

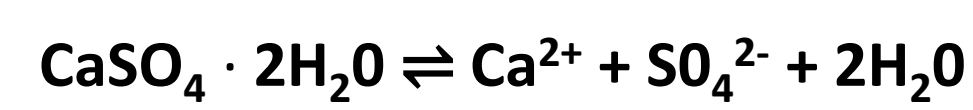
Feasibility of stormwater infiltration in areas with gypsum dissolution hazards : contribution of numerical modelling

Faisabilité de l'infiltration des eaux pluviales en zone d'aléa dissolution du gypse – apport de la modélisation numérique

Context

The gypsum dissolution phenomenon:

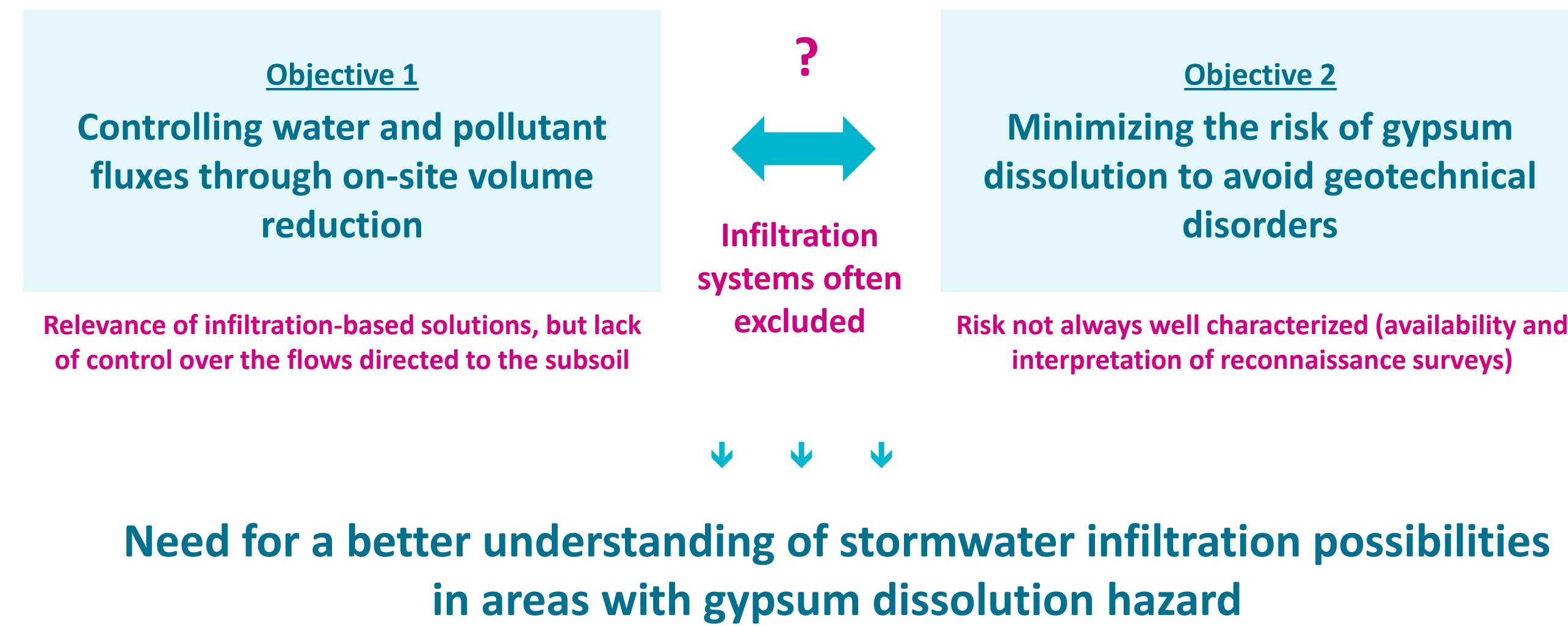
Gypsum = soluble evaporite, that can be found in various geological formations



Potential consequences: formation or reactivation of cavities, ground movements (e.g., subsidence, sinkholes...)

Main controls : amount of gypsum to be dissolved, water circulations, water dissolution potential, gypsum facies

A challenge for stormwater management:



The case study

An eco-district project in the North of Paris

45 ha including housings, public facilities and tertiary activities over former railway installations in the municipality of Pantin (Seine-Saint-Denis).

