On the fate of micropollutants in the environment: Dynamic modelling of Bisphenol A and heavy metals in wastewater treatment plants

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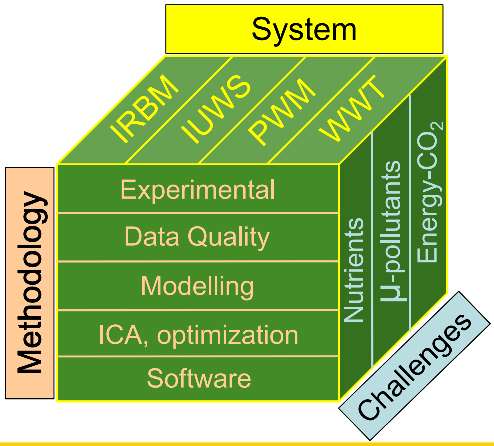
modelEAU : its logo …

- Location
  - Québec, along a river
- Relation with our long term objectives
  - Data collection
  - Urban waters
  - Continuous (automated)
  - Data quality
- Its name : Modelling water systems

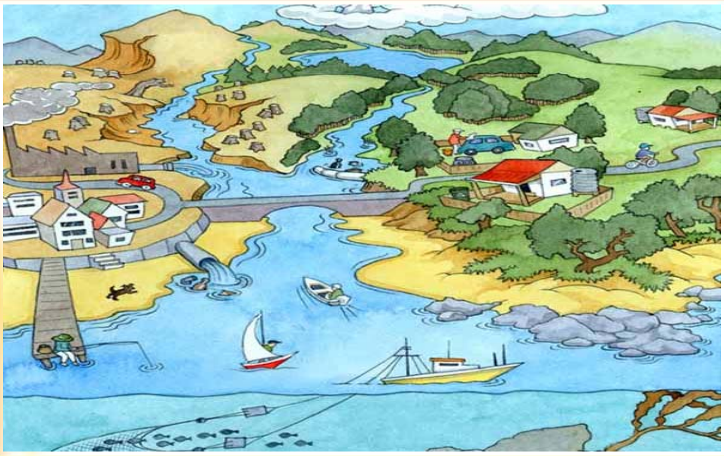
3D schematic of modelEAU's research ("cubEAU")



Overview

- Problem statement
- Objectives
- Materials and methods
- Modelling
- Results
- Conclusion

Problem statement



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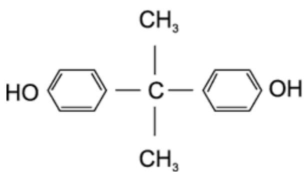
Problem statement

- Example: Bisphenol-A (BPA)
  - Use
    - Polycarbonates (Bottles, CDs)
    - Epoxyresins (canned goods)



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Problem statement

- Example: Heavy metals
  - Origin
    - Tires (Zinc, Cupper, Chrome)
    - Car parts (Lead, Cadmium)
    - Roofs (Zinc, Cupper)

Problem statement

- Protect the environment:

Problem statement

- Influent of a WWTP:
  - Traditional pollutants:
    - Organic matter (excrements, kitchen, shower, leaves)
    - Nitrogen (urine, fertilizer)
    - Phosphorus (detergents, fertilizer)
  - Toxic products
    - Xenobiotic organic compounds (perfumes, detergents)
    - Heavy metals

Micropollutants
Emerging pollutants
Priority pollutants

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Problem statement

- Effluent of a WWTP
  - A certain amount of pollutants will be rejected
  - Which fraction?
  - How can we improve the situation?
    - Limit the use of certain products
    - Modify the configuration/operation of the WWTP

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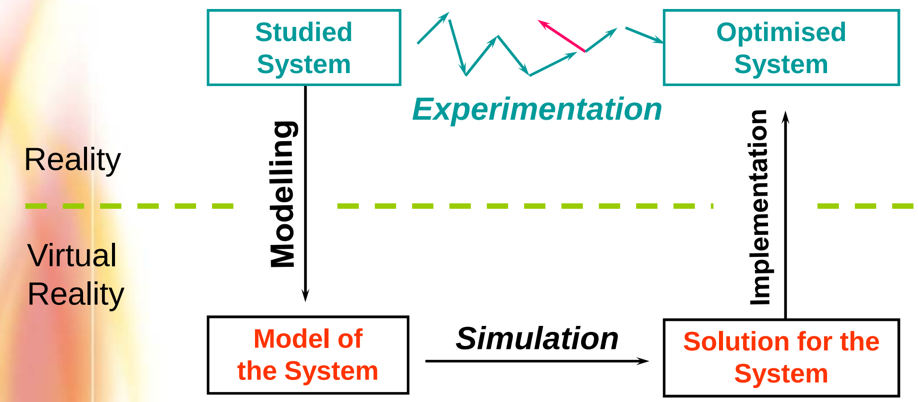
Problem statement: Why modelling ?



