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PSE
THE ADVANCED PROCESS MODELLING COMPANY

Model-based energy audit of WWTP

The power of Advanced Process Modelling

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gPROMS THE gPROMS PLATFORM

gWATER

APM
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Presentation Outline

- What is a Waste Water Treatment Plant (WWTP) ?
- How can first-principle modelling (FPM) improve the operation of plants
- Example : model-based energy audit and retro-fit of a bio-filtration process
- Technology trends in water industry and influence of emerging environmental laws
- Conclusions

Urban WWTP overview

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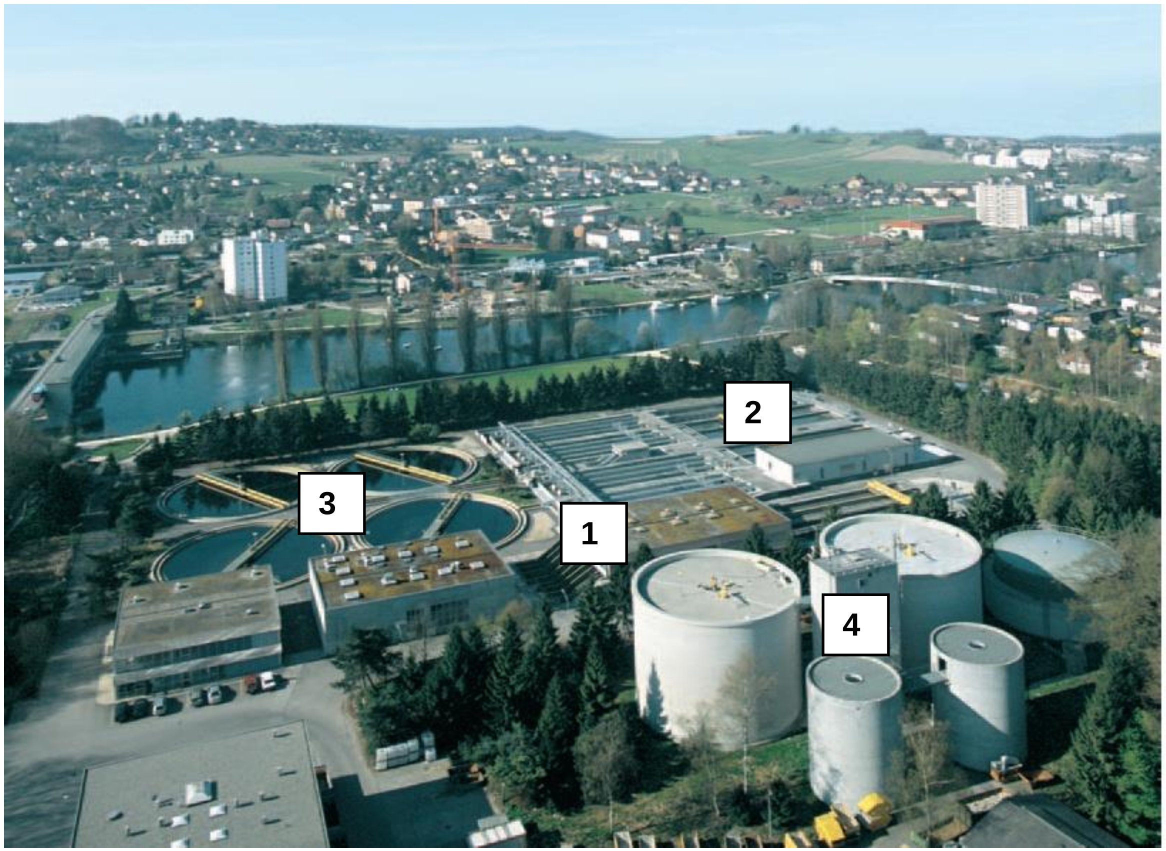
Municipal Water treatment consists in 4 major steps:



1 – Primary treatments :
Separate oil and particles from water

2 – Biological treatments :
Remove dissolved pollution from water (Carbon, Nitrogen, Phosphorus)

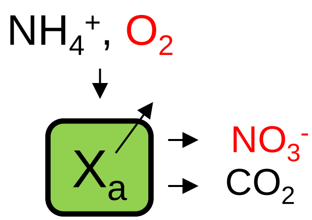
3 – Secondary separation :
Remove growing bacteria from water

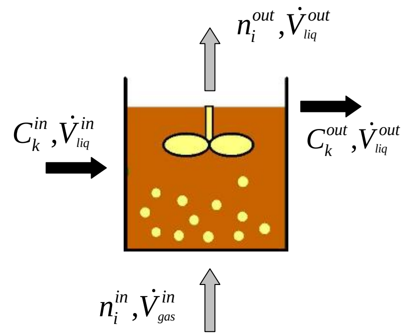
4 – Sludge disposal :
Anaerobic digestion of sludge, dewatering/drying,…

Microbial activity in Bio-degradable Water

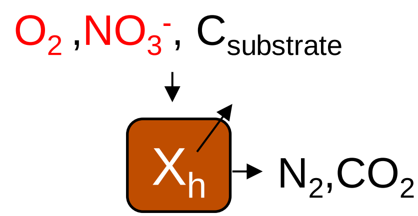
Two main consortium of bacteria are naturally active in waste water

Autotrophs :
Nitrification





Heterotrophs :
C-removal + De-nitrification



$$NH_4^+ + 1.86O_2 + \ldots \rightarrow 0.02X_a + 0.98NO_3^- + \ldots$$

$$0.65C_{substrate} + 4.89NO_3^- + \ldots \rightarrow X_h + 2.27N_2 + \ldots$$

Autotrophs requires oxygen to grow

Heterotrophs can use oxygen or nitrate to grow

The level of dissolved oxygen (with the nitrate concentration) in the reactors is a way to control the activity of bacteria.

Electricity costs for Urban Water Treatment

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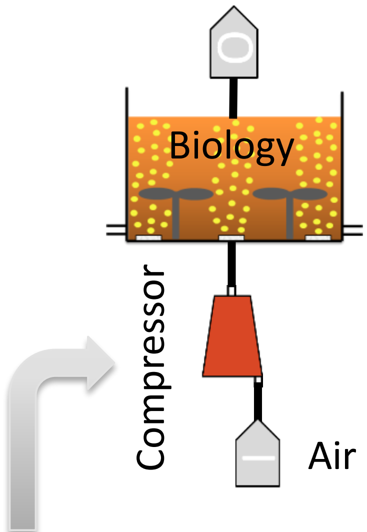
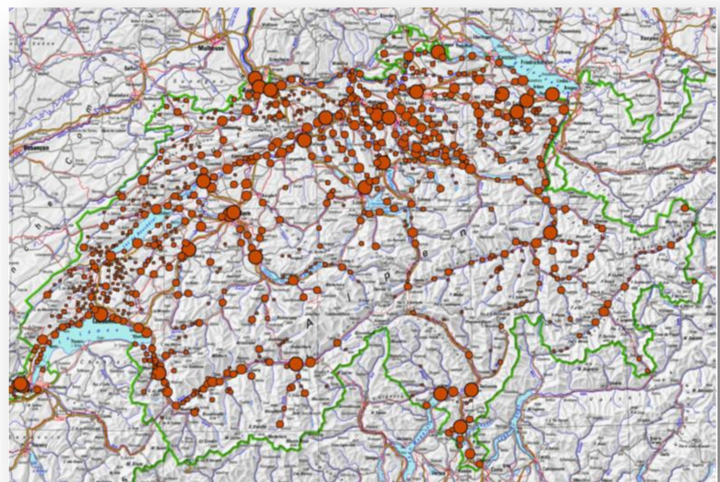
Microbial activity is the "engine" of water purification

- Aeration is 60 to 80 % of the total electricity bill of a plant





Swiss WWTP map

Electricity,
is the *"fuel"* of aerobic processes.

