ADVANCED PROCESS MODELING FORUM **2014**

Wastewater systems optimization

New technology for solving old problems

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gPROMS

Acknowledgements

- PSE Wastewater Treatment BU
  - Nicolas Descoins, Technical Manager
  - Leandro Salgueiro, Business Manager

PSE-BlueWatt

INDUSTRIAL ENERGY SYSTEMS LABORATORY LENI

Prof. François Maréchal

Leading work in energy systems optimization

Spin-out

BlueWatt ENGINEERING

Integrated within PSE

PSE

Advanced Process Modeling technology & services to the process industries

BlueWatt ENGINEERING

PSE's Wastewater Treatment Business Unit

gPROMS Platform

Wastewater system optimization

gWATER

gPROMS product family

PSE

General mathematical modeling

gMODEL

gPROMS ModelBuilder
Advanced process modeling environment

Sector-focused modeling tools

Chemicals & Petrochemicals

gPROCESS

gPROMS ProcessBuilder
Advanced process simulation

AML: GLC
AML: FBCR
AML: FT
AML: BCR
AML: TBR

Advanced model libraries for reaction & separation

Life Sciences, Consumer, Food, Spec & Agrochem

gSOLIDS

Solids process optimization

gCRYSTAL

Crystallization process optimization

gCOAS

Oral absorption

Power & CCS

gCCS

CCS system modeling

Fuel Cells & Batteries

gFUELCELL

Fuel cell stack & system design

Oil & Gas

gFLARE

Flare networks & depressurisation

Wastewater Treatment

gWATER

Wastewater systems optimization

gPROMS

The gPROMS platform

Equation-oriented modeling & solution engine

Materials modeling

gSAFT
INFOCHEM Multiflash
OLI

Model deployment tools

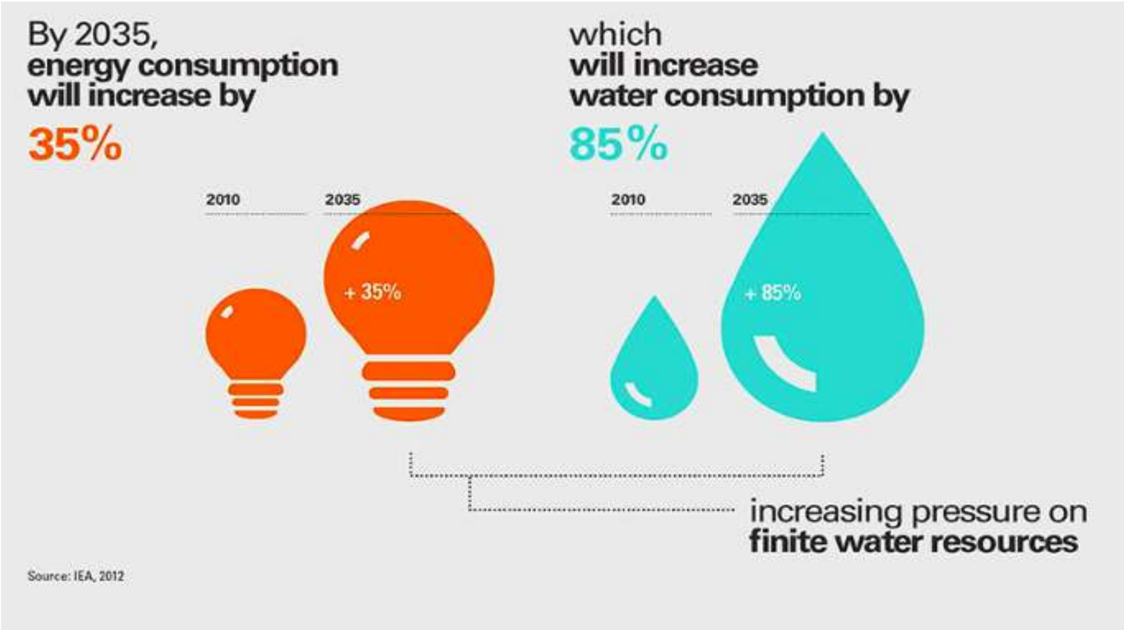
Enterprise
Objects

Deploy models in common engineering software

Introduction and context

Water – a precious resource

Main drivers in water treatment – industry



«Thirsty energy»
WorldBank.org

Water is needed for energy production….

… and energy is needed for water treatment.

- up to 20% of urban energy usage

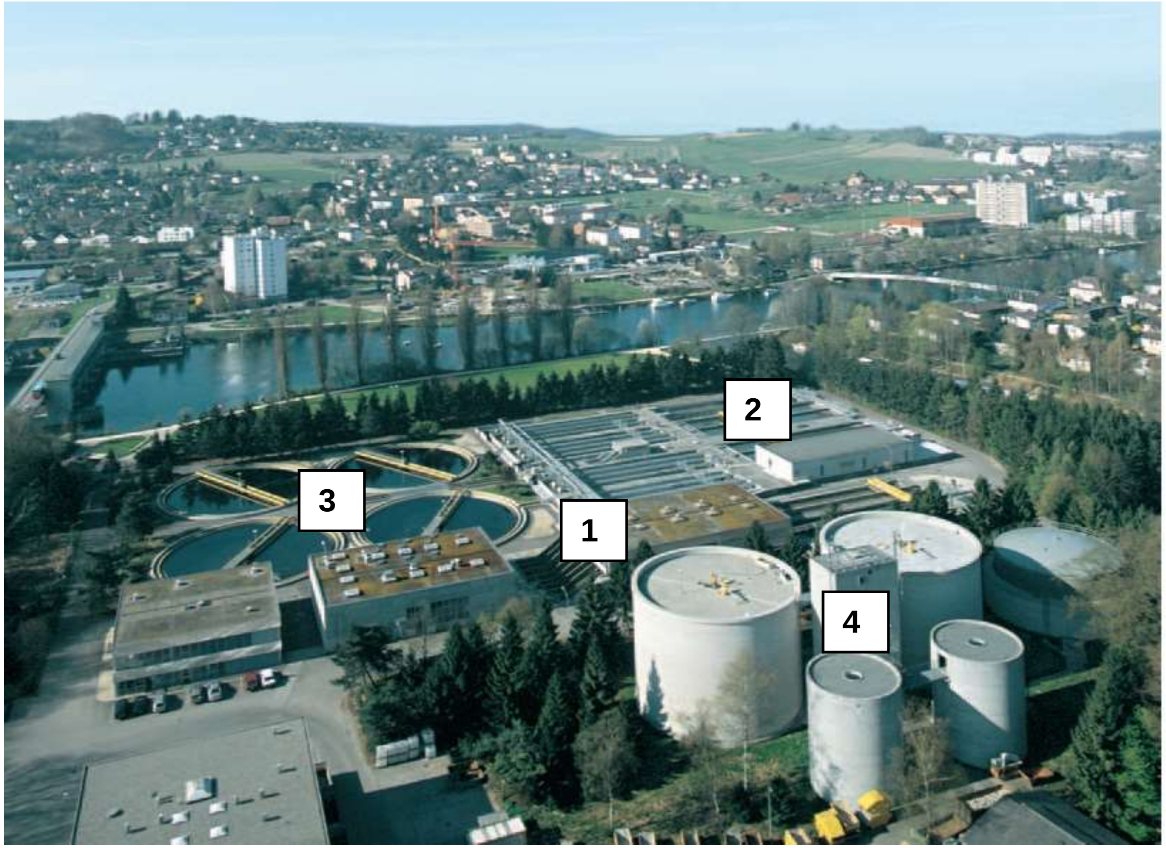
Water treatment is a crucial stage.

- Promote water reuse
- Minimize impact on environment
- Minimize onsite water consumption

Minimizing WT operating and investments costs can provide a competitive advantage

Urban WWTP overview

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)

