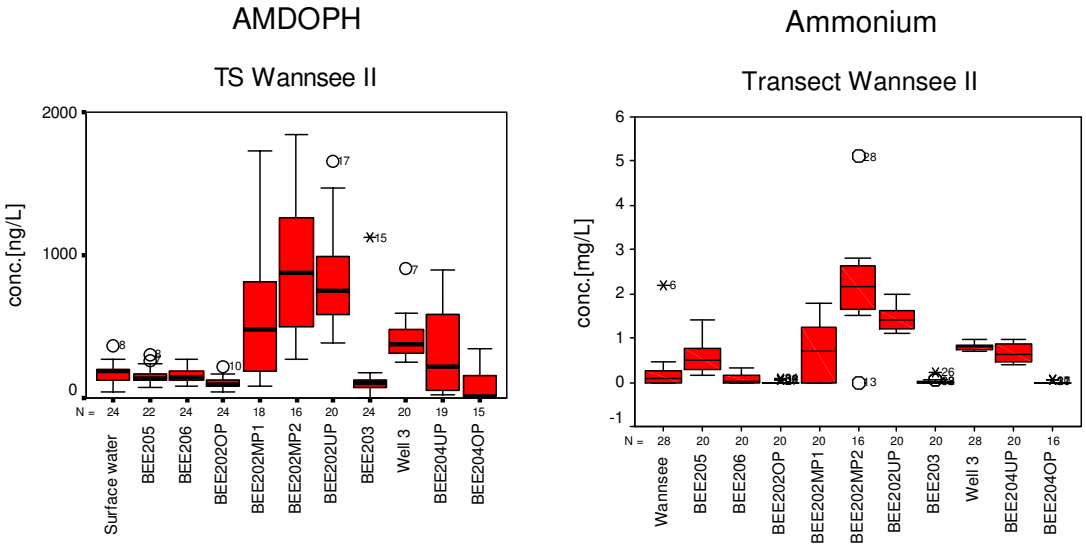


Figure 82. Distribution of AMDOPH (left) and ammonium (right, data by BWB) concentrations at transect Wannsee 2.

1.4.6.2 Propyphenazone

In the surface water propyphenazone was detected with a median concentration of 80 ng/L. It was attenuated below the limit of quantification at BEE203 as shown in Figure 83. Similar to AMDOPH concentrations of propyphenazone at the multi-level well BEE202 are increasing from 15 ng/L up to 350 ng/L. In the landward multi-level well only in the deeper part (BEE204UP) 20 ng/L of propyphenazone were detected. In the upper part only traces were identified.

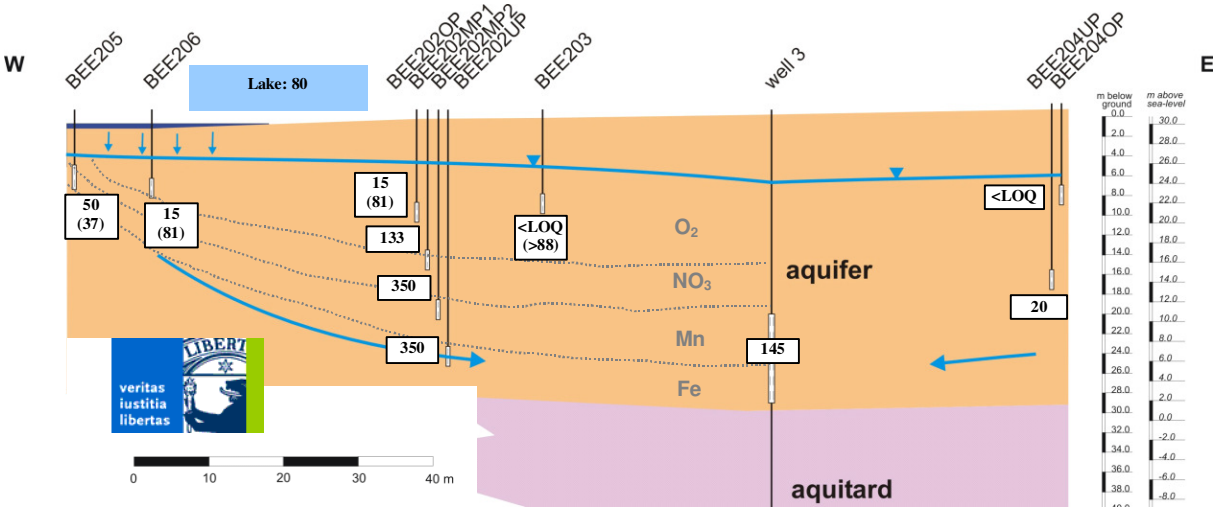


Figure 83. Transect Wannsee 2 - median concentrations of propyphenazone at the different monitoring wells and the water supply well 3. Attenuation rates in percent are given in brackets.

The distributions of detected propyphenazone concentrations at the different sampling locations shown in Figure 84 were comparable to previously described distributions of AMDOPH.

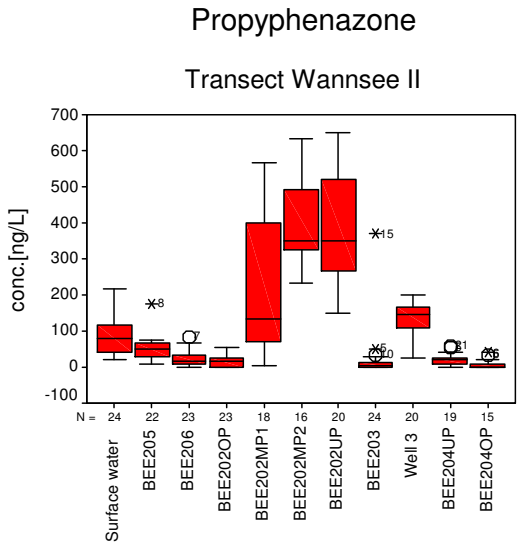


Figure 84. Distributions of propyphenazone concentrations at transect Wannsee 2.

1.4.6.3 Carbamazepine

Within the analytical measurement accuracy the observed median concentration of 380 ng/L found in surface water of lake Wannsee was not significantly decreased up to BEE206 as

shown in Figure 85. The monitoring well under the lake BEE206 only shows a minor attenuation rate of 24 %. During further infiltration along BEE202OP and BEE203 concentrations between 218 ng/L and 260 ng/L were detected and represent a removal rate of carbamazepine of around 38 %.

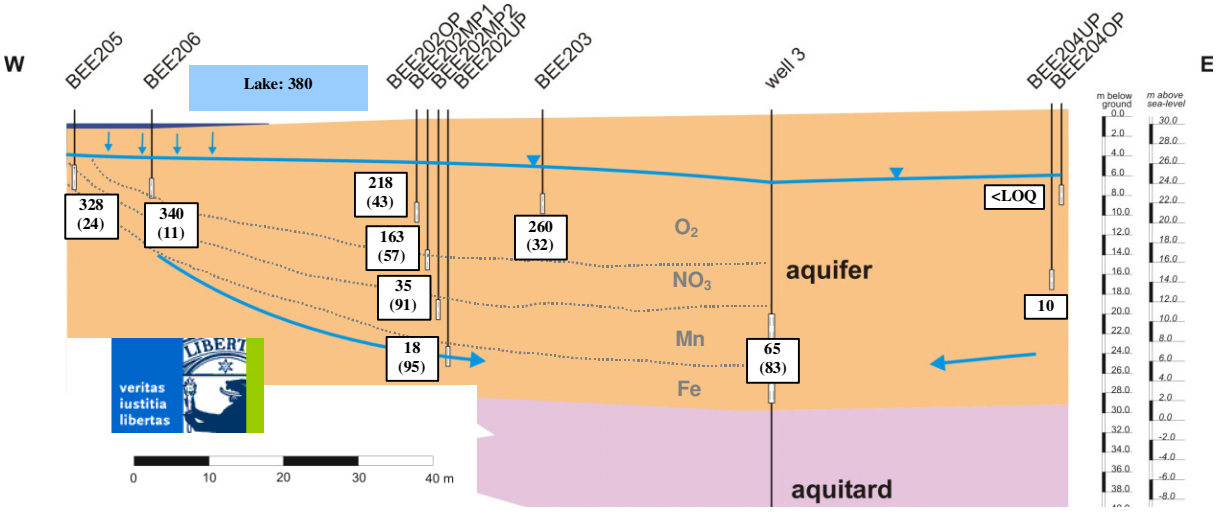


Figure 85. Transect Wannsee 2 - median concentrations of carbamazepine at the different monitoring wells and the water supply well 3. Attenuation rates in percent are given in brackets.

As can be seen in Figure 86, surface water concentrations of carbamazepine are increasing during the third quartile of 2004 up to maximum of around 750 ng/L in September 2003. Concentrations were also temporaily shifted at monitoring wells BEE203 and BEE202OP in December 2003. This is in accordance with the determined travel times between the surface water and the monitoring wells BEE203 or BEE202 of 2-4 months (NASRI Report 1, Chapter 1.5.7.). Thus, the behaviour of carbamazepine is in line with this assumption. Looking at the surface water concentrations during the intensive sampling period (Sep. 03 - Oct. 03) a high variability of detected concentrations was noticed. That means a monthly sampling deliver only a minor resolution and is only a compromise between analytical costs and good and better reproducible data.

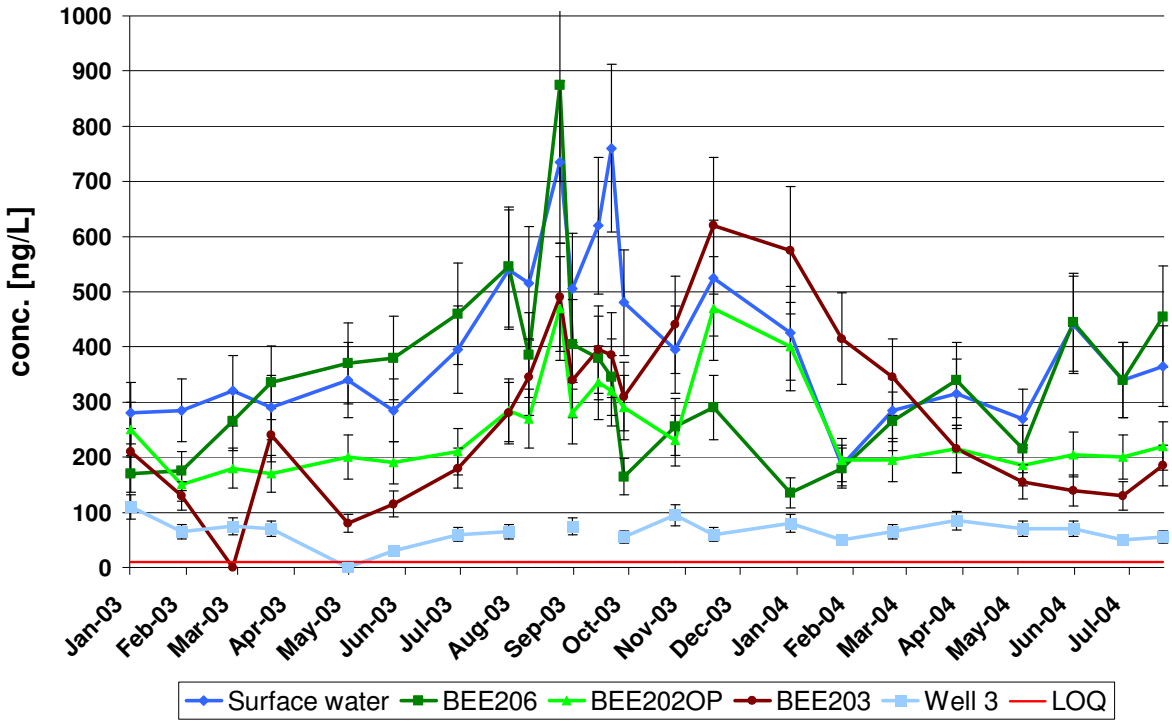


Figure 86. Concentrations of carbamazepine at the different sampling locations inclusive the intensive sampling period from September the 15th until October 20th in 2003.

In contrast to AMDOPH and propyphenazone, median concentrations for carbamazepinewere decreased at multi level well BEE202 by depth to a minimum of 18 ng/L that means an attenuation rate of 95 %.

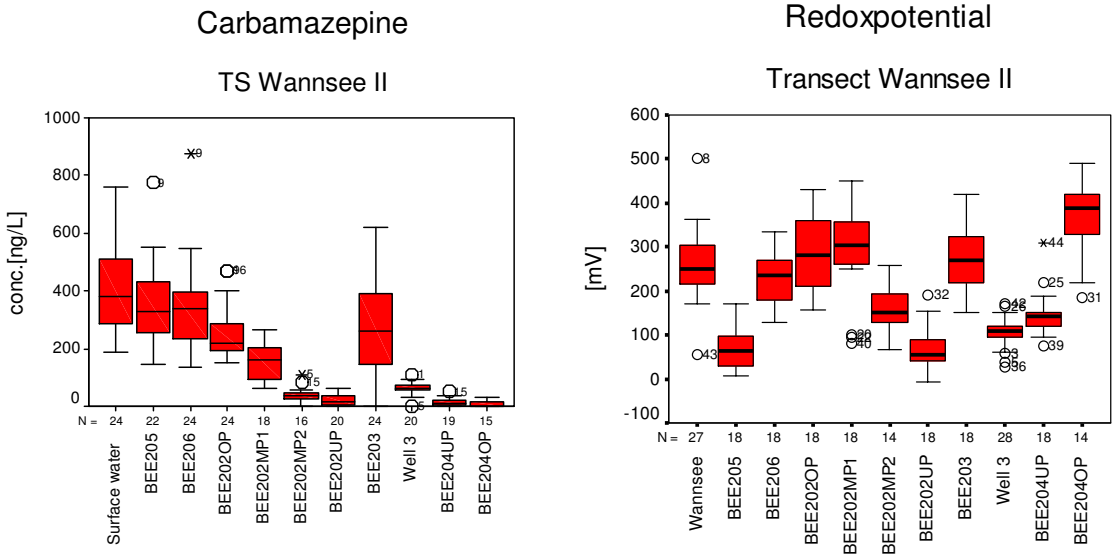


Figure 87. Distribution of carbamazepine (left) and the redox potential (right, data by BWB) concentrations at transect Wannsee 2.

Observed median concentrations in landward groundwater were around the limit of quantification of 10 ng/L. At water supply well no. 3 a median concentration of 65 ng/L was detected and that correspond an attenuation of 83 %. As illustrated distributions of carbamazepine and the redox potential didn't show a similarity like it was observed at transect lake Tegel.

1.4.6.4 Clofibric acid

The median concentration of 48 ng/L obtained at surface water of lake Wannsee was decreased to 5 ng/L and 15 ng/L at the shallow monitoring wells BEE205 and BEE206, respectively as shown in Figure 88. During soil passage to monitoring well BEE202OP a removal greater than 90 % was recognized.

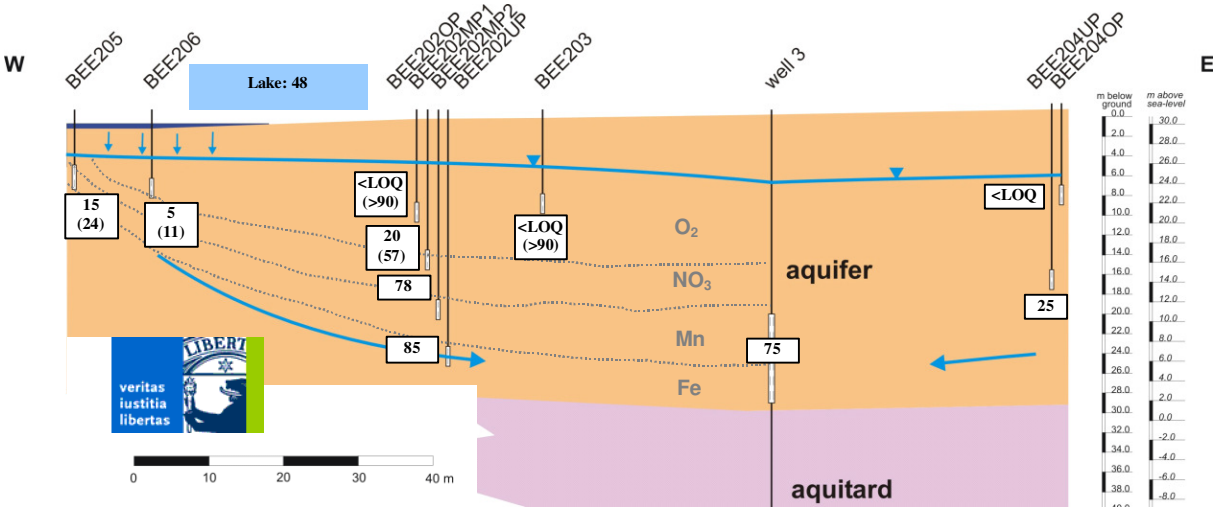


Figure 88. Transect Wannsee 2 - median concentrations of clofibric acid at the different monitoring wells and the water supply well 3. Attenuation rates in percent are given in brackets.

The presented distributions of concentrations in Figure 89 are comparable to the behaviour of AMDOPH and propyphenazone. Similar to AMDOPH and propyphenazone, the detected median concentrations at multi-level well BEE202 are increasing by depth up to a maximum of 85 ng/L. At the deeper land sided monitoring well BEE204UP a median concentration of 25 ng/L was observed and at the upper part of this multi-level well, only traces of clofibric acid were identified. The supply well no. 3 showed a median concentration of 75 ng/L, caused by mix of just infiltrated water and older bank filtrate / groundwater.

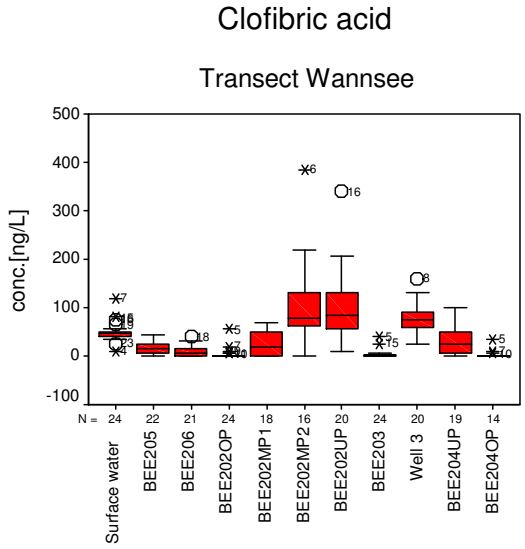


Figure 89. Distribution of clofibric acid concentrations at transect Wannsee 2.

1.4.6.5 Diclofenac

As presented in Figure 90, the median concentration of 65 ng/L was detected at surface water. After infiltration at BEE205 an attenuation of 48 % was observed. Diclofenac was removed by 85 % at BEE206 and was not quantifyable in BEE203. Surprisingly, diclofenac was detected in median concentrations between 15 ng/L and 33 ng/L in the multi-level well BEE202 and the water supply well no.3. In the landward monitoring wells BEE204UP and BEE204OP only traces were identified.

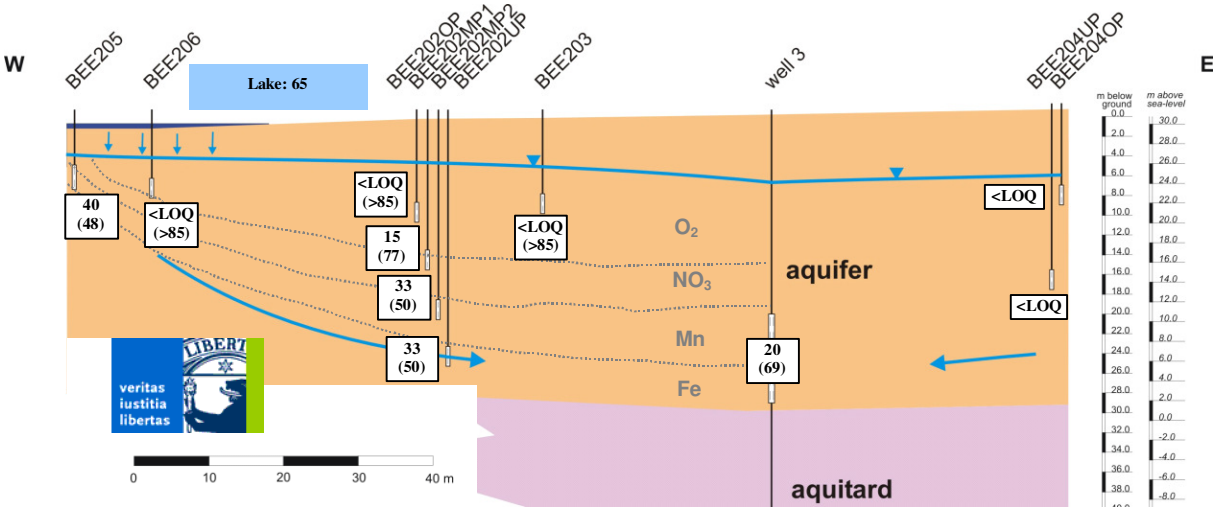


Figure 90. Transect Wannsee 2 - median concentrations of AMDOPH at the different monitoring wells and the water supply well 3. Attenuation rates in percent are given in brackets.

As shown in Figure 91, the distribution of diclofenac concentrations are decreasing quickly after infiltration as it was also observed for bezafibrate and indometacine (not illustrated). However, in monitoring wells drilled in deeper layers of the aquifer minor concentrations were sporadically quantified.

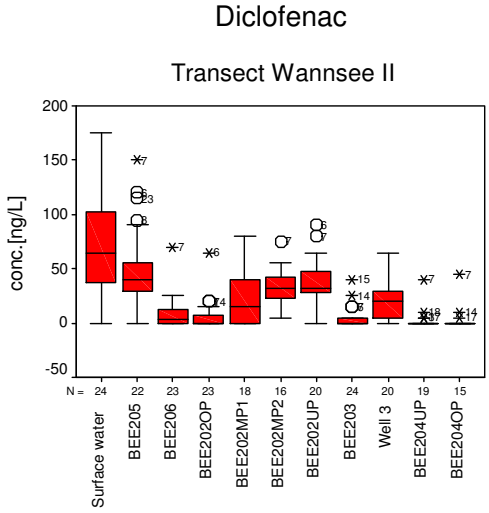


Figure 91. Distribution of diclofenac concentrations at transect Wannsee 2.

1.4.6.6 Primidone

Primidone was detected with a median concentration of 130 ng/L at surface water of lake Wannsee as presented in Figure 92. The observed attenuation rates at the first monitoring wells BEE205 and BEE206 were lower than the analytical measurement accuracy of 20 %. Similar to this, the attenuation at BEE202MP1, BEE202MP2 and BEE202UP were negligible.

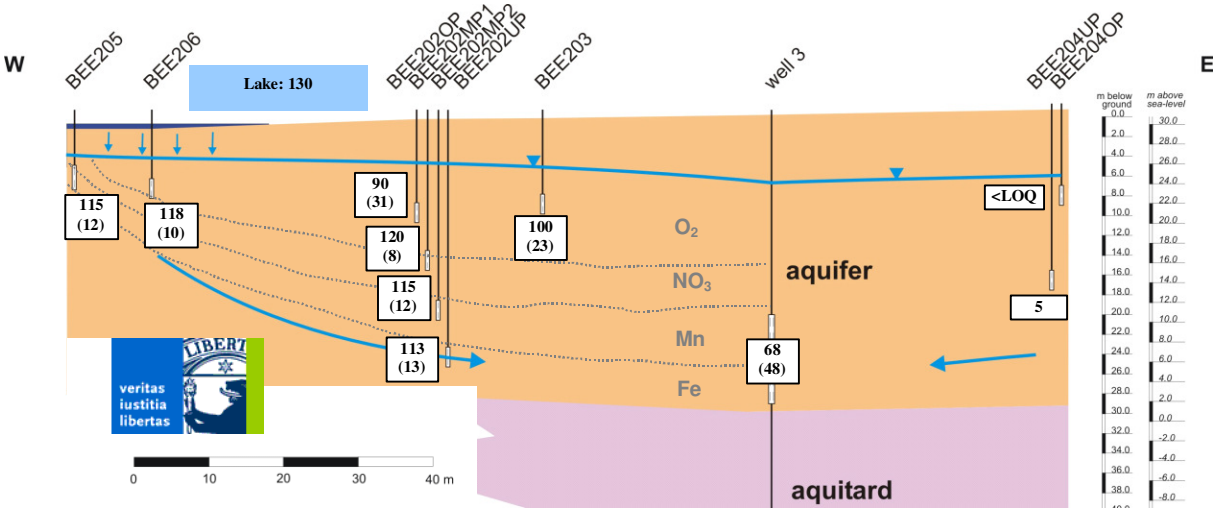


Figure 92. Transect Wannsee 2 - median concentrations of primidone at the different monitoring wells and the water supply well 3. Attenuation rates in percent are given in brackets.