- Switzerland total WWTP electricity : 400 GWh/year
- Represent almost 15 % of the total electricity bill of a city
- *Most of the plants operate at sub-optimal conditions*

Model-based support to plant operation

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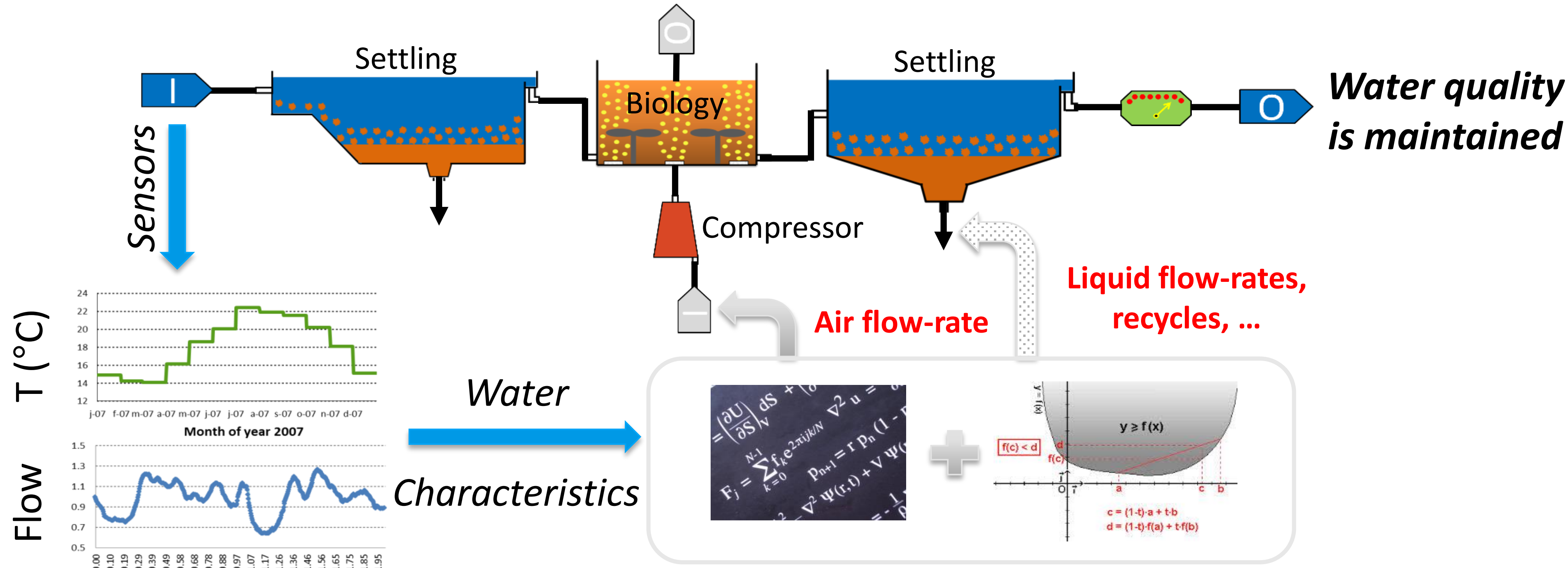
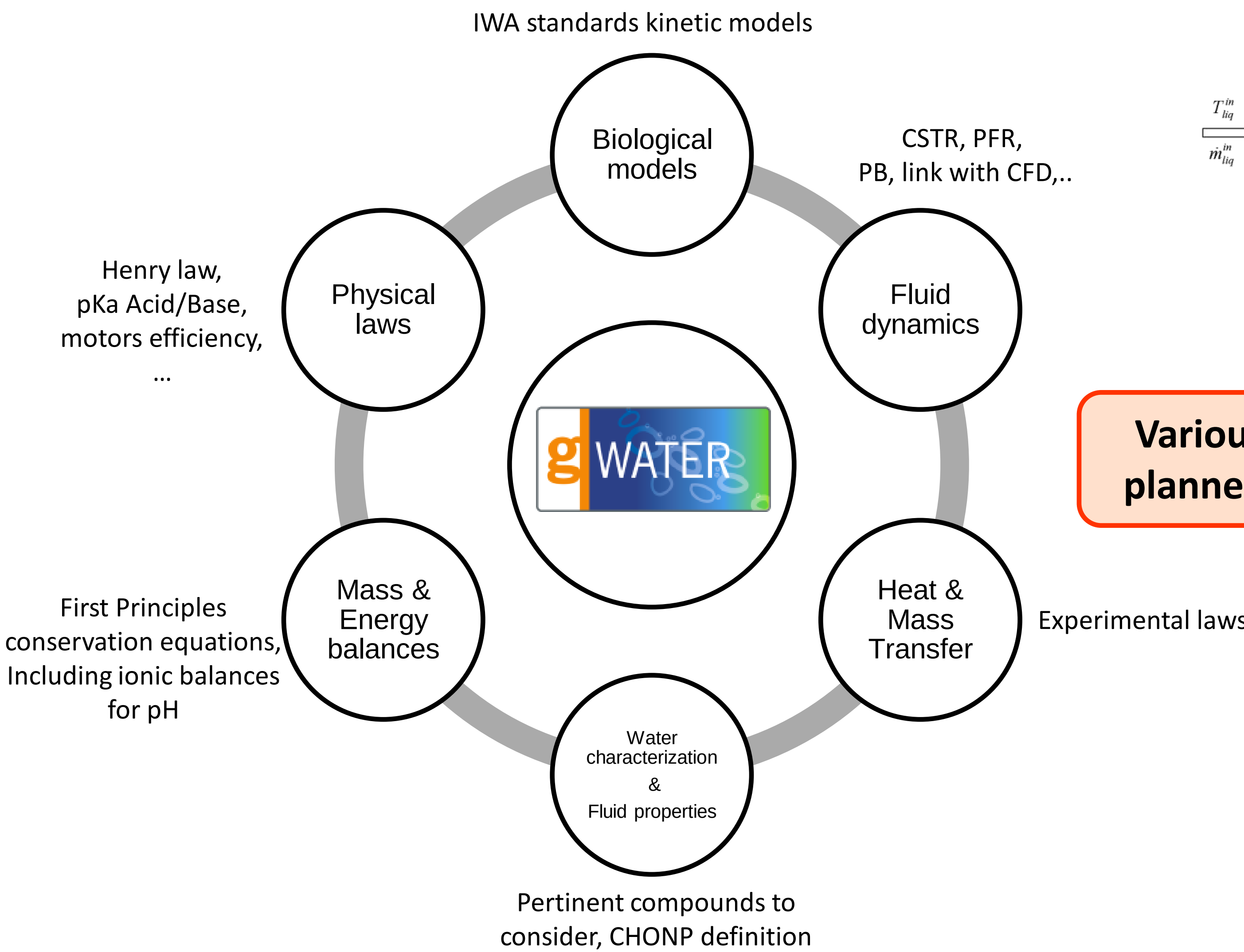
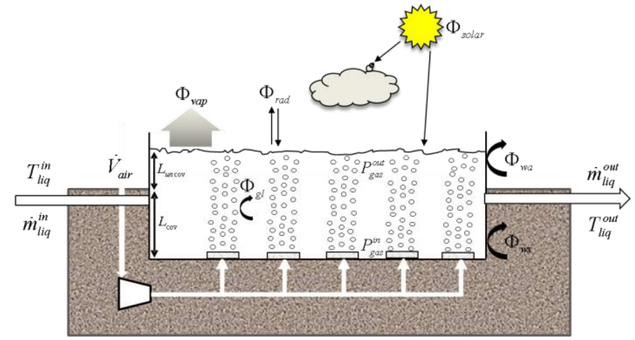


