

# Uptake and fate of organic contaminants in plants of constructed wetlands

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## Introduction

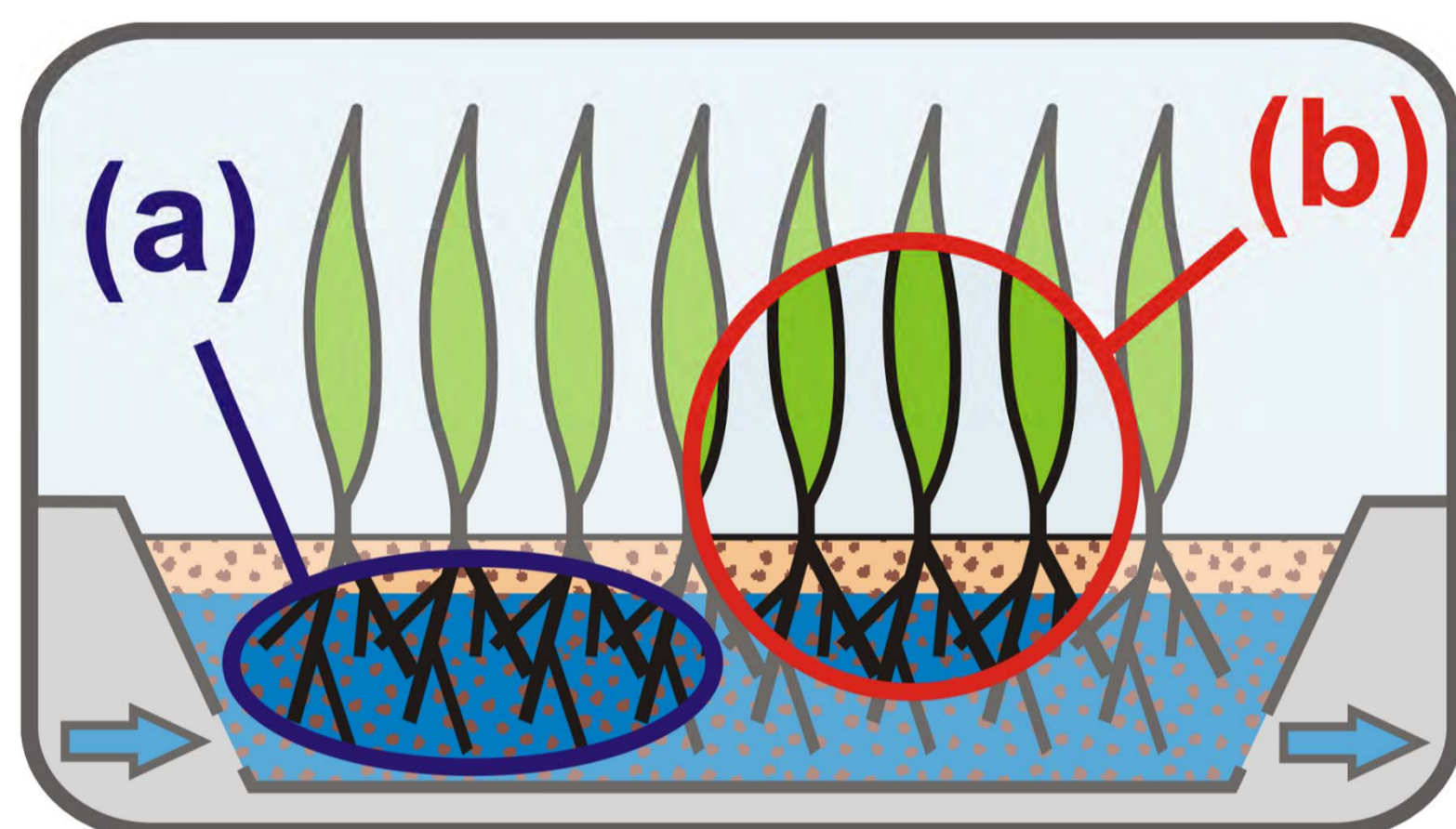
- Constructed or natural wetlands may act as buffer stripes for polluted groundwater with high metabolic activity between groundwater and rivers
- Experimental wetlands established in Leuna and Bitterfeld, Germany [1]
- In the presence of plants, a significant stimulation of substance removal (e.g. benzene, MTBE) was observed

