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Treatment of micropollutants in stormwater biofilters: comparing model results with field and lab data

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11^e Conférence internationale

LYON 2023 — L'eau dans la ville | Urban water

Organisée par



nôvateCH
L'eau dans la ville | Urban water

Traitement de micropolluants par une noue filtrante : confrontation d'un modèle aux données expérimentales

Treatment of micropollutants in stormwater biofilters: comparing model results with field data

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Road runoff pollution

- **Road runoff**: one of the **most polluted** types of urban stormwater



- Pollutant **sources**
 - Road surfaces
 - Tires
 - Break pads
 - Exhaust fumes
 - Vehicle components
 - Fuel, oil, lubricants
 - Road paint and signs...

(Markiewics et al., 2016; Müller et al., 2020)

Road runoff pollution

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Traditional concerns:

- Suspended solids
- Trace metals
- Petroleum hydrocarbons
- Polycyclic aromatic hydrocarbons (PAH)

(Brown and Peake, 2005; Huber et al., 2016 ; Kayhanian, 2012)

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More recently:

Organic micropollutants

- Alkylphenols
- Phthalates
- Bisphenol-A...

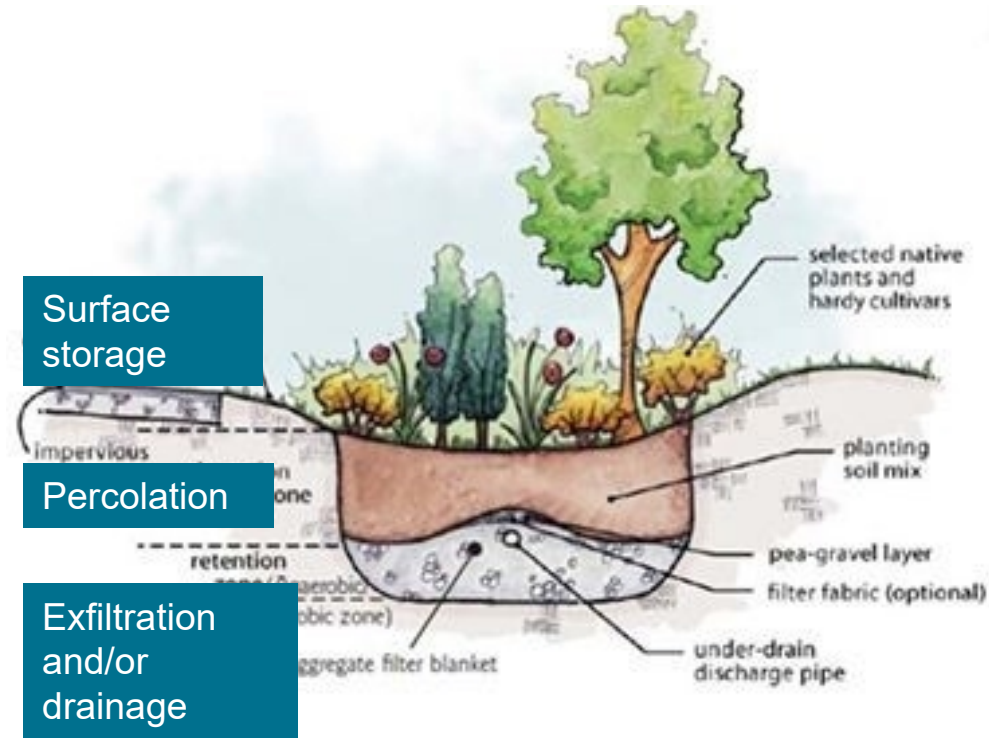
(Markiewics et al., 2016; Gasperi et al., 2022)