First-principle models combined with optimization

- Can deal with hydrodynamic and load typical variations
- **Can deal with temperature effects**
- Well suited technology for attached biomass processes (biofilm)
- **Predictive capabilities** : can deal with various time scales

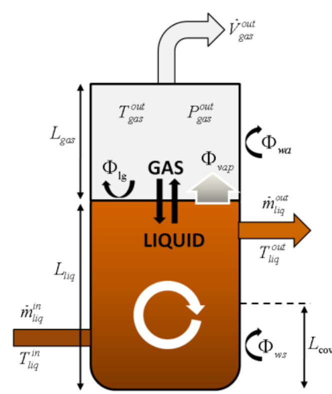
gWATER Modeling Framework





Two phases Activated Sludge Plug Flow Reactor

Various Process Units models are planned to be included in gWATER



Two phases Anaerobic Digestion Completely Stirred Tank Reactor

Example : optimization of bio-filtration

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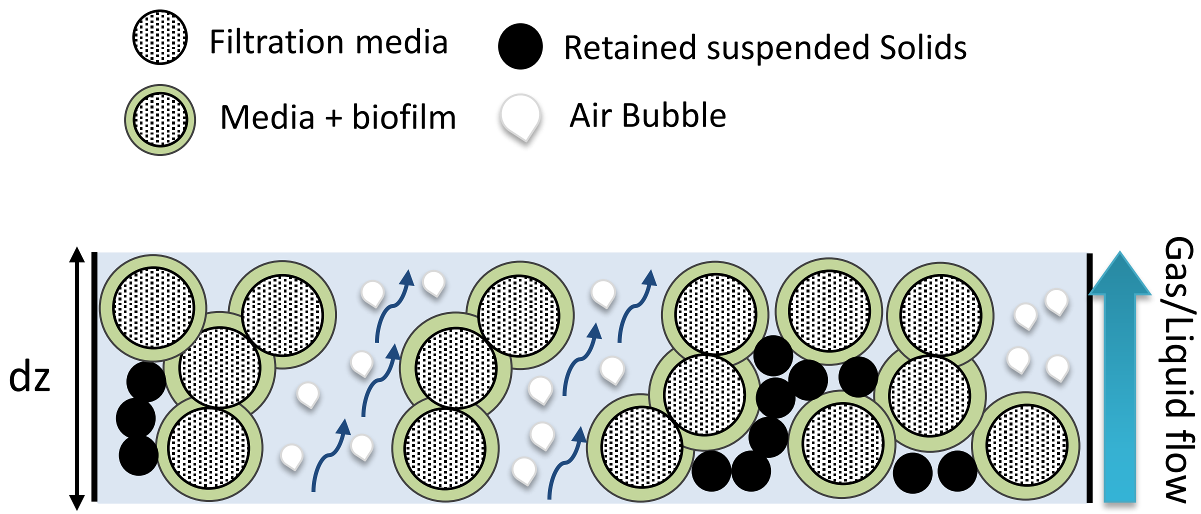
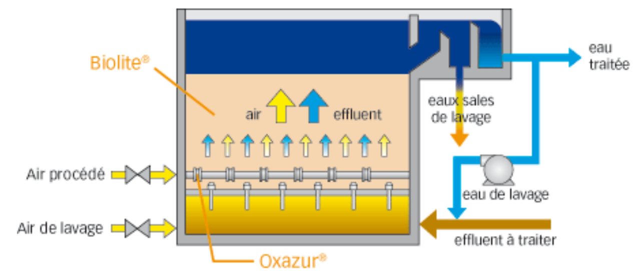
Energy audit and aeration control system retro-fit

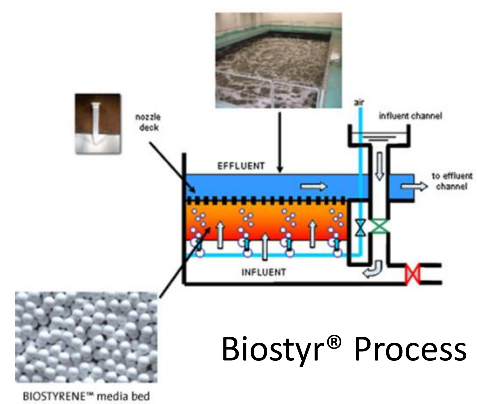
Physical phenomena involved in Bio-filtration



- Fluid mechanics: Two-phase flow trough a porous media
- Mass transfer phenomena: Gas/Liquid and Biofilm/Liquid
- Suspended Solids retention through the media
- Waste Water Microbial Biology modelling : IWA models
- Fully Dynamic process : progressive fouling, periodic backwashes

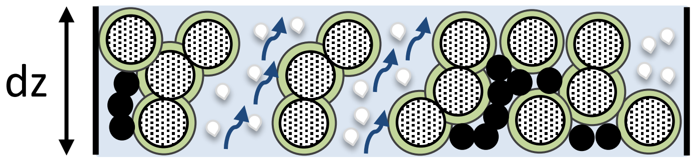


Biofor® Process (Degremont)



