Vertical-flow constructed wetland to treat raw wastewater: the French system

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Domestic wastewater treatment for small communities

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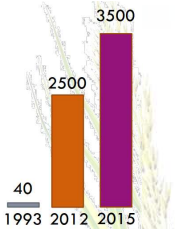
Wastewater treatment technologies for small communities (< 2000 Population Equivalent)

- Activated sludge and other suspended-growth systems
- Rotating disks and other biofilm systems
- Lagoons, ponds and other aquatic systems
- CONSTRUCTED WETLANDS



Number of constructed wetlands in France*

*Molle, 2012 ; Bellin, 2016

The technology has become number one for small communities in France over the last decade with close to 3500 plants in operation

What is a constructed wetland (CW) ?

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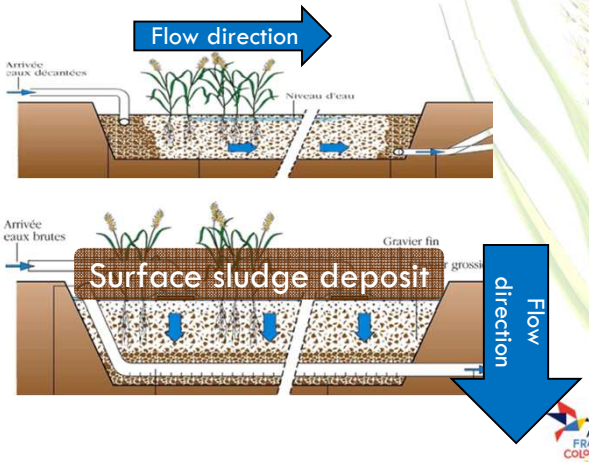
CW can be defined as **engineered water saturated area** in which the natural **removal processes for the water pollutants** are reproduced and enhanced in order to **optimize the purification performances**

CW

- Horizontal (HFCW)
- Vertical (VFCW)



French Vertical Flow Constructed Wetlands (VFCWs)

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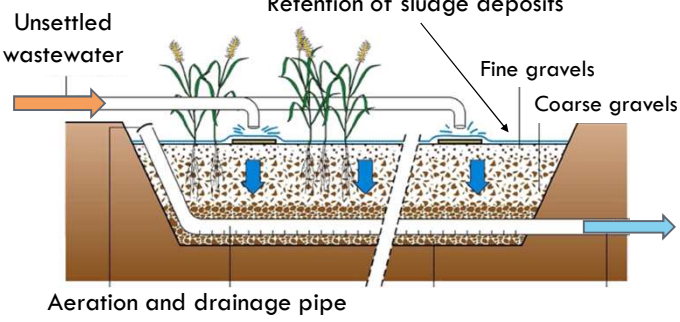
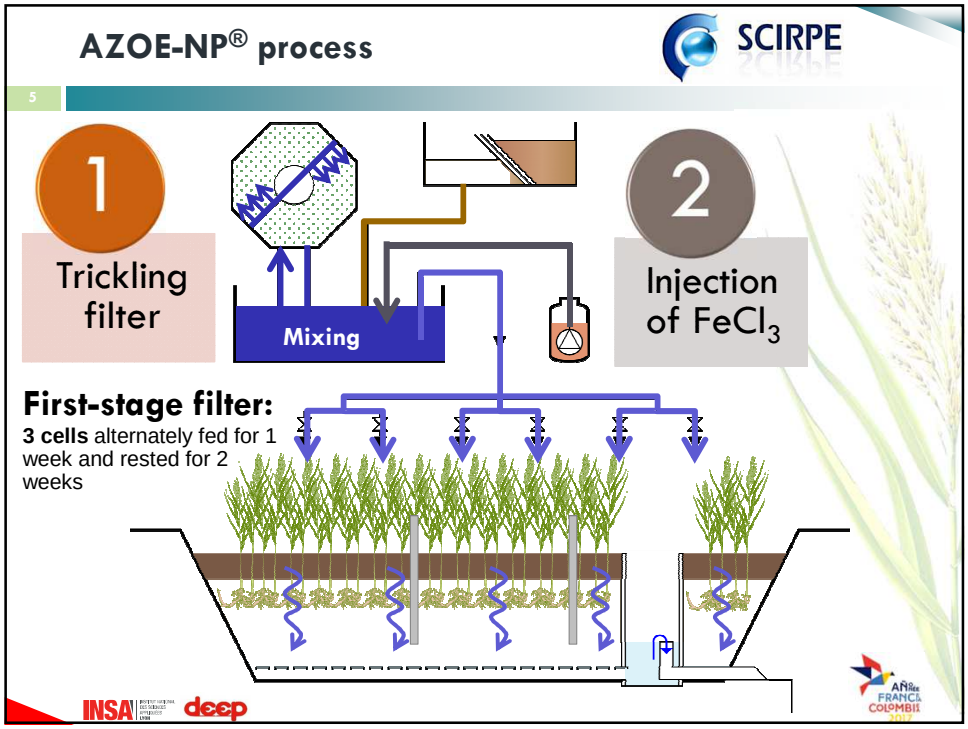
Reed Bed Filters

