

Water content and metal pollution dynamics in the surface layer of urban soils: first results of the PROFILES project

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Presentation outline

- The PROFILES project
- The Zero Flux Plane (ZFP)
- Study case
- Field activity
- Lab activity
- Numerical activity
 - Inferring properties along the soil profile
 - Numerical simulations
- Results
- Conclusions

The PROFILES project

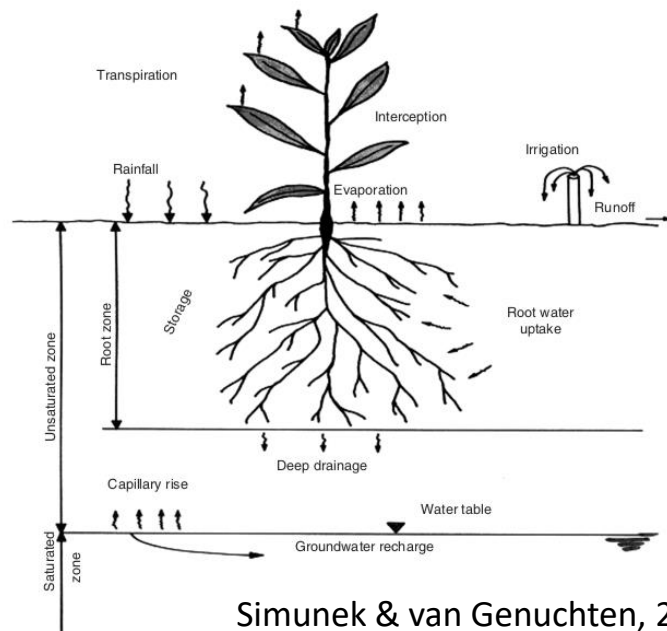
Water-driven dynamics of heavy metals in anthropogenically-enriched soils

Main objectives

1. Study of the water content and zero flux plane (ZFP) dynamics in the surface layers of urban soils;
2. Evaluation of the heavy metal enrichment vertical distribution in soils near a ferroalloy production facility;
3. Identification of a possible correlation between water content dynamics and the distribution of metal pollutants in the surface layer of urban soils.

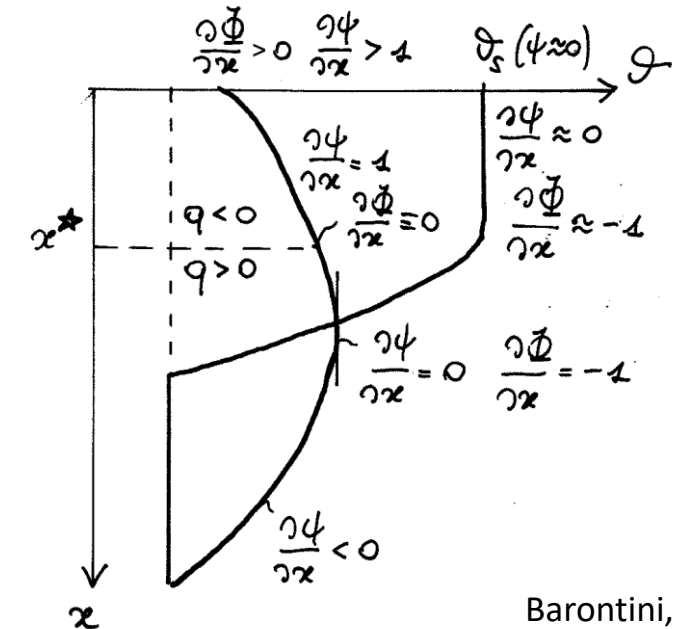
The Zero Flux Plane (ZFP)

Richards (1954): “it is convenient to use some special term such as *static zone* to designate the locus of points above which water movement is upward and below which water movement is downward”



Zero Flux Plane (ZFP)

A surface, assumed planar, which is generated in a thoroughly wet soil profile in which evaporation and drainage occur simultaneously, and which separates the areas with upward and downward water flow

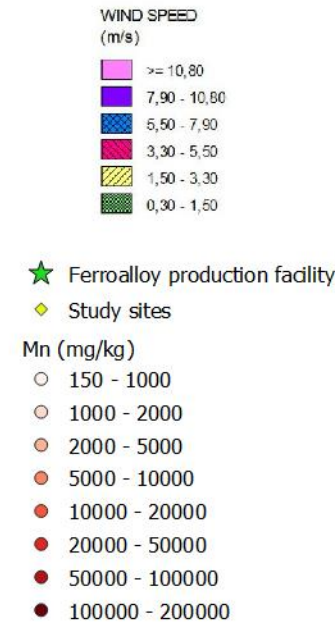
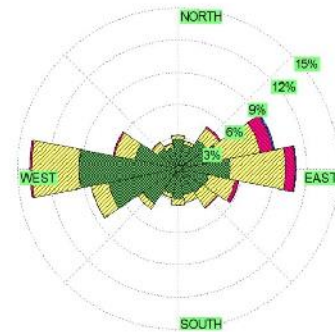
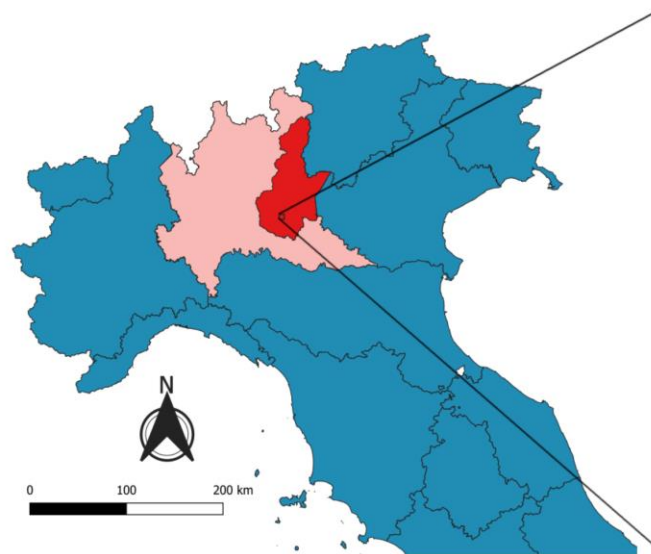


