

4^e colloque recherche
de la **Fédération Gay-Lussac**
La chimie et la ville de demain



Luc Schuiten

BIOFILTERS TO IMPROVE ROAD RUN-OFF QUALITY: INTERACTIONS BETWEEN WATER, SOIL AND THE BIOSPHERE

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HUMAN IMPACT ON THE ENVIRONMENT

GLOBAL IMPACTS:

Climatic changes, *UNESCO, Giec, international summits*
Biodiversity loss, *Millenium ecosystem assessment*
Air, water and soil pollution

IMPACT of CITIES:

Water cycle disturbance
Soil degradation (compaction, sealing...)
Air pollution (Nox, O₃, SO₂,...)

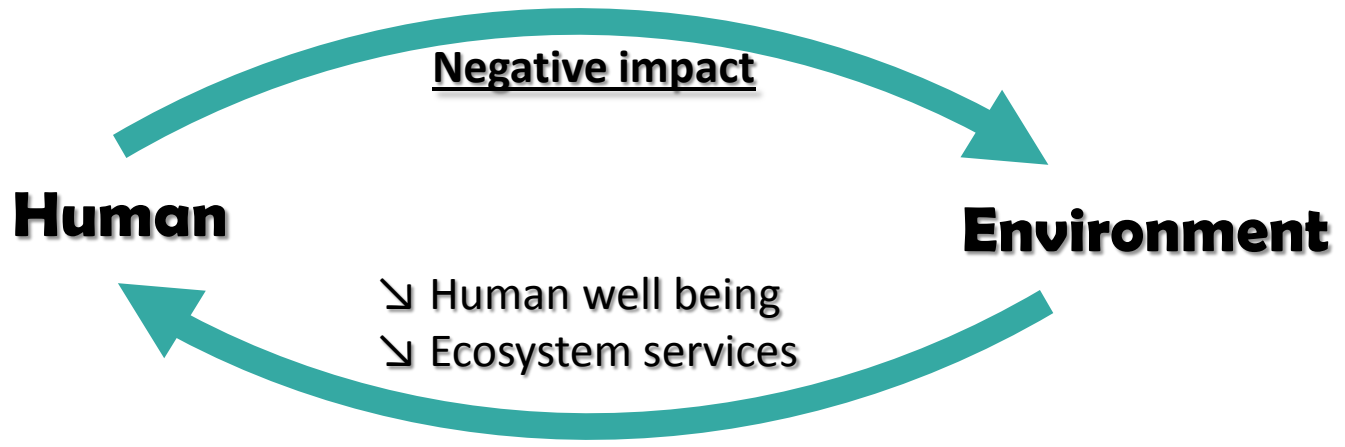


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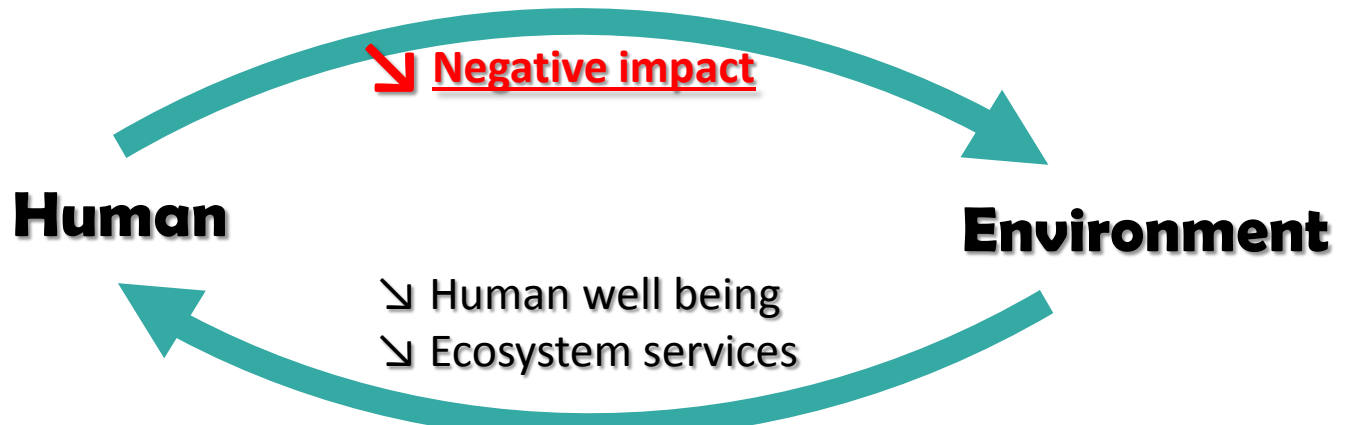