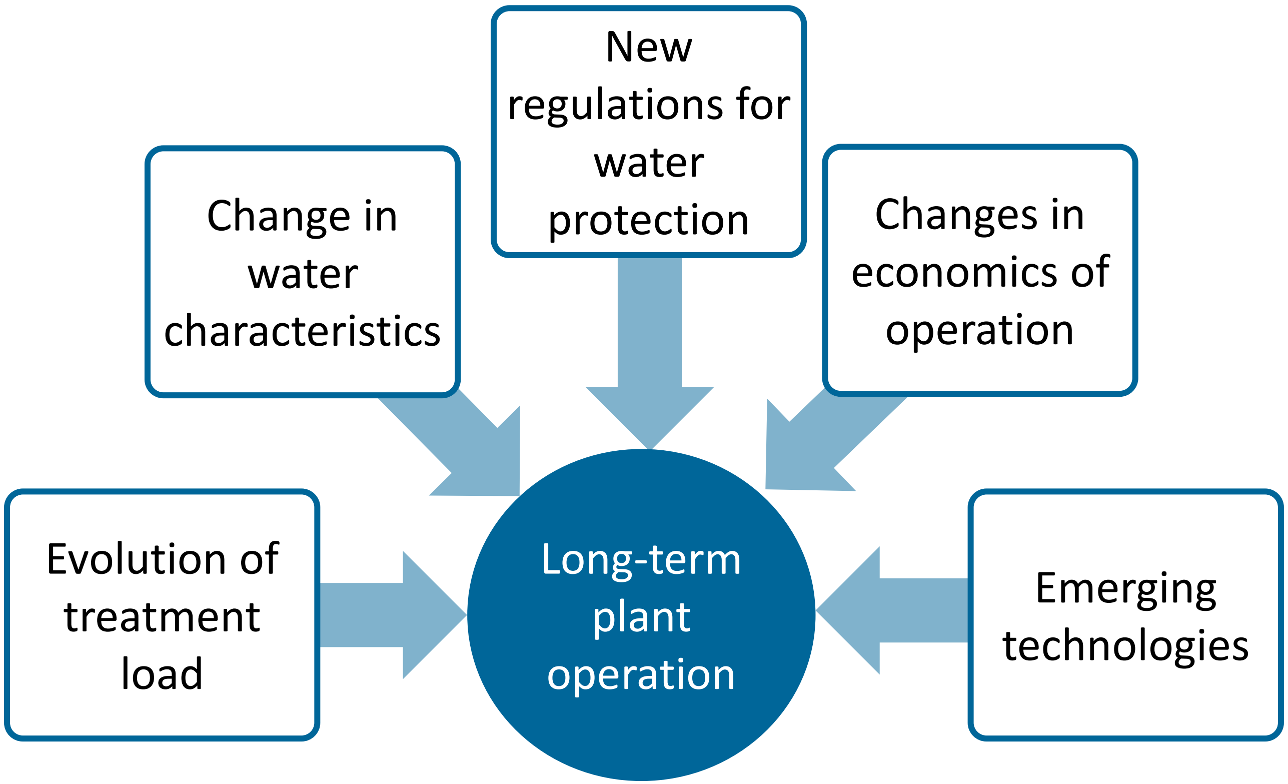
3 – Secondary separation :
Remove growing bacteria from water

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

Challenges for water treatment

WWTPs are usually built and design to treat wastewater for more than 30-40 years.

Many significant changes over this time …



Initial plant design is challenging because of long term uncertainty

Safety margins are often important in the initial design

Operation is key to efficiently treat water, given a non-optimally-sized plant

Main drivers in water treatment – urban

Current situation

Less space available in cities

More compact processes

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

New legislation for water protection

New treatments and technologies

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

Future :

20–50 % increase in electricity
Increase in chemicals usage
Increased investment

Where does modeling come in?

- Traditional ways of design and operates wwtp will not give the best solution
- Need to:
  - Improve and optimize operation and design
  - Perform detailed evaluation of design scenarios
  - Improve process understanding
  - Improve process monitoring
  - Support and train plant operators

Applies to :

Urban wastewater

Industrial wastewater

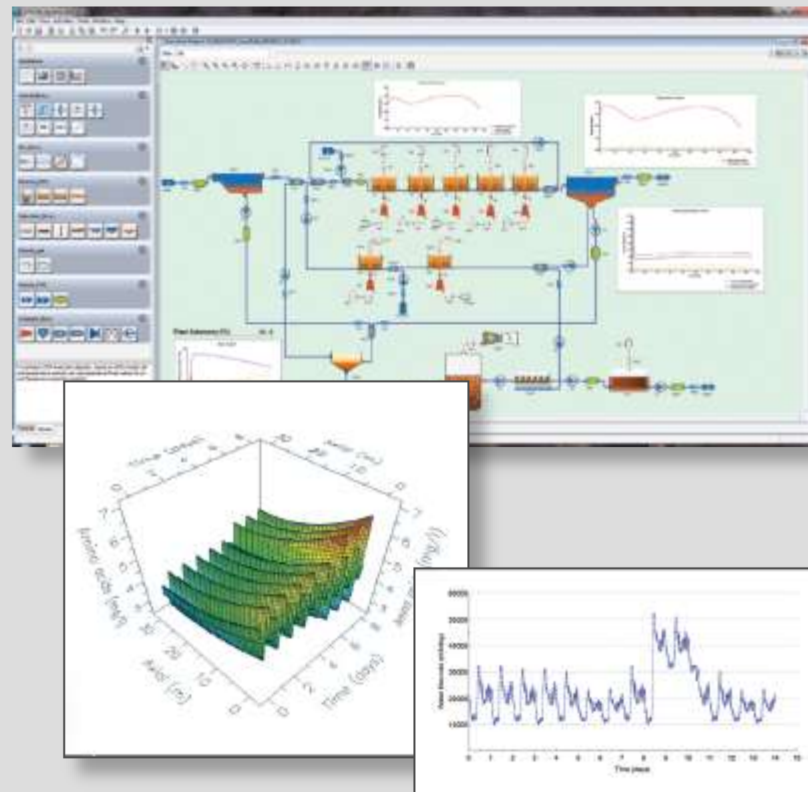
- Chemicals
- Pharma
- Food / Agriculture
- Pulp & paper
- Mining & minerals
- Oil & Gas
- others…

Ideal application for model-based engineering and operations

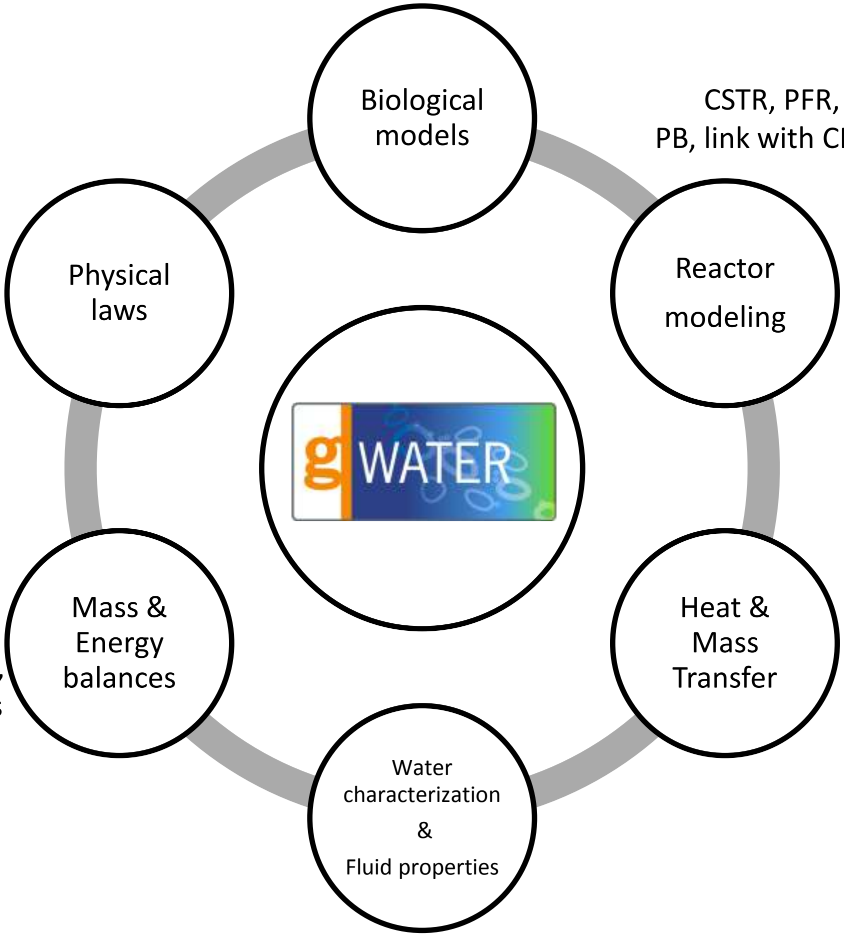
gWATER

- A comprehensive, modular, customizable and flexible modeling environment for WWT
- Built on the gPROMS platform
- Embody best of recent research
  - International Water Association
  - EPFL, EAWAG, others
- Single unit to plant-wide models
- Urban & industrial waste

Wastewater systems optimization



gWATER – phenomena



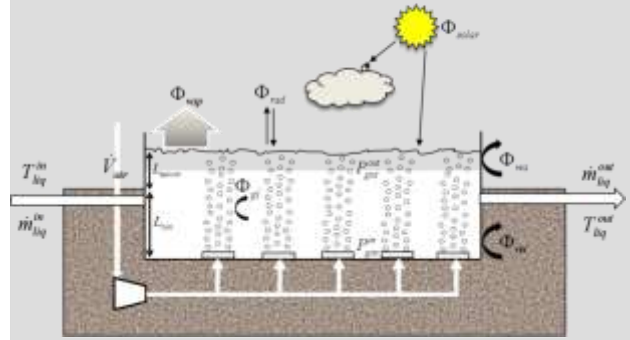
CSTR, PFR,
PB, link with CFD,..

