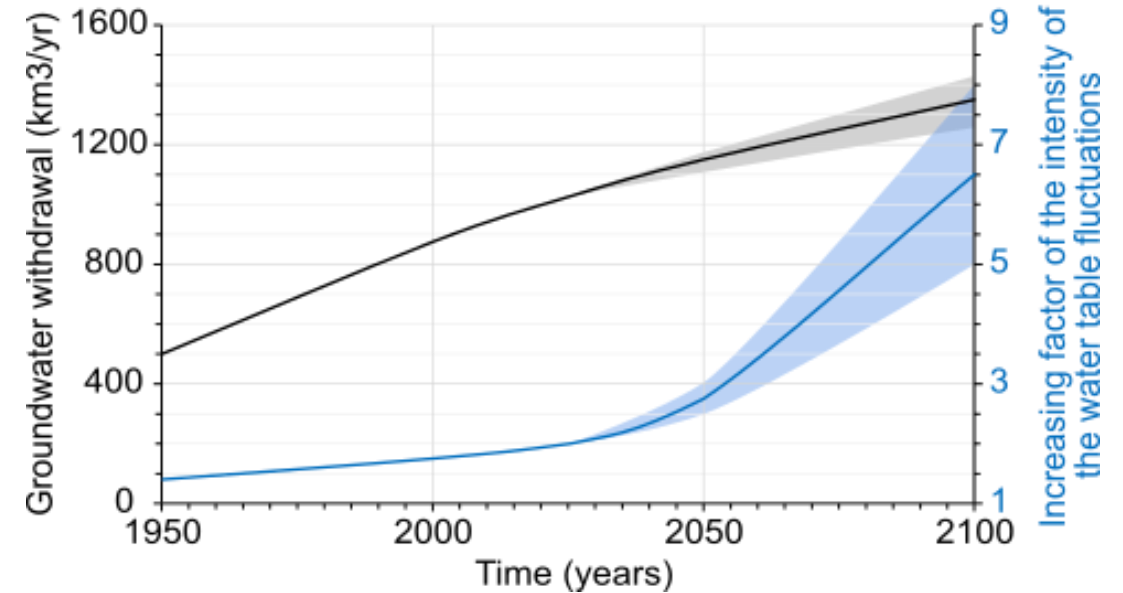
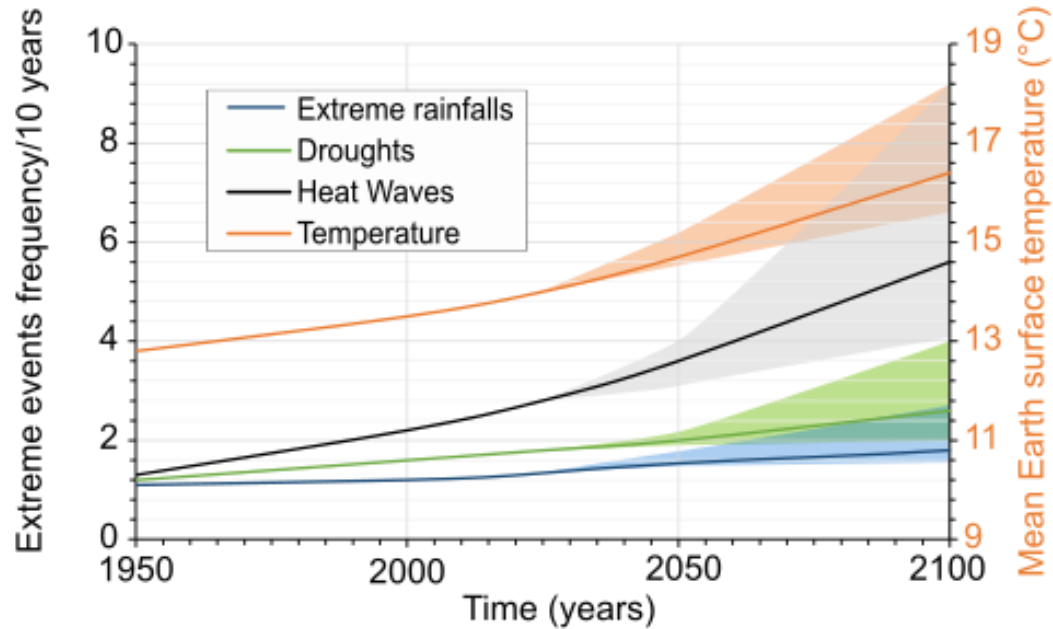


## New lysimetric experiments to assess the effect of water table-level variations on the fate of petroleum hydrocarbon pollutants (LNAPL) in soils in the climate change context.

*Amélie Cavelan*<sup>\*1</sup>, *Fabrice Golfier*<sup>2</sup>, *Stéfan Colombano*<sup>3</sup>, *Anne-Julie Tinet*<sup>2</sup>, *Constantin Oltean*<sup>2</sup>, *Hossein Davarzani*<sup>3</sup>, *Jacques Deparis*<sup>3</sup>, *Catherine Lorgeoux*<sup>2</sup>, *Noële Enjelvin*<sup>4</sup>, *Pierre Faure*<sup>1</sup>

<sup>1</sup>Université de Lorraine, CNRS, LIEC, France ; <sup>2</sup> Université de Lorraine, CNRS, GeoRessources ; <sup>3</sup>BRGM ; <sup>4</sup> Université de Lorraine, INRAE, LSE, GISFI.

- Historical data and predictions (IPCC, 2021, EEA and Wada 2016)



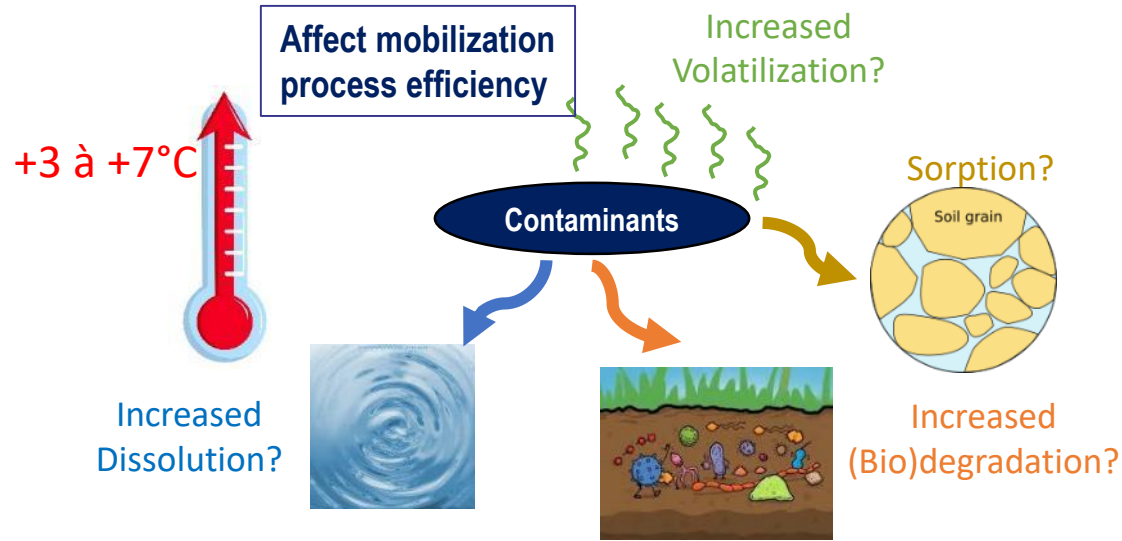
- Higher Earth surface, surface, and groundwater temperatures
- More intense but less frequent precipitation events

- More intense groundwater level fluctuations
- Significant increase in the pressure exerted on groundwater resources

**But today, due to contamination, 24% of the European groundwater resource is already unsuitable for consumption.**

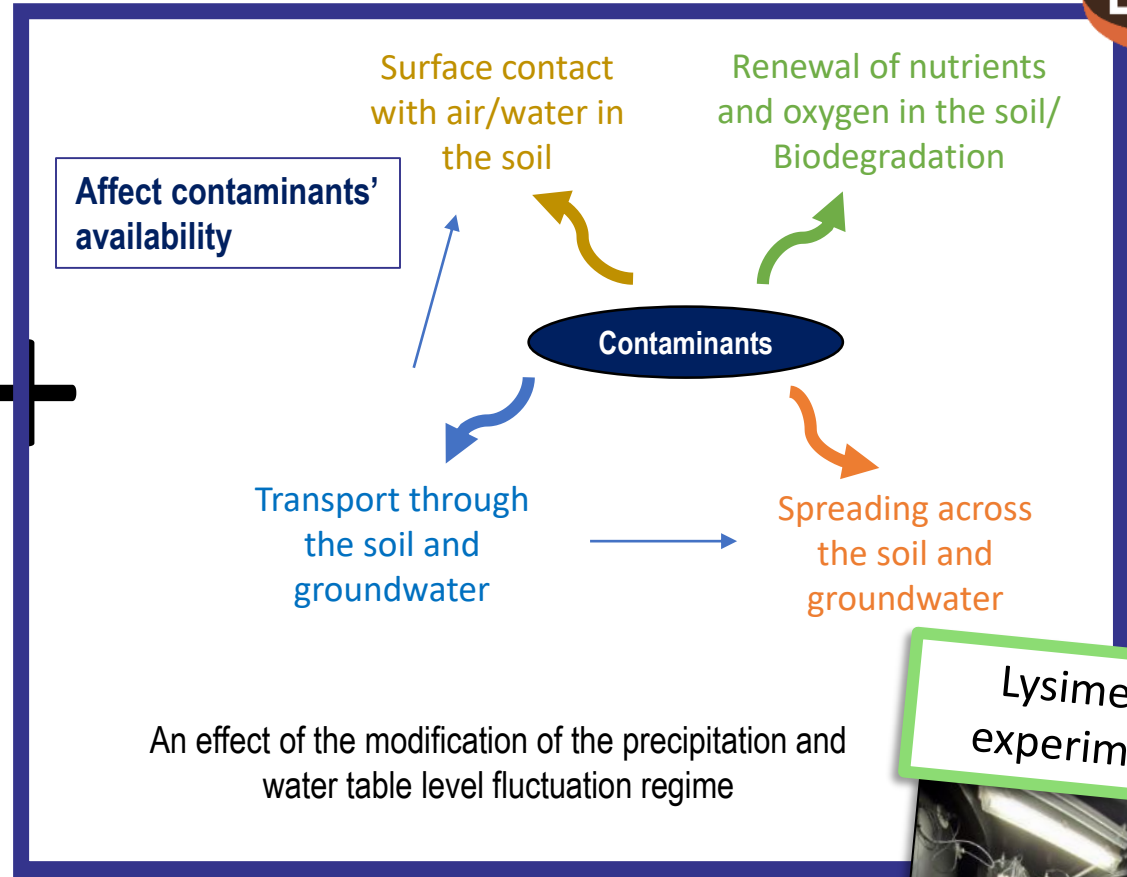
# Introduction / Climate change and LNAPLs contaminations

- How can climate change affect contaminated soils and groundwater tables?



An effect of the increased soil and groundwater temperature

How can we do that?