## Objective & Aim

- Objective:** developing a model approach for evaluating the effect of plants on chemical removal from water & modelling of experimental wetlands
- Aim:** identification of relevant processes and prediction of contaminant fate and removal potential

## Wetland & simulation studies

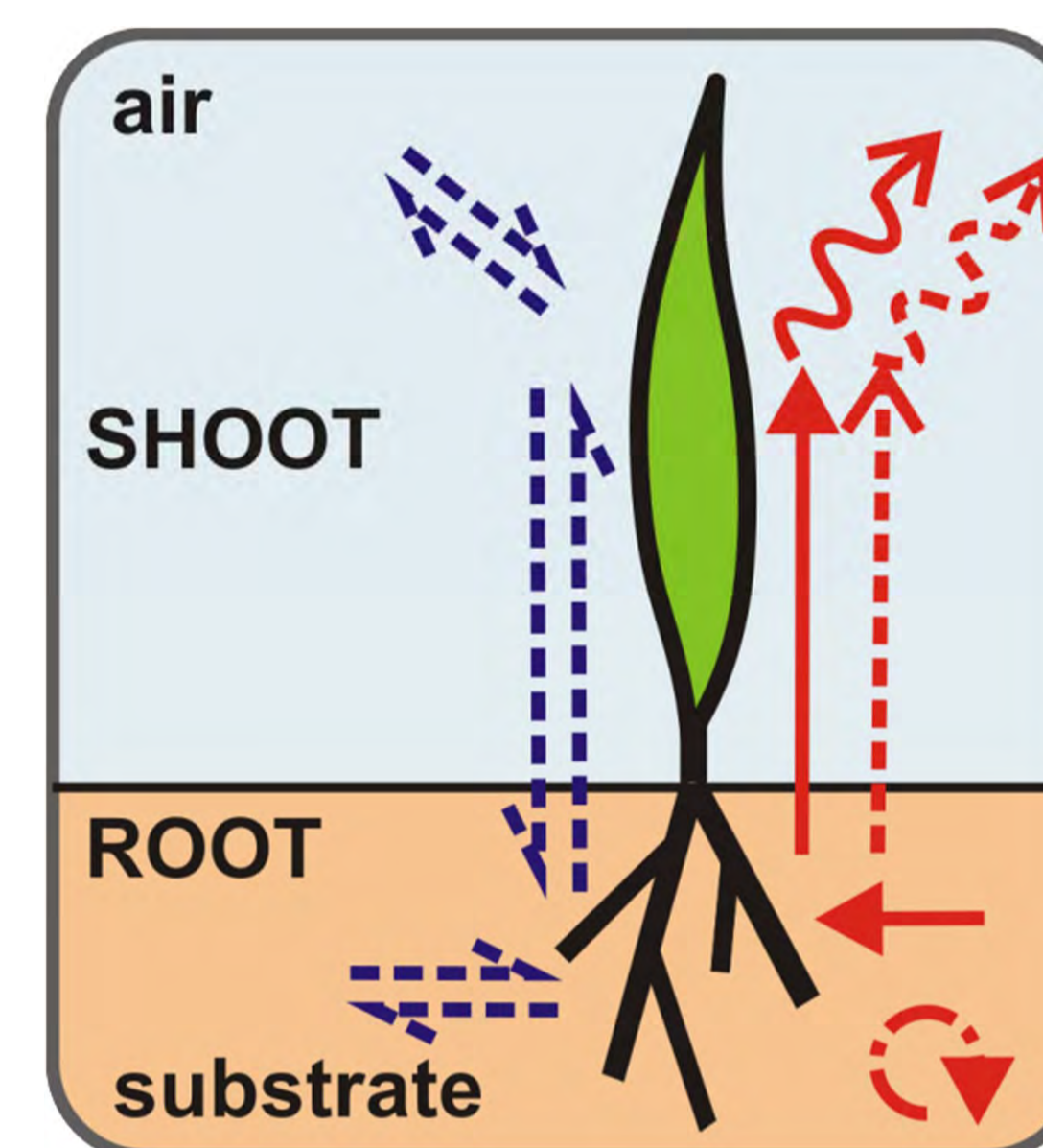
- Horizontal flow subsurface wetland, planted with reed (*Phragmites australis*) & unplanted controls [1]



(a) reactive transport modelling with MIN3P, unsaturated and saturated flow [2]; root uptake included as loss term