- French common system : feeded with **raw water** and combines **2 vertical flow** treatment stages.
- **advanced degradation** of pollutants thanks to **aerobic processes.**

First-stage filter



Filter surface area required : around 2 m² per PE in general


AZOE-NP® process
SCIRPE
5
1
Trickling filter
Mixing
2
Injection of $FeCl_3$
First-stage filter:
3 cells alternately fed for 1 week and rested for 2 weeks
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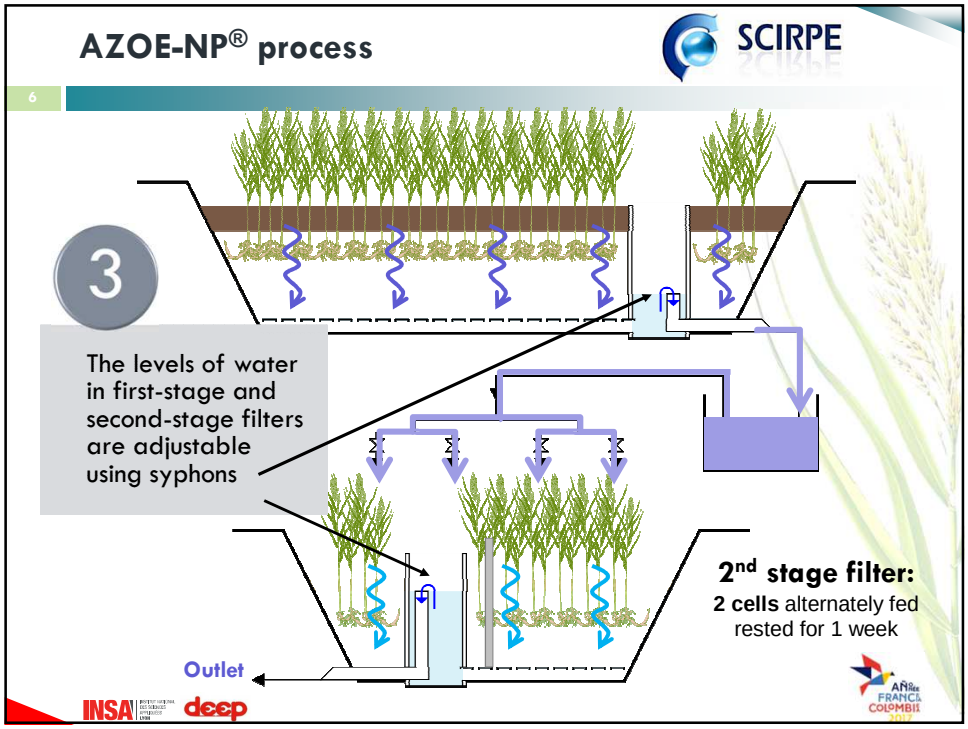
AZOE-NP® process
SCIRPE
6
3
The levels of water in first-stage and second-stage filters are adjustable using syphons
2nd stage filter:
2 cells alternately fed rested for 1 week
Outlet
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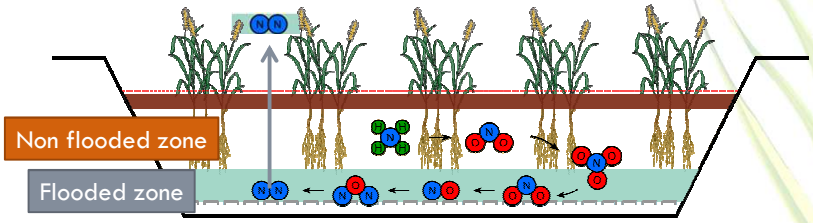
Nitrogen treatment in AZOE-NP® process