An effect of the modification of the precipitation and water table level fluctuation regime

Lysimetric experiments



Higher temperatures, more intense water table fluctuations, and more intense but less frequent precipitation regimes may affect :

- Contaminants availability, mobilization, and attenuation rates
- contaminated soils and groundwater quality

=> A better understanding of these processes is required for a better prediction and management of the groundwater resource

## ▪ The example of light non aqueous phase liquids (LNAPLs) contaminations:

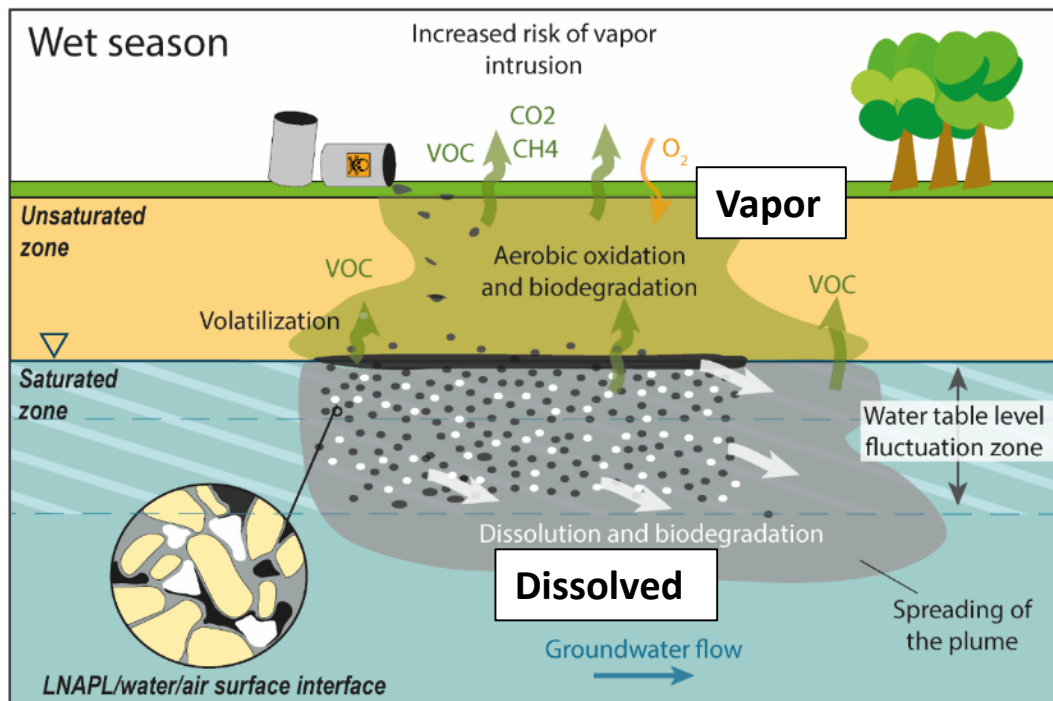
- 37% of soil and groundwater contaminations (EEA, 2019)
- Accidental release of fuel, diesel oil, crude oil, etc.
- Hydrophobic, non-ionic and low density than water
- Strong spatial and temporal variations of the soil LNAPL saturation
- Mobilization processes tied with groundwater table fluctuations (Gupta et al., 2019; Cavelan et al., 2022)



Contamination of water by fuel

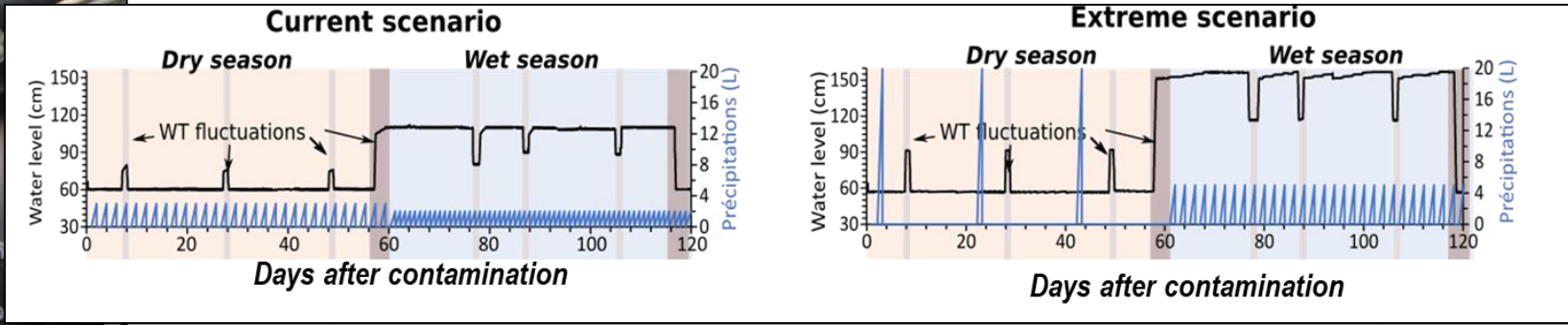
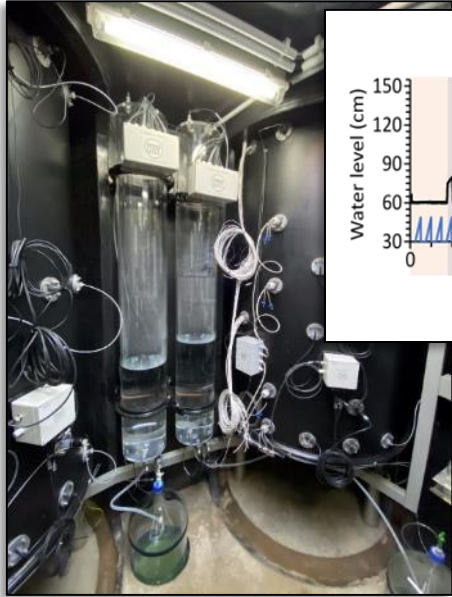


Diesel + water

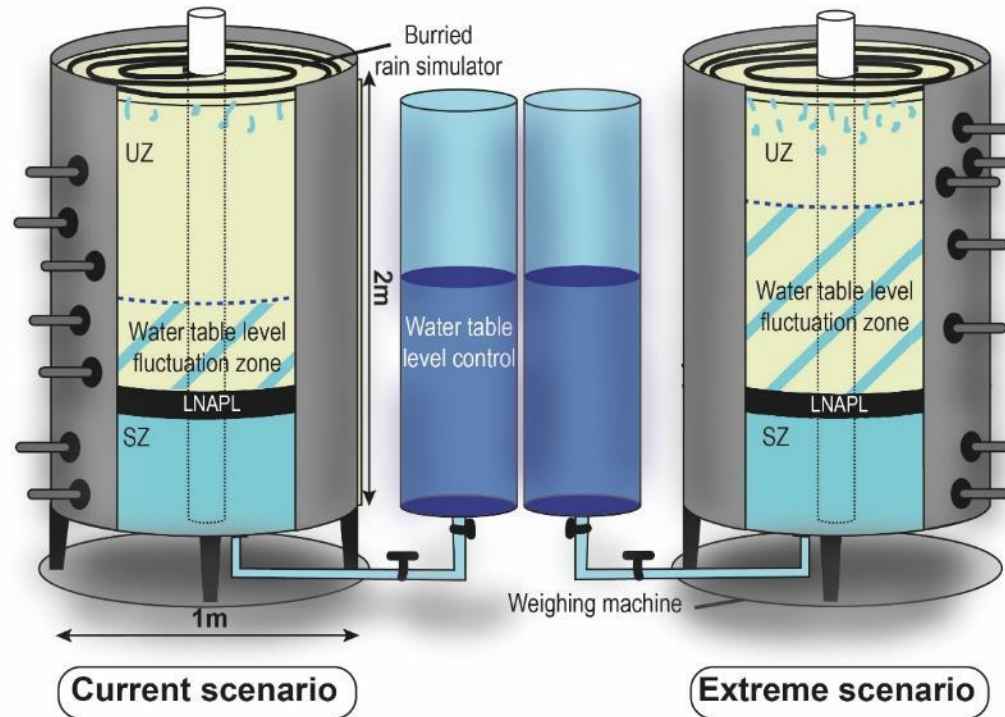


(Cavelan et al., 2022)

- Our objectives:**
- Understanding the impact of groundwater table fluctuations intensity on LNAPL remobilization processes
  - Improve in situ monitoring methods



50L of diesel fuel/lysimeter

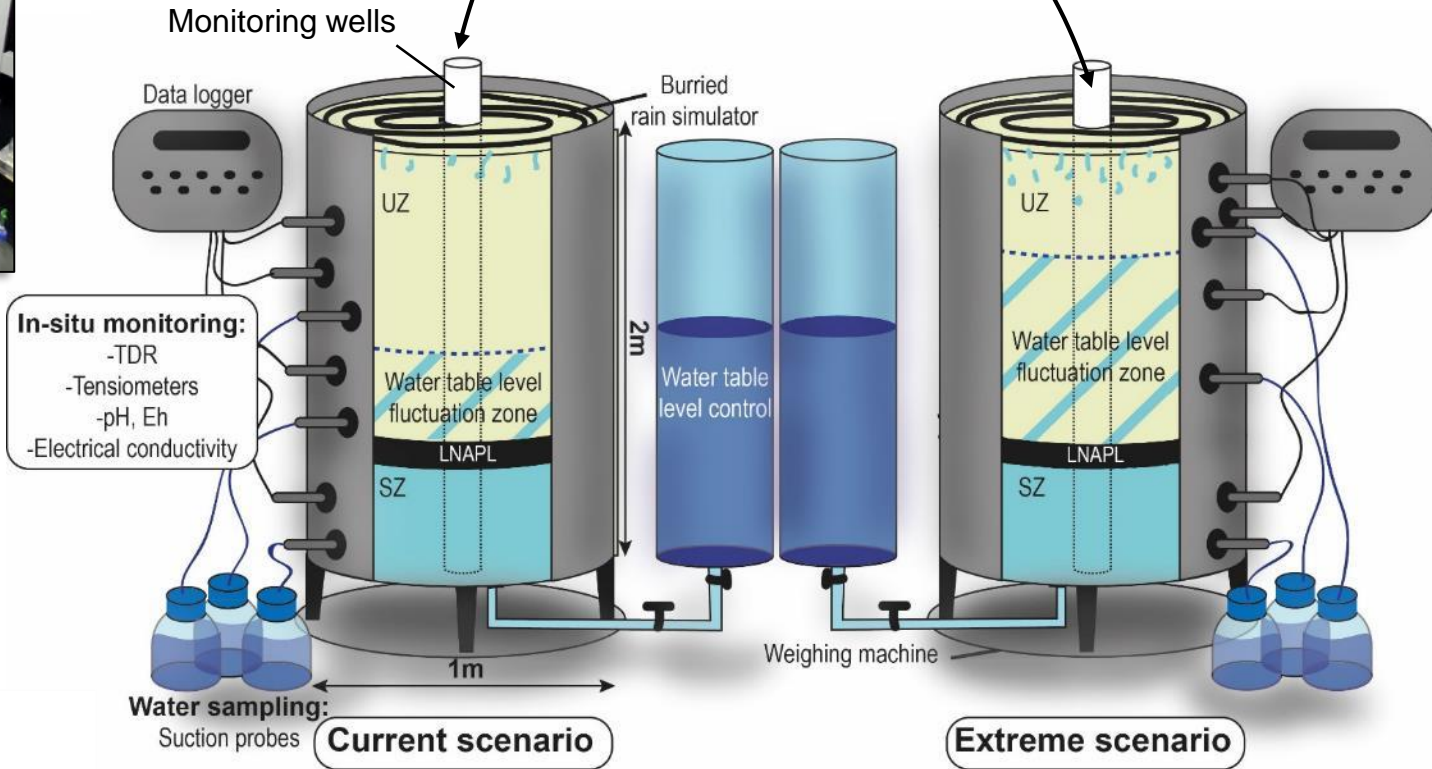


Monitoring of two contaminated soil columns under 2 controlled scenarios of precipitation and groundwater fluctuation regimes