Henry's law,
pKa Acid/Base,
motors efficiency,
…

Experimental laws

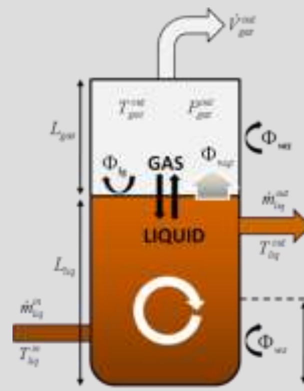
First Principles conservation equations,
Including ionic balances for pH

relevant compounds,
CHONP and charge definition



Two phases Activated Sludge Plug Flow Reactor

Sub-models are combined to build reactors models



Two phase Anaerobic Digestion Continuous Stirred Tank Reactor

gWATER scope

gWATER

Raw WasteWater

Raw Separation
- Grid Screening

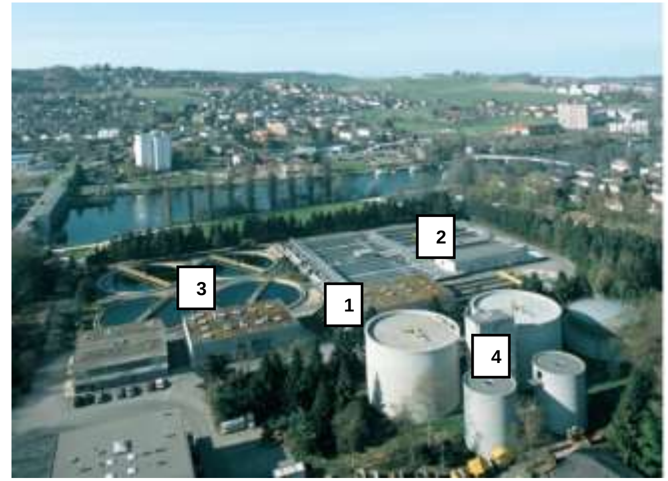
Oil / Water Separation
- Air Flotation
- Oil Skimming

Liquid / Solid Separation (colloids / particles)
- Standard Settling
- Physico-chemical enhanced settling
- Cyclone Centrifugation

Biological Treatment
- Activated Sludge : C/N-removal
- Sequencing Batch Reactor
- Biological Aerated Filtration
- Membrane Biological Reactor
- Fluidized Bed Biological Reactor
- Anaerobic Treatment

Liquid / Solid Separation (colloids / biological flocs / particles)
- Standard Settling
- Sand filtration
- Membrane Separation

Advanced treatment / disinfection
- Ozonation reactors
- Actived Carbon reactors / filters
- UV reactors
- Chlore reactors



Sludge Treatment
- Thickeners
- Anaerobic Digestion
- Dewatering Units
- Dryers

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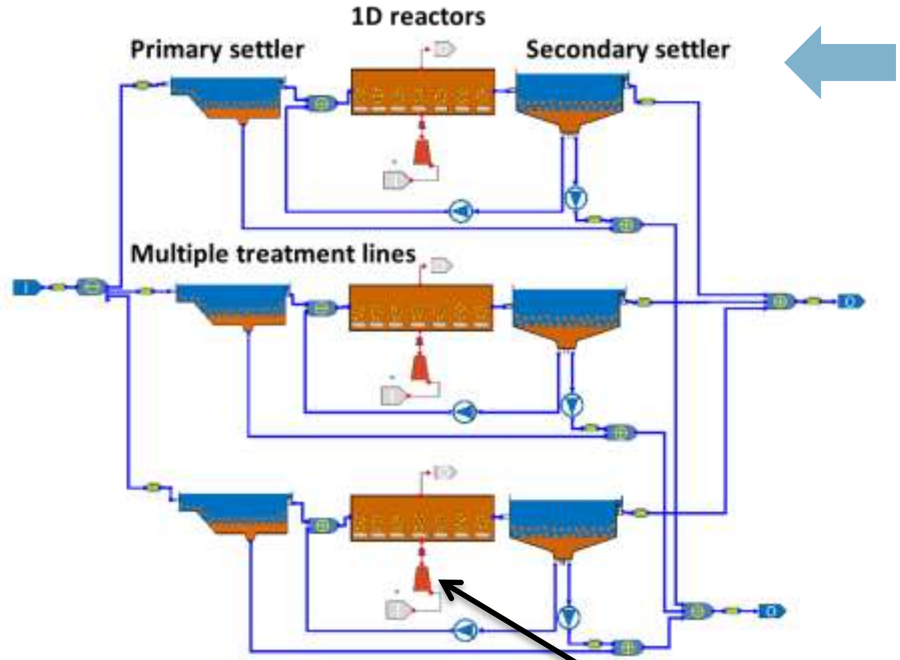
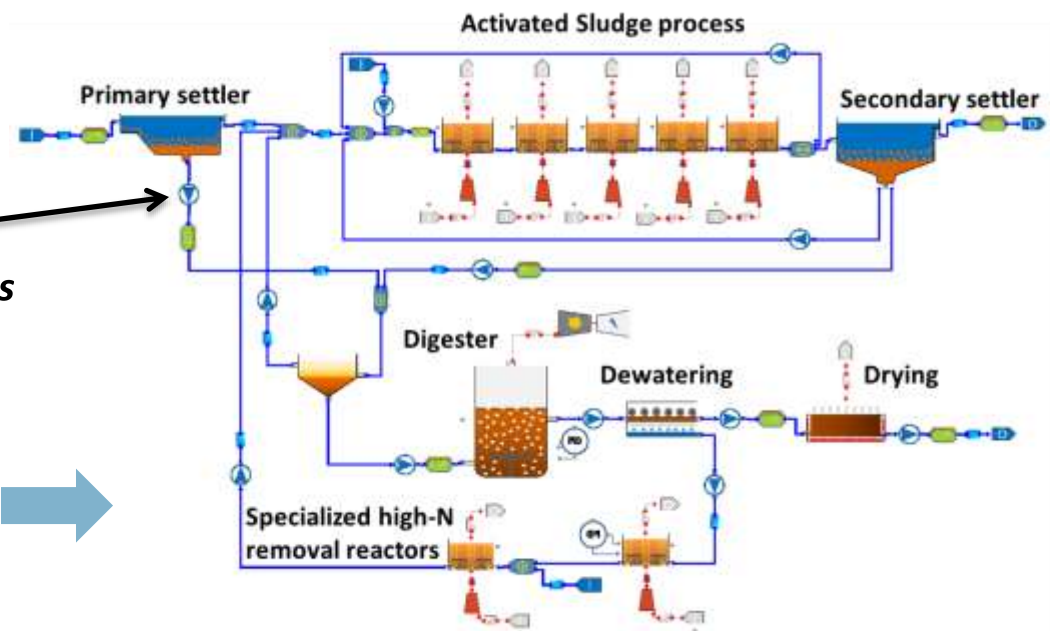
Typical applications



Multiples **1D Plug Flow Reactors with axial dispersion**

Systematic evaluation of electricity consumption / production and link with biological performances, in all flow-sheets

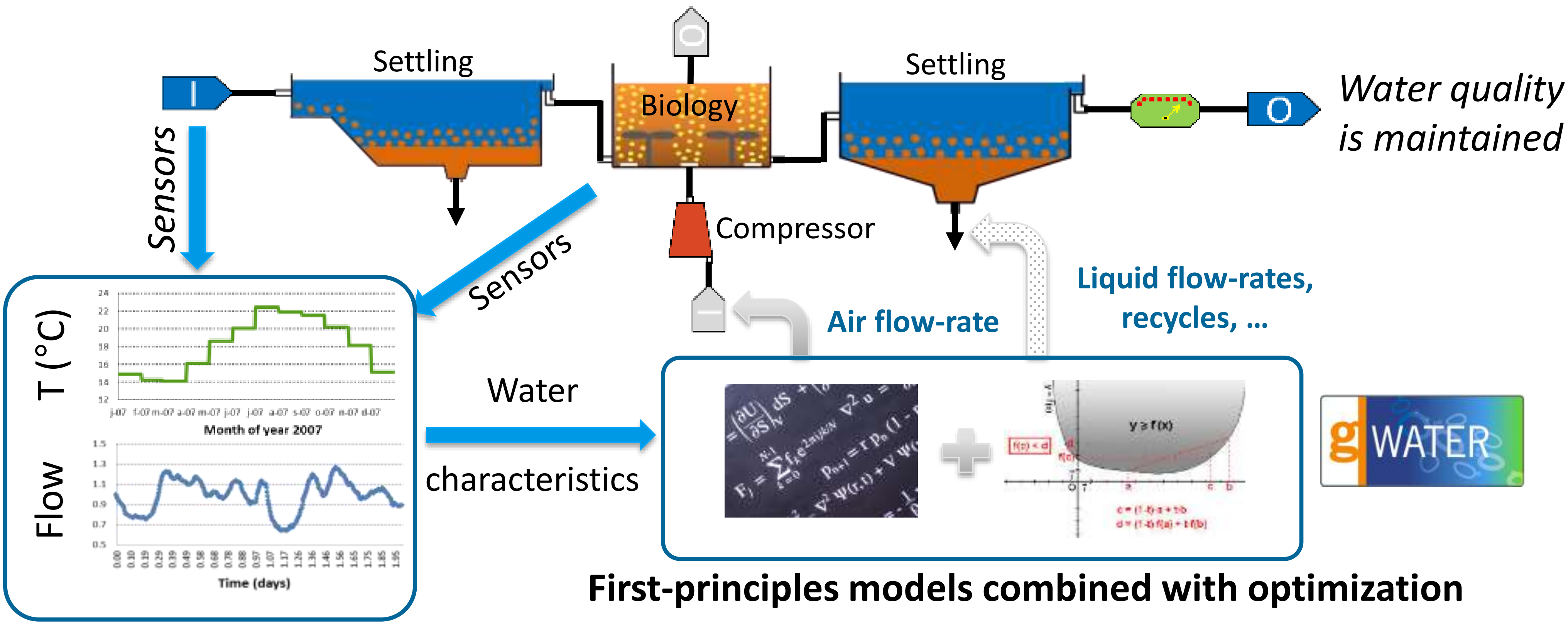
Compressors / pumps models



Plant-wide modeling
including Anaerobic Digestion and Nitrogen specialized treatment processes