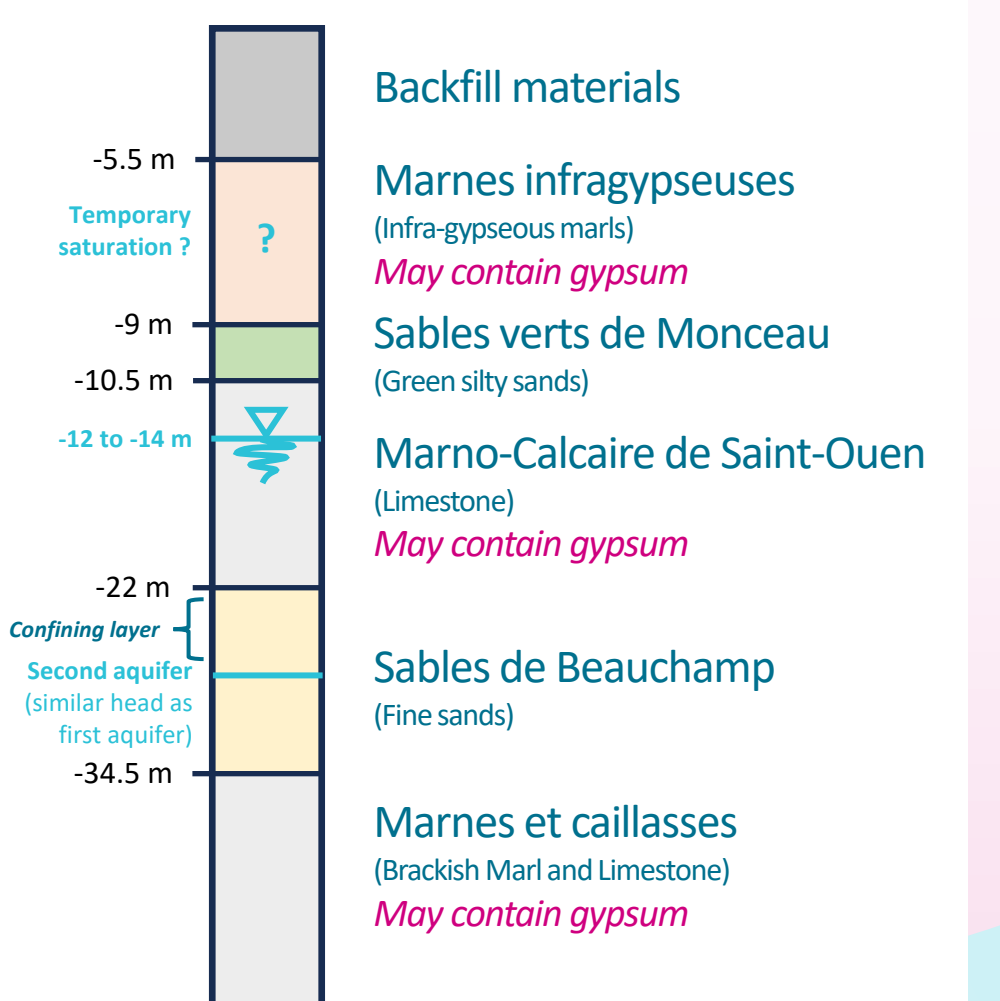
Originally, a strong proportion of sealed surfaces (~70 to 80%).

Ambitious stormwater management objectives (no-discharge, at least for small rain events) and reasonable proportion of green spaces (22%) ...until presence of gypsum was suspected on the basis of preliminary studies



Left: current land cover; Right: future land cover (in green: green areas; in blue: stormwater infiltration basin; in purple: lots to be developed and for which land cover is not yet defined)

Geological log and groundwater levels (center of the study area)



Methodology

1) **Hydrogeological and geochemical site characterization:** analysis of existing geotechnical investigations; GW level and conductivity monitoring for the 2 aquifers (9 piezometers equipped with probes); GW sample analysis ; sulfate concentrations in/from backfill materials...

2) **Modelling the impact of the project** for contrasting stormwater management scenarios:

- **Impact on GW recharge:** water balance for different soil-cover profiles and stormwater management systems (ad hoc 1D-modelling approach derived from URBS¹ for profile conceptualization and Oasis² for unsaturated zone modelling) – simulation for 15-yr rainfall and evapotranspiration records (Paris region) → distributed recharge values (20x20m grid) for current and future conditions
- **Impact on sulfate concentrations in GW:** hydrogeological model (including the two aquifers) with conservative transport (MODFLOW + MT3DMS) – steady state modelling from recharge estimates under current conditions (calibration from GW levels and sulfate concentrations) and future conditions (impact on sulfate concentrations below the project and downstream)

Objectives, based on a case-study:

- 1) Find ways to improve current practices for characterizing of the presence of gypsum (reconnaissance surveys, data interpretation...)
- 2) Understand the potential impacts of stormwater infiltration on groundwater (GW) recharge and geochemical equilibrium in the subsol
- 3) Identify stormwater management options to meet volume reduction targets in sensitive hydrogeological contexts