(b) PLANT MODELLING

## Model concept & processes



- Uptake** into plants with water & subsequent phytovolatilisation
- Chemical efflux** through plant aerenchyma with air (CO<sub>2</sub>)
- Aerobic, anaerobic & rhizome mediated **degradation**
- Oxygen balance**, O<sub>2</sub> influx & CO<sub>2</sub> efflux via aerenchyma
- Gaseous deposition & volatilisation to/from substrate

## Model details

- Inhomogeneous linear ordinary differential equations (ODEs) for the change of concentration in **substrate, root and shoot**
- Multi-cascade approach** [3,4]: analytical solution of the ODEs, principle of superposition to obtain the dynamic solution: simulation subdivided into 24 periods with constant conditions (concentration vector **C(t)** at the end of specific period serves as initial conc. vector **C(0)** for next period in all compartments); the model follows flow of water through wetland, each of the 24 periods cover 1/24<sup>th</sup> of hydraulic retention time

Change of concentration in substrate:

$$\frac{dC_s}{dt} = \left( \frac{A_s P_s \rho_{s,wet} (1-f_p)}{K_{AW} K_{WS} M_s} + \frac{A_s v_{dep} f_p}{M_s} \right) C_A - \left( \frac{Q K_{WS}}{M_s} + \frac{A_s P_s \rho_{s,wet} 1000 L m^{-3}}{M_s} + k_{anaerobic} + k_{aerobic} + k_{rhizome} + k_{efflux with CO_2} \right) C_s$$

Annotations:   
 -  $C_A$ : input from air (gaseous & particulate deposition)   
 -  $v_{dep}$ : volatilisation loss   
 -  $\frac{Q K_{WS}}{M_s}$ : root uptake from substrate water with transpiration stream   
 -  $k_{anaerobic} + k_{aerobic} + k_{rhizome} + k_{efflux with CO_2}$ : rate constants for degradation and efflux with CO<sub>2</sub>