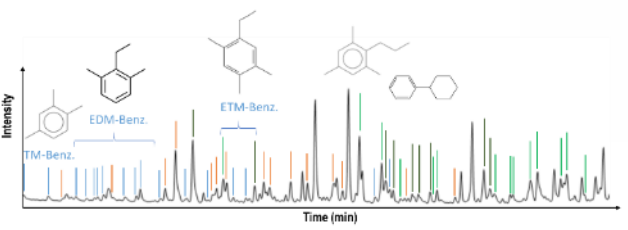


**In-situ and ex-situ measurements**

**Pure phase**  
Apparent thickness in well,  
composition (GC/MS)



**Dissolved phase**  
Composition and concentration  
(COD, GC-MS)



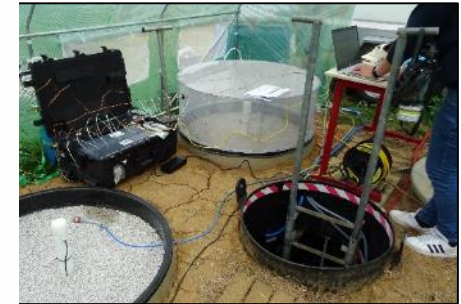
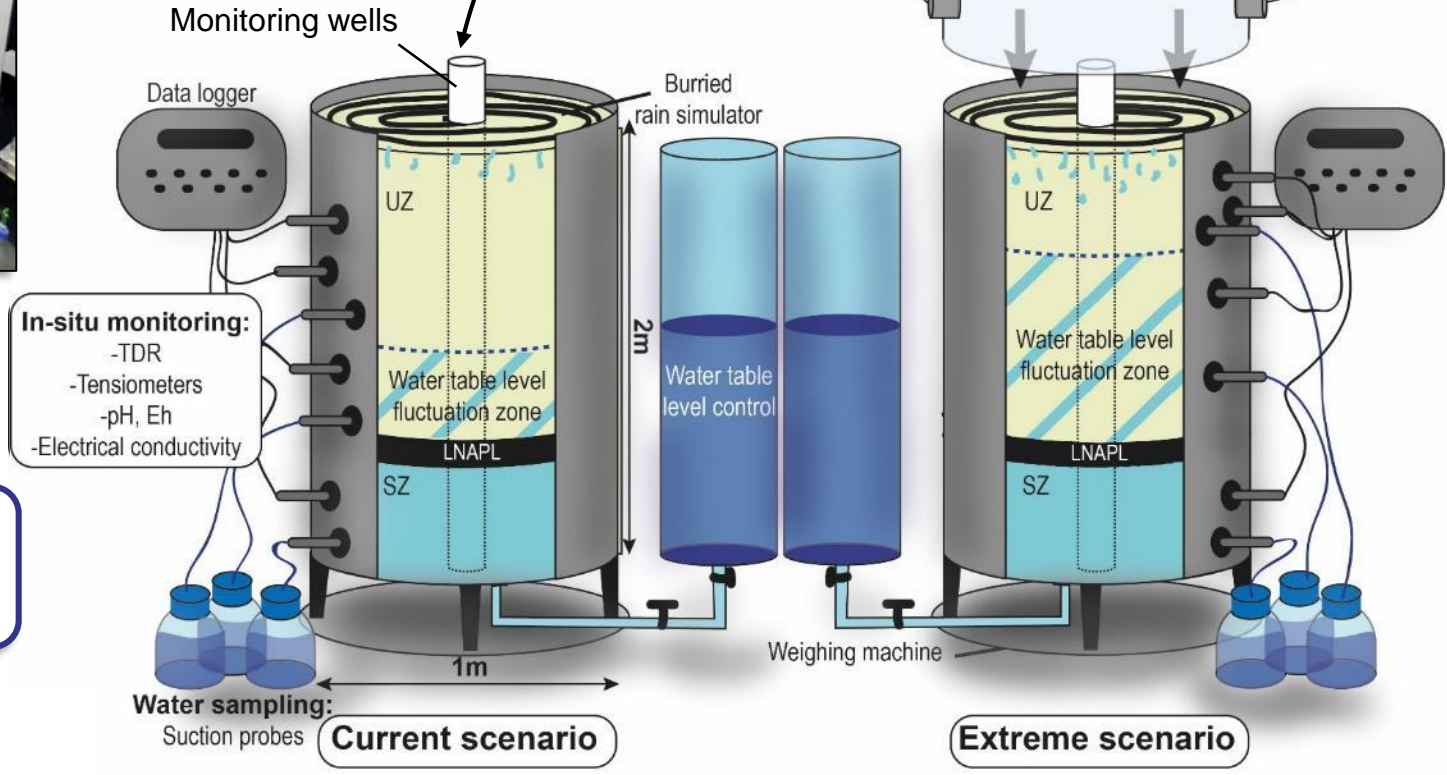
**Monitoring of two contaminated soil columns under 2 controlled scenarios of precipitation and groundwater fluctuation regimes**



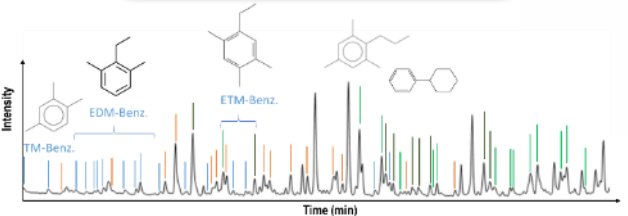
**In-situ and ex-situ measurements**

**Pure phase**  
Apparent thickness in well, composition (GC/MS)

**Vapor phase**  
Composition and fluxes ( $\mu$ GC, GC/MS)



**Dissolved phase**  
Composition and concentration (COD, GC-MS)



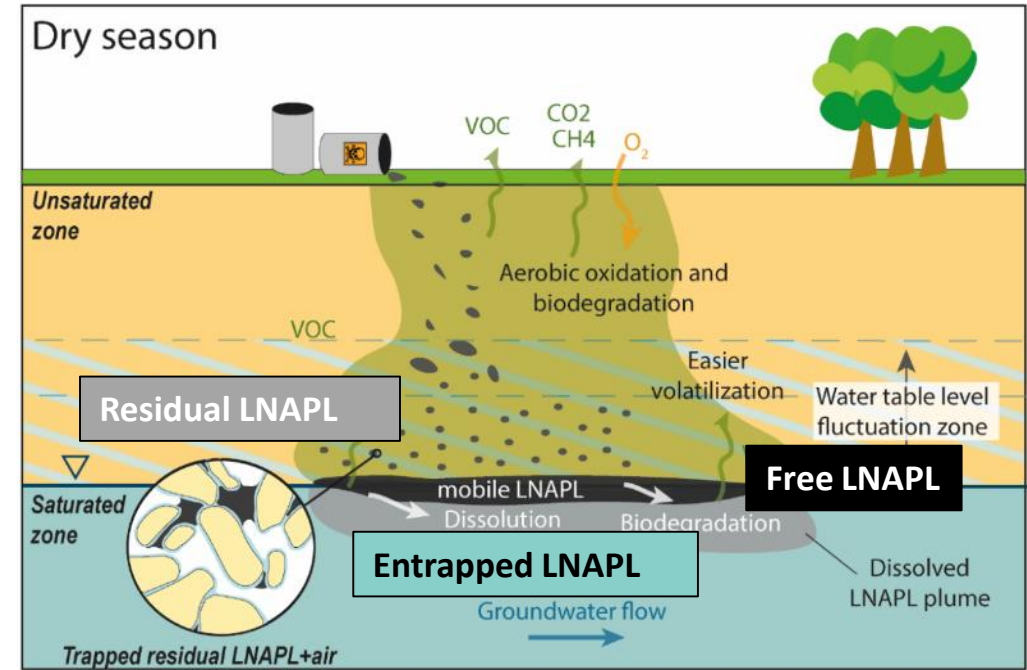
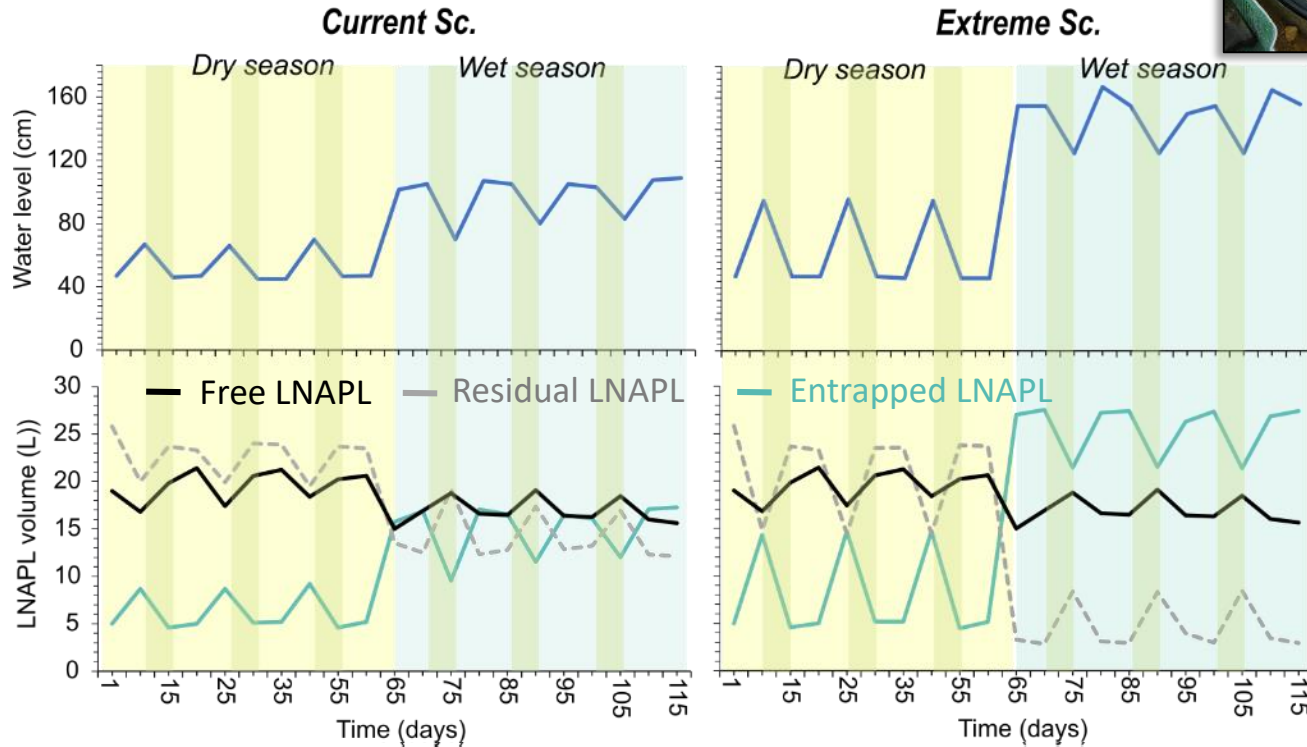
**Monitoring of two contaminated soil columns under 2 controlled scenarios of precipitation and groundwater fluctuation regimes**

# Results / Pure floating free phase thickness and LNAPL soil distribution

- Apparent thickness measured in monitoring wells
- Real thickness and volumes of LNAPL calculated from apparent thickness and soil hydrological properties (Lenhard et al., 2017).