Stormwater treatment using biofiltration

Biofiltration / bioretention devices



Photo: Emilie Payne, Monash University



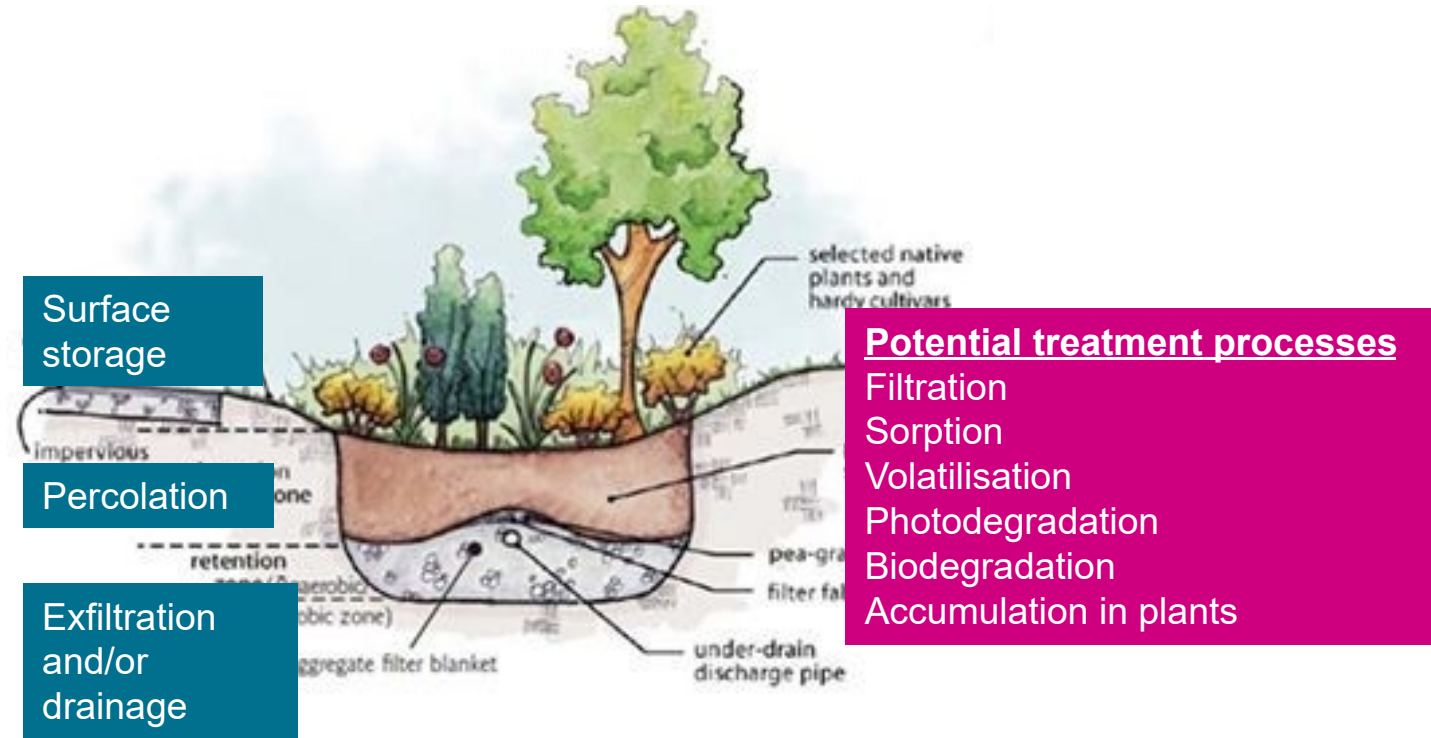
Schema: Better Ground

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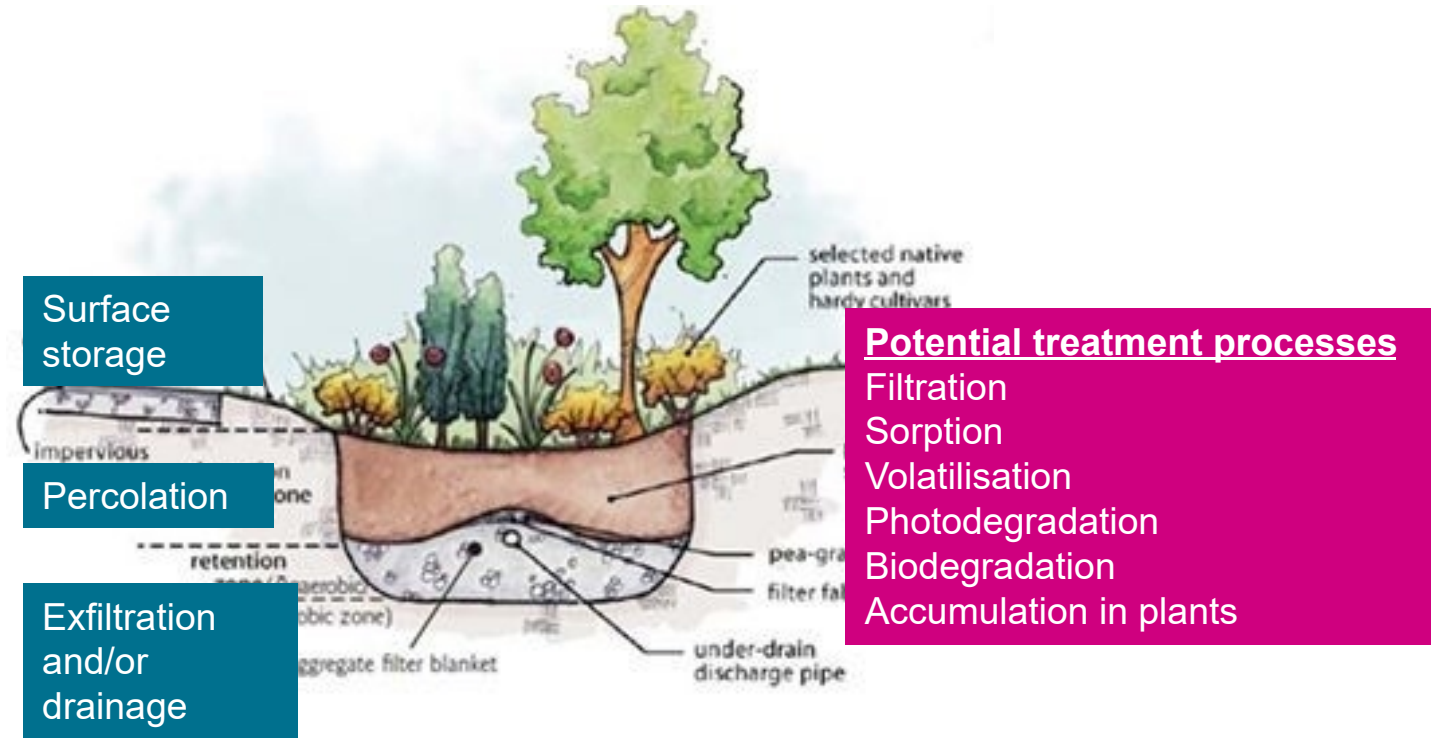
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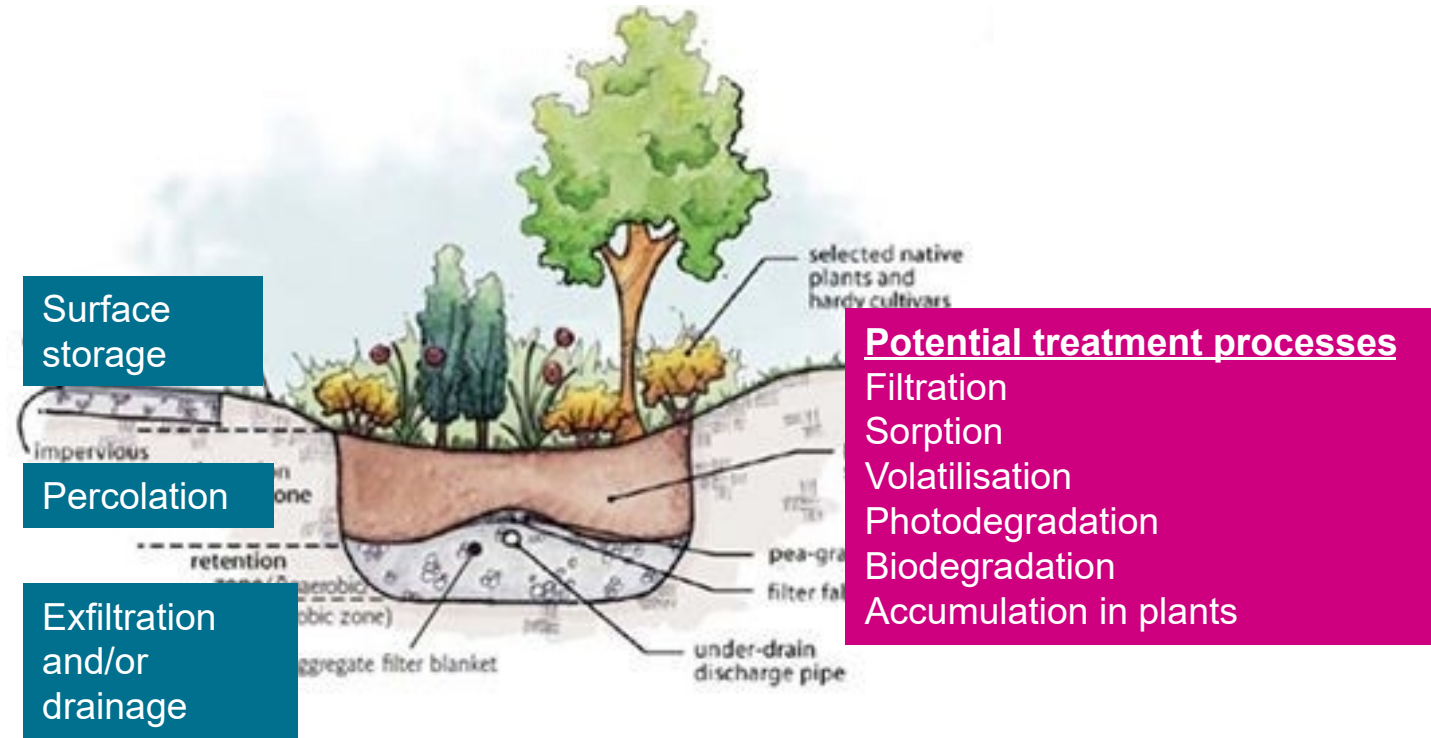
✓ Biofiltration can effectively treat organic micropollutants (Flanagan et al., 2018; Beryani et al., 2023)

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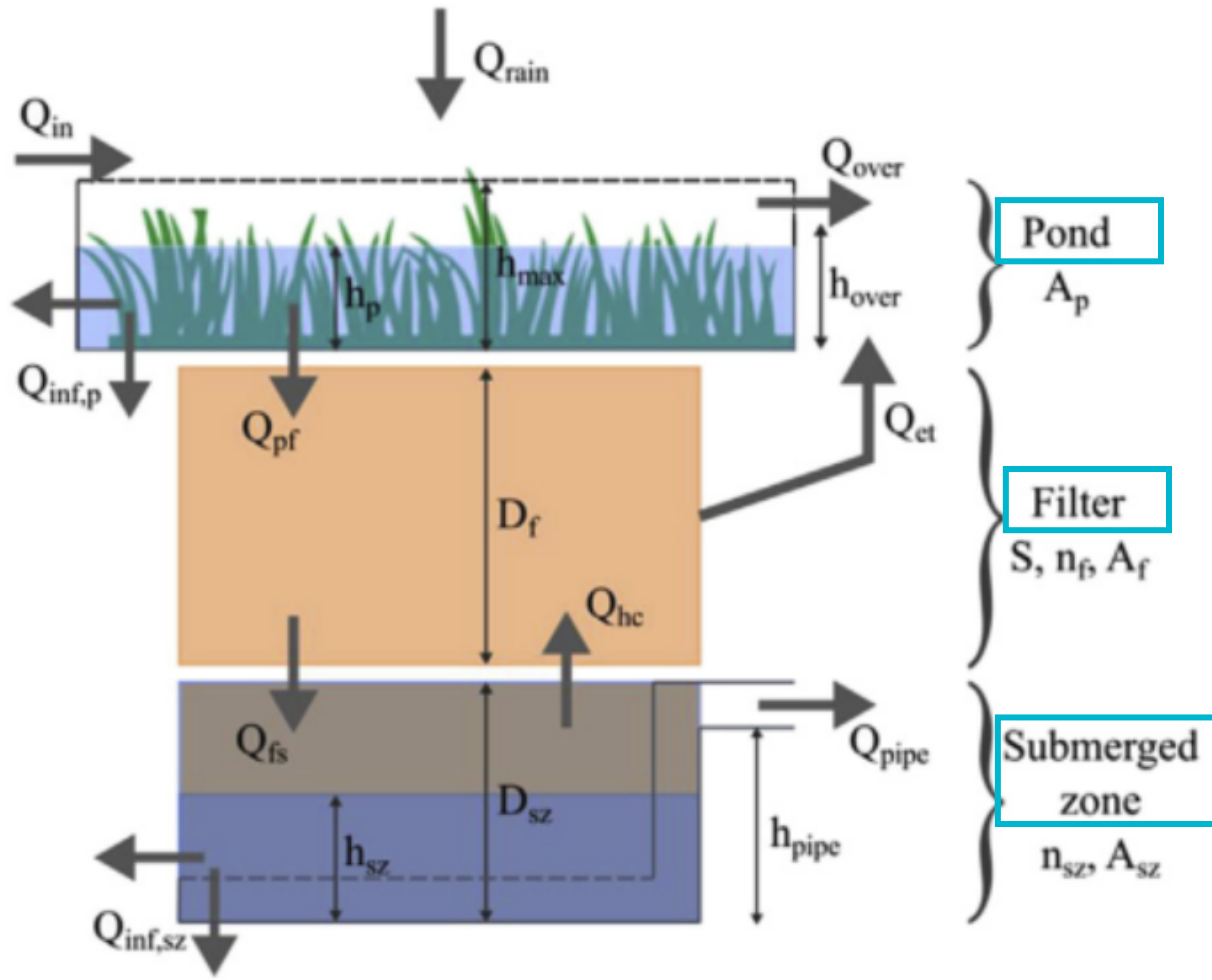