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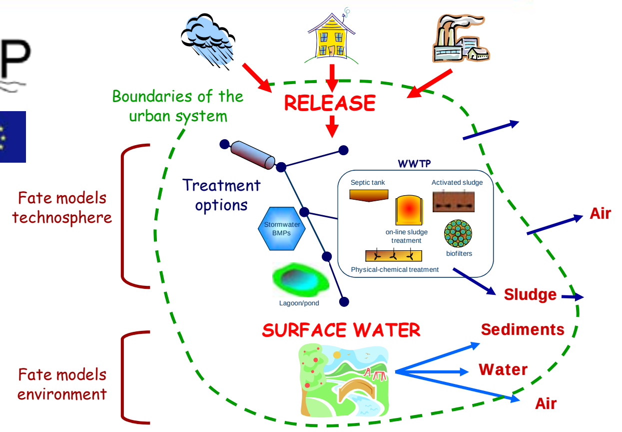
Objectives

- Develop a model able to describe the fate of micropollutants on top of traditional pollutants in a WWTP
  (and in the sewer system and the river)
- Score-PP
  - Source Control Options for Reducing Emissions of Priority Pollutants

Objectives



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Materials and methods

- WWTP of Norwich, UK
- Activated sludge with anaerobic digestion
- Data collected in 1986
  - COD, SS, NH_4, 6 heavy metals
  - 10 days, 3h interval
  - Different sample locations in the WWTP
  - Unique data set in the world

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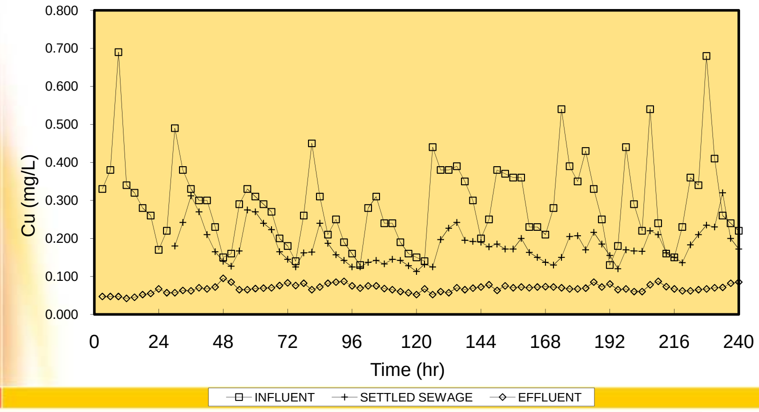
Materials and methods

- Example of data series: Cupper



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Materials and methods

Source: Paul Lessard

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Materials and methods

Source: Paul Lessard

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Materials and methods

Source: Paul Lessard

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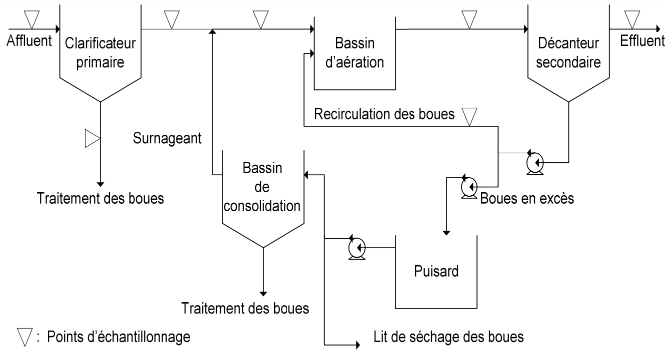
Materials and methods

