Impact of non-conventional waters on the unsaturated zone

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SEP GROUP

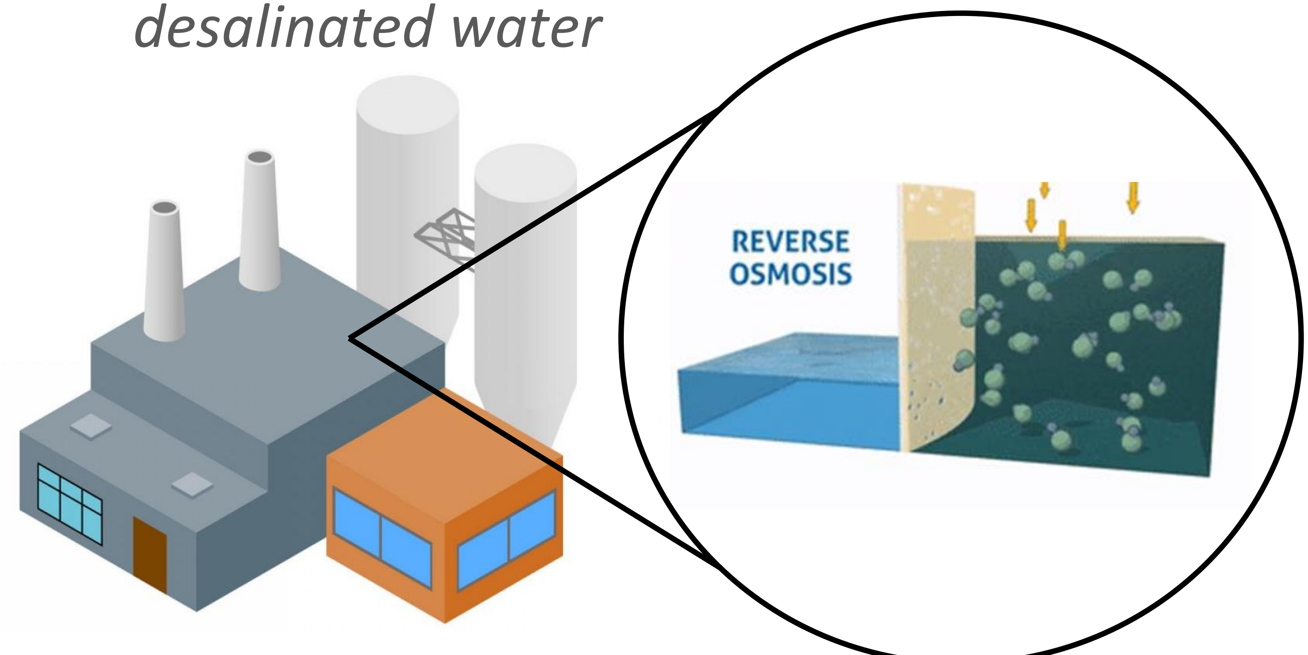
Subsurface Environmental Processes

www.sepgroup.ethz.ch

Non-conventional waters

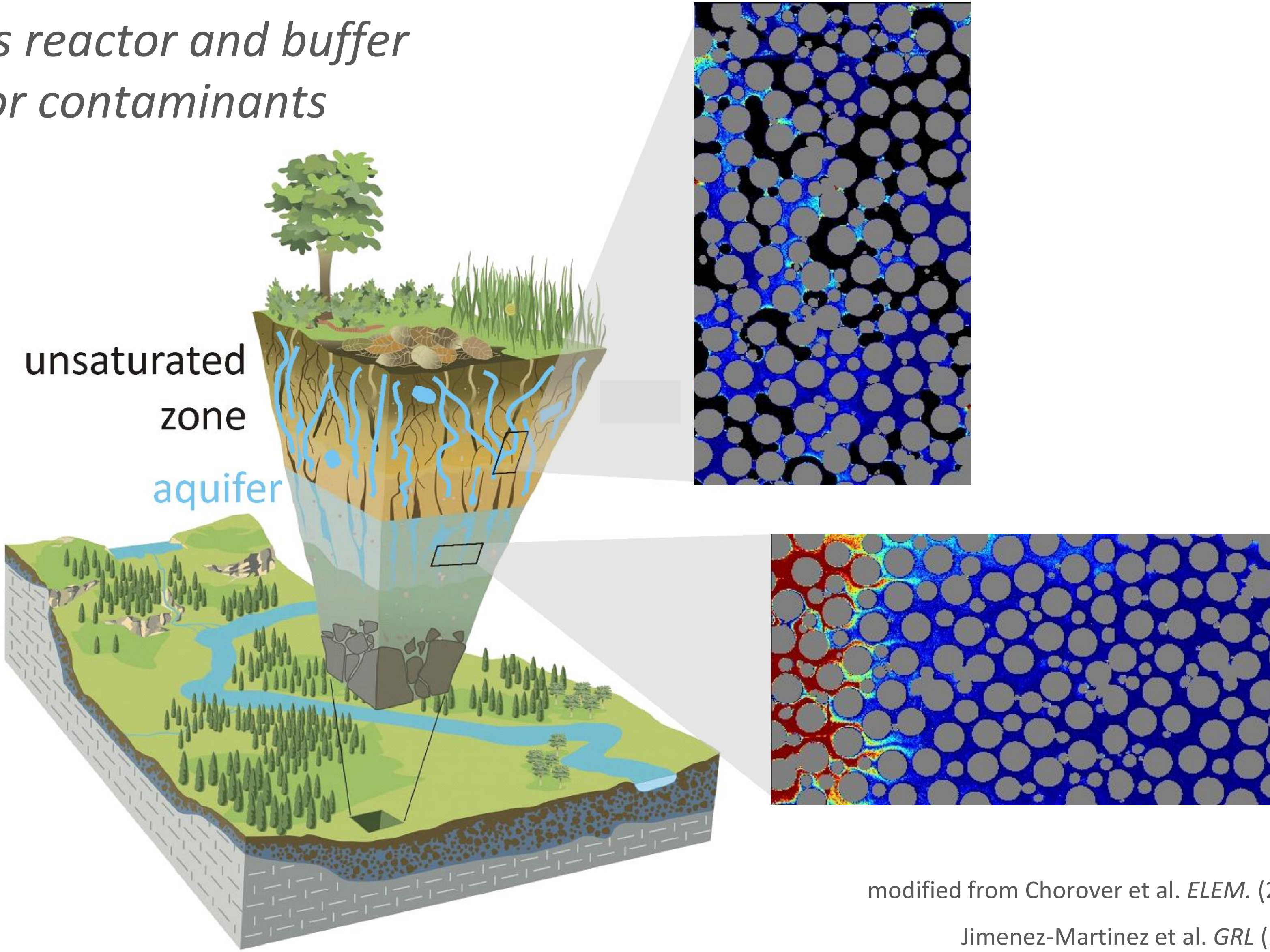
treated wastewater + sewage sludge

desalinated water



The unsaturated zone

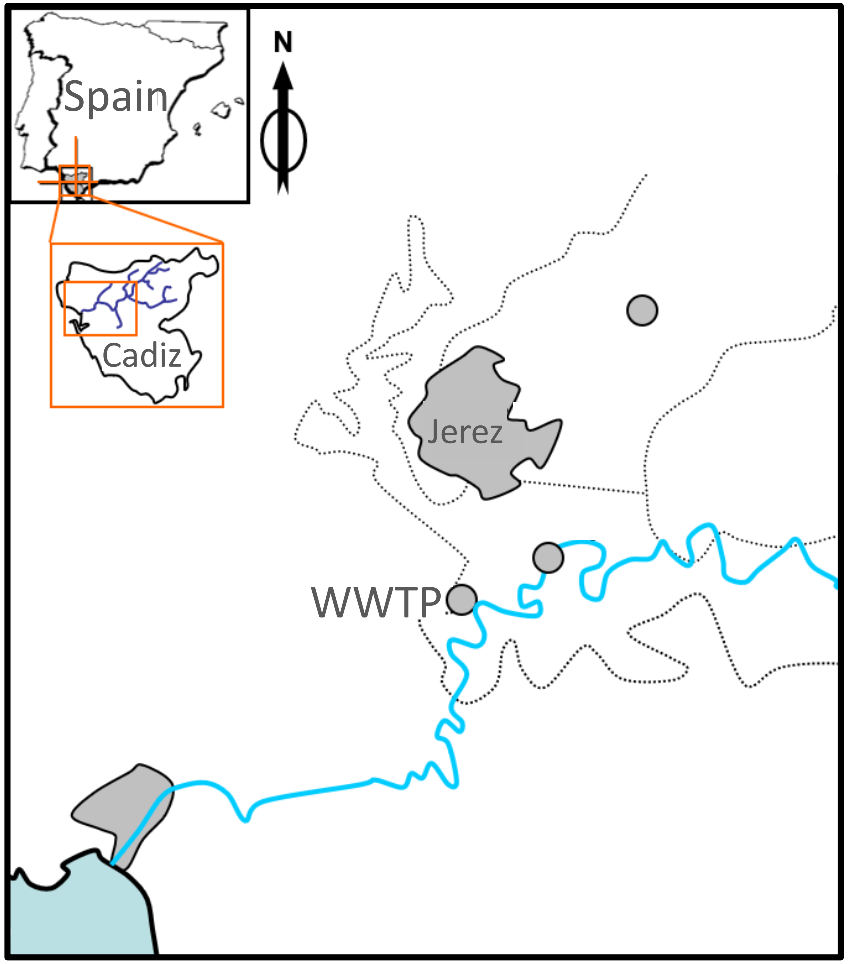
as reactor and buffer for contaminants



modified from Chorover et al. *ELEM.* (2007)

Jimenez-Martinez et al. *GRL* (2015)

Impact from treated wastewater



Corada-Fernandez et al. *CHEM* (2015)

pharmaceuticals (64 compounds)

using indicators such as pK_a / log K_{ow} / D_{ow}

non-polar compounds
tendency to be adsorbed in soil
photodegradation

low concentrations

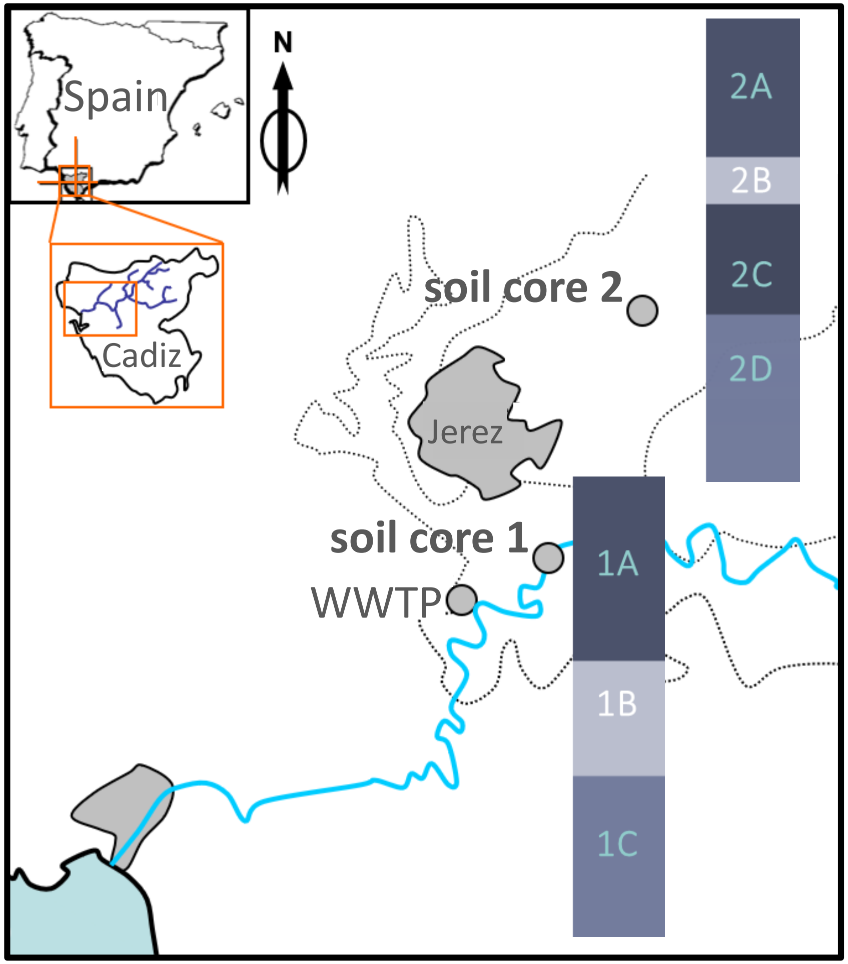
surfactants

linear alkylbenzene sulfonates (LAS)
alcohol ethoxysulfates (AES)
nonylphenol polyethoxylates (NPEOs)
alcohol polyethoxylates (AEOs)