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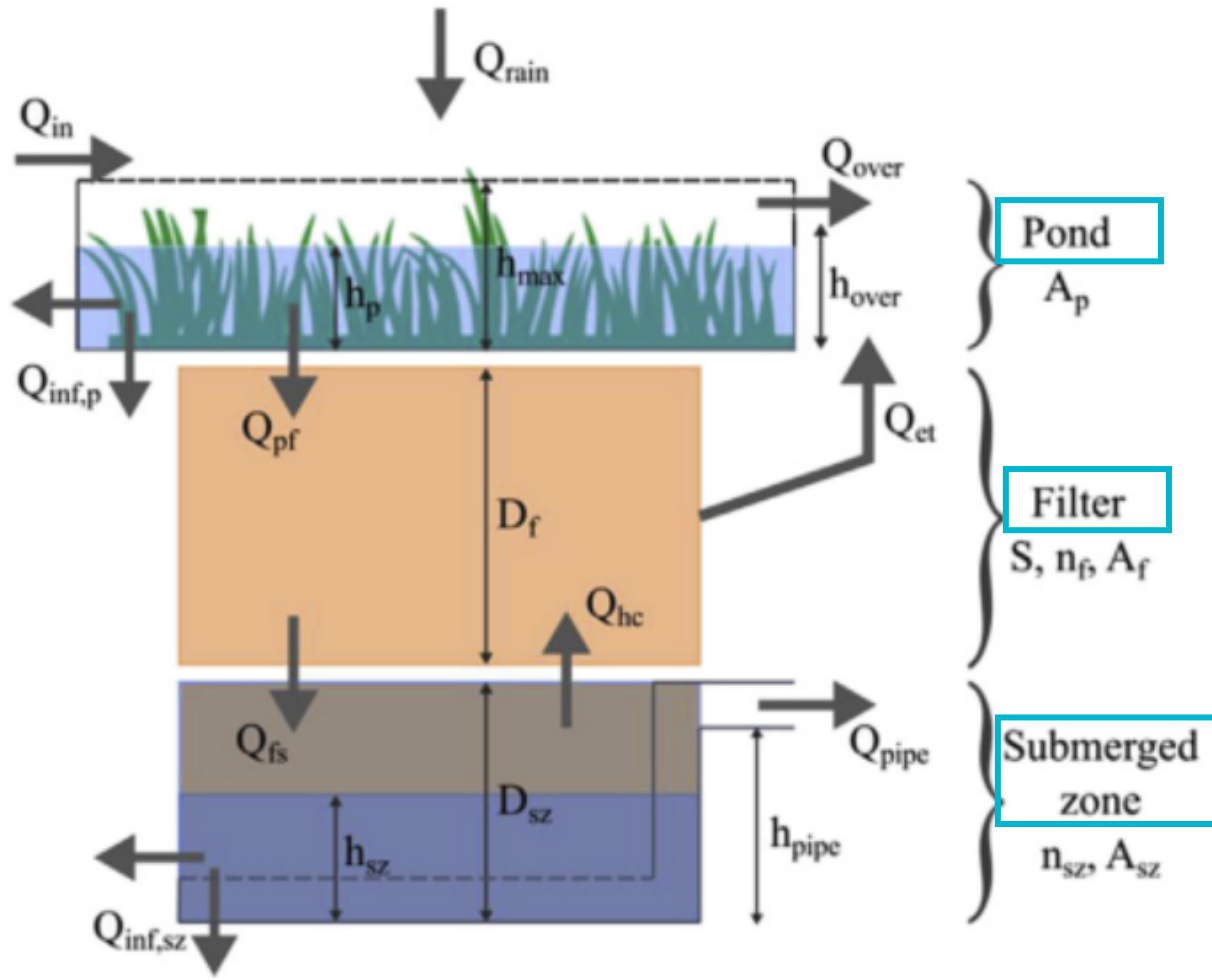
Models of treatment needed to understand dominant processes and predict performance

