



WETLANDS IN A COMPLEX WORLD

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Pharmaceutical Removal in Tropical Subsurface Flow Constructed Wetlands

Dongqing Zhang, Katherine
Junfei Zhu
Tao Hua
Richard M Gersberg
Soon Keat Tan

Nanyang Technological University

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Ecological Engineering

- “the design of human society with its natural environment for the benefit of both” (Mitsch & Jørgensen, 1989);
- “.....a specially designed system of production process in which the principles of the species symbiosis and the recycling and regeneration of substances in an ecological system are applied.....(Ma, 1988)”

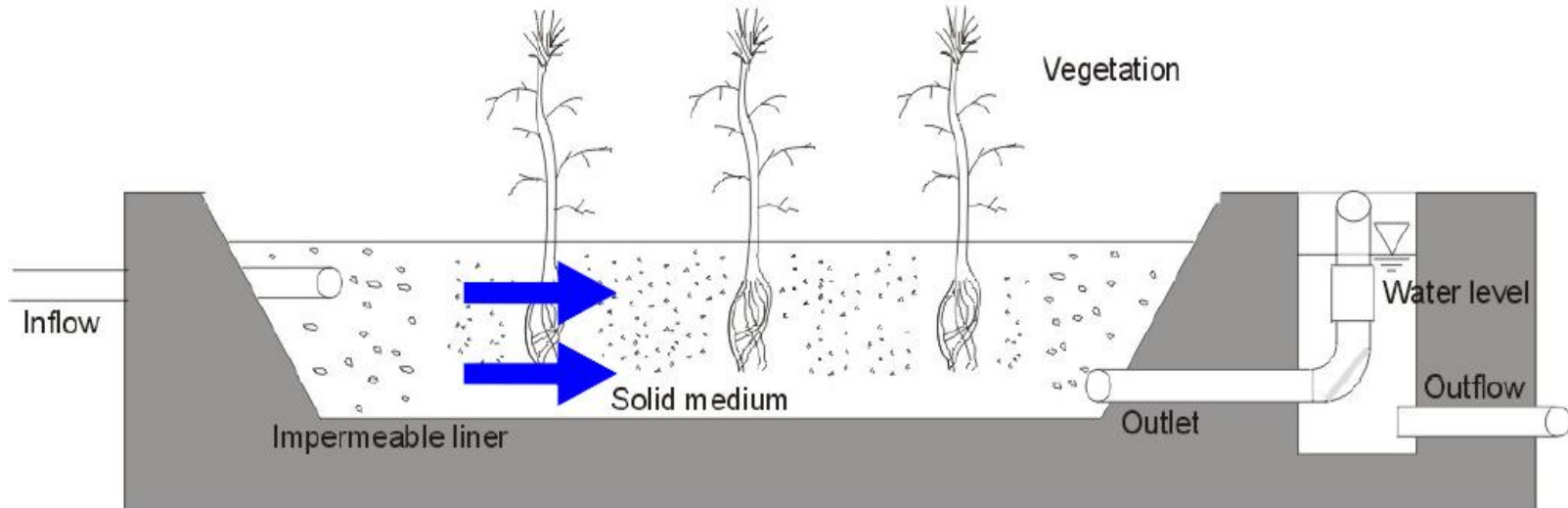
Benefits of constructed wetlands



Used primarily to treat wastewater, constructed wetlands also can be an attractive natural setting where wildlife builds habitat and humans visit. Above is the Hayfield Site at the Tres Rios demonstration constructed wetlands (Photo: Bing Brown, Phoenix Water Services)