What impact on the contaminants' fate?



- Water table fluctuations = pure LNAPL phase remobilization across the soil porosity
- Spreading of the contamination inside the water table fluctuation zone.

*Decrease in the water level = part of the entrapped LNAPL become free again or be trapped as residues in the USZ*

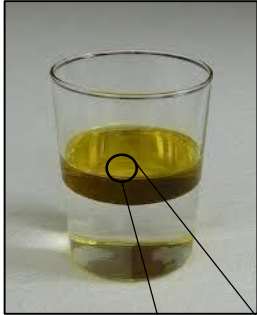
More intense LNAPL remobilization through the soil column for the extreme scenario



# Results / Pure floating free phase composition

Pure LNAPL phase composition (commercial diesel fuel):

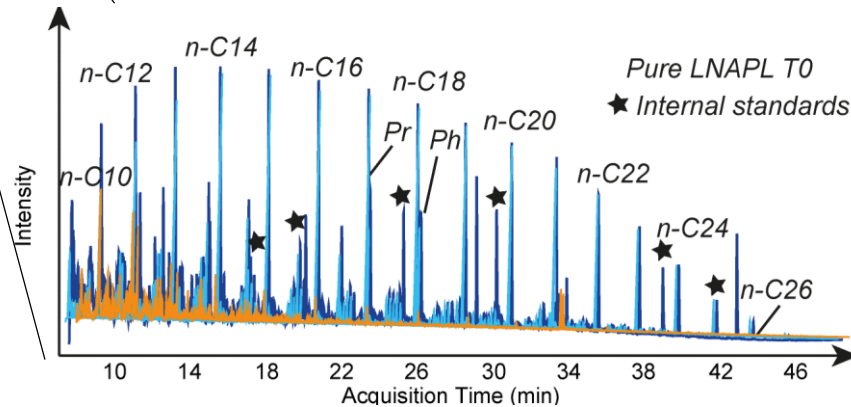
- sampled in monitoring wells at 0, 90, and 120 days after the contamination.
- analyzed by GC/MS (TQD for quantification)



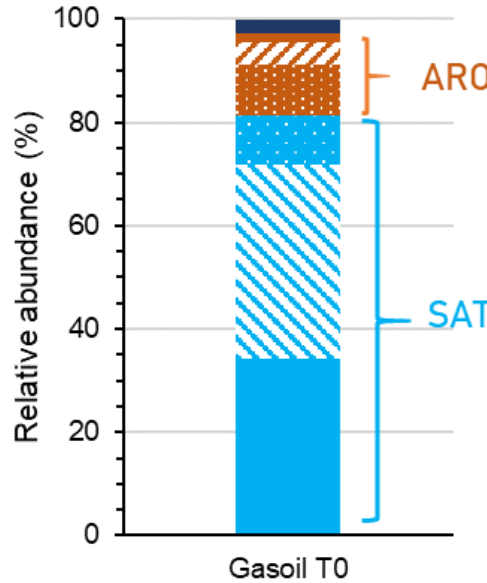
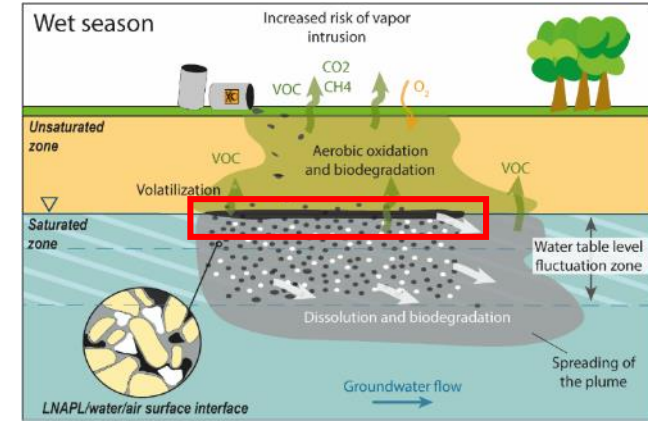
GC-TQD



Torion



Chromatogram of the free LNAPL phase at T0



■ Polars

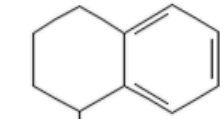
■ Phenanthrenes+  
Fluorenes+ Biphenyles  
■ Naphtalenes

■ Benzenes + Indenenes

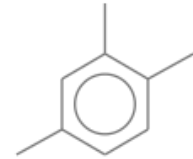
■ Cyclic alkanes

■ b-alkanes

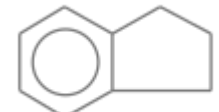
■ n-alkanes



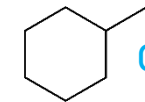
Naphtalenes



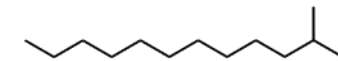
TM-benzenes



Indenenes



Cyclic-alkanes



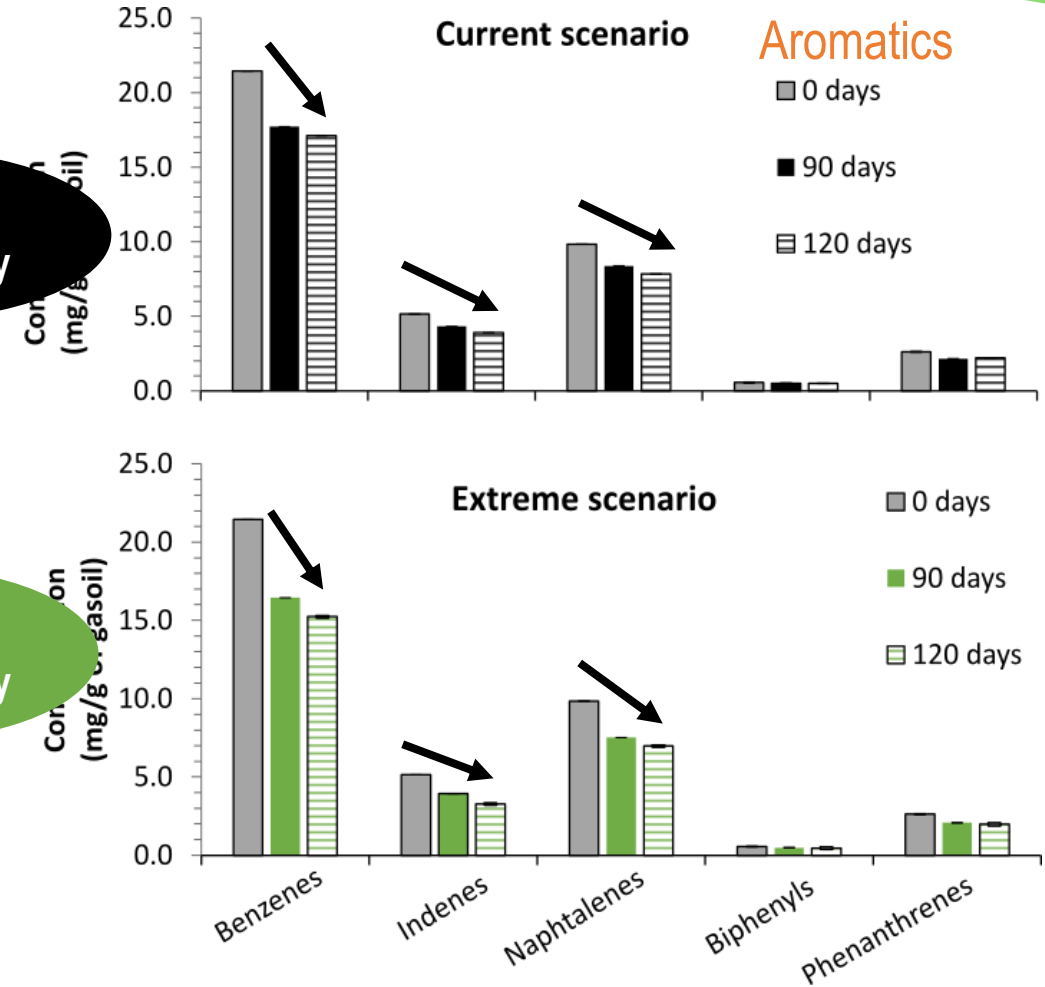
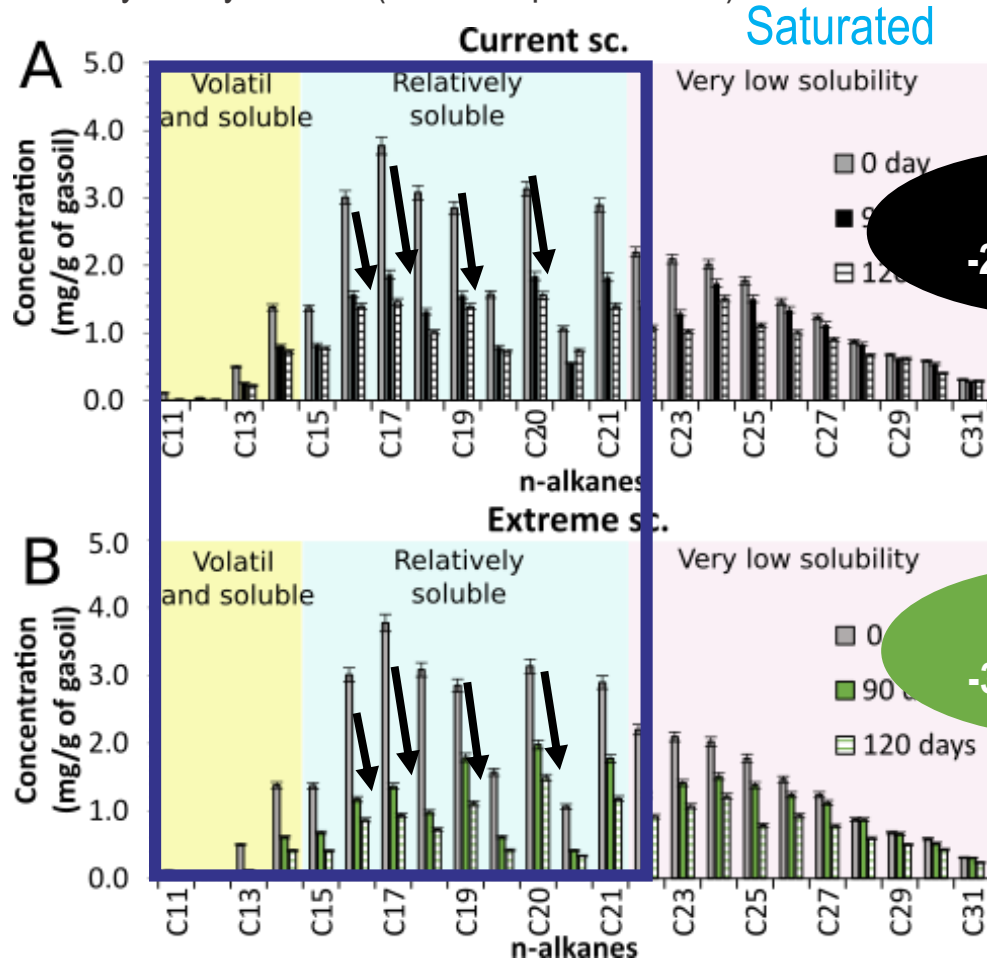
Branched and n-alkanes