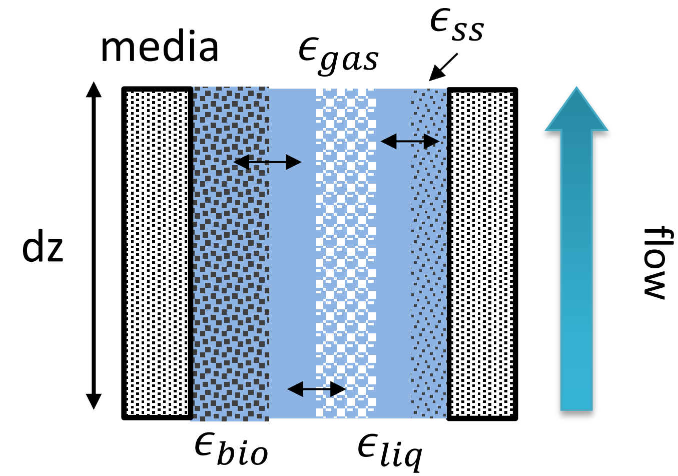
Biostyr® Process (Veolia)

Modelling approach : Gas / Liquid / Biofilm



A-BAF model

A mean transversal representation



Some constitutive equations solved by gPROMS :

1D transport equations in a Packed Bed

$$\frac{\partial(\varepsilon C)}{\partial t} + u\frac{\partial C}{\partial z} = \frac{\partial}{\partial z}\left(\varepsilon K \frac{\partial C}{\partial z}\right) + \dot{r_{gl}} - \dot{r_{bl}}$$

1D transport equations in a flat Biofilm

$$\frac{\partial(S)}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial S}{\partial x}\right) + \dot{r_{bl}} + \dot{\theta}_{bio}$$