Typical application

Model-based support of plant operation



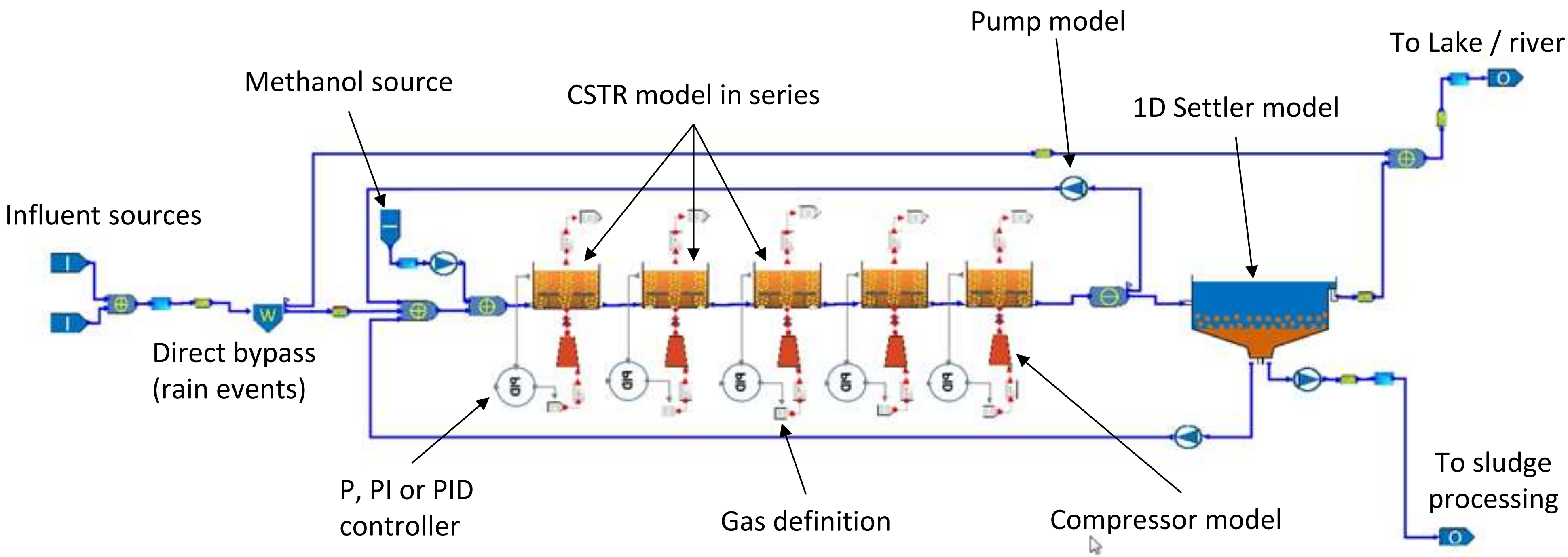
First-principles models combined with optimization

- **Predictive tool** capable of operating over short and long term perspectives)
- Can deal with **varying operating & economic conditions / regulatory requirements**
- Well suited technology for **more complex new** processes

Application

BSM1 – Standard industry benchmark

A simple example : the BSM1 layout

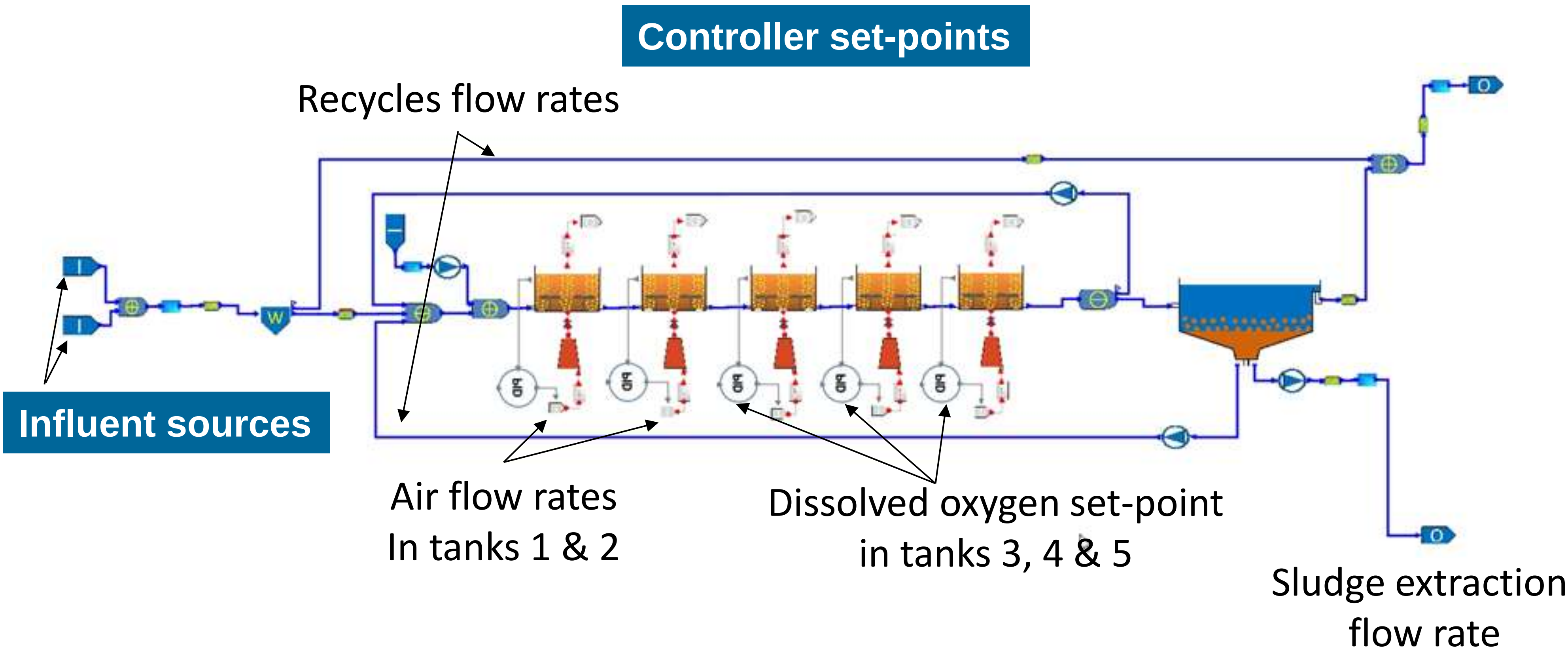


All the models are set-up accordingly to the benchmark report,
See http://www.benchmarkwwtp.org/ for all details

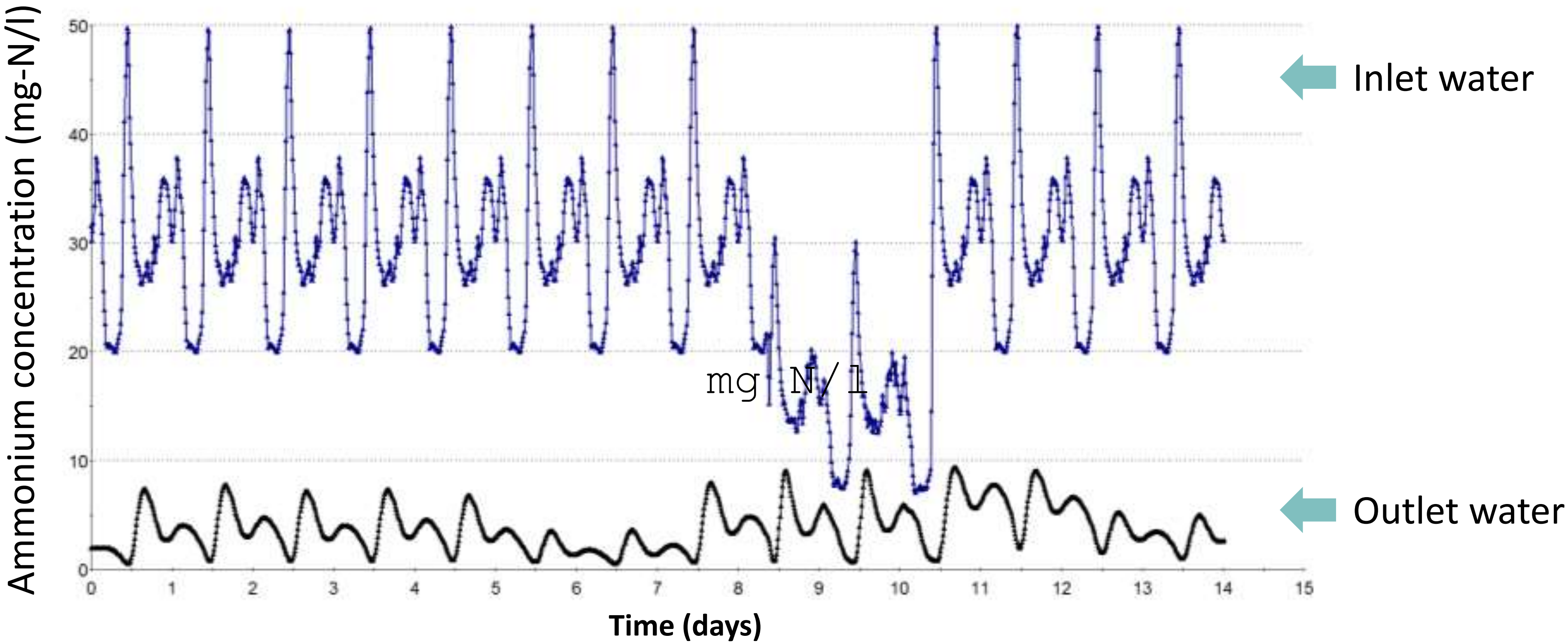
Set-up of a dynamic simulation

Specifications:

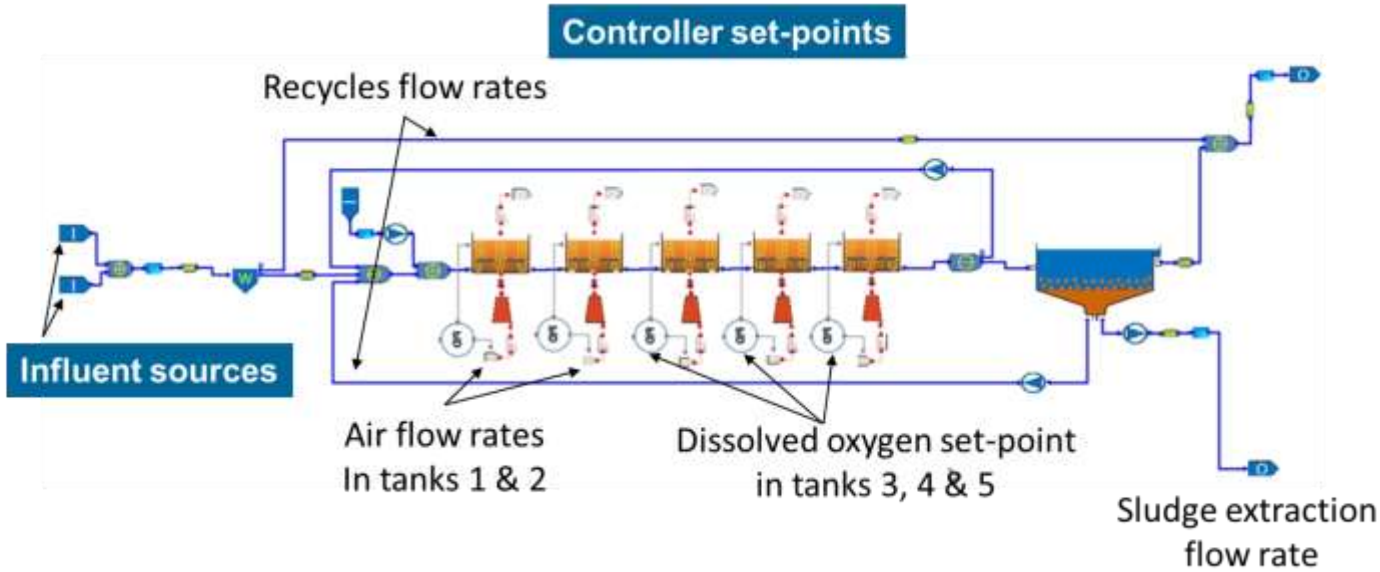
- influent characteristics, equipment volumes, controller set-points



Results snapshot



- KPI: Nitrogen content (mg/l)
  - influent 20-50 mg N/l
  - effluent 0 to 10 mg N/l



Optimization

Perform true optimization, not just “optimization by simulation”

Optimization benefit

- Direct solution based on rigorous mathematical analysis
- Much faster approach compared to the “multiples simulation approach” or the “scenario evaluation approach” (which may not find optimum)
- Steady-state and dynamic optimization possible
- Possibility to use multi-objective algorithms for most advanced applications

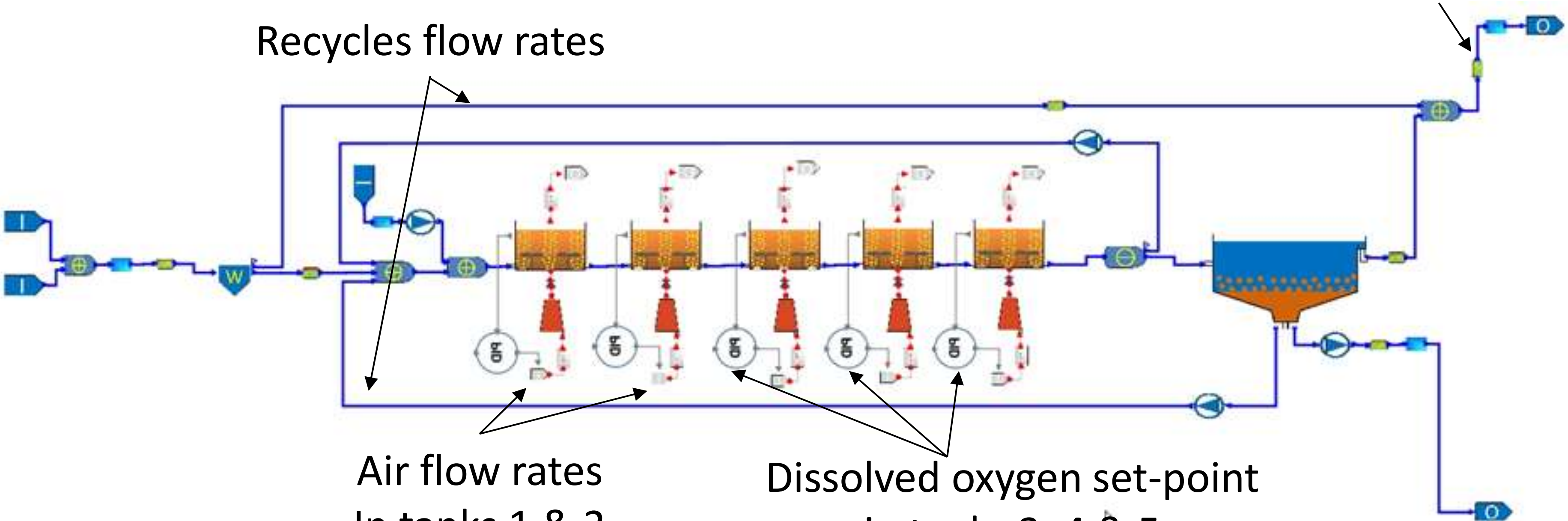
Steady-state optimization based on average values

Objective

Minimize $\dot{E} = \dot{E}_{aer} + \dot{E}_{pump} + \dot{E}_{mix}$

Water quality constraints

- $N\text{-}NO_3 < 18\ gN/m^3$
- $COD < 60\ gCOD/m^3$
- $N\text{-}NH_4 < 2\ gN/m^3$



Decision variables

Optimization results

- Energy use: objective function minimized

240 Wh/m³ → **152 Wh/m³**

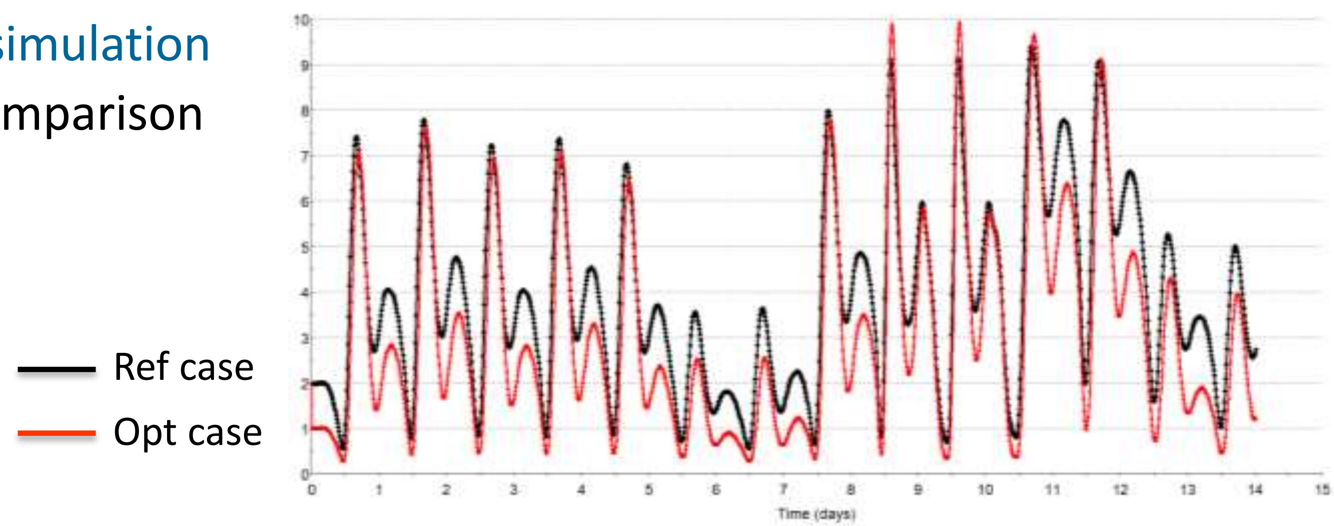
35 % savings

- All constraints met
  - 60 gCOD/m³
  - 2.0 gN/m³
  - 15 g/m3 Rejected NO_2 (max 18)