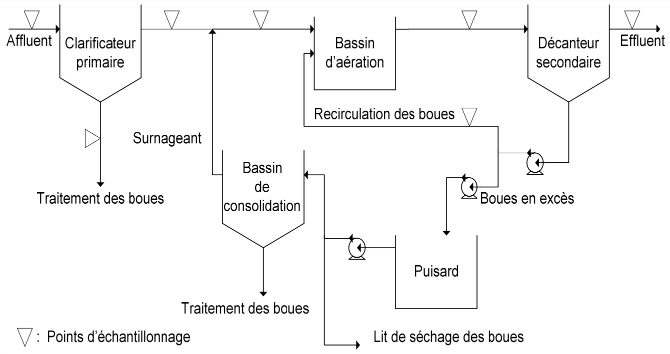


Activated sludge system at the Norwich WWTP
(Lessard and Beck, 1993)

Materials and methods

- WEST® simulator
  - Developped by:
    - BIOMATH UNIVERSITEIT GENT
    - MOSTforWATER
  - Functionality:
    - Dynamic simulation
    - Add/extend models yourself
    - Extensions for sewers (KOSIM) and rivers (RWQM1)

Materials and methods



Activated sludge system at the Norwich WWTP
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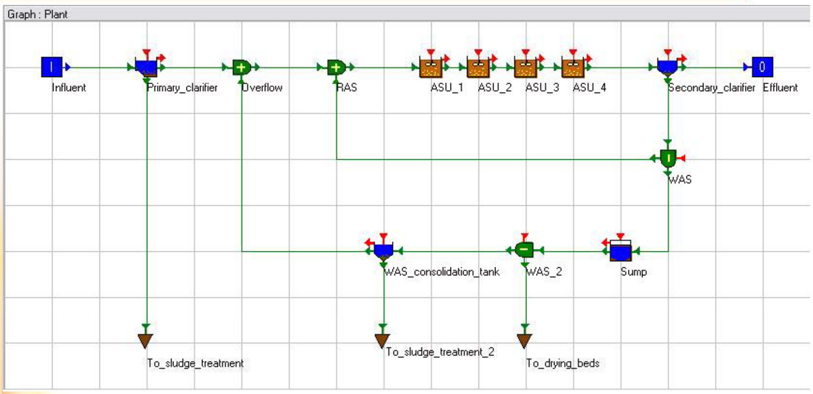

The Norwich WWTP in the WEST simulator

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Modelling

Transport

Reactions

- Mass balance

$$\frac{dMétal}{dt} = \frac{Q_{in}}{V}\left(Métal_{in} - Métal_{out}\right) - \cancel{\text{Dég. bio.}} - \text{"Sorption"} - \cancel{\text{Volatilisation}}$$

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Modelling

- Describe sorption:

$$Métal_{Dissous} + X_{TSS} \xrightarrow{k_{sorption}} Métal_{Sorbé}$$

$$Métal_{Sorbé} \xrightarrow{k_{désorption}} Métal_{Dissous} + X_{TSS}$$

$$Métal_{Dissous} + X_{TSS} \underset{\frac{k_{sorption}}{K_D}}{\overset{k_{sorption}}{\rightleftarrows}} Métal_{Sorbé}$$

$$K_D = \frac{k_{sorption}}{k_{désorption}}$$

$$Rate = k_{sorption} \cdot \left(S_{Métal} \cdot X_{TSS} - \frac{X_{Métal}}{K_D} \right)$$

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Modelling

Transport | Reactions

- Mass balance

$$\frac{dMétal}{dt} = \frac{Q_{in}}{V}(Métal_{in} - Métal_{out}) - \text{~~Dég. bio.~~} - \text{"Sorption"} - \text{~~Volatilisation~~}$$

$$\frac{dS_{Métal}}{dt} = \frac{Q_{in}}{V}(S_{Métal,in} - S_{Métal,out}) - k \cdot \left(S_{Métal} \cdot X_{TSS} - \frac{X_{Métal}}{K_D} \right)$$

$$\frac{dX_{Métal}}{dt} = \frac{Q_{in}}{V}(X_{Métal,in} - X_{Métal,out}) + k \cdot \left(S_{Métal} \cdot X_{TSS} - \frac{X_{Métal}}{K_D} \right)$$