$$\frac{\partial(X)}{\partial t} + \frac{\partial(u_{bio}X)}{\partial x} = -\dot{\theta}_{bio}$$

- Gas / Liquid mass transfer via an experimental law
- Biological model (IWA ASM1 model)
- **1D growing Biofilm model (IWA model)**
- Kozeny-Carmann equation for head losses
- **Boundary layer modelling for liquid / biofilm transfer**
- **1D Filtration equation**
- **Theorical model for filtration coefficient**

2 stage bio-filtration process : Bacteria competition

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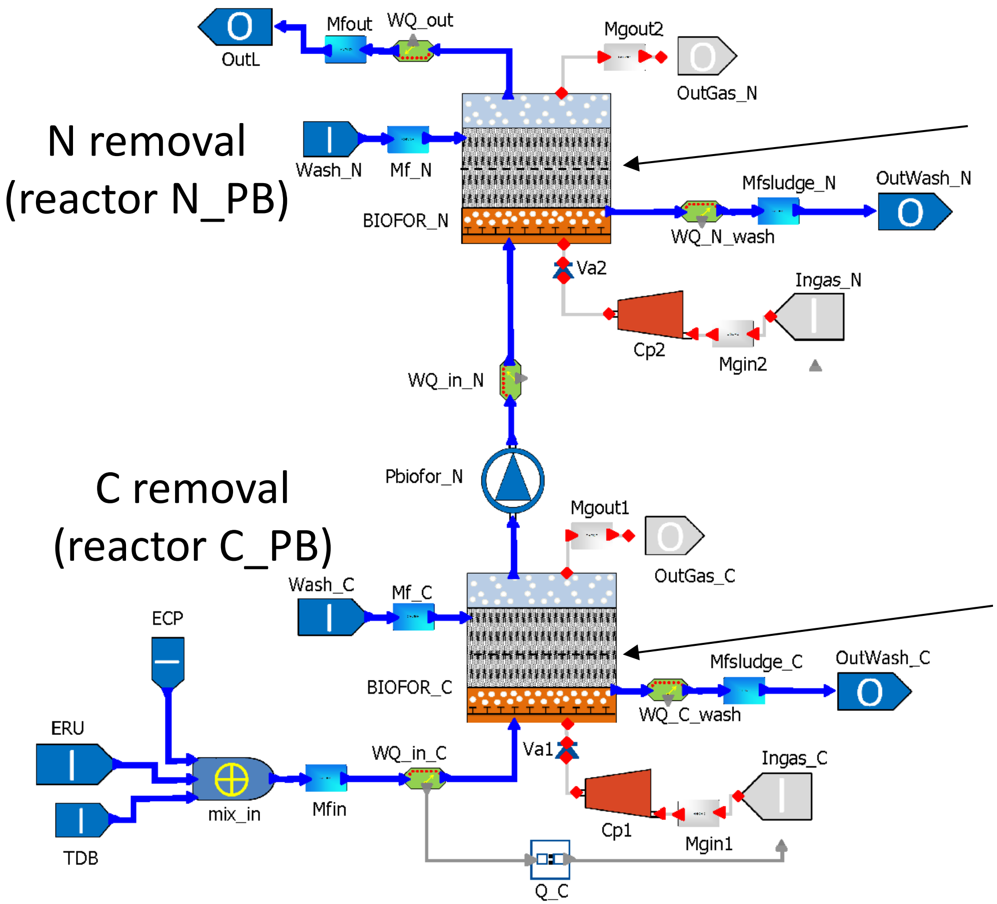
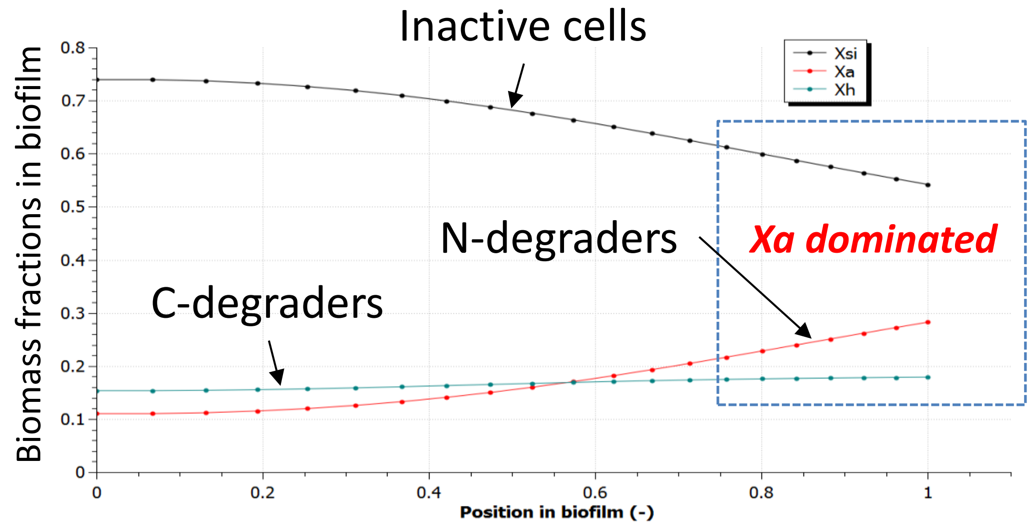
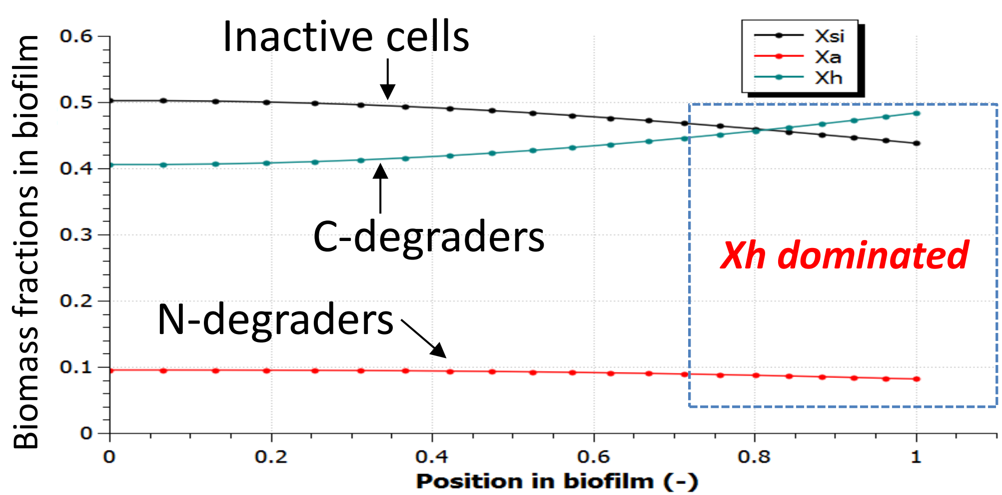
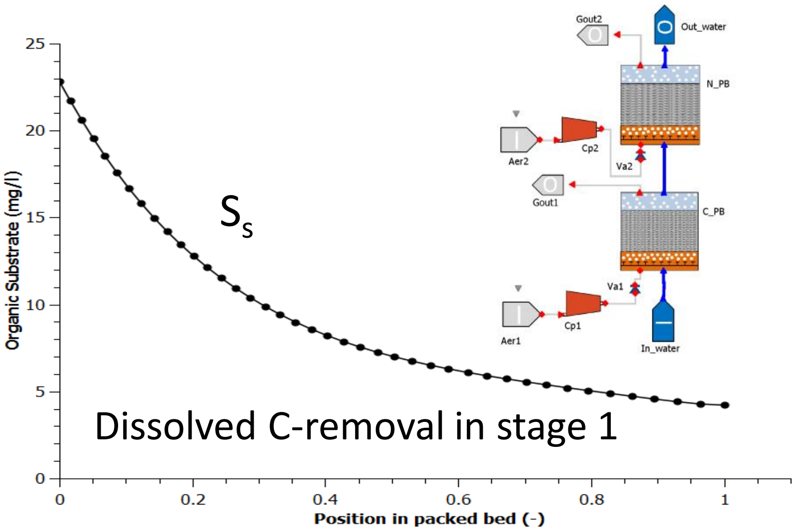
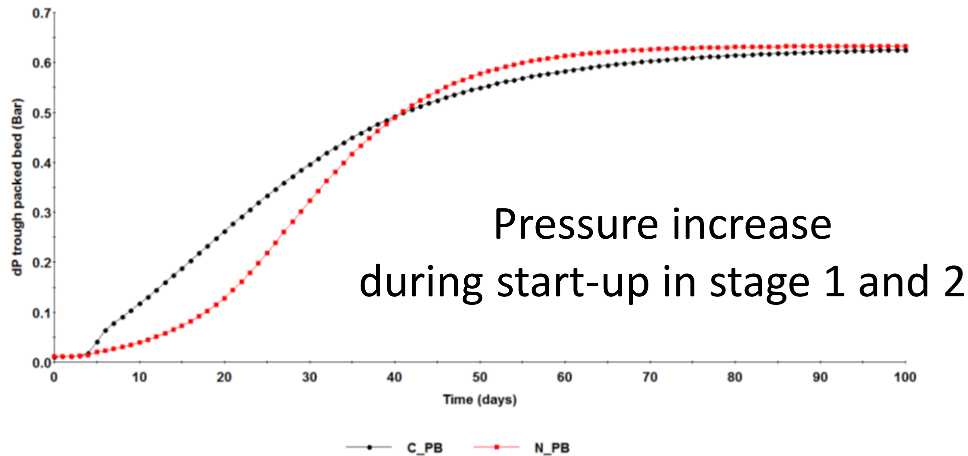