degradation

metabolites

Impact from treated wastewater



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degradation

metabolites

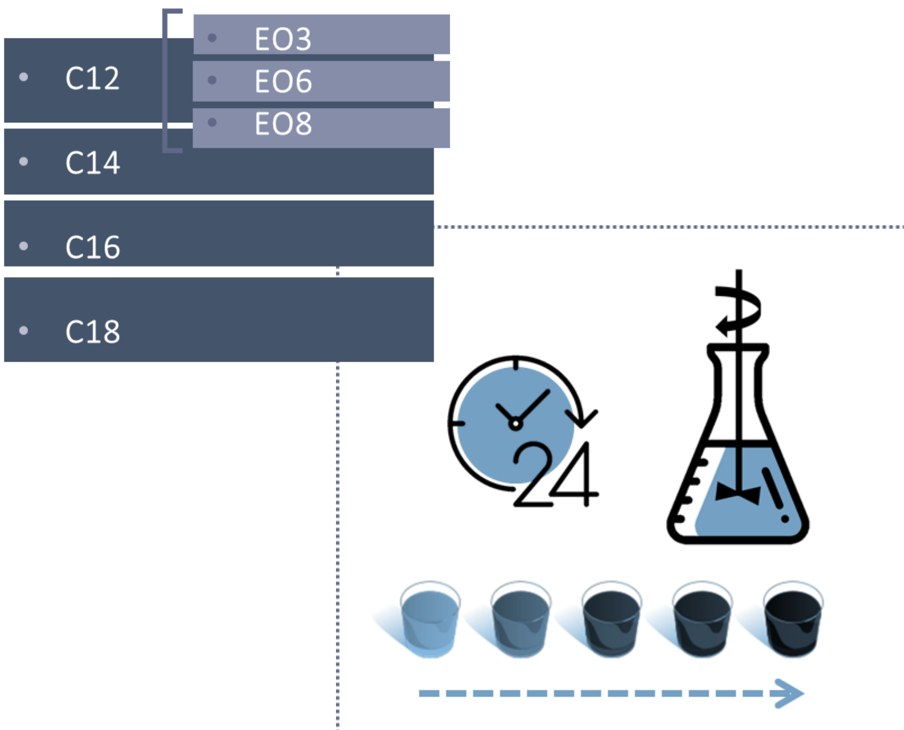
Non-ionic surfactants – isotherms and transport

alcohol polyethoxylates (AEOs)

$$CH_3\text{-}(CH_2)_{\varepsilon}\text{-}(O\text{-}CH_2\text{-}CH_2)_{\varepsilon'}\text{-}OH$$

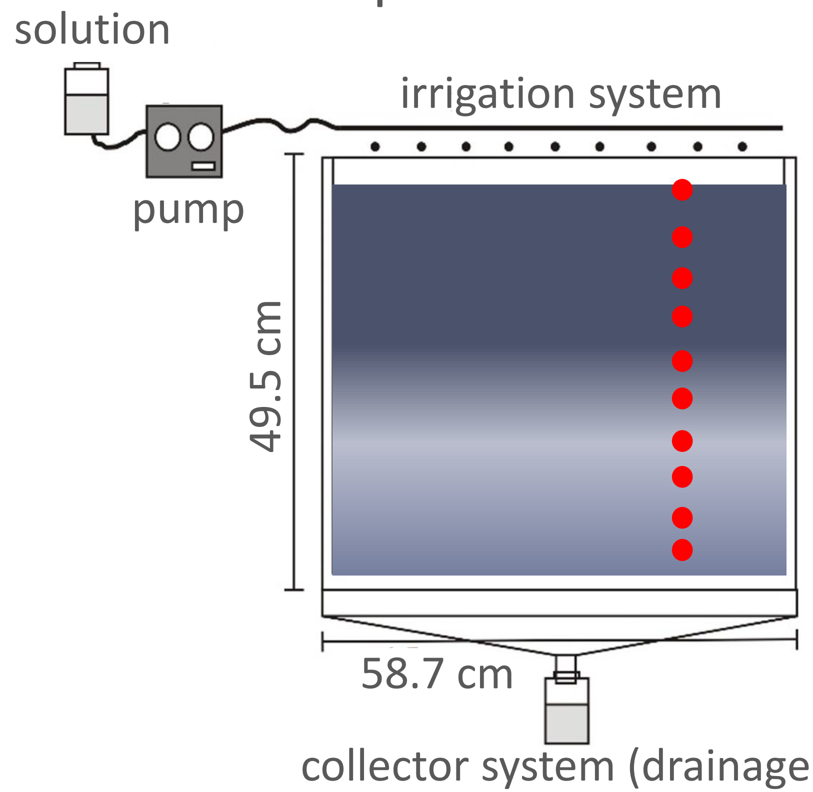
$$11 \leq \varepsilon \leq 17$$
$$1 \leq \varepsilon' \leq 20$$

adsorption isotherms – Batch



Corada-Fernandez, Botella-Espeso et al. (*in prep.*)

transport – flow cell



Non-equilibrium chemical transport

unsaturated flow – impact on hydraulic properties (direct simulation)

$$h(\theta, C_w) = \frac{\sigma}{\sigma_o}\ h(\theta, C_{wo})$$

$$K(\theta, C_w) = \frac{v}{v_o}\ K(\theta, C_{wo})$$

e.g., Smith and Gillham *WRR* (1994, 1999)

negligible at very low concentrations

e.g., Paweena Kanokkarn et al. *CSA* (2017)

reactive processes (inverse method)

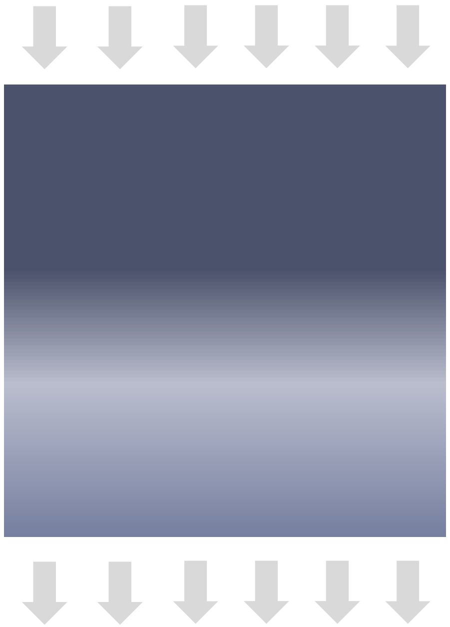
adsorption $$C_s = \frac{K_d C_w^{\beta}}{1 + \eta C_w^{\beta}}$$

degradation $$C_w = C_{wo} e^{-\mu t}$$

$$Pe = \frac{\tau_d}{\tau_a} = \frac{u}{D_m} \Delta x \qquad Da = \frac{\tau_a}{\tau_r} \qquad \tau_r = 1/(C_{wo} k)$$

$Pe < 1$ $\qquad$ $Da << 1$

constant flow



free drainage

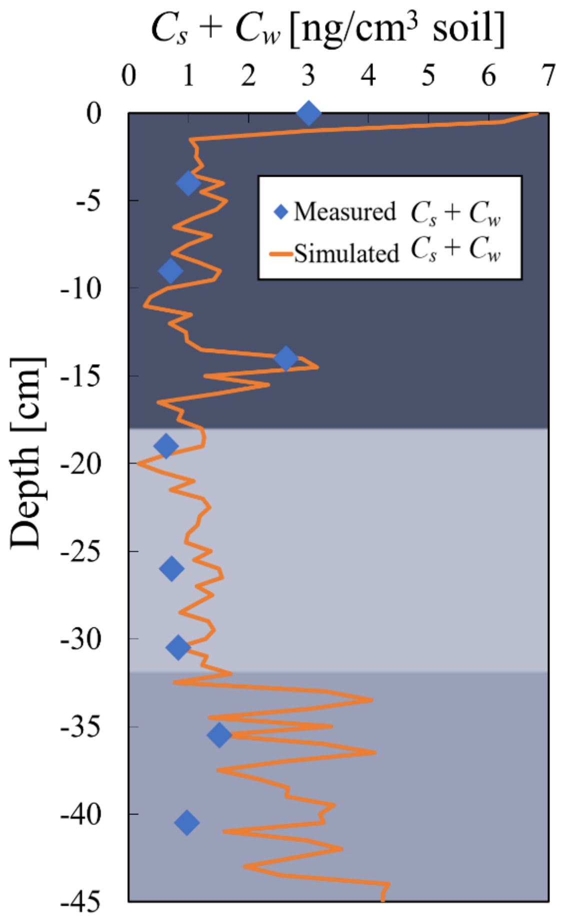
Hydrus 1D – Simunek et al. (2006)
Rosetta – Schaap et al. *JofH* (2001)

Corada-Fernandez, Botella-Espeso et al. (*in prep.*)

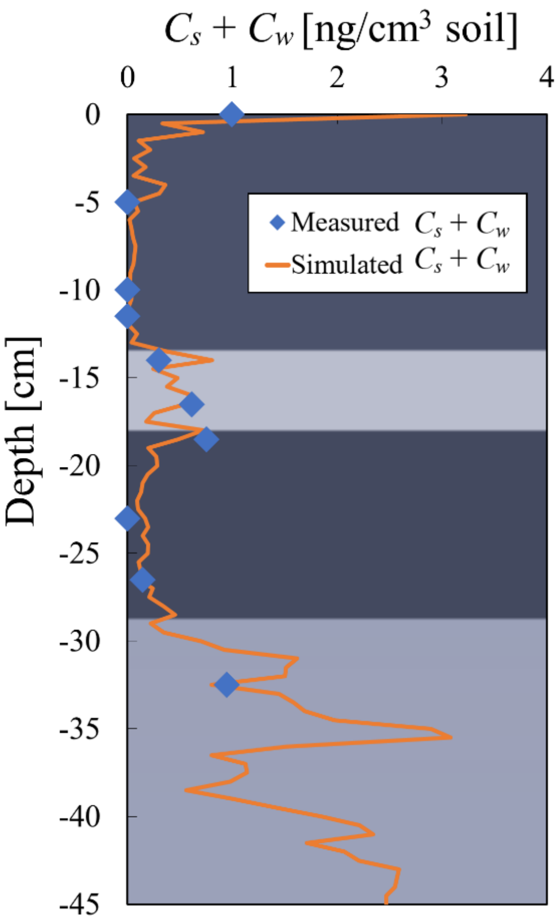
Non-ionic surfactants – fate and transport

C14 AEO EO8

soil core 1 (t = 192h)



soil core 2 (t = 69h)