Barontini,
2017

Study case

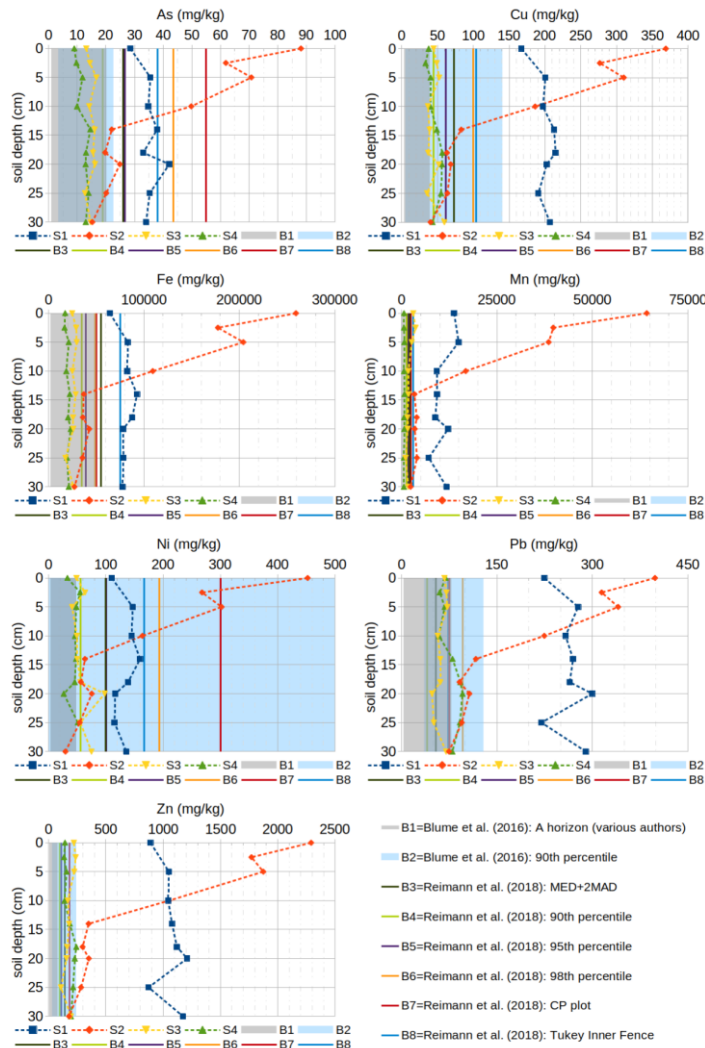
Bagnolo Mella

- 16 km S-SE from the city of Brescia;
- Ferroalloy production 1974-2015;
- Po plain: winds along O-E;
- Water table depth: 6 m (± 1 m)



Peli et al. (2021)

Field activity



Peli et al. (2021)

Tension infiltrometer



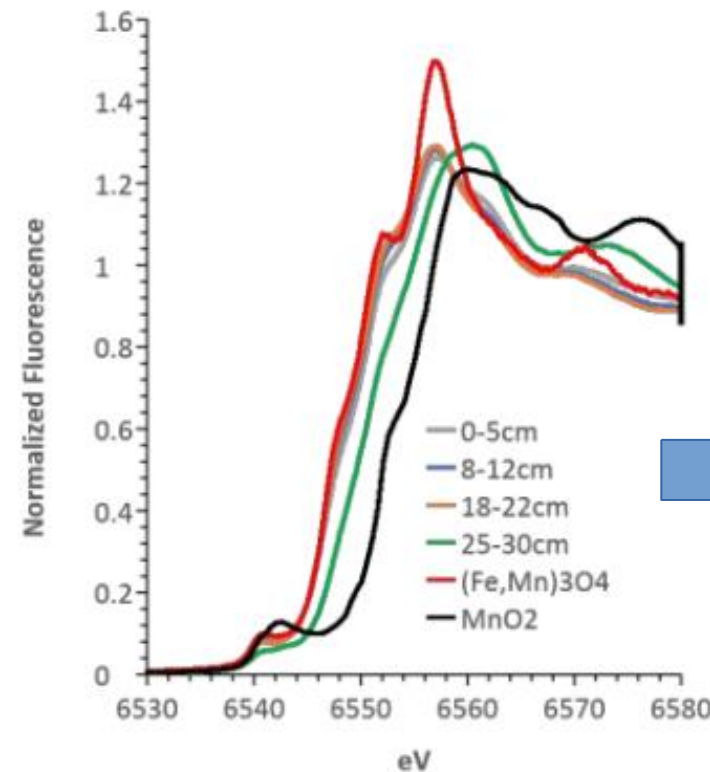
pXRF

SITO	Ks,sup	Ks,inf
	m/s	m/s
S1	3,15E-05	6,11E-06
S2	1,65E-04	1,41E-04
S3	4,69E-06	3,39E-06
S4	4,90E-06	2,77E-06

Lab activity

1. Physico-chemical properties (grain-size distribution, pH, CE, OM, C/N, CEC) evaluated on soil samples were found to be rather homogeneous

2. Mn XANES spectra at different depths along the soil profile in site S2: Mn from samples collected in the first 20 cm (where it exceeded background levels) was present in the hybrid form of magnetite ($\text{Fe, Mn}_3\text{O}_4$), resistant to acid dissolution



Peli et al. (2021)