Transport | Sorption/Desorption

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Modelling

- Importance of TSS:

$$\frac{dS_{Métal}}{dt} = \frac{Q_{in}}{V}\left(S_{Métal,in} - S_{Métal,out}\right) - k \cdot \left(S_{Métal} \cdot X_{TSS} - \frac{X_{Métal}}{K_D}\right)$$

$$\frac{dX_{Métal}}{dt} = \frac{Q_{in}}{V}\left(X_{Métal,in} - X_{Métal,out}\right) + k \cdot \left(S_{Métal} \cdot X_{TSS} - \frac{X_{Métal}}{K_D}\right)$$

  - We need good quality TSS simulations!
  - We need a model that describes growth/decay of biomass and the accumulation of org. matter

ASM1
(Activated Sludge Model No.1)

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Modelling

- Importance of TSS – WWTP
  - Primary clarifier
    - r_H [m³/g] = 0.00026 (0.00019) ← Hindered sedimentation
    - r_P [m³/g] = 0.00054 (0.00070) ← Individual sedimentation
    - Average waste flow [m³/d] = 201.5 ← Not constant
  - Aeration tanks
    - k_La [j^{-1}] = 220, 60, 14, 12
    - K_S [g/m³] = 20 (130)
  - Secondary clarifier
    - Average waste flow [m³/d] = 575.5

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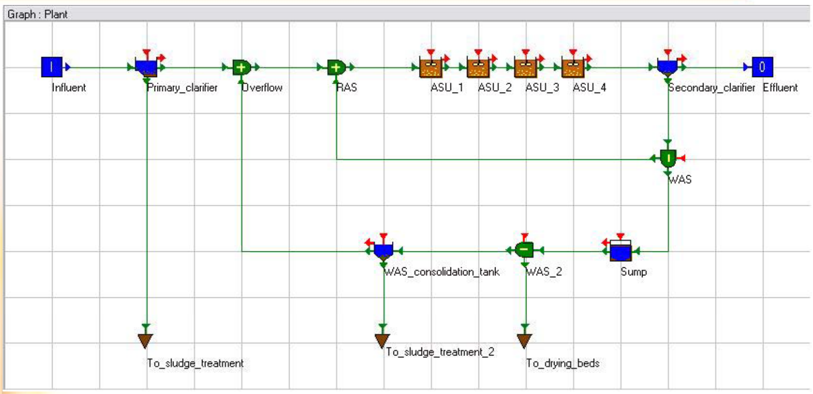
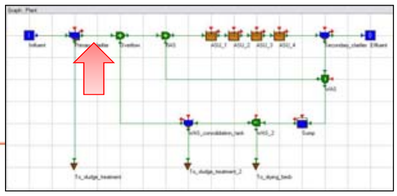
Results