Results

Presence of gypsum

- No evidence of gypsum in the unsaturated zone or within the 1st aquifer (+ anomalies suggesting that gypsum was already dissolved)
- Gypsum found in the 2nd aquifer (with increasing quantities downstream)
- In previous studies: poor interpretation gamma ray logs; need to more specifically target gypsum and shallow horizons

Hydrogeology

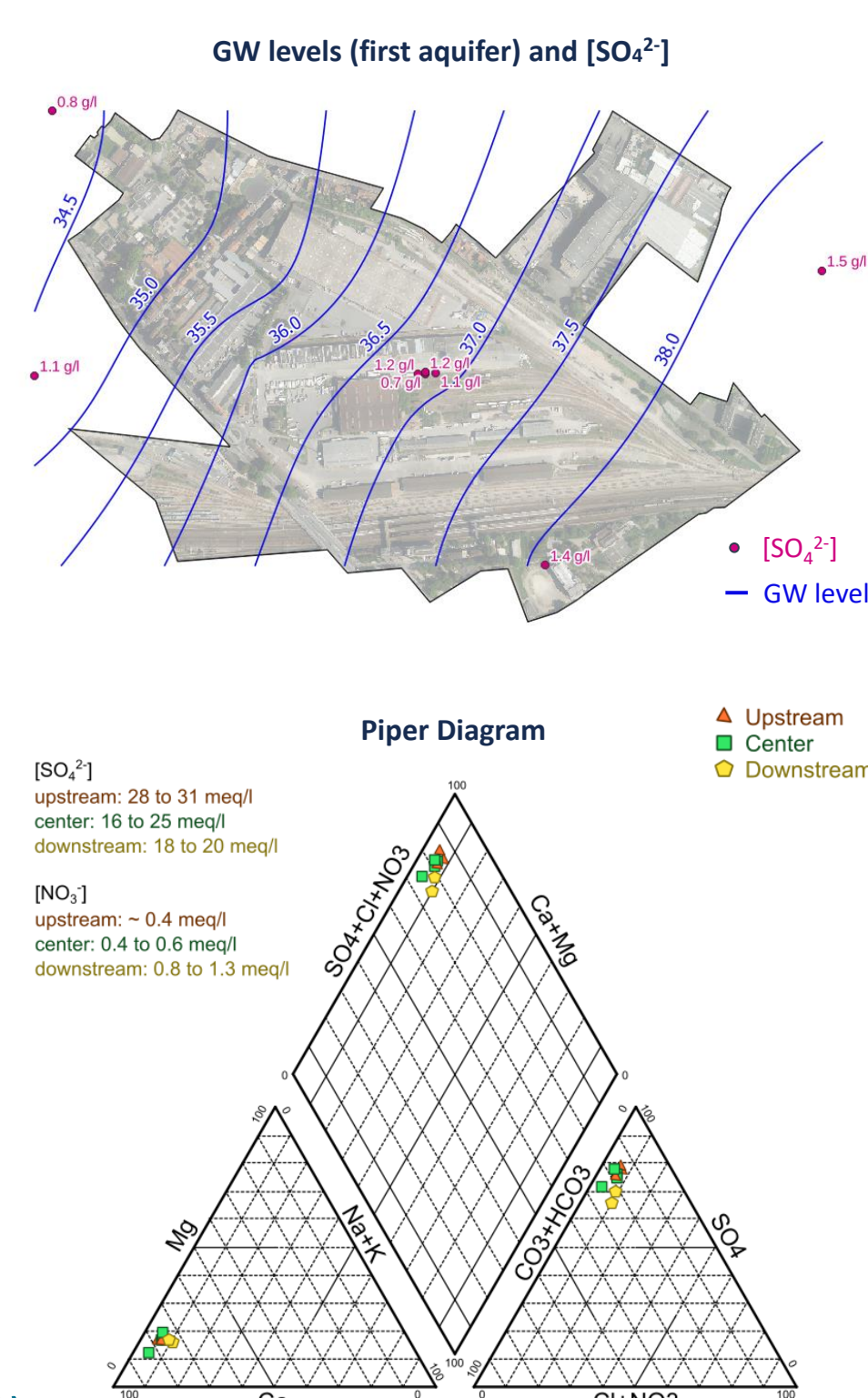
- Limited interactions between the two aquifers evidenced through pumping tests

Geochemistry

- Strong sulfate and calcium concentrations in both aquifers (controlled by a gypsum pole and along dilution line)
- A dilution by anthropogenic sources (NO₃²⁻) from upstream to downstream in the 1st aquifer ?
- Steadier concentrations (near saturation) in the 2nd aquifer ?