# Results / Pure floating free phase composition

Pure LNAPL phase composition (gasoil):

- sampled in monitoring wells at 0, 90, and 120 days after the contamination.
- analyzed by GC/MS (TQD for quantification)

**Volatilization and dissolution, biodegradation ?**



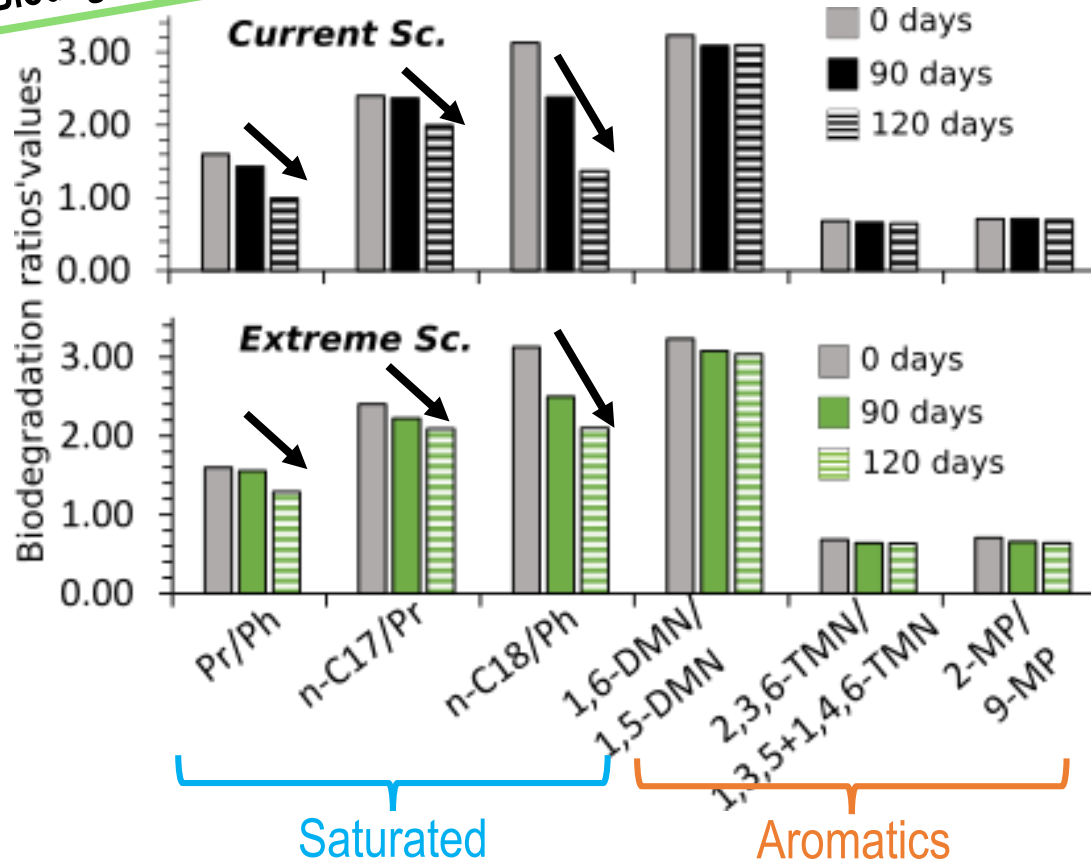
- Decrease in the concentrations of the most soluble and volatile n-alkanes and aromatics for the two scenarios.
  - **More intense loss of compounds for the extreme conditions**

# Results / Pure floating free phase composition

Pure LNAPL phase composition (gasoil):

- sampled in monitoring wells at 0, 90, and 120 days after the contamination.
- analyzed by GC/MS (TQD for quantification)

Biodegradation ?



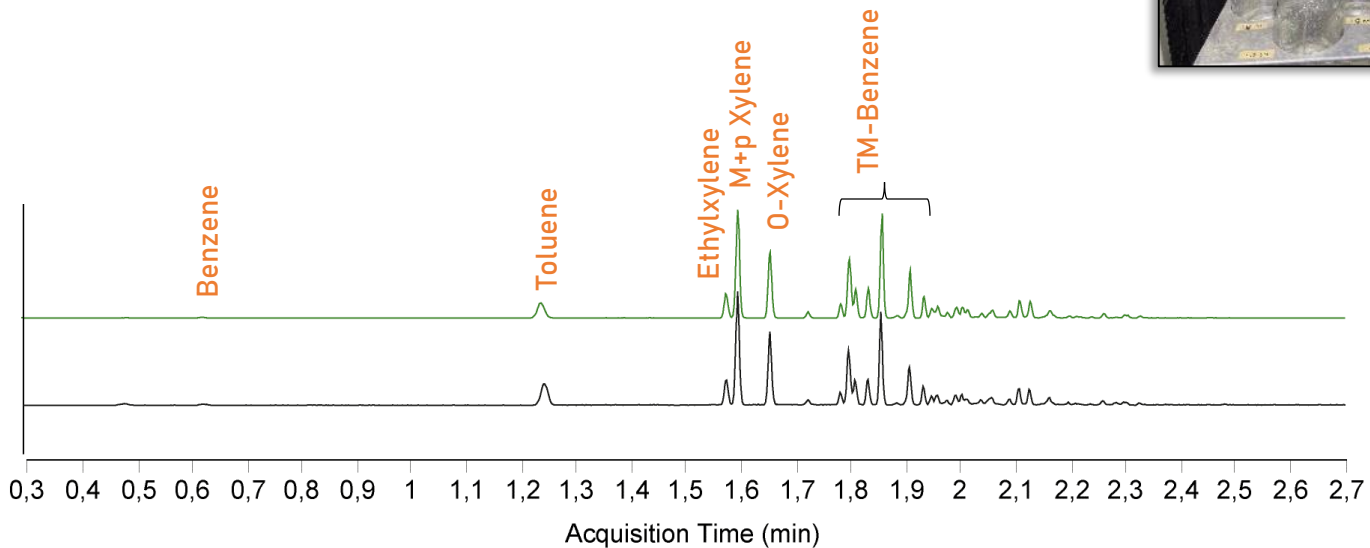
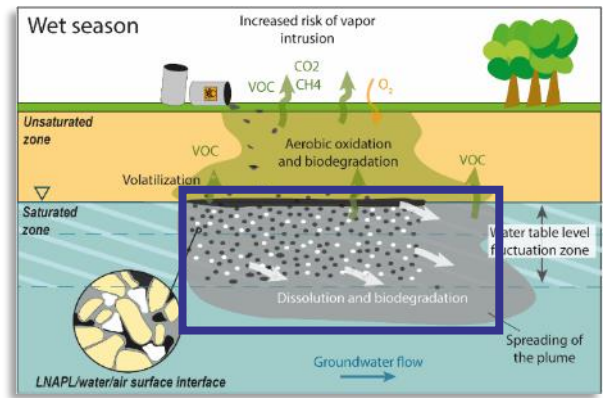
- Decrease in the relative proportion of the most biodegradable saturated compounds.
- No clear evolution for aromatic compounds.
- Biodegradation of saturated components?

Ratio = concentration of an easily degradable compound / a more resistant compound of the same species

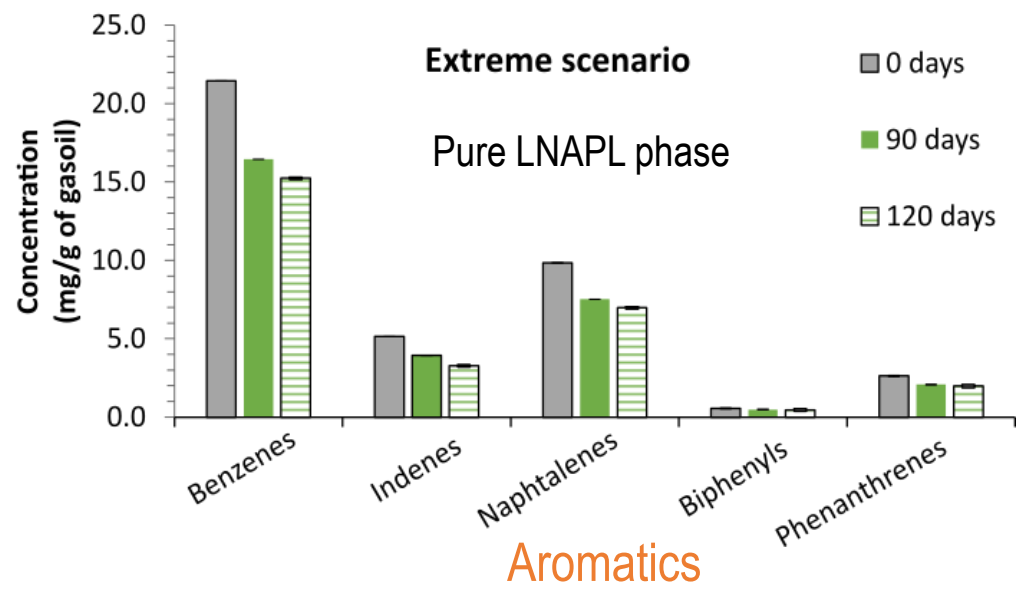
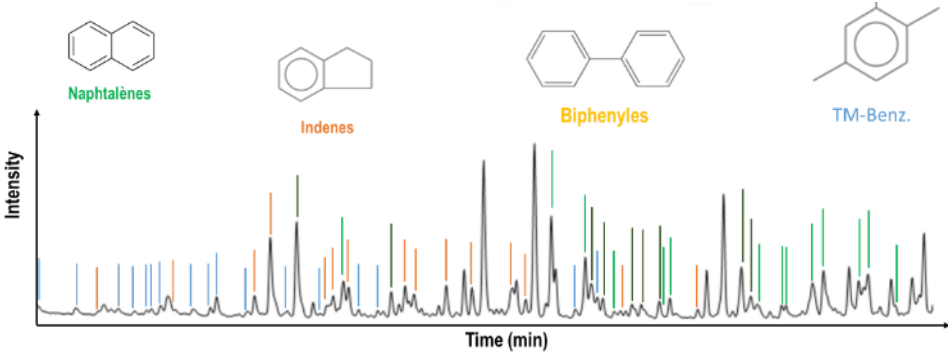
**Dissolution?**

- Water sampling by suction probes
- Analysis: GC/MS (GC-TQD, Torion)