## Example results - BENZENE in the Leuna wetlands

SIMULATED

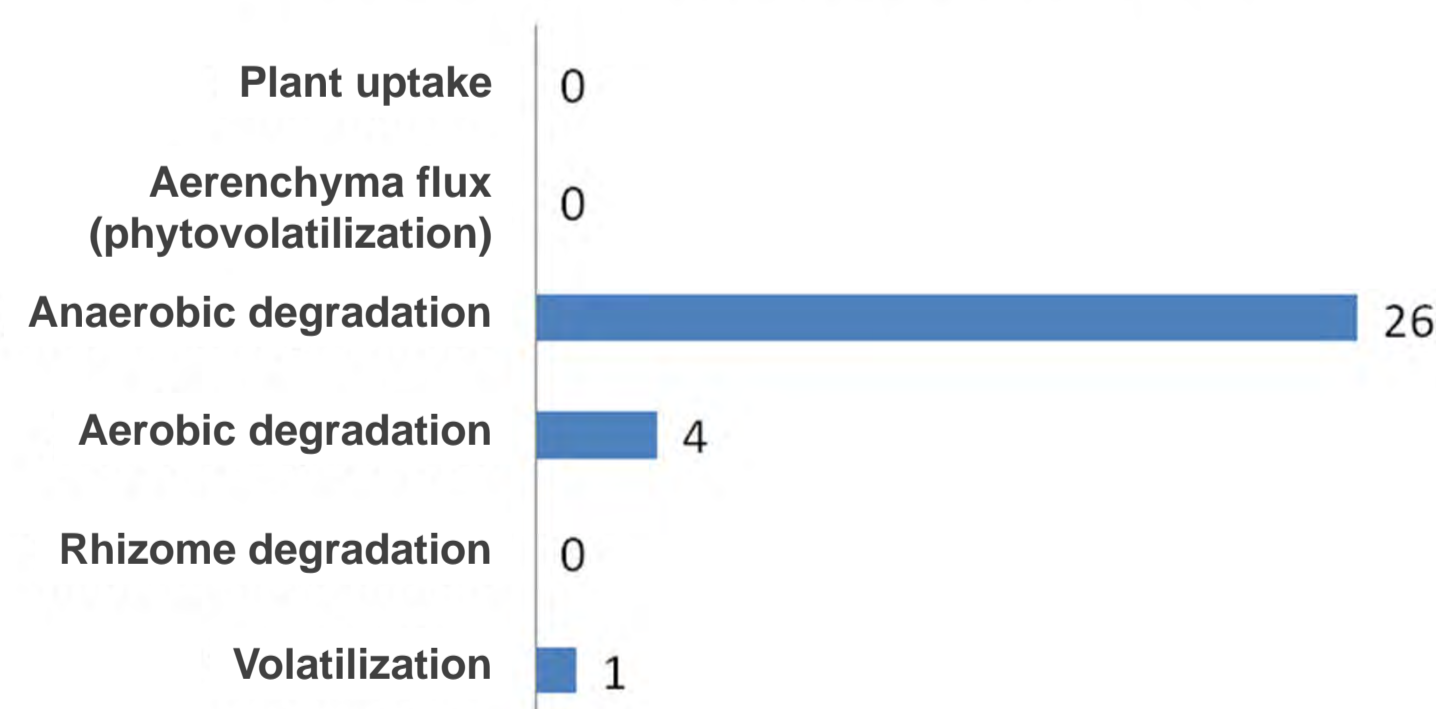


MEASURED

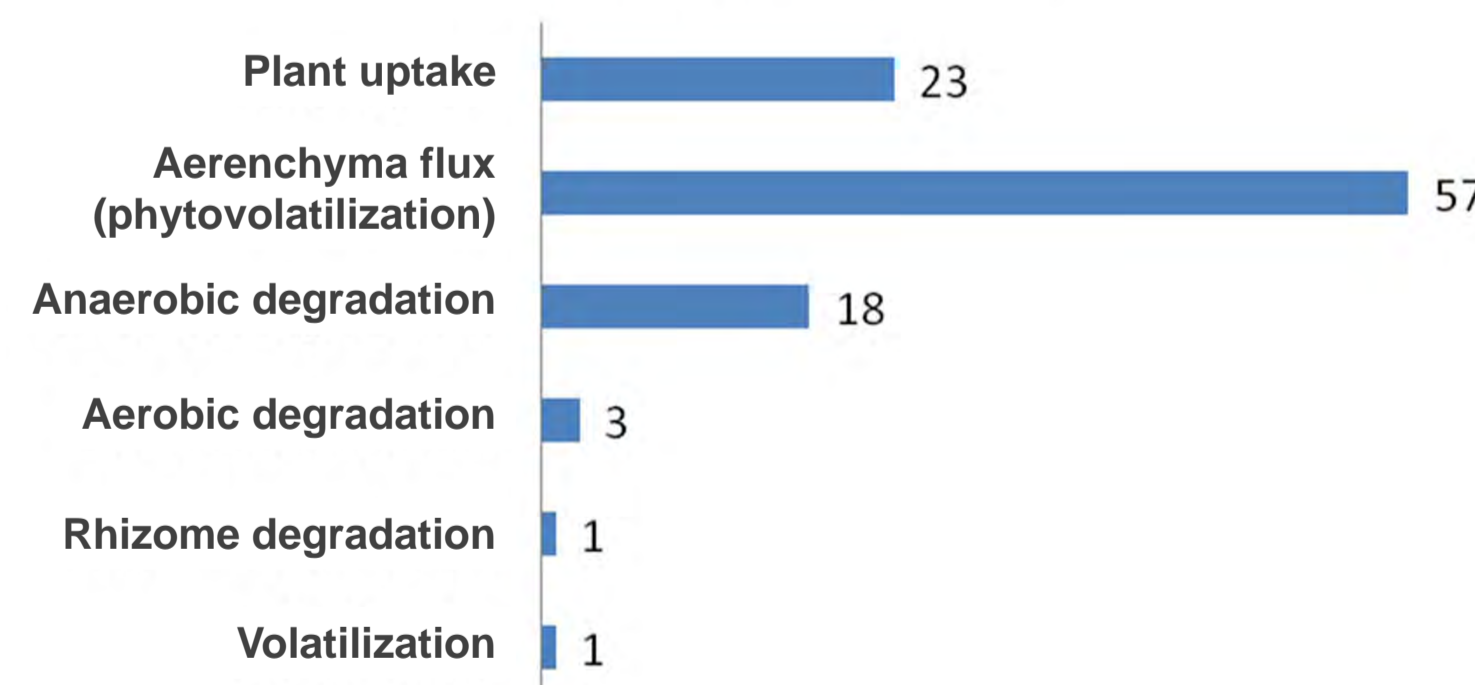
Measured fluxes [5,6]	Control wetland	Planted wetland	Period
Total removal	22 %	89 %	Summer
	23 %	27 %	June
		59 %	Feb/March
Volatilisation	0 %	2.3 %	February
	0.24 %	1.8 %	Summer
	0 %	0.1 %	June
	0 %	0.8 %	February