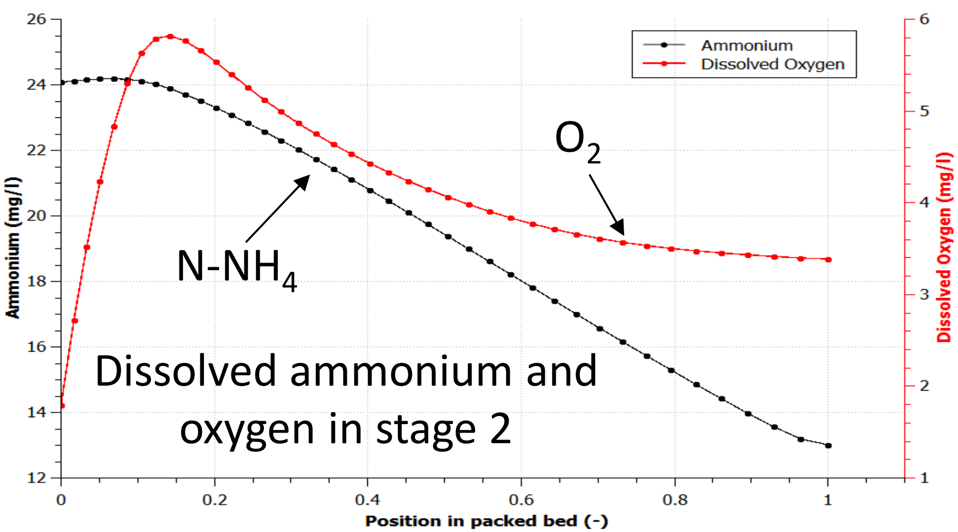




Dissolved Carbon-Nitrogen profiles inside biofilter





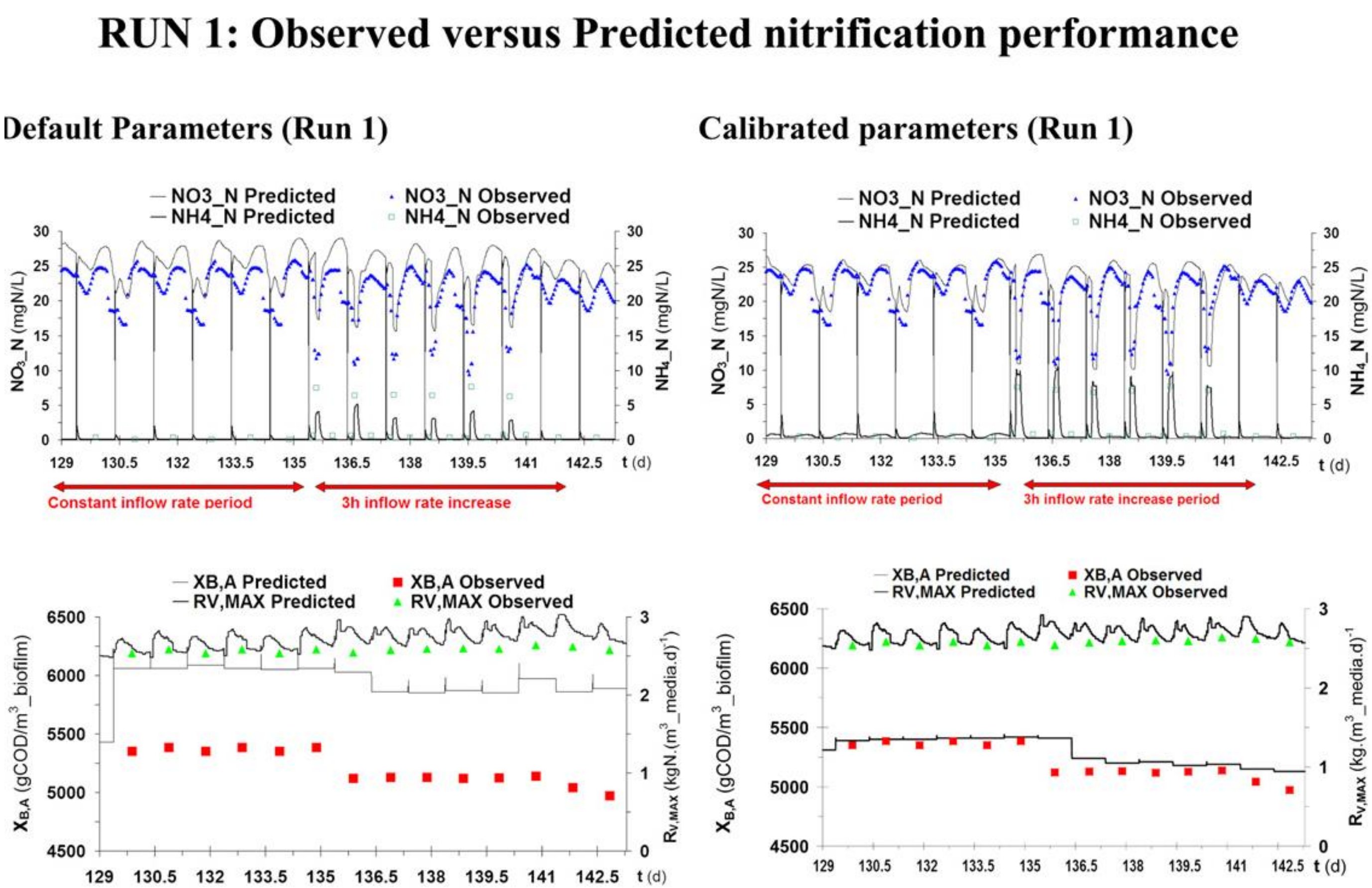


Most of the physical variables involved in bio-filtration and associated dynamics are accessible :

Valuable research and engineering tool

Bio-filtration modelling accuracy in literature

BioStyr® Modelling vs experiments on a pilot in the literature



A good calibration procedure can lead to accurate predictions of nitrogen removal in the pilot

Two parameters are crucial:

Biofilm Specific Surface
Biofilm Density

Results reproduced from ***E. Vigne phD***

Example of calibration results on a real plant

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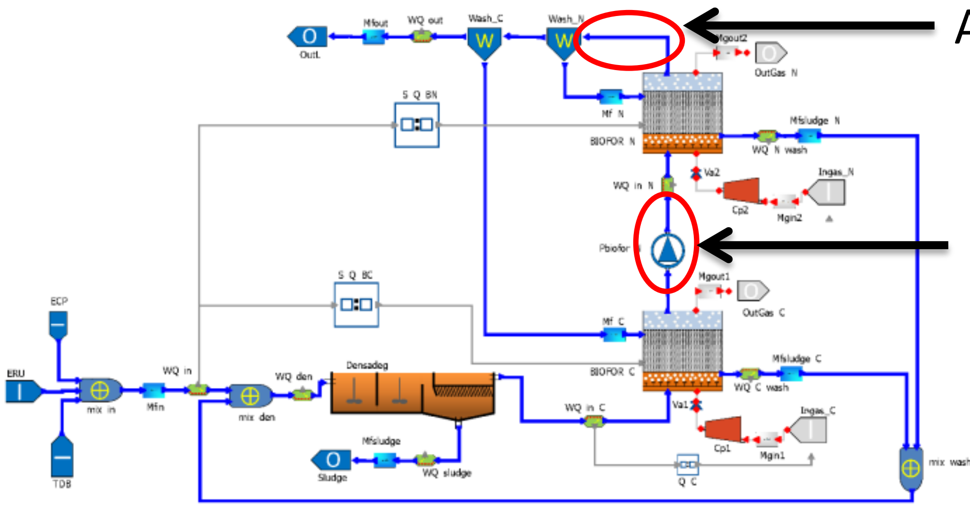


Available data

Proposal for a new ammonium sensor

Jaquetan WWTP, ***Switzerland***

- Improved Calibration
- Improved Monitoring
- Optimize aeration rates

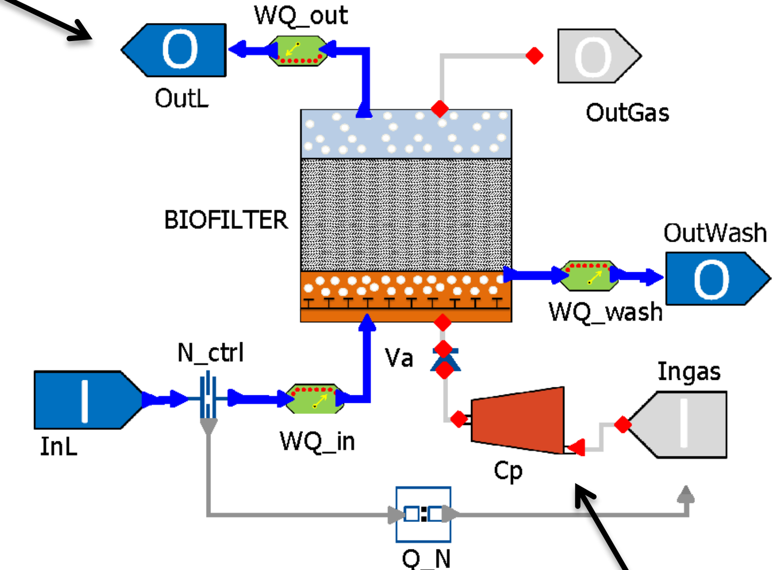
	TSS (mg/l)	COD (mg/l)	N-NH_4 (mg-N/l)	N-NO_x (mg/l)	P_{tot} (mg-P/l)
Model results Stage 1 (measurements not yet available)	28.8*	49.3	6.7*	50.1	1.1
Models results Stage 2	**7.9**	**24.5**	**0.4**	**56.3**	**0.9**
Measurements (mean 2012)	**7.0**	**25.0**	**0.4**	**59.0**	**0.5**