### Identification of light compounds (TORION)



### Identification and quantification of medium compounds (GC-TQD)

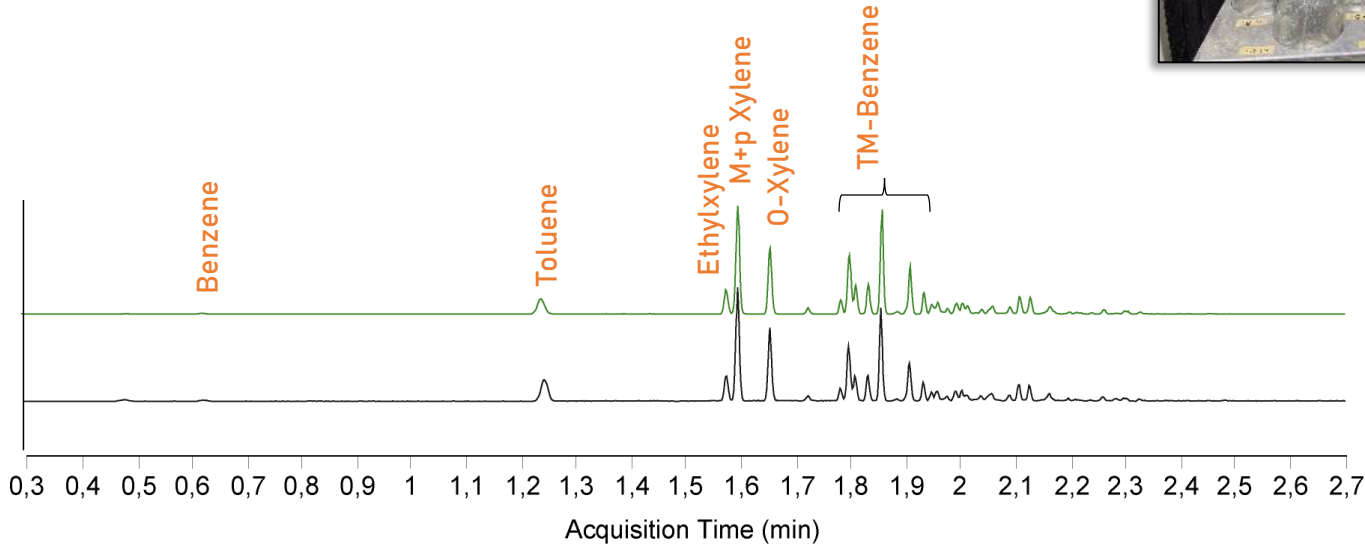
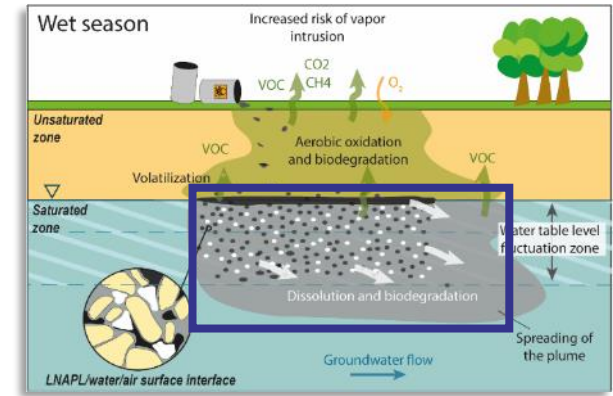


Dissolution of a part of the most soluble aromatic compounds from the pure phase

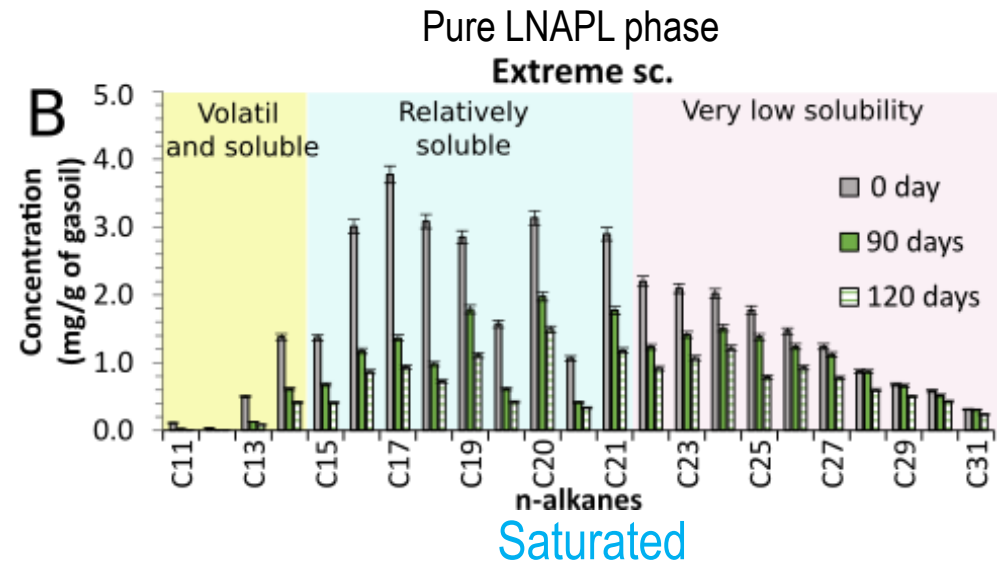
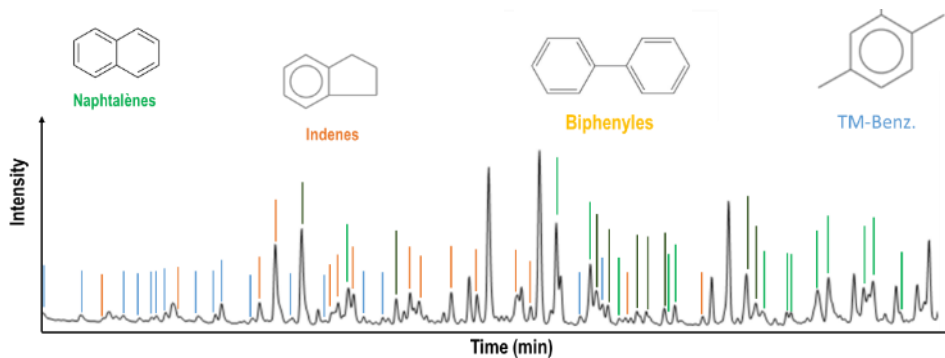
**Dissolution?**

- Water sampling by suction probes
- Analysis: GC/MS (GC-TQD, Torion)

## Identification of light compounds (TORION)



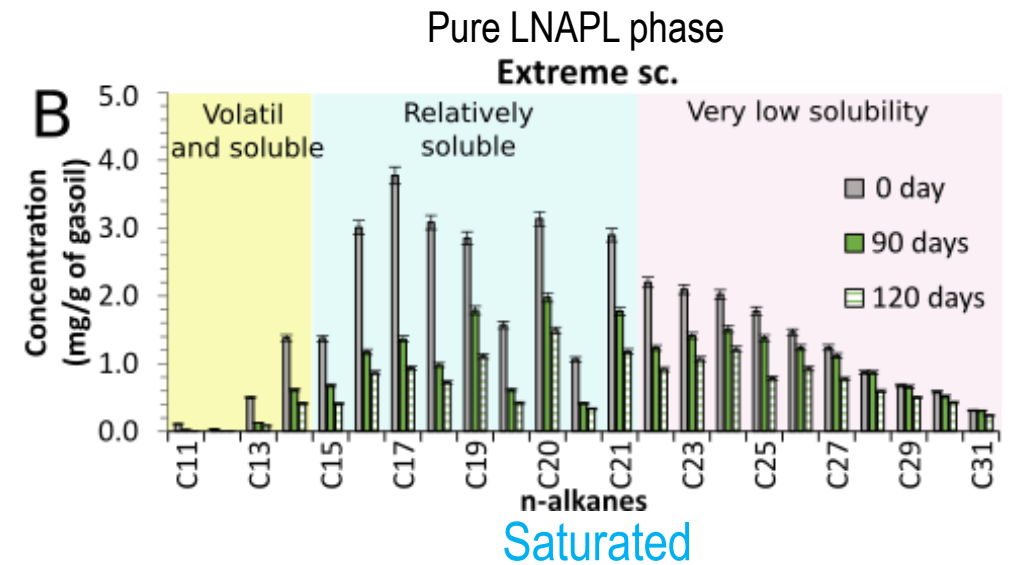
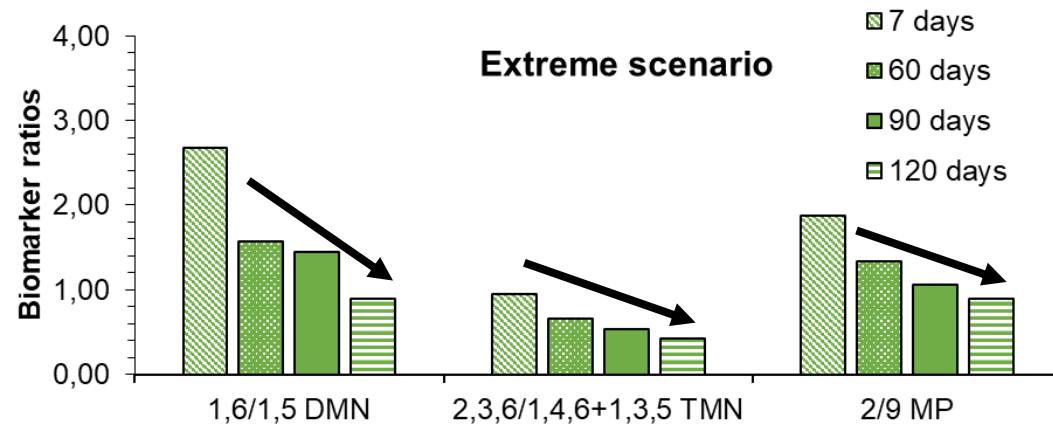
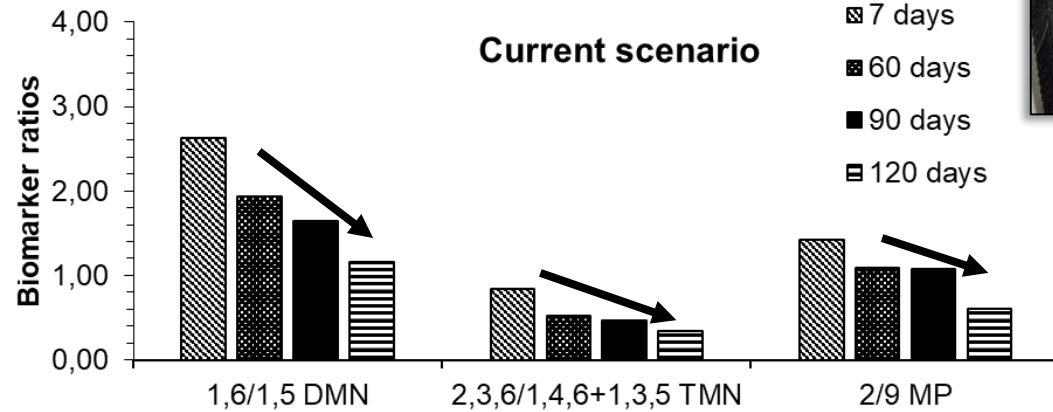
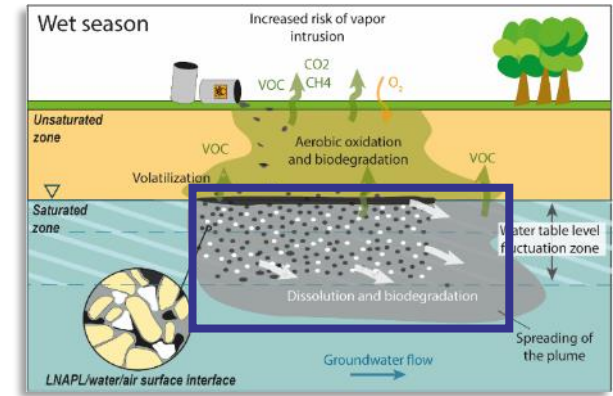
## Identification and quantification of medium compounds (GC-TQD)



No saturated compounds => Biodegradation?