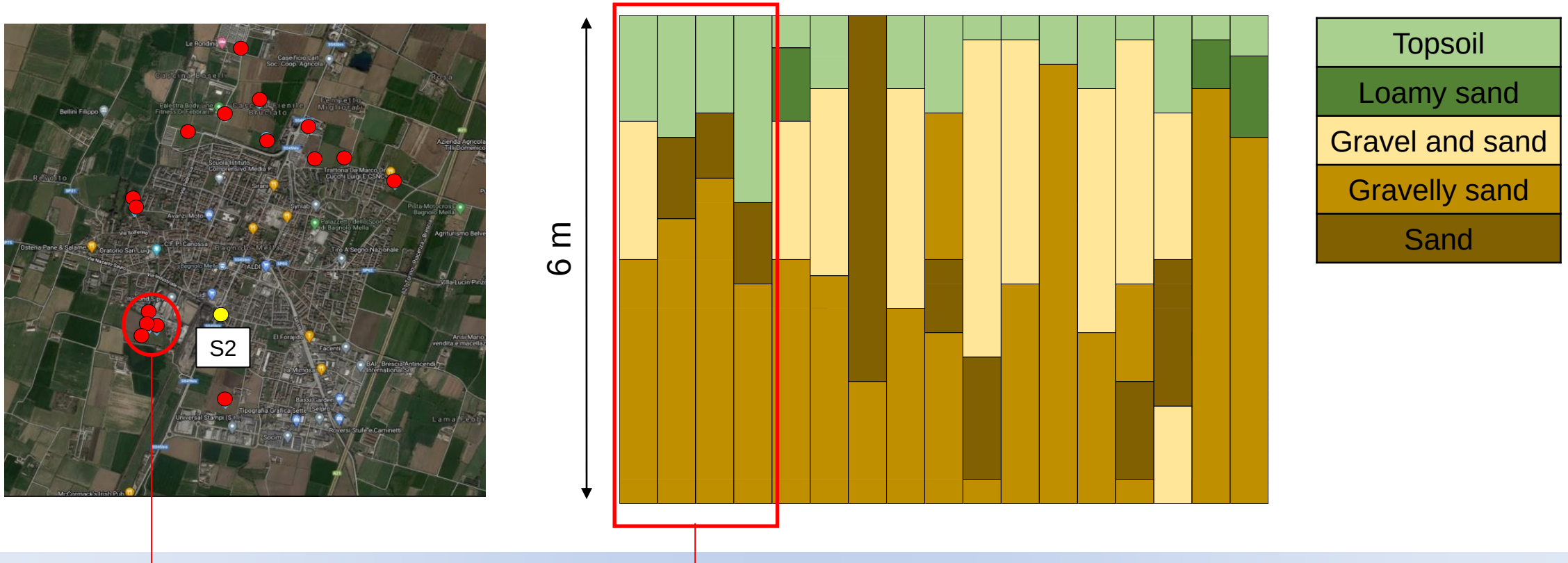
Transport

~~Diffusion~~

~~Reaction~~

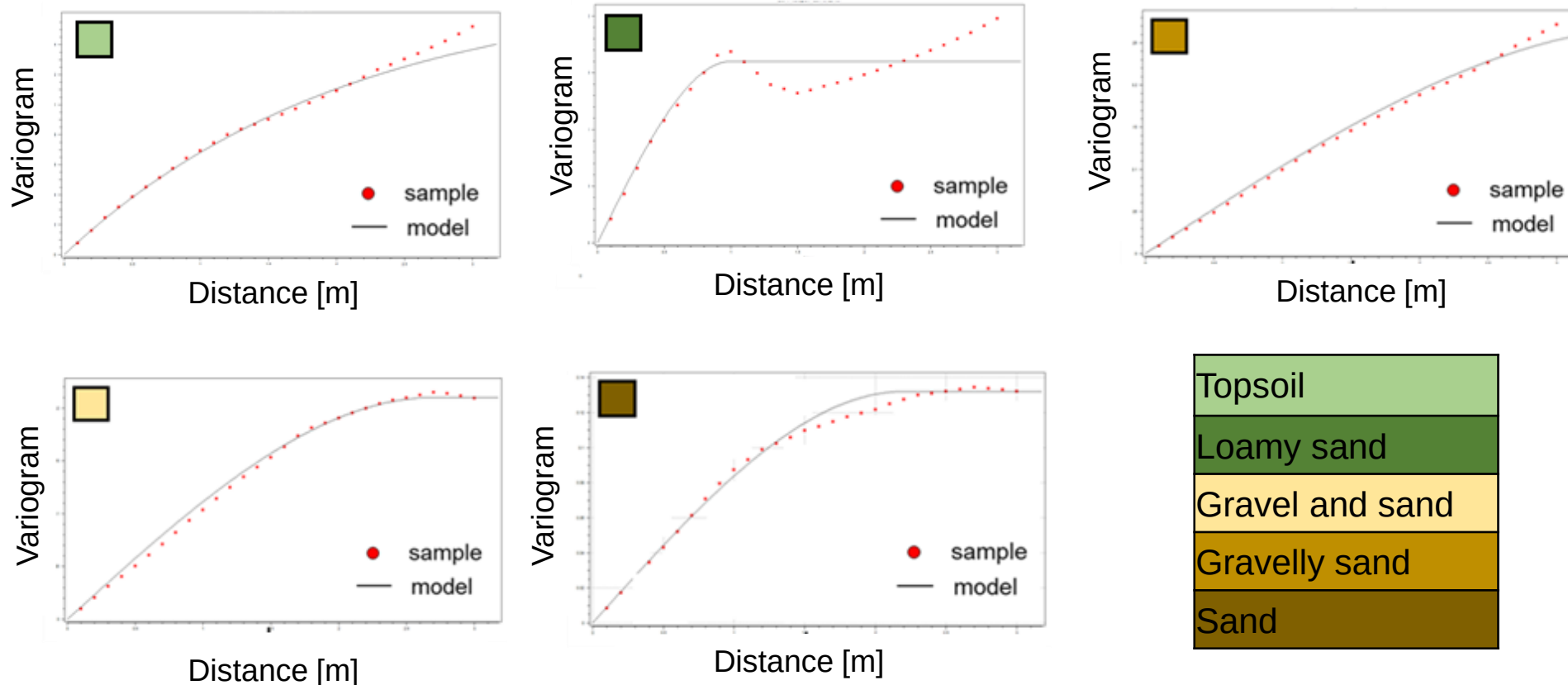
Numerical activity: Inferring properties along the soil profile

- 16 available stratigraphic surveys in the surroundings, 5 principal soil categories were identified: *topsoil*, *loamy sand*, *gravel and sand*, *gravelly sand* and *sand*



Numerical activity: Inferring properties along the soil profile

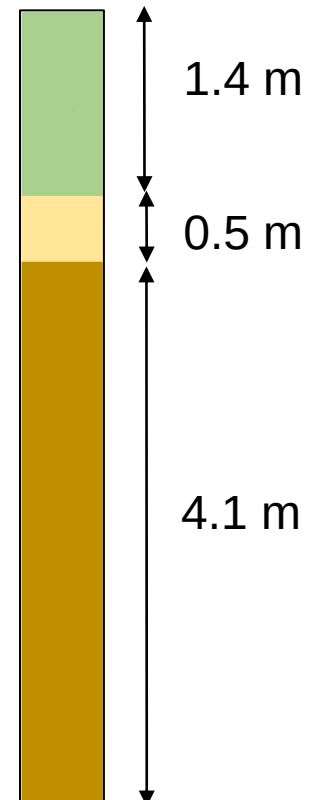
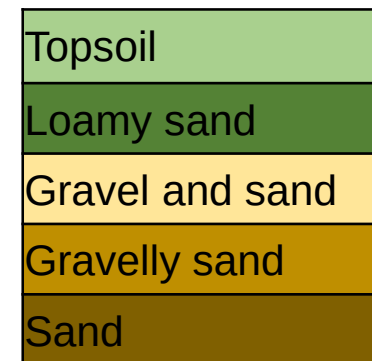
- Variogram parameters estimation for each soil category