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Restablisment

Directives
European directive framework

Regulations
Carbon tax
Stormwater tax

Innovation

ALTERNATIVE RUN-OFF MANAGEMENT

Low impact developpement (LID) technologies

stress reduction of runoff generation

management of runoff through **filtration and infiltration**

Stagge et al., 2012

Reintroduce living soil and green in cities

Performance information necessary

Integration into highway planning, design development and construction processes

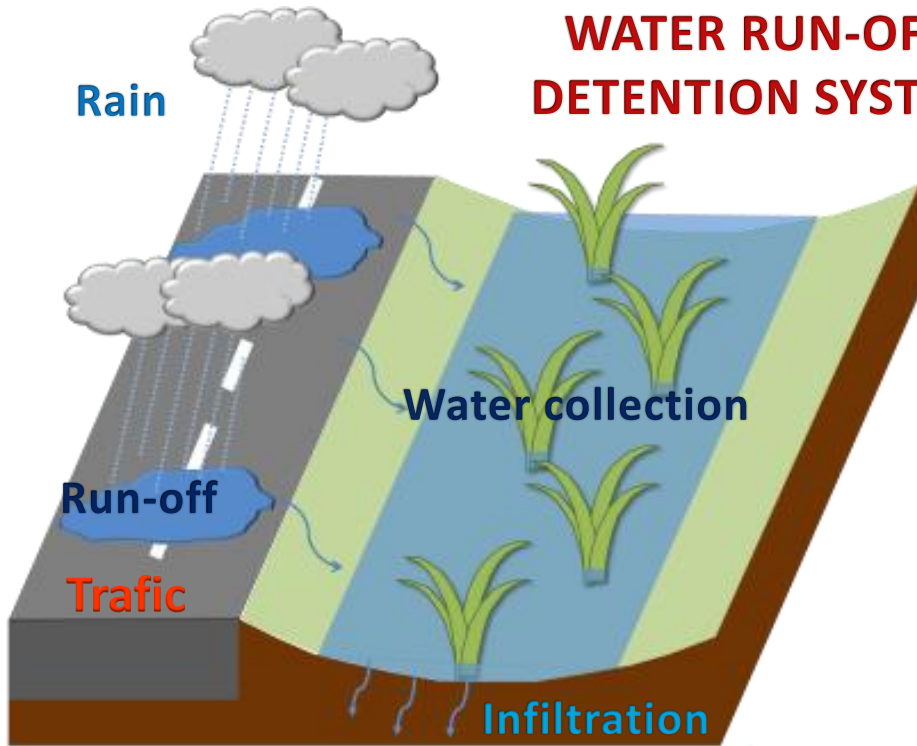


New York Green Infrastructure, 2012 annual report

ALTERNATIVE RUN-OFF MANAGEMENT

POLLUTION SOURCES

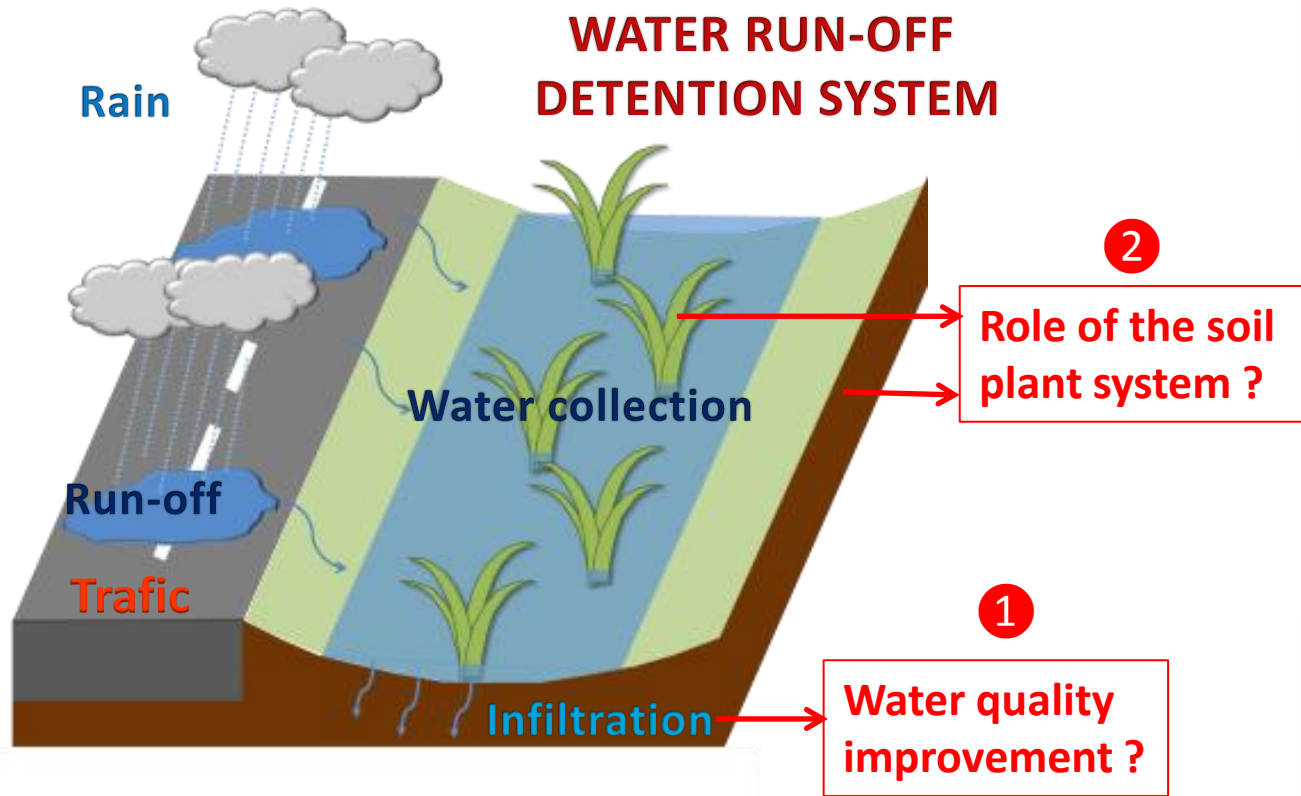
WATER RUN-OFF DETENTION SYSTEM



Swales are shallow, flat-bottomed channels that receive flow laterally through vegetated side slopes

ALTERNATIVE RUN-OFF MANAGEMENT

POLLUTION SOURCES



Swales are shallow, flat-bottomed channels that receive flow laterally through vegetated side slopes

1) Contaminant follow up

- a) Targeted contaminants
- b) Sampling strategy
- c) Contaminant analysis

2) Processes at water-soil-plant interfaces

- a) Water quality improvement

—————> *Road side swale under real conditions*



- b) Soil-plant system processes

—————> *Mesocosm experiment*



3) Conclusion and perspectives



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TARGETED CONTAMINANTS

Six contaminant targeted



A real concern in Upper-Normandy region
air and soil quality

*Ministère de l'écologie, du développement
durable, des transports et du logement., 2011*

INORGANIC POLLUTANTS : Trace Elements (TEs)

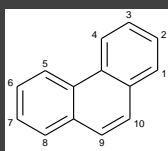
Lead

Zinc

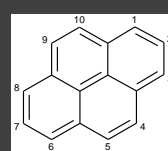
Cadmium

ORGANIC POLLUTANTS : Polycyclic Aromatic Hydrocarbons (PAHs)

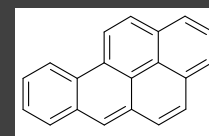
Phenanthrene



Pyrene



Benzo(a)pyrene

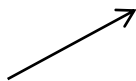


TARGETED CONTAMINANTS SOURCES

ANTHROPOGENIC SOURCES

Global sources

→ Atmospheric deposition



Industrial processes

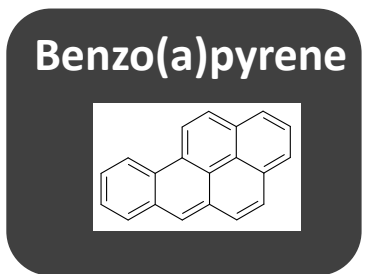
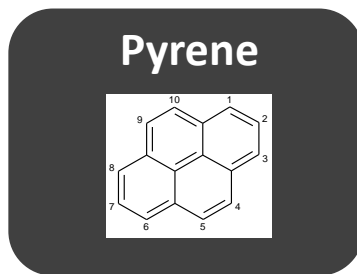
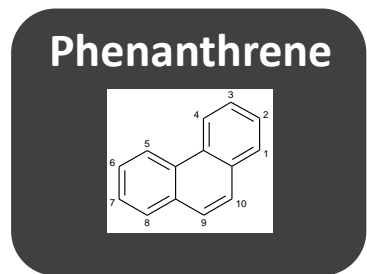
Lead