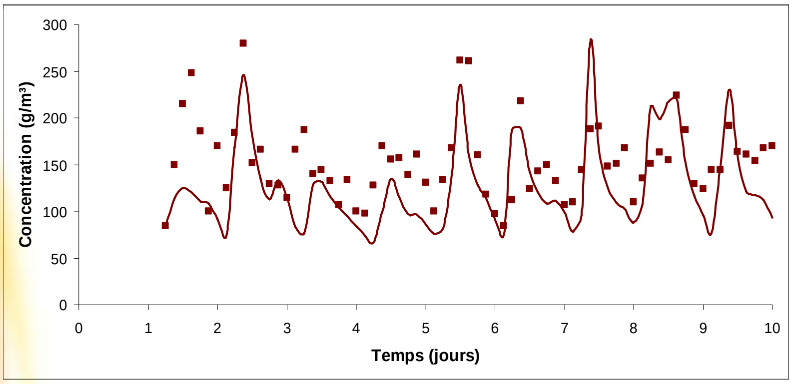


The Norwich WWTP in the WEST simulator

Results

- TSS in PC effluent





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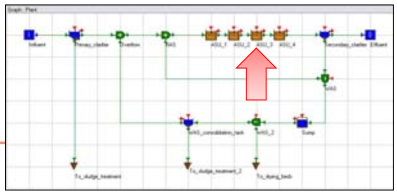
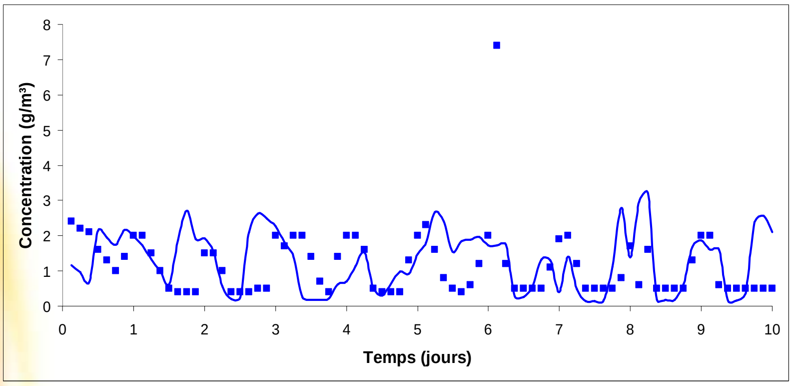
Results

- Dissolved oxygen





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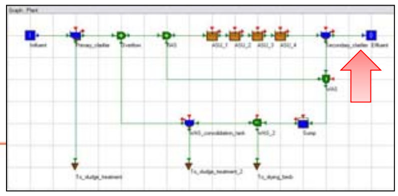
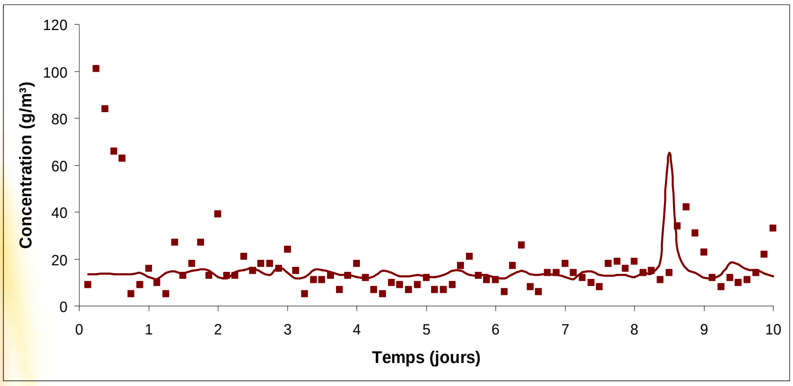
Results

- Effluent TSS



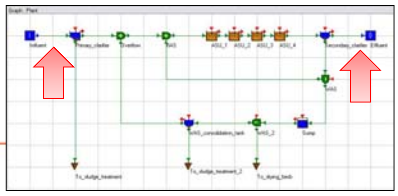


Results

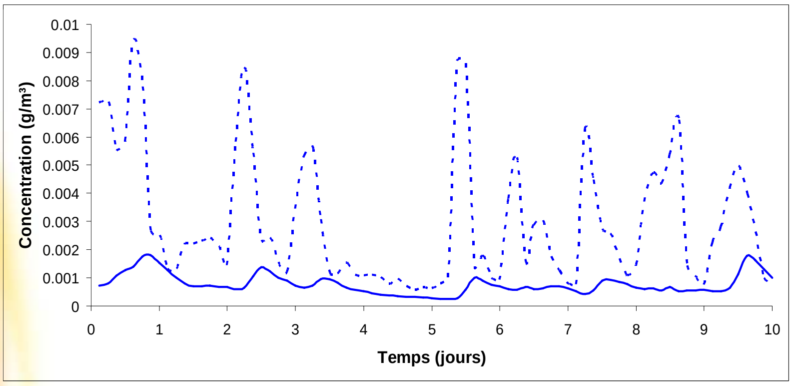
- Studied heavy metals

Parameters	Units	Cupper	Zinc	Lead	Cadmium	Chrome	Nickel
$k_{sorption}$	L/mg.d	0.0008	0.0001	0.0023	0.0002	0.0015	0.0008
$Log(K_D)$	L/kg	4.0 (3.1 – 6.1)	5.1 (3.5 – 6.9)	4.6 (3.4 – 6.5)	4.6 (2.8 – 6.3)	4.6 (3.9 – 6.0)	3.9 (3.5 – 5.7)
Removal	%	90.2	80.1	93.3	75.6	86.5	71.6