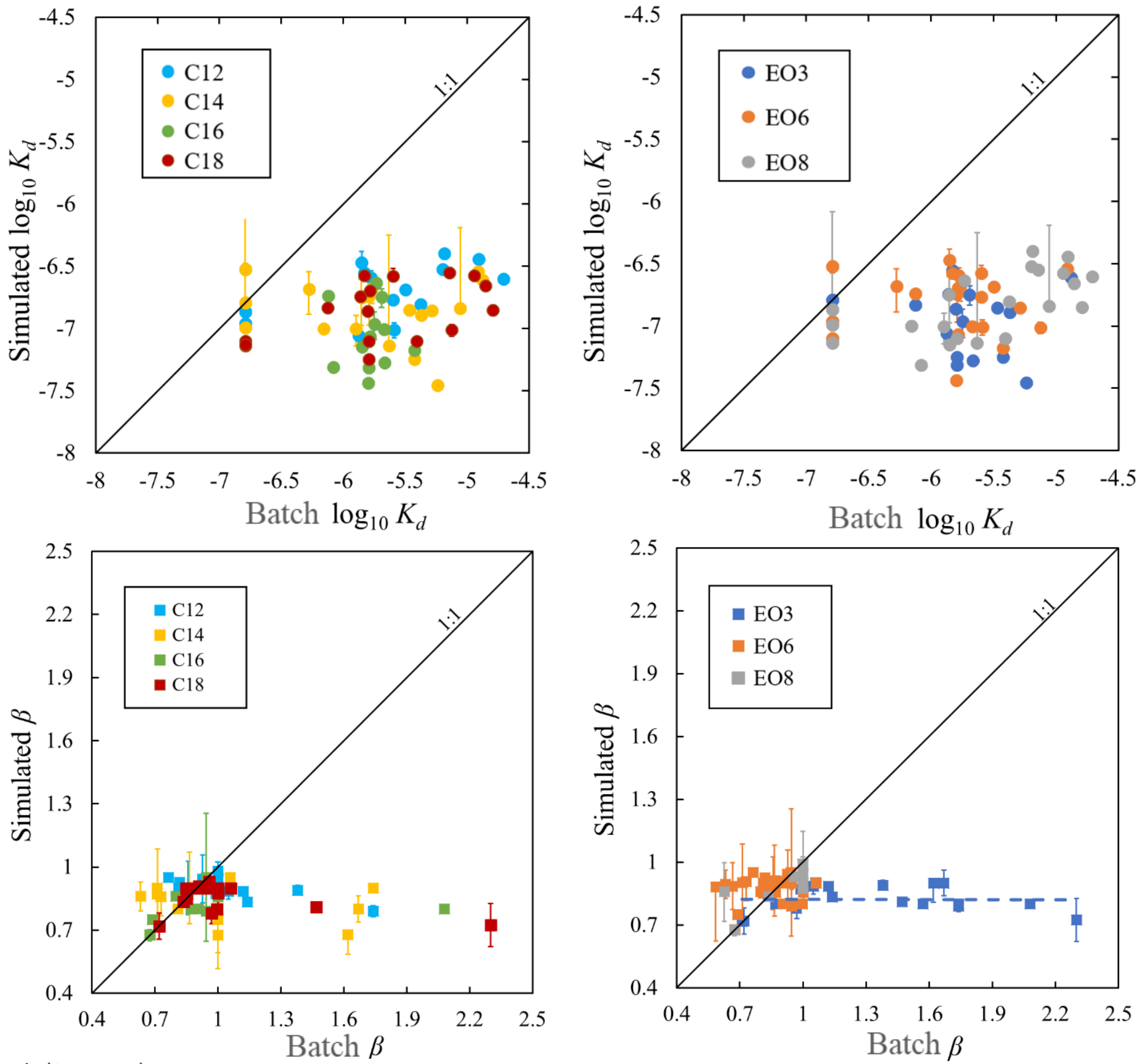


Corada-Fernandez, Botella-Espeso et al. (*in prep.*)

Non-ionic surfactants – fate and transport

$$C_s = K_d \ C_w{}^{\beta}$$

Freundlich

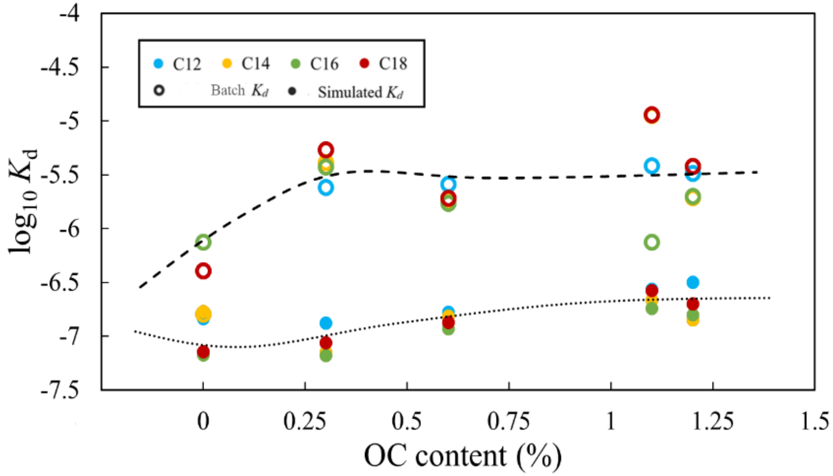


Corada-Fernandez, Botella-Espeso et al. (*in prep.*)

Isotherm coefficients dependence on soil properties

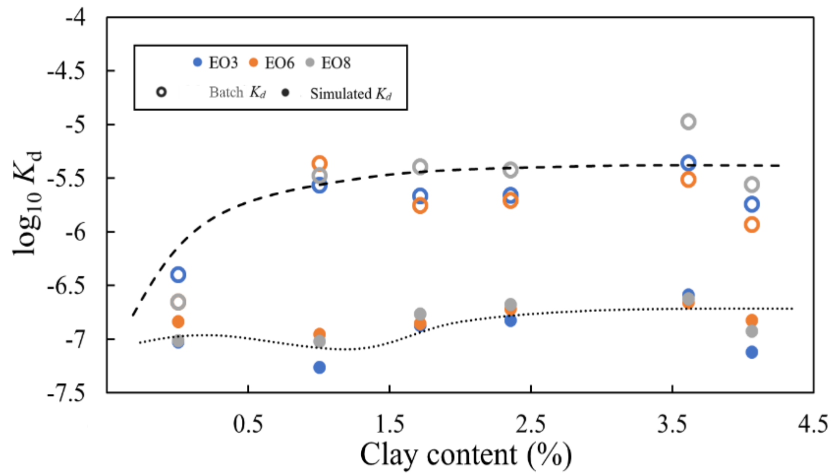
OC content

carbon chain length



clay content

ethoxylated groups



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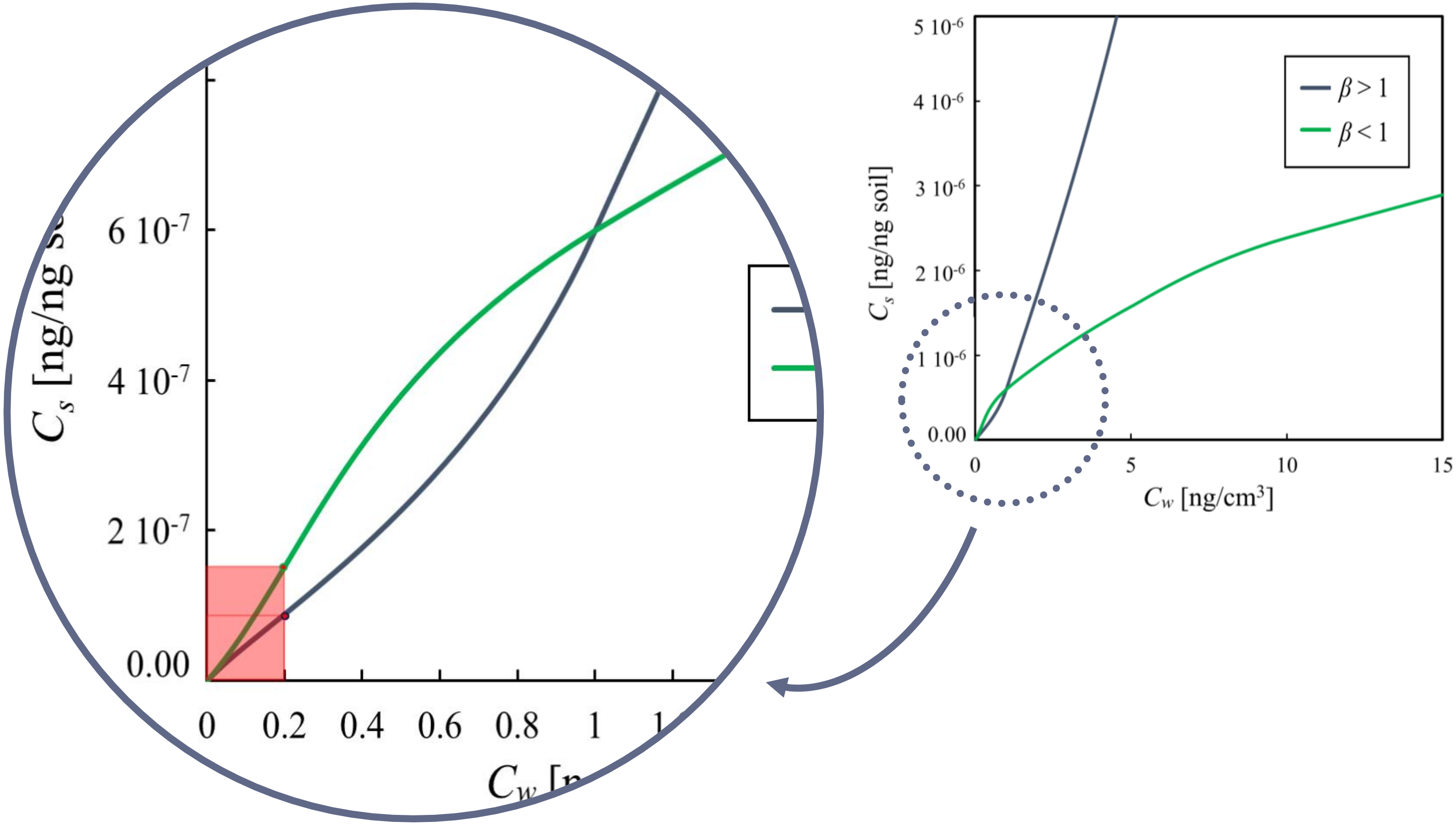
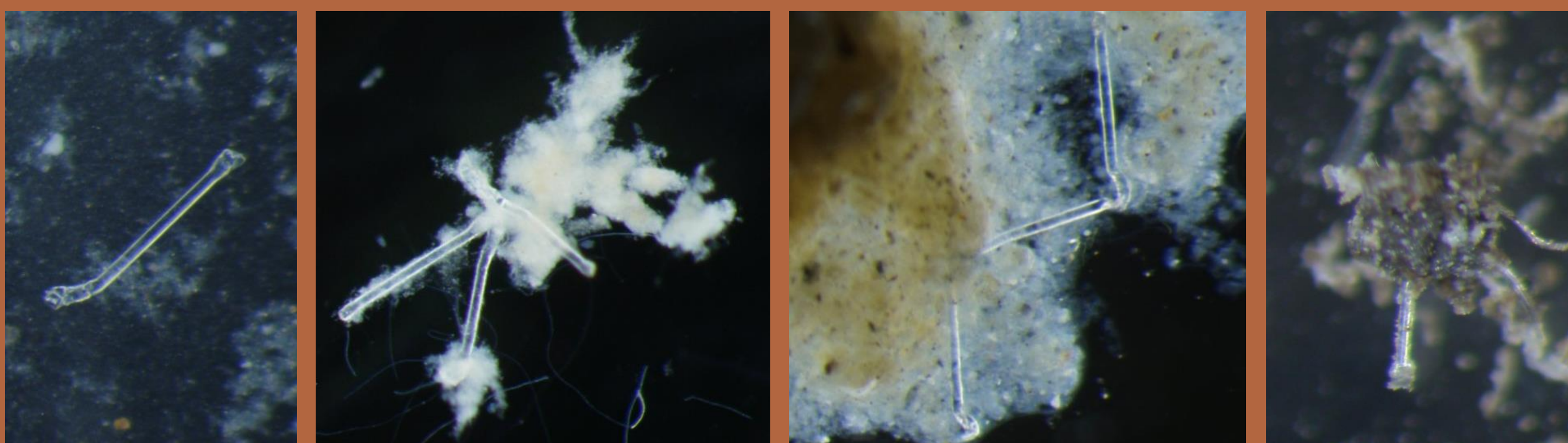
Isotherm coefficients dependence on soil properties



Corada-Fernandez, Botella-Espeso et al. (*in prep*.)