- Each filtration stage consists of **two different zones**:
  - the **upper zone** which is not flooded → **nitrification**
  - the **lower zone** which is flooded → **denitrification**

  → These conditions allow **good total nitrogen removal**.

7 N Nitrogen 14.007



→ The depth of the flooded zone can be adjusted to optimize efficiency.

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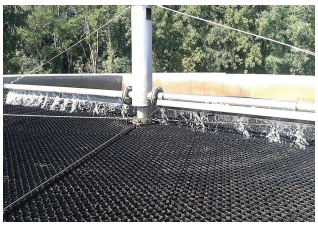
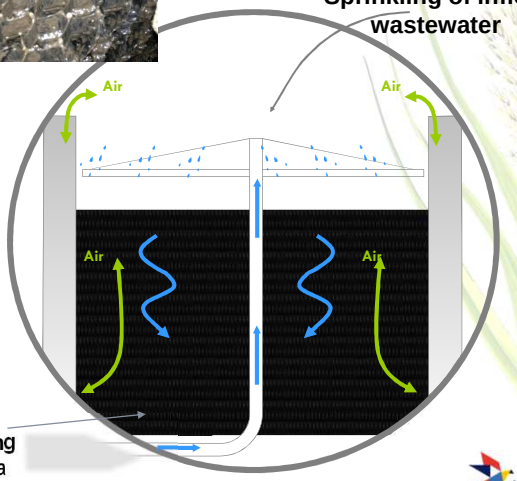
Trickling filter (TF) design

SCIRPE



Role of the TF :

- Good elimination of dissolved COD
- Humification of particulate organic matter
- Enhancement of nitrification



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Monitoring of real scale treatment plant

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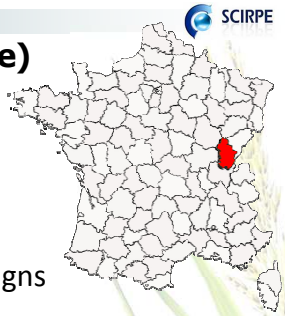
SCIRPE

- **Vercia treatment plant (Jura, France)**
- In operation since 2004 (20-25 cm sludge)
- Maximum capacity: 1100 PE
  Nominal hydraulic capacity of 77 m^3 day^{-1}
  Nominal organic load of 55 kg day^{-1} (BOD_5)

→ 8-year program with more than 40 campaigns



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Monitoring of real scale treatment plant

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- 24h inflow / outflow performance of Vercia plant

Variable	Inlet (mg L^{-1})	Outlet (mg L^{-1})	Removal rate (%)
pH	7.86 ± 0.28 (39)	7.95 ± 0.19 (39)	Non applicable
Suspended solids	450 ± 104	3.4 ± 0.7	98.8% ± 0.5
BOD_5	286 ± 65 (43)	3.2 ± 0.6 (43)	97.9 % ± 1.1 (38)
COD	794 ± 179 (44)	25 ± 3 (44)	94.4 % ± 2.5 (39)
P tot	9.5 ± 1.6 (40)	2.8 ± 0.4 (40)	59.6 % ± 12 (35)
N tot	71 ± 10 (40)	17 ± 3 (39)	70.9 % ± 6.2 (35)
$N_{org} + N_{NH3}$	70 ± 9 (42)	1.6 ± 0.3 (43)	97.2 % ± 1.0 (37)
N_{NO3}	1.4 ± 1.4 (40)	15 ± 3 (40)	Non applicable

Figures in brackets show the number of monitoring campaigns

Performance evaluation of partially saturated vertical-flow constructed wetland with trickling filter and chemical precipitation for domestic and winery wastewaters treatment

B. Kim, M. Gautier, S. Prost-Boucle, P. Molle, P. Michel, R. Gourdon

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The porous media of a French VFCW