- Indicator kriging



S2 stratigraphy



Numerical activity: Inferring properties along the soil profile

- Occurrence proportions

Topsoil	0.138
Loamy sand	0.024
Gravel and sand	0.238
Gravelly sand	0.475
Sand	0.125

- Soil hydrological properties estimation by PTFs

- USDA textural classes
- Fine materials content

- Estimation refinement depending on the coarse materials content x_{sk}

Topsoil	S:65%, L:18%, A:17%
Loamy sand	Loamy sand
Gravel and sand	Sand
Gravelly sand	Sand
Sand	Sand

$$x_{sk} = \frac{P_{sk}}{P_s}, \quad \text{being } P_s = P_{s,m} + P_{sk}$$

$$\phi_m = \frac{V_{v,m}}{V_{t,m}} \approx \theta_{s,m} \text{ from Rosetta, } \phi = \frac{V_v}{V_t} = \phi_m \cdot \frac{1 - x_{sk}}{1 - x_{sk}\phi_m}$$

$$\theta = \theta_m \cdot \frac{\phi}{\phi_m}$$

$$K_{s,eq} = K_{s,m} \cdot \frac{\phi}{\phi_m}$$

Numerical activity: Numerical simulations

CASE 1: parameters estimation



θ_R	0.073
θ_S	0.438
α [1/cm]	0.006
n	1.622
K_s [m/s]	1.53E-06

θ_R	0.027
θ_S	0.193
α [1/cm]	0.035
n	3.180
K_s [m/s]	3.84E-05

θ_R	0.046
θ_S	0.324
α [1/cm]	0.035
n	3.180
K_s [m/s]	6.44E-05

CASE 2: parameters estimation + field data



θ_R	0.073
θ_S	0.438
α [1/cm]	0.416
n	1.622
K_s [m/s]	1.6E-04

θ_R	0.027
θ_S	0.193
α [1/cm]	0.035
n	3.180
K_s [m/s]	3.84E-05

θ_R	0.046
θ_S	0.324
α [1/cm]	0.035
n	3.180
K_s [m/s]	6.44E-05

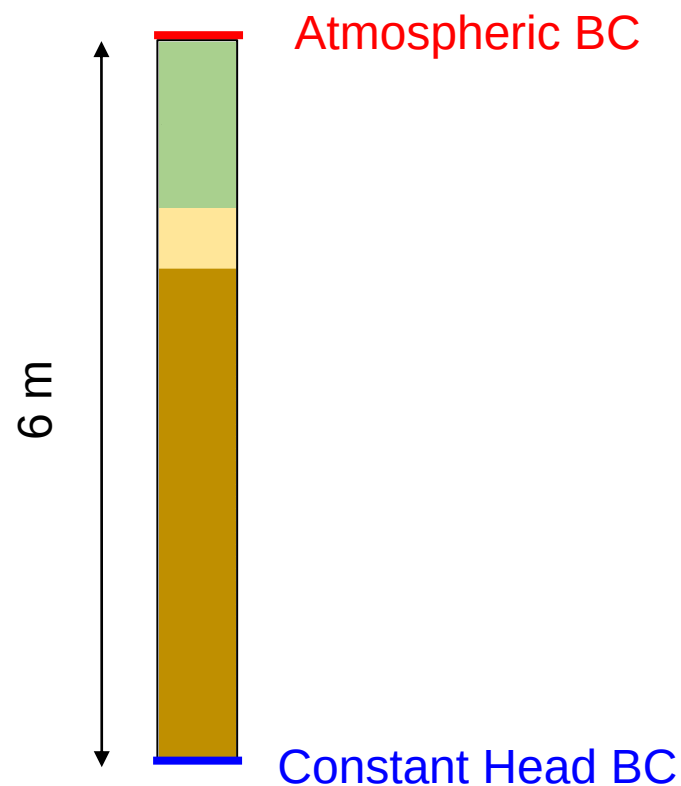
CASE 3: homogeneous soil with field data