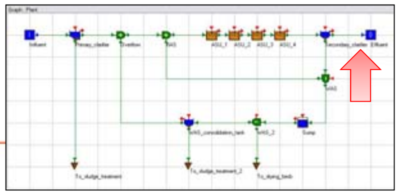
Results



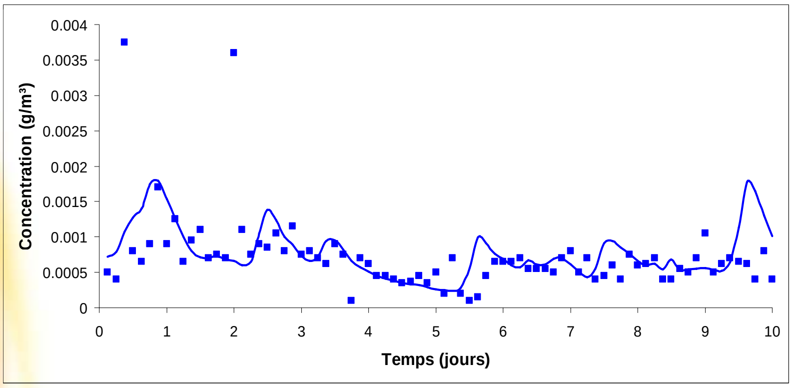
- Cd: Influent - effluent



Results

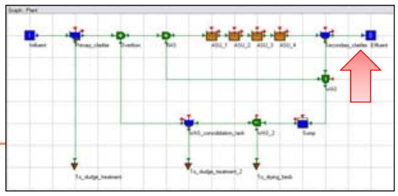


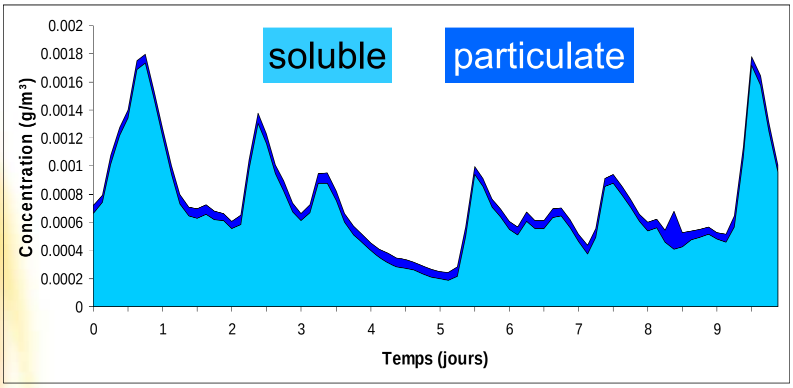
- Cd: Effluent



Results

- Cd: partitioning





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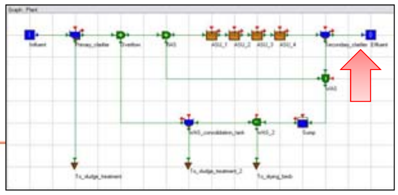
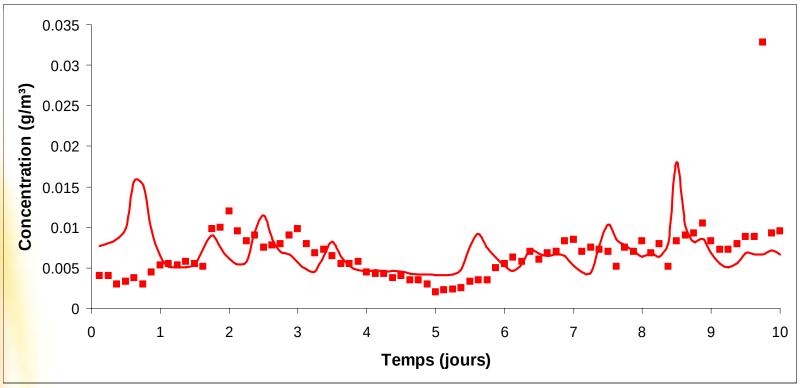
Results