Backfill materials

- High sulfate concentrations (from building materials, quarry waste ?)
- Leaching during percolation (suction plate experiment), possibly counterbalancing the dilution effect from anthropogenic sources ?



Stormwater management scenarios

- Set-up with the project coordination team
- General approach : no discharge for small rain events, peak-flow attenuation for the 10-yr return period
- Different ratios between infiltration area (Si) and runoff production area (S_{prod})

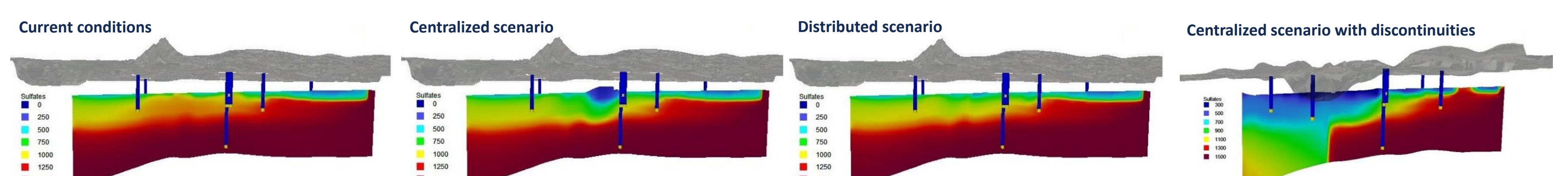
Impact on GW recharge:

- Two references: current land-cover conditions and green-area profile (theoretical reference)
- 2 hypotheses regarding the saturated hydraulic conductivity of the unsaturated zone (taken as homogeneous): 10⁻⁶ and 10⁻⁵ m/s

→ Upper and lower bounds estimates for recharge

Impact on sulfate concentrations in GW:

- **Centralized scenario:** significant dilution in the first aquifer (up to 60%) and non-negligible impact in the underlying one (3 to 7% dilution)
- **Diffuse scenario:** limited impact with a slight decrease of [SO₄²⁻] in the first aquifer (up to 30%), and no impact below (less than 3% dilution)
- **Additional scenario:** centralized infiltration with a 20 m diameter sinkhole below the basin → Impact of poorly known discontinuities ?



Scenario	At the lot scale	On public spaces
Centralized (initial project)	Infiltration systems (S _i /S _{prod} = 10%), designed to capture 80% of the annual rainfall volume	A single basin (S _i /S _{prod} = 0.9%) collecting runoff and from public spaces and potential discharge from the lots
Distributed	Extensive green roofs (7cm depth) combined with infiltration systems (same as above, S _i /S _{prod} = 10%)	Swale network (S _i /S _{prod} = 6% to 27%) collecting runoff from public spaces and potential discharge from the lots

Scenario	Recharge	Deviation from current conditions	Deviation from green-area profile
Green-area	90 to 170 mm/year	+17 / +64 %	- / -
Current conditions	80 to 110 mm/year	- / -	-14 / -39 %
Centralized	160 to 200 mm/year	+104 / +84 %	+74 / +12 %
Diffuse	100 to 130 mm/year	+31 / +23 %	+12 / -15 %

Limited increase of GW recharge with the distributed scenario, although the contribution of infiltration systems remain significant (30% of the total recharge)

Conclusions

Hydrogeological and geochemical site characterization : although the site is identified as a gypsum dissolution hazard area, stormwater infiltration presumably remains possible (no gypsum found in shallow horizons and within the first aquifer, limited interactions between the two aquifers, sulfate input from backfills...) → Relevance of more in-depth geotechnical and hydrogeological studies in the case of large development projects

Impact on sulfate concentrations in GW: centralized infiltration causes a non-negligible decrease of [SO₄²⁻] in the second aquifer, which could accelerate gypsum dissolution. The problem could be exacerbated by discontinuities in the confining layer (likely to increase with higher hydraulic gradients). Diffuse infiltration allows maintaining [SO₄²⁻] close to current conditions and should hence be preferred.

Impact of infiltration on GW recharge: centralized infiltration is associated with a significant increase of GW recharge (with locally extreme values) and should clearly be avoided. Combining green-roofs and diffuse infiltration can effectively limit the increase of GW recharge. However, increasing the area of infiltration systems only marginally contributes to reducing recharge, and limiting the amount of water to be infiltrated (through appropriate control of soil-sealing) should be the preferred strategy.

Limits of the study: elementary description of the unsaturated zone (homogeneity assumption; no preferential flows; basic description of evapotranspiration; no anthropogenic sources...); poorly known subsurface heterogeneities that may strongly affect GW flows; relatively simple GW modelling (steady-state regime; conservative transport with zero inflow concentration); limited data for calibration...