Optimal aerations rates : control retro-fit

Water Quality constraints

- No constraint on Nitrate (no De-Nitrification)
- COD removal > 90 %
- TSS removal > 90 %
- NH_4 < 1.5 mgN/l

The objective is to determine what could be improved regarding the aeration control strategy



Aeration rate set-point : Nm^3/kg-N

Decision variables

The set-point of the existing control system is set as a decision variable

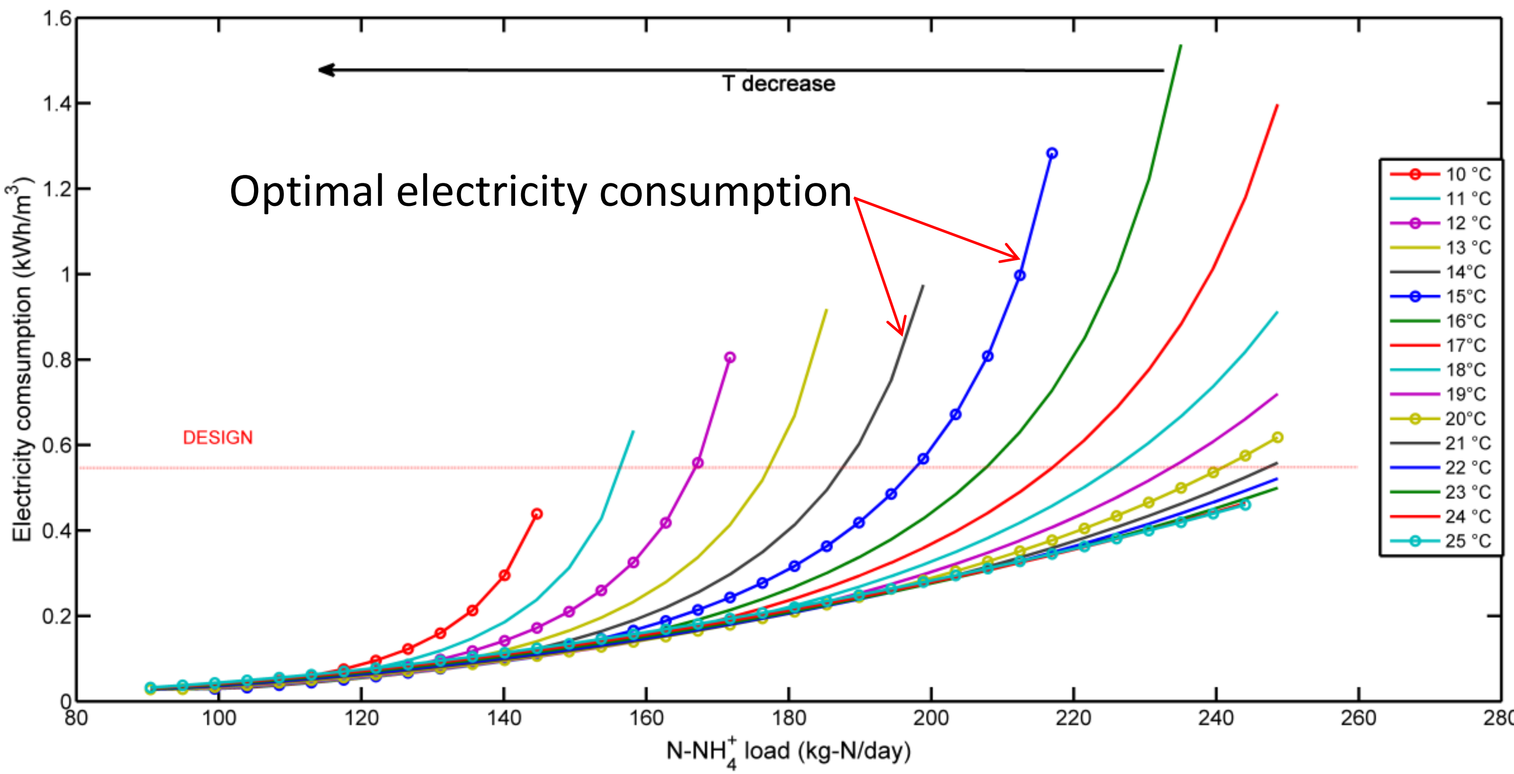
Objective :

Minimize electricity consumed by compression

First results : Minimal electricity consumption

Autotrophs bacteria growth rate is strongly affected by temperature for temperature below 15° C

The water temperature seems to have a strong effect on global biological performances