Zinc

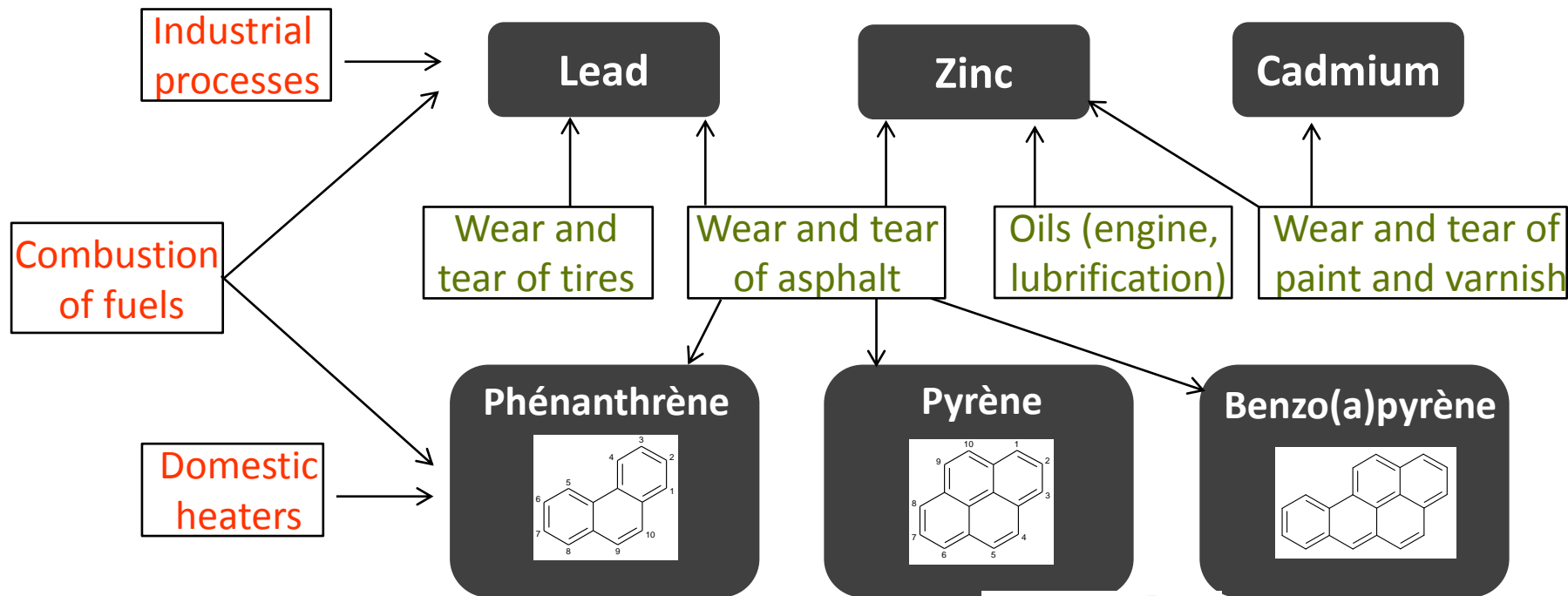
Cadmium

Combustion of fuels

Domestic heaters



TARGETED CONTAMINANTS SOURCES



TARGETED CONTAMINANTS TOXICITY

TOXICITY

5 are **carcinogenic, mutagen and reprotoxic**

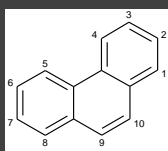
Zn is a nutrient at low content in soil and becomes a contaminant at high content

Lead

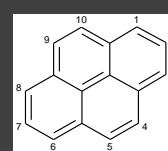
Zinc

Cadmium

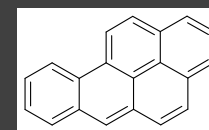
Phénanthrene



Pyrene



Benzo(a)pyrene



1) Contaminant follow up

- a) Targeted contaminants
- b) **Sampling strategy**
- c) Contaminant analysis

2) Processes at water-soil-plant interfaces

- a) Water quality improvement

—————> *Road side swale under real conditions*



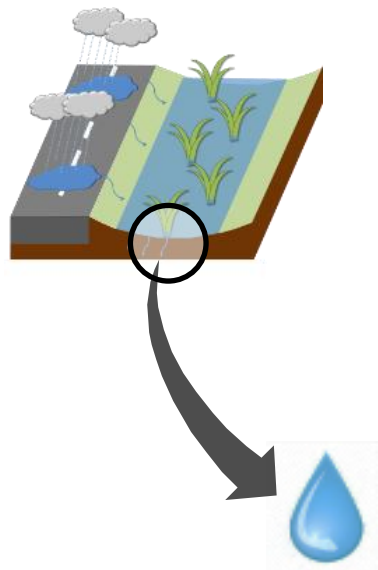
- b) Soil-plant system processes

—————> *Mesocosm experiment*



3) Conclusion and perspectives

WATER INVESTIGATIONS



7 ANALYSIS

Quality indicators { **BOD₅**: Biological oxygen demand
COD: Chemical oxygen demand
SS: Suspended Solids

Nutrients { **N_K**: Nitrogen Kjeldhal
P: Total phosphorus

Contaminants { **TEs**: Trace Elements (Cu, Pb, Zn, Cd, Ar, Hg)
HC: Total hydrocarbons
PAHs: Polycyclic Aromatic Hydrocarbons

3 TREATMENTS

- Run-off water
- Grass swale
- Vegetated swale

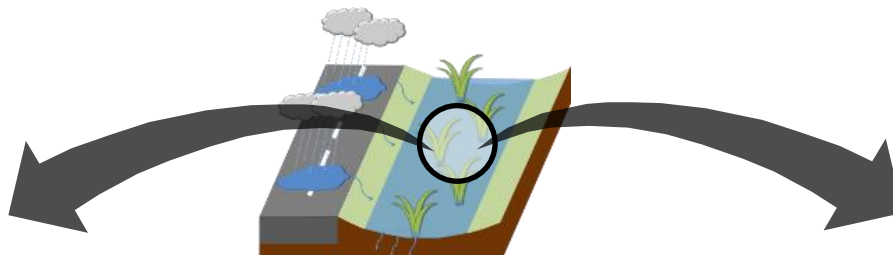
5 RAINING EVENTS

- 10/04/2012
- 20/04/2012
- 01/02/2013
- 08/03/2013
- 03/07/2013

SOIL-PLANT SYSTEM INVESTIGATIONS



Above ground Bellow ground



Soil-plant system



Soil

Rhizosphere

0-15 cm deep

Attached to roots

ANALYSIS

- TEs content



ANALYSIS

- TEs and PAHs content
- Microbial assessment :
Enzymatic activities
Biomass (total, bacterial, fungal)

MONITORING OVER TIME

Sampling every 6 months during 3 years

1) Contaminant follow up

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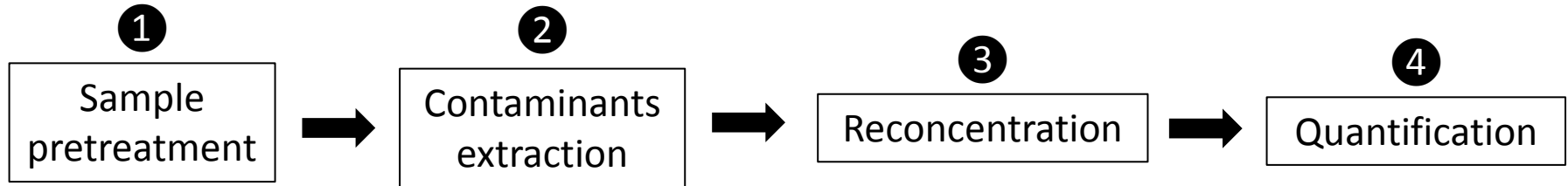
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ANALYSIS METHODS