- Cr: Effluent





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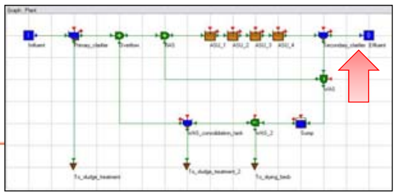
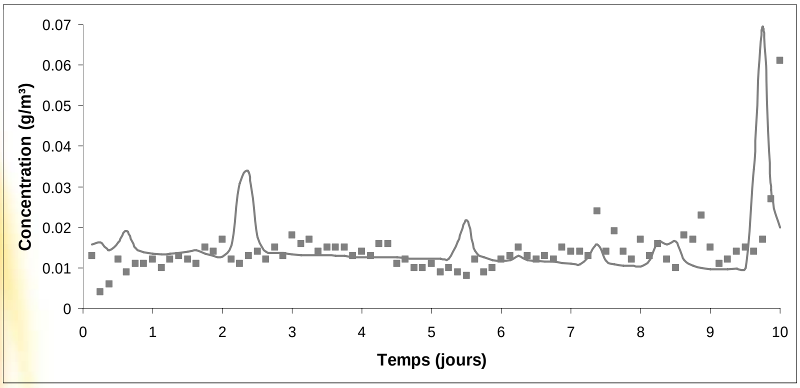
Results

- Pb: Effluent





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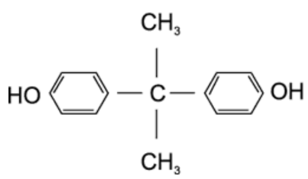
Problem statement

- Example: Bisphenol-A (BPA)
  - Use
    - Polycarbonates (Bottles, CDs)
    - Epoxyresins (canned goods)

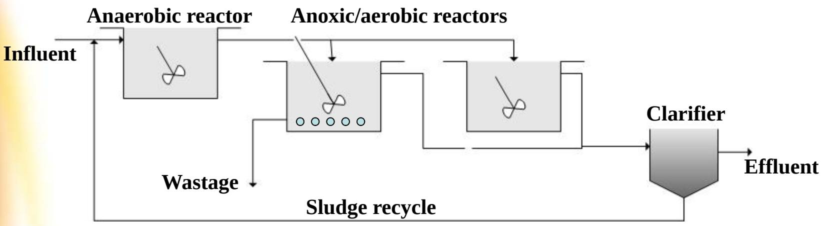


Problem statement

- Example: Bisphenol-A (BPA)
  - Endocrine disruptor
    - Modifies the hormonal equilibrium of an organism
  - Is extracted from materials, especially when:
    - Cleaned with strong detergents
    - Heated to high temperatures
    - Contacted with strong acids
  - Typical concentration in wastewaters:
    - between 5 and 10 µg/L

Materials and methods

- Pilot plant at Copenhagen (Denmark)
  - WWTP Lynetten
  - Biodenipho™ process
  - Total volume of the reactors: 11.6 m³



Materials and methods

- Pilot plant at Copenhagen (Denmark)

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Materials and methods

- Pilot plant at Copenhagen (Denmark)

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Modelling

$$\frac{dXOC}{dt} = \frac{Q_{in}}{V}\left(XOC_{in} - XOC_{out}\right) - \text{Dégradation biologique} - \text{Sorption} - \sout{\text{Volatilisation}}$$

- Bisphénol A is non-volatile
- Biodegradation by a specialised bacterium
- Biodegradation only in presence of O_2

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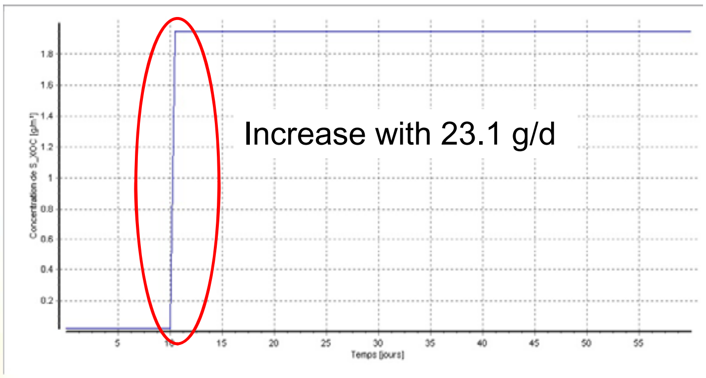
Results

- Experiment: Step load change to BPA



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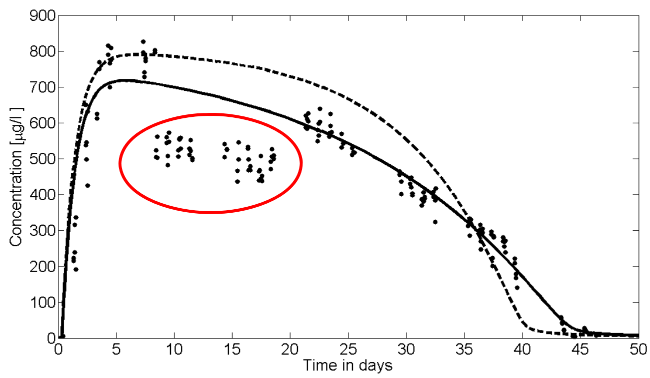
Results