θ_R	0.073
θ_S	0.438
α [1/cm]	0.41
n	1.622
K_s [m/s]	1.6E-04

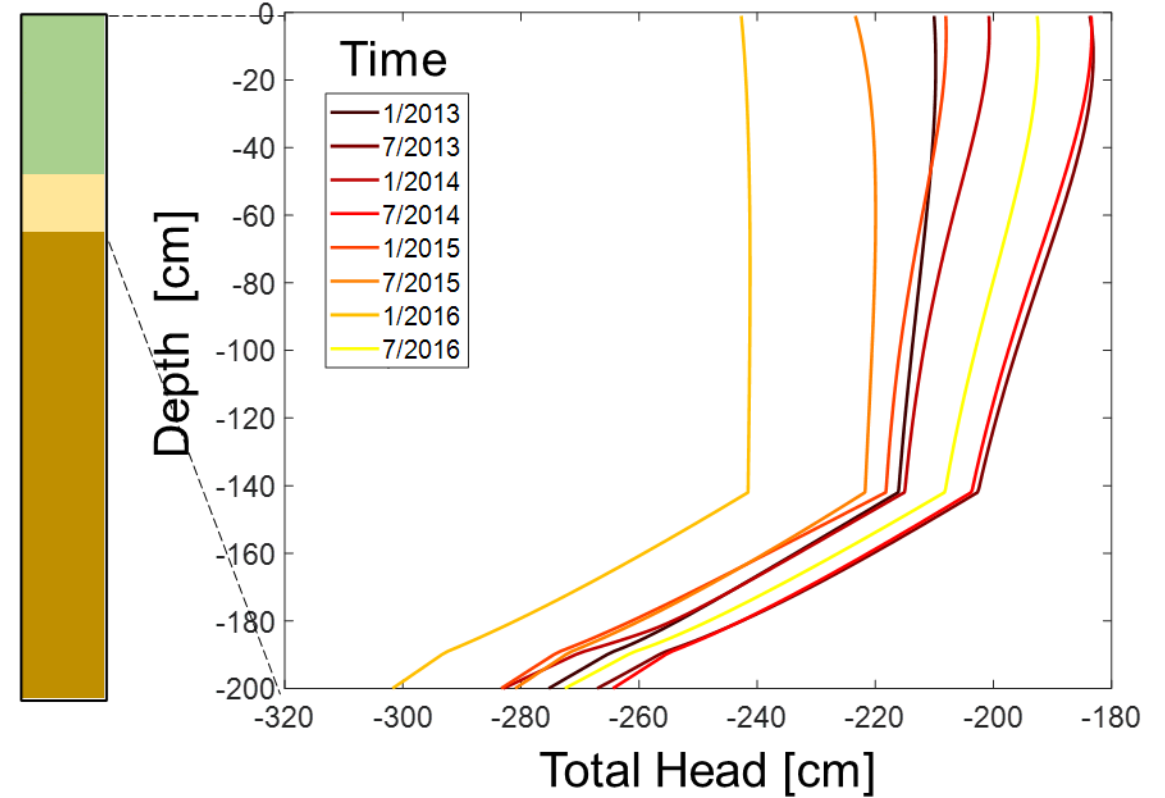
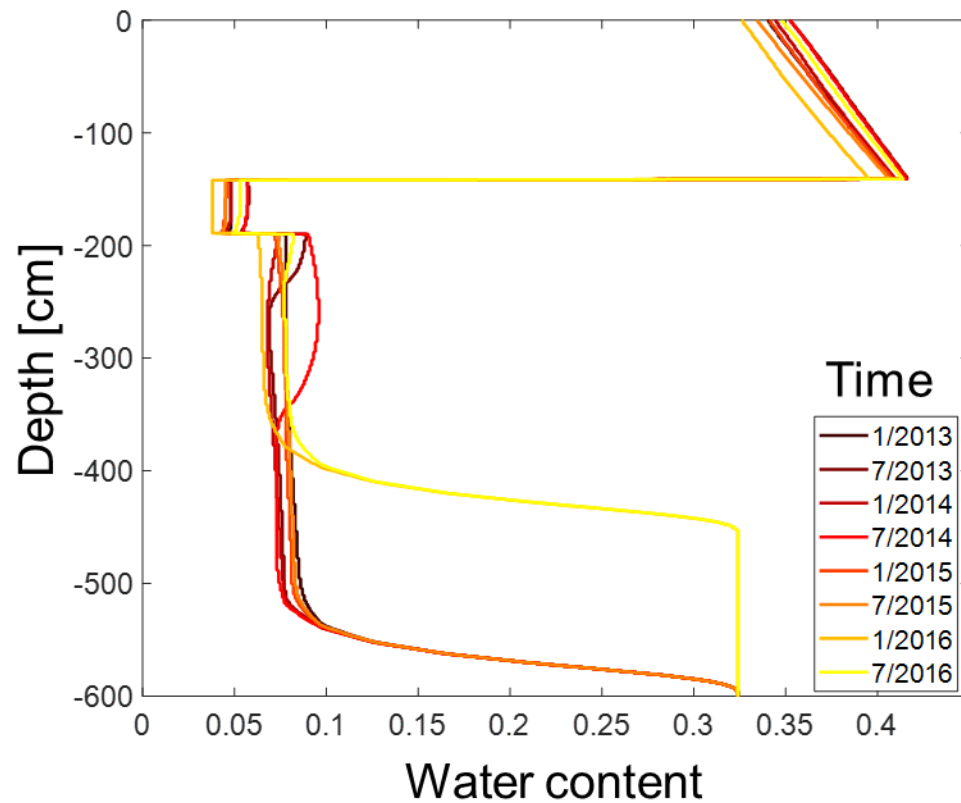
Numerical activity: Simulations setup

Numerical simulations with HYDRUS 1D: water dynamics along the uppermost 6 meters of soil over a time range of 4 years (2013–2016)

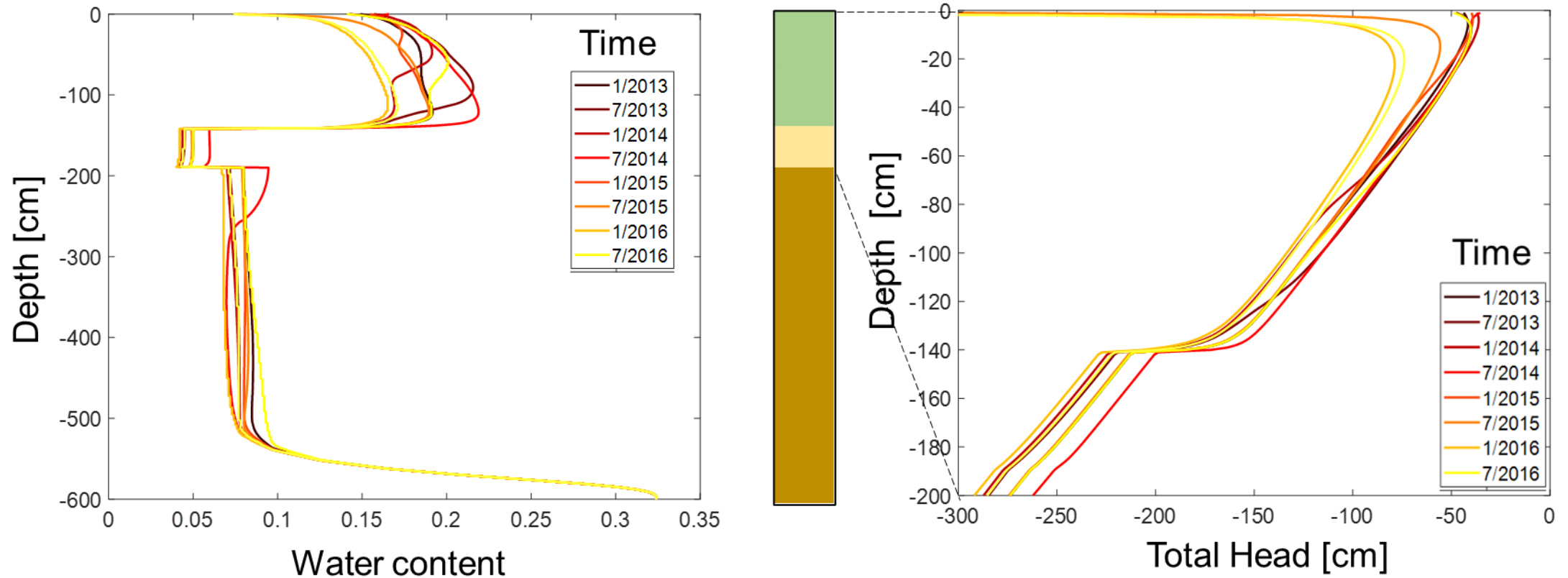


- Spatial resolution: 1 cm (600 cells)
- Time step: min = 6 s $\leftrightarrow$ max = 1 h
- Atmospheric BC (hourly data):
 - Precipitation
 - Temperature, solar radiation, air humidity, wind velocity to calculate evapotranspiration
- Constant Head BC: water table depth
- Initial conditions: pressure head linear distribution with depth