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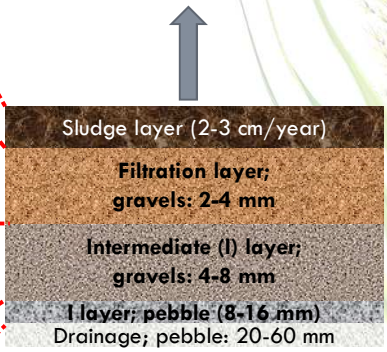
• **Sludge layer: the more reactive part**
→ Often considered as a **risk for clogging**
→ **Role in the performance** of the system ?



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Role of the surface sludge deposit in VFCW ?

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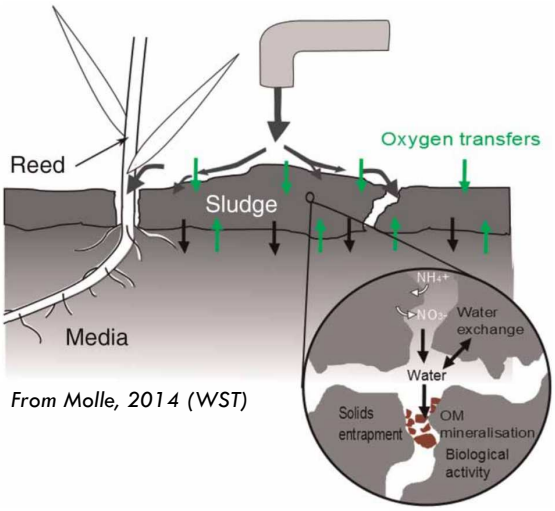
• Schematic representation of processes implied in the deposit layer



From Molle, 2014 (WST)

• **Limit to provide** a good **carbon supply** to support denitrification ?
• How the **organic matter** is **mineralised** ?
• **Act as a reactive barrier** for **pollutants** ?

→ **Better caracterization of the surface sludge deposit was needed**

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Fate of phosphorus in surface sludge deposit

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15 P Phosphorus 30.974

Boram Kim's PhD SCIRPE

Organic matter and mineral phases

- **Methodology**

OM content
Calcination at 550°C

Crystallized mineral phases
X-Ray Diffraction (XRD)

Nature / stability of OM and informations about mineral phase
Fourier Transform Infrared / Thermal analysis

P fractionation
Sequential chemical extractions
P K-edge X-ray Absorption Near Edge Structure (XANES)
Nuclear Magnetic Resonance (NMR) of ^{31}P in extracts

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Fate of phosphorus in surface sludge deposit

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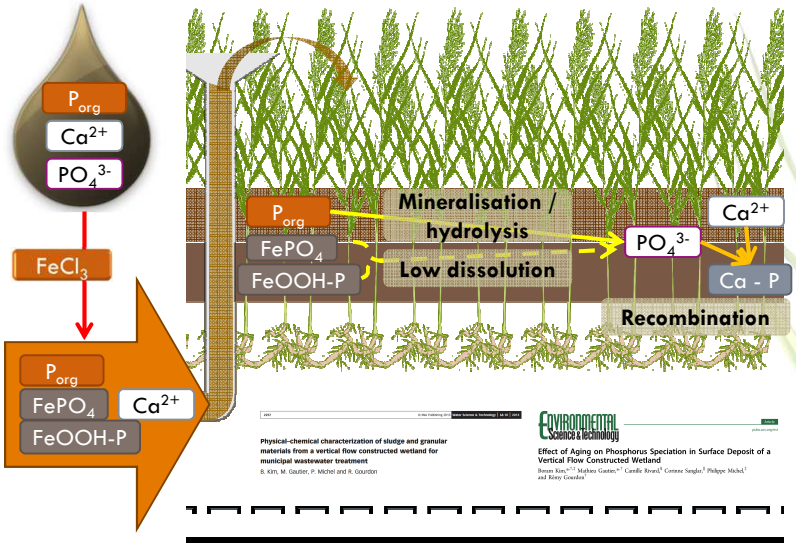