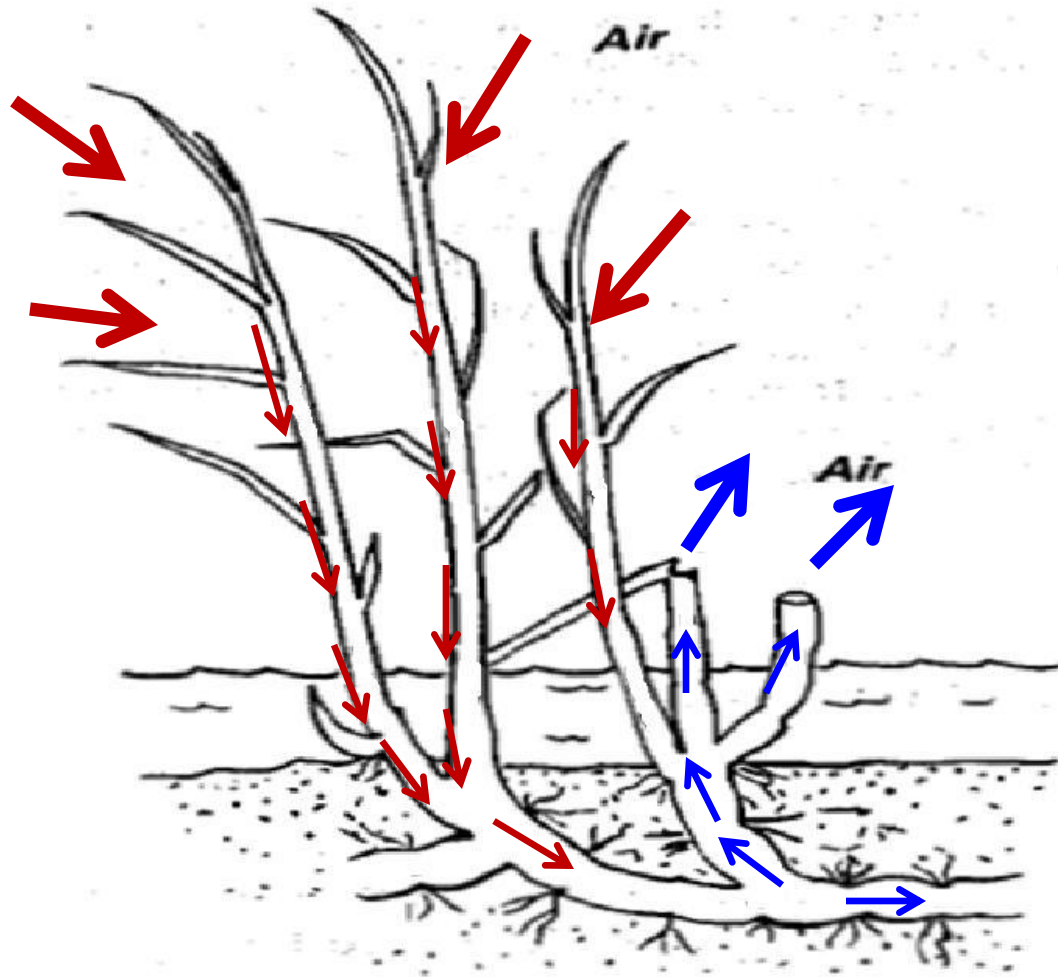
- Easy to maintain and operate resulting in low operating cost;
- Low energy consumption;
- Robust, dynamic and effective treatment;
- Significant habitat value;
- Low carbon footprint;
- Environmental education opportunities.

Constructed wetland designs (Horizontal subsurface flow - HSSF)