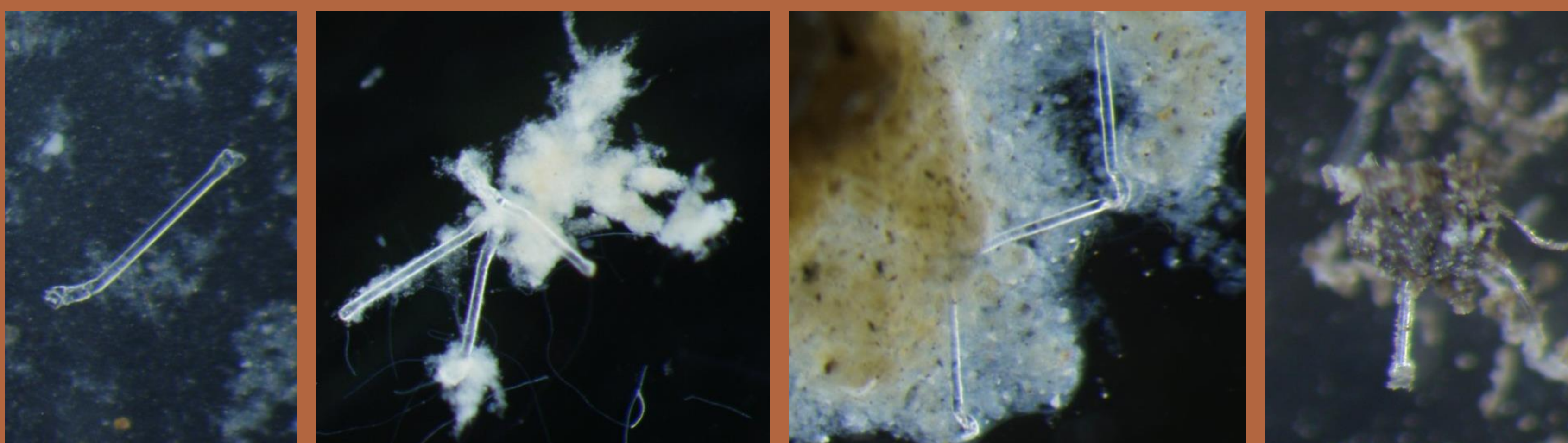
Impact from sewage sludge – particulate plastic



Keller et al. (*under review*)

Impact from sewage sludge – particulate plastic

entry
into the sewer system

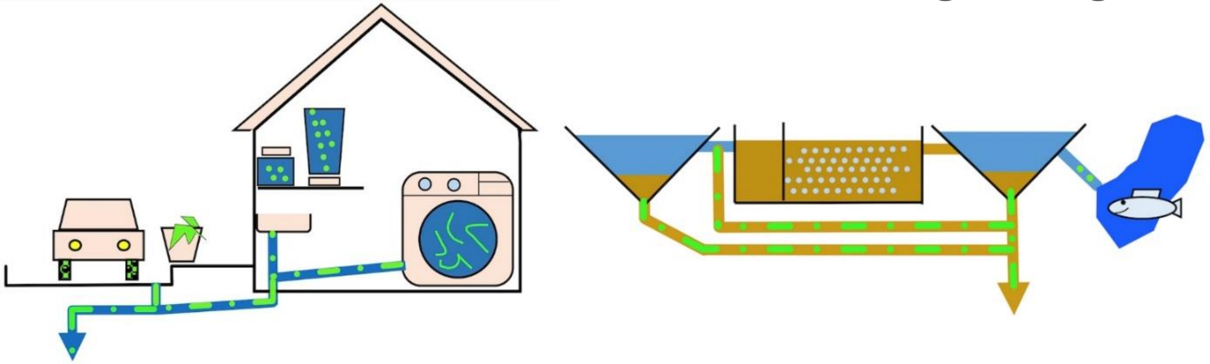


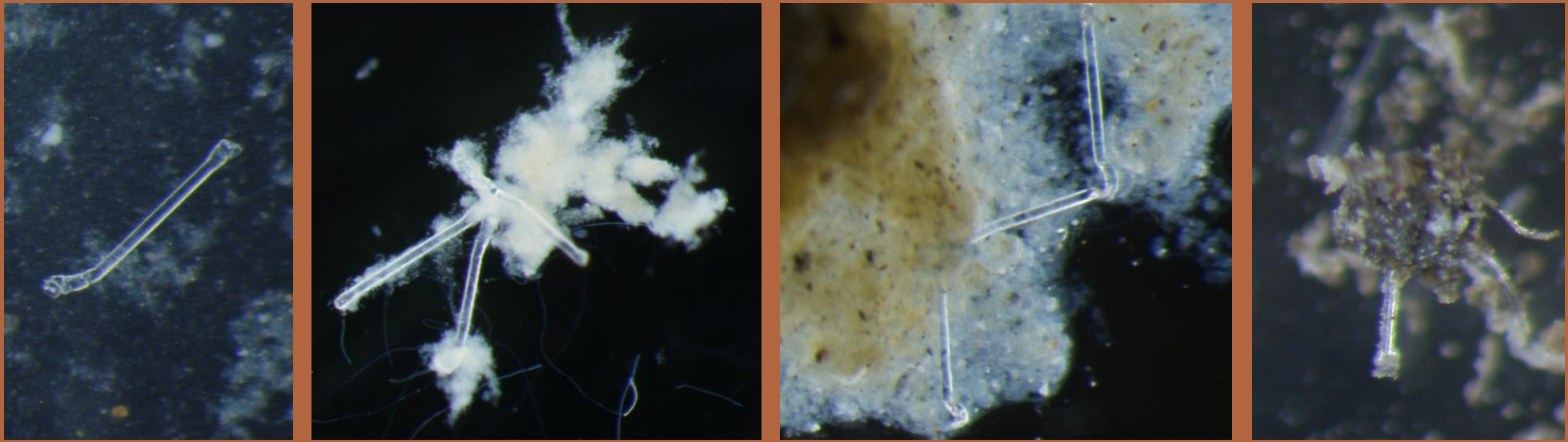
Keller et al. (*under review*)

Impact from sewage sludge – particulate plastic

entry
into the sewer system

accumulation
in the sewage sludge





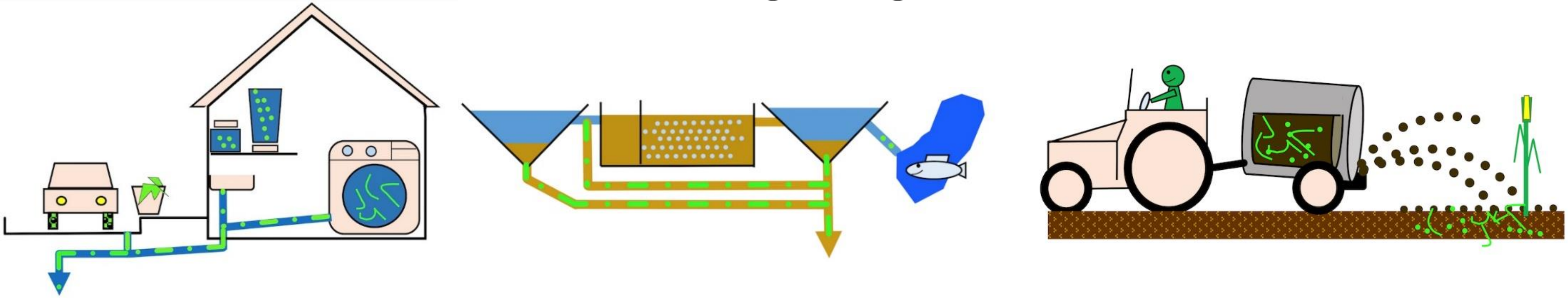
Keller et al. (*under review*)

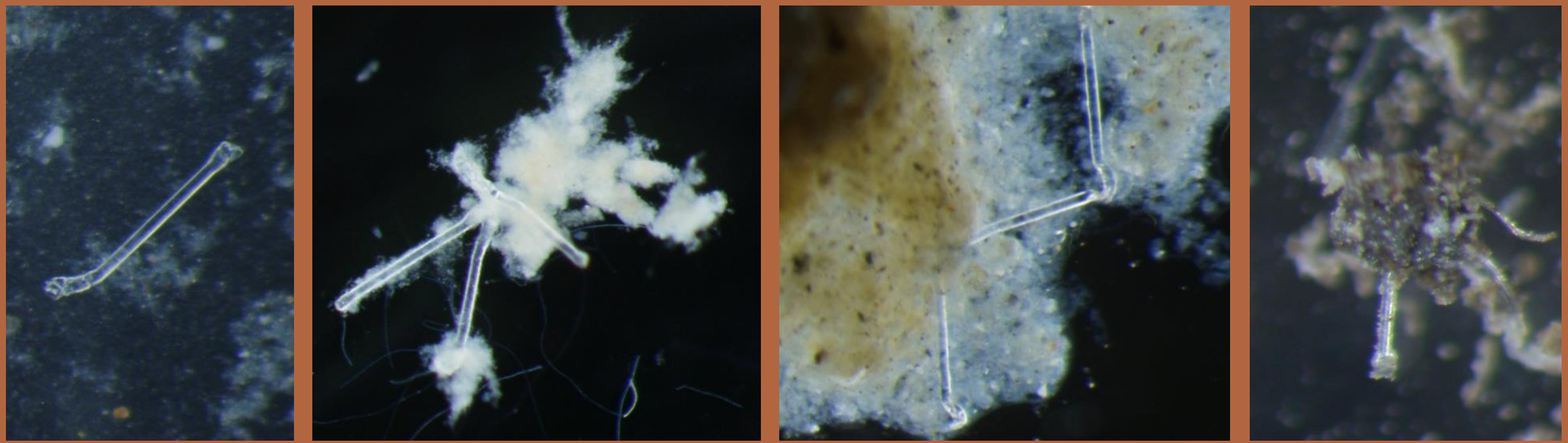
Impact from sewage sludge – particulate plastic

