Antibiotic Fate and Transport in Three Effluent Dominated Streams

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Introduction

- Antibiotics enter aquatic systems through direct input from municipal wastewater treatment plant (WWTP) and agricultural effluent discharges, as well as surface runoff from some sources.
- Sewage particulate matter can serve as a mode of transportation for antibiotics in the effluent discharge.
- Particulate matter is often retained in the streambed or benthic biofilm within several kilometers downstream from the effluent discharge.
- Antibiotics in effluent discharges that decay slowly and/or adsorb less readily to soil and sediments are more likely to be transported further downstream.

Methods

- Water column and bed material samples were collected at three effluent dominated streams, Mud Creek, Spring Creek, and Decatur Branch, in northwest Arkansas during August and September 2006.
- Water samples were collected at one site upstream of the influence of the WWTP and at four sites downstream from the effluent discharge at each stream and analyzed for five classes of antibiotics (beta-lactams, macrolides, quinolones, sulfonamides and tetracyclines).
- The solute spiraling concept provided methodology to evaluate the transformation and retention of solutes within a stream.
- Bed material samples were collected from various sites downstream of the effluent discharge at each stream reach and analyzed for the same classes as the water samples.

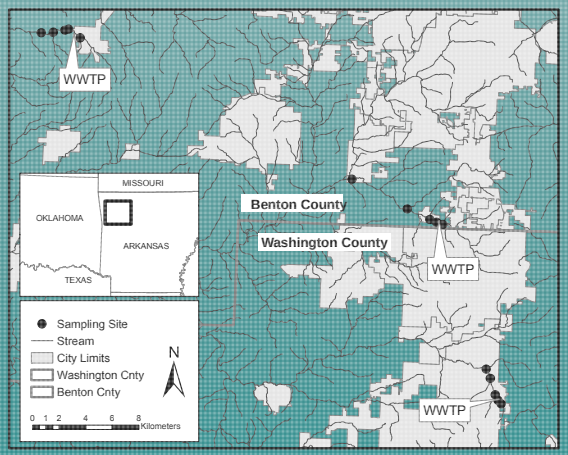


Figure depicting selected sampling sites on Mud Creek, Spring Creek and Decatur Branch in the Ozarks of northwest Arkansas.

Objectives

- We evaluated the transport of antibiotics and associated degradation products through a stream reach downstream from three WWTP effluent discharges by estimating:
  - net uptake length (S_{net}) $[C_x=C_o e^{kx};\ S_{net}=-1/k]$
  - net mass transfer coefficient ($v_{f\text{-}net}$) $[V_{f\text{-}net}=h\cdot u/S_{net}=Q/(S_{net}\cdot w)]$
  - net uptake rate (U_{net}) $[U_{net}=(C_o\cdot Q)/(S_{net}\cdot w)=v_{f\text{-}net}\cdot C_o]$
- We evaluated the partitioning of antibiotics and degradation products between the water column and bed material (i.e. benthic sediment).

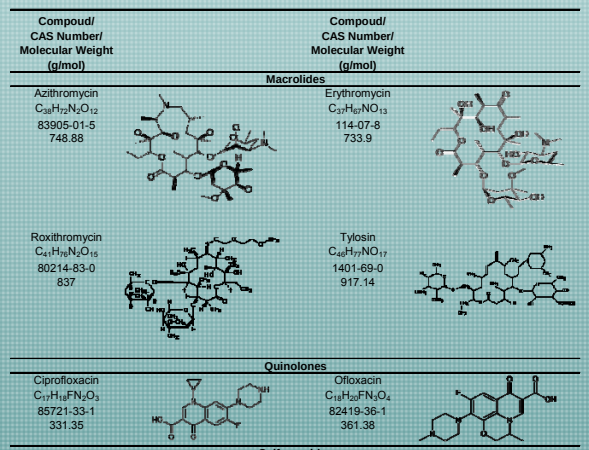


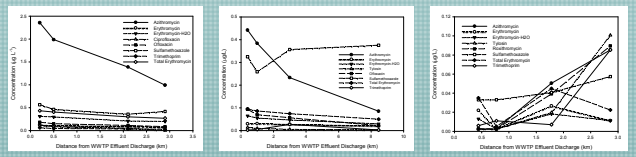
Figure of specifications and structures of antibiotics detected in the water column at some sites (above).

Spring Creek (upper left), Decatur Branch (lower left), and Mud Creek (right) reaches.

Results

- Antibiotics and associated degradation products within the classes macrolides, quinolones, and sulfonamides were detected in the water column at all three stream reaches.
- Some antibiotics and degradation products were significantly retained at Mud Creek and Spring Creek; some antibiotics and degradation products were significantly released at Decatur Branch.
- The same classes of antibiotics detected in the water column, as well as the class tetracyclines, were detected in the bed material at all three stream reaches.
- Antibiotic and degradation product contents in the bed material were significantly greater than the concentrations in the water column.