MPiRE model



Model for micropollutant treatment in biofilters

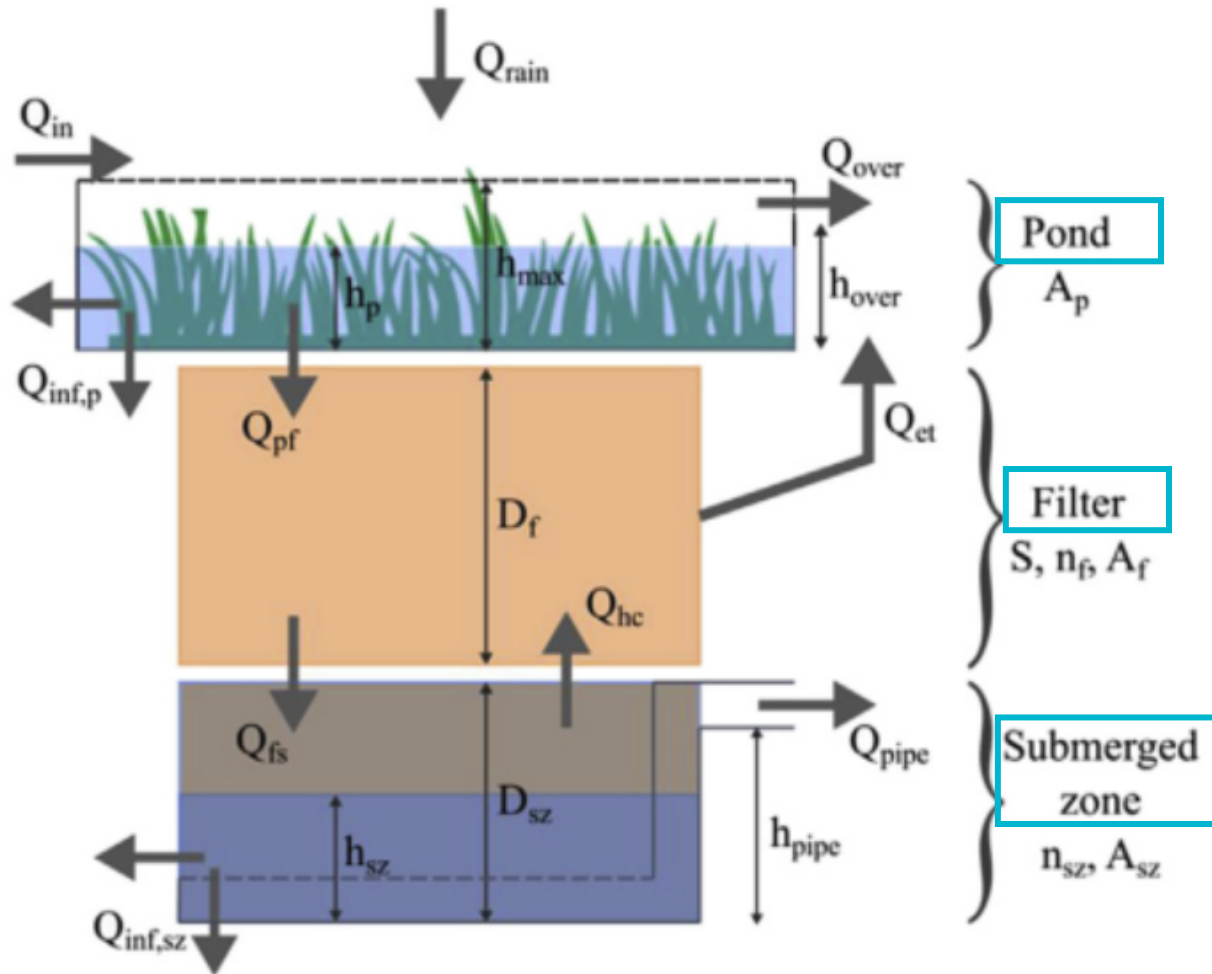
MPiRE model



Model for micropollutant treatment in biofilters

Hydrologic module

MPIRE model



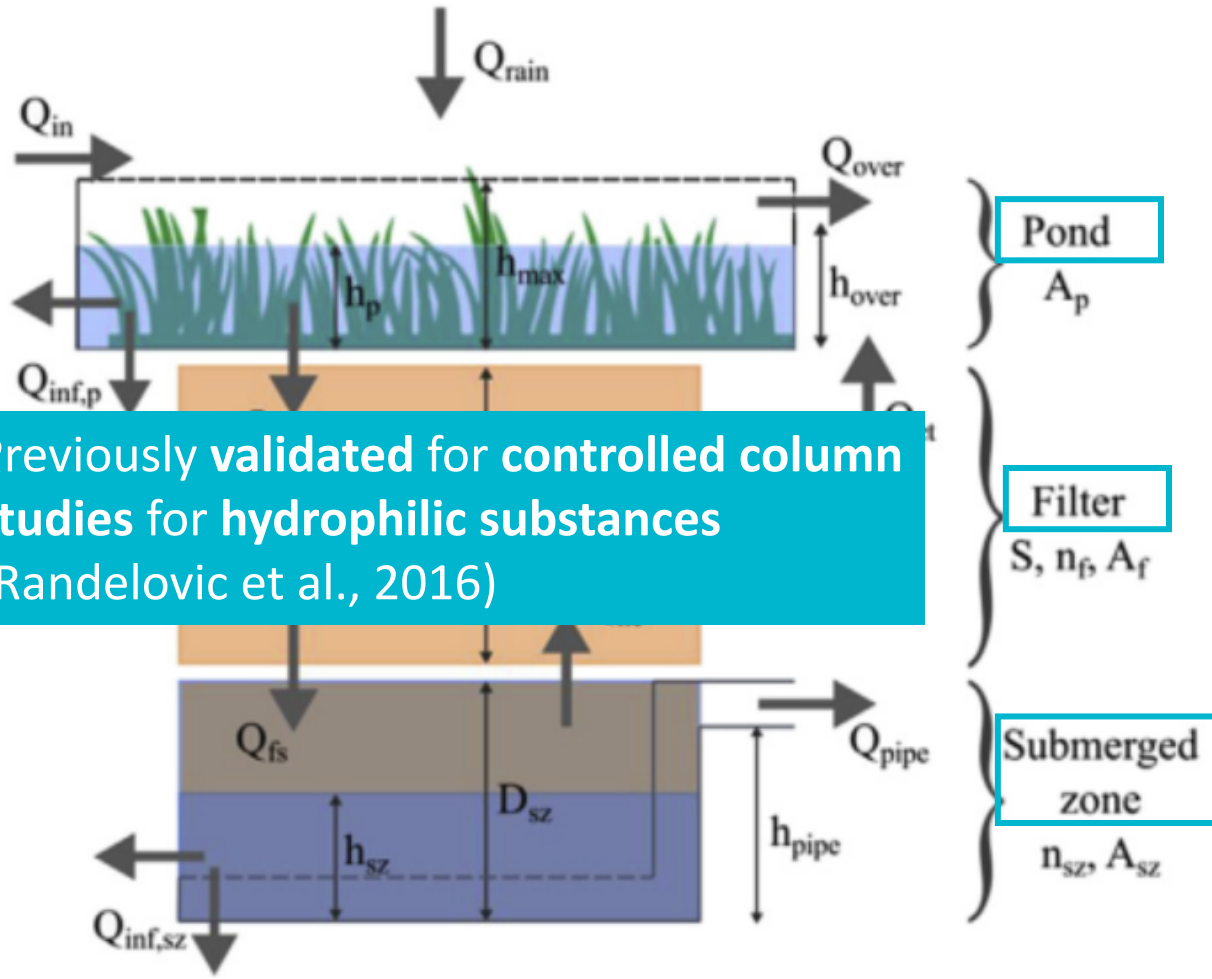
Model for micropollutant treatment in biofilters

Hydrologic module

Process-based **pollutant transport** module:

- **Advection**
- **Dispersion**
- **Volatilisation**
- **Sorption**
- **Biodegradation**

MPiRE model



Previously validated for controlled column studies for hydrophilic substances (Randelovic et al., 2016)

Model for micropollutant treatment in biofilters

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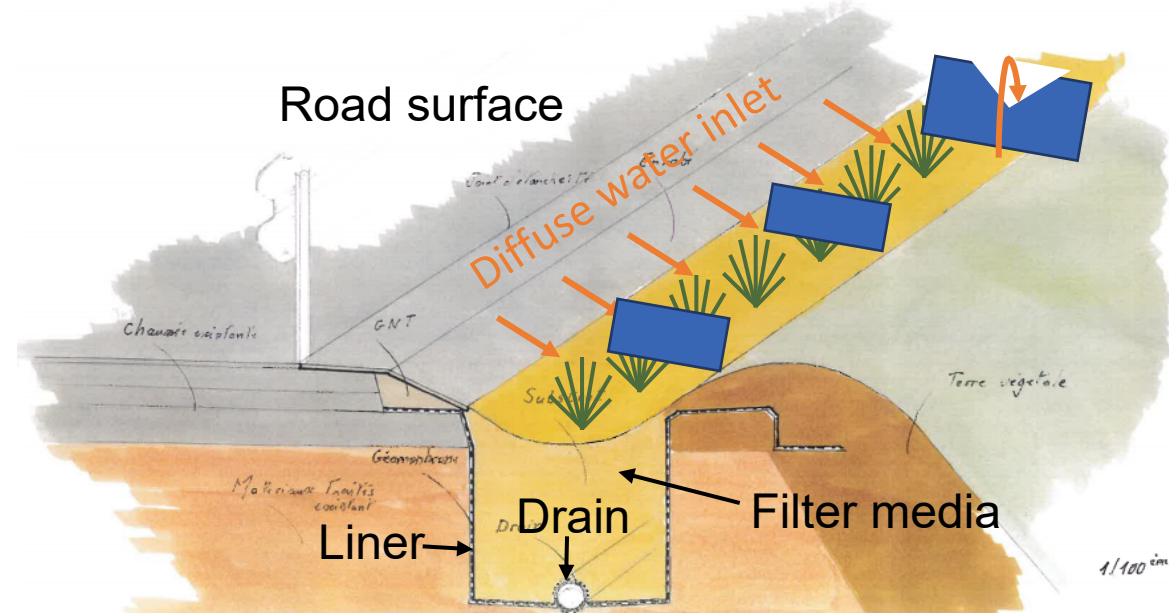
Compare 1-year pollutant loads (with uncertainty propagation) established from field data and model

- 2 Trace metals
 - Copper
 - Zinc
- 2 PAHs
 - Pyrene (Pyr)
 - Phenanthrene (Phen)
- 1 Phthalate
 - DEHP
- 2 Alkylphenols
 - Nonylphenol (NP)
 - Octylphenol (OP)

Diversity of physico-chemical properties (K_D , K_{OW} , degradability...)