However, at BEE202OP and BEE203 a slightly removal between 23 % - 31 % was noticed. In the landward monitoring wells only traces of primidone were detectable and in the receiving water supply well no. 3 a median concentration of 68 ng/L was detected. Looking at the distributions of primidone concentrations in Figure 93 no significant decreasing effect during bank filtration were observed. Comparing primidone with boron, the antiepileptic drug behaves similar with the exception of higher boron concentrations found at BEE202MP2 and BEE202UP. These are most likely caused by the mixture of recently infiltrated surface water with older bank filtrate and deeper groundwater with higher amounts of boron from geogenic sources.

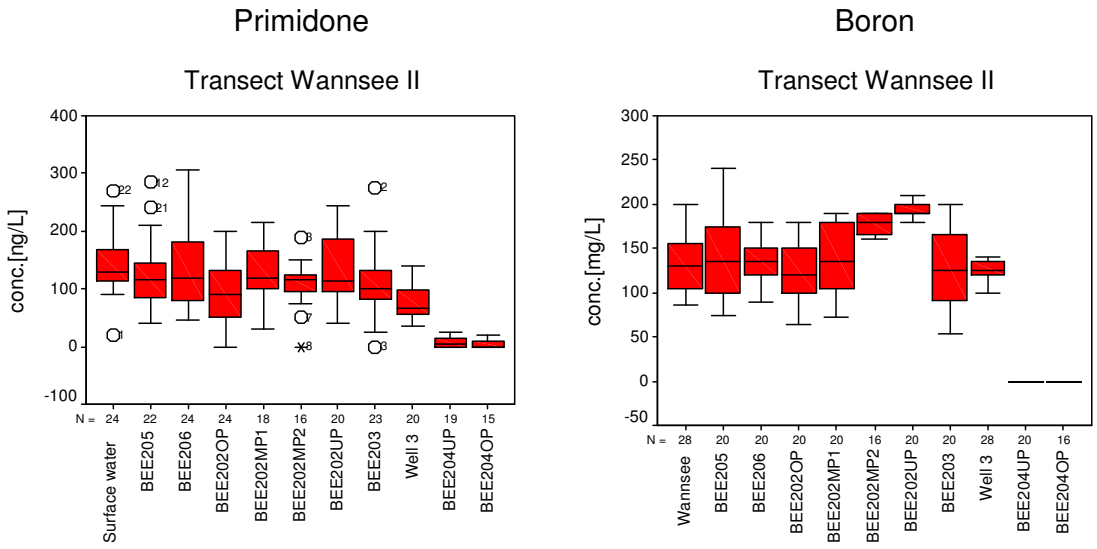


Figure 93. Distribution of primidone (left) and boron (right) concentrations at transect Wannsee 2.

1.4.6.7 Other observed polar residues

Similar to the investigations at transect Tegel, bentazone and mecoprop (pesticides) and 2,2-bis(4-chlorophenyl)acetic acid (p,p'-DDA) metabolite of a pesticide and its isomer 2-(2-chlorophenyl)-2-(4-chlorophenyl)-acetic acid were detectable at trace concentrations around the limit of quantification along all monitoring wells and water supply well no. 3. NPS, metabolite of a corrosion inhibitor, was observed in surface water of lake Wannsee with a median concentration about 25 ng/L. Like AMDOPH, clofibric acid and propyphenazone, NPS concentrations at multi-level well BEE202 are increasing with a maximum median concentration of 260 ng/L at BEE202MP2. At the landward monitoring well BEE204 only 25 ng/L were found and result in a median concentration of 95 ng/L in the receiving water of supply well no. 3.

1.4.7 Conclusions

In conclusion the previously presented results for the field sites at lake Wannsee showed that eight of the investigated drug residues occurred in the surface water. Six of them were observable in the monitoring wells along the infiltration path. Their behavior during bank filtration at both transects were comparable and could be divided into three groups with different attenuation rates as shown in Table 28 & Table 29.

Table 28. Classification of target compounds according to their rates of attenuation at transect lake Wannsee 2

Group	Compound	Median rate of attenuation at BEE203	Median rate of attenuation at WSW 3	
1 low removal rates 0-45 %	AMDOPH	43 %	-103 %	(exceptional case)
	Carbamazepine	32 %	83 %	
	Primidone	23 %	48 %	
2 medium removal rates 46-95 %	Clofibric acid	> 90 %	- 58 %	(exceptional case)
	Diclofenac	> 86 %	69 %	
	Propyphenazone	> 88 %	- 81 %	(exceptional case)
3 high removal rates > 95 %	Bezafibrate	> 97 %	> 97 %	
	Indometacine	> 95 %	> 95 %	

Bezafibrate and indometacine were observed in surface water close to their limit of quantification and they were completely removed during the infiltration process. Diclofenac, clofibric acid and propyphenazone show medium attenuation rates between 62 % and 90 % at the shallow monitoring wells in front of the receiving water supply wells. AMDOPH, carbamazepine and primidone were not significantly removed during bank filtration and the obtained attenuation rates at the monitoring wells in front of the water supply wells were between 23 % and 43 %. In the receiving water supply well no. 3 where the generated raw water is a mixture of bank filtrate and groundwater the determined attenuation rates for carbamazepine and diclofenac were greater than 69 % For primidone only a minor attenuation rate of 48 % was observed. Carbamazepine concentrations shows a temporary shift between the surface water and wells BEE202 or BEE203 which is similar to the travel times determined in age dating experiments conducted by the hydrogeology group. AMDOPH, propyphenazone and clofibric acid are exceptional cases because their detected concentrations in the deeper wells were significantly higher than surface water concentrations. The explanation of this behavior of AMDOPH and propyphenazone is a formerly production spill from a pharmaceutical plant in the city Oranienburg located north-west of Berlin [Reddersen et al., 2002].

Table 29. Classification of target compounds according to their rates of attenuation at transect lake Wannsee 1

Group	Compound	Median rate of attenuation at 3335	Median rate of attenuation at WSW 4	
1 low removal rates 0-45 %	AMDOPH	13 %	- 88 %	(exceptional case)
	Carbamazepine	14 %	94 %	
	Primidone	17 %	91 %	
2 medium removal rates 46-95 %	Clofibric acid	89 %	- 133 %	(exceptional case)
	Diclofenac	62 %	> 99 %	
	Propyphenazone	49 %	74 %	(exceptional case)
3 high removal rates > 95 %	Bezafibrate	> 97 %	> 97 %	
	Indometacine	> 95 %	> 95 %	

The exceptional case of the metabolite clofibric acid could be explained by formerly higher application rates for the precursor compounds clofibrate ethyl, etofyllinfibrate and etofibrate. At transect Wannsee the upper screen of water supply well no. 4 is almost blocked and pumped raw water is only slightly influenced by bank filtration. Due to this only traces of PhAC's were detectable.

1.5 Overall conclusions

As reported in previous investigations (Reddersen, K., 2004) pharmaceutical residues are discharged by municipal STPs and are present at considerable concentrations in Berlin's surface waters. These contaminants are also reaching the surface water in lake Tegel and lake Wannsee which are used as resources for bank filtration or groundwater recharge. During the investigations eight PhACs, the metabolites AMDOPH and clofibric acid, the blood lipid regulating drug bezafibrate, the antiepileptics carbamazepine and primidone, as well as the analgesic / antiphlogistic drugs diclofenac, indometacine, propyphenazone, were detected at the groundwater replenishment site Tegel (GWA), the surface water preparation plant Tegel (OWA) and the bank filtration sites at lake Tegel and lake Wannsee. The observed behaviour for the investigated compounds during the infiltration process at the GWA Tegel and transects Tegel and Wannsee were comparable. According to their attenuation behavior, the detected compounds were assigned to three groups as shown in Table 30.

Table 30. Classsification of the observed drug residues according to their rates of attenuation

		GWA		TS Tegel		TS Wannsee 1		TS Wannsee 2	
Group	Compound	TEG248	WSW 20	TEG372	WSW 13	3335	WSW 4	BEE203	WSW 3
1 low removal rates 0-45 %	AMDOPH*	31%	-245%	45%	-256%	13%	-88%	43%	-103%
	Carbamazepine	9%	55%	41%	86%	14%	94%	32%	83%
	Primidone	30%	26%	0%	31%	17%	91%	23%	48%
2 medium removal rates 46-95 %	Clofibric acid*	83%	75%	90%	14%	89%	-133%	> 90 %	-58%
	Diclofenac	75%	93%	85%	80%	62%	> 99 %	> 86 %	69%
	Propyphenazone*	93%	67%	90%	-38%	49%	74%	> 88 %	-81%
3 high removal rates > 95 %	Bezafibrate	> 97%	> 97%	> 97 %	> 95 %	> 97 %	> 97 %	> 97 %	> 97 %
	Indometacine	> 95%	> 95%	> 95 %	> 97 %	> 95 %	> 95 %	> 95 %	> 95 %

* exceptional cases

When passing the OWA Tegel, only propyphenazone showed a attenuation around 37 %. All other detectable compounds were not affected by the treatment process. AMDOPH and propyphenazone are exceptional cases because their main loads entered the aquatic environment of Berlin during a production spill in the late 1970s when high amounts of these

compounds infiltrated into the groundwater aquifers under influent conditions (Reddersen et. al. 2002). The drug metabolite clofibric acid also represents an exceptional case because ground water concentrations are partly higher than surface water concentrations. This is most likely caused by higher amounts of the precursor drugs (clofibrate ethyl, etofibrate and etofyllinclofibrate) administrated in the past. In laboratory and semi-technical investigations the behaviour observed at the field sites could partly be confirmed. The mobility and persistence of AMODOPH (classified as group 1 compound), the metabolite of dimethylaminophenazone, was confirmed in long column and small column experiments where attenuation rates up to 45 % were observed as also presented in Table 31. The antiepileptic drug carbamazepine (classified as group 1 compound) also proved its mobility and high persistence during the batch, enclosure and small column experiments with only low attenuation rates of up to 45 %. Additionally, attenuation rates for primidone (classified as group 1 compound) an antiepileptic pharmaceutical were determent up to 45 % during enclosure and small column experiments.

Table 31. Comparison of labratory and semi technical experiments. Additionnally results of two reported column studies are shown

	Voigt SSF3b	Voigt SSF5d	Voigt E2o	Voigt E3d	Licht E4d & E5d	Wicke	Hagemann	Hagemann	Ternes column	Mersmann column
Distance [cm]	80	80	80	80	80	84	1 m	1 m	80	35
k [m/s]	$2 *10^{-3}$	$2 *10^{-3}$	$2 *10^{-3}$	$2 *10^{-3}$	$2 *10^{-3}$	$1 *10^{-4}$	Bank	Aquifer	$2,9 *10^{-3}$	$5 *10^{-4}$
Temperature [°C]	9	20	21	16	7	15	15	15	k.A.*	22
Filtration velocity [m/d]	2,1	1,2	1,2	1,2	1,1 – 1,2	0,3	0,17	0,17	1,25	0,33
AMDOPH (rec. [%])	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	80 - 100	~ 80 - 100	~ 80 - 100	n.a.*	n.a.*
Bezafibrate (rec. [%])	n.d.***	n.d.***	n.d.***	n.d.***	n.a.**	n.d.***	n.d.***	n.d.***	n.a.**	n.a.**
Carbamazepine (rec. [%])	n.a.**	n.a.**	n.a.**	n.a.**	90 - 100	n.a.**	~ 80 -100	~ 80 - 100	60 - 80	85 - 97
Clofibric acid (rec. [%])	70	85	35	55	90 - 100	45 - 60	~ 60	~ 60	40 - 60	100
Diclofenac (rec. [%])	30	30	15	60	90 - 100	15 - 20	~ 60	~ n.d.***	20 - 40	90 - 100
Ibuprofen (rec. [%])	n.d.***	n.d.***	n.d.***	n.d.***	20 - 30	n.d.***	~ n.d.***	~ n.d.***	20 - 40	45
Primidone (rec. [%])	n.a.**	n.a.**	n.a.**	n.a.**	~ 80 -100	n.a.**	~ 80 -100	~80 - 100	n.a.**	n.a.**

k.A * no information available n.a. ** not analyzed n.d.*** not detected

The behaviour of clofibric acid (classified as group 2 compound) during the different laboratory and semi technical experiments shows a high variability starting from no observed attenuation (E4d & E5d) up to a maximum attenuation of 65 % (E2o) (See Chapter 1.3.2.4). Diclofenac (classified as group 2 compound) was observed with attenuation rates between 40 % and 85 % during the investigations at slow sand filters, enclosures (with the exception

of E4d & E5d) and small columns. Photochemical degradation reported by Buser et. al. (1998) and Tixer et al. (2003) was confirmed during slow sand filter experiments. Attenuation tendencies of propyphenazone (classified as group 2 compound) during small column experiments yielded medium removal rates between 46 % and 95 %. Behaviour of bezafibrate and indometacine (classified as group 3 compounds) was also observed during small column investigation with real bank / aquifer material where these compounds were completely removed. Summarizing these conclusions, bank filtration and artificial ground water recharge were identified as efficient tools for a sustainable removal of several pharmaceutical residues including bezafibrate and indometacine. Other compounds such as clofibric acid, diclofenac and propyphenazone are also significantly attenuated. Concentrations of highly persistence and mobile substances like AMDOPH, carbamazepine and primidone are decreased up to the receiving water supply wells by dilution with non contaminated groundwater. Thus, both recharge techniques are useful tools for the pre-treatment of contaminated surface water but will be not sufficient for the complete removal of all kinds of pharmaceutically active compounds occurring in surface water under the influence of non-purified or purified municipal sewage effluents.

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2 Antibiotics

2.1 Introduction

The objective of the sub-project “Bank Filtration: Drug Residues” was the investigation of the occurrence of antibiotic residues in surface waters under the influence of municipal sewage effluents and their behavior and fate during bank filtration.

An analytical method has been developed for the trace analysis of 21 compounds from important human-use antibiotic classes (penicillins, sulfonamides, macrolide groups, fluoroquinolones, and tetracyclines) to identify antibiotics which are environmentally relevant. A screening of surface water samples collected from lake Wannsee and lake Tegel showed that only five antibiotic compounds and two metabolites are important for bank filtration in Berlin, Germany. The antibiotics occurring in the surface water include the macrolides clarithromycin, roxithomycin and erythromycin (measured as metabolite dehydro-erythromycin), the sulfonamide sulfamethoxazole, its main human metabolite acetyl-sulfamethoxazole, the sulfonamide synergist trimethoprim and the lincosamide clindamycin. Except for acetyl-sulfamethoxazole, these substances were subject for detail studies. Batch sorption studies and small column experiments were carried out, to get more information about the behavior of these antibiotic residues during soil passage. Additionally, the distributions of these antibiotic compounds in lake Wannsee as well as the occurrence of these substances in further adjacent surface waters (the river Unterhavel, lake Kleiner Wannsee, and the Teltowkanal, a sewage-prone canal) were determined. Investigations at the phosphate elimination plant OWA Tegel provided further information about the antibiotic loads in lake Tegel. From May 2003 to August 2004, the occurrence and fate of all environmentally relevant antibiotics was investigated monthly at three transects located at lakes Wannsee and Tegel. The following report describes the results of the investigations in detail.

2.2 Method

A highly selective and sensitive multi-residue method was developed for the trace-level analysis of antibiotics in environmental water samples (see also Figure 94). The method allows the determination of 21 antibiotics belonging to various prescriptions classes including macrolide antibiotics, sulfonamides, fluoroquinolones, penicillins and tetracyclines. The antibiotic residues are measured using high-performance liquid chromatography with positive electrospray ionization and tandem mass spectrometric detection (LC/ESI-MS/MS). After

solid phase extraction (cartridges: OASIS HLB (Waters, Milford, MC, USA)) at pH 4 and consecutive two step elution (1. acetonitrile, 2. acetonitrile/water/triethylamine), samples are dried and dissolved in acetonitrile 10 vol% in water. The analysis of the resulting sample extracts was performed in multiple reaction monitoring mode (MRM) using a Quadro-LC tandem-mass spectrometer from Micromass, Manchester, UK. Standard addition method was used for the quantification of the antibiotic residues. The method is described in detail by Fanck and Heberer [1].

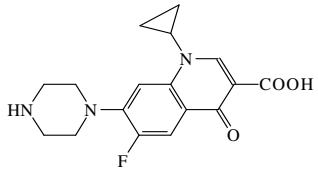
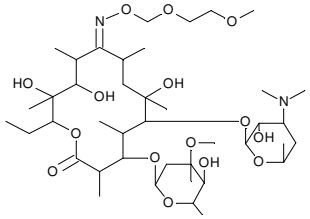
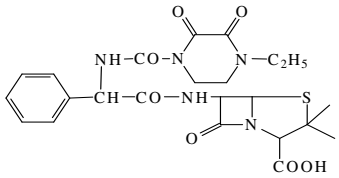
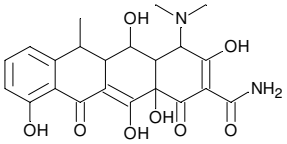
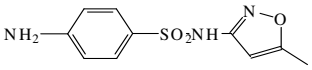
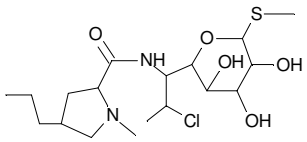
Fluoroquinolone (4)	**Macrolides (3+1)**	**Penicillins (3)**
Ciprofloxacin	Roxithromycin	Piperacillin
		
Tetracyclines (3)	Sulfonamides (2+1)	Others (4)
Doxycycline	Sulfamethoxazole	Clindamycin
		

Figure 94: Chemical structures of selected compounds for each of the investigated classes. In brackets: investigated number of compounds from each class

2.3 Surface water investigations

Only five out of the 19 investigated compounds, the macrolides clarithromycin and roxithromycin, the sulfonamide sulfamethoxazole, the sulfonamide synergist Trimethoprim, and the lincosamide clindamycin were detected in the surface water of the transects. Additionally, dehydro-erythromycin, the metabolite of the macrolide erythromycin and acetyl-sulfamethoxazole, the main human metabolite of sulfamethoxazole, were found.
Tetracyclines and penicillines were not detected in any sample. This is in line with the results from other studies [2-8]. Tetracyclines have shown to be strong chelators and can sorb strongly to soil organic matter and mineral particles and are therefore rarely found as free molecules in surface waters [3-6]. Penicillines are not expected to occur in surface water because the ß-lactam ring, a common moiety in their structures, is unstable. It can easily be cleaved by ß-lactamase, a widespread enzyme in bacteria, or by chemical hydrolysis. Thus, intact penicillins do not frequently occur in the environment [2]. Fluoroquinolone antibiotics were also not found in surface or ground water because they are substantially removed during wastewater treatment (65-100%) mainly by sorption to sewage sludge [1,9-11].

2.3.1 Lake Wannsee

Trimethoprim, clarithromycin, and roxithromycin were detected in Lake Wannsee with concentrations between two and 69 ng/L. These three analytes showed a very similar, time-dependent concentration trend (see Figure 95). In winter, they were found at higher concentrations than during summer. The opposite might be expected regarding the low surface water flows measured during summer. From a medical health care position, elevated concentrations and loads in winter might be assigned to higher seasonal consumption of antibiotics which are mainly prescribed against respiratory infections. These observations are also in line with investigations at the sewage treatment plant (STP) in Berlin-Ruhleben which have also shown seasonal variations. In winter, residues from these compounds were found at increased concentrations both in samples collected from the influents and the effluents [1]. In the same study, better removal of residues of macrolide antibiotics was observed during summer.

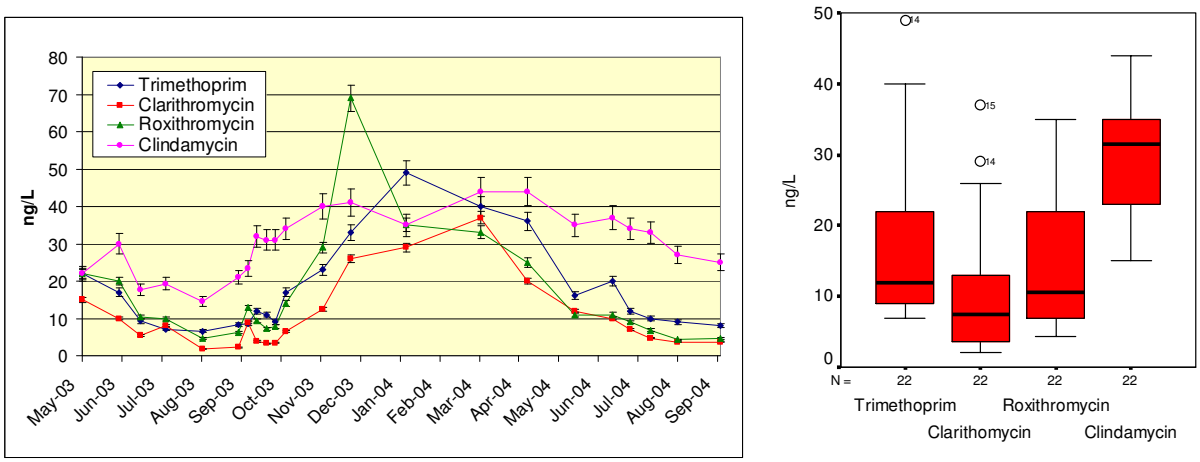


Figure 95: ***Lake Wannsee – Concentrations for Trimethoprim, Clarithromycin, Roxithromycin and Clindamycin***

Clindamycin was detected in the lake with a median concentration of 31ng/L. Its concentration profile did not show such a strong time-dependent trend as the substances mentioned before (see Figure 95). This result is also consistent with those obtained from the study at the STP in Ruhleben where the influent and effluent concentrations of clindamycin were similar during summer and winter [1]. The prescription of clindamycin does apparently not vary with the season. This might be explained by its use pattern in dentistry and against abdomen and pelvis infections, which all are independent from the season.

The highest concentrations in lake Wannsee were determined for the drug metabolite dehydro-erythromycin and the bacteriostatic sulfonamide drug sulfamethoxazole (see Figure 96). Dehydro-erythromycin, formed by hydrolysis from the macrolide erythromycin, was detected in lake Wannsee at concentrations between 33 and 94 ng/L. Sulfamethoxazole occurred in the lake at concentrations between 100 and 326 ng/L. Beside the penicillins, both compounds belong to those antibiotics with the highest consumption volume in Germany [1]. The individual concentrations measured for both compounds varied significantly and a seasonal variation was not observed. Additional investigations at the STP Ruhleben have shown similar effluent concentrations for sulfamethoxazole in winter and summer. The higher consumption of sulfamethoxazole in winter was balanced by higher removal rates observed for this compound during winter [1]. Acetyl-sulfamethoxazole, the main human metabolite of sulfamethoxazole, was detected in lake Wannsee at very low concentrations between 4 and 14ng/L. For acetyl-sulfamethoxazole, a removal rate of more than 99% was found in the sewage treatment plant of Ruhleben [1]. This metabolite exhibits no more bacteriostatic effect.

A weekly sampling in September/ October 2003 showed that in contrary to the other antibiotics, the concentration of sulfamethoxazole in front of the transect varies considerably. For this substance a monthly sampling of the surface water was not sufficient to derive a

reliable input concentration. Additional investigations of the lake Wannsee also showed a large variability of the surface water quality in front of the transects (e.g. by variations of the electrical conductivity and the $\delta^{18}O$ values). Thus, a monthly sampling of the lake may not be sufficient to obtain representative samples characterizing the surface water used as a resource to feed the bank-filtration field sites.

