Water and contaminants transfer in the chalk critical zone

Undergound quarry of Saint Martin le Noeud

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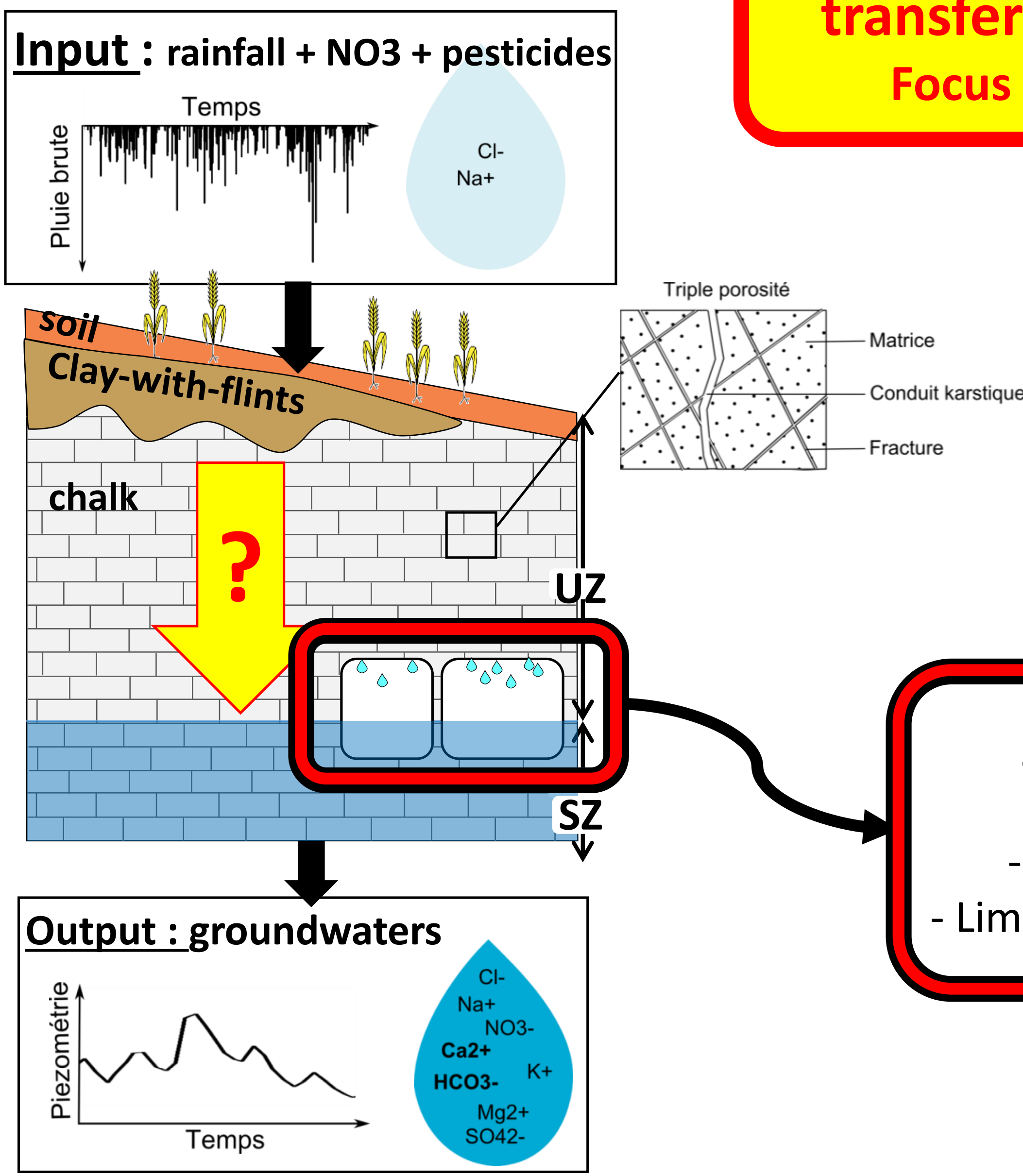
INTRODUCTION

CHALK AQUIFER → Important resource for drinking water

QUESTION: Water and contaminant transfers in the chalk critical zone?