entry
into the sewer system

accumulation
in the sewage sludge

use
as fertilizer

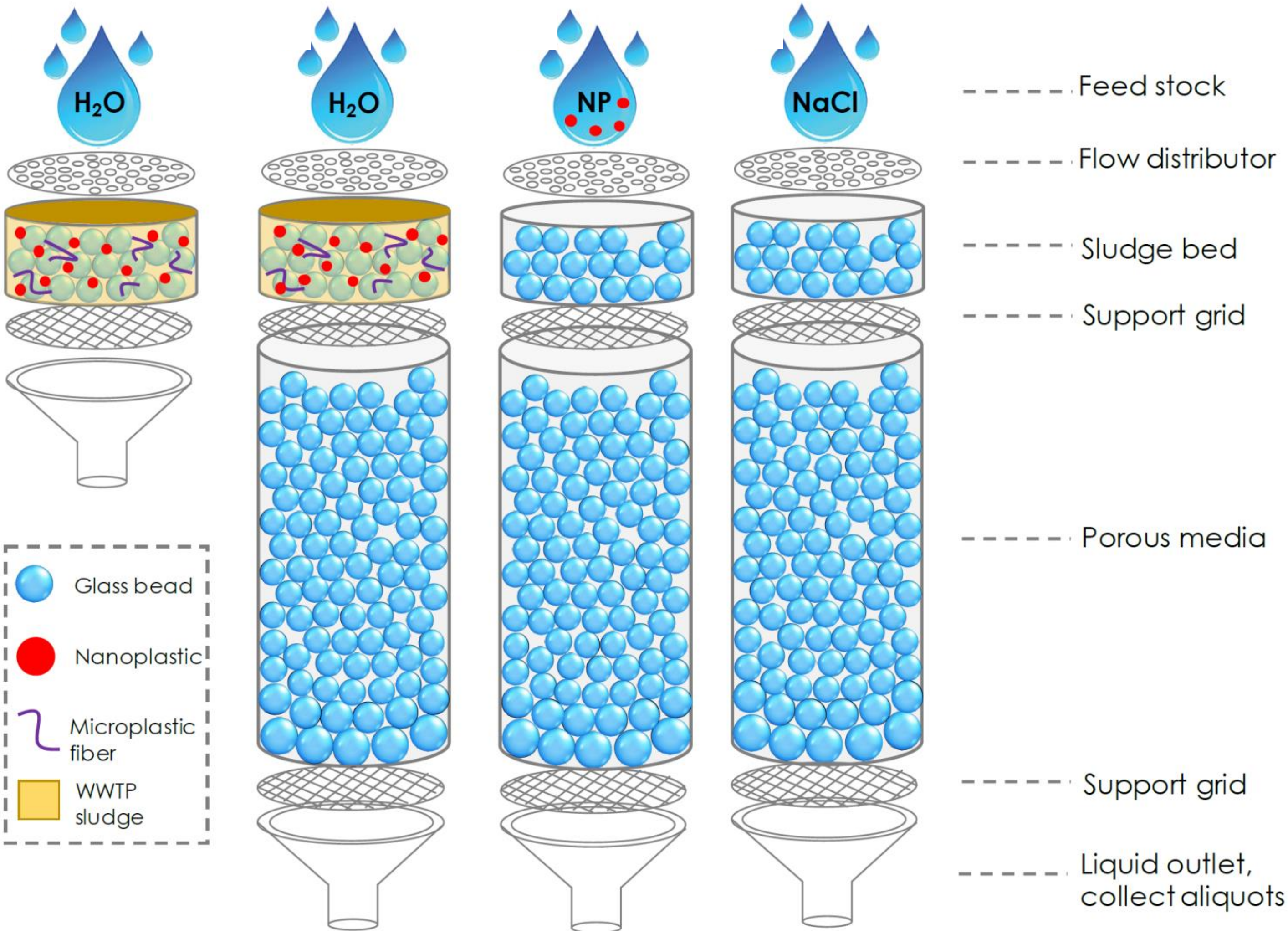




Keller et al. (*under review*)

Leaching from sludge and transport through the soil

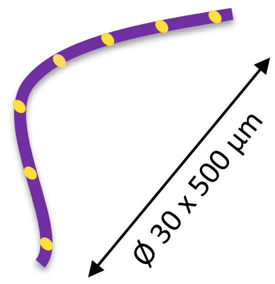
column experiments

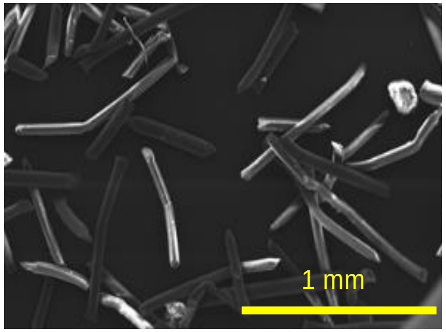


Keller et al. (*under review*)

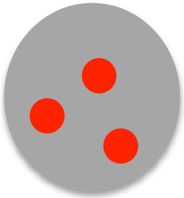
Metal doped particulate plastic

microplastic fibres – Indium

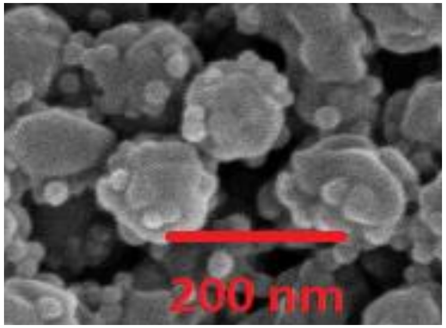




nanoplastic particles – Palladium



Ø 200 nm



Keller et al. (*under review*)
Mitrano et al. *Nat. Nano.* (2019)

Metal doped particulate plastic

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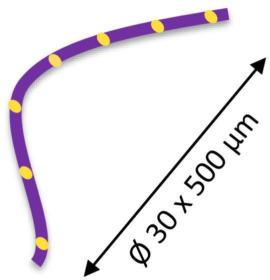
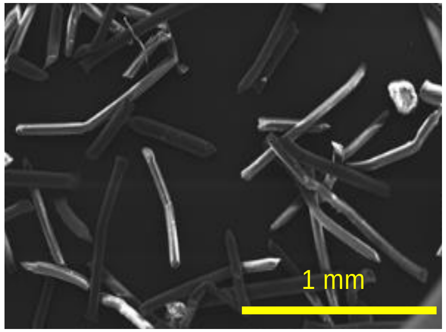
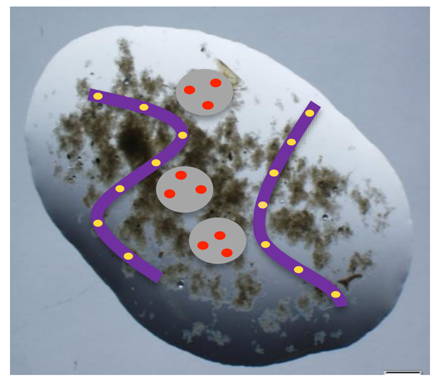




spiking in complex matrix



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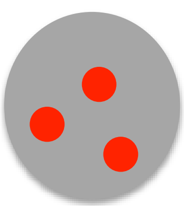

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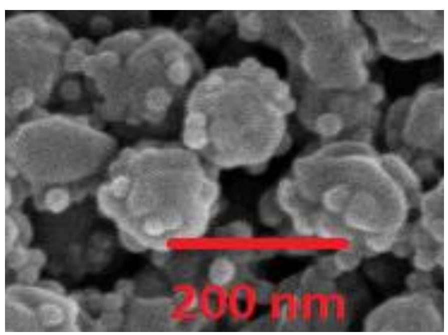

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Mitrano et al. *Nat. Nano.* (2019)

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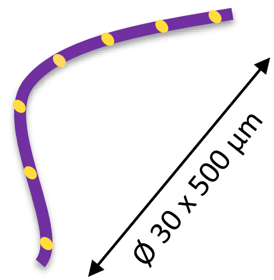

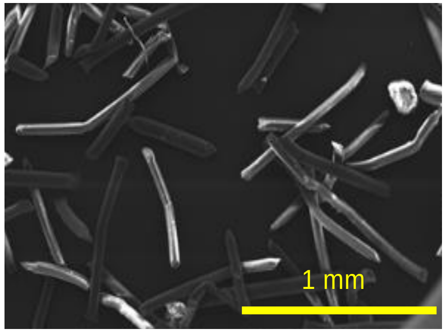

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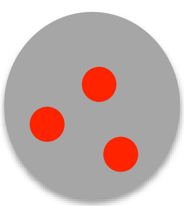

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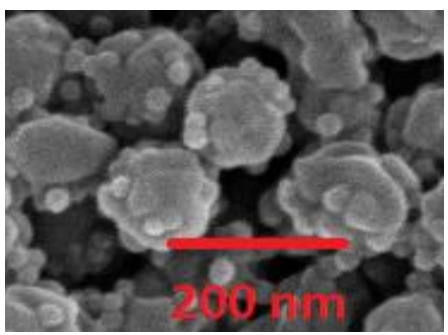

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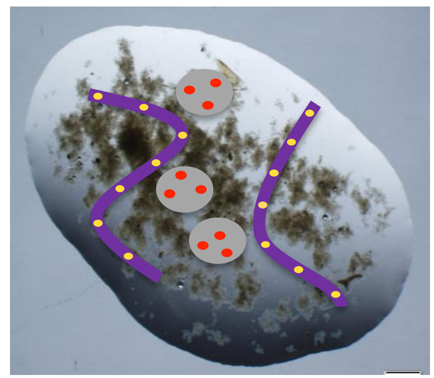
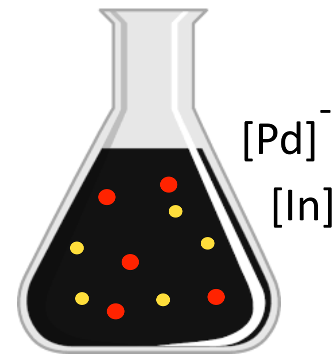
complex matrix



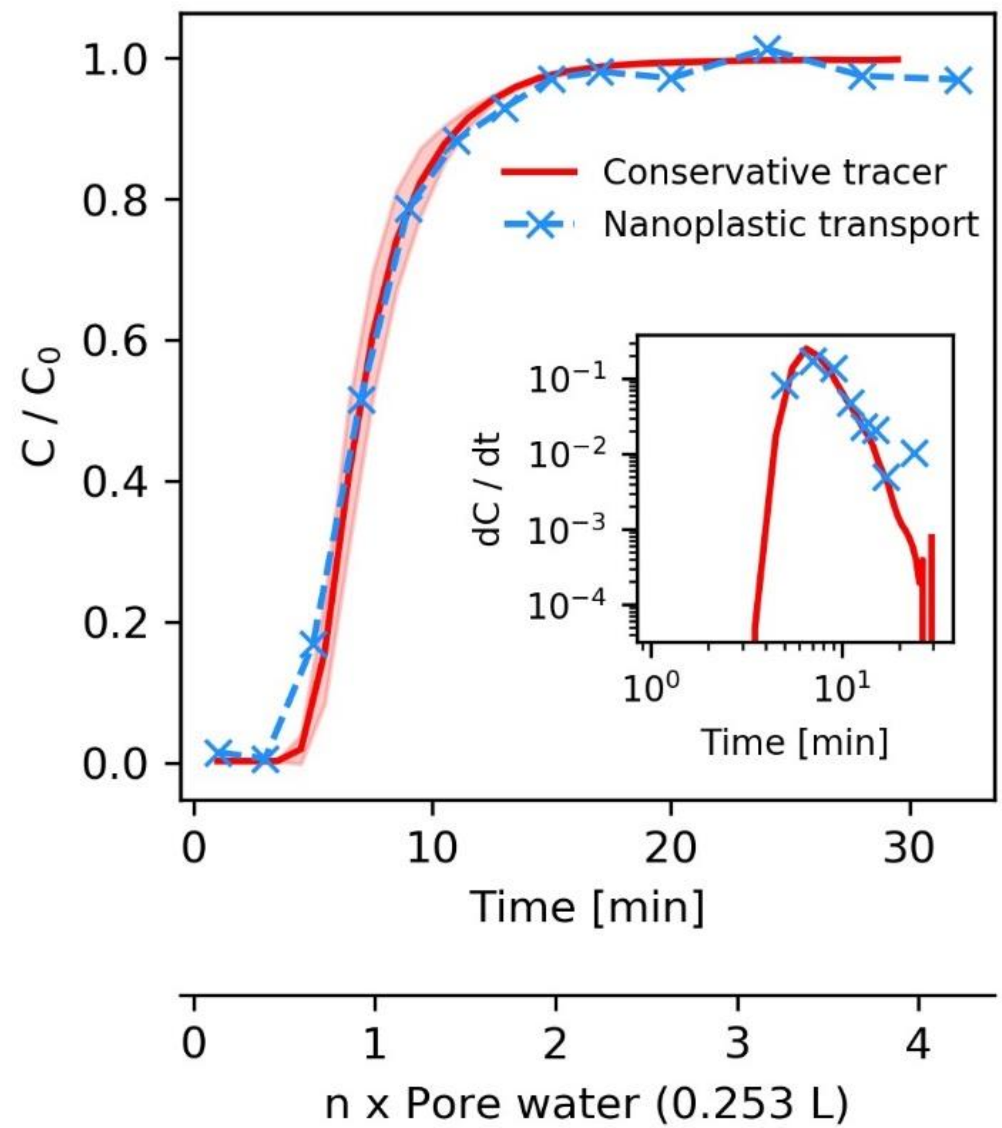
analysis by
Acid Microwave Digestion
ICP-MS



Keller et al. (*under review*)
Mitrano et al. *Nat. Nano.* (2019)