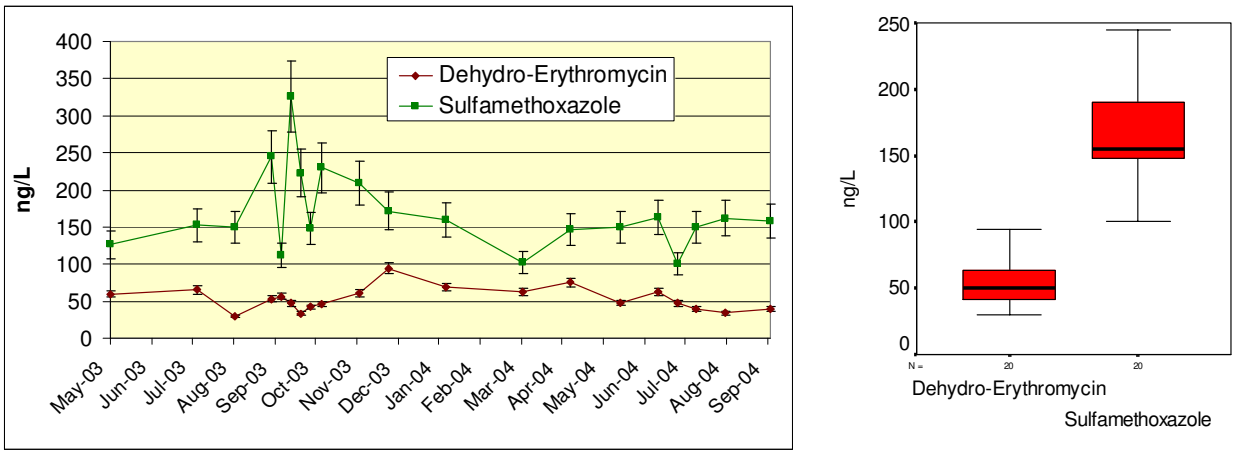


Figure 96: ***Lake Wannsee – Concentrations for Dehydro-Erythromycin and Sulfamethoxazole***

In terms of a diploma thesis additional investigations have been carried out at lake Wannsee. The distributions of the antibiotic residues in the lake as well as the occurrence of these compounds in further adjacent surface waters (river Unterhavel, lake Kleiner Wannsee and Teltowkanal) were determined.

The distributions of the antibiotic residues in the lake Wannsee were investigated in March and July in 2004. The concentration profiles measured for all detected antibiotics show a similar distribution in the lake. For the comparison of the two sampling series, the measured total concentrations at the respective sampling points are shown in Figure 97.

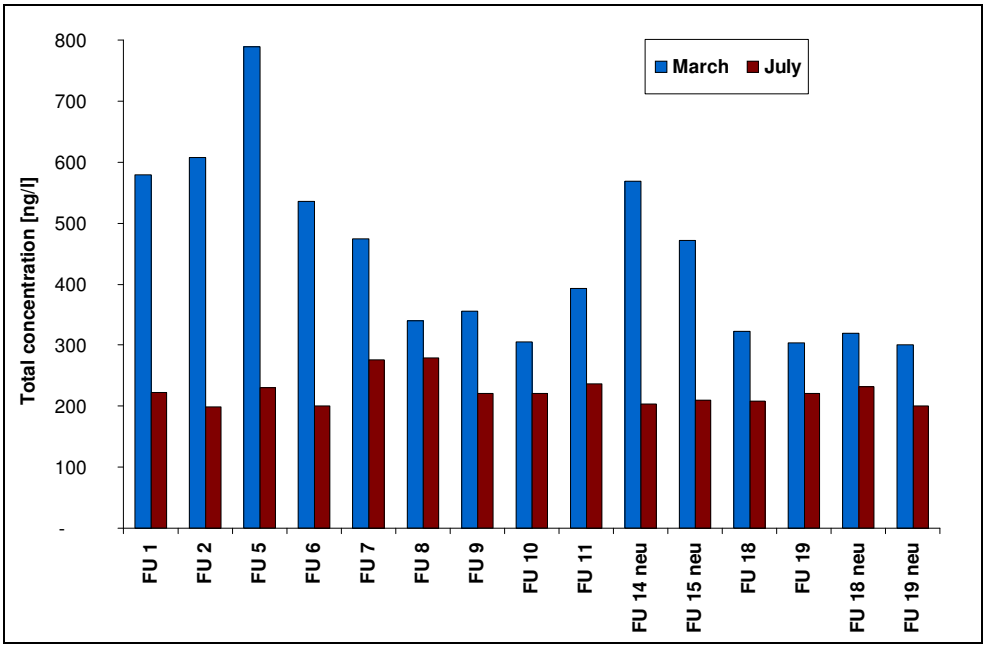


Figure 97: ***Lake Wannsee - Comparison of the total concentrations of antibiotics at different sampling locations in March and July 2004.***

In March, total concentrations of antibiotics between 300 and 800 ng/L were detected at different sampling locations in lake Wannsee. The large variations between the different sampling points are indicating a poor mixing of the sewage-prone waters that are entering the lake via the river Havel and the lake “kleiner Wannsee”. The highest concentrations of the antibiotics were determined at sampling point FU 5 which is located close to the merger of both lakes. The high concentration measured at this point can be explained by the waste water loads originating from the Teltowkanal with approximately one third of its surface water flowing into and through lake “kleiner Wannsee”. In former investigations, concentrations of pharmaceutical residues determined in lake kleiner Wannsee were identical to those measured in the surface water of the Teltowkanal before it is leaving this highly sewage-prone canal. In March, the lowest concentrations of antibiotics were measured in the northern part of the lake. This shows that the river (Unter-)Havel contributes only to a small extent to the total degree of antibiotics found in this lake.

In July, antibiotics were only detected at much lower total concentrations in the lake ranging between 200 and 300 ng/L. The differences in the concentrations between March and July can be attributed to higher consumption of antibiotics during winter (see chapter 2.3.2). Additionally, the concentrations show a rather even distribution. It was assumed that in the summer an intensified shipping traffic might be responsible for a better mixing and a more evenly distribution. This becomes also clear in Figure 98, where the distributions of the concentrations of clarithromycin in March and in July are compared. In March, the decrease of the concentration on the eastern bank proceeded more slowly than on the western bank. Consequently, in March sewage-prone surface from lake kleiner Wannsee flows

predominantly along the eastern bank of lake Wannsee where the transects and the wells from the water works in Berlin-Beelitzhof are located.

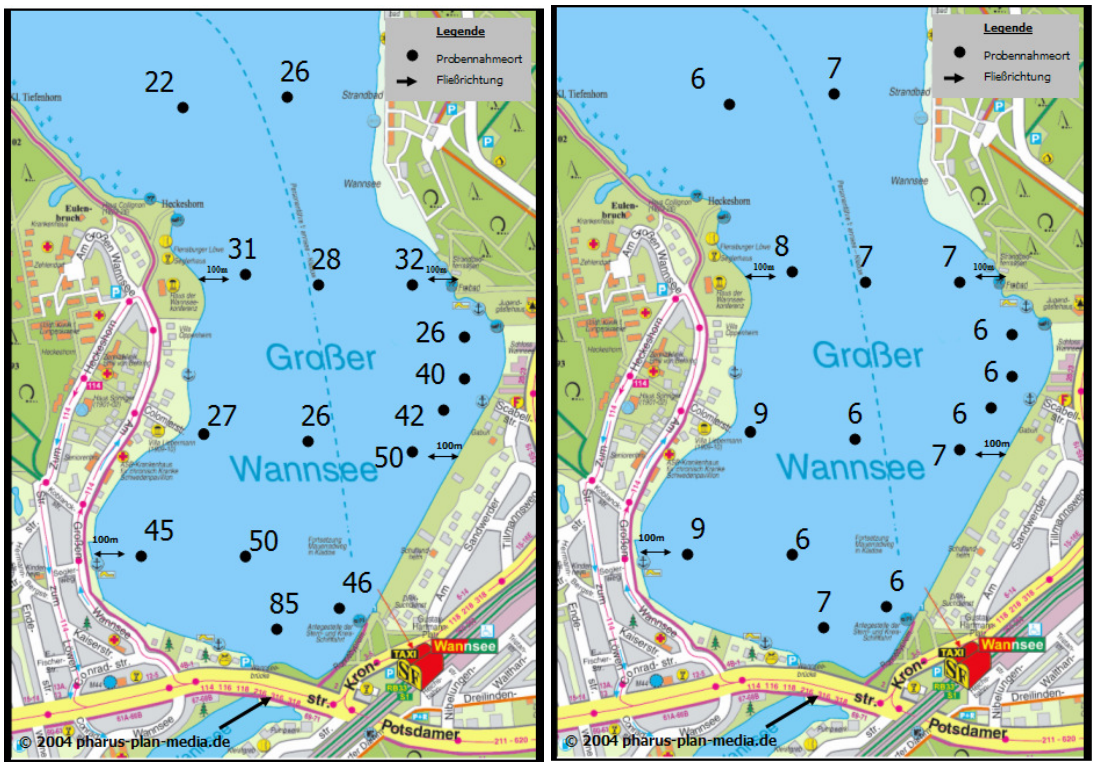


Figure 98: ***Lake Wannsee - Comparison of the concentrations of Clarithromycin in March and July 2004.***

Figure 99 shows this by the example of trimethoprim and its concentrations measured in September 2004 in lakes Wannsee and kleiner Wannsee and upstream in the Teltowkanal. Depending on the season, up to three STPs discharge their purified effluents into the Teltowkanal.

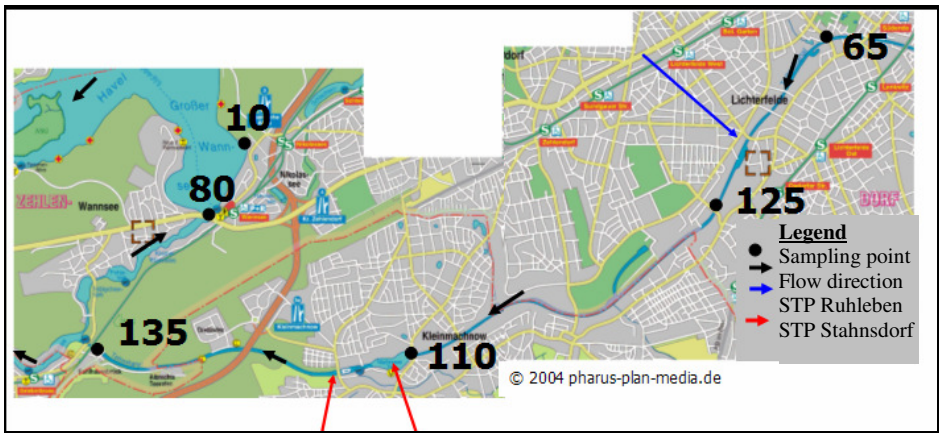


Figure 99: ***Concentrations for Trimethoprim [ng/L] along the Teltow channel and in Lake Wannsee in September 2004.***

Figure 100 shows that slightly increased concentrations of antibiotic residues were also detected in the river Havel. However, these concentrations were evidently diluted in before

the lower part of the river (Unterhavel) reaches lake Wannsee. This means that the loads from the Unterhavel are not crucial for the high concentrations of antibiotics determined in lake Wannsee although they also add to the total loads found in this lake.

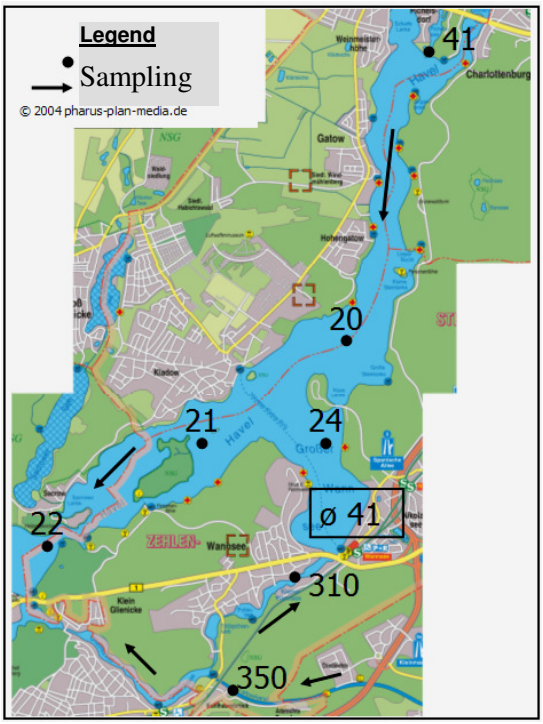


Figure 100: ***Concentrations for Dehydro-Erythromycin [ng/L] determined in the surrounding area of Lake Wannsee in July 2004.***

The anthropogenic impact of sewage-prone surface water on the water quality of lake Wannsee was also confirmed by other waste water indicators such as boron (see Figure 101) showing a similar distribution pattern in the surface water of the lake.

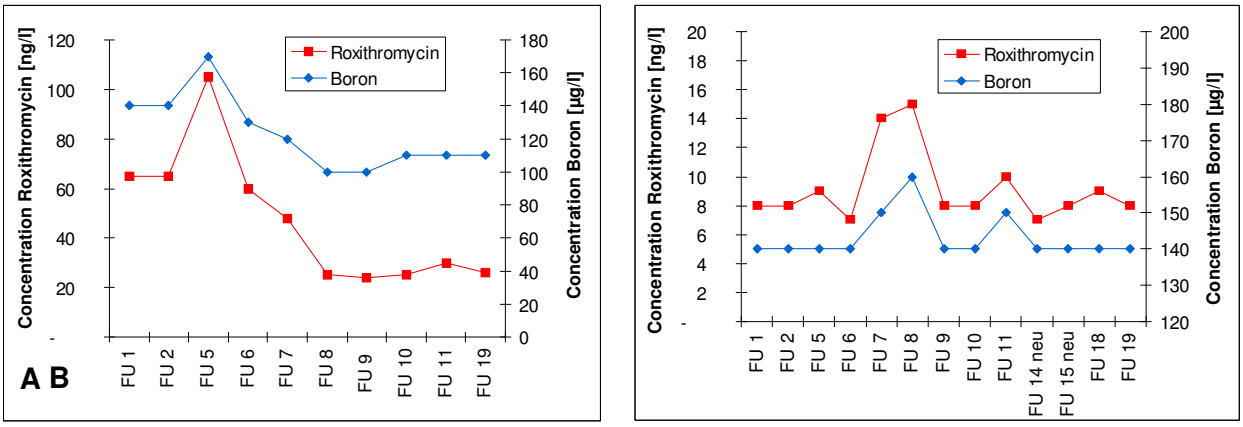


Figure 101: ***Lake Wannsee - Comparison of the concentrations of Roxithromycin and Boron (BWB data) in A) March and B) July 2004.***

In another sampling series, samples were collected at different depths in the center of lake Wannsee. No significant differences in the concentrations of the measured antibiotics was observed (data not shown). Thus, no distinct formation of layers was found in the lake.

2.3.2 Lake Tegel

In general, antibiotic residues were found at higher concentrations in Lake Tegel than in Lake Wannsee. Trimethoprim, clarithromycin, and roxithromycin were found in the lake Tegel at concentrations between nine and 85ng/L (see Figure 102). As already reported for lake Wannsee, a seasonal variation was observed for these compounds. However, in lake Wannsee this trend is more distinct.

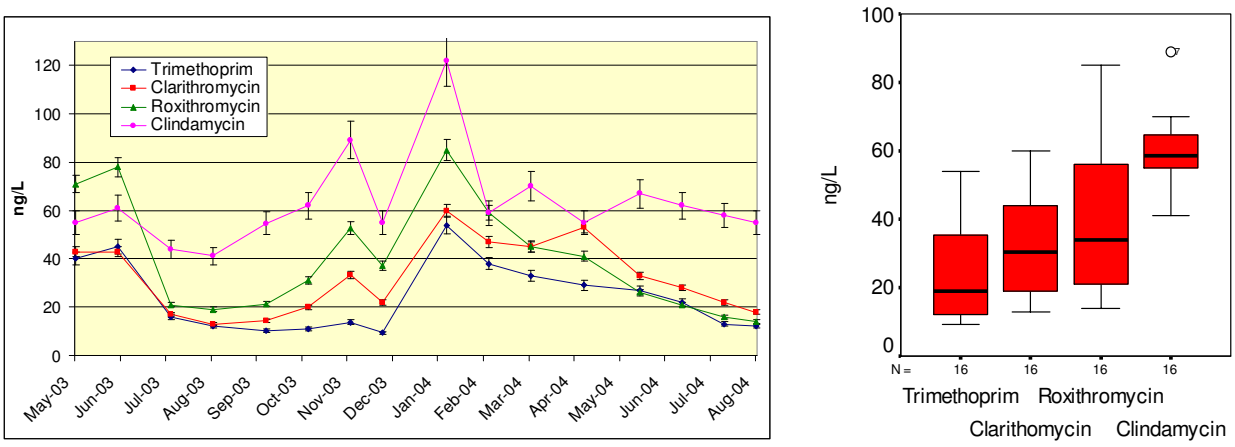


Figure 102: ***Lake Tegel – Concentrations for Trimethoprim, Clarithromycin, Roxithromycin and Clindamycin***

The lincosamide clindamycin was found in the lake at concentrations between 41 and 122 ng/L. Again, it did not show such a strong time-dependent trend as the substances mentioned before (see Figure 102). For more explanations also refer to chapter 2.3.1. Figure 102 shows a decrease of all concentrations in December 2003. A comparison with other waste-water indicators such as sulfate and chloride (see Figure 103) also shows lower concentration values in December 2003. The reason for this could not to be clarified (e.g. sampling error).

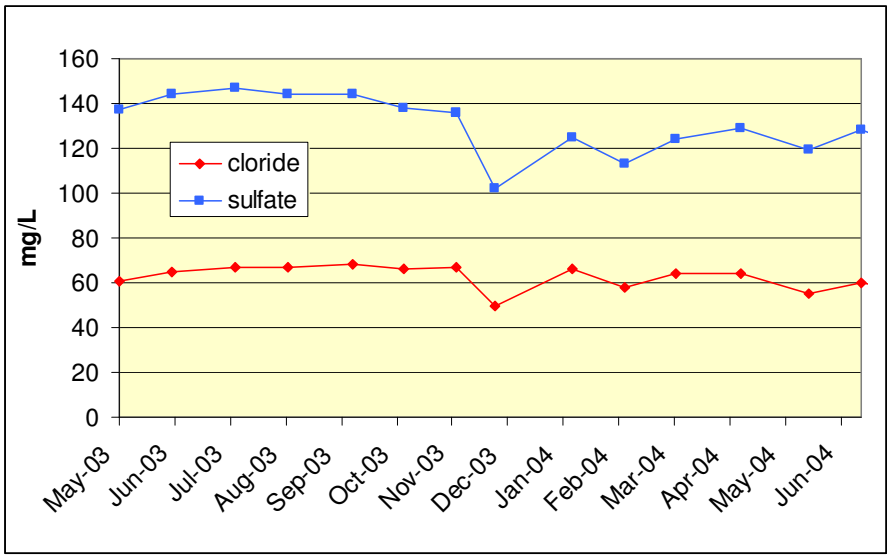


Figure 103: ***Lake Tegel – Concentrations for Chloride and Sulfate (BWB data)***

Figure 104 presents the concentrations measured for dehydro-erythromycin and sulfamethoxazole in lake Tegel. Again, they were found at higher concentrations than all the other antibiotic substances. They were detected with median concentrations of 118 and 286 ng/L, respectively. Both compounds did not show any seasonal variations (see also chapter 2.3.1). The results for sulfamethoxazole are comparable to screening results (n=5) reported earlier by Hartig et al. [14].

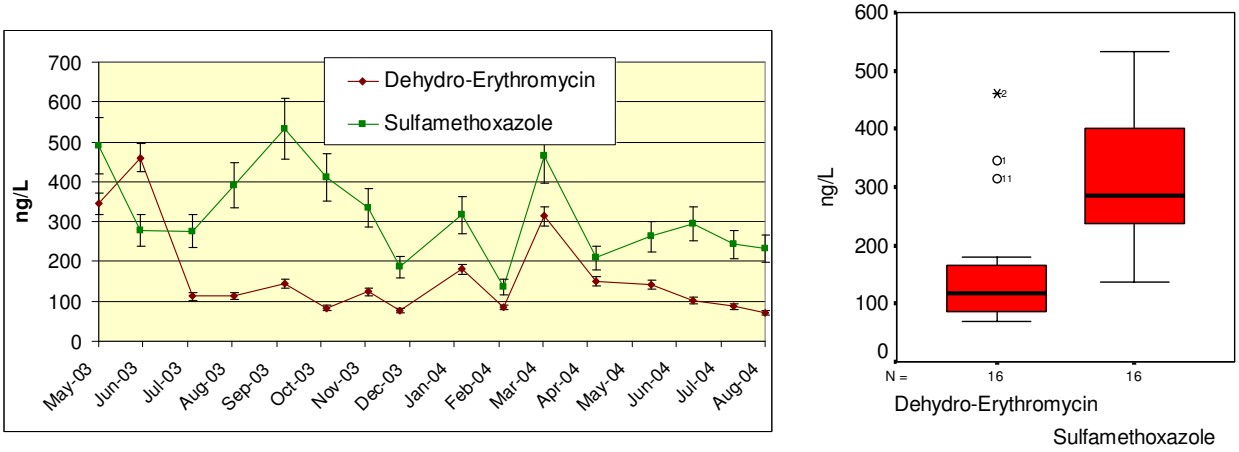


Figure 104: ***Lake Tegel – Concentrations for Dehydro-Erythromycin and Sulfamethoxazole***

The pharmacologically inactive human metabolite of sulfamethoxazole, acetyl-sulfamethoxazole, occurred in lake Tegel at very low concentrations between eight and 30 ng/L. For acetyl-sulfamethoxazole, a removal rate of more than 99% was reported for the STP in Ruhleben [1].

Primary source of antibiotic residues in the lake Tegel are the effluents from the phosphate elimination plant (OWA) in Berlin-Tegel. The OWA Tegel receives its water from the Tegler Fließ and the Nordgraben, which is almost exclusively fed by effluents from the STP in Schönerlinde. The STP Schönerlinde is located north of Berlin. It purifies municipal sewage from Berlin's northern districts and from several other municipalities located north of Berlin. In terms of a diploma thesis influents and effluents of the OWA Tegel were analyzed for the occurrence of various drug residues. These investigations also provided some information about the behavior of the antibiotic residues during the passage through the OWA Tegel and about the loads of antibiotics entering lake Tegel. From January to July 2004 composite samples collected monthly from the influents and the effluents of the OWA. Additionally, water samples from the river Havel (Oberhavel) were investigated. These samples were collected directly in front of a pipeline feeding the OWA with additional surface water during low flow conditions. Eight antibiotic compounds were detected in the influents and the effluents collected from the OWA Tegel. In Table 32, the results of the OWA Tegel effluent samples are compared with the results obtained for the surface water samples collected from lake Tegel in front of the bank filtration transect. Generally, antibiotic residues were detected at higher concentrations in the OWA Tegel than in the lake. As already mentioned for the investigation of Berlin's surface waters, the highest concentrations of antibiotic residues in the OWA Tegel were determined for dehydro-erythromycin (322ng/L), the main degradation product of erythromycin, and for the bacteriostatic sulfamethoxazole (420ng/L). Beside the penicillins, both compounds belong to the antibiotics with the highest consumption in Germany but are not eliminated completely in the STP's [1]. The macrolide antibiotics roxithromycin and clarithromycin were determined with similar concentrations of 165ng/L and 146ng/L, respectively, in the OWA effluent. This might be due to their similar structures, a similar behavior in the STP and due to similar quantities of prescription. The lincosamide clindamycin was detected with a median concentration of 148ng/L. It is prescribed in quantities similar to those of roxithromycin and clarithromycin. In medical therapy, trimethoprim is usually used in combination with sulfamethoxazole in a ratio of 5:1 ("Cotrimoxazol"). However, trimethoprim is to a lower degree also used alone or in combination with other sulfonamides. With regard to its primary use in the combinatory formulation "Cotrimazol", trimethoprim is expected occur in smaller quantities in the aquatic environment compared to those of sulfamethoxazole. Thus, it was detected in the OWA effluent at a median concentration of only 124ng/L. Acetyl-sulfamethoxazole also occurred in the OWA effluent but only in minor concentrations of 25 ng/L. As mentioned before, this compound is eliminated almost completely in STPs [1]. Additional to the antibiotic compounds occurring in the lake, the cephalosporine ceftazidime was also found in the influents and effluents of the OWA Tegel with concentrations between 26 and 264ng/L.