METHOD MEDIA		TEs		PAHs		Microbiology	
		2	3	2	3	Structure	Fonction
	Water	Acid extraction at high pressure and high temperature under magnetic agitation	ICP-AES	Solid Phase Extraction	HPLC-Fluo	None	
	Soil			Microwave Assisted Extraction in solvents	GC-MS	Total, bacterial and fungal biomass	Enzymatic activities (FDA, xylanase, laccase)
	Rhizosphere						
	Plant	None		None			

Method development in progress



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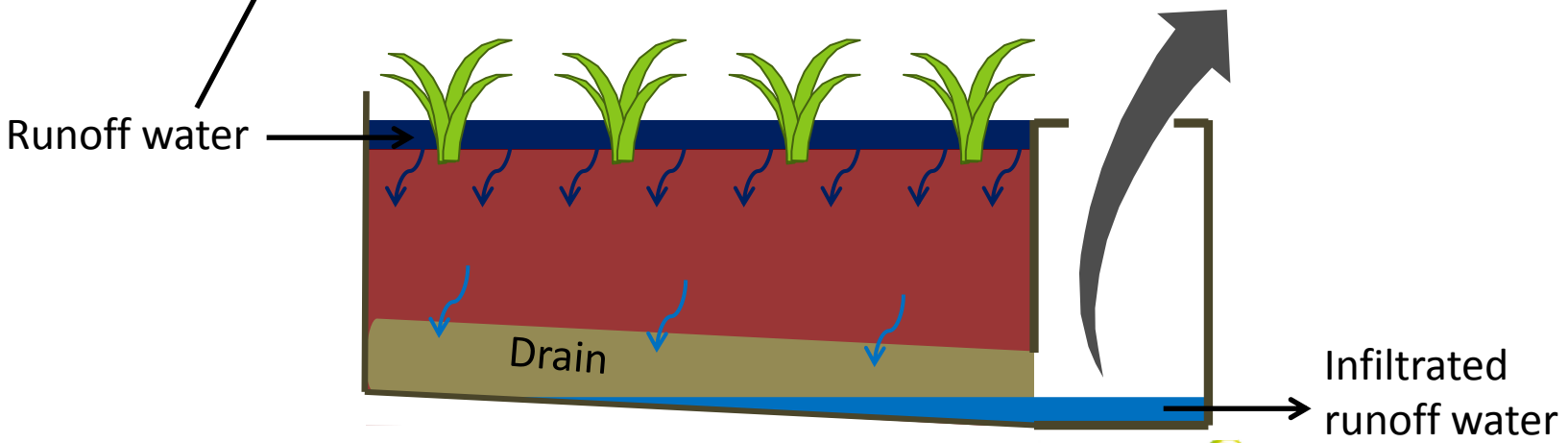
—————> *Mesocosm experiment*



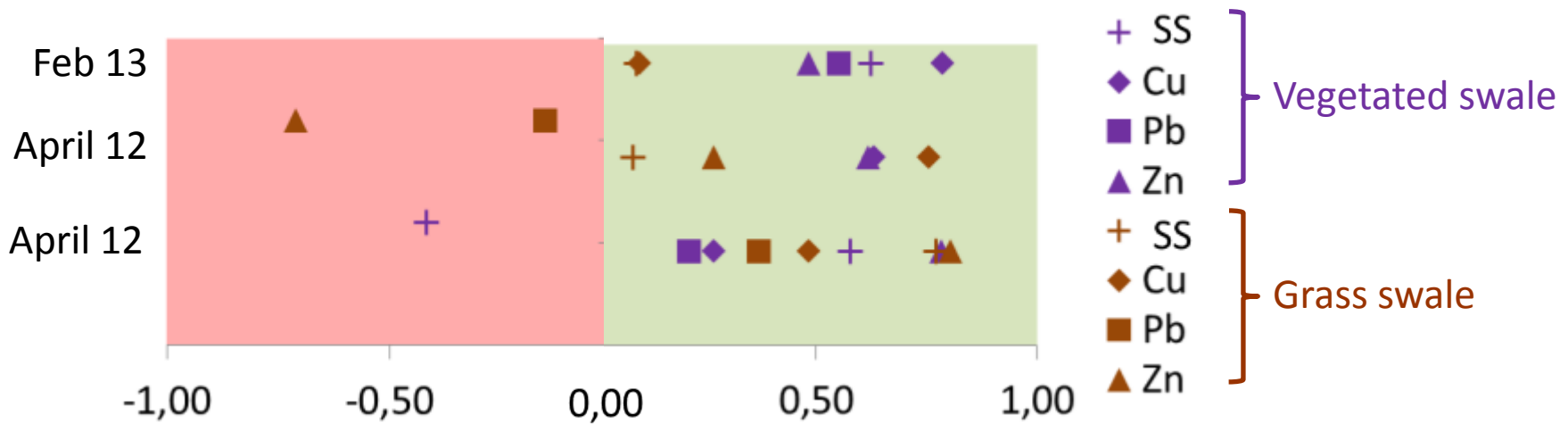
3) Conclusion and perspectives



ROAD SIDE SWALE DESIGN



RESULTS : WATER QUALITY IMPROVEMENT



$$1 - \frac{C_{infiltration}}{C_{runoff}}$$

If < 0
No water quality improvement

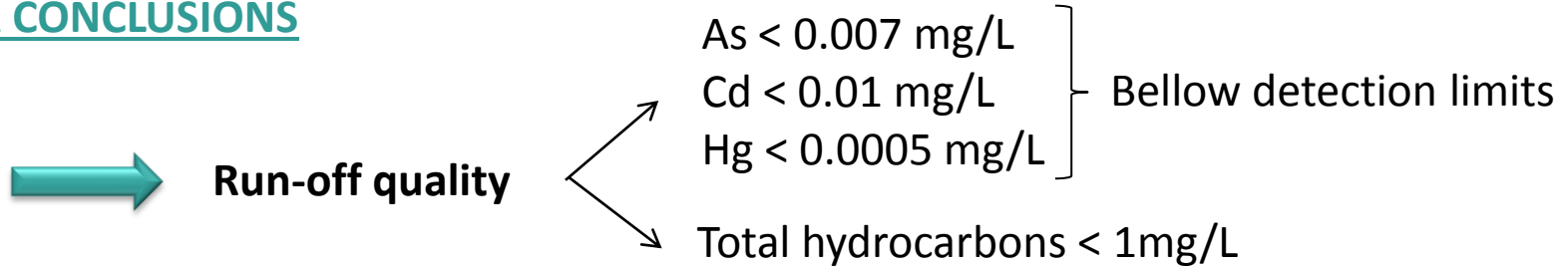
If 0 < x < 1
Water quality improvement

Example :