Pristine nanoparticles and tracer transport

anomalous (*non-Fickian*) transport



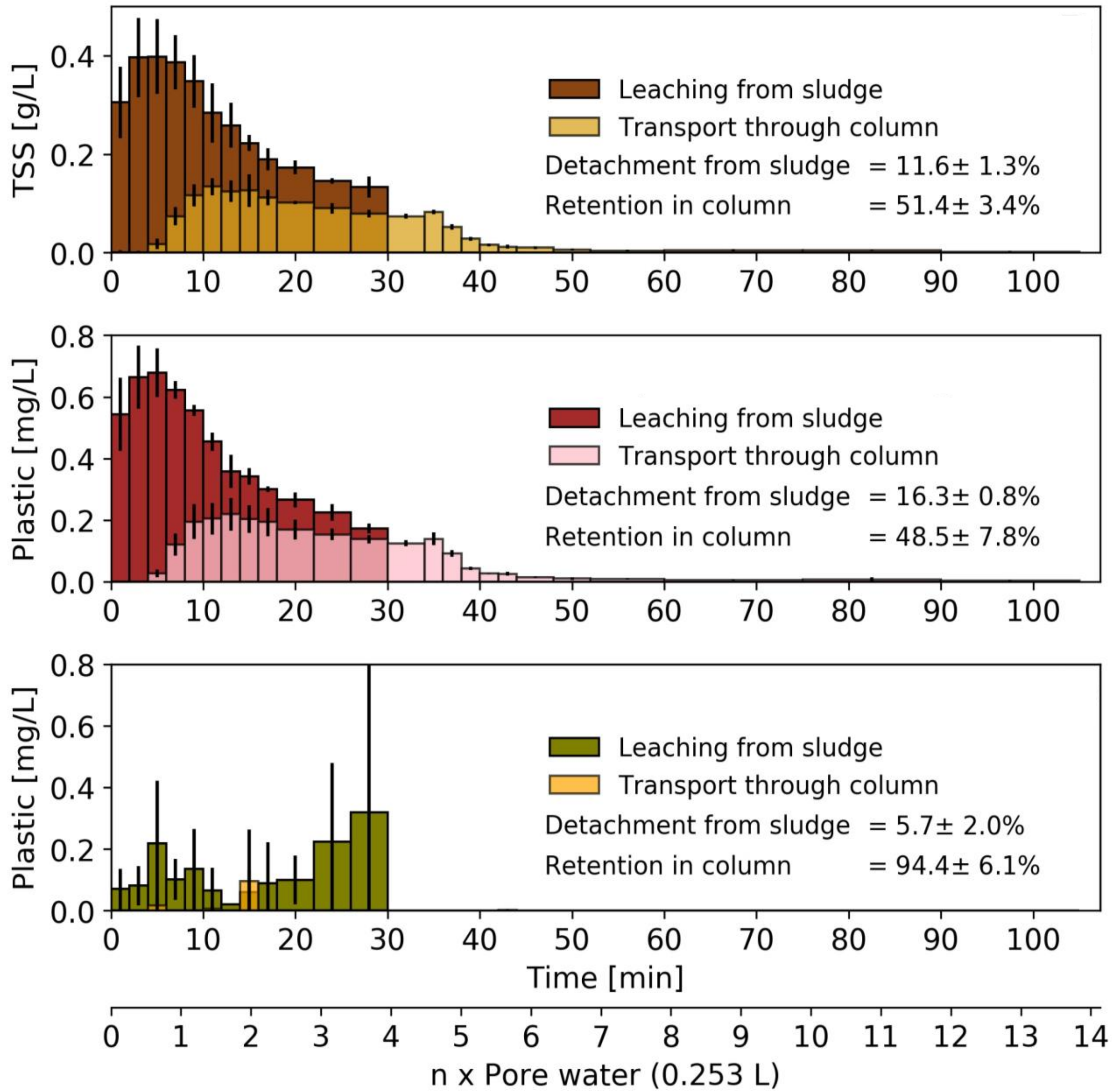
Keller et al. (*under review*)

Leaching from sludge and transport through the soil

organic solids

nanoplastics

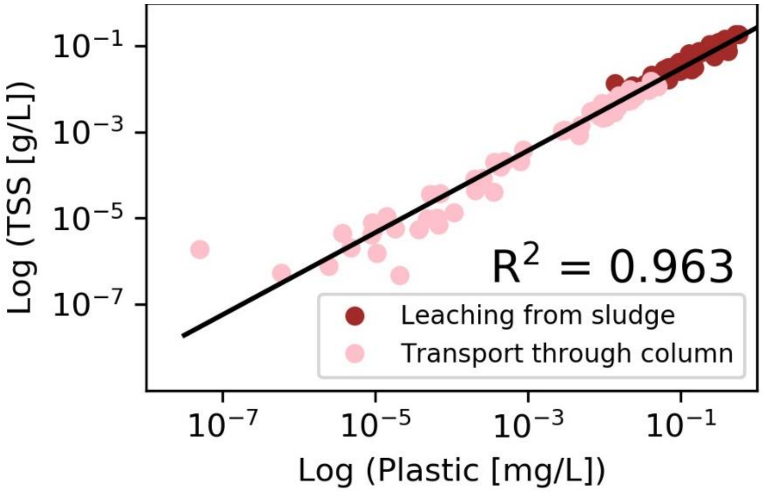
microplastics



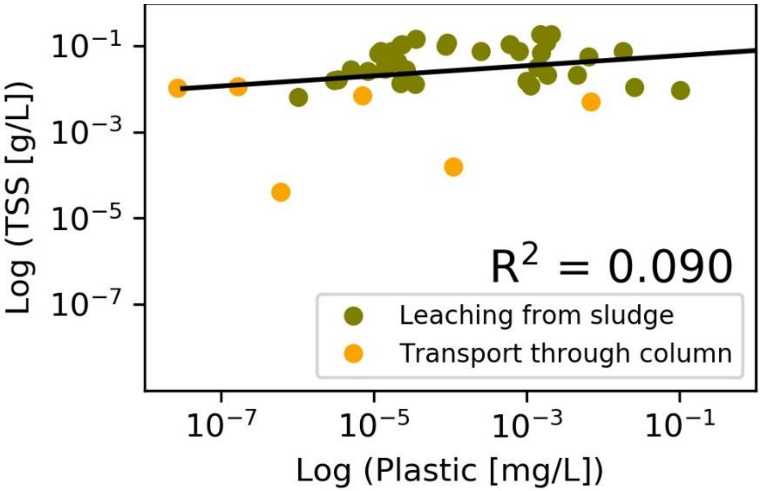
Keller et al. (*under review*)

Nanoplastics co-transport and microfibers straining

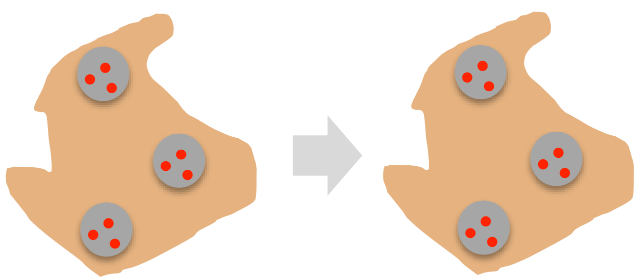
nanoplastic particles



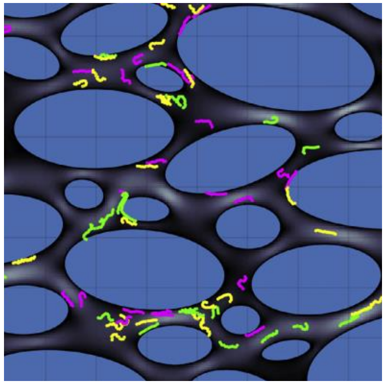
microplastic fibers



co-transport



straining



Engdhal *AWR* (2018)

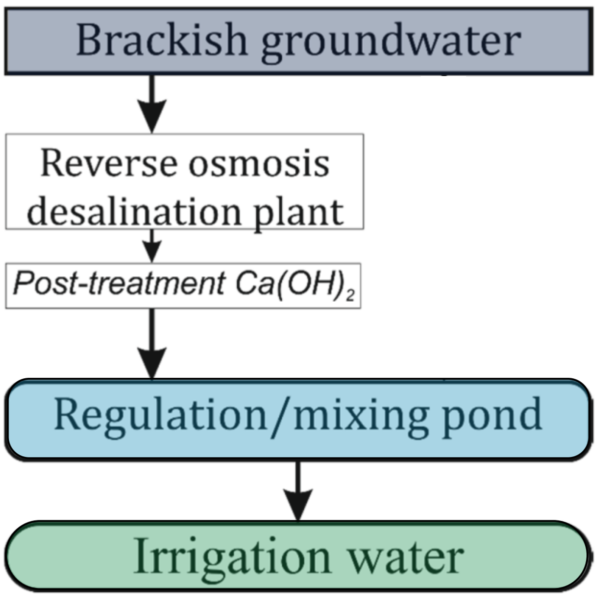
ionic strength << hydrodynamics

e.g., Predelus et al. *JNP* (2017)

Keller et al. (*under review*)

Impact from desalinated water

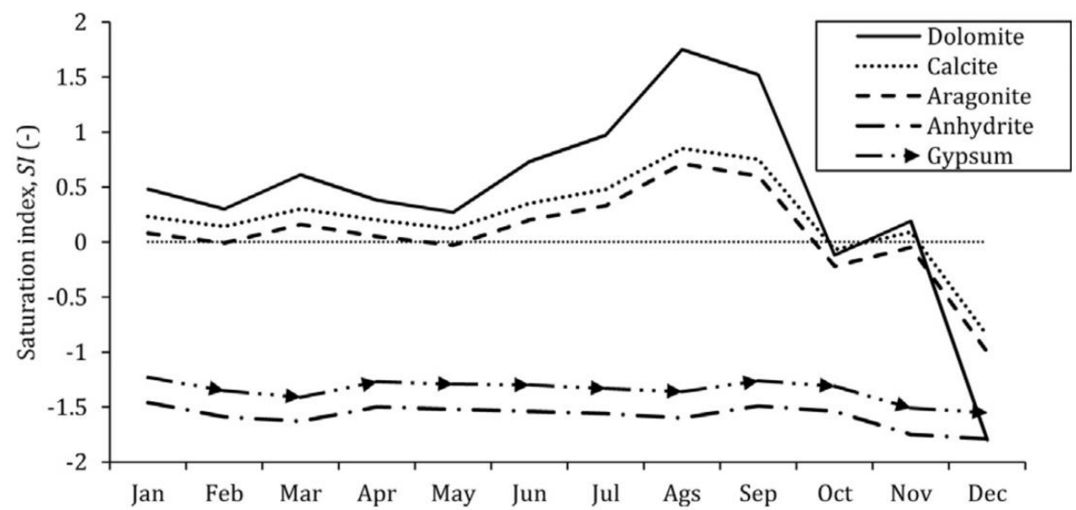
irrigation water production



Valdes-Abellan et al. *DWT* (2013)

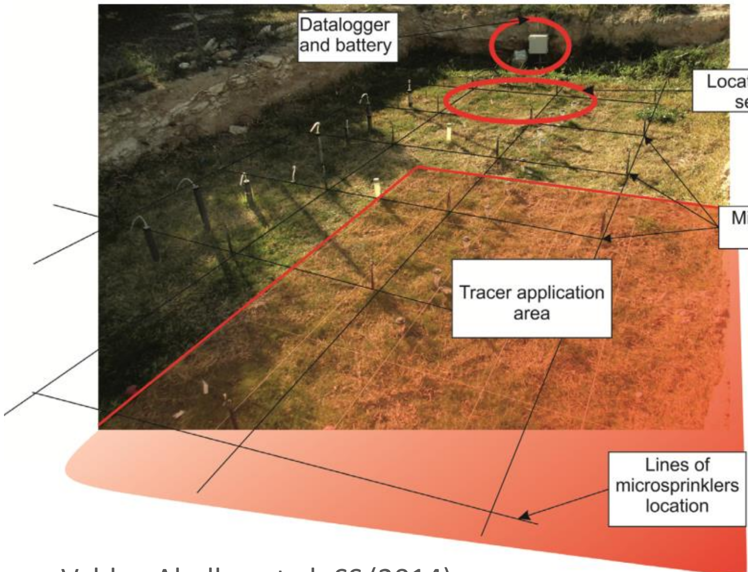
minerals saturation

Dolomite	$CaMg(CO_3)_2 = Ca^{2+} + Mg^{2+} + 2CO_3^{2-}$
Calcite	$CaCO_3 = Ca^{2+} + CO_3^{2-}$
Aragonite	$CaCO_3 = Ca^{2+} + CO_3^{2-}$
Anhydrite	$CaSO_4 = Ca^{2+} + SO_4^{2-}$
Gypsum	$CaSO_4 \cdot 2H_2O = Ca^{2+} + SO_4^{2-} + 2H_2O$