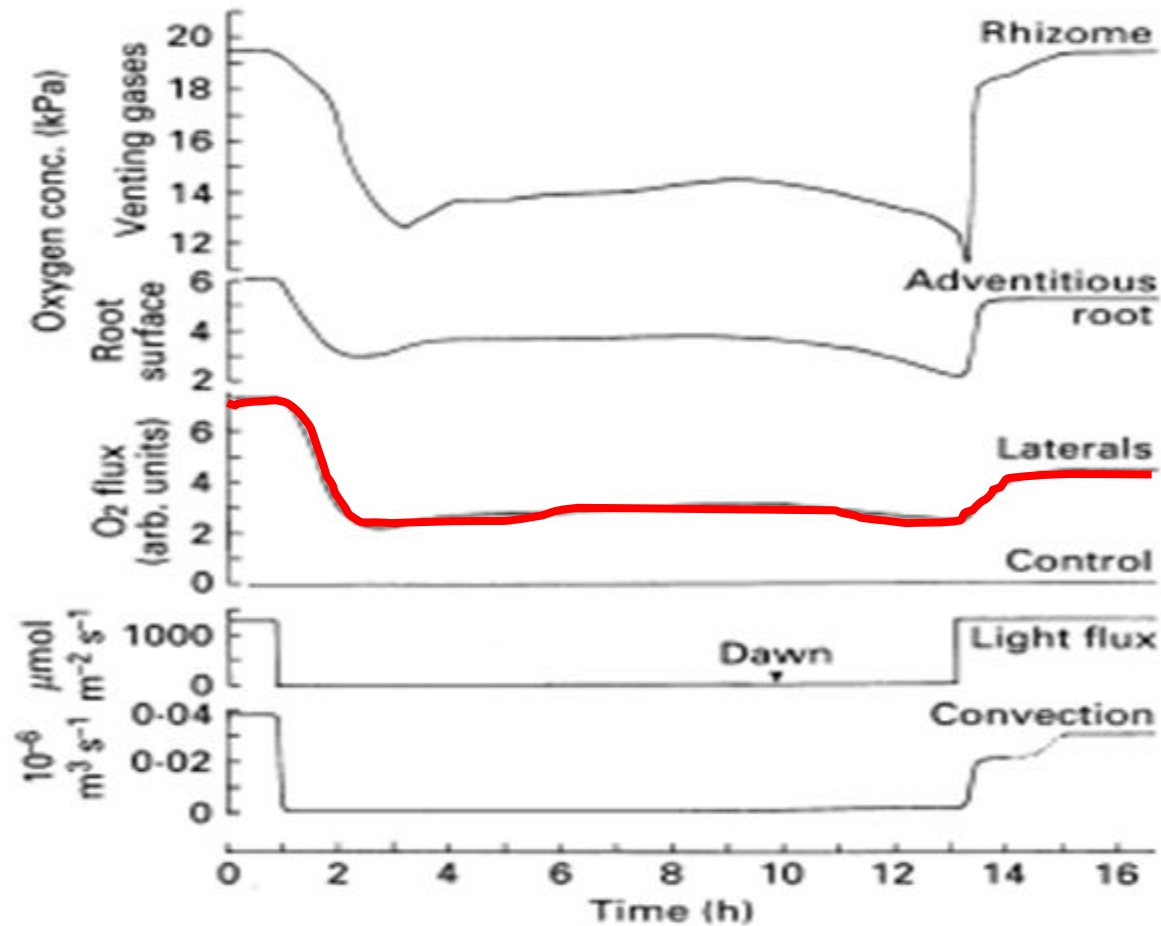


Source: Langergraber, 2006. Constructed Wetlands – Introduction and principles.
Workshop on “Constructed Wetlands”, 22 January, 2006, Ramallah, Palestine.