Typical situation

Test of settings in dynamic simulation

Reference / optimal case comparison

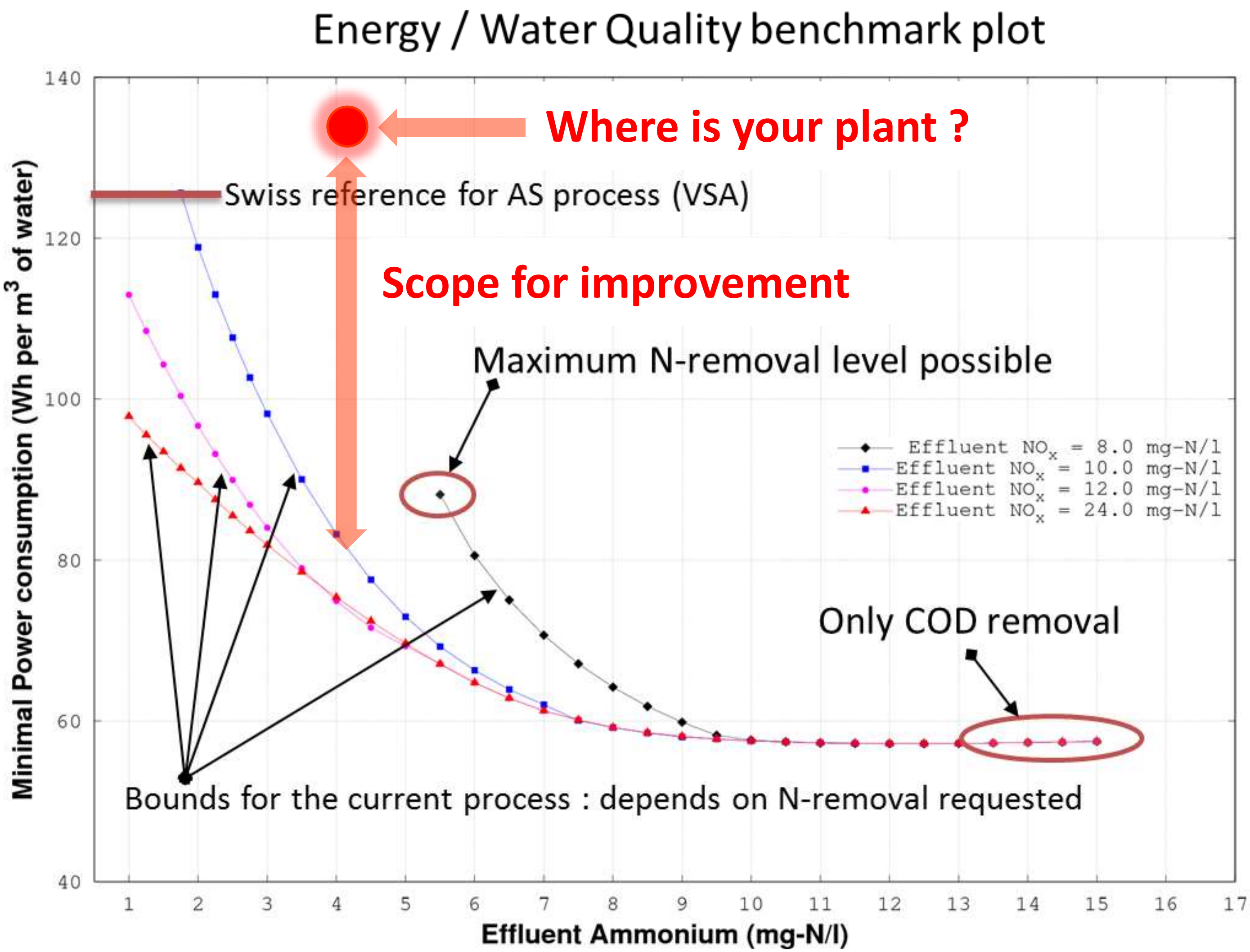


Further optimization applications

Optimal solution mapping

Plant-wide optimization

Optimal solution mapping : Water Quality Diagram

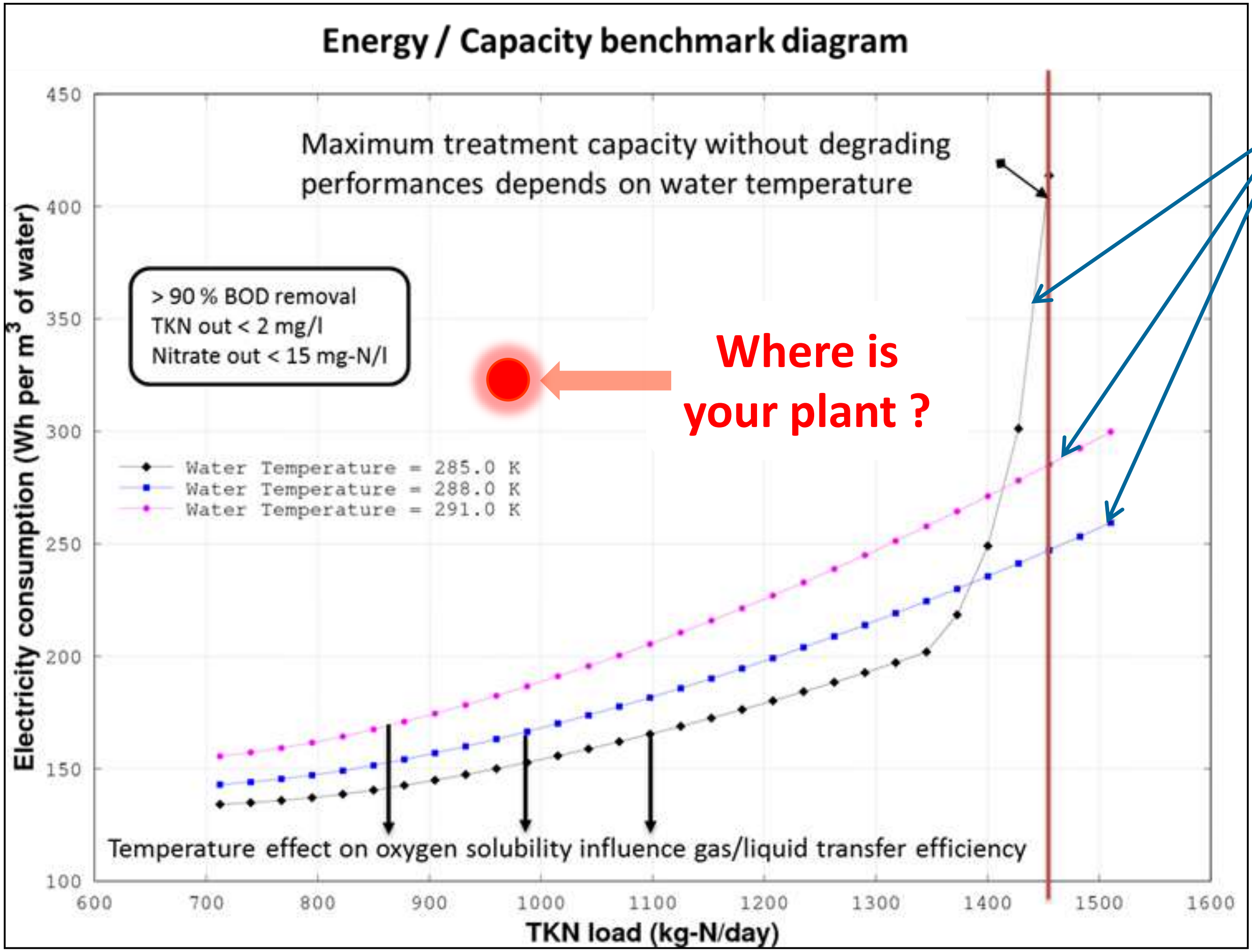


Multiples optimizations are performed sequentially

Each time, the constraints on nitrogen compounds are changed

Energy Audit Service
Locate your plant on this chart

Optimal solutions Mapping : Capacity diagram



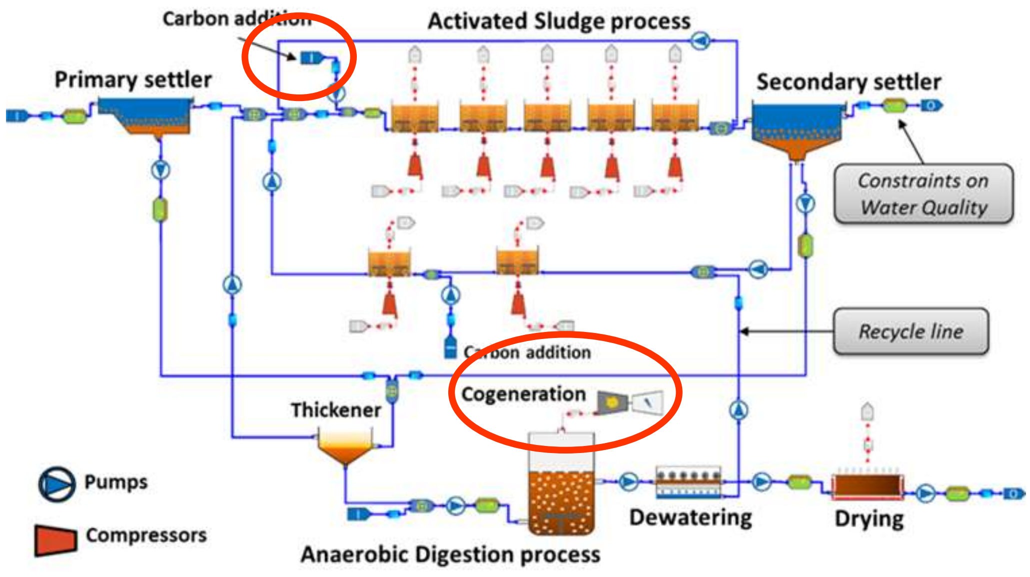
Multiples optimizations are performed sequentially