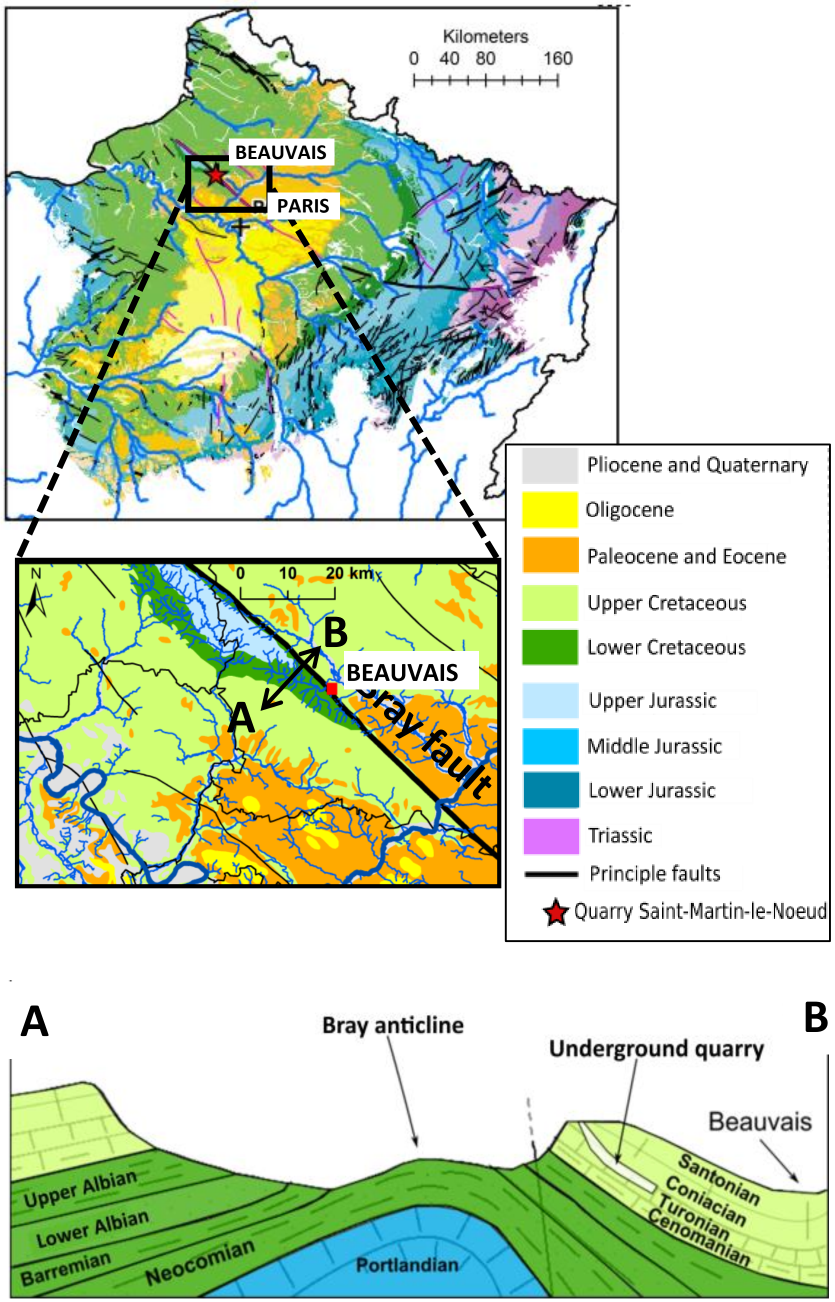
Focus on agricultural contaminants

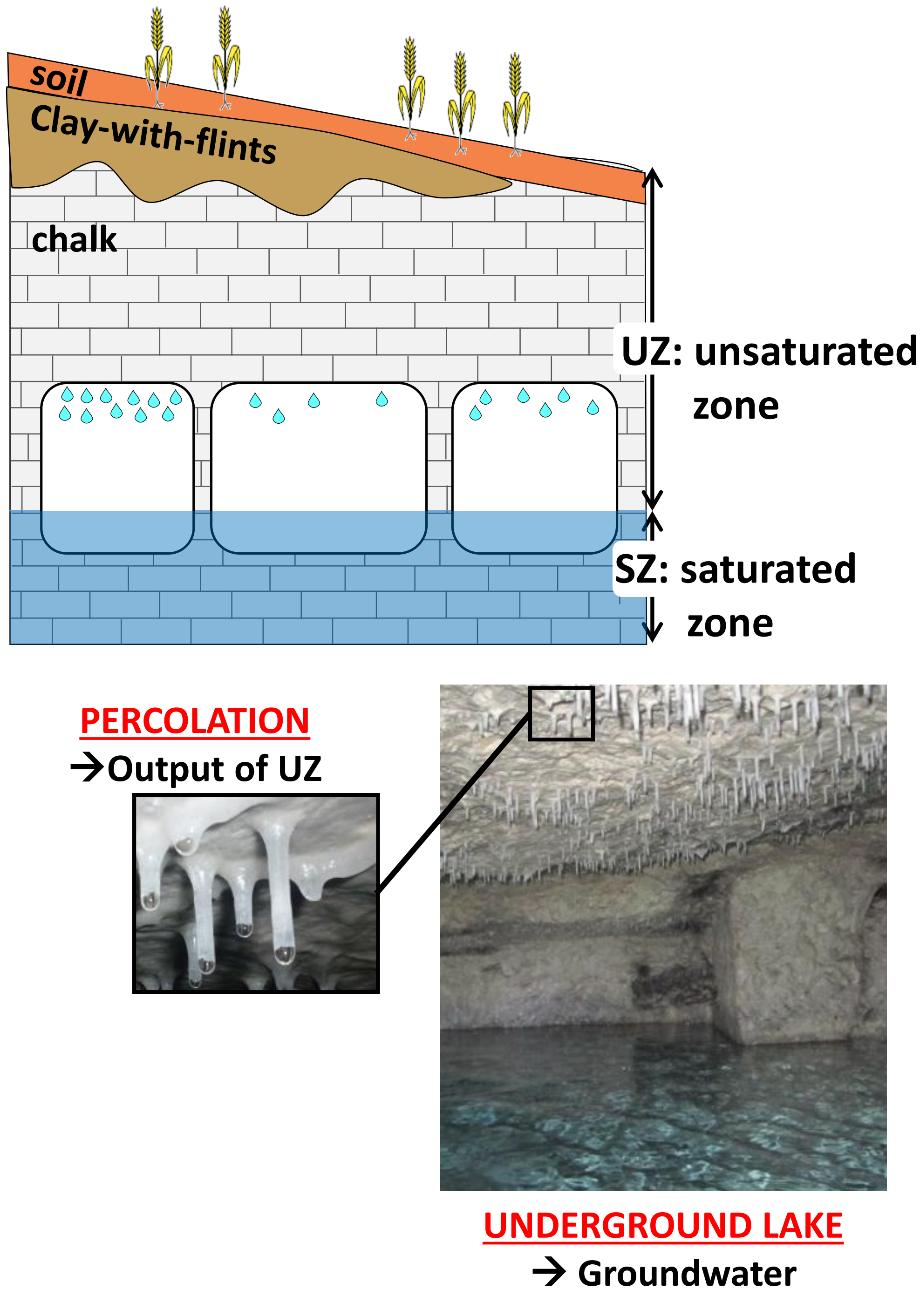


Underground Quarry of Saint Martin le Nœud

- Direct access in the aquifer
- Limit Unsaturated /saturated zones

STUDY SITE: underground quarry