Table 32: ***Median concentration for antibiotic residues in the OWA effluent and the Lake Tegel and calculated median antibiotic loads from the OWA effluent in the Lake Tegel (n≤7).***

Substances	Median concentration [ng/L]		Median loads	
	OWA effluent (n≤7)	Lake Tegel (n=16)	[g/d]	[kg/year]
Acetyl-Sulfamethoxazole	25	12	8	3
Trimethoprim	124	19	134	49
Clarithromycin	146	31	23	9
Roxithromycin	165	34	36	13
Clindamycin	148	59	30	11
Dehydro-Erythromycin	322	118	34	12
Sulfamethoxazole	420	286	69	25
Ceftazidime	112	n.d.	23	8

On the basis of these investigations, average annual loads of antibiotic residues were determined that flow via the OWA effluents into lake Tegel. The calculation was carried out by multiplying the monthly OWA effluent discharge volumes with the corresponding average effluent concentrations of each individual compound. As shown in Table 32, the average annual loads of antibiotics discharged via the OWA into lake Tegel was 130kg in 2004. Sulfamethoxazole (49kg/year) was the compound with the highest annual load of all detected antibiotics. Dehydro-erythromycin (25kg/year) was in second place. For none of the antibiotics a decrease in concentration during OWA passage was observed. To a lesser degree, antibiotic residues may also reach lake Tegel via the river Havel. However, the quantities that were detected in water samples collected from the river Havel were clearly below those discharged by the OWA. The concentrations of antibiotics detected upstream the Havel river were in general also lower than those detected in front of the bank filtration transect in lake Tegel. This is also demonstrated by the example of clarithromycin in Figure 105.

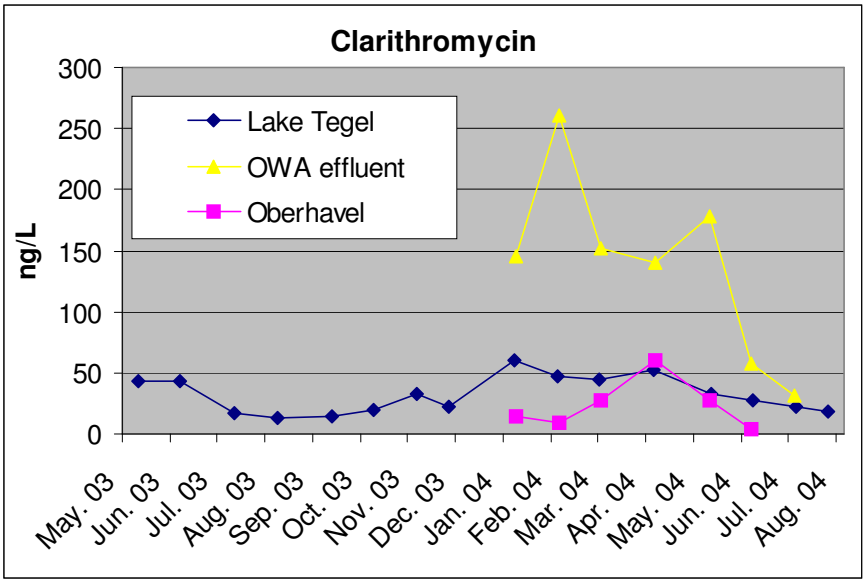


Figure 105: Concentrations for clarithromycin in Lake Tegel in front of the transect Tegel, in the OWA effluent, and in the surface water of the Oberhavel.

2.3.2.1 Conclusions

Purified effluents discharged by the municipal STPs were identified as the main sources for the occurrence of antibiotic residues in Berlin's surface waters. These residues discharged into the receiving waters such as the Teltowkanal or the Nordgraben are also reaching areas such as lake Wannsee or lake Tegel which are used as resources for groundwater recharge. Five compounds, the sulfonamide sulfamethoxazole, the sulfonamide synergist trimethoprim, the macrolides clarithromycin and roxithromycin, and the lincosamide clindamycin were detected in surface water samples collected from these lakes. Additionally, dehydro-erythromycin, the metabolite of the macrolide erythromycin and acetyl-sulfamethoxazole, the main human metabolite of sulfamethoxazole, were found.

In general, antibiotic residues were detected at higher concentrations in lake Tegel than in lake Wannsee. Trimethoprim, clarithromycin, and roxithromycin were detected in the lakes at concentrations between two and 85ng/L. The seasonal variation of the concentrations of these substances in the lakes reflects the consumption pattern of these antibiotics. The highest concentrations of all antibiotic compounds were determined for dehydro-erythromycin and sulfamethoxazole. Dehydro-erythromycin, formed by hydrolysis from the macrolide erythromycin, was detected in lake Tegel and lake Wannsee with median concentrations of 118ng/L and 52ng/L, respectively. Sulfamethoxazole occurred with median concentrations of 286ng/L and 155ng/L and in lake Tegel and lake Wannsee, respectively. In investigations of effluents discharged by the OWA Tegel an average annual total load of antibiotics of 130kg was calculated for lake Tegel.

2.4 Bank Filtration Field Sites

Since May 2003, the occurrence and fate of 19 environmentally relevant antibiotics and two of their metabolites (see also Figure 94) was investigated at three transects located at lakes Wannsee (Wannsee 1 and Wannsee 2) and Tegel. A comparison of the three field sites revealed a similar behavior of the detected compounds during the riverbank filtration.

2.4.1 Transect Wannsee 1 and 2

Table 33 and Table 34 present ranges of concentrations measured in the water samples collected from both transects located at lake Wannsee. At transect "Wannsee 1" well 3335 was only sampled during an "intensive" sampling series in September/ October 2003 and the deep wells 3332, 3334 and 3336 were only investigated in March 2004. Well 3338 could not be sampled in these investigations because the groundwater level was always beyond the screen of the wells. In the monitoring wells 204OP and 204UP, used to investigate background groundwater, no antibiotic residues were found.

Table 33: Positive findings of antibiotic residues and their concentration range [ng/L] at transect "Wannsee 1"

ng/L	surface water (n=21)	3337 (n=16)	BEE 201OP (n=15)	BEE 201UP (n=12)	3335 (n=5)	well 4 (n=11)
Acetyl-Sulfa-methoxazole	4-14	n.d	n.d	n.d	n.d	n.d
Trimethoprim	7-49	n.d	n.d	n.d	n.d	n.d
Clarithromycin	2-43	n.d	n.d	n.d	n.d	n.d
Roxithromycin	4-69	n.d	n.d	n.d	n.d	n.d
Clindamycin	15-48	1-9	0.4-2	n.d.-2	n.d.-2	n.d
Dehydro-Erythromycin	33-94	0.7-5	1-8	n.d.-3	n.d.-1	n.d
Sulfamethoxazole	100-326	1-136	<LOQ-2	n.d.-6	18-26	n.d
Sulfadimidine	n.d.	n.d.-4	<LOQ-5	3-8	n.d.-<LOQ	n.d

Not detected (n.d.): Benzylpenicillin, Ceftazidim, Ciprofloxacin, Doxycycline, Metronidazole, Moxifloxacin, Norfloxacin, Ofloxacin, Oxytetracycline, Phenoxymethylpenicillin, Piperacillin, Tetracycline, Tylosin;

>LOQ: > limits of quantification; n: number of samples

No antibiotic residues were found in samples collected from water-supply well 4. Unfortunately, the upper screen of well 4 was blocked. Since this is the only screen which is directly influenced by bank filtration, transect "Wannsee 1" was not found to be suitable for the investigation of the behavior of sewage-borne residues during bank filtration.

Table 34: Positive findings of antibiotic residues and their concentration range [ng/L] at transect "Wannsee 2"

ng/L	surface water (n=21)	BEE 205 (n=19)	BEE 206 (n=20)	BEE 202OP (n=19)	BEE 202MP1 (n=17)	BEE 202MP2 (n=11)	BEE 202UP (n=14)	BEE 203 (n=19)	well 3 (n=15)	BEE 204UP (n=15)	BEE 204OP (n=11)
Acetyl-Sulfa-methoxazole	4-14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Trimethoprim	7-49	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Clarithromycin	2-43	n.d.-3	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Roxithromycin	4-69	n.d.-7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Clindamycin	15-48	16-34	0.4-5	n.d.-<LOQ	n.d.	n.d.	n.d.-<LOQ	n.d.-<LOQ	n.d.-<LOQ	n.d.	n.d.
Dehydro-Erythromycin	33-94	n.d.-8	n.d.-10	n.d.-<LOQ	n.d.	n.d.- 4	<LOQ-2	n.d.-<LOQ	n.d.-<LOQ	n.d.	n.d.
Sulfa-methoxazole	100-326	n.d.-22	34-251	16-138	5-73	n.d.	n.d.	21-121	1-4	n.d.	n.d.
Sulfadimidine	n.d.	n.d.-6	n.d.-<LOQ	n.d.-<LOQ	<LOQ - 5	3-9	3-8	n.d.-<LOQ	<LOQ	n.d.	n.d.

Not detected (n.d.): Benzylpenicillin, Ceftazidim, Ciprofloxacin, Doxycycline, Metronidazole, Moxifloxacin, Norfloxacin, Ofloxacin, Oxytetracycline, Phenoxymethylpenicillin, Piperacillin, Tetracycline, Tylosin;

>LOQ: > limits of quantification; n: number of samples

In the field site investigations the antibiotic residues showed a different attenuation behavior during infiltration. Trimethoprim, clarithromycin, and roxithromycin were efficiently removed by the bank filtration. They were detected in the lakes and sometimes also in the first wells but mostly at concentrations below their limits of quantification (LOQs). Photodegradation does not play a significant role for these substances. Trimethoprim absorbs light with a wave

length greater than 290 nm. However, it was found to be stable in seawater for up to 20 weeks when exposed to UV light [15]. Further investigations such as column and batch experiments (see Chapter 2.5.1 and 2.5.2) showed a very fast and complete decrease of the concentrations for these three compounds. Both sorption and biodegradation may play an important role for their attenuation. In these studies, roxithromycin and clarithromycin showed a very similar behavior as might also be expected with regard to their similar chemical structures. In the batch experiments, clindamycin and dehydro–erythromycin have shown a weaker sorption behavior than other antibiotics such as trimethoprim, clarithromycin, and roxithromycin.

Figure 106 presents the results from the investigation of clindamycin at transect “Wannsee 2”. Based on solubility data (See Chapter 2.5.1), this compound is expected to be relatively mobile. However, the residues of clindamycin were completely attenuated during the soil passage. Clindamycin only occurred at trace levels in the wells close to the bank.

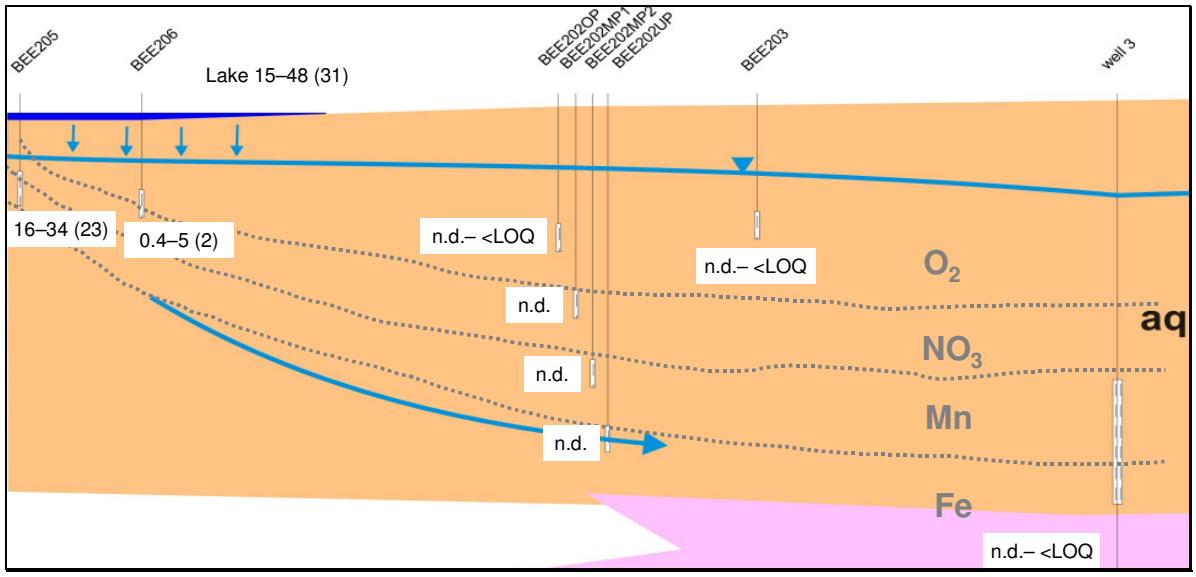


Figure 106: Transect “Wannsee 2” – Results for Clindamycin [ng/L]

(Median values are given in parentheses; n.d.: not detected; >LOQ: > limits of quantification = 0,1ng/L)

In well BEE205, it was detected with an average concentration of 23ng/L. Whereas in well BEE206, it was only found with less than 7% of the average concentration measured in the lake (15-48ng/L) (see Figure 108).

The concentrations of the macrolide metabolite dehydro-erythromycin are also significantly decreased during the soil passage (see Figure 107). In the lake it was found with concentrations between 33 and 94 ng/L. Compared to clindamycin, dehydro-erythromycin shows, however, a better attenuation rate (~98%) in monitoring well BEE205 (see Figure 108).

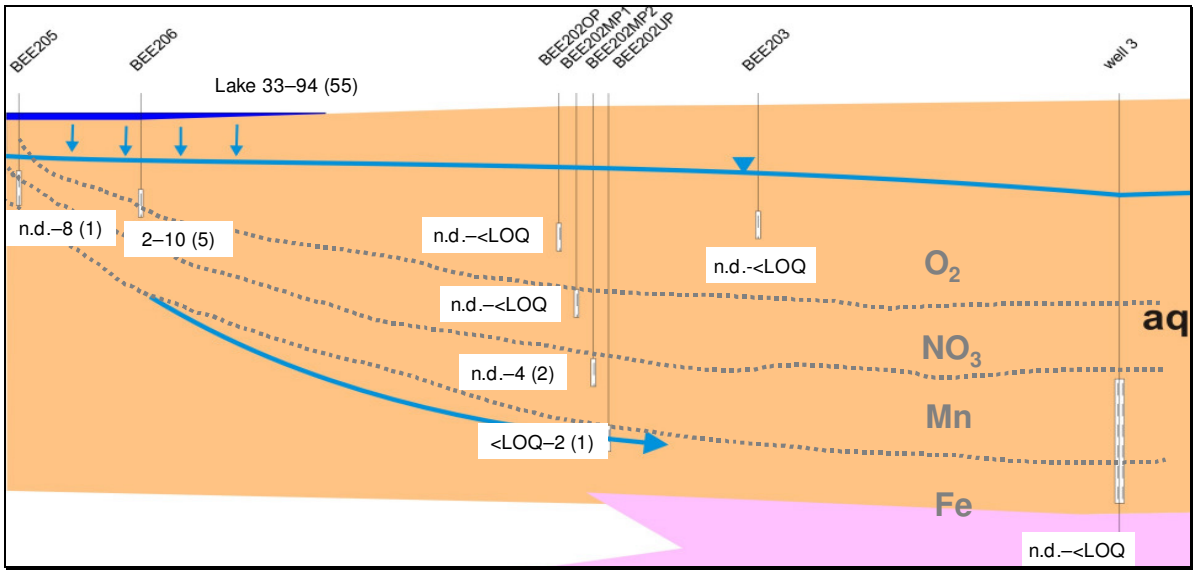


Figure 107: Transect "Wannsee 2" – Results for Dehydro-Erythromycin [ng/L]

(Median values are given in parentheses; n.d.: not detected; >LOQ: > limits of quantification = 0,5ng/L)

Wells BEE205 and BEE206 have different redox–conditions. The water in well BEE205 tends to be more reducing than that in well BEE206 (NASRI Report 1, Chapter 1.5.). This indicates that under reduced conditions dehydro–erythromycin might be better degradable than clindamycin. Further investigations could not conclusively confirm this observation: In the small column experiments, anaerobic conditions comparable to those observed in well BEE205 were not achieved. The column experiments have shown that both substances are most efficiently degraded under oxic conditions with dehydro-erythromycin being slightly better removed. However, clindamycin and dehydro-erythromycin were also readily degraded under strongly denitrifying conditions.

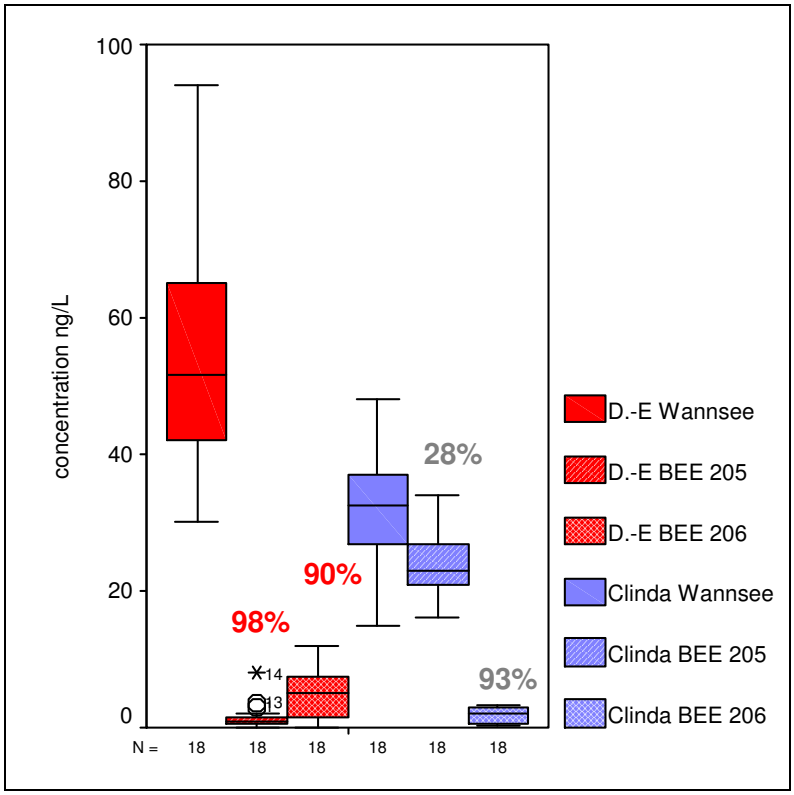


Figure 108: ***Boxplots and attenuation rates of dehydro-erythromycin (D.-E) and clindamycin (Clinda) at transect " Wannsee 2".*** (Data reported between May 2003 and August 2004, N = number of samples for respective well.)

In general, the sulfonamide sulfamethoxazole was found at higher concentrations than the other antibiotic compounds and it also clearly showed the highest mobility of all six antibiotics. For sulfamethoxazole, a significant but not a complete removal was observed during bank filtration. It is the only antibiotic residue that was also detected in water-supply well 3. However, the median concentration in well 3 corresponds only to about 1% of the median surface water concentration. This might be caused both by sorption and/or degradation processes and by dilution with non-polluted groundwater. The results obtained from the investigations of transect "Wannsee 2" are shown in Figure 109.

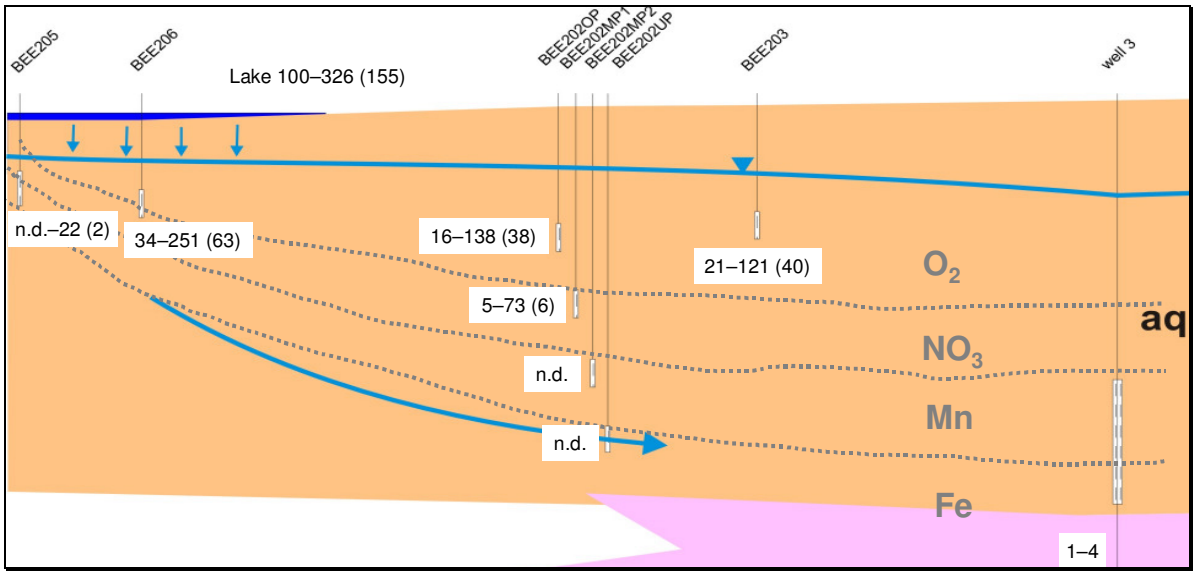


Figure 109: Transect "Wannsee 2" – Results for Sulfamethoxazole [ng/L]

(Median values are given in parentheses; n.d.: not detected; >LOQ: > limits of quantification = 1ng/L)

In Figure 110, the concentrations measured for sulfamethoxazole in monitoring well BEE206 are compared with the corresponding values measured in the same samples for manganese, nitrate, and oxygen and with decrease of the temperature given as a 10 divided by the value of the temperature. As already proposed for dehydro–erythromycin, a better degradation under reduced conditions can be assumed for residues of sulfamethoxazole (also see Figure 111).