**Dissolution?**

- Water sampling by suction probes
- Analysis: GC/MS (GC-TQD, Torion)



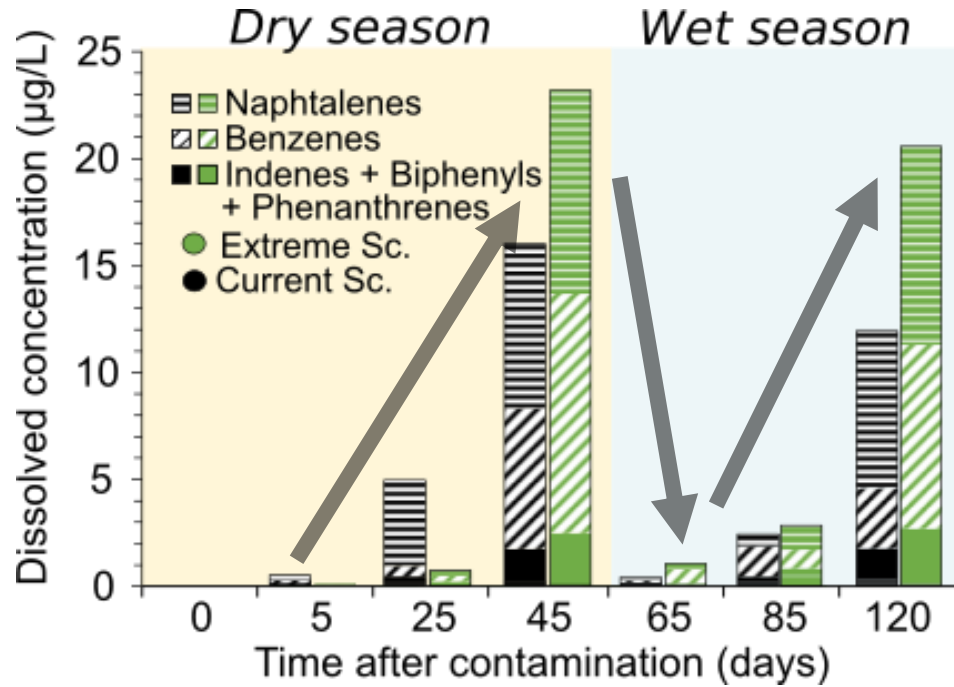
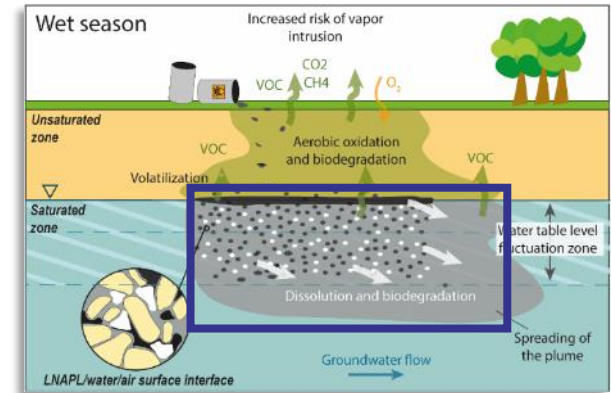
No saturated compounds => Biodegradation?

Possible biodegradation of aromatics => fully degraded alkanes ?

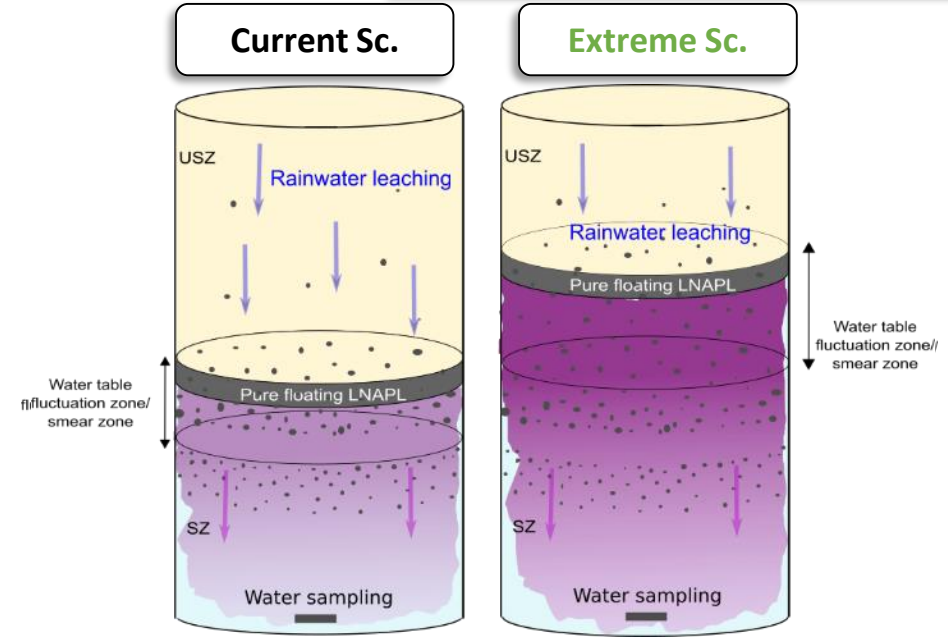
## Dissolution?

- Water sampling by suction probes
- Analysis: GC/MS (GC-TQD, Torion)

### Evolution of the dissolved phase concentration and composition with time



Extreme climatic conditions favor the LNAPL release towards the dissolved phase

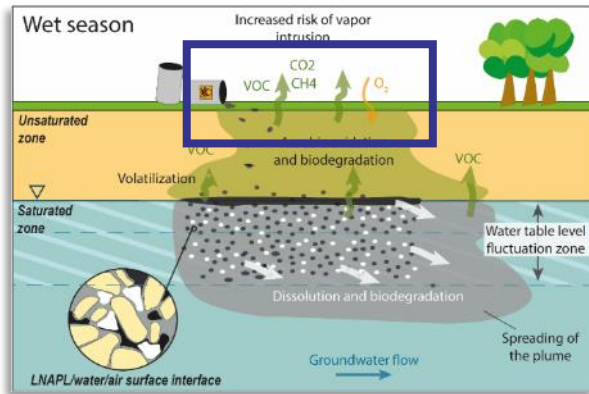


- Dilution of the dissolved plume at the beginning of the wet season (60 days)
- Higher dissolved concentrations for the extreme conditions

# Results / Vapor phase composition and fluxes

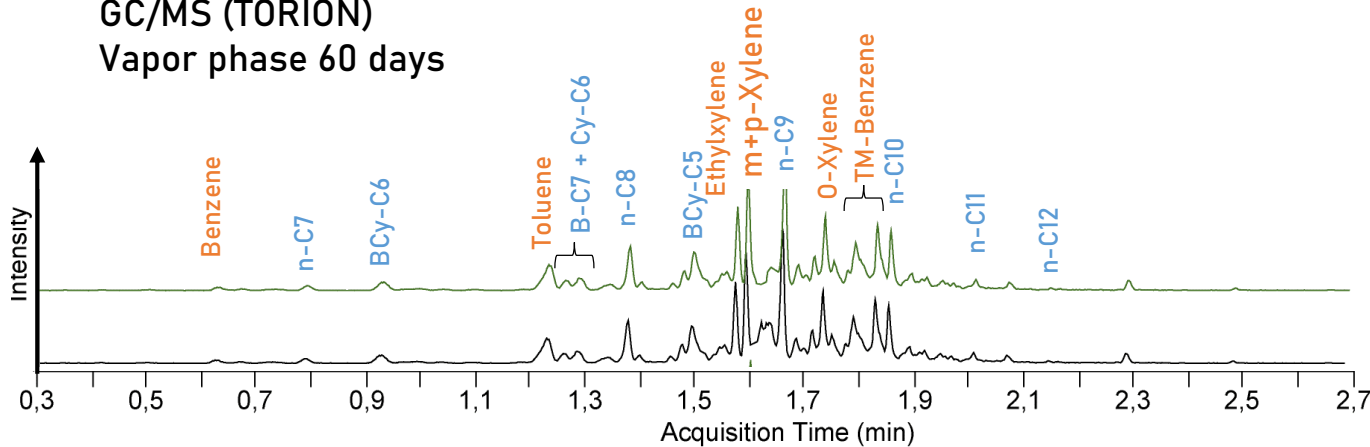
- Gaz was analyzed at the surface of each lysimeter by  $\mu$ GC in gas chambers.
- Sampled in Tedlar bags for GC/MS analyses (TORION)