Physical-chemical characterization of sludge and granular materials from a vertical flow constructed wetland for municipal wastewater treatment
B. Kim, M. Gautier, P. Michel and R. Gourdon

Environmental Science & Technology
Effect of Aging on Phosphorus Speciation in Surface Deposit of a Vertical Flow Constructed Wetland
Boram Kim, Mathieu Gautier, Camille Rivard, Corinne Sergler, Philippe Michel, and Rémy Gourdon

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Pilot-scale study

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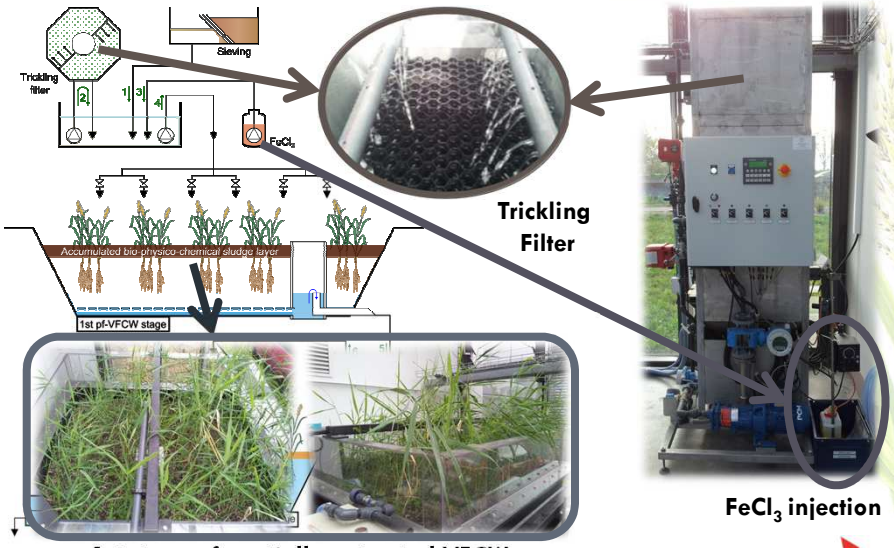

Pilot-scale study : effect of flooding

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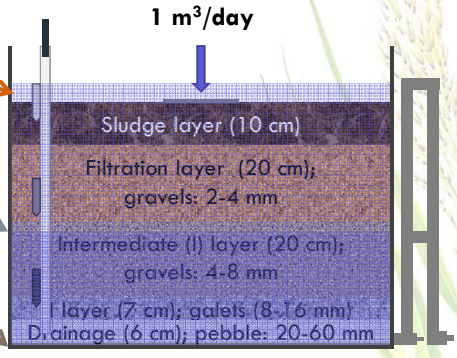
Methods

70 cm: Flooding
→ extreme condition

30 cm:
Partially saturated condition as in AZOE-NP® process

0 cm:
Aerobic condition as in classical French VFCW



Feed/rest periods: 1/3 week feeding, 2/3 week resting

Experimental sequences of 2-weeks 0cm → 30 cm → flooded → 0 cm

Pilot-scale study : effect of flooding

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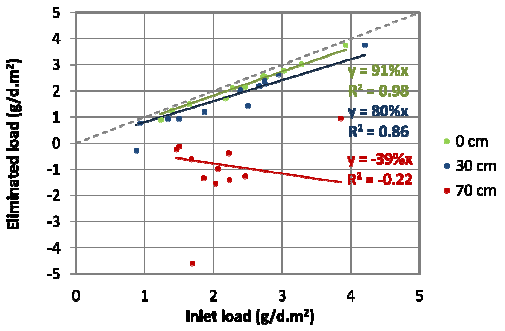
Some of the results about P :



Ecological Engineering

Influence of the water saturation level on phosphorus retention and treatment performances of vertical flow constructed wetland combined with trickling filter and $FeCl_3$ injection

B. Kim, M. Gautier, P. Molle, P. Michel, R. Gourdon

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Pilot-scale study of vertical flow constructed wetland combined with trickling filter and ferric chloride coagulation: influence of irregular operational conditions

B. Kim, M. Gautier, G. Olvera Palma, P. Molle, P. Michel and R. Gourdon

Journal of Environmental Management

Research article

pH and Eh effects on phosphorus fate in constructed wetland's sludge surface deposit