Each time, the water flow-rate and temperature are increased

Energy Audit Service
Locate your plant on this chart

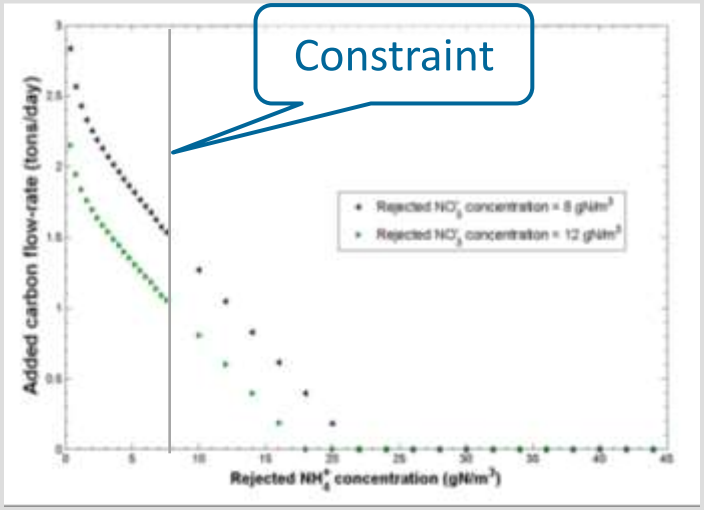
Plant-wide modeling optimization

- E.g. determine optimal methanol addition rate
  - required for correct C:N balance
  - expensive!
- E.g. maximize co-generated electricity to grid

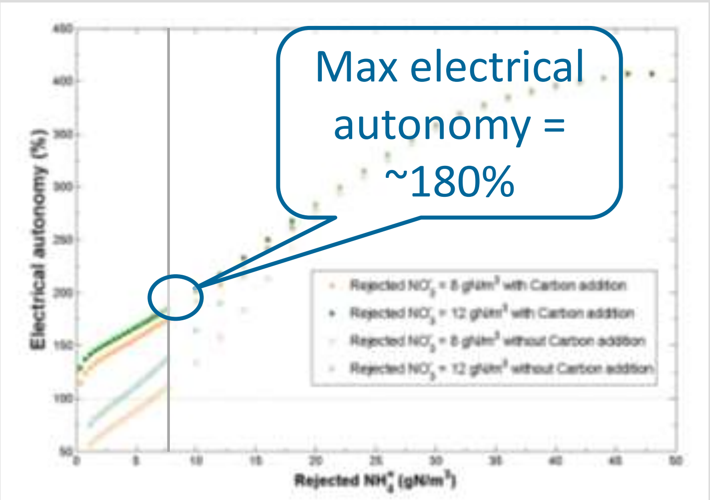


See *Descoins et al.*, Energy

Optimal quantities of added methanol



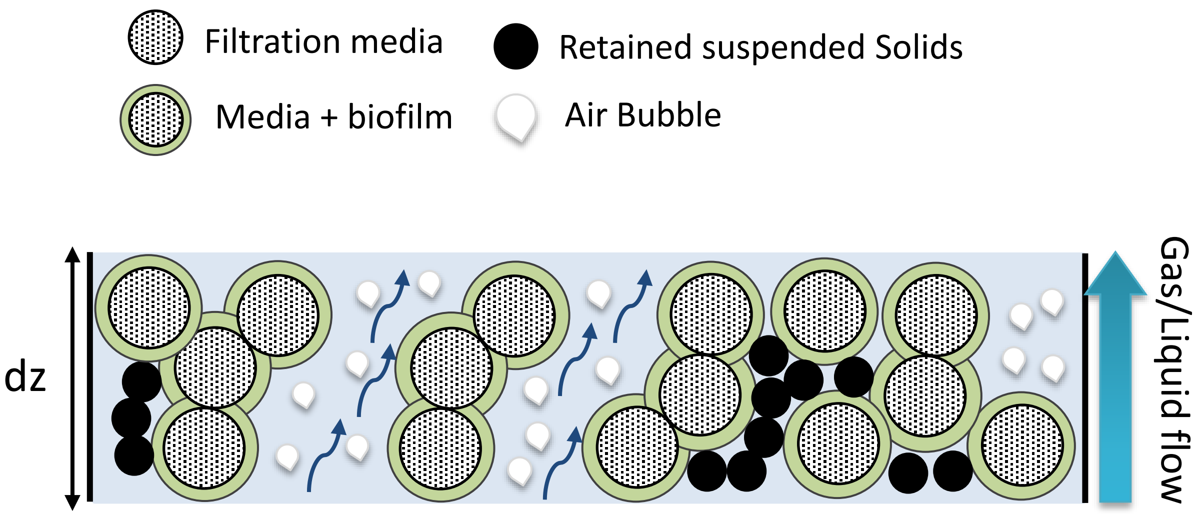
Plant optimal electrical autonomy as function of nitrogen removal

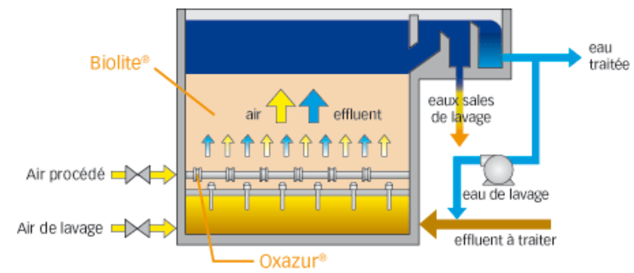


Example of advanced modeling

Support for rollout of new technologies

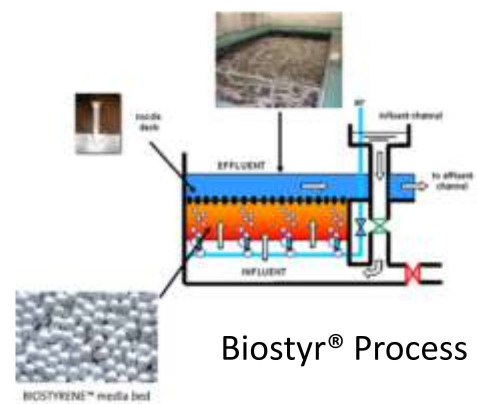
Physical phenomena involved in Bio-filtration





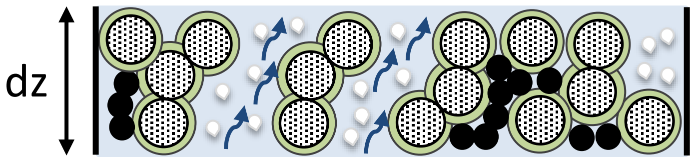
Biofor® Process (Degremont)

- 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 modeling : IWA models
- Fully Dynamic process : progressive fouling, periodic backwashes



Biostyr® Process (Veolia)

Modeling approach : Gas / Liquid / Biofilm



Some constitutive equations solved by gWATER :

1D transport equations in a Packed Bed

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

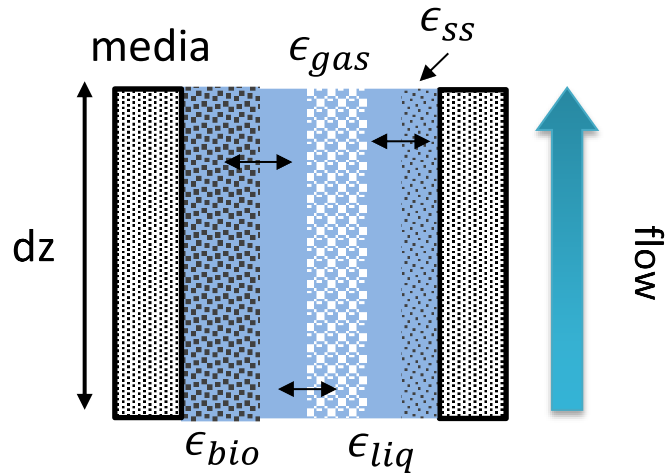
1D transport equations in a flat Biofilm

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

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

BAF model

Equivalent surface representation



- Gas / Liquid mass transfer via an experimental law
- Biological model (IWA or customized model)
- **1D growing Biofilm model (IWA model)**
- Kozeny-Carmann equation for head losses
- **Boundary layer modeling for liquid / biofilm transfer**
- **1D Filtration equation**