**Volatilization?**

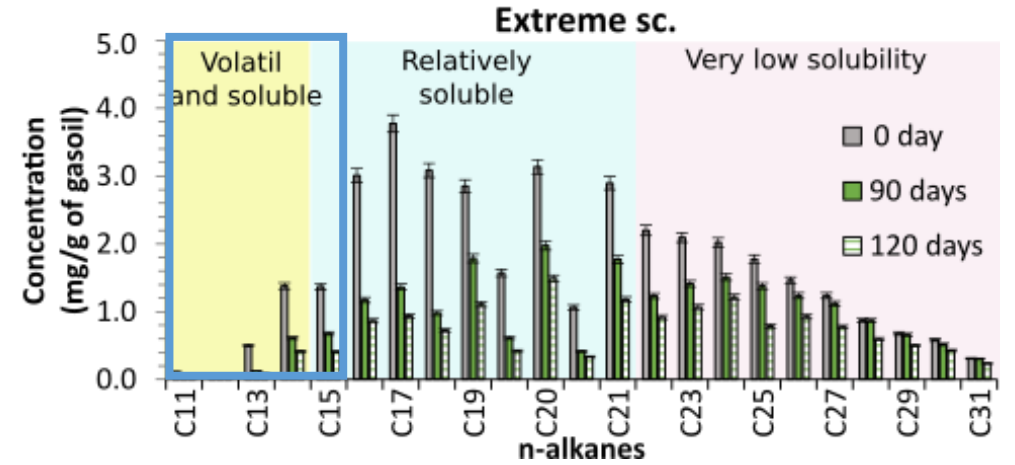


## Gaseous phase composition

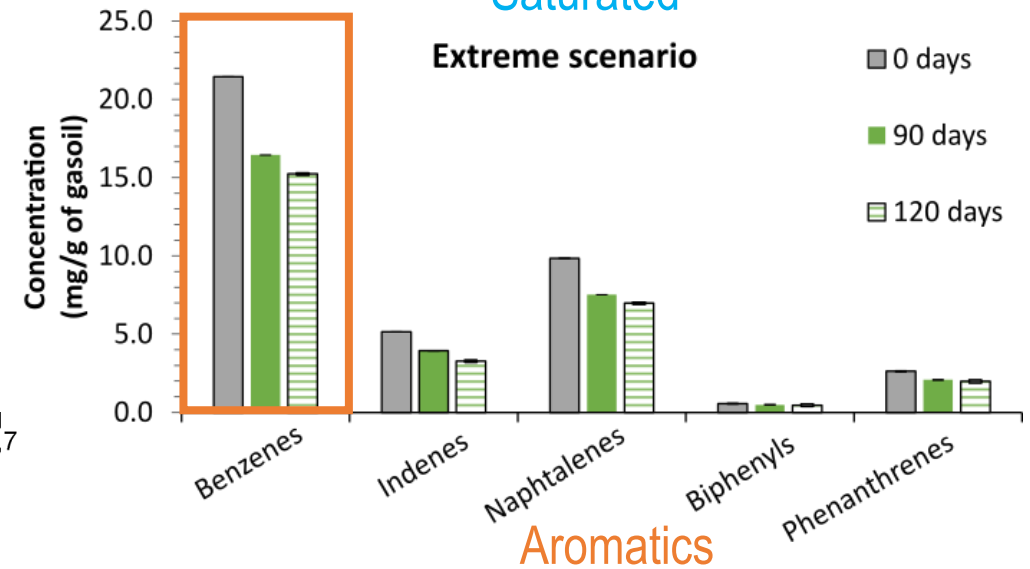
GC/MS (TORION)  
Vapor phase 60 days



## Pure phase



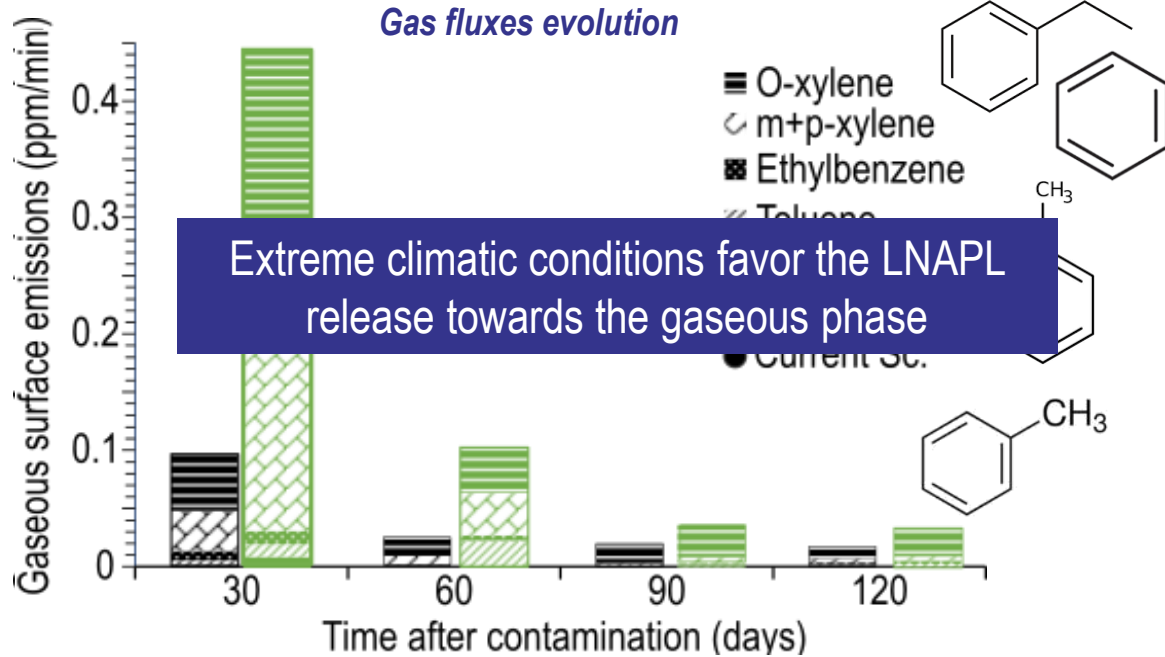
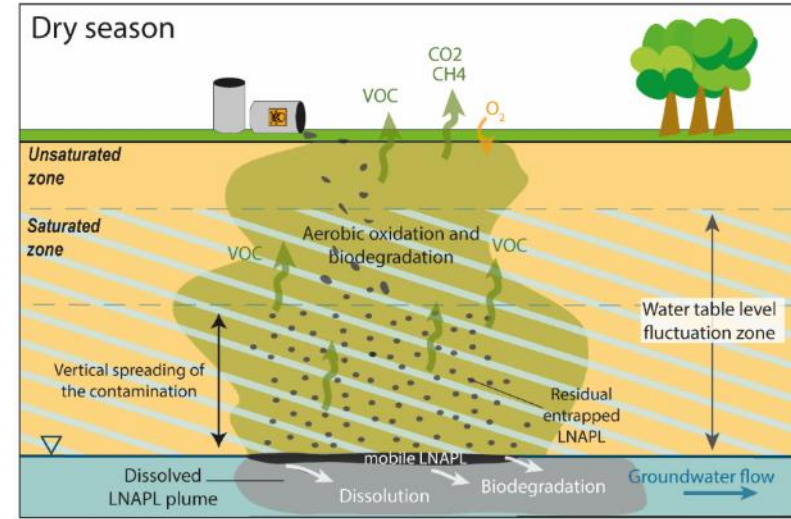
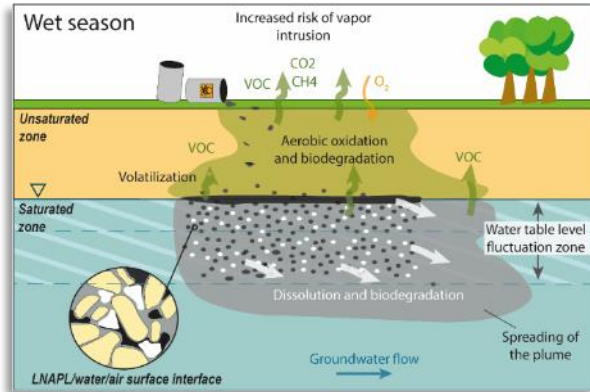
## Saturated



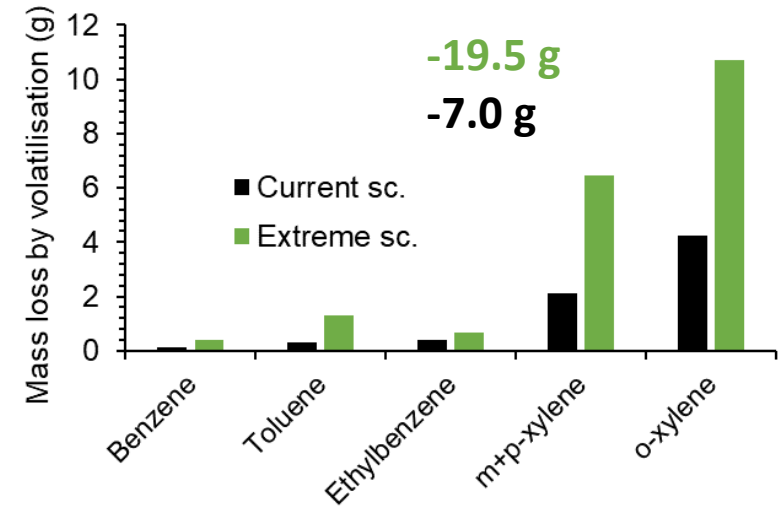


# Results / Vapor phase composition and fluxes

- Gas was analyzed at the surface of each lysimeter by  $\mu$ GC in gas chambers.
- Sampled in Tedlar bags for GC/MS analyses (TORION)



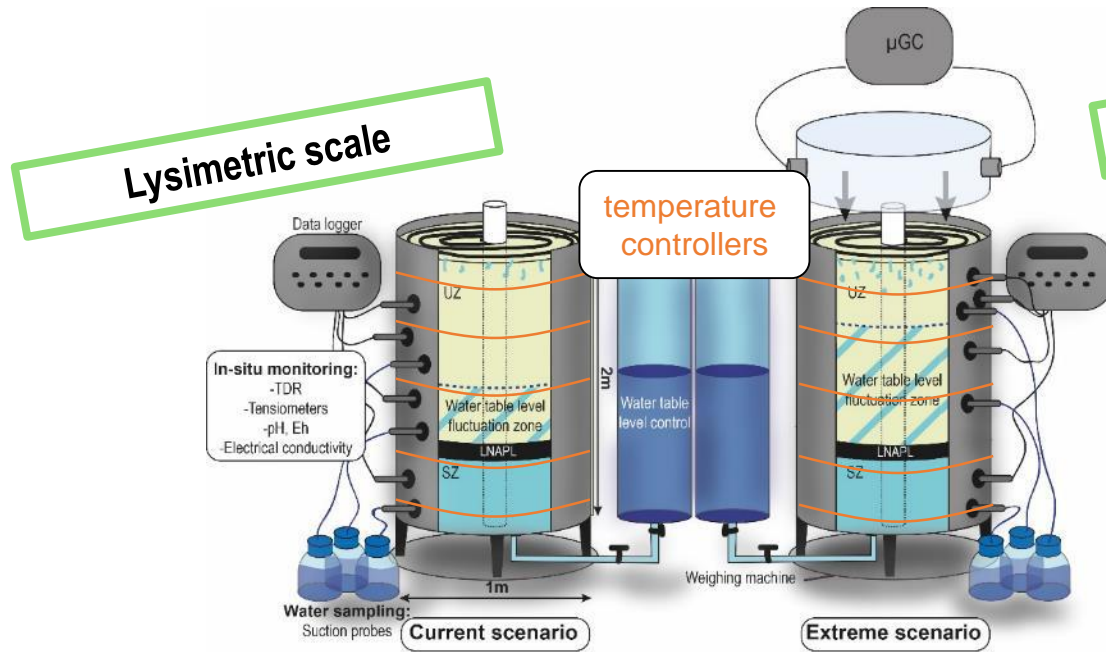
- Decrease in mobilized gas flux with time.
- Surface mobilized gas fluxes are higher for the extreme scenario.



**Volatilization is not the main LNAPL mobilization process**

- The experimental device allows us to follow the effect of climatic scenarios on contaminations.
- Increase of the intensity of groundwater table fluctuations =
  - A more excellent pure LNAPL phase is spreading across the soil.
  - Greater gas fluxes at the surface.
  - Slightly higher dissolution rates toward the groundwater.

## The "BatMobile" project



**Lysimeters in "natural conditions"**  
 Natural soil, LNAPL from a contaminated site,  
 active biodegradation  
 Controlled temperatures

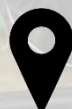
Monitoring of a LNAPL contaminated site  
 by coupling *in-situ* and *ex-situ* monitoring  
 techniques



Thanks for your attention !



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<http://gisfi.univ-lorraine.fr/fr/>