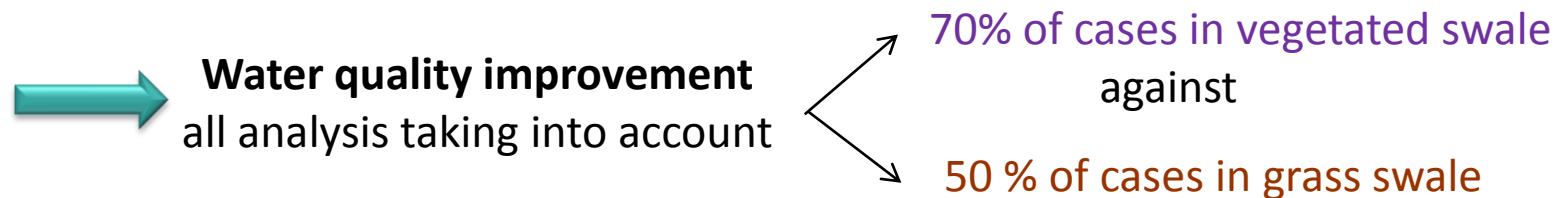
Improvement quality of :
 Cu: from 27 to 79 %
 Pb: from 21 to 55%
 Zn: from 20 to 80%

RESULTS : WATER QUALITY IMPROVEMENT

MAJOR CONCLUSIONS




Run-off water low contaminated (2250veh/d)




Better improvement in soil-macrophyte system

LIMITS OF THE ROAD SIDE SWALE

Low contamination



Does not allow to go through bio- and phyto-remediation processes
No control on contaminant entrance



Contaminated mesocosms



1) Contaminant follow up

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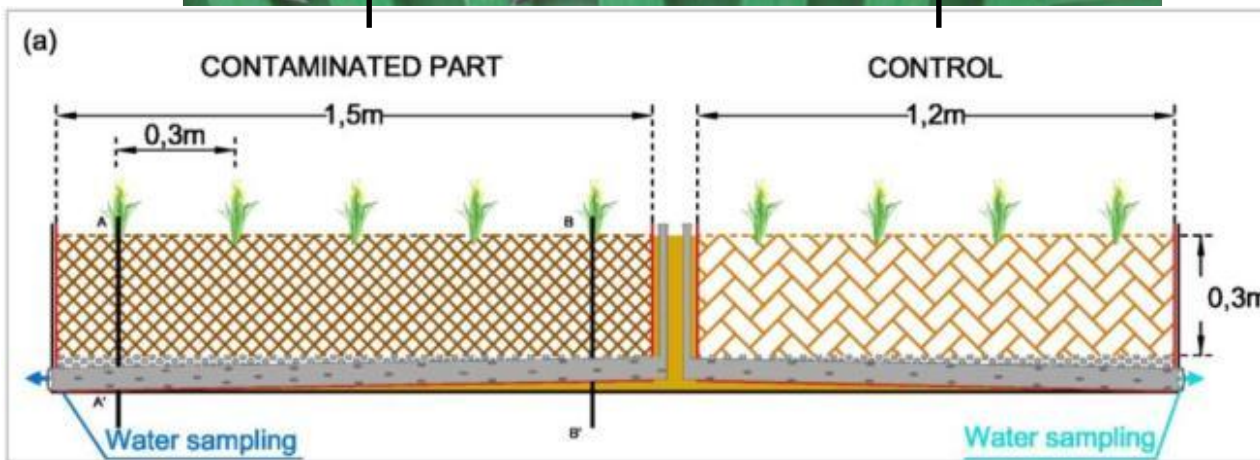
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MESOCOSMS DESIGN



- Graminaceae
Lolium perenne, Festuca sp.
- Yellow iris
Iris pseudacorus
- Reed canary grass
Phalaris arundinaceae
- Soft rush
Juncus effusus



- Legend:**
- Sand for filling
 - Contaminated soil
 - Gravel to prevent drain clogging
 - Non contaminated soil
 - Drain
 - Water level control + cap
 - Impervious geomembrane
 - Tank

SOIL MESOCOSMS CONTAMINATION

ARTIFICIAL CONTAMINATION

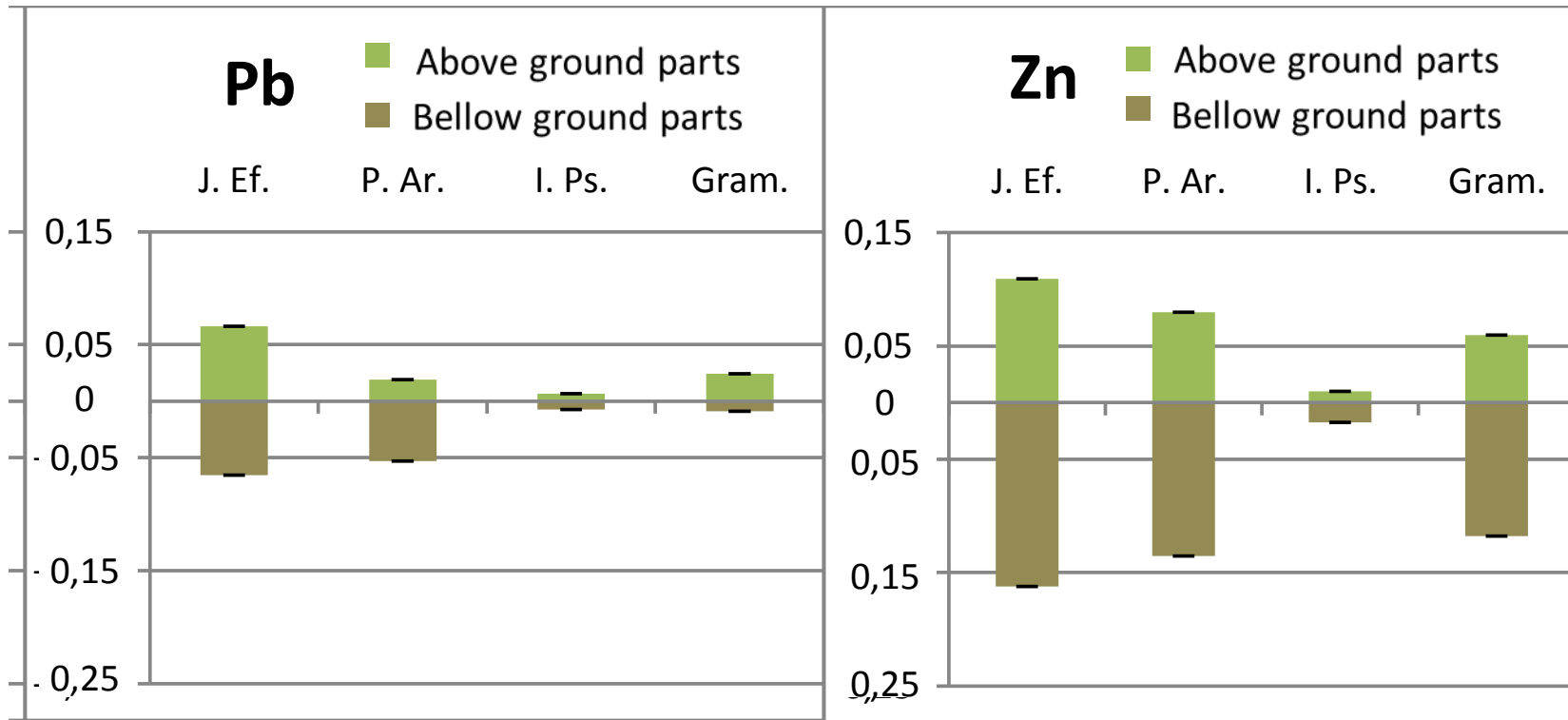
- One shot and surface contamination
- Targeted concentrations in soil (mg/kg dry weight):