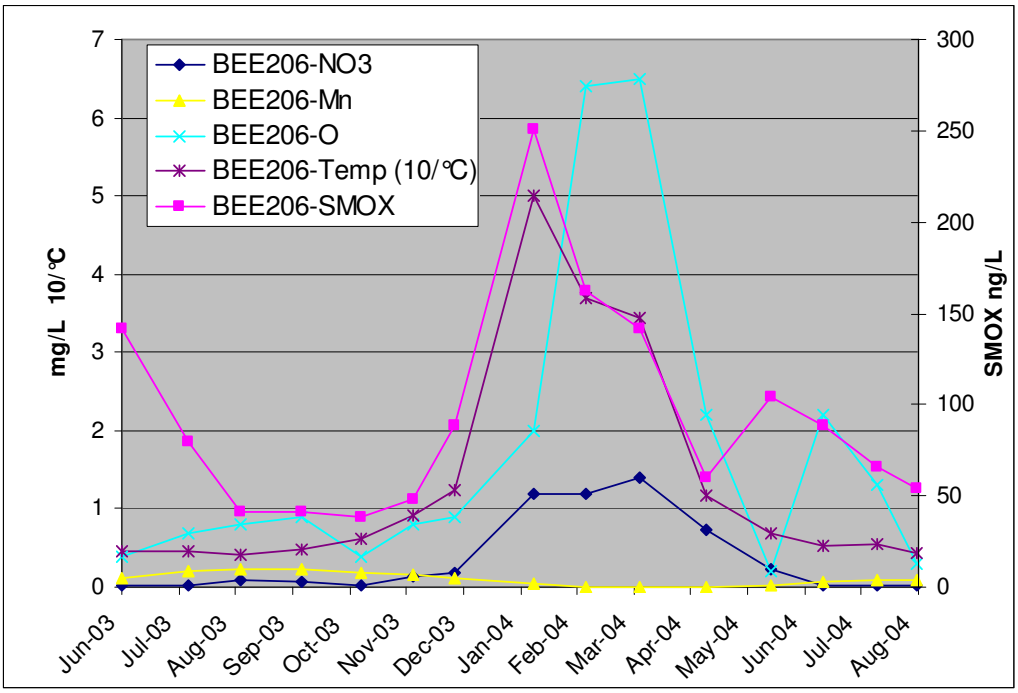


Figure 110: ***BEE206 – Concentrations of nitrate (NO3), manganese (Mn), oxygen (O) [BWB data] and sulfamethoxazole (SMOX) and the temperature given as a 10 divided by the value of the temperature.***

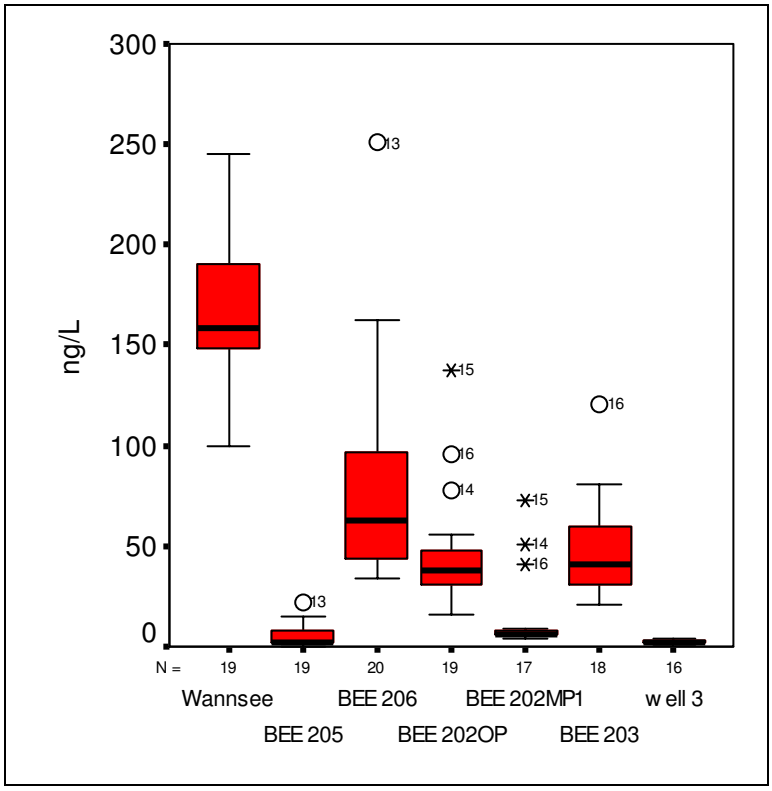


Figure 111: ***Boxplots and attenuation rates of Sulfamethoxazole at the transect "Wannsee 2".*** (Data from **May 2003-August 2004, N = number of samples for respective well.)**

Figure 112 shows that in the first half of the year 2004 the concentrations of sulfamethoxazole were increasing in some of the monitoring wells. This increase is temporarily shifted between the different monitoring wells according to the travel times of the groundwater in the aquifer (NASRI Report 1, Chapter 1.5.). In wells BEE206 and BEE205 the maximum concentrations were measured in January, whereas the water in wells BEE202OP and BEE202MP1 was detected with maximum values in March and BEE203 in April 2004. In monitoring well BEE206, the peak concentration of sulfamethoxazole was equal to the values measured in the surface water and about five times higher than those concentrations measured before and after this incident. Besides all variability, a similar increase of the concentrations was not observed in the lake.

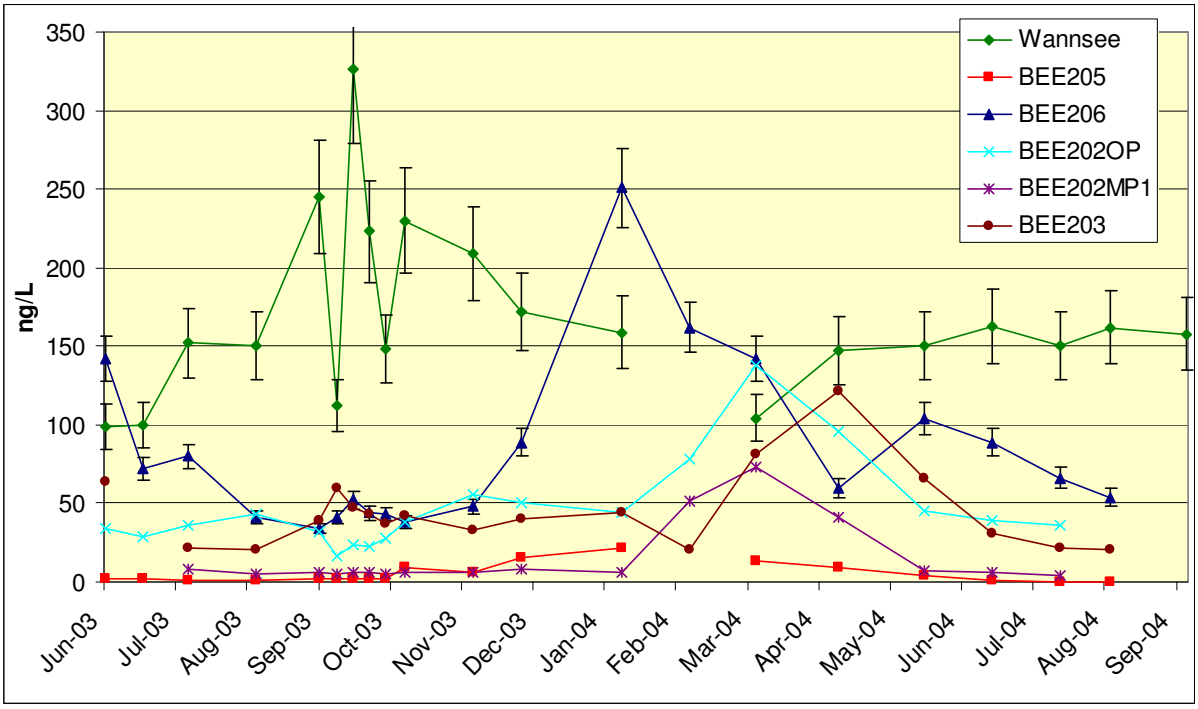


Figure 112: ***Transect "Wannsee 2" – Temporal changes of the concentrations of Sulfamethoxazole***

Surprisingly, the sulfonamide drug sulfadimidine was detected at low concentrations (between 3 and 9 ng/L) in some of the deeper wells (BEE202MP2, BEE202UP) (see Figure 113) but not in the surface water samples.

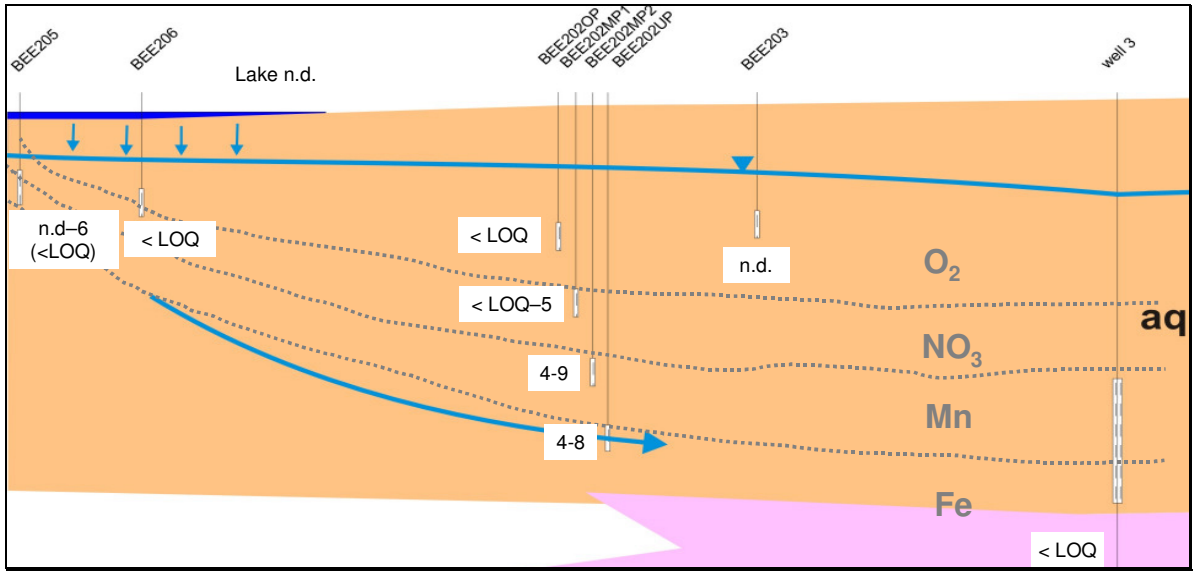


Figure 113: "Wannsee 2" – Results for Sulfadimidine [ng/L]

(Median values are given in parentheses; n.d.: not detected; >LOQ: > limits of quantification = 3ng/L)

Age dating investigations shown that in the multi-level wells BEE202 the share of young bank filtrate decreases by depth (NASRI Report 1, Chapter 1.5.). Sulfadimidine has only been used for veterinary purposes in Germany. Thus, occurrence of sulfadimidine might be explained by the use of large quantities of this compound in the past, when it was used as a growth promotor in livestock farms north of Berlin.

2.4.2 Transect Tegel

Table 35 gives an overview of the found concentration ranges determined in samples collected at transect “Lake Tegel”. At transect “Lake Tegel” the shallow wells 3311, 3310 and 3308 could not be sampled during June and September because the groundwater level was beyond the screen of the wells. Since January 2004 the deep well TEG374 was included in the investigation. However, in this well and in well 3304 (representing background groundwater) no antibiotic residues were found.

Table 35: Compounds with positive findings and their concentration range [ng/L] at transect "lake Tegel"

ng/L	surface water (n=16)	3311 (n=7)	3310 (n=7)	3301 (n=15)	3308 (n=7)	TEG 371OP (n=16)	TEG 371UP (n=15)	3302 (n=16)	TEG 372 (n=16)	3303 (n=10)	TEG 374 (n=8)	well 13 (n=16)	3304 (n=16)
Acetyl-Sulfa-methoxazole	8-30	n.d.	5-13	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Trimethoprim	9-54	N.D.	N.D.-<LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Clarithromycin	13-60	n.d.-<LOQ	n.d.-<LOQ	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Roxithromycin	18-85	n.d.-<LOQ	N.D.-4	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Clindamycin	41-122	3-8	12-40	1-3	n.d.-0.3	0.2-7	0.3-3	n.d.-0.8	n.d.-<LOQ	n.d.	n.d.	n.d.-<LOQ	n.d.
Dehydro-Erythromycin	70-460	3-6	5-75	n.d.-3	n.d.-<LOQ	n.d.-8	n.d.-3	n.d.-3	n.d.-<LOQ	n.d.-<LOQ	n.d.	n.d.	n.d.
Sulfa-methoxazole	136-533	57-254	146-662	n.d.-200	69-407	24-316	n.d.-77	20-233	26-197	34-151	n.d.-<LOQ	3-22	n.d.
Sulfadimidine	n.d.	n.d.	n.d.	n.d.-4	n.d.	n.d.-<LOQ	n.d.-7	n.d.-<LOQ	n.d.-<LOQ	n.d.-<LOQ	n.d.-<LOQ	n.d.-<LOQ	n.d.

Not detected (n.d.): Benzylpenicillin, Ceftazidim, Ciprofloxacin, Doxycycline, Metronidazole, Moxifloxacin, Norfloxacin, Ofloxacin, Oxytetracycline, Phenoxymethylpenicillin, Piperacillin, Tetracycline, Tylosin;

>LOQ: > limits of quantification; n: number of samples

Again, clarithromycin, roxithromycin (macrolide), trimethoprim (synergist for sulfonamides) and acetyl-sulfamethoxazole (metabolite) were efficiently removed by bank filtration. Residues of clindamycin (lincosamide) and dehydro-erythromycin (metabolite) were completely attenuated during the soil passage. For sulfamethoxazole (sulfonamide), a significant but not complete removal during bank filtration was observed. It was the only compound that was also detected at trace levels in samples collected from water-supply well 13. In general, the data obtained from the investigation conducted at transect "lake Tegel" confirmed the results from the field study at transect "Wannsee 2". The results are also in line with results from a preliminary study on sulfamethoxazole conducted by Hartig [14]. In 1999, Hartig [14] investigated water samples from transect "lake Tegel" collected at six sampling dates. A comparison of the mean concentrations measured in this and the current study (NASRI 2003-04) are shown in Table 5. Especially, the concentrations measured for sulfamethoxazole in the surface water and in water-supply well 13 are very similar in both studies. Thus, the above mentioned proposal of an almost but not complete removal of sulfamethoxazole during bank filtration was confirmed by both studies.

Table 36: Comparison of mean concentrations for sulfamethoxazole at transect "lake Tegel" reported by Hartig [14]] and the NASRI project.

[ng/L]	Hartig 1999 (n≤6)	Nasri 2003-04 (n≤16)
Lake Tegel	223	286
3311	22	165
3310	85	328
3308	34	219
3301	21	65
3302	24	73
3303	17	66
Well 13	2	9

2.5 Laboratory experiments

2.5.1 Sorption and degradation of selected antibiotics in soil-water systems (batch-experiments)

2.5.1.1 Introduction

The occurrence of some investigated antibiotics in surface water (like Lake Wannsee) but their absence in well waters along the transect for the most part leaded to the necessity to get some general information about the behaviour of the detected compounds concerning soils. In order to support the results of the transect investigation and possibly explain their environmental fate respectively laboratory investigations in cooperation with the NASRI project partners FU/Hydrogeology were performed to determine the sorption and (bio)degradation behaviour.

A mixture of six antibiotics were batched to different soil-water systems of three sediments from lake Wannsee mixed with either lake water (Wannsee) or distilled water. Some soil suspensions were put together with the very toxic substance sodium azide to inhibit microbial activity.

The goal of the experiment was to estimate the adsorption and degradation behaviour of the substances on sediments from the investigated transects. Different adsorption and degradation processes could not been distinguished by using this method. Adsorptions occurring on colloids generated by the soils are not taken into account 0.

2.5.1.2 Materials and methods

***T*est antibiotics**

In surface waters of Berlin observations in context of the NASRI- project showed five relevant antibiotics: trimethoprim, clindamycin, sulfamethoxazole, clarithromycin and roxithromycin and two antibiotic derivates: acetyl- sulfamethoxazole (a human metabolite of sulfamethoxazole) and dehydro-erythromycin (a degradation product of erythromycin), see

Table **37**. Except acetyl-sulfamethoxazole all of them are selected for these investigations.

Table 37: Investigated antibiotics and their properties 0.

Substance	**Molecular Weight [g/mol]**	**Water Solubility [mg/l]**	**pK_a**	**log K_{ow}**
Trimethoprim	290	hardly soluble	6.6-7.2	0.91
Clindamycin	425	hardly soluble	7.6	1.02
Sulfamethoxazole	253	unsolvable	5.6-5.99	0.89 / 0.74
Dehydro-Erythromycin	716	hardly soluble		
Clarithromycin	748	hardly soluble	8.76	2.6
Roxithromycin	837	hardly soluble	7.1-9.2	2.5

Test sediments and water

- Two sediments of the Wannsee transect from October 2003 were used: “W2” is a mixture of different aquifer parts; “W3” comes from the bottom of the lake Wannsee (the first 10 cm) near the bank. A third sediment used for the experiments was W3 glowed at 800°C for about 12 hours. In November 2004 when experiments started W2 was already dried (at 40°C) and sieved (2 mm) whereas most part of W3 was in moist condition, both stored cool. W3 was then treated the same as W2 und mixed with some already dried sediment of W3.W2 was obvious more coarse-grained than W3 but contained more very fine sediment which was visible during sampling because in both cases some fine material was hardly deposited. See also the results of the sieving analysis by FU/Hydrogeology [1]. Both sediments are mostly free of silt and clay (< 1%).W3 contained an easy visible amount of shell fragments and organic material (< 2mm), the organic carbon content was 0.573 %. W2 contained 0.162 % of organic carbon 0.More geochemical properties of the sediments W3 and W2 are described elsewhere (see 0).Glowed W3 changed colour from beige-green of W3 to light red. Organic material was obviously gone and shell fragments appeared to be clean white. The colour of W2 was red brown.

- Lake water comes from Lake Wannsee in November 2004.

Preliminaries

- Soil to solution ratio: An appropriate ratio guarantees that the percentage adsorbed is above a minimum and concentration of test substances in the aqueous phase are kept high enough to get accurate results. A generally recommended soil/solution ratio of 1:5 was used 0, 0.
- Equilibration time: To determine the amount of test substance adsorbed to a soil it should be measured when the system has reached a plateau. Since experiments were performed to get results during a long period (four weeks) to better observe biodegradation it was necessary to take several samples at the beginning until plateau was possibly reached (three days) and only few samples were necessary for the rest of the period (see "sorption experiments").
- ***Stability of test substances:*** To check general stability of the test substances stock solutions with distilled water of same concentration as in containers used for experiments were prepared in duplicate with and without sodium azide. Samples were taken and analyzed immediately, after eight days and after four weeks. Following conditions were kept: Temperature of 20°C, darkness, glass bottles, no agitation.
- ***Starting concentration and stock solution:*** Solution of the antibiotic mix was prepared in pure water without any solubilizing agent such as methanol or acetonitrile (concentration: 100 mg/l). Only Clindamycin was easy soluble but six hours of ultrasound stirring produced a clear solution of the substance mix. The stock solution was stored at 10°C. An appropriate amount of this solution was added to the testing systems. Detection limits of all substances are close to 1ng/l. Starting concentration in containers were chosen three orders of magnitude higher (1 µg/l) 0. This ensures accurate measurements concerning the methodology used. Unfortunately occurrence in the environment means concentrations which are one to two orders of magnitude lower than 1 µg/l.
- ***Filter materials:*** Available filters were tested to make sure that no losses of substances occur during filtering. No significant losses were detected.
- ***Controls:*** In order to check the starting concentration, the stability of the test substances in agitation and its possible adsorption on the surface of the test vessels respectively controls with only water but no sediment were also started 0.
- ***Sodium azide concentration:*** In addition to sorption biodegradation can play a role. A toxic system to inhibit microbial activity was found to be economical and easy workable in comparison to sterilization. However, sodium azide has the following

disadvantage: Changing the kind of electrolytic solution means possibly changes in sorption properties of the test substances dependent on concentration of the additional electrolyte. However, with low concentration of the toxin it is difficult to preserve effective inhibition of microorganism important for degradation during a long period. Quite the reverse it is presumed that for batch experiments a rather larger amount of toxic substance is needed than usually used in column studies where continuous addition of toxin means permanent revival of toxic effects.

A sodium azide concentration as low as possible but high enough to inhibit microorganism effectively during four weeks was needed. In practice concentrations of 5 – 10 g/l with continuous addition are usual but there are no standardized recommendations because it depends on the soil/solution system.

Therefore different amounts of sodium azide (0.5/5/10/20 g/l) were added to mixtures of W3 and lake water (ratio of 1:5) and agitated for four weeks under almost same conditions as in batch experiments. A fluid culture medium for testing water/soil samples of being sterile ("R2A", TU/Environmental Microbiology) was used to check each aqueous phase of inhibition effect every week.

The culture medium went little cloudy only with water from the soil/solution system with sodium azide concentration of 0.5 g/l while with larger amounts of sodium azide no visible growth was discovered for four weeks. A sodium azide concentration of 5 g/l was then expected to inhibit sufficiently in batch experiments.

Sorption experiment

For each of 11 sediment/solution systems (control samples inclusive) a duplicate sample was prepared and pre-equilibrated 84 hours by shaking overhead. Partly systems were prepared in triplicate but samples of the third container could not been analyzed. After antibiotic batching and further agitation an aliquot of the aqueous phase was taken and frozen immediately at six defined time intervals. Experiment continued always with the original mixture until the next aliquot was taken (serial method). The amount of test substances remaining in the aqueous phase was analyzed directly after quick thawing and filtering for comparison to the amount of substances which were initially batched (indirect method). A direct determination of the amount of the adsorbed substances by analyzing the soil was not carried out 0.

The necessary concentration of the test substances and the kind of analyzing method has to be used required a rather large sample volume of 150 ml at each sampling. To provide an appropriate starting volume 5 l petrol containers were filled with 900 g sediment and 4.5 l water and were agitated overhead while packed firmly in concrete mixers (Fig. 1) 0. In some

cases 22.5 g sodium azide per canister were added. By batching the antibiotic mix 45 µl of the stock solution with a concentration of 100 ng/µl was added to every container.

Figure 114: Concrete mixer with firmly packed petrol containers. For agitating it was additionally covered.

After batching the antibiotic-mix and short shaking first sampling was carried out during at most fifteen minutes (time point t_1). Following samplings took place after agitation time in concrete mixers of one (t_2), 24 (t_3), 72 (t_4), 168 (t_5) hours and four weeks (t_6) 0. Sodium azide activity was checked with culture medium at the time point's t_1, t_5 and t_6. Four controls without sediment but only 4.5 l water were run the same way: 1. Lake water (Wannsee), 2. Distilled water, 3. Lake water with sodium azide, 4. Distilled water with sodium azide. Room temperature was nearly constant over the whole testing period of about 20°C. Figure 3 show all tested soil-water combinations and the controls.

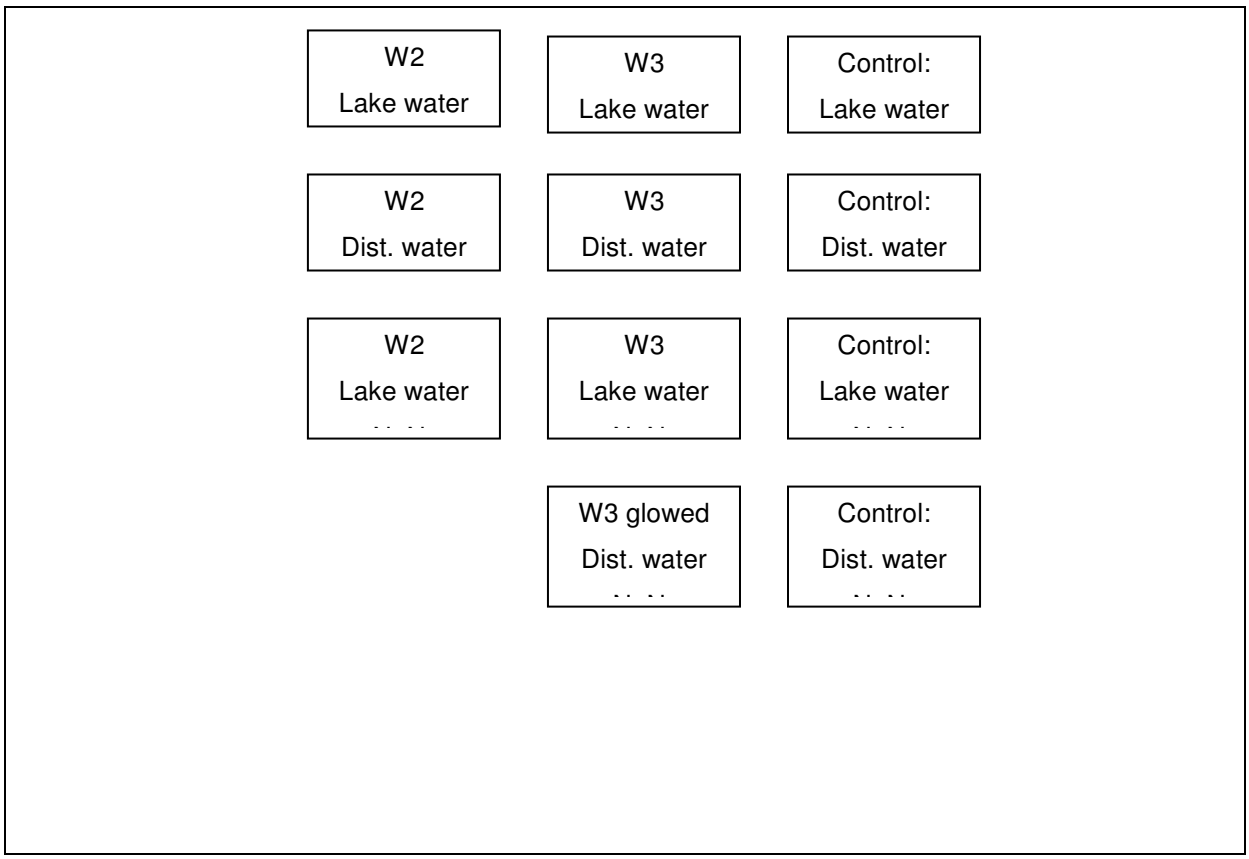


Figure 115: Testing scheme

Analysis method

Two volumes of 50 ml of each filtered sample were thinned with 250 ml water and then preconcentrated via solid phase extraction (SPE) and quantified using HPLC- electrospray-tandem- mass spectrometry (See Chapter 2).