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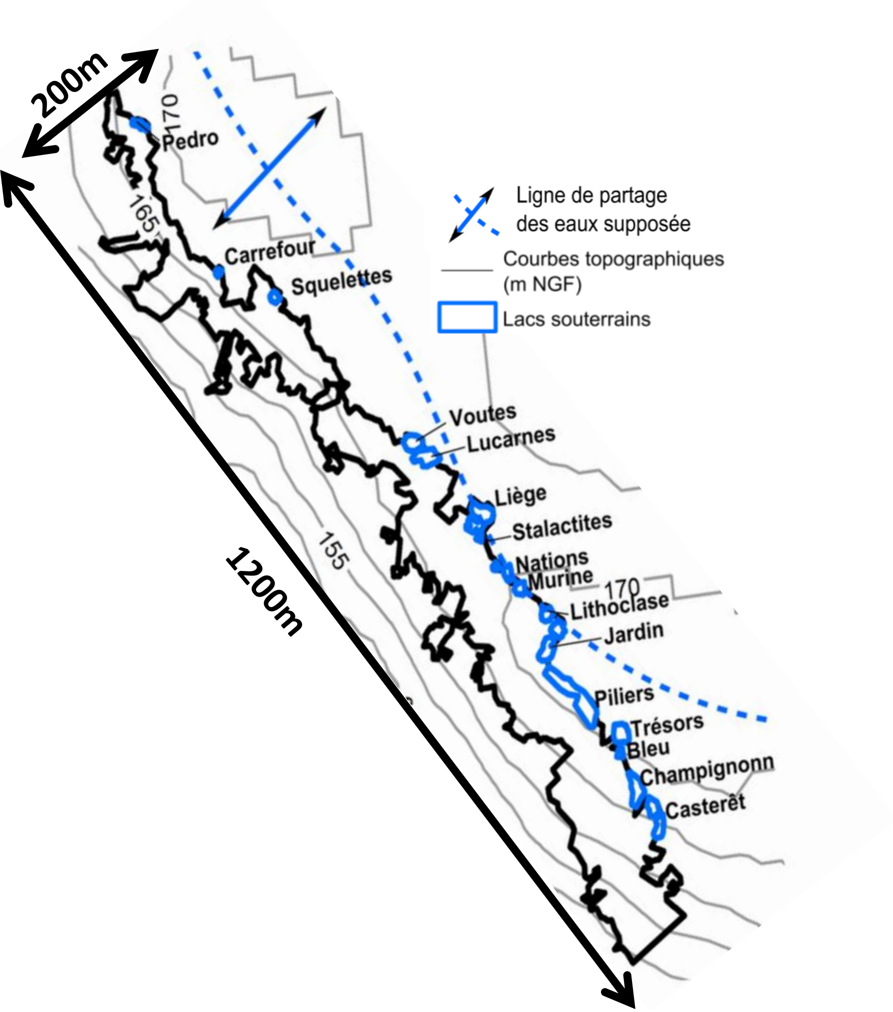
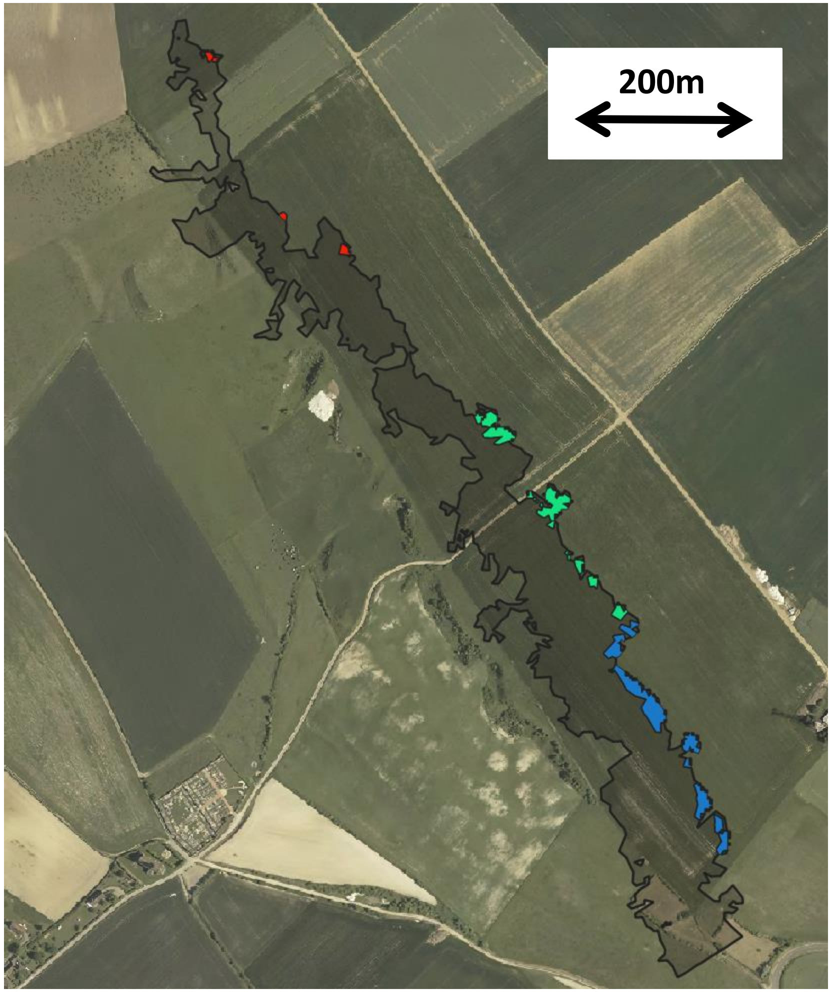


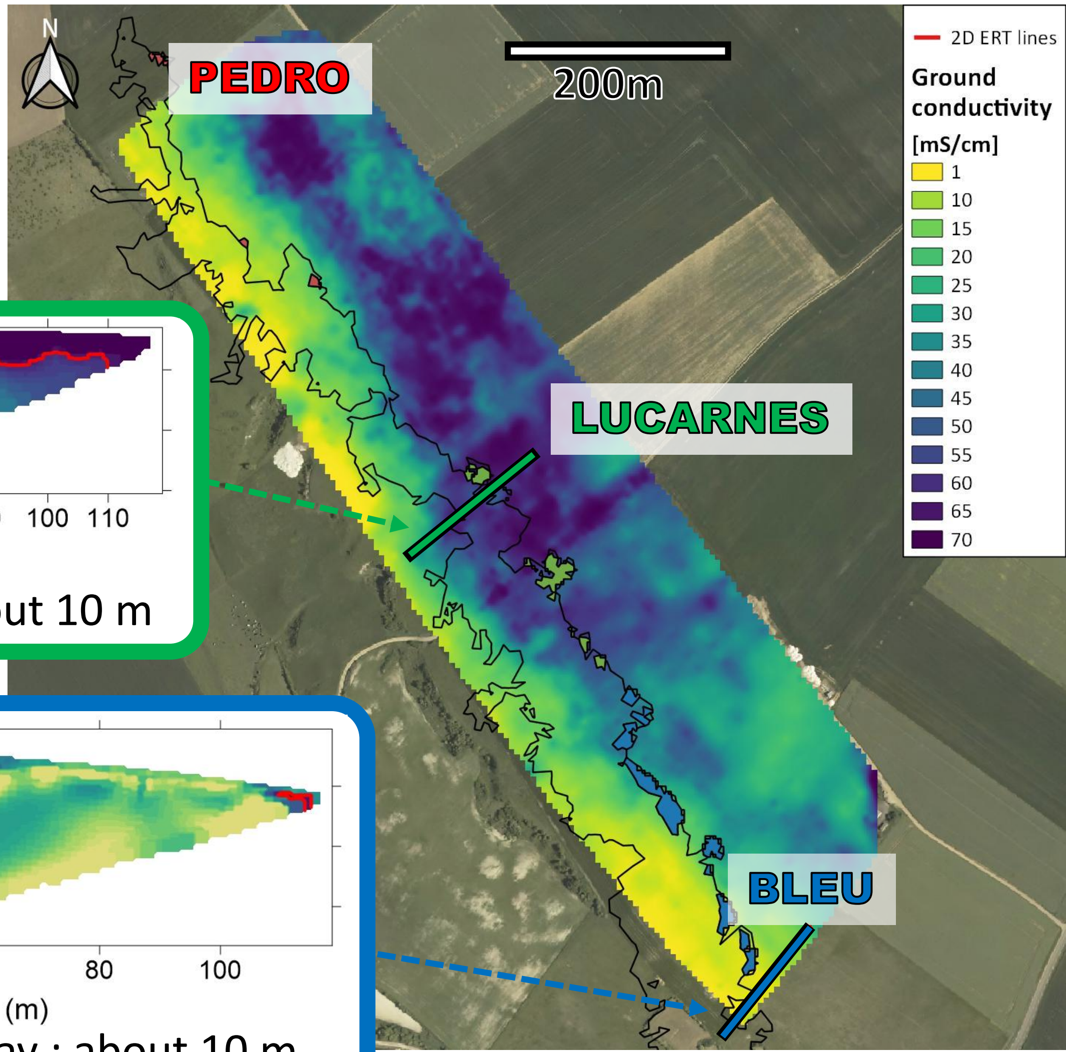


16 underground lakes
17m < depth <30m

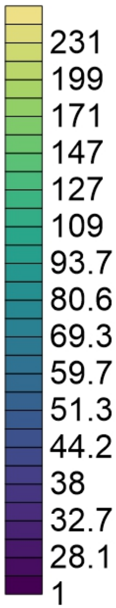
Land Use: agriculture
Fertilizers : nitrate, pesticides (atrazine)
(time series available from 1960)