Trace Elements (TE)			Polycyclic Aromatic Hydrocarbons (PAHs)		
Cd	Pb	Zn	Phenanthrene	Pyrene	Benzo[a]pyrene
2	100	300	10	10	10



RESULTS : TE BIOACCUMULATION BY PLANTS

Coefficient of soil-plant transfer (plants were grown 6 months)

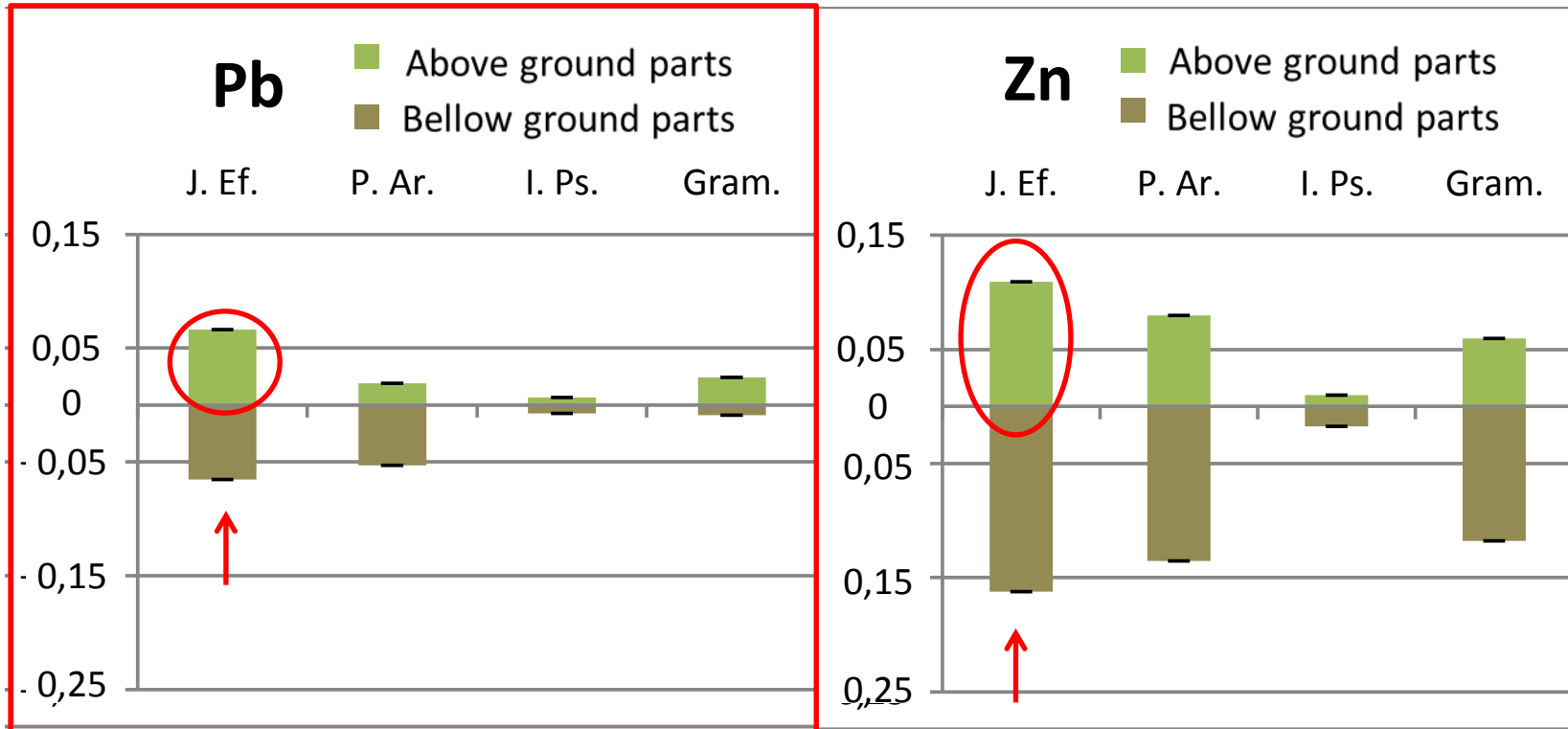


$$CT = \frac{Q_{Plant}}{Q_{Soil}} = \frac{C_{Plant} \times Biomass}{C_{Soil} \times M_{Soil}}$$

With :
 Q, metal quantity in soil or plant (mg)
 C, metal concentration (mg/kg)
 Biomass, plant mass (kg)
 M_{sol}, mass of soil (kg)

RESULTS : TE BIOACCUMULATION BY PLANTS

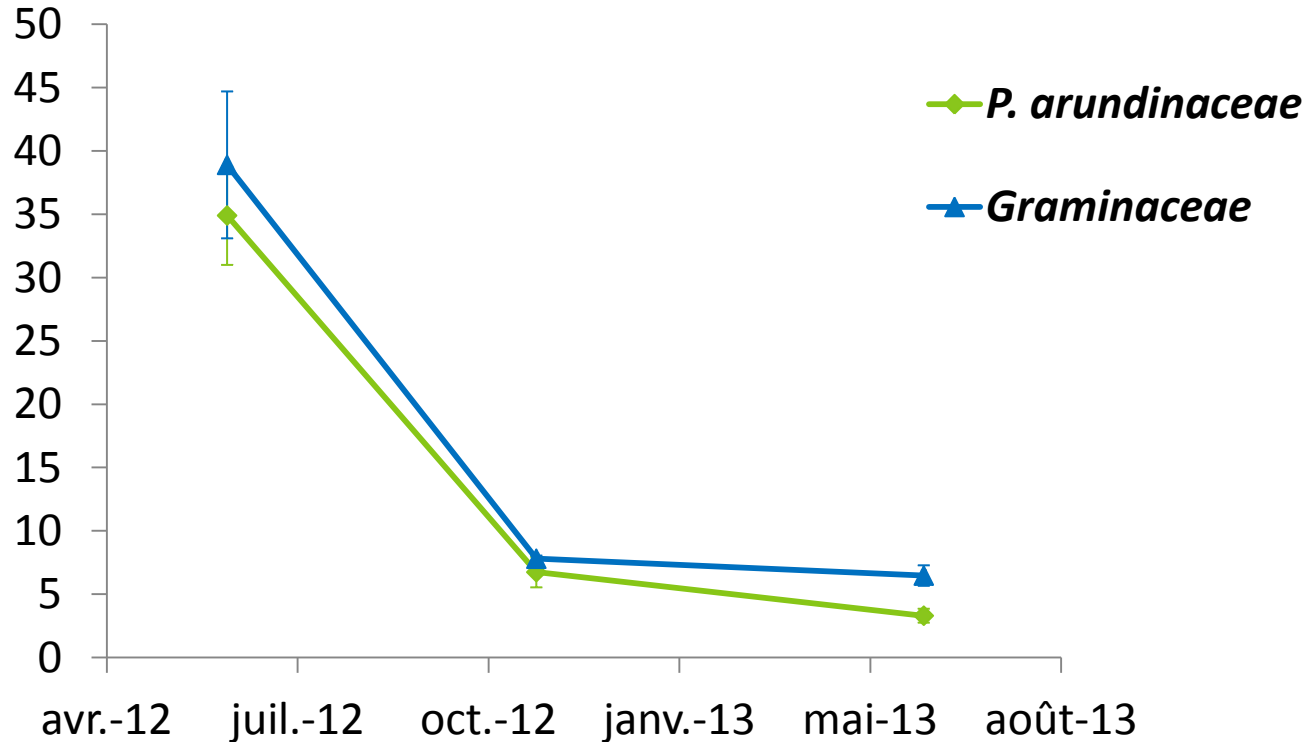
Coefficient of soil-plant transfer (plants were grown 6 months)