Chemical and physical properties of aqueous phases

After antibiotic analyzing rest of thawed samples were stored at 10 °C. Chemical and physical properties (see appendix) were investigated later with photometric tests ("Dr. Lange Küvetten Test"). First and last sample of each container was analyzed once.

2.5.1.3 Results and discussion

Intensity of reaction

The substance concentrations in the aqueous phase were always high enough to be measured accurately although clarithromycin and roxithromycin were partly measured near their limit of quantification of 0.5 ng/l.

On the other hand a minimum of 20% adsorption of substance, preferably more than 50% is useful for further evaluation like calculating distribution coefficients 0. Table 38 shows that in most cases of this experiment the loss of substances after 72 hours of agitating is sufficient to give an opinion of the processes.

Table 38: Percentage of loss of substance in the aqueous phase after 72 h (* after 168 h) on the basis of the nominal initial concentration.

Substance	W3/lake	W3/dist	W3/NaN3/ lake	W2/lake	W2/dist	W2/NaN3/ lake	W3gl/NaN3/dist
Trimethoprim	76	70	33	81	71	72	7*
Clindamycin	62	59	26	67	68	52	57
Sulfamethoxazole	88	83	14*	43	26	4*	7*
Dehydro-Erythromycin	45	55	31	70	83	56	71
Clarithromycin	97	98	91	99	99	96	88
Roxithromycin	96	97	89	99	99	96	89

Only some sodium azide samples, e.g. sulfamethoxazole, shown too little reaction, it seems that no or only little sorption took place (4 –14% loss after 168 hours). To determine distribution coefficient, batch experiment must have been repeated with more soil but same water amount (for example with soil/solution ratio of 1:1). Possibly adsorbed amount must directly be determined in addition 0. The other extreme is the very fast and nearly complete attenuation of roxithromycin and clarithromycin on W2 (99%) and W3 (96 –98%). Soil/solution ratio of 1:50 to 1:100 would produce favorable measurement results.

Figure 3 shows a typical sorption reaction (equilibration reaction) from the experiments (Trimethoprim with W3/lake water) in comparison to a very weak reaction (Sulfamethoxazole with W2/lake water and sodium azide) and to a very strong reaction (Clarithromycin with W2/lake water).

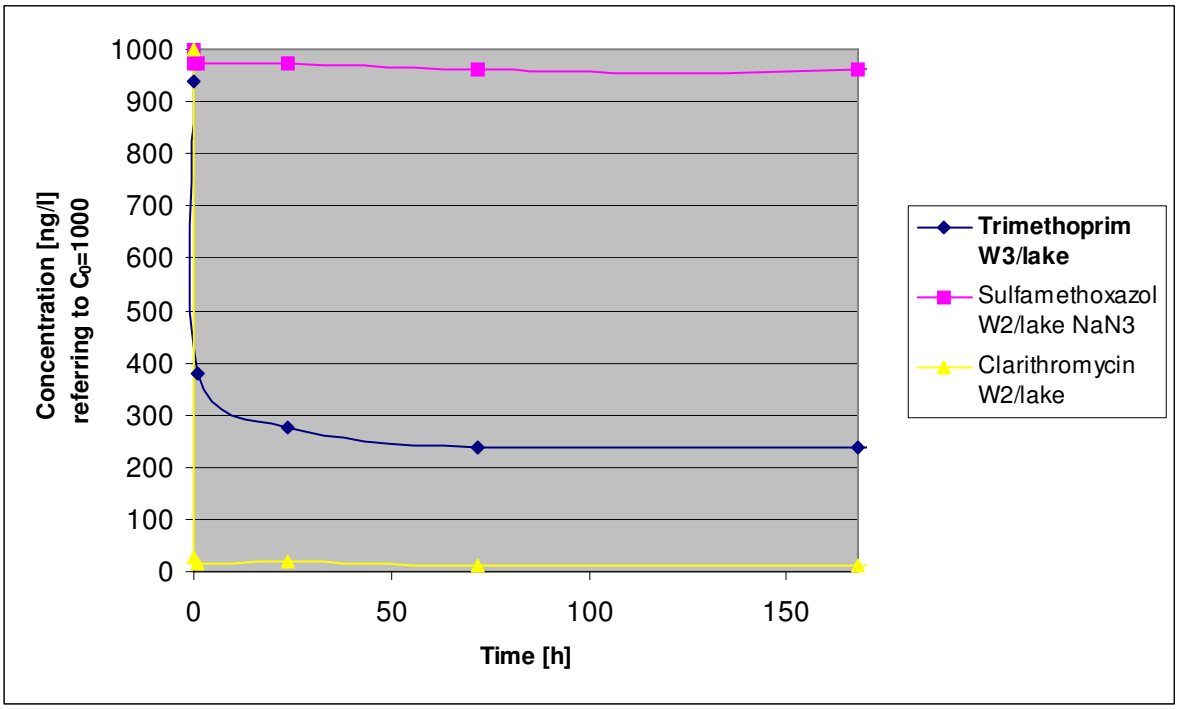


Figure 116: Mean concentration of duplicate samples of three example substances in the aqueous phase versus time referring all to an initial concentration of 1 µg/l. Here an equilibrium reaction is only observed with trimethoprim. (W3 = lake bottom, W2 = aquifer mix)

Adsorption and degradation processes

A sorption reaction is found when achievement of an equilibrium plateau can be observed 0. Distribution coefficients can be calculated by determining the time after which sorption equilibrium is attained (equilibration time). If no plateau after 24 to 72 hours is achieved but a steady increase of supposed adsorption is found, there are also other processes like slow diffusion or biodegradation (which is in the following always expressed as “degradation”) in dissociation from adsorption as an equilibration reaction 0. Figure 5 shows an example from the experiments (Clindamycin with W3/distilled water): The degradation process(es) start before equilibrium of sorption reaction can be attained and continue four weeks. In case of biodegradation plateau should be achieved with sterilized/poisoned sample of the soil/water system which can be checked only for the lake water systems within these experiments. Here the process could be rather put down to slow diffusion or other processes because of decreased conductivity of aqueous phase of the W3/distilled water system in comparison to the W3/lake water system. Trimethoprim shows same reaction phenomena with W3 and W2.

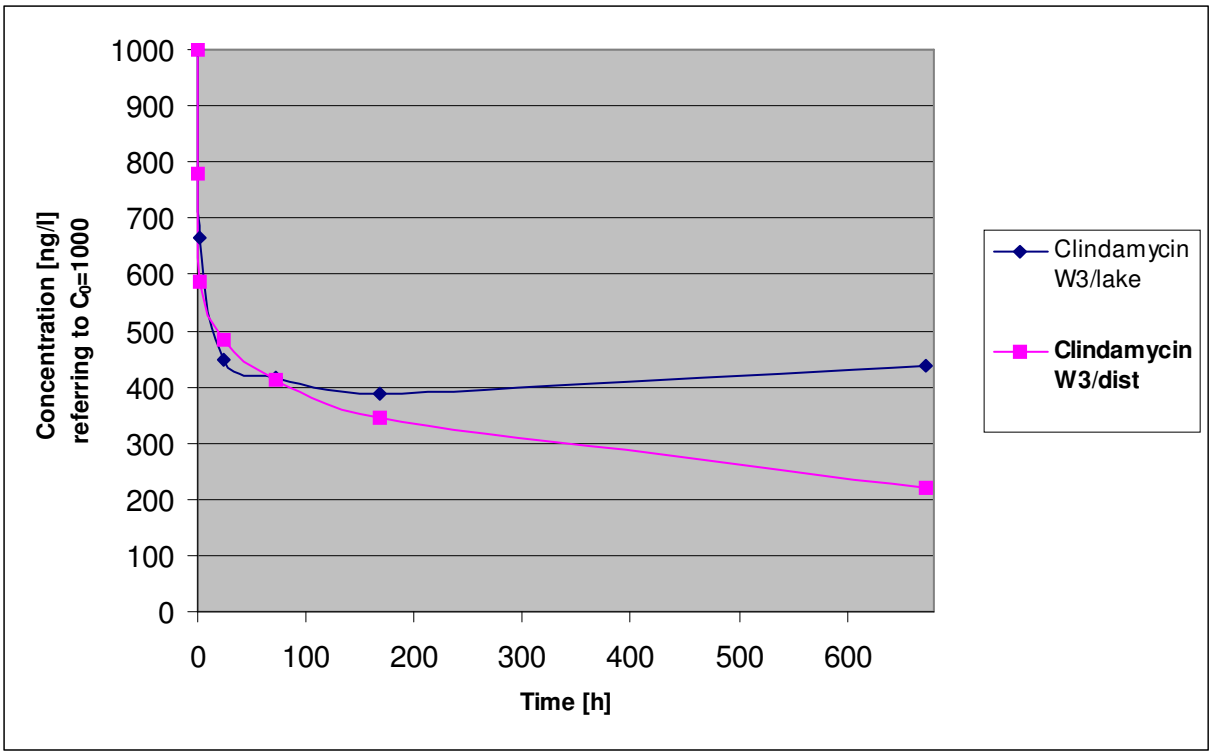


Figure 117: Mean concentration of duplicate samples of clindamycin in the aqueous phase versus time referring to an initial concentration of 1 µg/l. With W3/lake water an equilibration plateau is achieved after about 48 hours whereas with W3/distilled water a more steady decrease is observed. (W3 = lake bottom, W2 = aquifer mix)

A degradation reaction of substance from the more beginning of the test period like the example of Clindamycin showed above was observed with 33 % of the batch samples. 17 % showed degradation from later time points than t_3 (72 hours). There equilibration time was detectable.

Only seven of the samples with reaction intensity from 26 to 81 % loss of substance (17 % of all batch samples) showed purely a sorption reaction.

Test substance stability test and controls

Within the test, which was carried out with the substances in glass bottles without agitation, no significant losses could be detected over the four week period. This means that the substances showed chemical stability at room temperature.

Agitated controls in petrol containers (material: high density polyethylene) partly showed high losses (see Table 39). The highest losses are of sulfamethoxazole from 35 to 41% and roxithromycin of about 33% from the beginning on whereas in other cases losses were detected at later time points or only at the end of the testing period. After four weeks up to

66% loss were detected. Adsorptions on the surface of the containers or biodegradation or both have to be considered.

Table 39: Percentage of loss of substance in the controls after 0.25 / 72 / 672 hours on the basis of the nominal initial concentration as far as 10% loss was exceeded.

Substance	lake water	lake w./NaN_3	distilled water	dist. w./NaN_3
Trimethoprim	stable/stable/49	stable/stable/17	stable/stable/17	stable/stable/stable
Clindamycin	stable/stable/29	stable/19/17	stable/26/46	stable/49/stable
Sulfamethoxazole	41/58/58	stable/stable/stable	35/29/43	stable/stable/24
Dehydro-Erythromycin	stable/stable/20	stable/stable/17	23/24/57	stable/stable/stable
Clarithromycin	19/32/35	17/31/29	21/20/60	stable/stable/stable
Roxithromycin	33/45/39	stable/stable/33	32/17/66	stable/stable/stable

Controls should show stability of the substance up to the time plateau was reached in soil/solution samples to calculate distribution coefficient. If losses are detected in controls soil should be investigated directly to correct adsorption amount determined with the indirect method. The direct method was not carried out within these experiments.
Controls are also useful to possibly help understanding the observed courses from the soil/solution experiment but data cannot be directly extrapolated to those. The presence of soil will affect adsorption on the surface of the test vessels 0. According to the goals of the experiments and because soils could not be investigated directly data of controls was nevertheless quite used for estimating coefficients.

Sodium azide samples

Sodium azide activity (checked with test culture medium) was stable for four weeks. All sodium azide samples show less removal of investigated substances in comparison to the samples without sodium azide independent on whether degradation in the normal samples was observed or not (data not shown). This observation lets assume at first that for all substances also biodegradation play a role. Relating to the following points it is improbable that always only biodegradation alone is responsible for the lower concentration decrease. Like mentioned above it seems that sodium azide disturbs also the sorption reactions of the substances:
1. Even the very strong reactions of roxithromycin and clarithromycin with W2 are reduced. Triple amount of these substances in the toxic aqueous phase could be detected. The

reaction is very quick (within 15 minutes) which means that reduced reaction in the presence of sodium azide can hardly be due to an inhibition of biodegradation alone.
2. In four cases of non toxic samples no degradation over the whole period can be observed but only a typical equilibration reaction. With sodium azide equal reaction is expected but in the aqueous phase of the appropriate toxic samples double up to triple amount of test substances are detected.
3. From Table 39 appears that some non-toxic controls show immediately (time point t_1) a loss of some substances, e.g. sulfamethoxazole. In contrast substances are stable (clarithromycin with lake water is the only exception) with sodium azide. This suggests besides biodegradation also an adsorption on the surface on the test container which is prevented with sodium azide.
Since there are disturbing factors data from sodium azide samples could not be used for calculating coefficients.
Some substances of the sodium azide samples nevertheless show degradation mainly relating to time point t_6. Other processes than biodegradation could be considered.

Sorption

Mean concentrations in the aqueous phase were plotted versus time. Each case was checked carefully if sorption could be observed and equilibration time could be determined. If a plateau was reached within 24 to 72 hours equilibration time and related concentration in the aqueous phase was determined to calculate distribution coefficient.
The adsorption distribution is defined as the ratio of the pharmaceutical concentration in the soil (C_s [ng/g]) to the antibiotic concentration in the aqueous phase (C_{aq} [ng/ml]) after equilibration has been achieved 0. The distribution coefficient, K_d, and the adsorption percentage were calculated according to the following equations and are presented in Table 40:

$$K_d = C_s\,(eq)/C_{aq}\,(eq)\ \ [ml/g] \qquad A\ (\%) = (C_s/C_0) \times 100$$

C_{aq} was determined directly whereas C_s was measured indirectly as the difference between the initial (C_0 [ng/l]) and the final (mostly after 72 h) concentration in the solution (C_{aq} [ng/l]). C_{aq} refers to the freely dissolved molecules in the soil solution 0.

$$C_s = (C_0 - C_{aq}) * 4.5l/900g\ [ng/g]$$

Accurate determining of C_0 and C_{aq} are of great importance to get precise distribution coefficient. In comparison of those little changes (less than 1%) on the calculated amount of the adsorbed substances on the soil are the results when taking reduced volume at each time point into account 0 includes instructions on calculating corrected adsorption. For trimethoprim and the W3/lake water system an increase of adsorbed amount from 76 (uncorrected) to 77% (corrected) adsorption on the soil was calculated at time point t_4. Volume corrections then were not carried out because of high time requirements and larger dependency of K_d from test conditions and determining of equilibration time. The kind of K_d dependency on C_{aq} (linear/nonlinear) 0,0 is not taken into account here because several initial concentrations had to be investigated (Freundlich isotherm).

Anyway precise K_d could only be calculated in four cases where no additional degradation in the soil/solution system and stability of test substances in the control system could be observed (grey coloured rows at Table 40). For other cases K_d is estimated.

C_0 was the nominal initial concentration which was 1µg/l for distilled water systems and 1µg/l plus Lake Wannsee water content of each substance for the lake water systems.

If equilibration time hardly could be determined because of simultaneous degradation, K_d was estimated by using C_{aq} at a time point which was sufficient for most other cases (72 hours). Given value for K_d and sorption percentage then are always too high (marked with "<").

Equilibrium time could be determined from twelve samples as 24 to 72 hours with at most 72 hours. For comparative purposes within these experiment results all the calculated values for K_d are related then to 72 hours as sufficient equilibration time. Only for a few samples with very weak reaction 168 hours was a sufficient time because of varying values in between the duplicate sample at the beginning of the testing period.

Partly equilibration time could not be determined because of very quick sorption and only few sampling time points during the first 24 hours. Little more losses were observed from 24 hours until 72 hours time point and equilibration time of 72 hours for the calculating was also established.

Last case to look at was instability of test substance in the control. Those cases indicate a direct investigation of soil which could not been carried out here. If loss of substance in the control was observed from the first time point on (not observed with clindamycin and trimethoprim) adsorption on the test container was assumed. The initial concentration C_0 was corrected then by using the controls C_{aq} of the substance at time point t_1 to estimate K_d and the sorption percentage. For the other cases with instability of test substance in control at time point t_4 C_0 was not corrected. Loss of substance in control at time point t_4 compared to initial concentration was taken for calculating is given for both cases.

Table 40: Distribution coefficient and adsorption percentage at equilibration time (t4=teq) of 72 h.

Substance	Soil/ water	C_0 (t_0) [ng/l]	C_{aq} (t_{eq}) [ng/l]	loss in control (t_{eq}) [%]	K_d (t_{eq}) [ml/g]	Sorption A (t_{eq}) [%]
Trimethoprim	**W3/lake**	1015	239	stable	16.2	76
	W3/dist	1000	305	stable	<11.4	<70
	W2/lake	1015	209	stable	22.0	81
	W2/dist	1000	291	stable	<12	<71
Clindamycin	**W3/lake**	1039	392	stable	8.2	62
	W3/dist	1000	412	26	<7.1	<59
	W2/lake	1039	342	stable	<10.2	<67
	W2/dist	1000	321	26	<10.6	<68
Sulfamethoxazole	**W3/lake**	676*	142	17	<18.7	<79
	W3/dist	647*	174	stable	<13.6	<73
	W2/lake	676*	657	17	0.1	3
	W2/dist	647*	761	stable	0	0
Dehydro-Erythromycin	**W3/lake**	1065	581	stable	4.2	45
	W3/dist	768*	455	stable	<3.4	<41
	W2/lake	1065	316	stable	<11.9	<70
	W2/dist	768*	174	stable	<17.0	<77
Clarithromycin	**W3/lake**	817*	31	13	128	96
	W3/dist	795*	24	stable	161	97
	W2/lake	817*	11	13	354	99
	W2/dist	795*	6	stable	666	99
Roxithromycin	**W3/lake**	688*	40	12	88	95
	W3/dist	676*	29	15	111	96
	W2/lake	688*	12	12	288	98
	W2/dist	676*	9	15	388	99

*: Partly C0 is corrected to Caq of control at time point t1.

Loss in control: difference between C0 and Caq in control at time point t4.

Results of grey colored fields are from experiments with stability of test substances in control and no other observed processes than an equilibration reaction (sorption).

Results marked with "<" indicate other processes than sorption in addition until time point t4. Instability in controls at teq indicates possibly additional adsorption at the test containers surface.

W3 = lake bottom, W2 = aquifer mix; t4=teq=72 h

Substances with K_d < 1 are supposed to be very mobile concerning the tested soil because hardly any adsorption could be determined. Increasing values for K_d means increasing adsorption and decreasing mobility respectively. From Table 40 it is shown that in most cases a removal of at least <59% up to 81% on the investigated sediments could be determined. Dehydro-erythromycin was less adsorbed than the other antibiotics onto sediment W3 ("lake bottom"). Clarithromycin and roxithromycin were very strongly sorbed on both sediments (A = 95 to 99%) which is expressed with high K_d values of 88 up to 666 whereas the K_d values of the other antibiotics are most at 22.

The distribution coefficients for lake water systems compared to the distilled water systems show partly great differences but values are always of the same magnitude. The distilled water system of roxithromycin and clarithromycin show always a higher K_d value compared to the lake water system which means a higher adsorption percentage. For the other antibiotics in most cases the contrary is observed.

The adsorption of the compounds was generally higher in sediment W2 (aquifer mix) than in sediment W3 since the adsorption don't correlates positively with organic carbon content. The exception in sorption properties shows sulfamethoxazole with little or no adsorption on W2 but high sorption reaction to W3. It should be taken into account that controls show high losses for sulfamethoxazole from the very beginning and values for sulfamethoxazole of the controls are extrapolated to the values of the samples. Samples with no or little sorption should be repeated in further investigations with a sediment to solution ratio of 1:1 to determine distribution coefficient more exactly.

Table 41 shows all six tested antibiotics in the sequence of strength of reaction to the two sediments after 72h beginning with the weakest test substance.

Table 41: Sequence of sorption reaction strength to W3 = lake bottom, W2 = aquifer mix, soil/solution ratio 1:5, time point t4 = 72 h.

W3			W2		
Test Substance	**Sorption A [%]**	**K_d [ml/g]**	**Test Substance**	**Sorption A [%]**	**Kd [ml/g]**
Dehydro-Erythromycin	<41 - 45	<3.4 - 4.2	Sulfamethoxazole	0 - 3	0 - 0.1
Clindamycin	<59 - 62	<7.1 - 8.2	Clindamycin	<67 - 68	<10.2 - 10.6
Trimethoprim	<70 - 76	<11.4 - 16.2	Dehydro-Erythromycin	<70 - 77	<11.9 - 17.0
Sulfamethoxazole	<73 - 79	<13.6 - 18.7	Trimethoprim	<71 - 81	<12.0 - 22.0
Roxithromycin	95 - 96	88 - 111	Roxithromycin	98 - 99	288 - 388
Clarithromycin	96 - 97	128 - 161	Clarithromycin	99	354 - 666

For roxithromycin and clarithromycin the values for the distribution coefficient and the adsorption percentage could be accurately determined. Since the K_d is related to sediment/lake water systems it can not be directly compared to results from external investigations which in most cases use 0.01 M $CaCl_2$ solution 0 but it is assumed that values are of the same magnitude. For other cases further investigations on the additional processes and possibly adsorption on the surface of the test containers are recommended.
Data of sodium azide samples are present in a separate table only to show reduced reaction but not to characterize sorption of substances to the soils (see Table 42)!

Table 42: Distribution coefficient and adsorption percentage for sodium azide samples. See notice for Table 40. "+" equilibration time of 168 hours, Kd and sorption percentage of appropriate samples without sodium azide for comparison purposes. (W3 = lake bottom, W2 = aquifer mix)

Substance	**Soil/ water**	**C_0 (t_0) [ng/l]**	**loss in control (t_{eq}) [%]**	**K_d (t_{eq}) [ml/g]**	**Sorption A (t_{eq}) [%]**	K_d of approp. sample (t_{eq}) [ml/g]	Sorption of approp. sample (t_{eq}) [%]
Trimethoprim	W3/lake/NaN3	1015	stable	2.5	33	16.2	76
	W2/lake/NaN3	1015	stable	13.1	72	22.0	81
	W3glowed/dist/NaN3	1000	stable$^+$	0.4$^+$	7$^+$		
Clindamycin	W3/lake/NaN3	1039	19	1.8	26	8.2	62
	W2/lake/NaN3	1039	stable	5.5	52	<10.2	<67
	W3glowed/dist/NaN3	1000	49	<6.5	<57		
Sulfa-methoxazole	W3/lake/NaN3	1152	stable$^+$	0.8$^+$	14$^+$	<18.7	<79
	W2/lake/NaN3	1152	stable	0.2	4	0.1	3
	W3glowed/dist/NaN3	1000	stable$^+$	0.4$^+$	7$^+$		
Dehydro-Erythromycin	W3/lake/NaN3	1065	stable	2.2	31	4.2	45
	W2/lake/NaN3	1065	stable	<6.4	<56	<11.9	<70
	W3glowed/dist/NaN3	1000	stable	12.1	71		
Clarithromycin	W3/lake/NaN3	838*	14	41	89	128	96
	W2/lake/NaN3	838*	14	108	96	354	99
	W3glowed/dist/NaN3	1000	stable	<37	<88		
Roxithromycin	W3/lake/NaN3	1020	stable	41	89	88	95
	W2/lake/NaN3	1020	stable	122	96	288	98
	W3glowed/dist/NaN3	1000	stable	42	89		

Sodium azide samples of trimethoprim and clindamycin show half adsorption with W3 and little lower adsorption with W2 than normal samples. Sulfamethoxazole shows no sorption reaction in the presence of sodium azide whereas high percentage is adsorbed to W3 without sodium azide. Also for dehydro-erythromycin, clarithromycin and roxithromycin little reduced sorption is observed.
With the glowed sediment of “lake bottom” no sorption could be observed with trimethoprim and sulfamethoxazole but high adsorption percentage with the four other tested antibiotics.