Gas transport mechanisms in plants

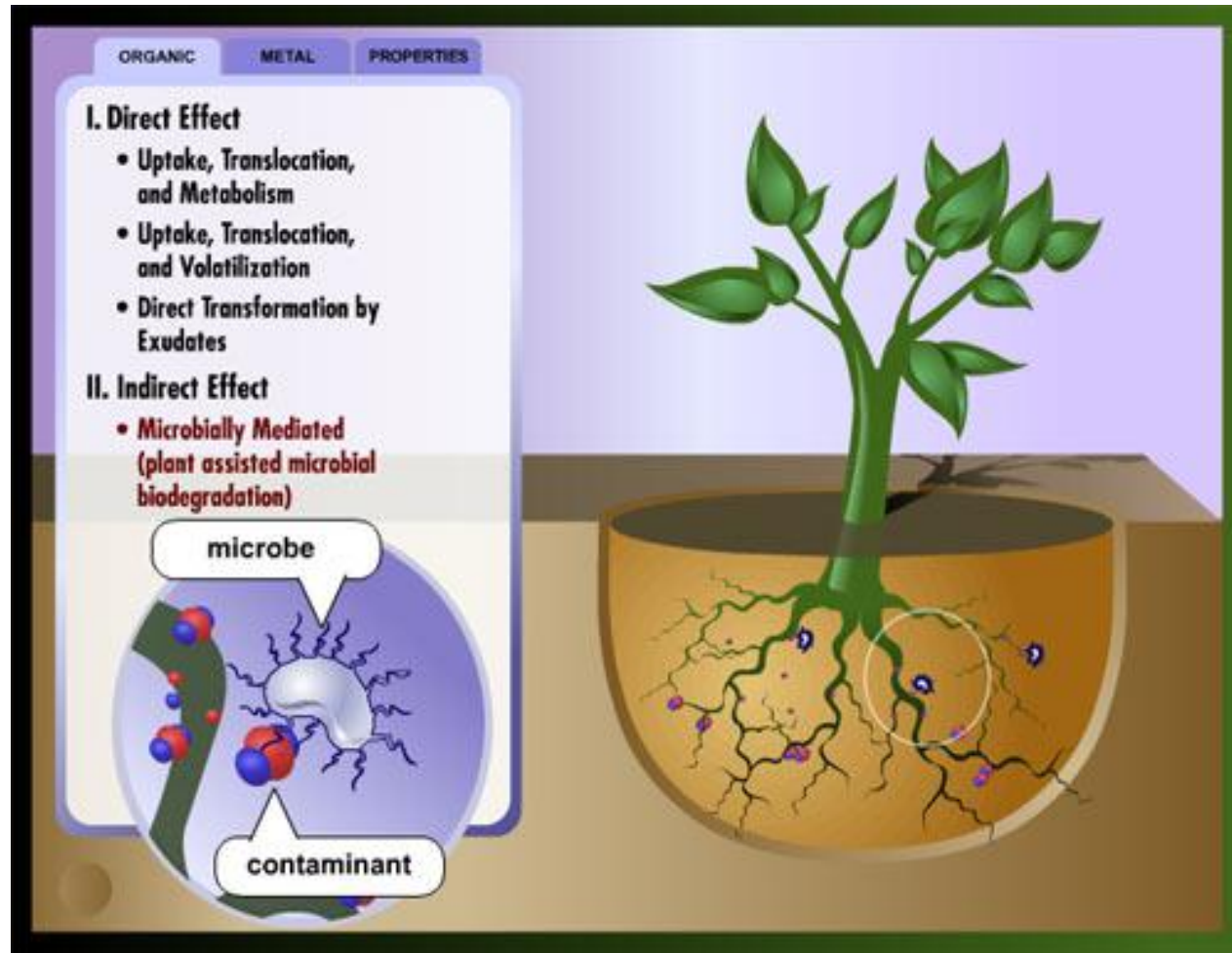


Photosynthetically-driven convective oxygen translocation



Source: Armstrong et al., 1990. New Phytologist, Vol 114, No.1, pp121-128

Phytoremediation



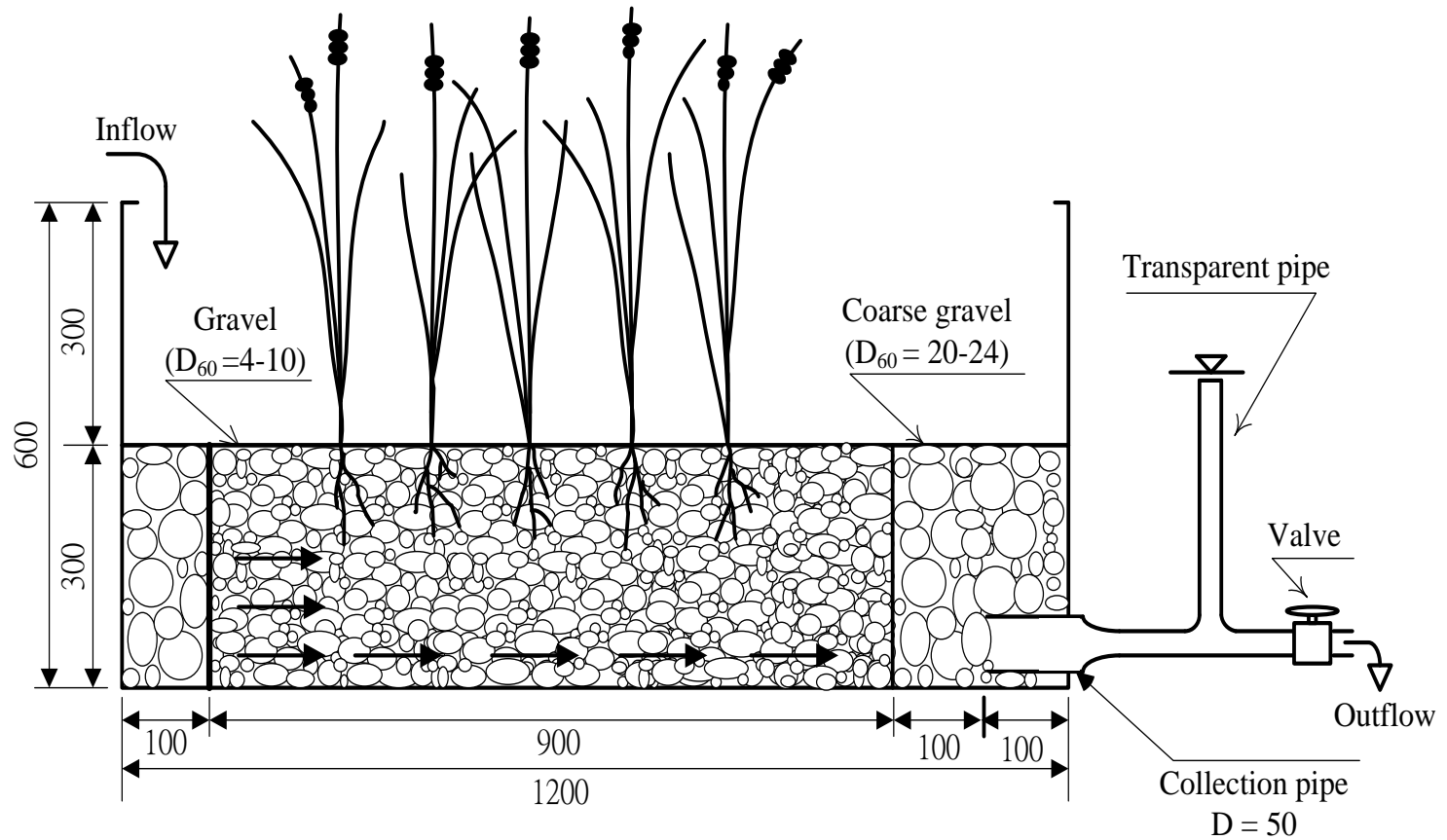
Rhizosphere effect



Layout of planted and unplanted beds at NTU campus



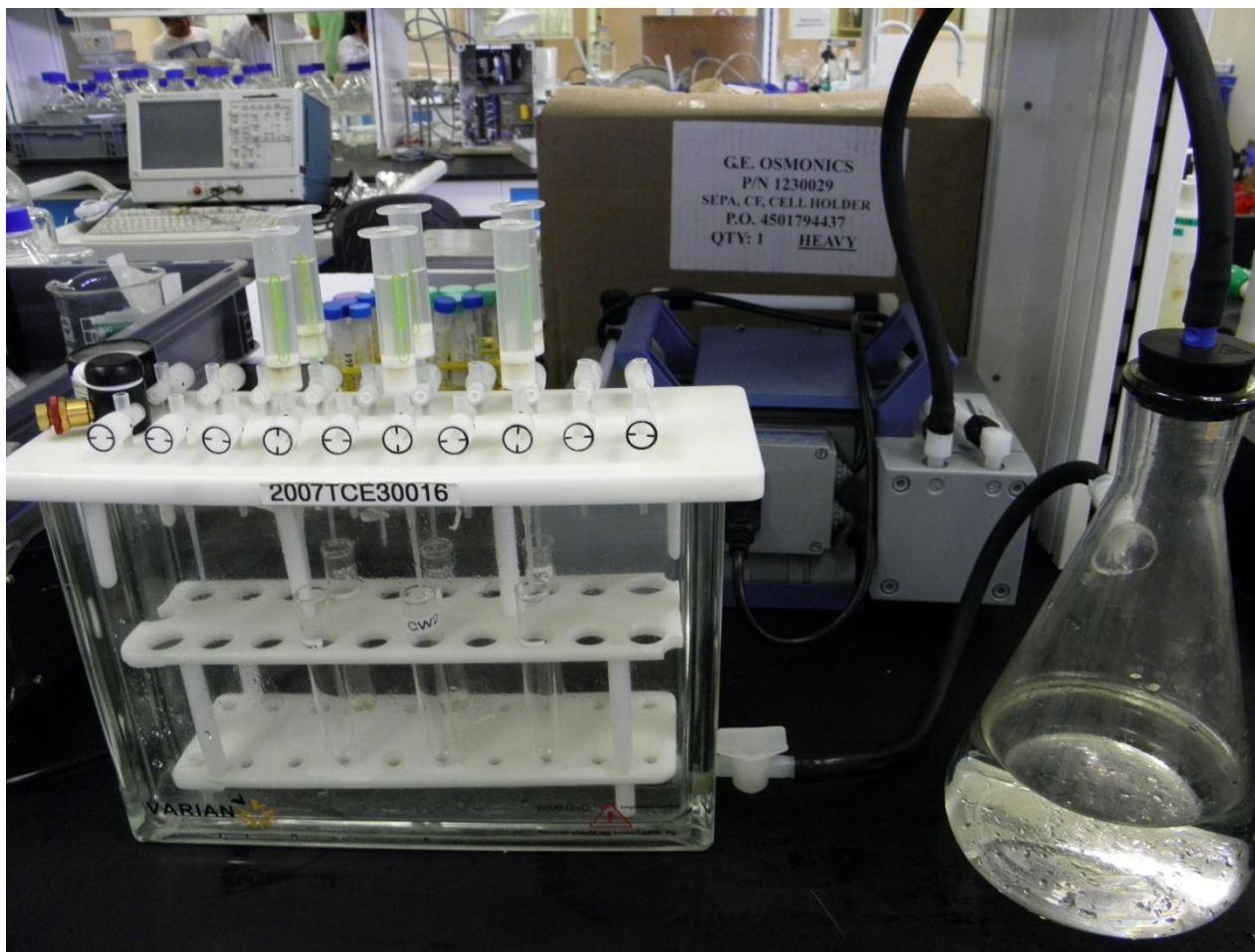
Layout of HSSF CW



Fine/coarse filtration



Solid Phase Extraction (SPE)



High Performance Liquid Chromatography (HPLC)



Mean effluent concentrations (in $\mu\text{g L}^{-1}$) and removal efficiencies (%)

Pharmaceutical compounds	HRT (2-d)		HRT (4-d)	
	Planted beds	Unplanted beds	Planted beds	Unplanted beds
Cabamazepine	18.3±3.2 27	18.9±3.8 24	18.1±2.0 28	18.4±2.3 26
Naproxen	4.8±2.7* 81	12.1±5.9* 52	1.7±0.8* 93	5.5±3.2* 78
Diclofenac	14.7±4.5* 41	17.1±4.2* 32	14.0±3.5* 44	19.1±3.8* 24
Ibuprofen	7.9±5.0* 68	9.8±3.9* 61	7.1±2.4* 72	12.1±3.3 52
Caffeine	4.1±0.7 84	4.6±0.9 82	2.4±0.5* 90	4.0±0.9* 84
Salicylic acid	3.4±1.4 86	2.9±1.4 88	2.6±1.6 90	3.0±1.7 88
Ketoprofen	2.2±0.9* 91	2.5±0.4* 90	1.0±0.4* 96	1.5±0.9* 94
Clofibric acid	16.4±5.7 34	16.7±6.8 33	15.3±5.6* 39	16.5±6.4* 34