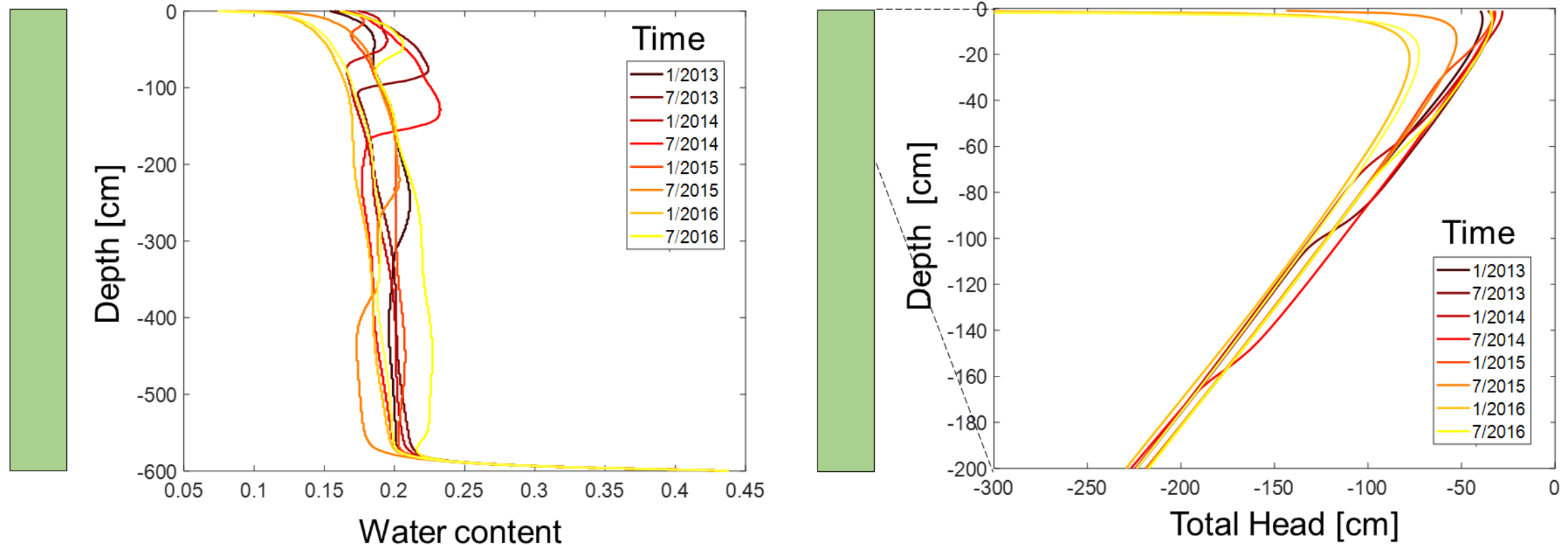
Numerical activity: Case 1 results



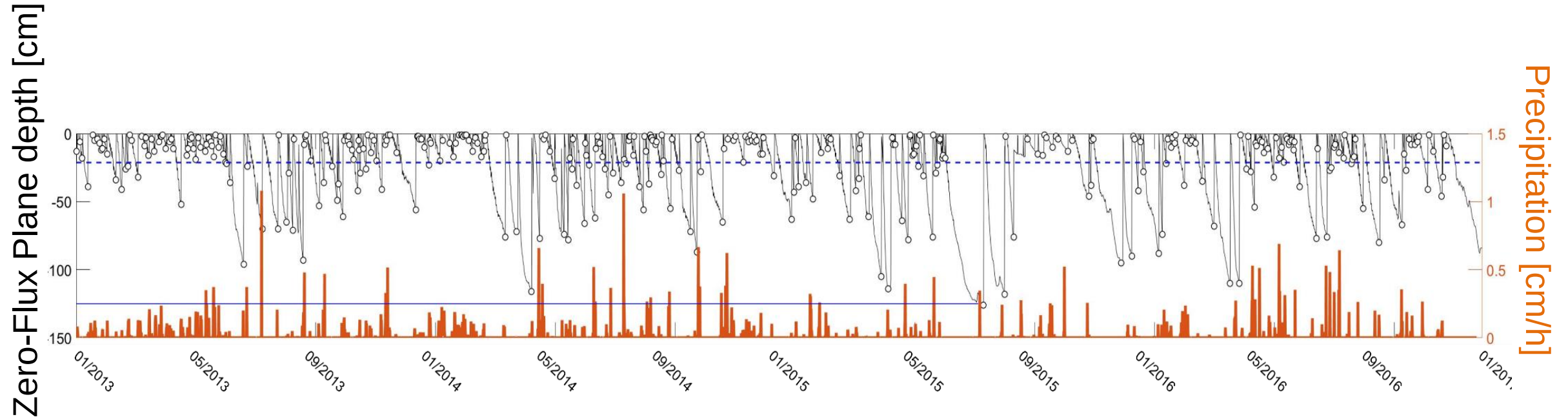
Numerical activity: Case 2 results



Numerical activity: Case 3 results