The organic carbon normalized adsorption coefficient K_{OC} which is a favored measure of sorption in environmental risk assessment 0 is not given here because the main purpose of K_{OC} is to reduce variability between K_d data of one compound in different soils. That requires dependency of the sorption from the organic carbon content of the soil which has been found for non-polar organic chemicals. For the existing test substances reduction of variability could not been found out.

Degradation

Partly other processes than a sorption equilibration reaction was observed with trimethoprim, clindamycin, sulfamethoxazole and dehydro-erythromycin. It is always a steady decrease and always starts before equilibration plateau could be observed and keep on going until experiment was stopped. There is only one exception with sulfamethoxazole and the “aquifer mix” W2 (see Table 43) and some sodium azide samples (see
Table 44) where degradation starts at a time point later than 72 hours. In four cases the other process at time point t_4=72 hours could be only observed with the distilled water system but not with the lake water system. It is not assumed that here is biodegradation the main process resulting in a steady decrease with distilled water but a slow sorption process.
Some sodium azide samples show also additional degradation processes though there was inhibition of microbial activity proved. The sodium azide samples were not suitable to prove biodegradation of the normal samples (see also above).
Data of the controls does not help to interpret the degradation behaviour of the samples here and can not be directly extrapolated to the samples. All the controls show losses at the end of the experiment which means that biodegradation is probable concerning all six tested substances. The exceptions are sulfamethoxazole, clarithromycin and roxithromycin in lake water controls where no difference was observed to the loss at time point t_4 = 72 hours. With distilled water great difference could be determined which is again not due to biodegradation because distilled water is supposed to be rather less microbial active.

Further investigations are essential to get an opinion about the processes.

Table 43: Percentage of degradation and sorption processes at time point t4=72 h in comparison to the loss in the controls on the basis of the nominal initial concentration.

Substance	Soil/ water	loss in control (t_1) [%]	loss in control ($t_{eq}=t_4=72h$) [%]	Degrad. + Sorpt. ($t_{eq}=t_4=72h$) [%]	Degrad. + Sorpt. ($t_6=672$ h) [%]	loss in control ($t_6=672$ h) [%]
Trimethoprim	**W3/lake**	stable	stable	no degrad.	no degrad.	49
	W3/dest	stable	stable	70	93	17
	W2/lake	stable	stable	no degrad.	no degrad.	49
	W2/dest	stable	stable	71	84	17
Clindamycin	**W3/lake**	stable	stable	no degrad.	no degrad.	29
	W3/dest	stable	26	59	78	46
	W2/lake	stable	stable	67	74	29
	W2/dest	stable	26	68	92	46
Sulfa-methoxazole	**W3/lake**	41	58	88	87	58
	W3/dest	35	29	83	90	43
	W2/lake	41	58	no degrad.	90	58
	W2/dest	35	29	no degrad.	62	43
Dehydro-Erythromycin	**W3/lake**	stable	stable	no degrad.	no degrad.	20
	W3/dest	23	24	55	68	57
	W2/lake	stable	stable	70	84	20
	W2/dest	23	24	83	95	57
Clarithromycin	**W3/lake**	19	32	no degrad.	no degrad.	35
	W3/dest	21	20	no degrad.	no degrad.	60
	W2/lake	19	32	no degrad.	no degrad.	35
	W2/dest	21	20	no degrad.	no degrad.	60
Roxithromycin	**W3/lake**	33	45	no degrad.	no degrad.	39
	W3/dest	32	17	no degrad.	no degrad.	66
	W2/lake	33	45	no degrad.	no degrad.	39
	W2/dest	32	17	no degrad.	no degrad.	66

Table 44: Percentage of degradation and sorption processes at time point t4=72 hours in comparison to the loss in the controls on the basis of the nominal initial concentration.

Substance	Soil/ water	loss in control (t_1) [%]	loss in control (t_{eq}) [%]	Degrad. + Sorpt. (t_{eq}) [%]	Degrad. + Sorpt. (t_6=672 h) [%]	loss in control (t_6=672 h) [%]
Trimethoprim	**W3/lake/NaN3**	stable	stable	no degrad.	52	17
	W2/lake/NaN3	stable	stable	no degrad.	no degrad.	17
	W3glowed/NaN_3	stable	stable	no degrad.	no degrad.	stable
Clindamycin	**W3/lake/NaN3**	stable	19	no degrad.	48	17
	W2/lake/NaN3	stable	stable	no degrad.	72	17
	W3glowed/NaN_3	stable	49	57	76	stable
Sulfa-methoxazole	**W3/lake/NaN3**	stable	stable	no degrad.	no degrad.	stable
	W2/lake/NaN3	stable	stable	no degrad.	no degrad.	stable
	W3glowed/NaN_3	stable	stable	no degrad.	no degrad.	24
Dehydro-Erythromycin	**W3/lake/NaN3**	stable	stable	no degrad.	38	17
	W2/lake/NaN3	stable	stable	56	84	17
	W3glowed/NaN_3	stable	stable	no degrad.	no degrad.	stable
Clarithromycin	**W3/lake/NaN3**	17	31	no degrad.	95	29
	W2/lake/NaN3	17	31	no degrad.	no degrad.	29
	W3glowed/NaN_3	stable	stable	88	99	stable
Roxithromycin	**W3/lake/NaN3**	stable	stable	89	95	33
	W2/lake/NaN3	stable	stable	no degrad.	no degrad.	33
	W3glowed/NaN_3	stable	stable	no degrad.	98	stable

Conclusions

Six antibiotic substances, including the macrolides clarithromycin, roxithromycin and erythromycin (measured as metabolite dehydro-erythromycin), the sulfonamide sulfamethoxazole, the sulfonamide synergist trimethoprim and the lincosamide clindamycin, were batched to different soil-water systems of three sediments from Lake Wannsee ("aquifer mix" (W2) , "lake bottom" (W3) and "lake bottom" glowed) mixed with either lake water (Lake Wannsee) or distilled water.

With this investigation it is possible to get a general idea of the sorption behavior of the tested antibiotics on the Wannsee sediments. As far as possible, the distribution coefficient K_d was calculated. However, partly further investigations are recommended to confirm the results. The values of K_d decreased in the following order: clarithromycin > roxithromycin > trimethoprim > clindamycin > dehydro-erythromycin > sulfamethoxazole.

For roxithromycin and clarithromycin no mobility could be found out. The investigation showed a fast removal (> 97%) of the concentration of these two substances. They are strongly sorbed to both sediments, which is expressed with high K_d values (K_d 88 – 161 for W3, 288 – 666 for W2).

Trimethoprim and clindamycin showed a similar concentration decrease in both kinds of sediment, whereby the concentration of trimethoprim (<70-81%) was reduced somewhat better than of clindamycin (<59-68%). Their values of K_d range from <7.1 to 22.0 which means weak mobility relating to the aquifer mix and the lake bottom.

Dehydro-erythromycin was less adsorbed than the other antibiotics onto sediment W3 ("lake bottom") (K_d <3.4 – 4.2) and the difference in adsorption strength between the two sediments is higher as it is of trimethoprim and clindamycin (K_d <11.9 – 17.0 for W2).

Generally, the adsorption of all compounds, except from sulfamethoxazole, was faster and higher at the sediment W2 „aquifer mix".

Sulfamethoxazole shows great difference and opposite reaction than the rest of the tested substances relating to the two sediments. It was found to be strong mobile concerning the sediment "aquifer mix" of the Wannsee transect (K_d max. 0.1) whereas it is only weakly mobile in sediment from Wannsee lake bottom (K_d < 13.6 – 18.7). Since sorption behaviour is far more complex in comparison to the other tested antibiotics sulfamethoxazole should be first if further investigations are possible.

For the differences in reaction strength of the two sediments organic carbon content of the two sediments is not the decisive factor because "aquifer mix" contents less organic carbon but reacts stronger. Variability of K_d concerning different soils could not be reduced by relating K_d to the organic carbon content which could be caused by the lack of dependency of the sorption from the organic carbon content of the soil.

Whether the higher content of very fine grained material (<0.063 mm) within the aquifer mix (W2) is due to stronger adsorption reactions is hard to decide because both sediment contain less than 1% 0.

For trimethoprim, clindamycin, sulfamethoxazole and dehydro-erythromycin other processes than sorption were observed in addition but there is no opinion about the reason. Further investigations are essential. Biodegradation can not be excluded and can not be proved either. For some cases slow sorption processes seem to be predominant.

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2.5.2 Attenuation behavior of selected antibiotics in laboratory experiments at small retention columns

Several investigations described the occurrence of antibiotics in the aquatic environment and are comprehensively reported in an extended review (Heberer and Adam, 2005, [1]). In surface waters of Berlin observations in context of the NASRI- project showed five relevant antibiotics and two antibiotic derivates; trimethoprim, clindamycin, sulfamethoxazole, acetyl-sulfamethoxazole (a human metabolite of sulfamethoxazole), dehydro-erythromycin (a degradation product of erythromycin), clarithromycin and roxithromycin [2]. Except acetyl-sulfamethoxazole all of them are selected for further investigations. Under influent conditions induced by bank filtration or artificial groundwater recharge antibiotics infiltrate into the subsoil while undergoing a natural attenuation. But little is known about attenuation behavior of the selected antibiotics. Possible ecotoxic effects of such pharmaceutically active compounds (PhACs) or a possible link between the occurrence of antibiotics at subinhibitory concentrations and bacterial resistance in the environment supply additional motivation for investigations to understand and optimize attenuation by artificially induced infiltration processes. Laboratory experiments in small retention columns should supply more detailed information about attenuation behavior. Samples were preconcentrated via solid phase extraction (SPE) and quantified using HPLC- electrospray- tandem- mass spectrometry. Experiments were conducted in co- operation with working group Prof. Jekel (“organics“, Department of water quality control, TU- Berlin) and working group Prof. Pekdeger (hydrogeology, FU- Berlin) as part of the NASRI project.

2.5.2.1 Short columns (TU- columns)

Setup / carrying out

Setup and carrying out were generally set in advance by Steffen Grünheid (working group organics).

Three experiments (A, B & C) were conducted, each of them over a time period of 4 weeks. Effluent sampling took place within every fourth week. Influent samples were taken approximately one week before and directly after effluent sampling at the end of each experiment, respectively. Following illustration shows target influent concentrations of target compounds in experiments A, B and C. Three effluent sample collections were conducted for experiment A and two effluent sample collections for experiments B and C.

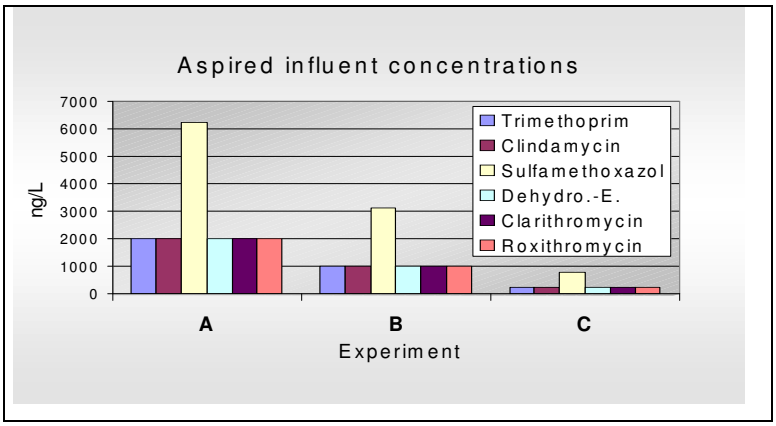

Figure 118: target influent concentration.

Aims

Influent concentrations of experiment A should guarantee measurable effluent concentrations. So in experiment concentrations were chosen ten to twenty times higher values than those which could be found in surface water (Bitte Verweis auf Brittas Teil einfügen). Furthermore influent concentrations in experiments B and C were reduced (factors 0.5 and 0.125 of stock solution from experiment A). All antibiotics were dissolved in purest water to avoid additional DOC. Evaluation should supply statements according to attenuation behavior of the selected antibiotics, for example about:

- Influence of free oxygen (oxic vs. anoxic conditions)
- Influence of denitrification (column No. 4, forced denitrification by NO3- addition in absence of free oxygen,)
- Effects of additional, easily degradable DOC (consequences of complete decrease of free oxygen and lack of other terminal electron acceptors with chemically bound oxygen like NO3- and so caused anaerobe conditions, see columns No.3 & No.6 and influence of the relatively short oxic redox zone at the beginning of column No.3)
- Influence of column length and column material (See column No.5 and comparison of columns No. 1 vs. No.7 vs. No.8)
- Effects of influent concentration level C0, (Comparison of experiments A, B & C)
- Differences and common features between attenuation behaviors of the selected antibiotics etc.

Results and discussion

Laboratory experiments with antibiotics started in September 2004 and operated until December 2004. Discovered influent and effluent concentrations with statistical deviation maximum are presented in appendix (Table 1-3). The data basis with mean concentrations is presented in the table below.

Table 45: Mean concentrations at sampling period

Experiment A (mean values for time period [ng/L])										
Date (time period)	18.09.-21.10.04	11.-15.10.04			18.09.-21.10.04	11.-15.10.04				
Measuring point	Anoxic influent	Effluent col. No.			Oxic influent	Effluent col. No.				
		5	4	6		3	1	7	8	0
Trimethoprim	2890	170	2030	680	2700*	250	30	1	1	830
Clindamycin	1810	1	110	1340	2300*	120	14	65	1	310
Sulfamethoxazole	6530	360	6180	2320	7100*	1610	90	55	376	2840
Dehydro-erythromycin	2030	3	110	2040	2800*	4	4	23	1	510
Clarithromycin	2120	40	70	1280	2400*	70	100	13	6	1040
Roxithromycin	1940	40	500	1410	2200*	20	40	12	2	220
Experiment B (mean values for time period [ng/L])										
Date (time period)	21.10.-22.11.04	15.-21.11.04			21.10.-22.11.04	15.-21.11.04				
Measuring point	Anoxic influent	Effluent col. No.			Oxic influent	Effluent col. No.				
		5	4	6		3	1	7	8	0
Trimethoprim	1320	670	780	400	1650	340	13	0	1	460
Clindamycin	840	23	90	860	1280	140	20	61	2	300
Sulfamethoxazole	3300	194	2500	900	4200	850	390	70	210	1040
Dehydro-erythromycin	1020	7	100	1020	1530	8	3	15	5	380
Clarithromycin	1000	14	1050	870	1380	5	5	8	1	270
Roxithromycin	900	33	940	860	1150	130	13	8	3	270
Experiment C (mean values for time period [ng/L])										
Date (time period)	22.11.-20.12.04	13.-19.12.04			22.11.-20.12.04	13.-19.12.04				
Measuring point	Anoxic influent	Effluent col. No.			Oxic influent	Effluent col. No.				
		5	4	6		3	1	7	8	0
Trimethoprim	280	470	260	260	260	130	1100	0	50	340
Clindamycin	240	13	28	450	250	50	180	60	12	180
Sulfamethoxazole	850	100	290	320	710	120	50	50	180	960
Dehydro-erythromycin	300	6	22	400	320	6	14	14	8	310
Clarithromycin	220	8	770	610	240	6	4	6	3	230
Roxithromycin	240	30	760	560	260	250	9	7	3	200

*calculated

$$c(A_{oxic}) = \frac{\{2 \times c(\exp erimentB) + 8 \times c(\exp erimentC)\}}{2}$$

In experiment C, where the influent concentrations were reduced in relation to experiment B again by the factor 0.25, some antibiotics showed higher effluent concentrations than the

influent concentrations of experiment C at the columns No. 5, 4, 6, 1 and 0 (see Table 45) now. That can be explained by a desorption that occurs now from the earlier experiments A and B with higher influent concentrations. So sorption of trimethoprim, dehydro-, clarithro- and roxithromycin could be recognized as a reversible process. With hindsight it would have been more favorable to begin with the smallest influent concentration (experiment C) followed from B and A.

Observed antibiotic concentrations in effluent samples showed partly a time dependent concentration course (see appendix) which makes interpretation surprisingly more difficult and reduces the meaning of data. Effluent concentrations of some antibiotics increased at several columns from the first sampling collection until the third sampling collection within experiment A. Affected substances and columns are listed in Table 46. The other measured concentrations showed constant values.

Table 46: Substances without constant effluent concentrations (exp. A)

Substance	Effluent column No.
Trimethoprim	5, 6, 3, 0
Dehydro-erythromycin	4, 0
Clarithromycin	4, 3, 0
Roxithromycin	4, 0

Possible reasons:
Increasing effluent concentrations indicate larger retention times and extended dispersions. So maximum concentration levels were not achieved for the cases mentioned above at sampling time. Therefore it could be concluded that the three weeks before effluent sampling were not sufficient and did not yielded equilibrium. But this explanation is assumed as not very likely, because of tracer experiment of the project partner showed a 6d (12d column No.5) retention time for the mobile phase [Bitte Querverweis Steffen einfügen]. According to this, after 21 days antibiotics should be appeared in effluent with concentration maximum and other reasons like desorption processes could be possible explanations for increasing values.

On the other site variations could be caused by antibiotic and column dependent lack of adsorption capacity with the consequence that several antibiotics (which are added continuously) reached the column effluents attenuated within the three weeks before effluent sampling, but already covered adsorption places disabled an equal adsorption of new infiltrating antibiotics and could cause the increasing concentrations. So equilibrium was not achieved for the cases mentioned above.

Antibiotics with strong sorption properties are concerned. Observations in batch experiments showed strong sorption for clarithromycin and roxithromycin (B.Fritz: Bitte Querverweis auf Batchteil einfügen).

Nevertheless to compare and evaluate the attenuation behavior of selected antibiotics during sampling period, the ratio C(mean)/C0 of experiment A and B were calculated, to show the attenuation behavior as a trend of attenuation at several redox conditions. Figure 119 demonstrated this exemplary for sulfamethoxazole. Data of experiment C could not analyzed this way, because concentrations of experiment C interfered with desorption of antibiotics which were immobilized in previous experiments A and B at higher C0 levels.

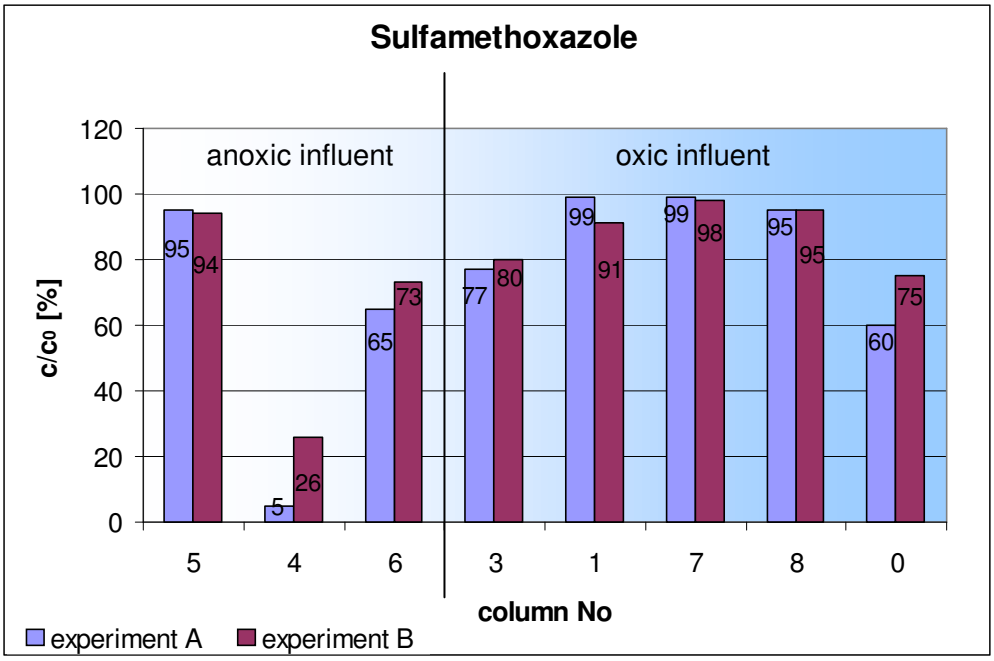

Figure 119: Sulfamethoxazole experiment A and B.

Sulfamethoxazole showed most effective attenuation under oxic conditions (see Figure 119). In this connection different column materials (technical sand [column No. 1] vs. bank material [column No. 7] vs. aquifer [column No. 8]) did not yield different attenuation performances. Column No. 5 showed with double soil passage under anoxic conditions comparably good attenuation like the columns with oxic influent and an oxic zoning.

In experiment A the effluent of column No. 4 shows a nearly complete break-through (c/c0≈95% → approx. 6200ng/L)) for sulfamethoxazole. In experiment B (influent concentration 1/2 of A) and in experiment C (influent concentration 1/8 of A, data here not shown) the attenuation capacity improves from a break-through of c/c0≈74% (approx. 2500ng/L) up to c/c0≈35% (approx. 300ng/L), respectively. Thus under denitrificated conditions a dependence on the influent concentration (within this range) of sulfamethoxazole becomes clearly. The relative decrease capacity improves with smaller becoming inlet concentration.

Detailed explanations for the other investigated antibiotics are given elsewhere [3]. Conclusions are listed in table 4 and in the summary.

Results overview

Table 47 shows a result overview. All investigated antibiotics showed most effective attenuation under oxic conditions. Different column materials (technical sand vs. bank material vs. aquifer) did not yield different attenuation performances under oxic conditions after 1m soil passage. The double soil passage under anoxic conditions resulted in a comparably good attenuation, trimethoprim excluded.

During observed removal by sorption always a reversible adsorption and not an irreversible absorption was assumed. That could be concluded, if in the subsequent experiments B and C (with halved and/or eight-divided inlet concentrations) in relation to experiment A worse depletion capacity were obtained and/or effluent concentration in experiment C were larger than the influent concentration of the experiment C. Due to the smaller inlet concentration here a desorption could occurred from in the preceding experiments with higher influent concentrations by adsorption immobilized antibiotics, which not became depleted yet by other mechanisms like e.g. biodegradation at the solid surface.

For sulfamethoxazole an improvement of the relative depletion capacity could be determined under anoxic conditions (column Nr.4, nitrate respiration) as only of the examined substances, if the inlet concentration is reduced. That applies to the investigated concentration range of approx. 7000-800ng/L. Clindamycin and dehydro-erythromycin were under these conditions almost completely attenuated.

Since with trimethoprim and sulfamethoxazole the depletion capacity under anoxic/anaerobic conditions was reduced and/or with starch addition in relation to oxic soil passages only weakly, it was further concluded that oxygen does not possess the prior role as terminal electron acceptor for the portion, which became biodegraded. Fermentation and anaerobic respiration as well as cometabolic degradation are considered equally by biodegradation.

In contrast to it oxygen has with the three examined macrolides (Dehydro -, clarithro and roxithromycin) as well as with the lincosamide, clindamycin, a greater importance for biodegradation than anaerobic respiration or fermentation. The anaerobic soil passage in column No.6 don’t effect a good decrease capacity particularly for these substances. However, an addition of starch with oxic influent leads only to an insignificant until no decrease of the depletion achievement with the macrolides.

Table 47: Results / conclusions over view (TU- column experiments)

TU- column, L = 1m bzw. 2m Ø=14cm, Q≈0,8L/d T=(15± 4)°C	Relative attenuation performance			Contribution to attenuation		Other influence factors to relative attenuation behavior	
	oxic	anoxic	anaerob	microbial	sorption	negative effects	C_0
trimethoprim	++	-	+	+	++ (reversible)	e. d. surplus DOC, monotonous, strong denitrification	No effect observed
clindamycin	++	++ (NO_3^-,col. 4)	-	++	- (reversible)	e. d. surplus DOC, (with anoxic influent)	No effect observed
sulfamethoxazole	++	+	+	++	-	e. d. surplus DOC, monotonous, strong denitrification	$A_A<A_B<A_C$ (anoxic)
dehydroerythromycin	++	++ (NO_3^-,col. 4)	-	++	- (reversible)	e. d. surplus DOC, (with anoxic influent)	No effect observed
clarithromycin	++	+	-	+	+ (reversible)	e. d. surplus DOC, (with anoxic influent)	No effect observed
roxithromycin	++	+	-	+	+ (reversible)	e. d. surplus DOC, (with anoxic influent)	No effect observed

\- no remarkable contribution
\+ good (or after double soil passage comparably good as under oxic conditions)
++ very good / very great
e. d. surplus DOC: easily degradable surplus DOC (simulated with 3mg/L starch)
C_0: Influent concentration
A_A: relative attenuation performance experiment A

oxic: free dissolved O_2 present
anoxic: no free dissolved O_2 present, but only chemical bound oxygen (for example NO_3^-)
anaerobe: no free and no chemical bound oxygen
present (Sequence of redox zones were determined by the project partner [3])

Weak or no sorption contribution was concluded, if in any column effluent of experiment (A) a nearly complete breakthrough could be observed. That could be observed with dehydro-erythromycin and sulfamethoxazole.