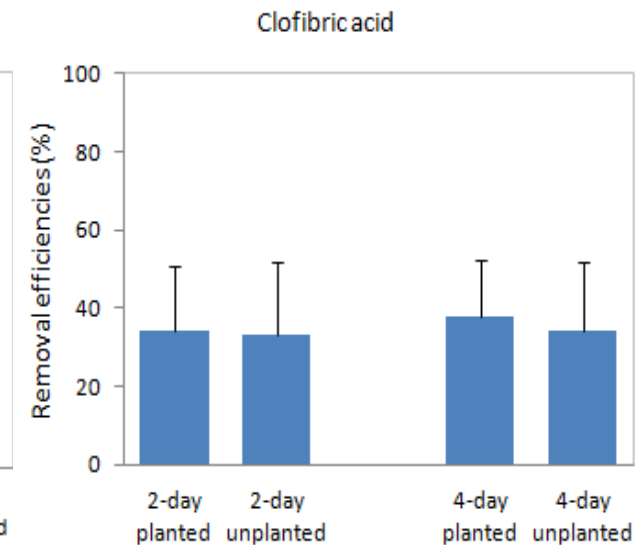
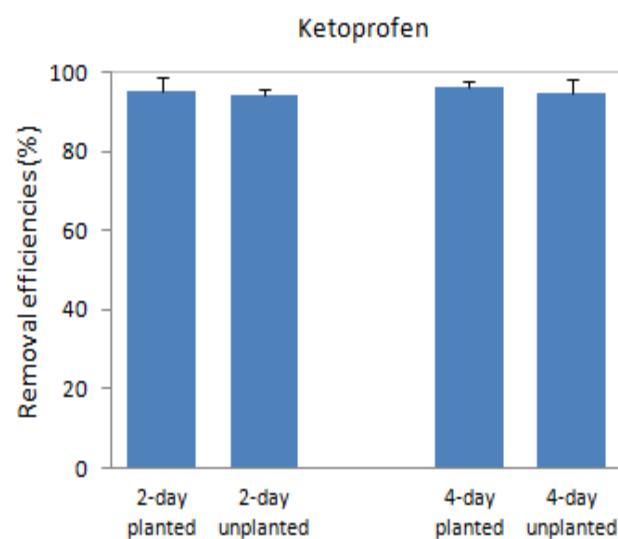
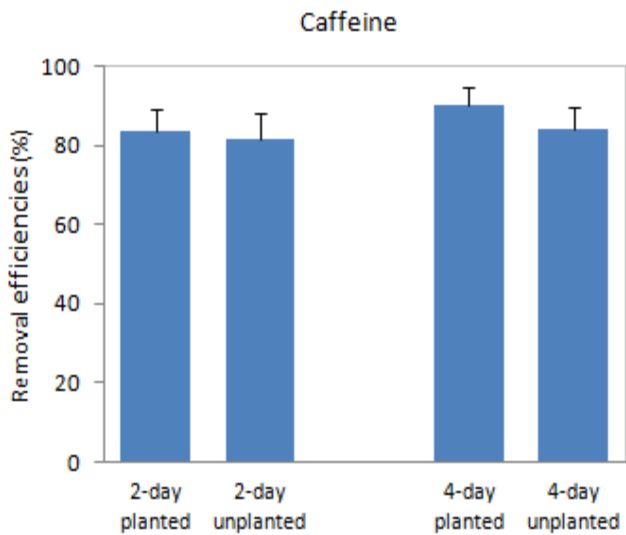
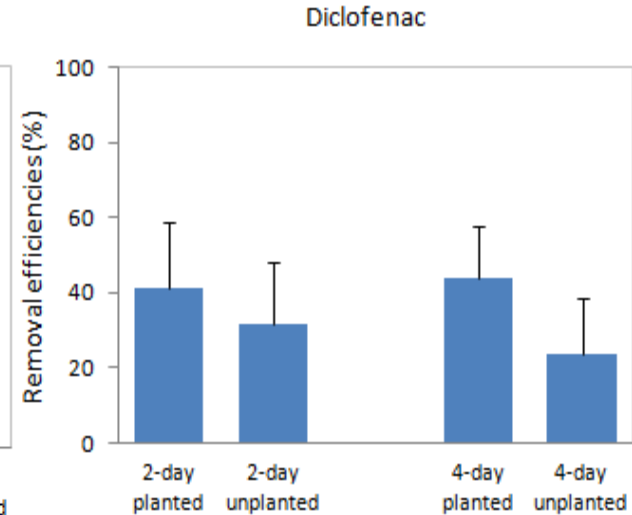
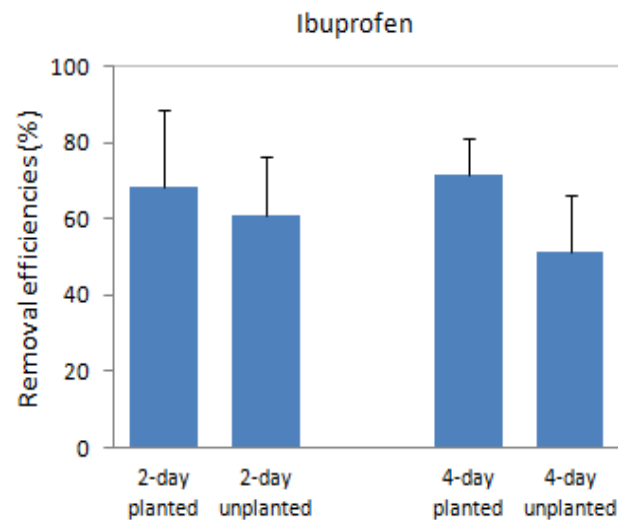
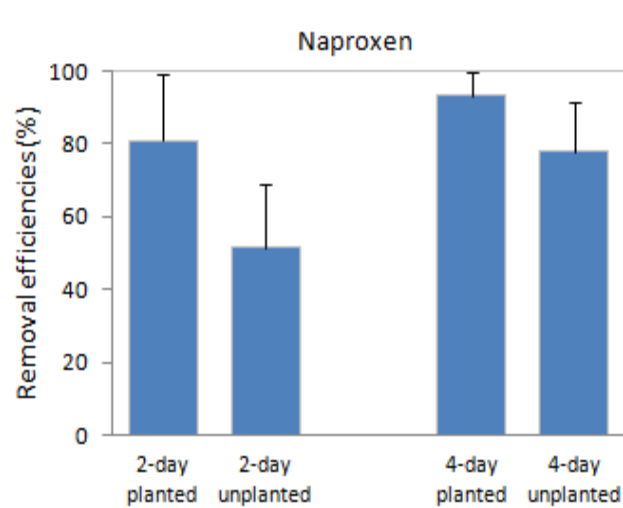
Note:

1. Mean (\pm standard deviation (SD));
2. *: Statistically significant differences at a significance level of < 0.05 (planted vs unplanted beds).

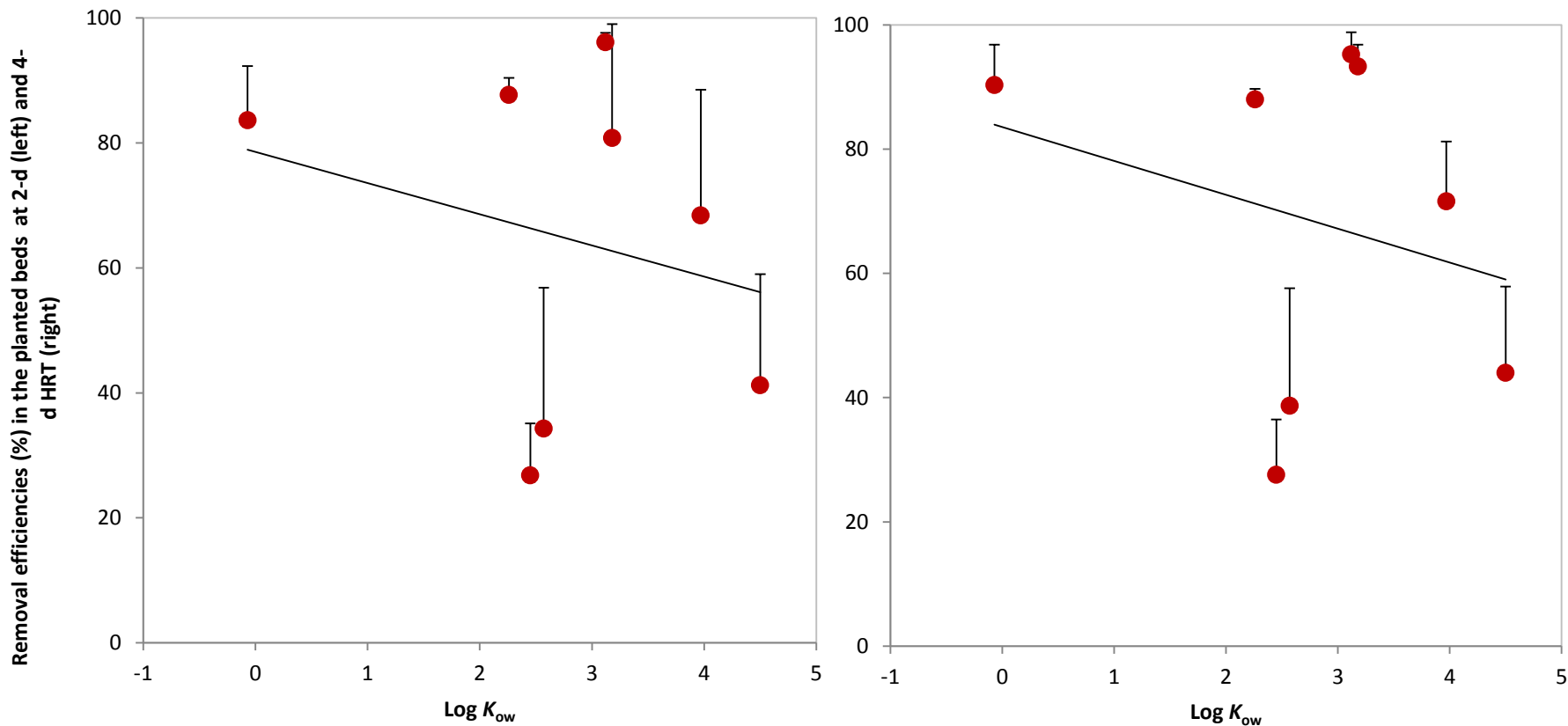
Mean pharmaceutical removal efficiencies (%) and comparisons with other studies