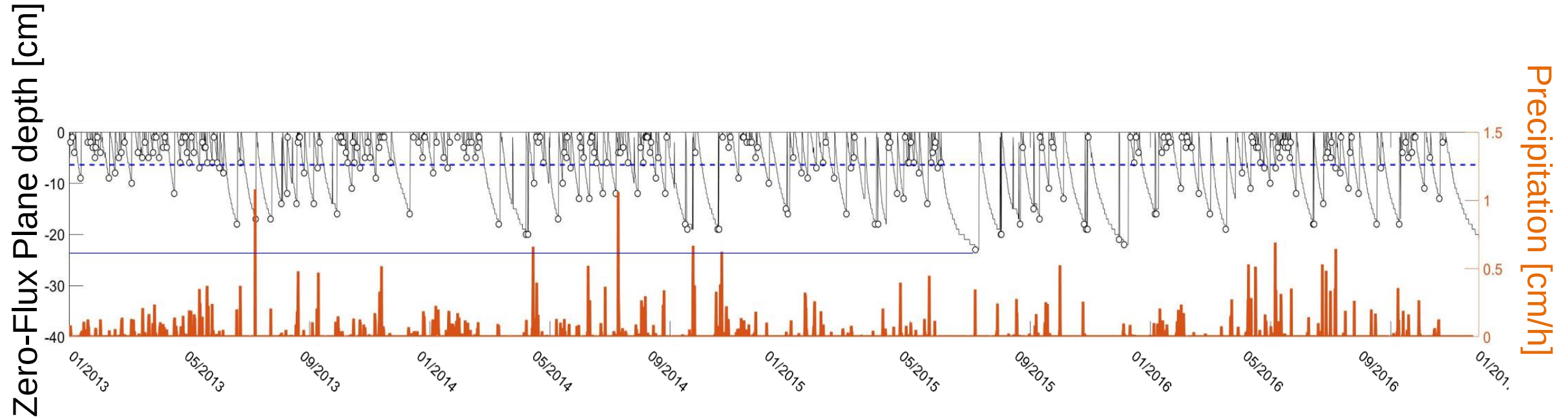


Numerical activity: Case 1 results



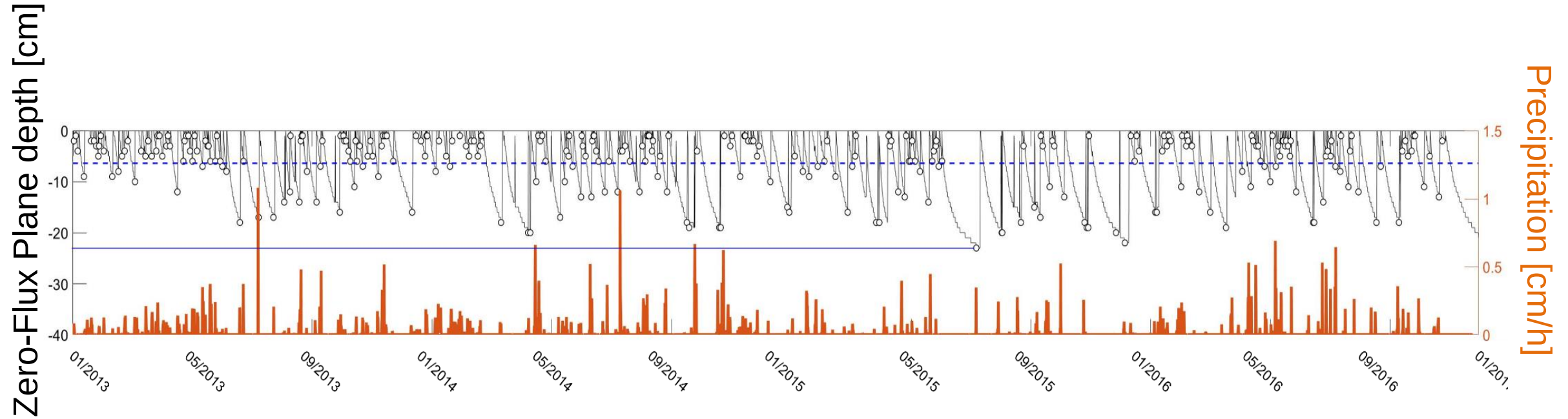
- Max ZFP depth: 126 cm
- Average ZFP depth: 21.2 cm