Methods Compans field data set

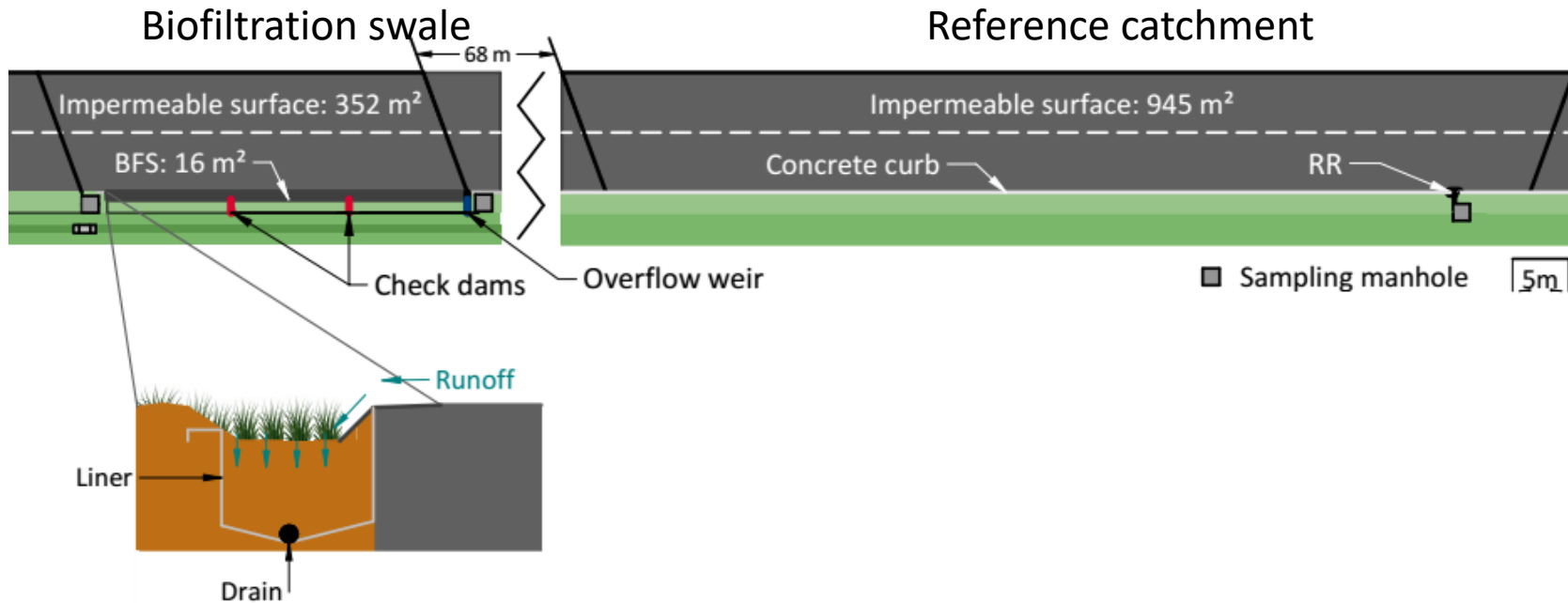
- Constructed **March 2016**
- **Drained, lined**, located directly at the road
- **50 cm filter media** (sandy loam, alkaline pH, low organic matter content)
- 30 m x 0.7 m
- **Check dams & overflow weir** (installed in June 2016)



Schema adapted from Eric Thomas

Compans data set

Sampling & Measurement



Flow proportional event mean water sampling

- **BFS**: drained water from the biofiltration swale (15 events)
- **RR**: untreated road runoff from nearby reference catchment (14 events)
- **Continuous flow and rainfall measurement**

(Flanagan et al., 2018)

Annual pollutant loads

$$M = \sum C_{ev} V_{ev}$$

Numerous uncertainties!

Monte-Carlo uncertainty propagation

Uncertain terms **varied** within a **distribution of possible values**

- Analytical uncertainty
- C_{ev} for unsampled events?
- V_{ev} when measurements unavailable or invalidated?
- Analytical or flow measurement uncertainties?

X 10 000 to characterize overall uncertainties in each term

(Flanagan et al., 2019)

Modelling approach

Calibration of hydrologic module using rainfall, potential evapotranspiration and drain outflow data



Uncertainty analysis of pollutant module: drain outlet pollutant concentrations and loads

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Initial loss model on catchment

Calibration of D (**depression storage**)

Adjustment of catchment surface

Semi-2D representation of biofiltration swale to account for slope and check-dams
(swale represented as three 1-D sections)

Calibration of Ks (**hydraulic conductivity**)

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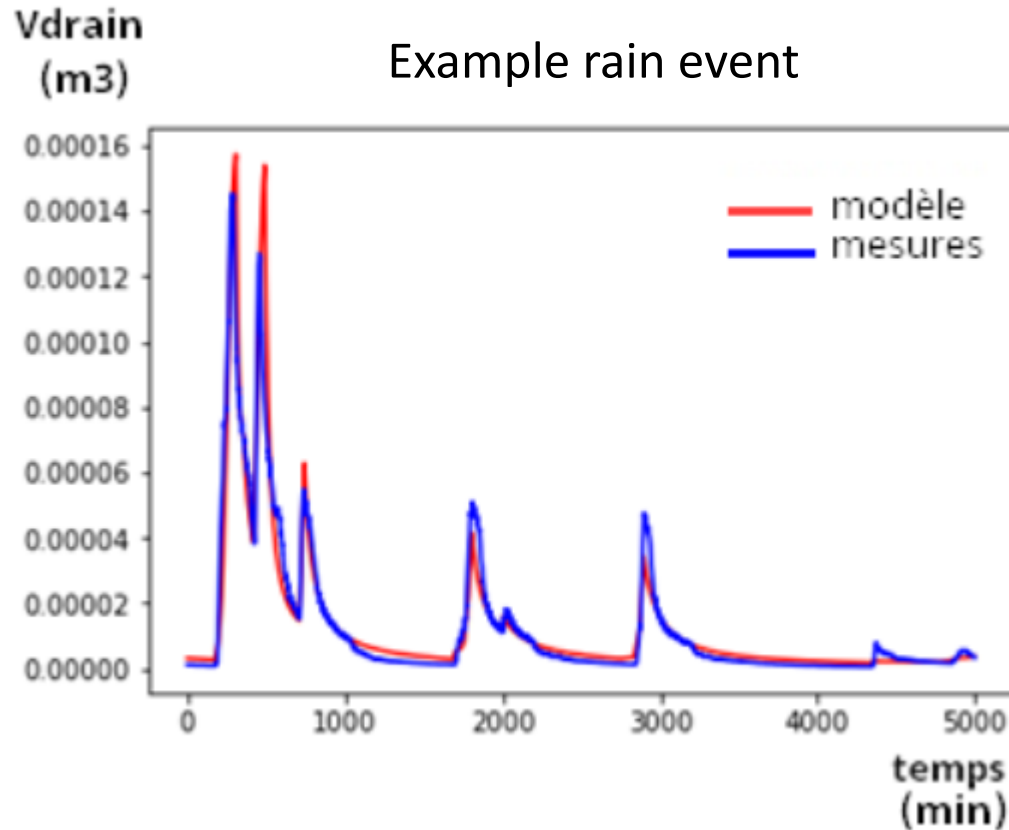
Calibration of Ks (**hydraulic conductivity**)

Monte-Carlo method

Variation of pollutant transport parameters in **possible ranges**

- H_c (**Henry's constant**)
- f_e (**fraction of sorption sites in instantaneous equilibrium**)
- K_{oc} (**organic carbon partition coefficient**)
- α_K (**rate of kinetic sorption**)
- $T_{1/2}$ (**biodegradation half-life**)
- α_L (**dispersivity**)

Results hydrologic module

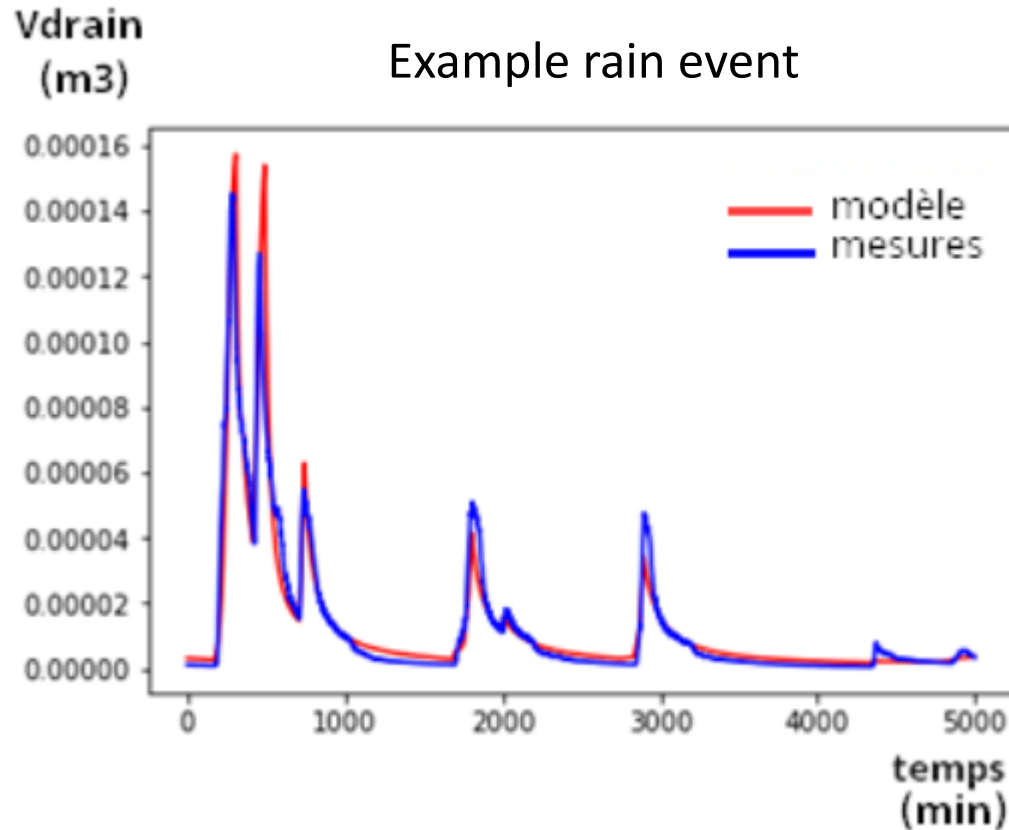


Final configuration of the biofiltration swale:

Nash-sutcliffe = 0.7

Modelled outflow volume = measured volume

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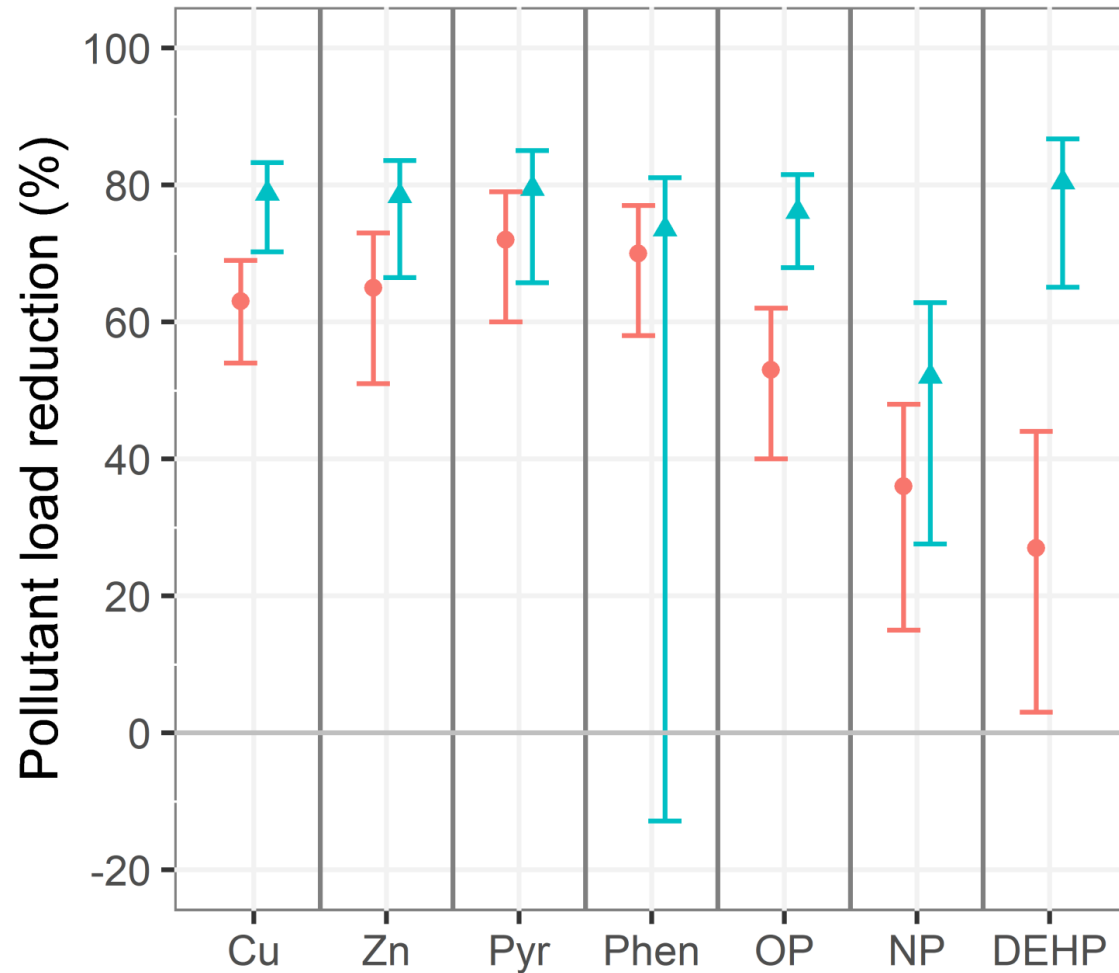
Final configuration of the biofiltration swale:

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Significant effort required to adjust model to the site
(Adjustment of configuration and parameters)

Results: load reduction

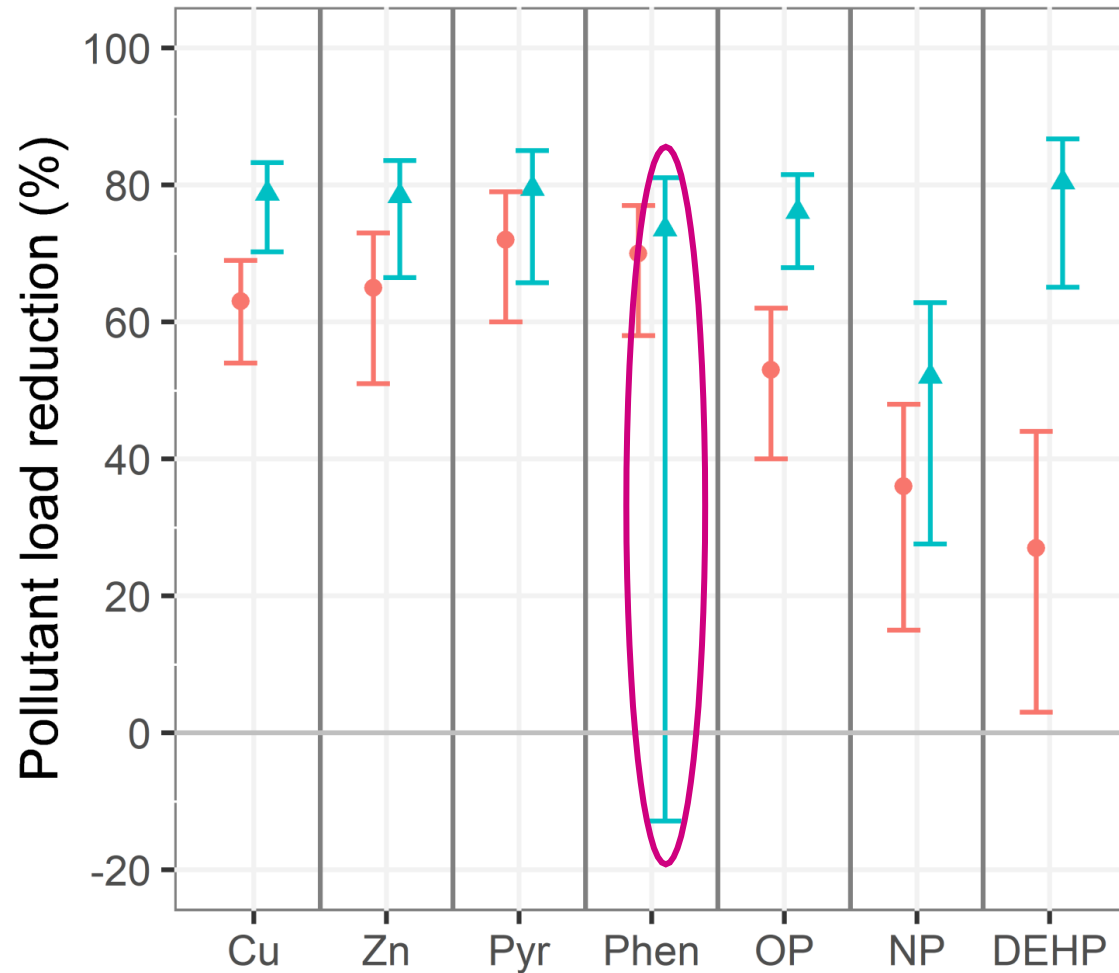


Legend

- Experimental
- Modeled

$$\text{Load reduction} = \left(1 - \frac{M_{\text{drain}} + M_{\text{over}}}{M_{\text{in}}} \right) 100$$