2.5.2.2 Clogging column

Setup / carrying out

Following graphic illustrates the column system. Extended descriptions are given by the project partner (working group hydrogeology) (B.Fritz: Bitte Querverweis auf Hydrogeologenteil einfügen) and elsewhere [3]. Influent concentration level were similar to

those values, which could be found in surface water (150ng/L to 400ng/L).Three sampling collections were conducted.

Results and discussion

Laboratory experiments with antibiotics started in February 2005 and were carried out until March 2005. Discovered influent and effluent concentrations with statistical deviation maximum are presented in appendix (Table 4).

To achieve a better comparison of attenuation performances for the individual antibiotics with given redox conditions, measuring point concentrations of the three experiments A, B and C were standardized and averaged. These values are illustrated in the following Table 48 and Figure 120.

Table 48: standardized and averaged data

Results: mean values C/C0 of the 3 experiments A,B,C

measuring point	remark	Trimetho.	Clinda.	Sulfa.	Dehydro-E.	Clarithro.	Roxithro.	depth [cm]
WS 2C1	influent	1	1	1	1	1	1	0
WS 2C2	tap1	0,27	0,88	0,79	0,88	0,88	0,83	2
WS 2C3	tap2	0,12	0,86	0,94	0,77	0,79	0,81	8
WS 2C4	tap3	0,11	0,80	1,01	0,73	0,17	0,39	12
WS 2C5	tap4	0,08	0,47	0,89	0,19	0,01	0,02	25
WS 2C6	tap5	0,01	0,26	0,86	0,10	0,01	0,01	50
WS 2C7	tap6	0,00	0,08	0,78	0,06	0,01	0,01	80
WS 2C8	tap7	0,01	0,08	0,92	0,06	0,01	0,01	90
WS 2C9	effluent	0,00	0,06	0,64	0,04	0,00	0,02	100

remark.: C/C0;

C:= concentration at measuring point

C0:= influent concentration (mean of both values, before and after sample collection for each experiment)

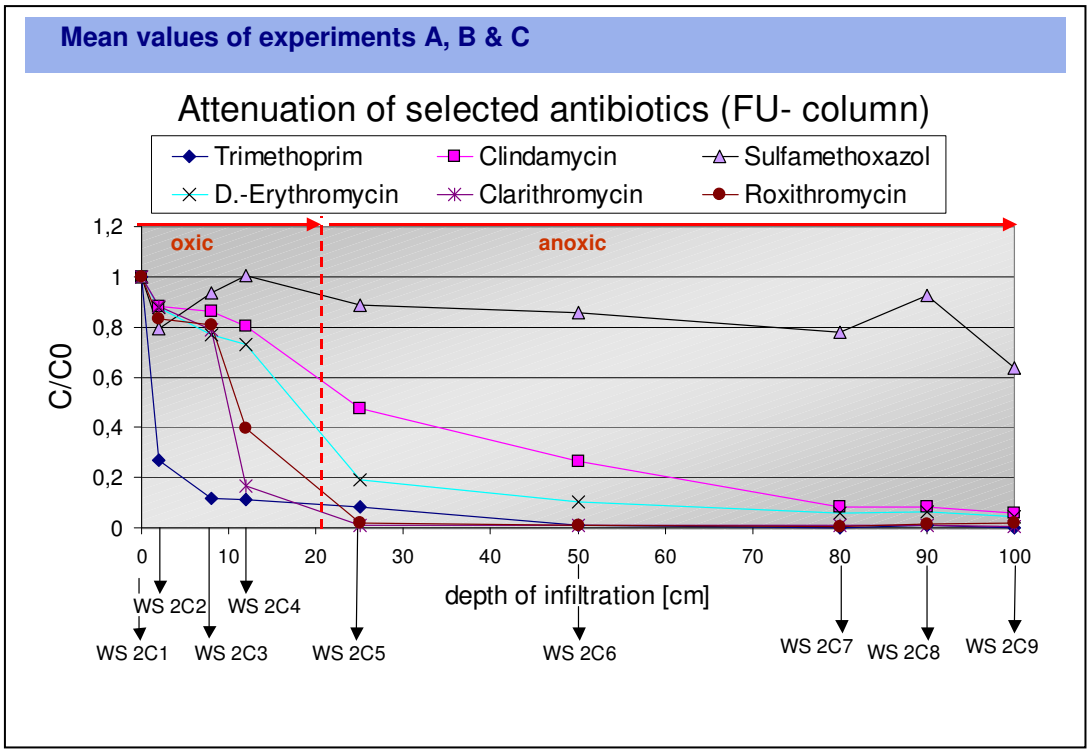

Figure 120: Results C/C0, FU- column

Trimethoprim, dehydro-erythro -, clarithro -, roxithro- and clindamycin were almost completely attenuated after 80cm soil passage. Alone sulfamethoxazole was not effectively held back or attenuated in contrast to the other examined antibiotics during the passage through the 1m sediment column, and the weak concentration reduction after column passage in experiment A could not be confirmed as significant reduction in the two repetition measurements (experiment B and C).

A complete reduction of free oxygen within the first 21cm of sediment could be observed, caused by oxidation of background DOC. Similarly to it strongest reduction of antibiotic concentrations was measured there, sulfamethoxazole excluded. This both is a sign of a biodegradation beside sorption. However, sorption can be made mainly responsible for the attenuation of trimethoprim. The observations showed also a good attenuation of clindamycin under anoxic conditions, which runs off somewhat faster under oxic conditions.

Detailed explanations for the other investigated antibiotics are given elsewhere [3]. Conclusions are listed in Table 49 and in the summary.

Table 49: Results / conclusions over view (FU- column experiments)

FU- column, L = 1m Ø=7cm, Q≈0,8L/d T=(20±3)°C	Relative attenuation performance		Contribution to attenuation	
	oxic	anoxic	microbial	sorption
trimethoprim	++	?	-	++
clindamycin	+	+	+	-
sulfamethoxazole	-	-	? / -	-
dehydroerythromycin	+	-	+	-
clarithromycin	+	?	+	? / -
roxithromycin	+	?	+	? / -

? not differentiable
- no remarkable contribution
+ good / great
++ very good / very great

oxic: free dissolved O_2 present
anoxic: no free dissolved O_2, but only chemical bound oxygen (for example NO_3^-)

A general difference of the two column systems exists in the quadruple higher flow rate per unit cross section of the FU- column opposite to the TU- columns with otherwise comparable column conditions such as pH value, temperature, length of the soil passage, the sediment as well as infiltrating surface water. Thus the ineffective attenuation of sulfamethoxazole at the FU- column in relation to the good attenuation at the TU- columns after one meter soil passage can be explained. These observations showed also as trend, that like already assumed, those oxic and anoxic attenuation performances with larger flow rates become smaller, because less time remains at the disposal for sorption processes and other reduction mechanisms.
Beyond that, the conclusions of both column experiments agree well and are confirmed mutually and supplementing.

Sulfamethoxazole

- Showed (with distance) highest mobility of all investigated antibiotics.
- Sorption supplied no remarkable contribution to attenuation (also confirmed in batch experiments for aquifer material (B.Fritz: Bitte Querverweis auf Batchteil einfügen)).

- No significant attenuation after 1m soil passage with a flow rate of approx. 20(mL/d cm2).
- Nearly complete attenuation after 1m soil passage with a flow rate of approx. 5(mL/d cm2), microbial processes could effect attenuation under several conditions (under oxic and double anoxic soil passage without additional DOC).
- Nearly complete breakthrough under anoxic conditions with forced denitrification (TU-column No.4) but attenuation dependent on influent concentration (C0); relative attenuation performance became larger with smaller becoming influent concentration: from approx. 5% in experiment A to approx. 65% in experiment C (investigated concentration range: C0: 7000-800ng/L).
- Negative effects: easily degradable, surplus DOC (simulated with 3mg/L starch, 20-30% breakthrough, TU- columns No.3 & 6) and monotonous, strong denitrification conditions reduced attenuation performance and yielded no complete retardation.

Trimethoprim

- Complete attenuation under oxic conditions (at both flow rates).
- Largest concentration reduction took place within the first 2cm (FU- column) with an relative attenuation of approx. 70%.
- Thus sorption could be found as main attenuation mechanism, which could be recognized as a reversible process in TU- experiments.
- Worse attenuation under anoxic / anaerobe conditions, especially under monotonous, strong denitrification conditions (breakthrough up to 70%, TU- column No.4).
- Lower attenuation in presence of easily degradable DOC (3mg/L starch),(approx. 10-30% breakthrough after 1m, TU- column No.3 & No.6).

Dehydro-erythro-, Clarithro-, Roxithro- und Clindamycin

- Nearly complete attenuation under oxic and double anoxic soil passage.
- There are serious indications for a microbial degradation as main attenuation mechanism (beside sorption for roxithromycin and clarithromycin).
- Sorption could be recognized as a reversible process.
- Clarithromycin und roxithromycin showed analogous patterns of behavior, explainable by the similar chemical structure and attenuation mechanisms (sorption + biodegradation) were relatively stronger than those of dehydro- and clindamycin, because attenuation became slower with increasing depth of infiltration than for clarithro- and roxithromycin, see FU- column (batch- experiments confirming these

conclusions, which showed stronger sorption for clarithro- and roxithromycin (See Chapter 2.5).

- Under oxic conditions intensity of relative attenuation performances of these four antibiotics can be reported in following sequence: clindamycin < dehydroerythromycin < roxithromycin ≤ clarithromycin, (see FU- experiment).
- Dehydro-erythromycin and clindamycin were also good attenuated under denitrification conditions, but observations for roxithromycin and clarithromycin are not allowing this statement; both antibiotics were almost effective aerobe attenuated, before nitrate respiration could begin (FU- column), and in TU- column No. 4 (experiment B & C) relative attenuation performances were interfered by desorption or data were invalid because of larger retention times and early sampling collections
- Negative effects to attenuation performances: easily degradable DOC (3mg/L starch) in combination with anoxic influent, so no satisfactory attenuation could be observed at TU- column No.6. (but in combination with oxic influent attenuation was good and was not significantly influenced).
- Aerobe microbial oxidation of back ground DOC included these four antibiotics (metabolic and / or co- metabolic) and yielded most effective attenuation within the first 21cm of sediment (oxygen reduction zone, FU- column) (behavior of the three macrolides and clindamycin at the TU- columns No.3 & 6 confirming these conclusions).
- So the three macrolides; dehydro-erythro-, clarithro- and roxithromycin as well as the lincosamide, clindamycin, showed attenuation patterns which situated between the both „extreme“ patterns of sulfamethoxazole and trimethoprim (sulfamethoxazole with no remarkable sorption and no significant attenuation by microbial processes within FU- column passage and trimethoprim with strongest sorption, (70% attenuation within the first 2cm FU- column passage).

2.5.2.3 References

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Table 1: TU- columns, experiment A

	meas.	Trimethoprim			Clindamycin			Sulfamethoxazole			Dehydroerythromycin			Clarithromycin			Roxithromycin			%int.deviation.		remark
date	point	conc.	△x		conc.	△ x		conc.	△ x		conc.	△ x		conc.	△x		conc.	△x		Sulfame-	Fenuron-	
2004	column nr.	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	thizol	D6	
18.-19.10.	influent (oxic)	51	6	12	167	28	17	351	80	23	155	26	17	163	32	20	127	20	16	3	4	without spiking
11.-12.10.	8	n.n.	-	-	1	0	0	326	53	16	n.n.	-	-	n.n.	-	-	1	0	0	1	0	
14.-15.10.	8	2	0	0	1	0	0	425	108	25	1	0	0	11	1	9	3	0	0	1	2	
11.-12.10.	7	n.n.	-	-	74	16	22	57	8	14	25	1	4	9	1	11	13	1	8	4	1	
12.-13.10.	7	n.n.	-	-	58	7	12	54	6	11	23	3	13	7	1	14	10	1	10	2	2	
14.-15.10.	7	3	0	0	62	13	21	53	9	17	20	1	5	24	2	8	12	1	8	2	1	
11.-12.10.	1	6	0	0	11	2	18	93	14	15	n.n.	-	-	6	1	17	15	1	7	3	0	
12.-13.10.	1	11	1	9	14	2	14	75	8	11	8	1	13	11	2	18	22	2	9	1	1	
14.-15.10.	1	74	4	5	16	3	19	114	20	18	3	0	0	288	33	11	81	7	9	7	2	
11.-12.10.	3	166	10	6	110	9	8	1606	171	11	n.n.	-	-	8	1	13	10	1	10	7	8	
12.-13.10.	3	212	21	10	118	15	13	995	169	17	6	1	17	9	1	11	13	1	8	4	6	
14.-15.10.	3	372	23	6	132	30	23	2228	703	32	7	0	0	180	19	11	30	2	7	4	1	
11.-12.10.	0	380	24	6	258	23	9	3046	371	12	377	35	9	4	1	25	6	0	0	7	3	
14.-15.10.	0	1286	95	7	366	33	9	2634	309	12	651	65	10	2072	361	17	439	39	9	10	9	
18.-19.10	influent(anox)	2	1	50	46	17	37	237	122	51	83	10	12	35	7	20	26	5	19	1	1	without spiking
18.-19.10	influent(anox)	9	2	22	53	19	36	284	162	57	93	11	12	51	10	20	40	7	18	19	2	without spiking
18.-19.10	influent(anox)	9	2	22	55	20	36	322	198	61	101	12	12	52	10	19	45	8	18	7	4	repetiton
05.-06.10.	influent(anox)	2866	267	9	1814	231	13	6527	1037	16	2034	276	14	2116	372	18	1940	239	12	4	2	
11.-12.10.	5	n.n.	-	-	n.n.	-	-	373	49	13	1	1	100	7	1	14	31	3	10	3	0	
12.-13.10.	5	45	4	9	n.n.	-	-	361	47	13	3	1	33	8	1	13	32	3	9	5	1	
14.-15.10.	5	458	37	8	4	1	25	333	42	13	4	1	25	96	12	13	49	5	10	7	1	
11.-12.10.	4	1993	165	8	101	9	9	6328	992	16	77	7	9	23	3	13	239	20	8	4	0	
12.-13.10.	4	1974	163	8	106	9	8	5847	887	15	103	9	9	23	3	13	436	39	9	3	3	
14.-15.10.	4	2131	180	8	123	11	9	6365	1001	16	144	13	9	167	18	11	819	80	10	7	1	
11.-12.10.	6	474	31	7	1115	123	11	2620	348	13	1920	253	13	1096	154	14	1201	128	11	6	4	
					1231	139	11	2105	262	12	1957	260	13	1218	176	14	1466	165	11	13	3	
					1279	146	11	2219	281	13	2170	299	14	1203	174	14	1490	169	11	6	0	repetiton
14.-15.10.	6	939	66	7	1630	201	12	2111	263	12	2019	271	13	1551	243	16	1545	177	11	7	0	

Δ x := statistical deviation maximum

Table 2: TU- columns, experiment B, discovered concentrations

	meas.	Trimethoprim			Clindamycin			Sulfamethoxazole			Dehydroerythromycin			Clarithromycin			Roxithromycin			%int.deviation		remark
date	point	conc.	△x		conc.	△ x		conc.	△ x		conc.	△ x		conc.	△x		conc.	△ x		Sulfame-	Fenuron-	
2004	column nr.	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	thizol	D6	
07.-08.12.	influent (oxic)	241	33	14	243	43	18	662	109	16	295	57	19	223	47	21	259	45	17	1	2	
19.-20.12.	influent (oxic)	282	39	14	259	47	18	761	131	17	344	69	20	260	57	22	266	47	18	5	3	
13.-16.12.	3	122	34	28	49	15	31	125	28	22	8	2	25	5	2	40	220	81	37	3	2	
16.-19.12	3	129	36	28	45	13	29	113	25	22	4	1	25	6	2	33	272	107	39	4	2	
13.-16.12.	1	1094	572	52	207	78	38	43	14	33	16	4	25	4	1	25	9	2	22	4	2	
13.-16.12.	1	1241	377	30	170	36	21	59	12	20	13	2	15	4	1	25	8	1	13	2	1	RP
16.-19.12	1	1008	162	16	170	24	14	37	5	14	13	2	15	4	1	25	9	1	11	3	0	
16.-19.12	1	1058	297		167	36		36	7		12	2		4	1		10	2		4	3	RP
13.-16.12.	7	n.n.	-	-	64	20	31	48	15	31	18	5	28	5	1	20	6	2	33	3	0	
16.-19.12	7	n.n.	-	-	56	17	30	47	15	32	10	3	30	6	2	33	8	2	25	4	1	
13.-16.12.	8	98	27	28	23	6	26	173	68	39	12	3	25	2	1	50	2	1	50	3	3	
16.-19.12	8	3	1	33	0	-	-	180	72	40	3	1	33	3	1	33	3	1	33	4	2	
13.-16.12.	0	342	49	14	202	35	17	1022	197	19	346	68	20	263	58	22	210	35	17	2	2	
16.-19.12	0	333	47		152	25		894	163		279	52		200	41		191	31		2	1	
07.-08.12.	influent(anox)	264	36	14	228	40	18	839	149	18	292	56	19	193	39	20	235	40	17	1	1	
19.-20.12.	influent(anox)	289	40	14	244	44	18	859	154	18	298	57	19	236	51	22	247	43	17	4	2	
13.-16.12.	5	466	170	36	12	3	25	106	38	36	11	3	27	8	2	25	34	10	29	5	2	
13.-16.12.	5	443	90	20	14	2	14	109	24	22	4	1	25	7	1	14	28	5	18	2	2	RP
16.-19.12	5	468	96	21	13	2	15	84	18	21	5	1	20	9	2	22	38	7	18	7	3	
16.-19.12	5	489	63	13	12	2	17	91	14	15	4	1	25	8	1	13	26	3	12	9	3	RP
13.-16.12.	4	289	27	9	30	3	10	288	39	14	24	3	13	733	154	21	774	125	16	7	0	
16.-19.12	4	220	20	9	25	3	12	308	42	14	16	2	13	800	174	22	749	120	16	4	1	
13.-16.12.	6	278	38	14	460	99	22	307	47	15	425	90	21	716	233	33	612	141	23	5	0	
13.-16.12.	6	294	27	9	472	68	14	353	49	14	431	61	14	572	110	19	602	89	15	2	2	RP
16.-19.12	6	217	19	9	415	58	14	297	40	13	347	47	14	533	100	19	474	66	14	2	1	

Δ x := statistical deviation maximum

Table 4: FU- column, discovered concentrations

	meas.	Trimethoprim			Clindamycin			Sulfamethoxazole			Dehydroerythromycin			Clarithromycin			Roxithromycin			%int.deviation.		remark
date	point	conc.	△x		conc.	△ x		conc.	△ x		conc.	△ x		conc.	△x		conc.	△ x		Sulfame-	Fenuron-	
2004	column nr.	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	ng/L	ng/L	%	thizol	D6	
09.-10.11.	influent (oxic)	1955	228	12	1581	271	17	5292	1088	21	1753	323	18	1682	386	23	1358	206	15	0	2	
09.-10.11.	influent (oxic)	1800	204	11	1397	226	16	4433	830	19	1712	310	18	1488	324	22	1260	185	15	1	0	RP
21.-22.11.	influent (oxic)	1183	115	10	862	117	14	2924	453	15	1135	175	15	982	177	18	845	108	13	1	1	
15.-18.11.	1	14	1	7	20	4	20	77	16	21	3	0	0	3	1	33	15	2	13	7	0	
18.-21.11.	1	11	1	9	20	5	25	704	358	51	2	0	0	6	1	17	11	2	18	4	1	
15.-18.11.	3	375	35	9	149	45	30	1381	503	36	6	1	17	2	1	50	128	16	13	2	0	
18.-21.11.	3	310	28	9	132	38	29	327	64	20	9	1	11	8	2	25	134	19	14	5	2	
15.-18.11.	7	n.n.	-	-	65	16	25	70	14	20	16	1	6	8	1	13	16	2	13	6	3	
18.-21.11.	7	n.n.	-	-	56	14	25	69	14	20	14	1	7	7	1	14	n.n.	-	-	3	2	
15.-18.11.	8	n.n.	-	-	2	0	0	213	58	27	8	1	13	n.n.	0	-	5	1	20	1	1	
18.-21.11.	8	2	0	0	1	0	0	203	55	27	1	0	0	1	1	100	n.n.	-	-	3	0	
15.-18.11.	0	476	38	8	326	35	11	1066	123	12	390	46	12	278	38	14	289	30	10	0	1	
18.-21.11.	0	437	34	8	278	30	11	1003	114	11	374	42	11	254	35	14	248	28	11	2	2	
09.-10.11.	influent(anox)	1392	142	10	837	112	13	3562	601	17	1074	162	15	1111	210	19	952	126	13	1	1	
21.-22.11.	influent(anox)	1248	123	10	849	114	13	3109	494	16	963	139	14	872	151	17	842	107	13	0	1	
15.-18.11.	5	650	73	11	23	5	22	193	51	26	5	1	20	12	2	17	35	4	11	1	3	
18.-21.11.	5	680	77	11	23	5	22	195	52	27	8	0	0	16	2	13	30	4	13	1	2	
15.-18.11.	4	641	54	8	67	6	9	2304	327	14	66	8	12	1149	223	19	1048	144	14	3	2	
18.-21.11.	4	927	84	9	113	11	10	2666	399	15	131	13	10	944	171	18	827	109	13	8	2	
15.-1					8	109	13	858	106	12	1015	149	15	904	161	18	970	130	13	5	5	
18.-2					3	122	14	950	120	13	1028	149	14	832	144	17	750	96	13	3	2	

Δ x := statistical deviation maximum

2.6 Overall conclusions

Purified effluents discharged by the municipal STPs were identified as the main sources for the occurrence of antibiotic residues in Berlin's surface waters. These residues discharged into the receiving waters such as the Teltowkanal or the Nordgraben are also reaching areas such as lake Wannsee or lake Tegel which are used as resources for groundwater recharge. Five compounds, the sulfonamide sulfamethoxazole, the sulfonamide synergist trimethoprim, the macrolides clarithromycin and roxithromycin, and the lincosamide clindamycin were detected in surface water from these lakes and in several cases also in the monitoring wells from the transects. Additionally, dehydro-erythromycin, the metabolite of the macrolide erythromycin and acetyl-sulfamethoxazole, the main human metabolite of sulfamethoxazole, were found. Surprisingly, the sulfonamide sulfadimidine was observed at low concentrations in some of the deeper wells. This observation was explained by the use of large quantities of sulfadimidine in the past, when it was used as a growth promotor in livestock farms north of Berlin.

With one exception, antibiotic residues are not found in the water-supply wells. Sulfamethoxazole was the only compound that could be detected at trace-levels in samples collected from monitoring and water-supply wells. Most of the other compounds are readily attenuated close to the bank where the surface water is infiltrated. Thus, most of the compounds are not or only found at trace levels in the first two monitoring wells located close to the bank. For sulfamethoxazole and dehydro-erythromycin it was assumed that an improved degradation occurs under reduced conditions, whereas compounds such as clindamycin are preferably degraded under oxic conditions.

The low quantities of sulfamethoxazole that have been detected in the raw water used for drinking water purification are, however, way too low to cause any toxic effects in humans. In general, bank filtration has proven as being an efficient method for the removal of antibiotic residues by natural attenuation and as a useful tool for the pre-treatment of surface water under the influence of sewage effluents for drinking-water supply.

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