CHARACTERIZATION OF THE CRITICAL ZONE

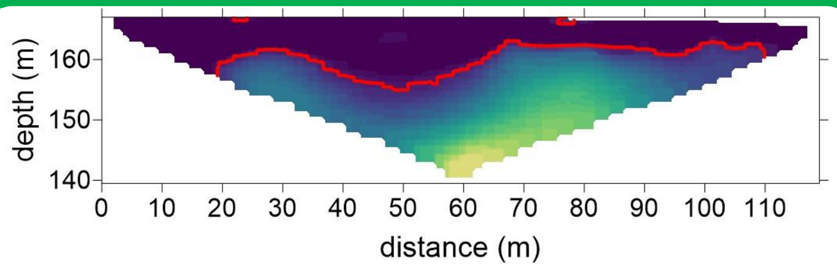
<u>Ground Conductivity (measured by CMD)</u>
= proxy of the clay with flints's thickness



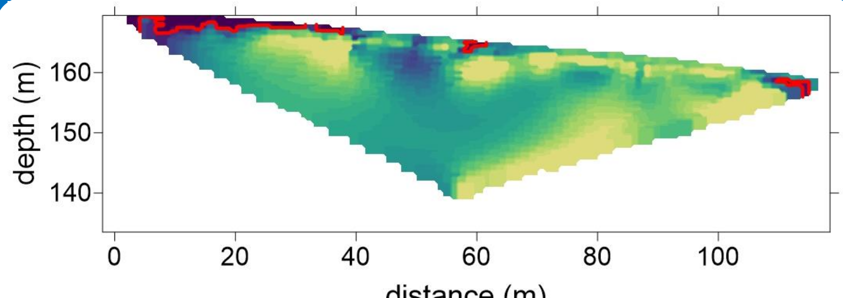
ERT profiles in contrasted areas



Resistivity (Ω.m)



→ Very thick layer of clay : about 10 m



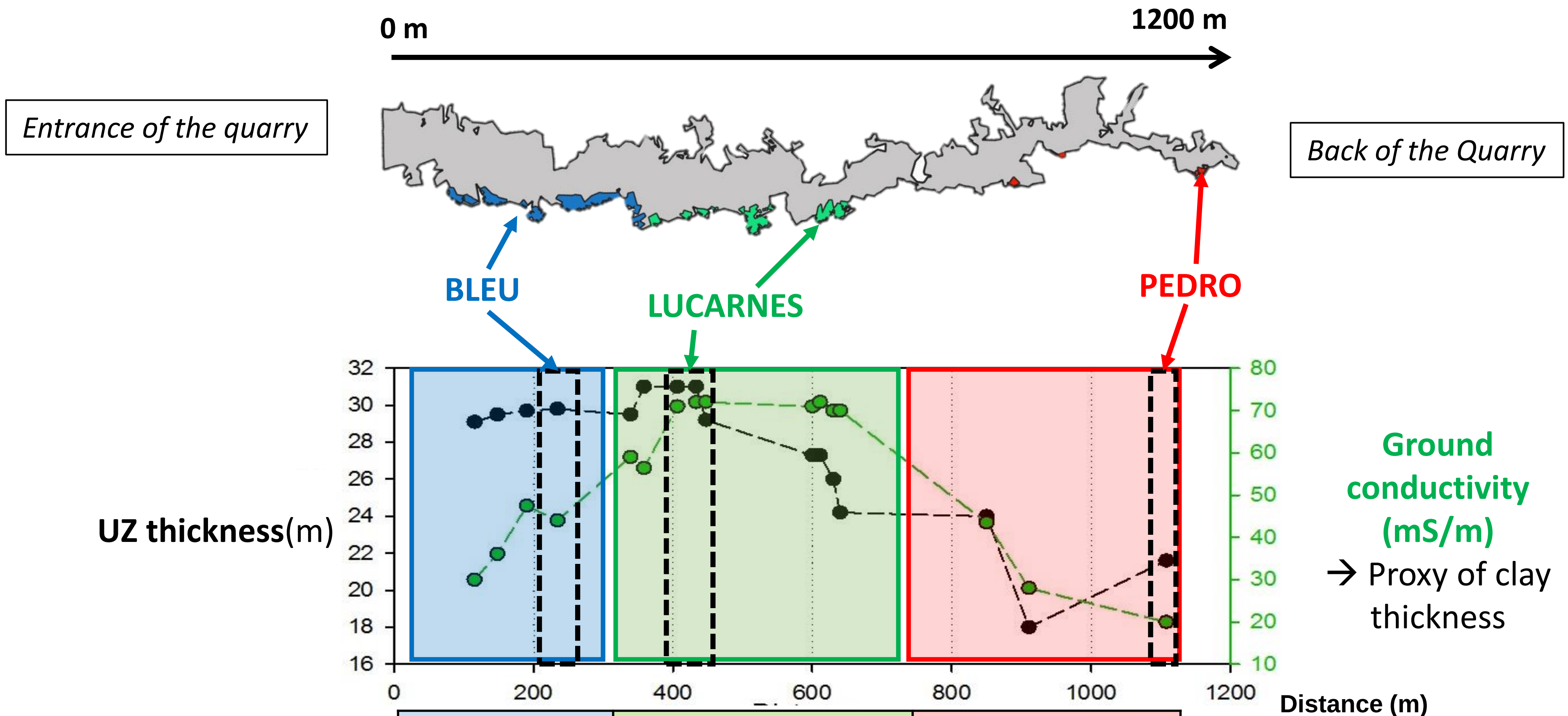
→ Very thin layer of clay : about 10 m

Spatial variation of the clay-with flints thickness → spatial variation of the infiltration processes

→ preferential infiltration points in the depressions with clay ?

→ Storage of water in surface in the areas with high thickness of clay?

CHARACTERIZATION OF THE CRITICAL ZONE

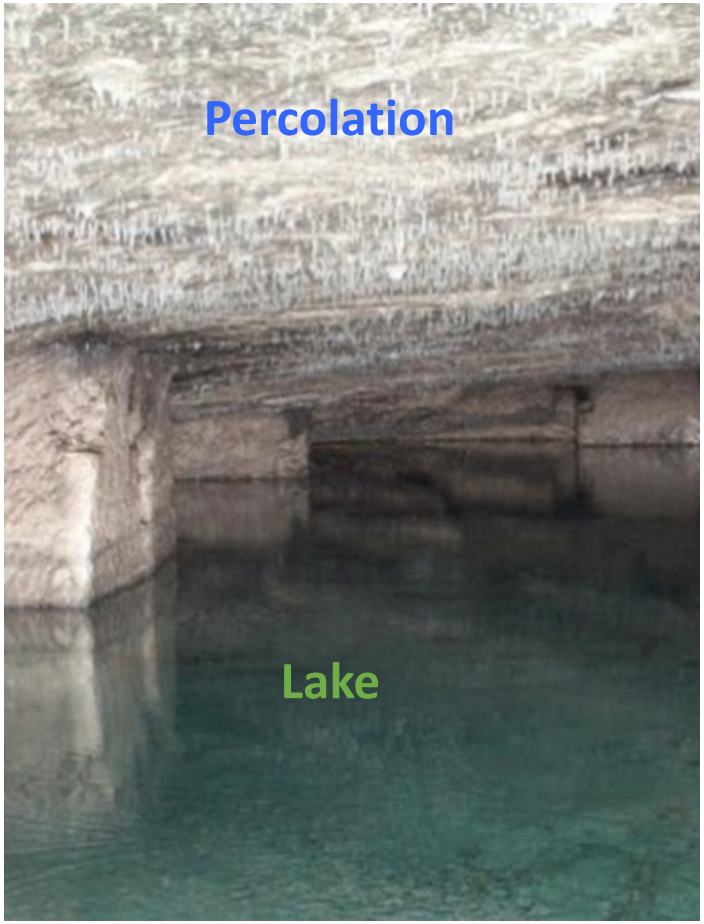


	Group 1	Group 2	Group 3
UZ thickness	≈ 30 m	≈ 30m	17 – 24m
Clay with flints thickness	+/-	+	-