Bioaccumulation by plants
Translocation to above ground parts
 Low **bioavailability** of lead due to low mobility

RESULTS : PAHS DECREASE IN SOIL

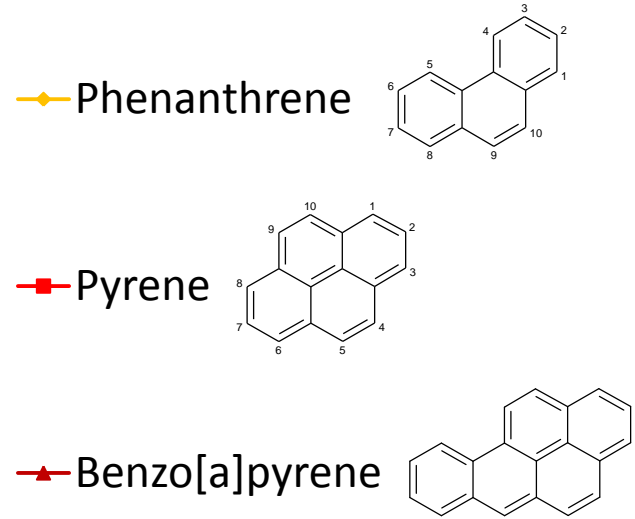
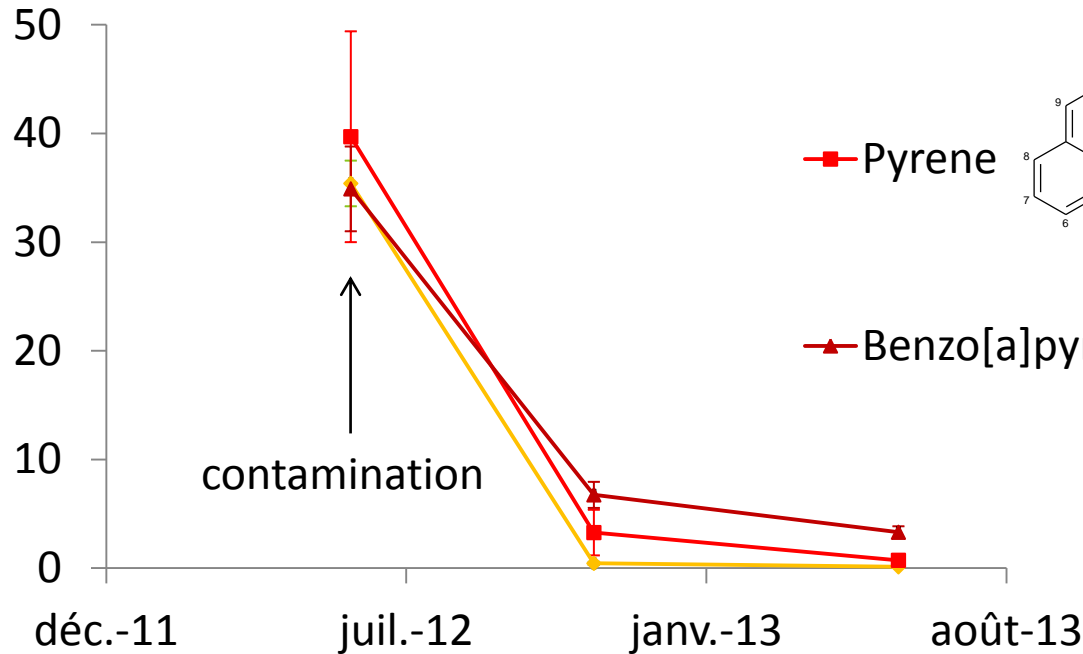
Benzo[a]pyrene in soil (mg/kg)



P. arundinaceae-soil system allow a higher PAHs decrease rather than grass

RESULTS : PAHs DECREASE IN SOIL

[PAHs] in soil (mg/kg)



Low **biodisponibility** of benzo[a]pyrene due to high **hydrophobicity**

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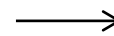
RUN-OFF WATER QUALITY

 **Low contaminant concentration in water** (2250veh/d)

Implications for urban planners



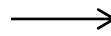
Total hydrocarbons < 1mg/L



**Hydrocarbons separator
not adapted**



**PAHs quantification
in water**

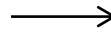


Method development in progress
(hydrophobicity, particles separation)