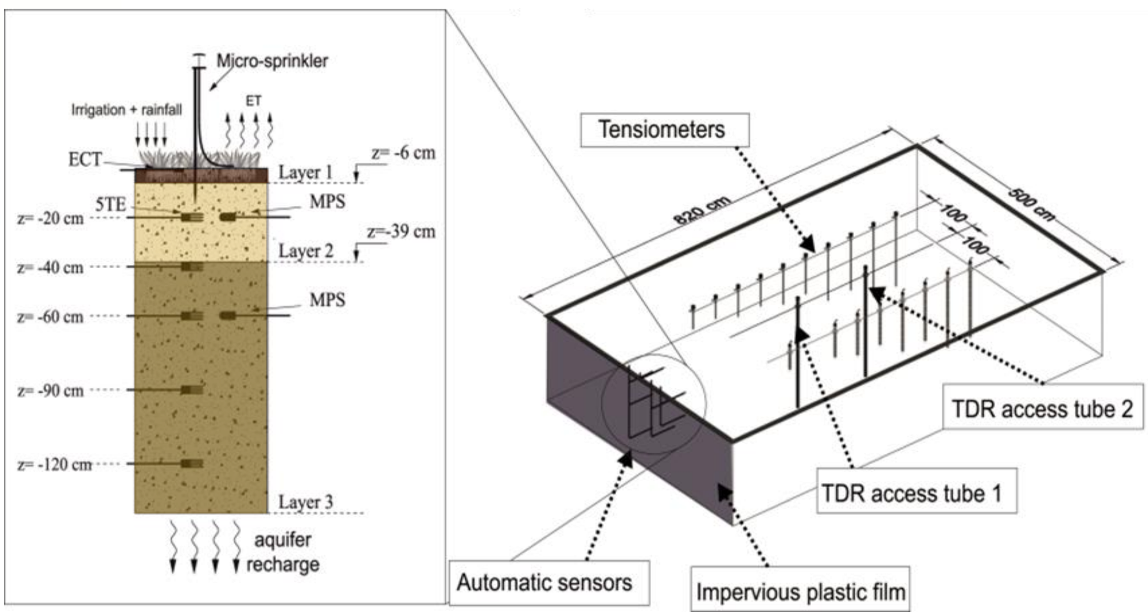


Impact from desalinated water

field experiment – experimental plot

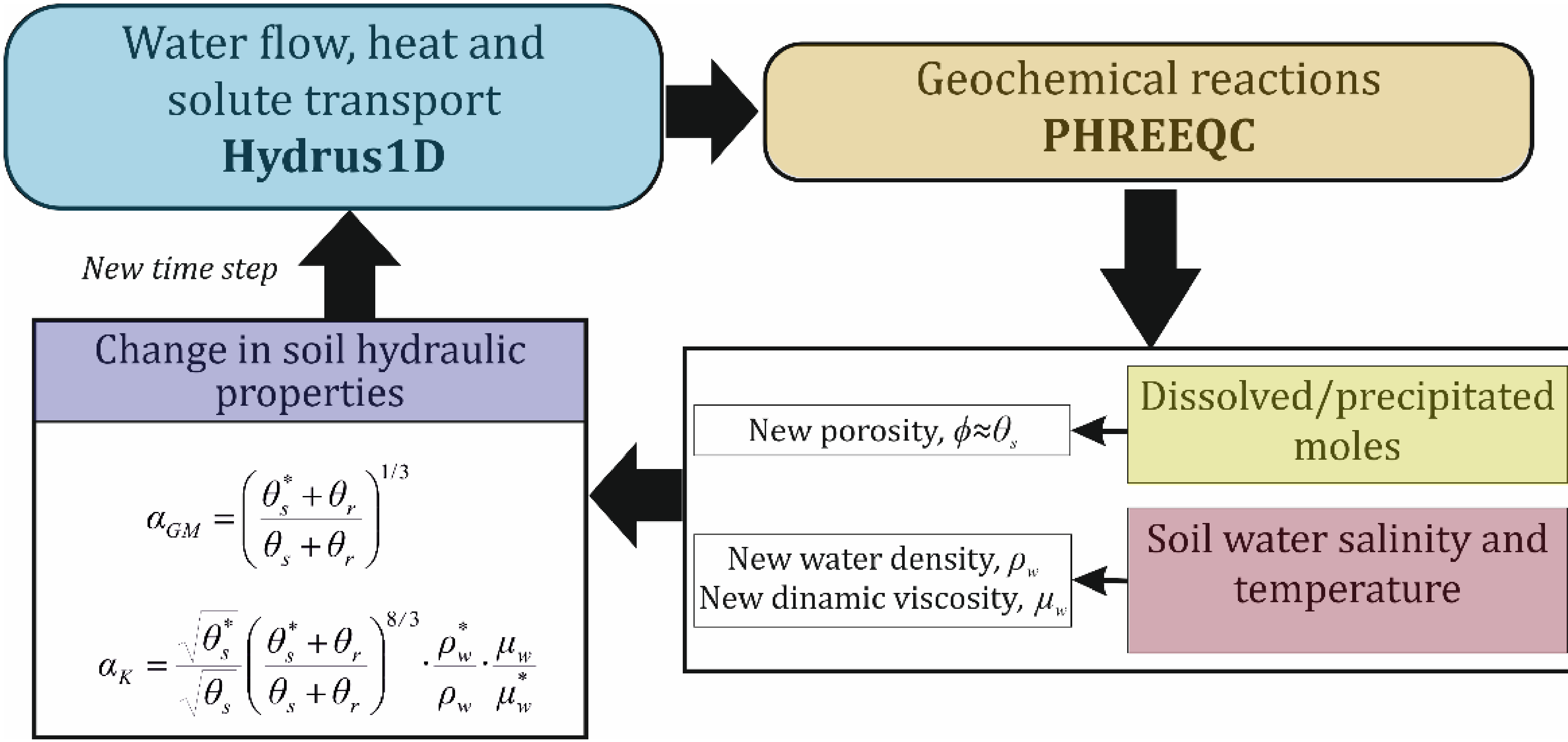


Valdes-Abellan et al. *SS* (2014)



Valdes-Abellan et al. *SJAR* (2015)

Non-isothermal multicomponent reactive transport

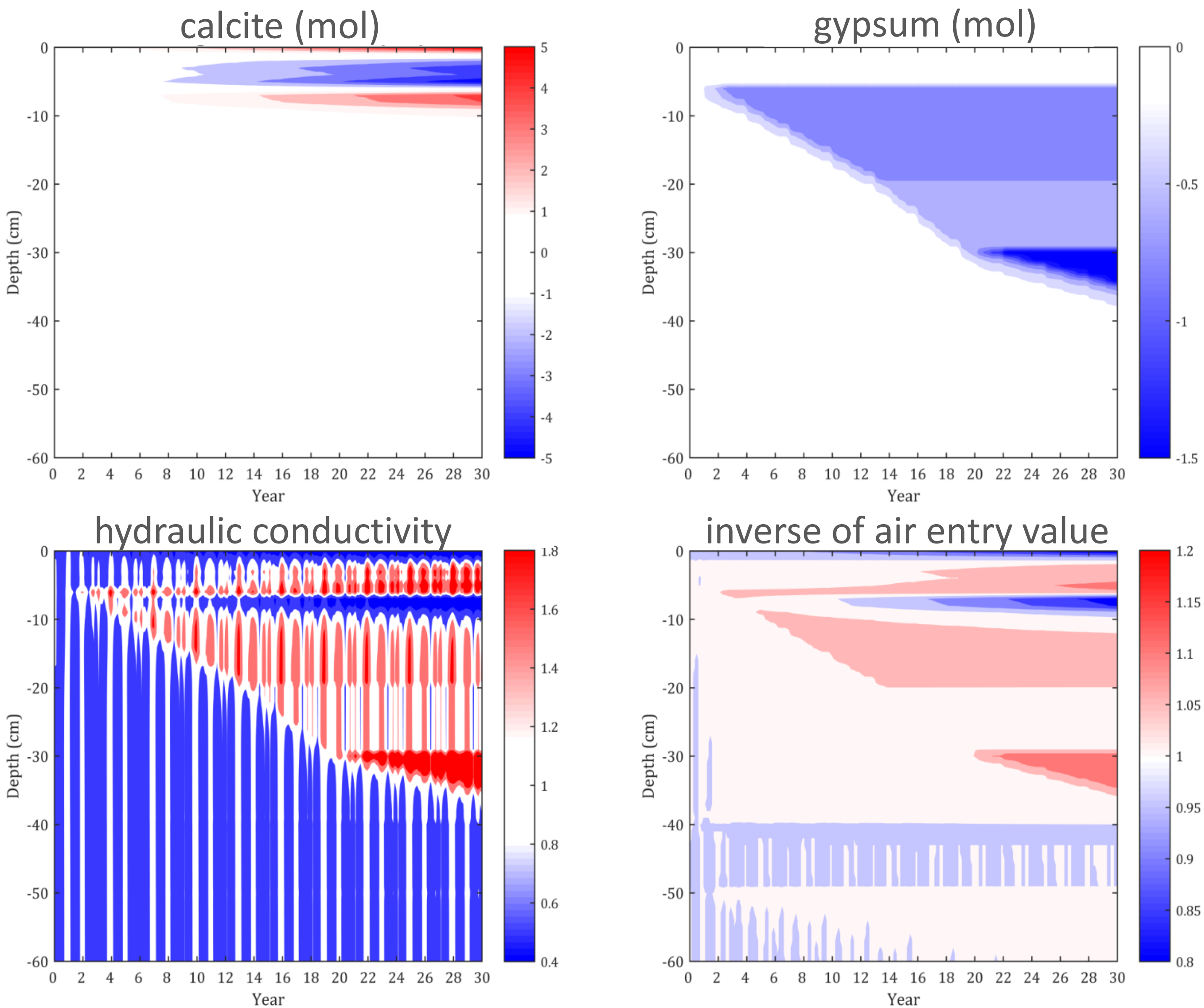


Valdes-Abellan et al. *JofH* (2017)