Spatial variation of the unsaturated zone characteristics

GROUNDWATERS: Data acquisition

16 sites (percolation + lake)



High frequency measurements (every hour)

- Percolating flow
- Lake level
- Conductivity and temperature of lake

Beaker installed to collect Percolation sample

Raingauge to record Percolation flow

Sampling of percolation and lake every 2 months

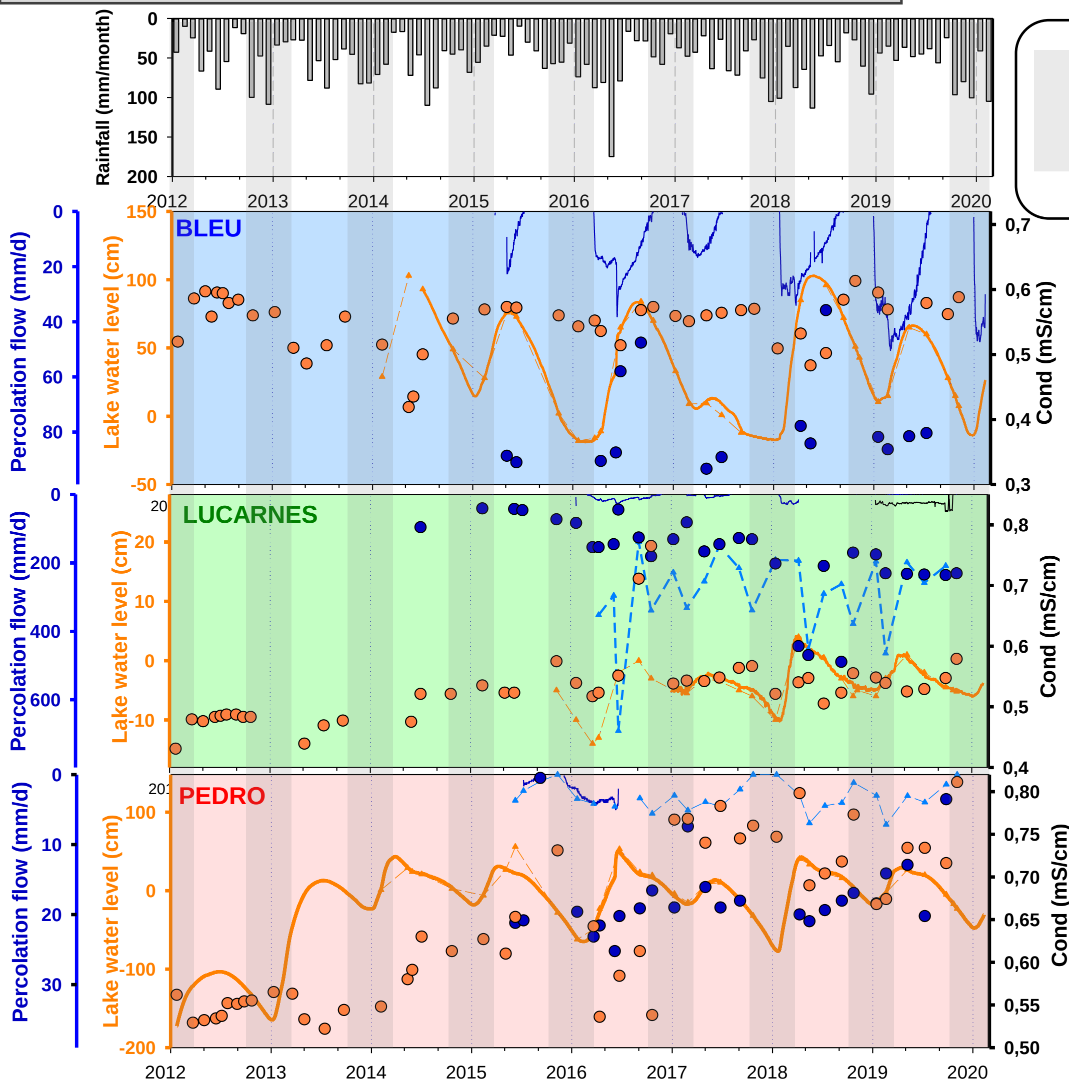
Chemical analysis:

- Major ions (K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-)
- Pesticides (atrazine and metabolites)

Rainfall data : daily time-series of Beauvais Station

GROUNDWATERS: Temporal approach

Hydrodynamics and elec. conductivity



Lake: Δh(/year) ≈ 100 cm
Perco discontinuous, summer: high , winter: Ø
Electrical conductivity: [lake] > [perco]
high seasonal variations (~200uS/cm/y)