Results: load reduction



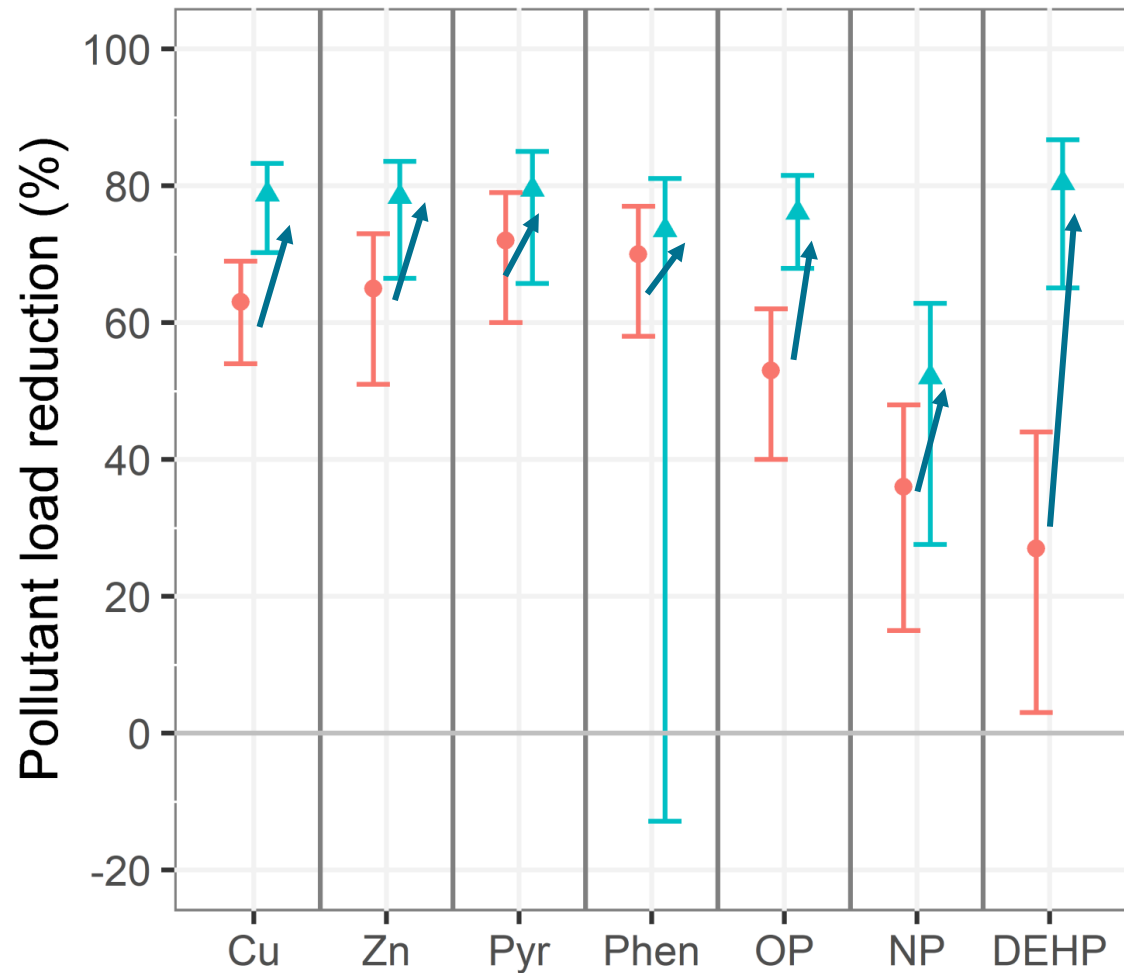
Large uncertainties in modeled load reduction

Especially for **phenanthrene**, which had $\log(K_{oc})$ in huge range: 2.42-6.02

Legend

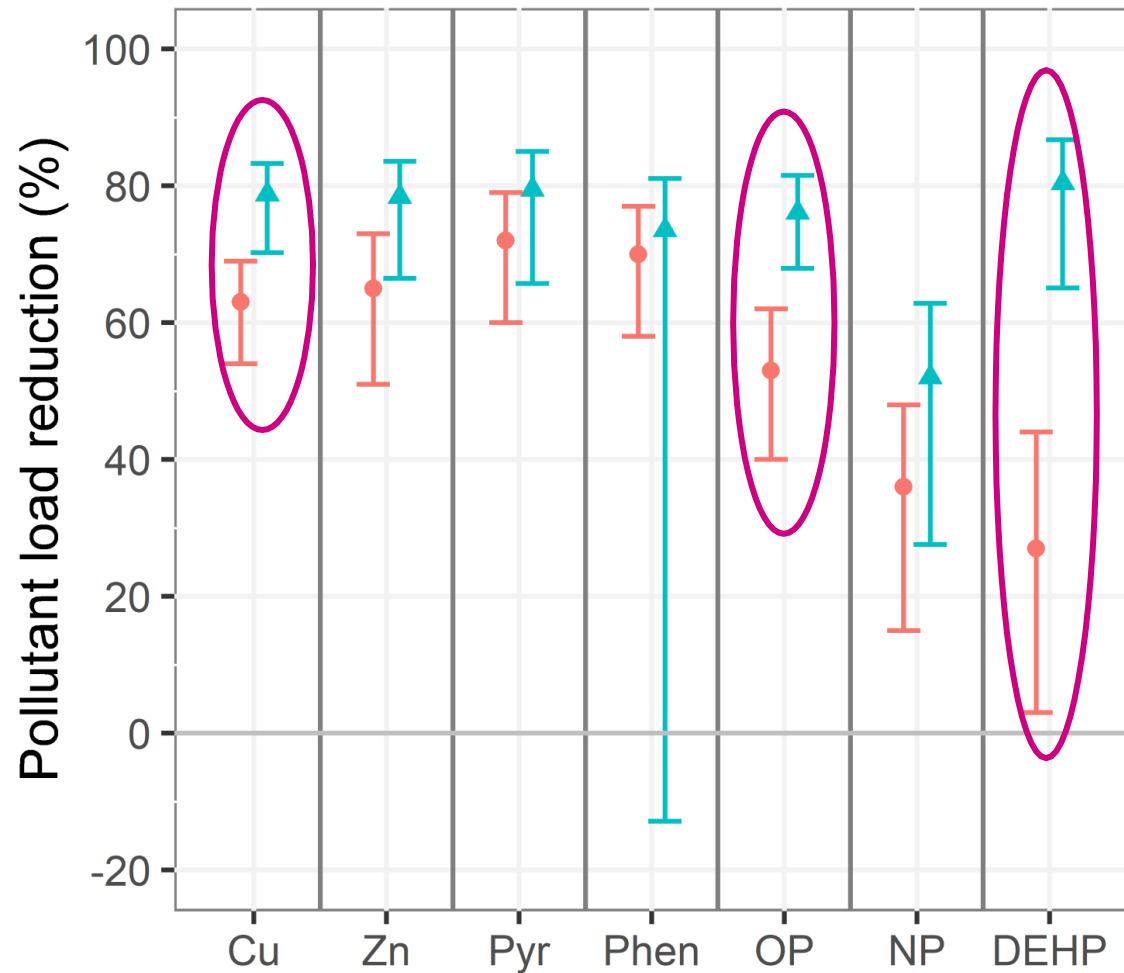
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Results: load reduction



Model tends to
**overpredict load
reduction**

Results: load reduction



Legend

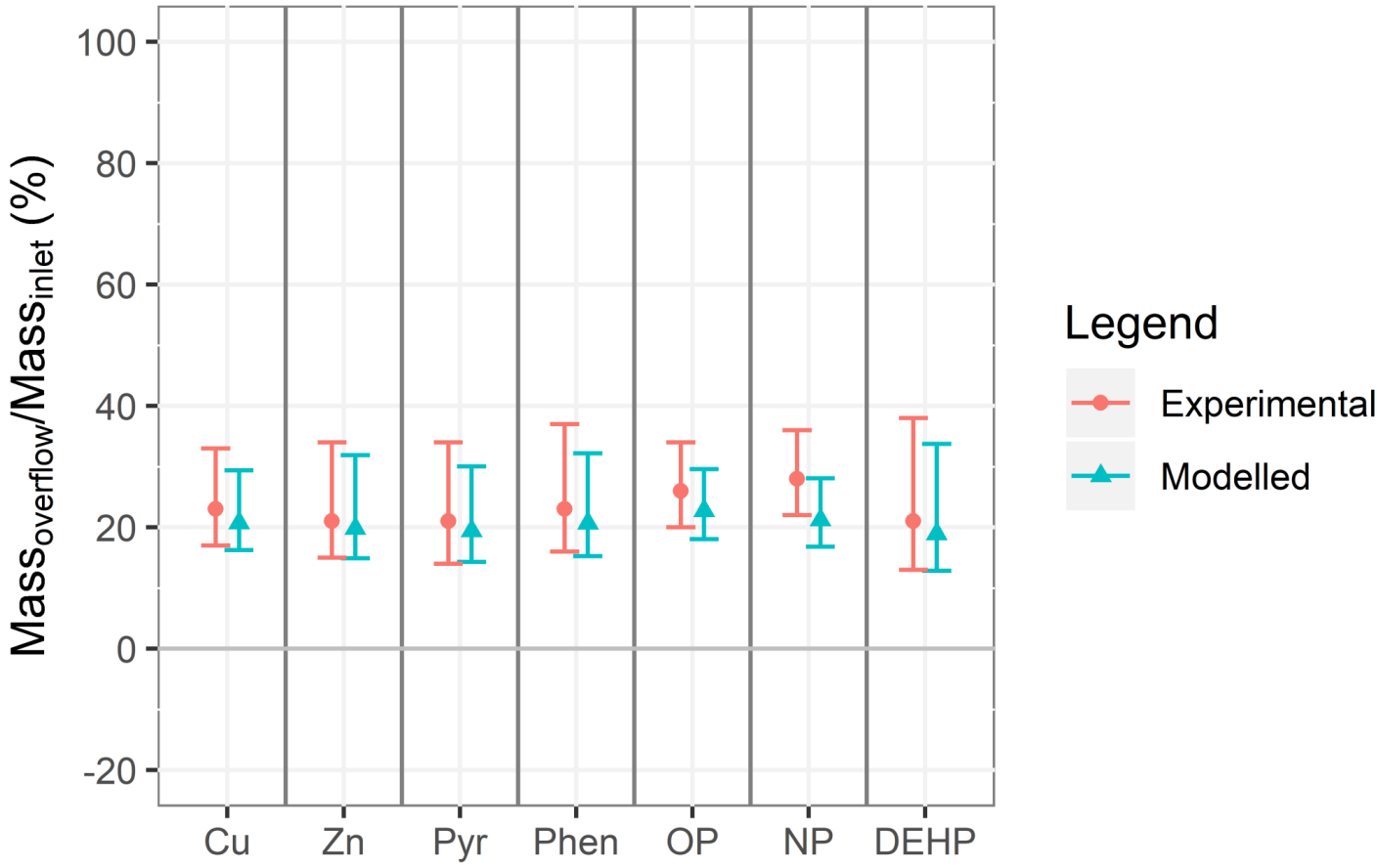
- Experimental
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Significant differences for
Cu, DEHP, OP