	CWs in this study	Other SFs	Other HSSF CWs	Other VSSF CWs	Other FWS CWs	Other hybrid CWs	Other WWTPs
Carbamazepine	24-28	8-11 ¹	38 ⁵ ; 5 ⁸	20-26 ¹	39 ¹⁰ ; 30 ¹²	-	7 ⁷ ; 8 ⁶ ; 30 ¹³
Naproxen	52-93	66-80 ¹	0-47 ² ; 80-90 ³ ; 90 ⁵ ;	62-89 ¹	72 ¹⁰ ; 92 ¹⁰	73-85 ⁹	66 ⁷ ; 40-55 ⁴ ; 93 ¹³ 55-98 ¹⁴
Diclofenac	24-44	39-76 ¹	0-11 ² ; 0-45 ³ ; 21 ⁵ ; 17-52 ² ;	53-73 ¹	85 ¹⁰ ; 96 ¹¹	65-87 ⁹	9-75 ⁷ ; 17 ⁶ 9-60 ¹⁴ ; 22 ¹³ 90 ⁷ ; 60-70 ⁴ ;
Ibuprofen	52-72	39-76 ¹	62-80 ³ ; 62 ⁵ ; 51 ⁸ ;	55-99 ¹	96 ¹⁰ ; 96 ¹¹	42-99 ⁹	96 ¹³ 79-100 ¹⁴
Caffeine	82-90	75-98 ¹	85-94 ² ; 94-99 ³ ;	82-99 ¹	-	83-96 ⁹	94 ¹²
Salicylic acid	86-90	77-98 ¹	77-97 ² ; 92-98 ³ ;	85-98 ¹	-	93-97 ⁹	-
Ketoprofen	94-96	-	0-69 ³ ; 90 ⁵	-	98 ¹⁰ 97-99 ¹²	77-81 ⁹	48-69 ⁷ 65 ¹³ 51-100 ¹⁴
Clofibric acid	33 -39	-	-	-	34 ¹⁰ ; 36 ¹¹	-	26 ¹²

Comparison of mean removal efficiencies (%) for pharmaceutical in the planted and unplanted beds



Correlations between $\log K_{ow}$ and pharmaceutical removal efficiencies



Conclusion

- CWs can offer comparable or even better removal efficiencies as compared to WWTPs;
- Pharmaceuticals could be categorized as i) very efficiently removed compounds with removal higher than 85% (ketoprofen and salicylic acid); ii) moderately removed compounds with removal efficiencies between 50 and 85% (naproxen, ibuprofen and caffeine); and iii) poorly removed compounds with elimination rate lower than 50% (carbamazepine, diclofenac, and clofibric acid);

Conclusion

- Except for carbamazepine and salicylic acid, removal efficiencies of the selected pharmaceuticals showed significant ($p < 0.05$) enhancement in planted beds as compared to the unplanted beds;
- Correlations between pharmaceutical removal efficiencies and $\log K_{ow}$ were not significant ($p > 0.05$), implying that their removal is not well related to the compound's hydrophobicity.

**Thank you very
much!**