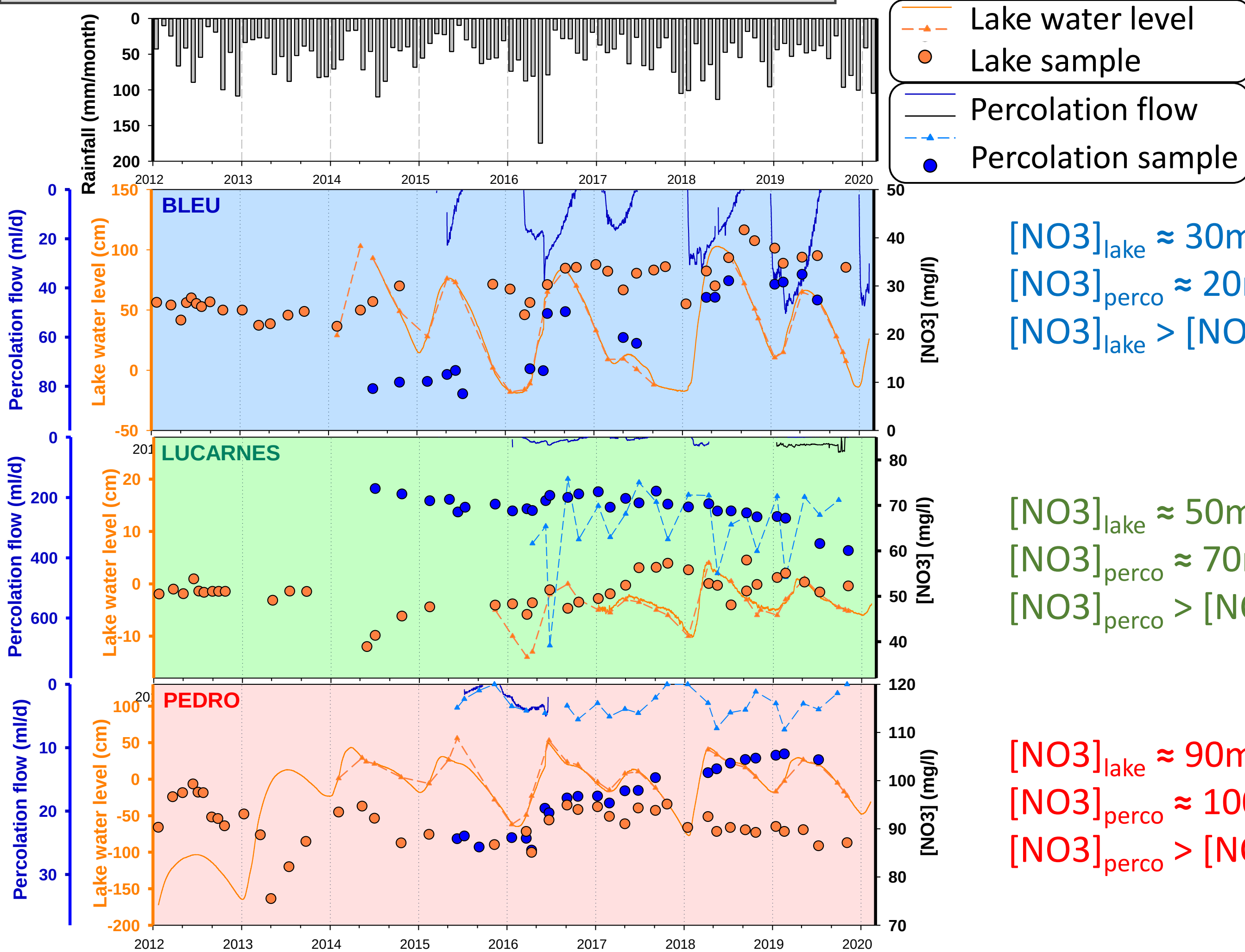
Lake: Δh(/year) ≈ 15 cm
Percolation continuous, during all the year
Electrical conductivity: [perco] > [lake]
low seasonal variations (<100uS/cm/y)

Lake: Δh(/year) ≈ 100 cm
Percolation seasonal: summer: high
winter:stops or decreases
Electrical conductivity: [lake] > [perco]
medium seasonal variations (~100uS/cm/y)

Hydrodynamic functionnings: response time: 2-3 months ≈ 100m/y → **velocity or celerity ?**
spatial differencies } Spatial variation of the transfer processes
Groundwater quality: spatial differencies → **processes controlled by the ZNS properties?**
lakes ≠ percolation } → **origin of the 2 different types of groundwater?**

GROUNDWATERS: Temporal approach

Nitrate concentrations



$[NO3]_{lake}$ ≈ 30mg/l, evolution: ↑
$[NO3]_{perco}$ ≈ 20mg/l evolution: ↑↑ ,
$[NO3]_{lake}$ > $[NO3]_{perco}$

$[NO3]_{lake}$ ≈ 50mg/l, evolution: ↔
$[NO3]_{perco}$ ≈ 70mg/l , evolution (1,5mg/l /y)
$[NO3]_{perco}$ > $[NO3]_{lake}$

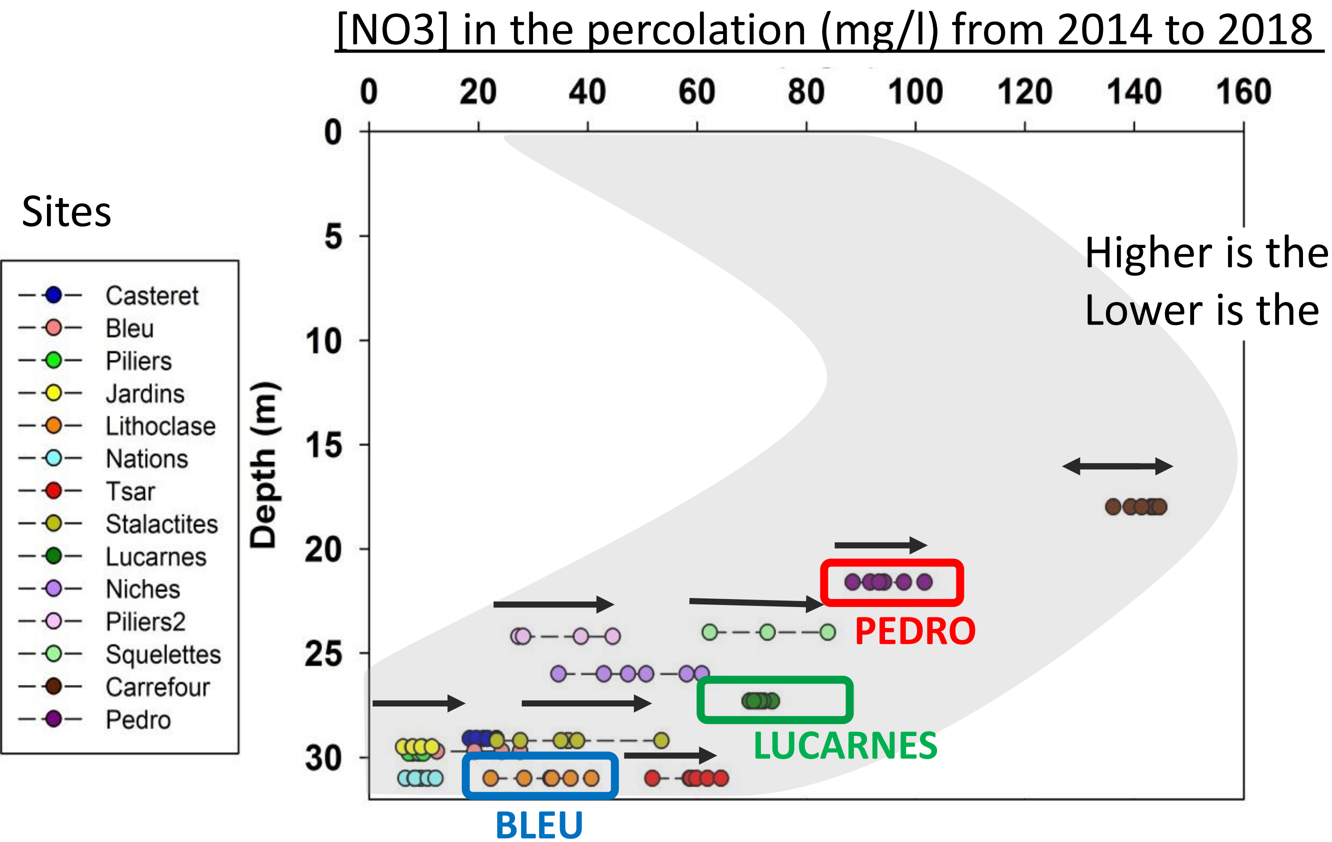
$[NO3]_{lake}$ ≈ 90mg/l, evolution: ↔
$[NO3]_{perco}$ ≈ 100mg/l , evolution: ↑↑
$[NO3]_{perco}$ > $[NO3]_{lake}$