Figures depicting measured antibiotic and degradation product concentrations throughout the Mud Creek Stream Reach (left), and dilution corrected antibiotic and degradation product concentrations throughout the Spring Creek (center) and Decatur Branch (right) reaches. Dilution was not significant at Mud Creek.



Tables indicating P-value, S_{net}, $v\text{-}f_{net}$, and U_{net} of antibiotics and degradation products detected within the Mud Creek (left), Spring Creek (center) and Decatur Branch (right) reaches. NS = not significant.

Antibiotic or Degradation product*	P-value	Sw-net (km)	vf-net (10^{-4} m s^{-1})	Unet (10^{-4} µg m^{-2} s^{-1})
Azithromycin	0.010	3.4	16.3	38.4
Erythromycin	0.040	5.7	9.7	1.2
Erythromycin-H_2O	0.016	5.6	9.8	0.0
Ciprofloxacin	0.120	0.6	65.0	7.7
Ofloxacin	0.017	3.9	14.2	2.6
Sulfamethoxazole	0.254	NS	NS	NS
Trimethoprim	0.065	4.3	12.9	0.8
Total Erythromycin	0.003	5.6	9.8	4.2

Antibiotic or Degradation product*	P-value	Sw-net (km)	vf-net (10^{-4} m s^{-1})	Unet (10^{-4} µg m^{-2} s^{-1})
Azithromycin	0.002	4.9	11.7	5.2
Erythromycin	0.010	20.2	2.9	0.1
Erythromycin-H_2O*	0.010	11.0	5.3	0.3
Total Erythromycin	0.004	13.2	4.4	0.4
Tylosin	0.053	5.9	9.8	0.1
Ofloxacin	0.059	5.9	9.8	0.9
Sulfamethoxazole	0.315	NS	NS	NS
Trimethoprim	0.934	NS	NS	NS

Antibiotic or Degradation product*	P-value	Sw-net (km)	vf-net (10^{-4} m s^{-1})	Unet (10^{-4} µg m^{-2} s^{-1})
Azithromycin	0.054	-0.8	-58.3	-0.1
Erythromycin	0.823	NS	NS	NS
Erythromycin-H_2O	0.639	NS	NS	NS
Total Erythromycin	0.746	NS	NS	NS
Tylosin	0.008	-0.6	-55.6	-0.1
Roxithromycin	0.035	-0.6	-56.1	-0.1
Sulfamethoxazole	0.019	-4.3	-8.0	-0.3
Trimethoprim	0.179	NS	NS	NS

Table of antibiotic and degradation product contents in the bed material and pseudo-partitioning coefficients of antibiotics between water column and bed material at various sites. += measured concentration greater than method detection limit; ND = not detected.

Site ID	MC2		MC3		MC4		SC1		DB2	
	Bed Material Content (ng g^{-1})	Partitioning Coefficient	Bed Material Content (ng g^{-1})	Partitioning Coefficient	Bed Material Content (ng g^{-1})	Partitioning Coefficient	Bed Material Content (ng g^{-1})	Partitioning Coefficient	Bed Material Content (ng g^{-1})	Partitioning Coefficient
Macrolides										
Erythromycin	-	-	-	-	-	-	-	-	-	-
Lincomycin	0.10	>20	0.10	<20	0.12	>24	0.09	>18	0.26	>52
Quinolones										
Ciprofloxacin	74.01	639	24.14	287	17.01	362	23.31	>4862	6.91	>1382
Ofloxacin	>13.27	622	34.49	233	35.55	320	87.64	552	27.74	>5548
Sulfonamides										
Sulfachloropyridazine	1.19	>220	ND	-	3.09	>618	1.01	>202	2.69	>538
Sulfamethoxazole	3.82	7	1.65	4	>1000	>2802	496.70	1491	1.80	57
Tetracyclines and Degradation Products*										
Chlortetracycline	80.65	>8065	94.88	>9488	32.25	>3225	21.61	>2161	38.52	>3852
Epi-iso-chlortetracycline*	ND	-	ND	-	ND	-	0.11	>11	ND	-
Iso-chlortetracycline*	ND	-	0.17	>17	ND	-	1.47	>147	ND	-
Tetracycline	3.08	>308	1.10	>110	ND	-	2.07	>207	1.74	>174
Other Various Antibiotics										
Ormetoprim	0.30	>60	0.28	>56	0.38	>72	0.41	>82	1.45	>290
Trimethoprim	2.69	>43	0.86	15	0.82	24	1.43	>286	1.36	124

Conclusions

- Wastewater treatment plant effluent discharges contributed low concentrations of various antibiotics to the receiving streams.
- Some antibiotics were significantly retained in the Mud Creek and Spring Creek reaches, but these antibiotics still traveled kilometer scale distances with low uptake velocities and rates.
- Some antibiotics increased in concentration at Decatur Branch, suggesting possible release from the fluvial channel or additional sources of antibiotics along the stream reach.
- The extent to which antibiotics partitioned between the water column and bed material varied among antibiotic classes.