- Case study Lynetten (Injection of 10 g/d of BPA)



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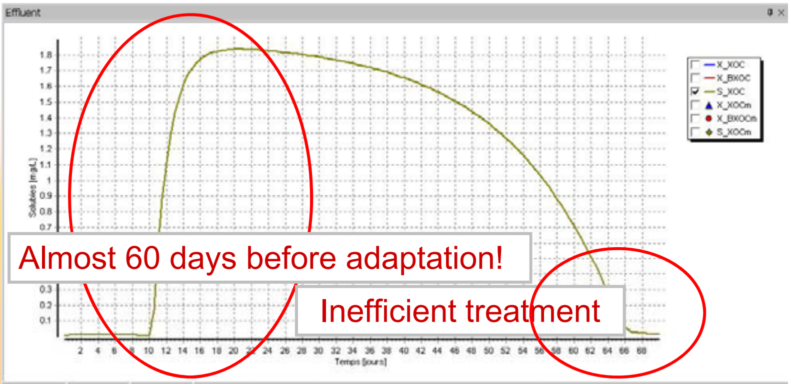
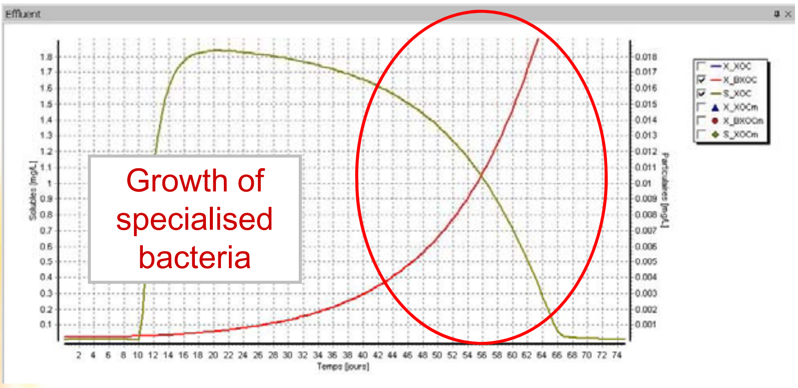
Results

- Effluent BPA concentration



Results

- Effluent BPA concentration



Results

- Use of the model:
  Effect of operational parameters:
  - Increase temperature and aeration
  - Injection of 1 g/d of BPA for 60 days in order to adapt the biomass to the new pollutant
  - No injection for 14 days
  - Injection of 10 g/d of BPA

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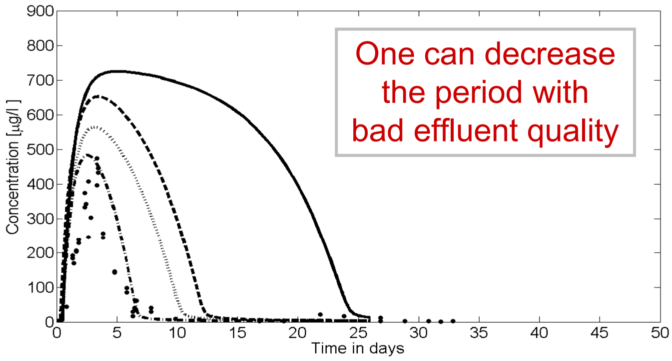
Results

- Effect of operational parameters



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Conclusion

- Case studies:
  - Xenobiotic Organic Compounds (XOC)
  - Heavy metals
- Development of a model that deals with:
  - Traditional pollutants
  - Heavy metals
  - Bisphenol A
- Potential of the model
  - Optimising the design/operation of WWTPs

$$k_{sorption} \cdot \left(S_{Métal} \cdot X_{TSS} - \frac{X_{Métal}}{K_D} \right)$$

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Conclusion

- Acknowledgement

Canada Research Chair
in Water Quality Modelling

  - Frédéric Cloutier
  - Guillaume Jalby
  - Paul Lessard
  - Erik Lindblom
  - Peter Steen Mikkelsen

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