Very high spatial variation of the [NO3] concentration
Important differencies between lakes and percolation
Globally, increase in the concentrations, in both lakes and percolations
Globally decrease of the [NO3] concentration in the lakes when the water level of lake increases

→ **Recharge with recent surface water (less contaminated)?**
→ **Nitrate storage in the unsaturated zone of chalk?**

GROUNDWATERS: contamination profile in the UZ - Chen (2019) PhD thesis

Percolation samples at different depths allow to show the vertical profile of contamination in the UZ Chalk



Higher is the UZ thickness, lower is [NO3]

Lower is the UZ thickness, higher is [NO3]

Storage of contaminants in the UZ of chalk

→**Nitrate vertical profile goes down .** $0,5\ m/y < V_{transfer} < 2\ m/y$

→**Peak of nitrate at 18m of depth**

Chen et al. (2019) – J of Hydrol, Chen (2019) PhD thesis

GROUNDWATERS : Pesticides

Focus on the lakes

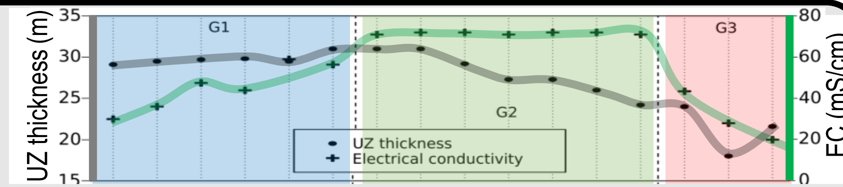
Pesticides :

- Focus on atrazine and desethylatrazine (DEA)
- DEA is a metabolite resulting from degradation of atrazine (probably near surface)
- DAR= degradation atrazine ratio
  DAR =atrazine/DEA

Results

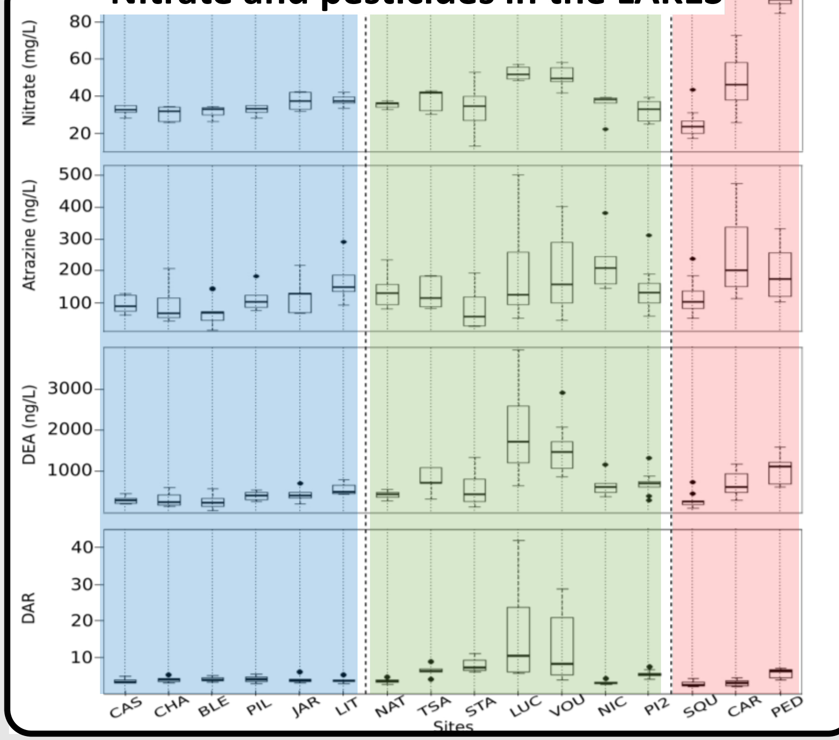
- Important differences of pesticides concentrations in the lakes
- Very high concentrations in atrazine and DEA in the lakes (specially in the group 2)
- DAR ≈ 3 for groups 1 and 3
  DAR >> 3 for group2 → important degradation processes

UZ



GROUNDWATERS
Data from 2016 to 2017

Nitrate and pesticides in the LAKES



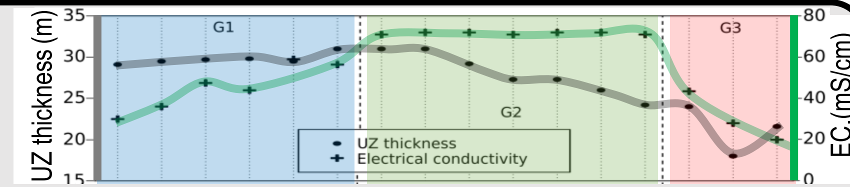
GROUNDWATERS / UZ characteristics

Focus on the lakes

Chen et al. (2019) showed $V_{transfer}$ is higher under a **thick** clay-with-flints layer

		Group 1	Group 2	Group 3
UZ	UZ thickness	≈ 30 m	≈ 30m	17 – 24m
UZ	Clay with flints thickness	+/-	+	-
GROUNDWATERS	[NO3]	-	+	+
GROUNDWATERS	[Atrazine]	-	+	+
GROUNDWATERS	[DEA]	-	++	+
GROUNDWATERS	Degradation (DAR)	-	++	-
GROUNDWATERS	Percolation flow	+	++	+
GROUNDWATERS	Water level variation	+	-	+
GROUNDWATERS	Vtransfer in UZ *(Chen et al. 2019)*	-	+	-