Boram Kim, Mathieu Gautier, Arnaud Simidoff, Corinne Sanglar, Vincent Chatain, Philippe Michel, Rémy Gourdon

- **Slight P release** was observed under flooded conditions but after several days [7 days].
- Retention performance was recovered within a couple of days when going back to normal conditions (**good resilience**)

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Fate of phosphorus in surface sludge deposit

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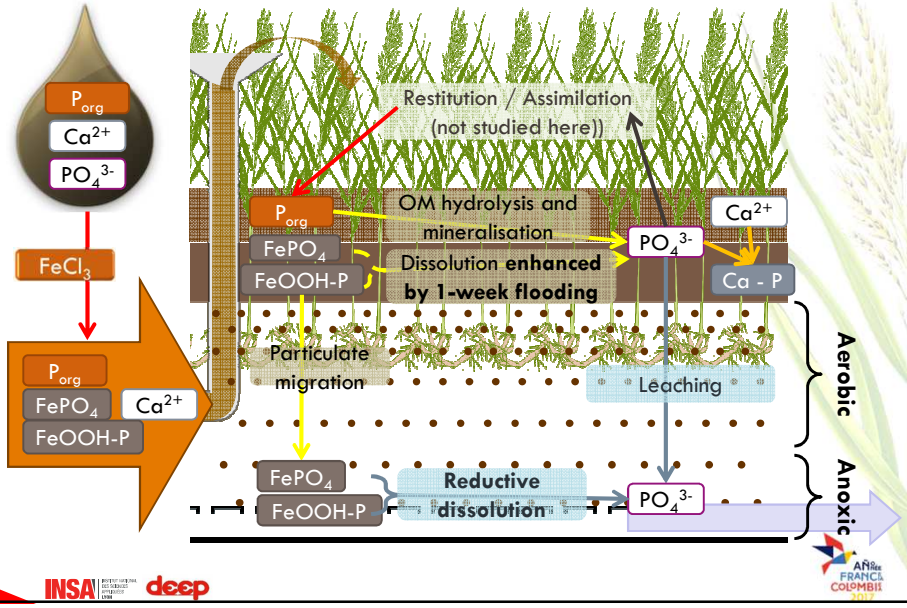

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The undergoing investigation

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Manon Kania's PhD

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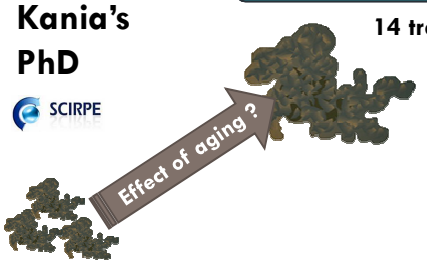
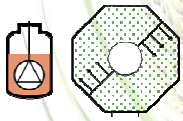
PARTICULATE ORGANIC MATTER EVOLUTION

14 treatment plants investigated

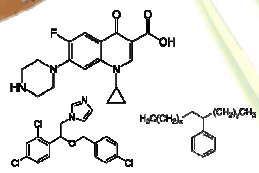




Role of additionnal pretreatment ?

carbone	azote	phosphore
6	7	15
C	N	P
12,0107	14,00674	30,973762

cadmium	zinc	nickel		
48	30	28		
Cd	Zn	Ni		
112,411	65,39	58,6934		
plomb	mercure	chrome	cuivre	
82	80	24	29	
Pb	Hg	Cr	Cu	
207,2	200,59	51,9961	63,546	



TREATMENT PERFORMANCE

+ geochemical modelling

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Conclusions

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French Vertical Flow Constructed Wetlands:

- **Well adapted** for **small communities** and **rural area**
- (Very) **efficient for C and N** removal
- Good solutions for **P treatment** (if needed).

In French VFCW sludge layer plays a major role in:

- **The performance of the system**

→ Pollutant retention (adsorption) and degradation

- **Resistance to changes** (i.e. flooding conditions) and to the **rapid resilience** of the system observed
- Additional pretreatment → limit the risks of clogging ?

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Thank you for your attention
Special thanks to Boram Kim, Manon Kania, Philippe Michel and Pascal Molle for their contributions in these works
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