- In summer: 4 times faster removal on planted wetland
- In winter: removal on planted wetland still somewhat higher
- negligible volatilization

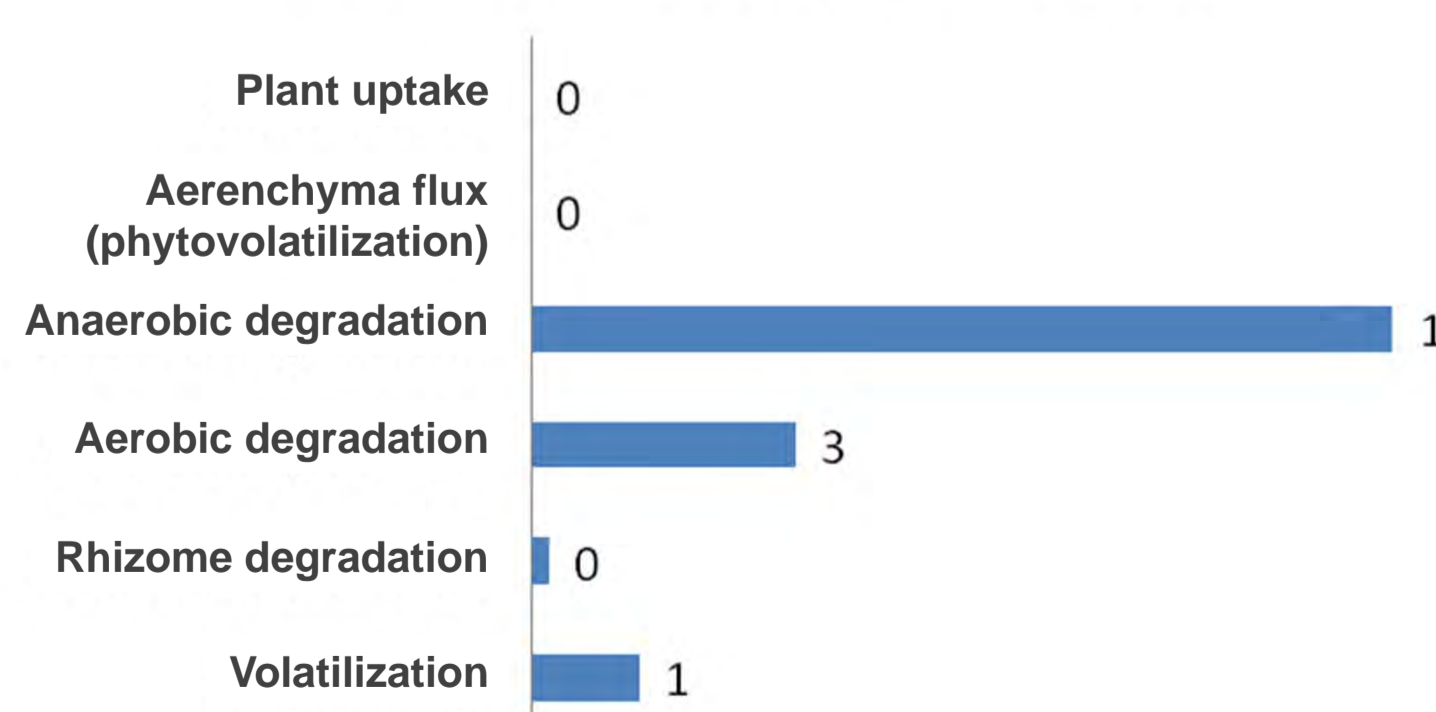
Summer no plants (% of inflow)