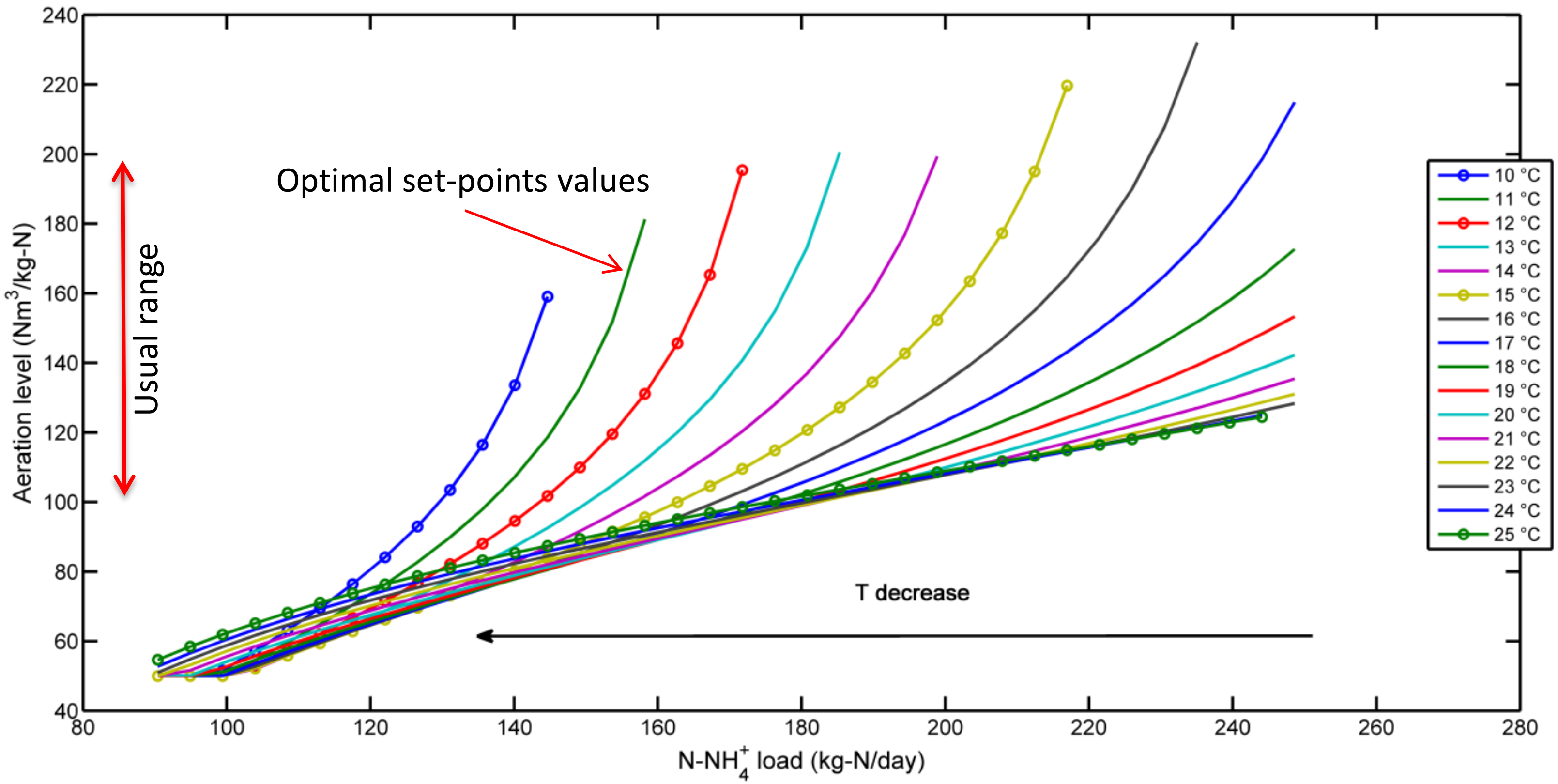


Depending on the existing control system,

Up to 40 % electricity savings are possible

First results : Optimal values for aerations rates

FPM combined with optimizations allow to determine optimal values for aerations rates.



Trends in Water Treatment industry

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Current situation

Less space available in cities

More compact processes

Bio-filtration (BAF)
Moving bed biofilm reactor (MBBR)
Membranes biological reactors (MBR)
Sequential Batch reactor (SBR)
...

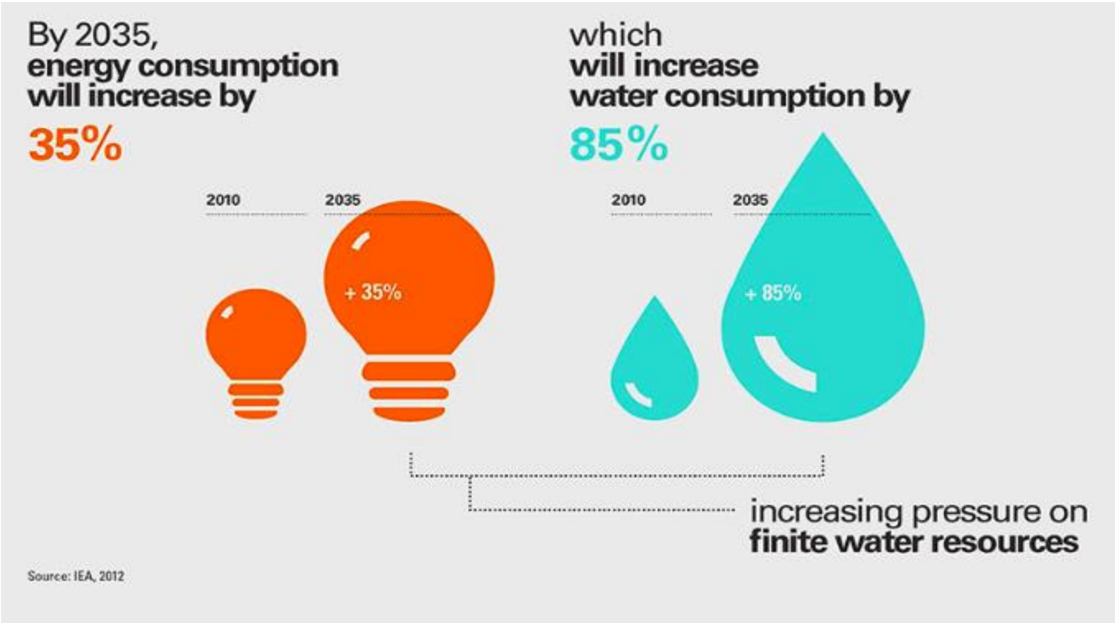
New legislations for water protection

New treatments and technologies

Ozonation
Active carbon
Micro-filtration
Hydrothermal gasification
Bio-plastic production
...

Future : **+20 – 50 % electricity for water treatment**

The link between energy and the water cycle

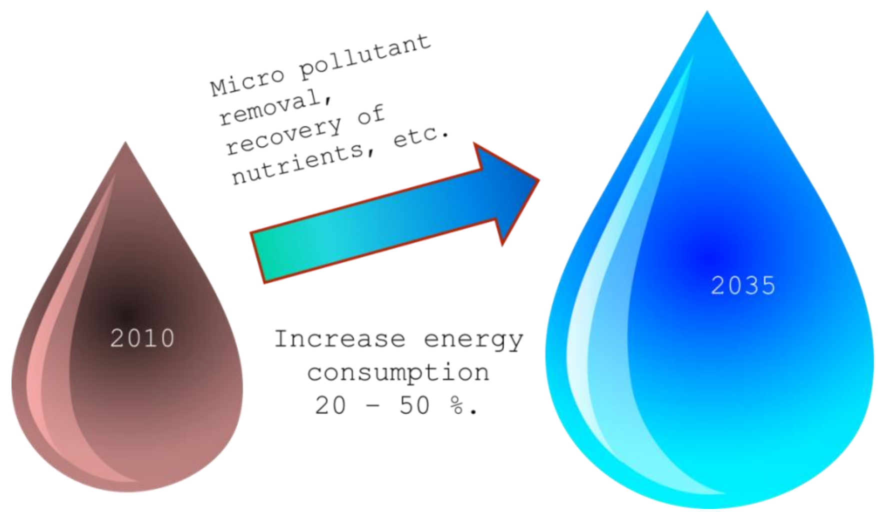


«Thirsty energy»
WorldBank.org

Water is needed for energy production....

... and energy is needed for water treatment.

Water Treatment is a crucial stage.



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Thank you for your attention

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Questions?