UZ



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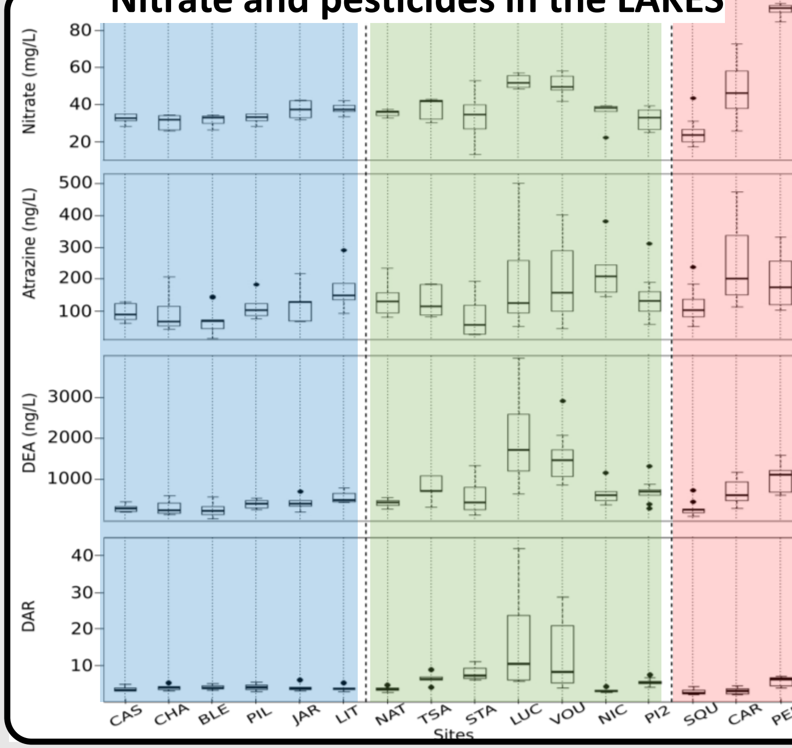
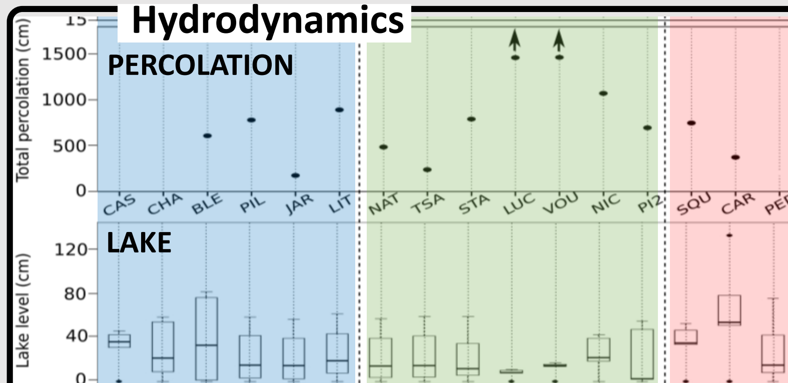


Hydrodynamics



GROUNDWATERS / UZ characteristics

Focus on the lakes

		G1	G2	G3
UZ	UZ thickness	≈ 30 m	≈ 30m	17 - 24m
UZ	Clay with flints thickness	+/-	+	-
GROUNDWATERS	[NO3]	-	+	+
GROUNDWATERS	[Atrazine]	-	+	+
GROUNDWATERS	[DEA]	-	++	+
GROUNDWATERS	Degradation (DAR)	-	++	-
GROUNDWATERS	Percolation flow	+	++	+
GROUNDWATERS	Water level variation	+	-	+
GROUNDWATERS	Vtransfer in UZ *(Chen et al. 2019)*	-	+	-

<u>Comparison Groups 1 and 2 :</u>

About same UZ thickness, clay thickness higher for Group 2

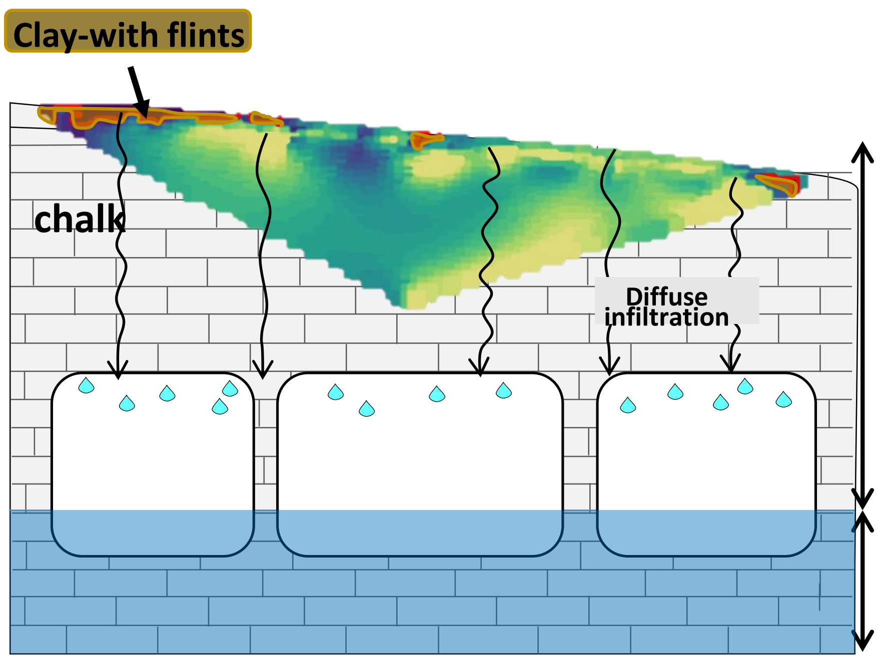
Under a thick clay-with fints layer, at the same depth

- Contamination is higher
  - → more rapid transfer
- DAR is higher
  - → more degradation processes on the surface
- Percolation is more important and continuous
- Lake's water level variation is lower
  - → continuous recharge (storage of water in UZ)
- Transfer velocities are higher

CONCLUSION: TRANSFER PROCESSES

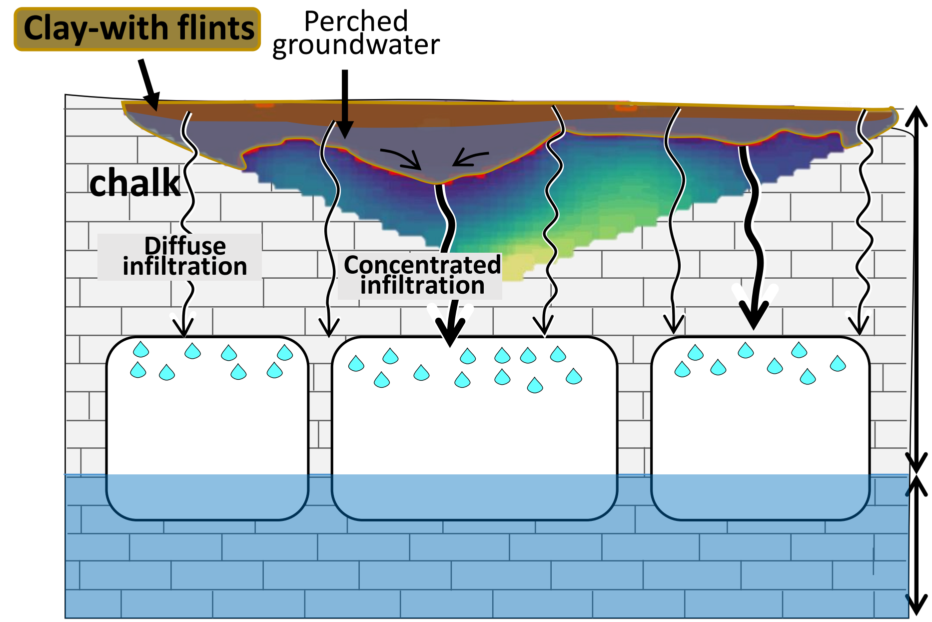
The clay-with-flints layer controls the transfer processes

Thin clay layer: BLEU Group 1:



Diffuse infiltration : low tranfer velocity
Seasonal recharge
Variation of percolation flow and water level

Thick clay layer: LUCARNES Group 2



Storage of water: perched groundwater
    allowing degradtion processes
Diffuse and concentrated infiltration (higher transfer velocity
Continous recharge from perched groundwater to water table
    allowing continuous percolation
    inducing low variation of lake's water level