Problems with overflow or drain masses?

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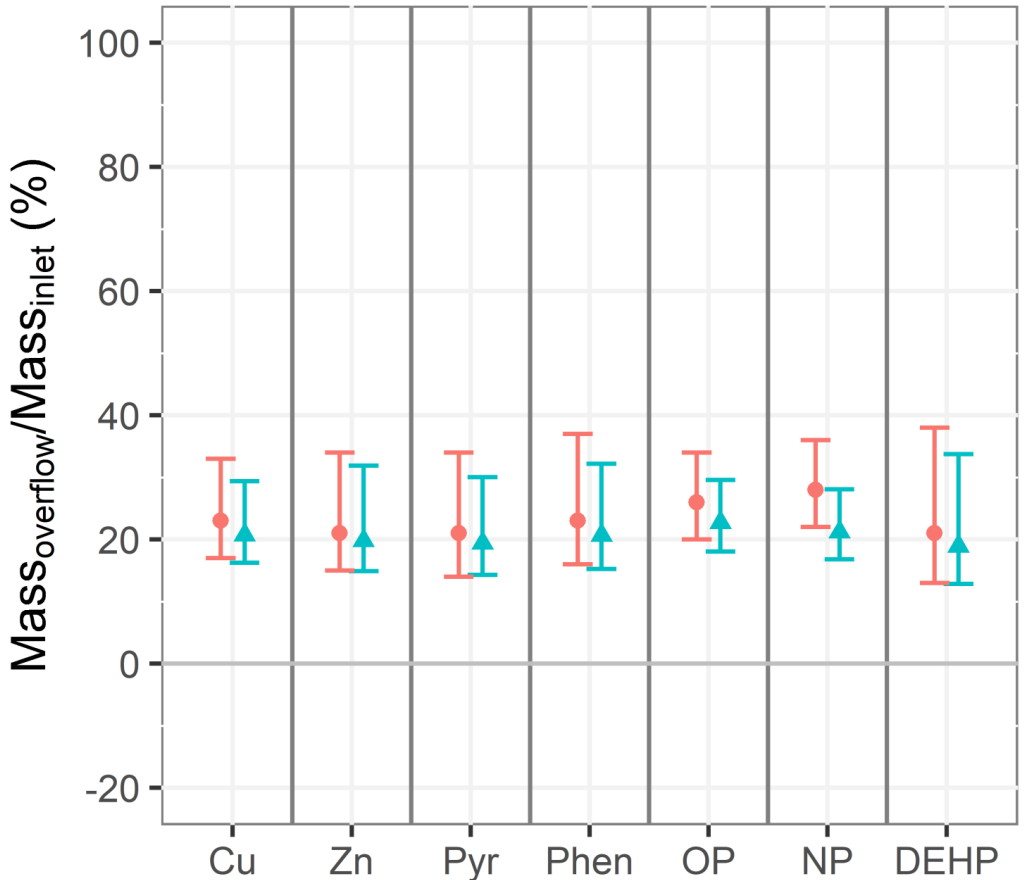
Proportion overflowed



✓ Basically okay

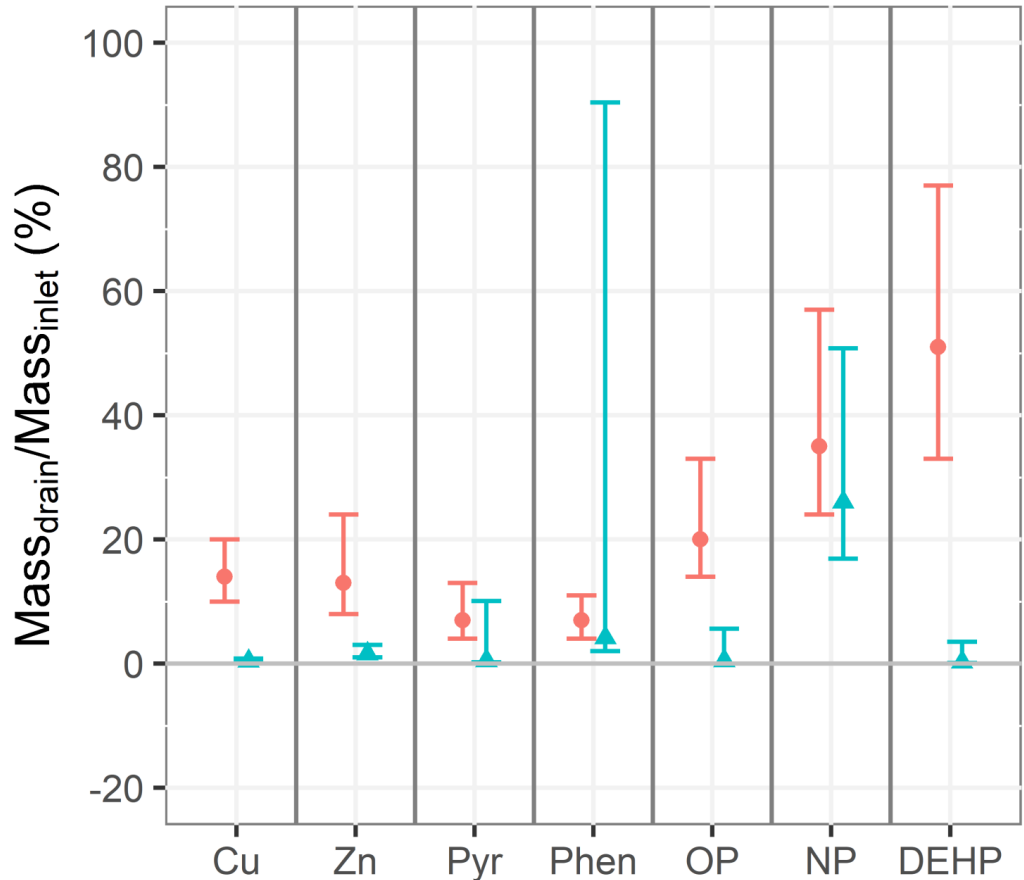
Problems with overflow or drain masses?

Proportion overflowed



✓ Basically okay

Proportion drained



Significant differences for Cu, Zn, OP and DEHP

Legend

- Experimental (red circle)
- Modelled (teal triangle)

What important processes is the model missing?

- Solid-liquid partitioning in the liquid phase
- Particle transport and physical filtration
 - In particular, colloidal transport (consider particle size as well as solid-liquid)

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But can we really desire or expect models to represent this?

Conclusions

- MPIRE's **hydrologic module** provided a good fit for outflow
 - Flow not evenly distributed: necessitates **semi 2D configuration**
- MPIRE's **pollutant transport** module tends to **over-predicts pollutant removal**
 - Speciation limiting treatability?
 - Unexpected processes (e.g. pollutant emissions from construction materials) cannot be represented by a model
- Applying **process-based models** to **field data** can allow us to develop a better **understanding of processes** occurring in biofilters



École des Ponts
ParisTech

Thank you!



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