Main scenario

precipitation
dissolution

soil properties

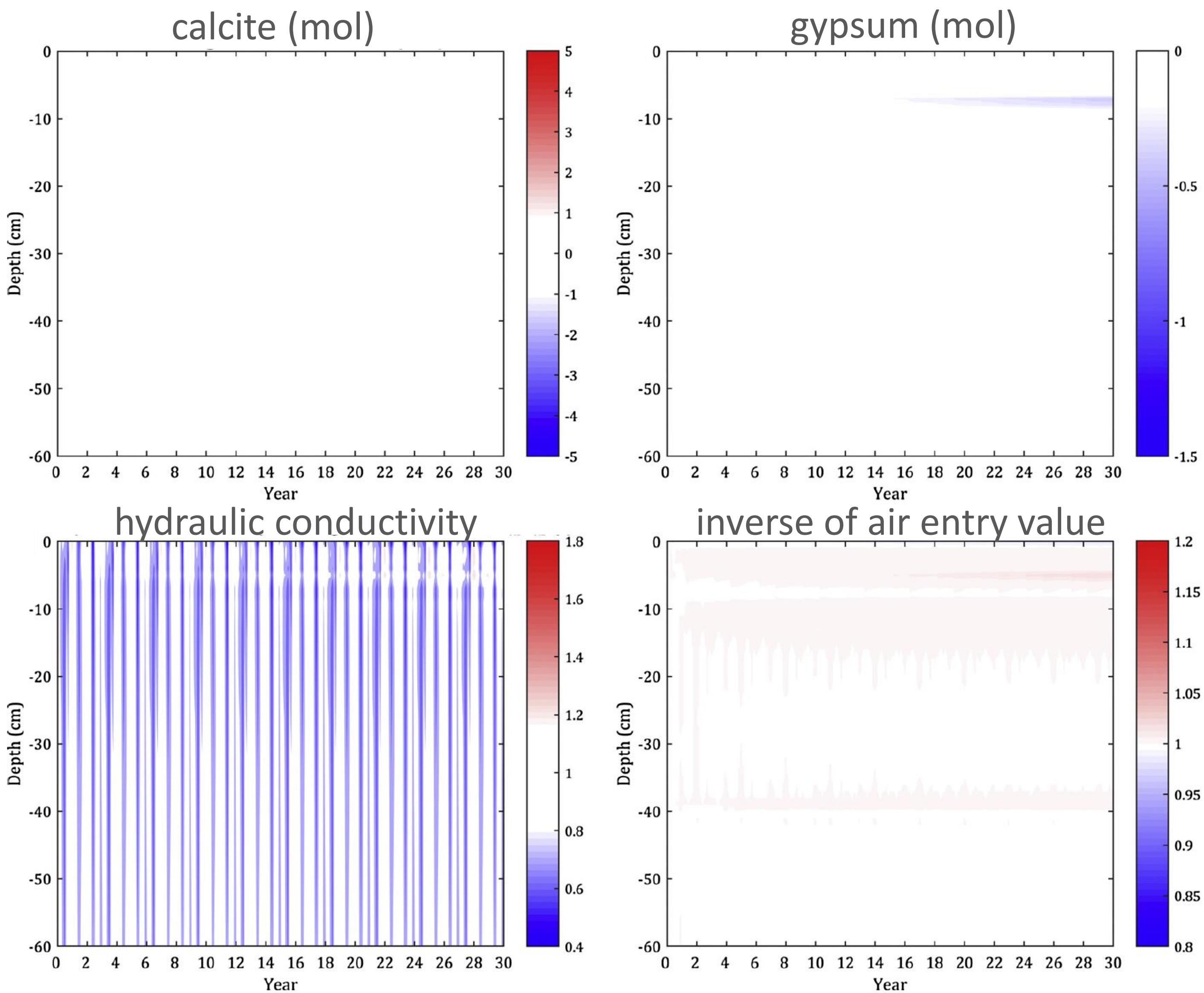


Valdes-Abellan et al. *JofH* (2017)

Rain-fed scenario

precipitation
dissolution

soil properties

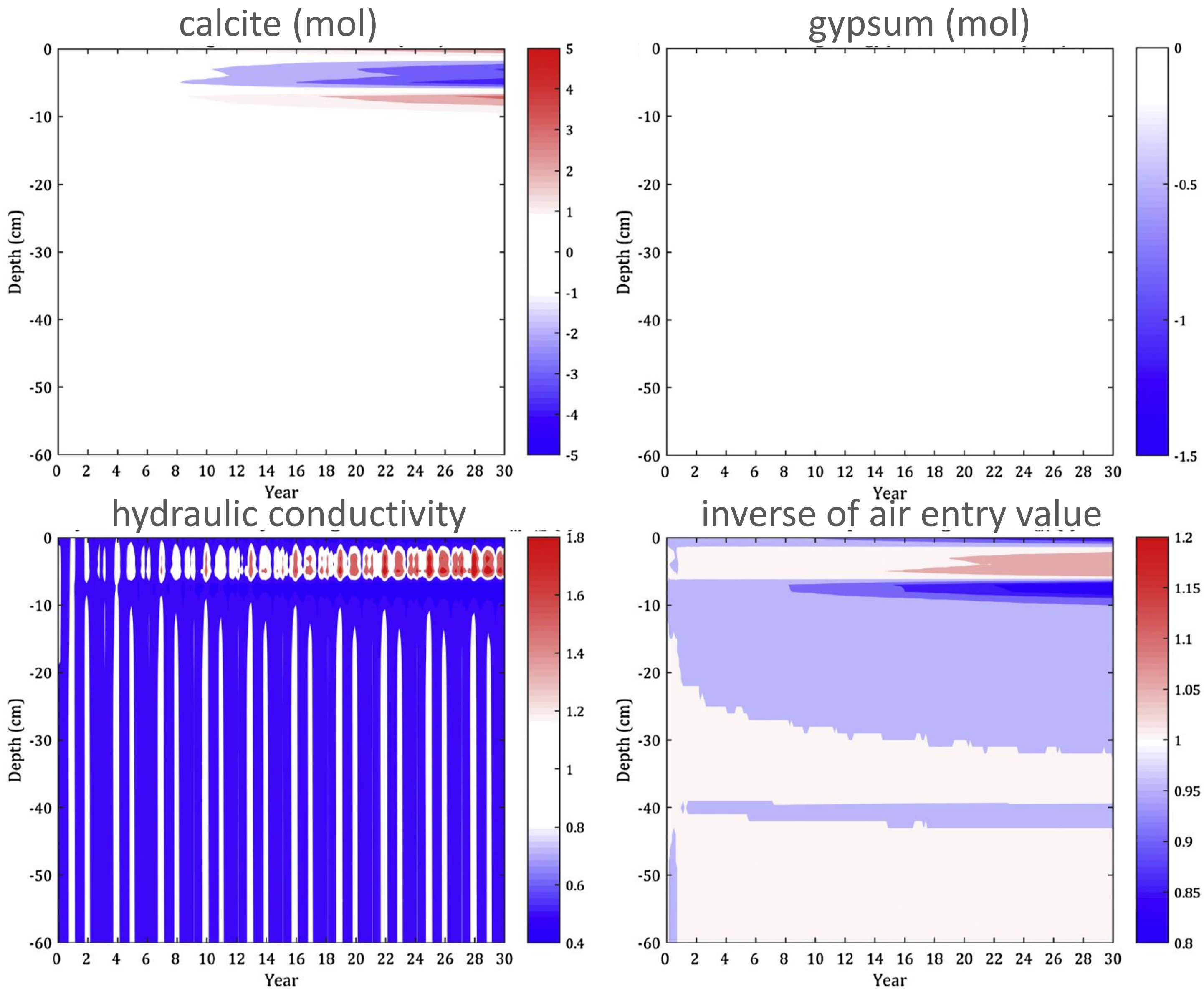


Valdes-Abellan et al. *JofH* (2017)

Gypsum-free soil scenario

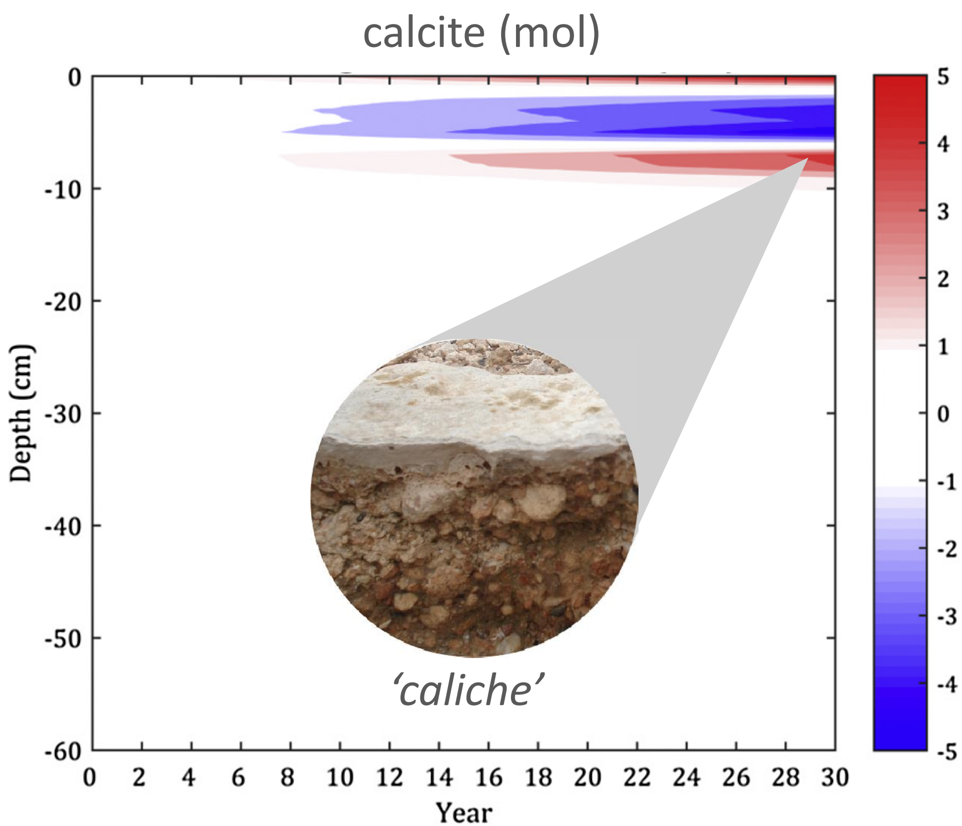
precipitation
dissolution

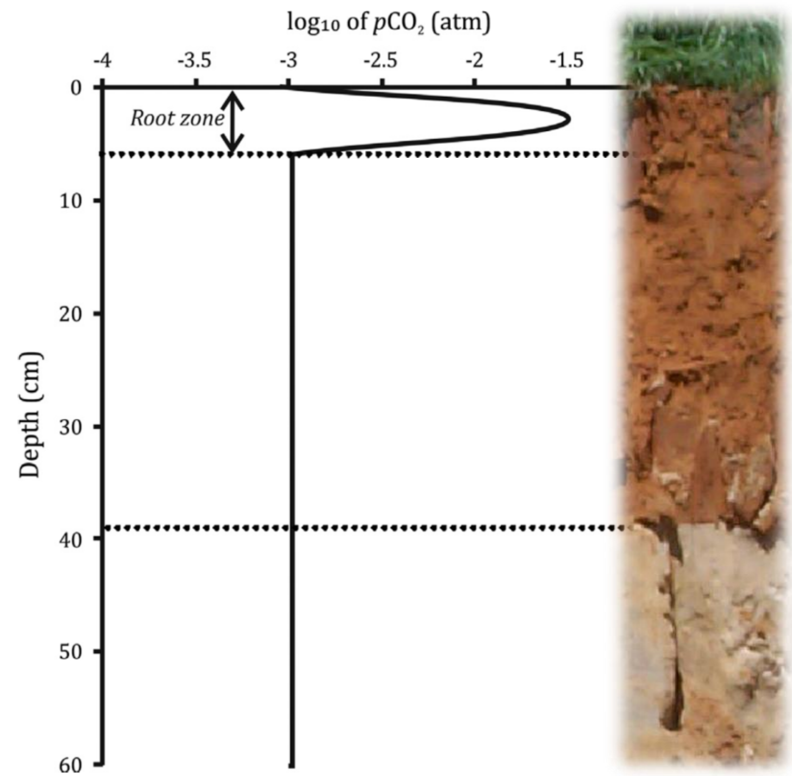
soil properties



Valdes-Abellan et al. *JofH* (2017)

Partial pressure of CO_2 in the root zone – soil respiration





Valdes-Abellan et al. *JofH* (2017)

Concluding remarks

non-ionic surfactants – alcohol polyethoxylates (AEOs)

- Batch kinetics not reliable at environmental conditions
- at low concentrations and low clay and organic matter content, no differences between homologs

co-transport of nanoplastic particles and organic solids, and straining of microplastic fibers

soil respiration at the root zone plays a key role in the long-term carbonates precipitation

Botella-Espeso, M. (SEP group)

Keller, A.; Mitrano, D. (Eawag, Switzerland)

Corada-Fernandez, C.; Lara-Martin, P.; Gonzalez-Mazo, E. (University of Cadiz, Spain)

Valdes-Abellan, J. (University of Alicante, Spain)

Candela, L. (IMDEA, Spain)

Jacques, D. (SCK-CEN, Belgium)