Numerical activity: Case 2 results



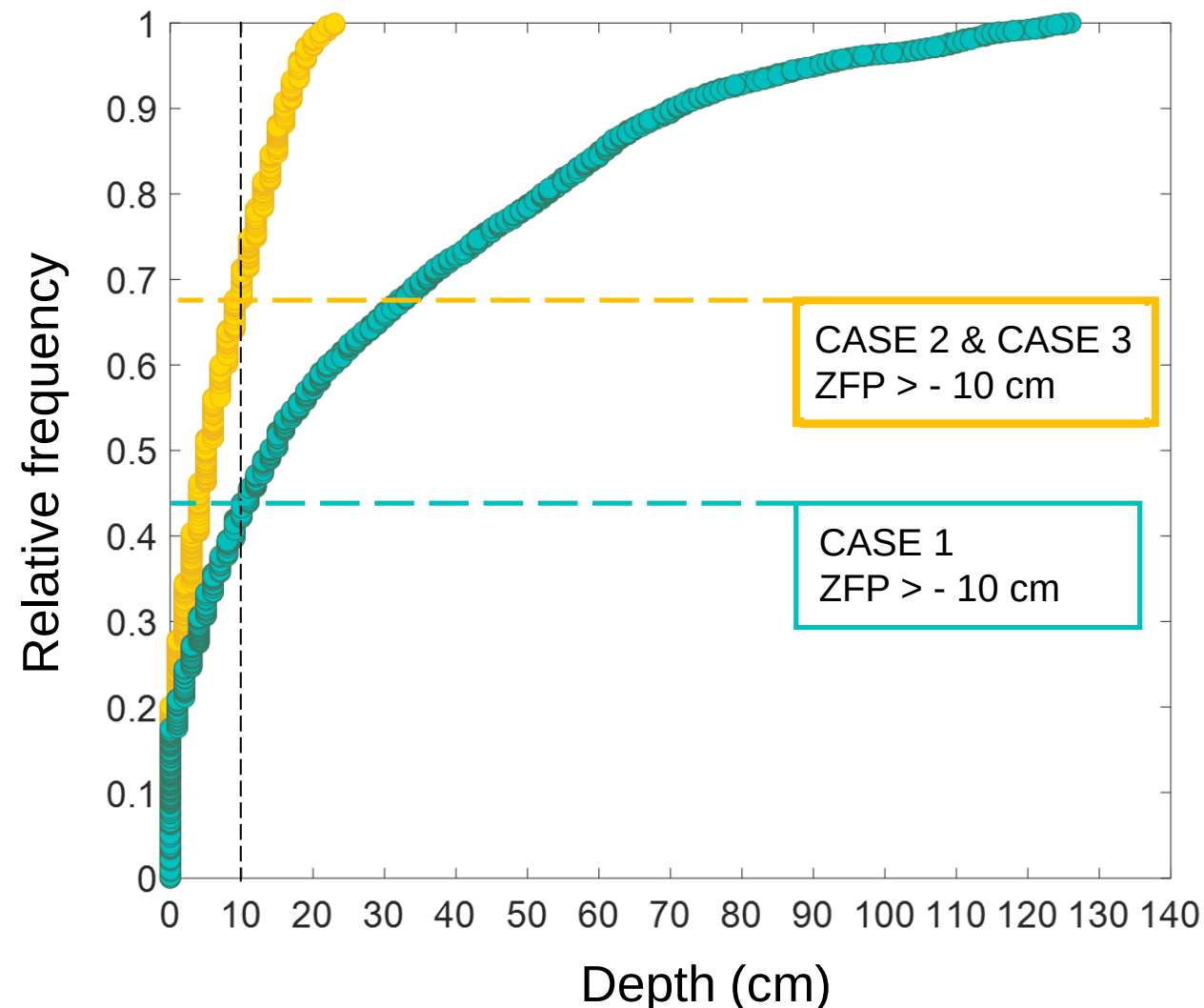
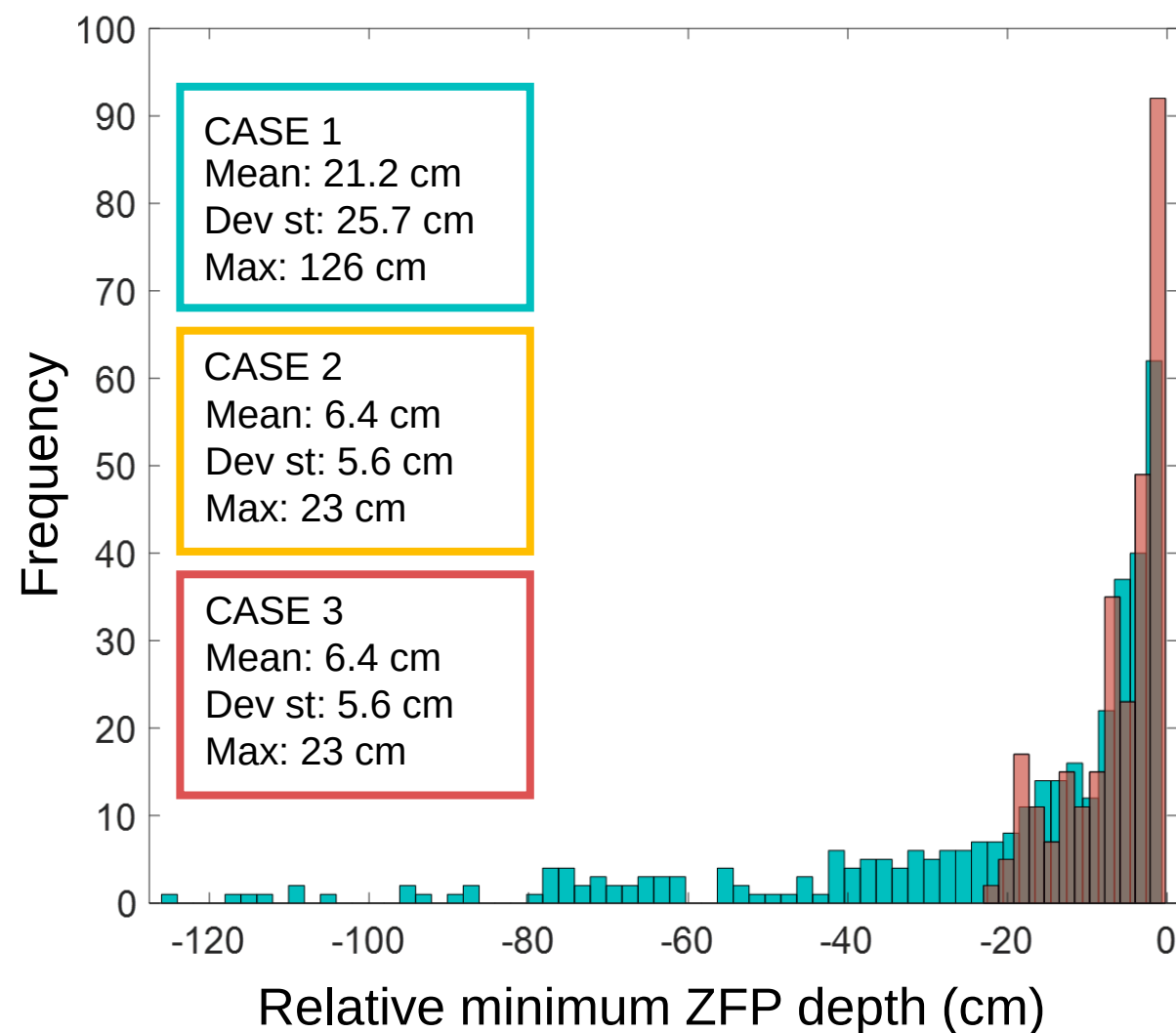
- Max ZFP depth: 23 cm
- Average ZFP depth: 6.5 cm

Numerical activity: Case 3 results



- Max ZFP depth: 23 cm
- Average ZFP depth: 6.5 cm

Numerical activity: Cases comparison



Conclusions

1. The field activity highlighted the **metal enrichment site-specificity** within the study area and its dependency from the local wind regime;
2. The lab activity supported the idea of considering **soil water dynamics as the main driver of metal contamination** transport in the investigated site;
3. Numerical simulations showed how for the whole simulated period, **the ZFP oscillation** ranges between the ground surface and a maximum depth of about 20 cm and **is consistent with the vertical range where peak concentrations of heavy metals were found**;
4. Simulations in the homogeneous and heterogeneous cases provided analogous results, highlighting the **importance of the characterization of the top surface layer**.

References

- 1 Richards, L. A. (1954). Multiple tensiometer for determining vertical component of the hydraulic gradient in soil. Soil Science Society of America Proceedings 18: 7–10.
- 2 Peli M., Bostick B. C., Barontini S., Lucchini R. G., Ranzi R. (2021). Profiles and species of Mn, Fe and trace metals in soils near a ferromanganese plant in Bagnolo Mella (Brescia, IT). Science of the Total Environment 755(2), 143123, doi:10.1016/j.scitotenv.2020.143123

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Thank you!

**Do not hesitate:
contact us for any question and comment**

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