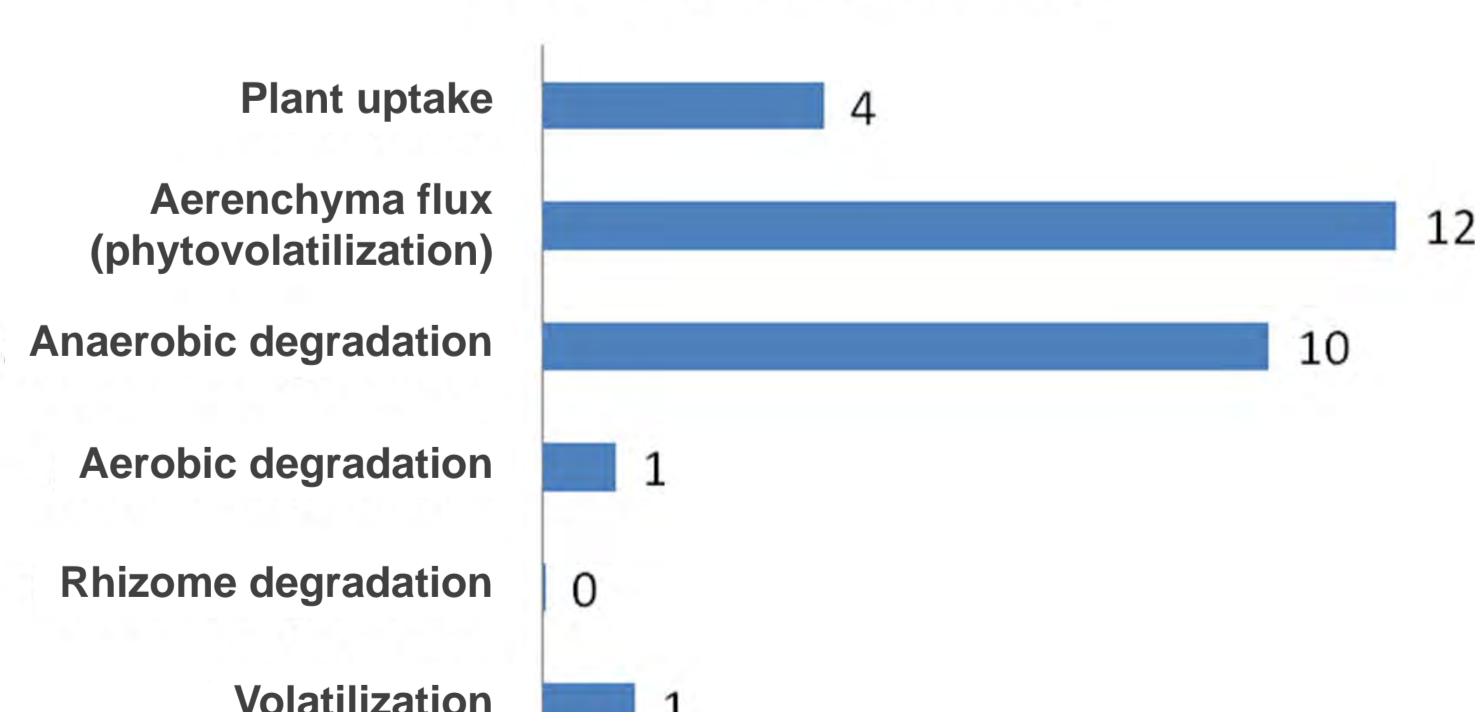
Summer (% of inflow)



Winter no plants (% of inflow)



Winter (% of inflow)



## Conclusions & outlook

- Important indirect effects identified: plants enable exchange between wetland substrate and air (O<sub>2</sub>, aerenchyma)
- Significant plant uptake in summer; probably plants degrade groundwater contaminants (benzene, TCE, chlorobenzene, MTBE)
- Further studies on plant uptake and degradation are on-going (including the support of plants for degrader microbes)
- Models for estimating the phytoremediation potential (including soil and groundwater contamination) will be (further) developed
- Future work will also include coupling of the plant uptake model to MIN3P for dynamic simulations of the whole system

### Acknowledgements

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### References

[1] Braeckvelt M. et al. *Ecological Engineering* 2011, 37(6): 903-913. [2] Maier U, DeBiase C, Baeder-Bederski O, Bayer P. *Journal of Hydrology* 2009, 369: 260-273. [3] Rein A, Legind CN, Trapp T. *SAR QSAR Env Res* 2011, 22: 191-215. [4] Legind CN, Kennedy CM, Rein A, Snyder N, Trapp S. *Pest Management Science* 2011, 67: 521-527. [5] Reiche N, Lorenz W, Borsdorf H. *Chemosphere* 2010, 79(2): 162-168. [6] Seeger EM et al. *Environ Sci Technol* 2011, 45, 8467-8474.

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