Perspectives

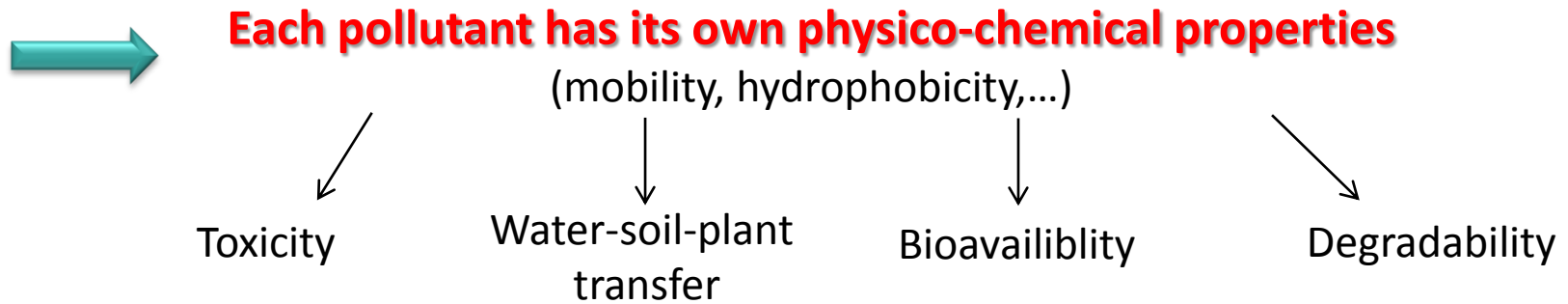


**Sampling more
rain events**



7 rains will be sampled in 2014

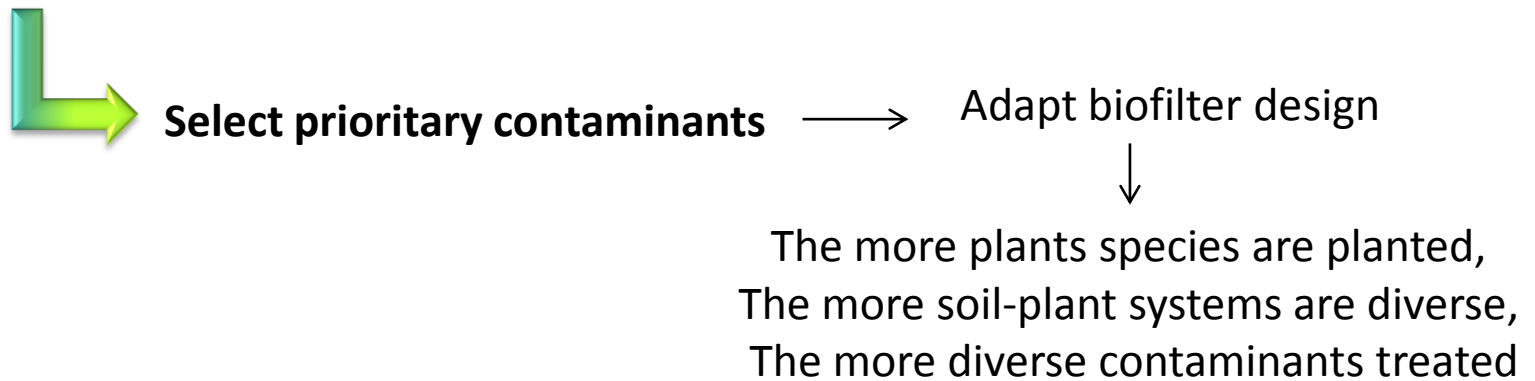
CONTAMINANTS BEHAVIOUR IN SOIL



➔ **TEs bioavailability sequence to plant: Cd > Zn > Pb**

➔ **PAHs content decrease in soil: phenanthrene > pyrene > benzo[a]pyrene**


Implications for urban planners



SOIL-PLANT PROCESSES


TEs accumulation by plants
 → J. Effusus best accumulator and best translocator


Fast PAHs decrease in soil
 → PAHs concentration divided by 10 to 250 in a year


Elucidate PAHs decrease in soil
 → PAHs quantification in water (leakage ?)
 Microorganisms susceptible for PAHs degradation

Perspectives


Distinguish the role of plant from the role of microorganism
 → Rhizosphere investigations

RUN-OFF WATER QUALITY IMPROVEMENT

 **Better improvement in soil-macrophyte system**

Implications for urban planners

 **Plant macrophytes rather than grass**

Perspectives

 **Total entity approach**

Determine macrophyte-soil system advantages/disadvantages

↙
FUNCTIONAL APPROACH
Water management
(hydraulic conductivity)

↓
ENVIRONMENTAL APPROACH
Other ecosystems services
(carbon sink, biodiversity)

↘
ECONOMIC APPROACH
Installation and
maintenance costs

4^e colloque recherche
de la **Fédération Gay-Lussac**
La chimie et la ville de demain



Luc Schuiten

THANK YOU FOR YOUR KIND ATTENTION



SOIL MESOCOSMS CONTAMINATION

➤ One shot and surface contamination



Trace Elements

Zinc	Lead
51,3 300	20,6 100
Cadmium	
0,2 2	

PAHs

Phenantrene	Pyrene
<chem>c1ccc2ccccc2c1</chem>	<chem>c1ccc2c(c1)ccc3ccccc32</chem>
<0,05 10	<0,05 10
Benzo[a]pyrene	
<chem>c1ccc2c(c1)ccc3ccccc32</chem>	
<0,05 10	



SOIL MESOCOSMS CONTAMINATION

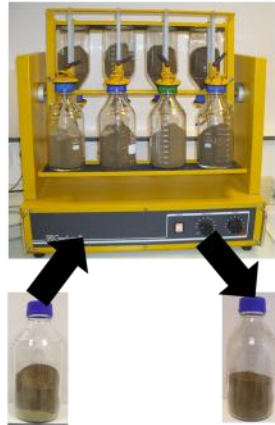
- 1) Contaminate 0,1% soil
 $[\text{PAHs}]_{\text{soil}} = 30\ 000\text{mg/kg}$



335g DW of soil per mesocosm were sterilised, powdered and mixed with 3,35 g of pyrene, phenanthrene and, benzo[a]pyrène dissolved in 200mL of acetone. The mud obtained was agitated 30min with a stir bar. Until acetone was completely volatilized, a manual agitation every 10min prevented soil agglutination.

$[\text{HAP}]_{\text{soil}} / 10$

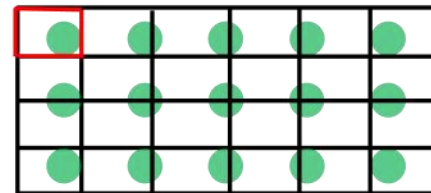
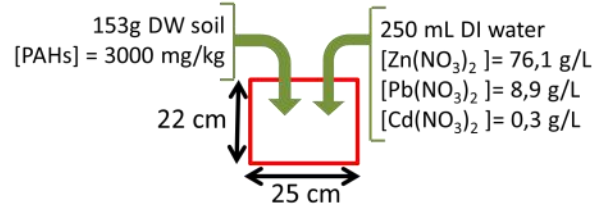
- 2) Mix contaminated soil with fresh soil
 $[\text{PAHs}]_{\text{soil}} = 3\ 000\text{mg/kg}$



43,1g of contaminated soil from step 1 was mixed 30min at 14rpm with fresh soil dried to ambient air and sieved at 2mm. This soil was not affected by sterilisation and kept its properties.

$[\text{HAP}]_{\text{soil}} / 100$

- 3) Spread on top of the mesocosm
 $[\text{PAHs}]_{\text{soil}} = 300\text{mg/kg}$



CONTAMINATED PART OF THE MESOCOSM

To make sure the contamination is homogeneous along the mesocosm, the contaminated part of the mesocosm was divided into 24 cells. In each cell, 153g of fresh soil contaminated with PAHs was spread on top of soil surface.

- 4) Water with contaminated water
 $[\text{Zn}]_{\text{soil}} = 200\text{mg/kg}$
 $[\text{Pb}]_{\text{soil}} = 100\text{mg/kg}$
 $[\text{Cd}]_{\text{soil}} = 2\text{mg/kg}$



Then, each cell was watered in different sweeping directions with 250mL of milli-Q water containing nitrate salts (lead, zinc, cadmium).