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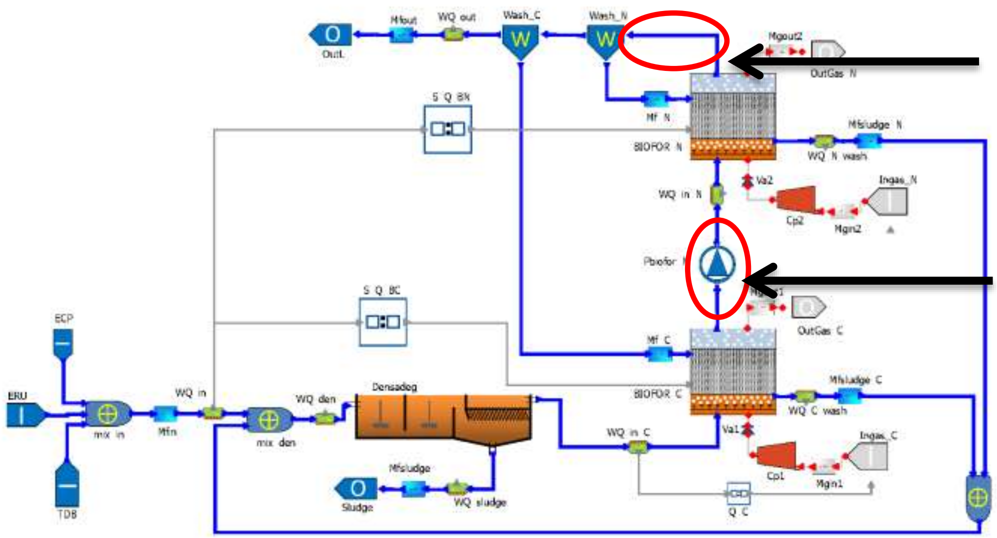
Example: Biofiltration



Available data

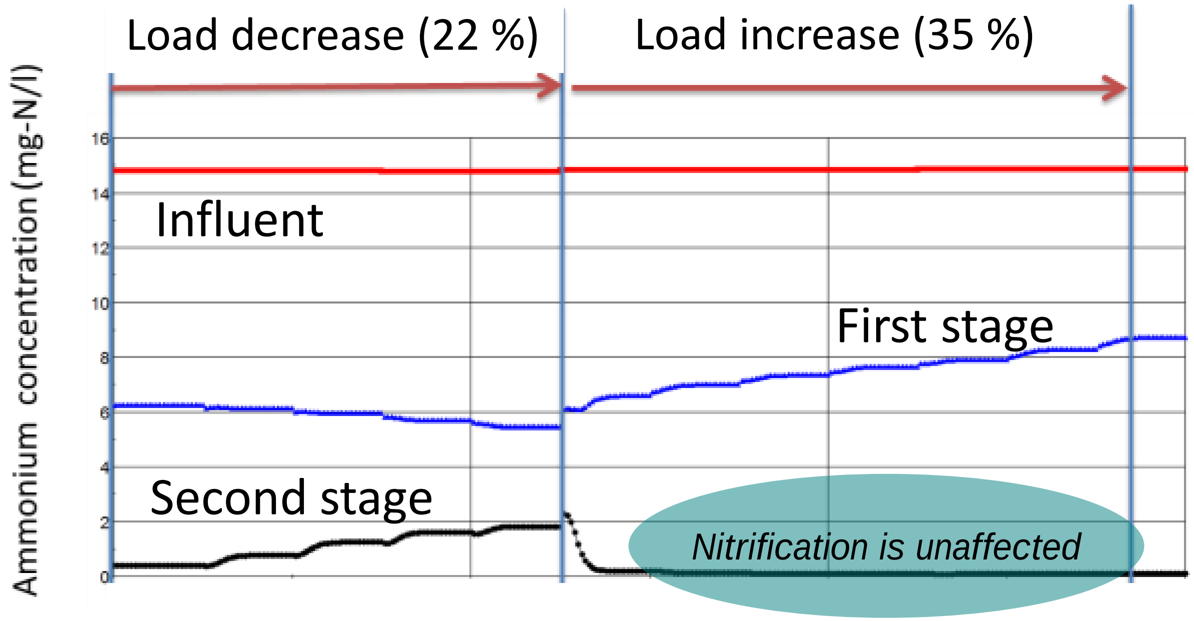
Jaquetan WWTP,
Switzerland

Proposal for a new ammonium sensor

- Improved Calibration
- Improved Monitoring
- Optimize aeration rates
- Optimize active cells numbers

	TSS (mg/l)	COD (mg/l)	$N\text{-}NH_4$ (mg-N/l)	$N\text{-}NO_x$ (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

Biofiltration example : output and analysis



Plant operators have already stopped 2 bio-filters in the second stage

20 % electricity savings already achieved for the same quality of water

The main conclusion obtained during the first part of the project are :

- The plant is **40 % oversized** regarding actual load data
- Most of the nitrification **already occurs in the first stage**
- The number of active bio-filters in the second stage can be reduced and more **accurately adjusted to the load**, without degrading global performances

Challenge: how to make this accessible to end-users ?

Web-based interface

How to make it accessible to end-users ?

- Making the models and optimizations accessible to plant operators and engineers has always been a challenge

- Today it's possible to deploy the models in a simple and decentralised way

- A web-based system provide several advantages
  - Models are built and calibrated by modelers
  - Simplicity for the non-expert users
  - Continuous modeler support and transparent models update
  - Extensively customisable
  - Possible connections to measurements and automation system
  - …

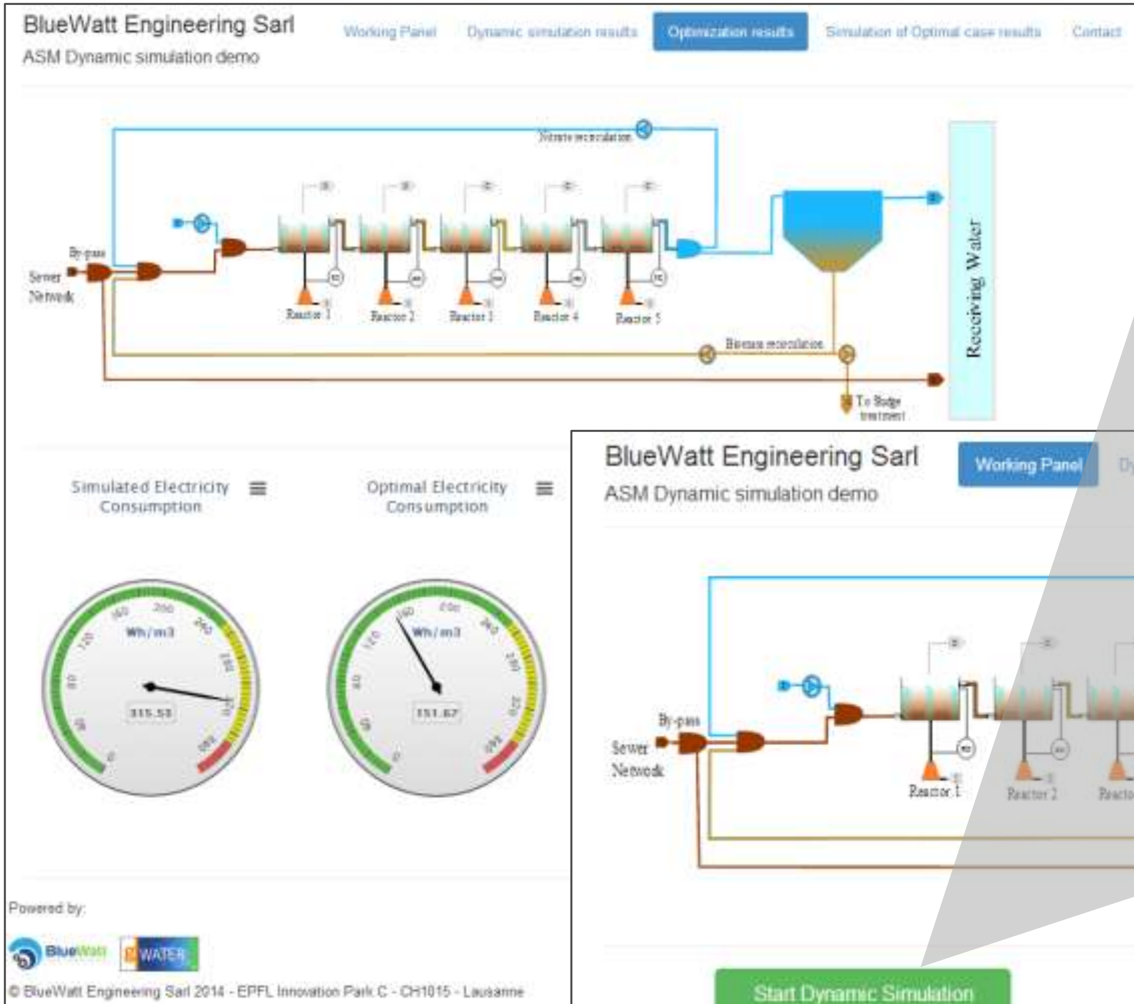
Web system

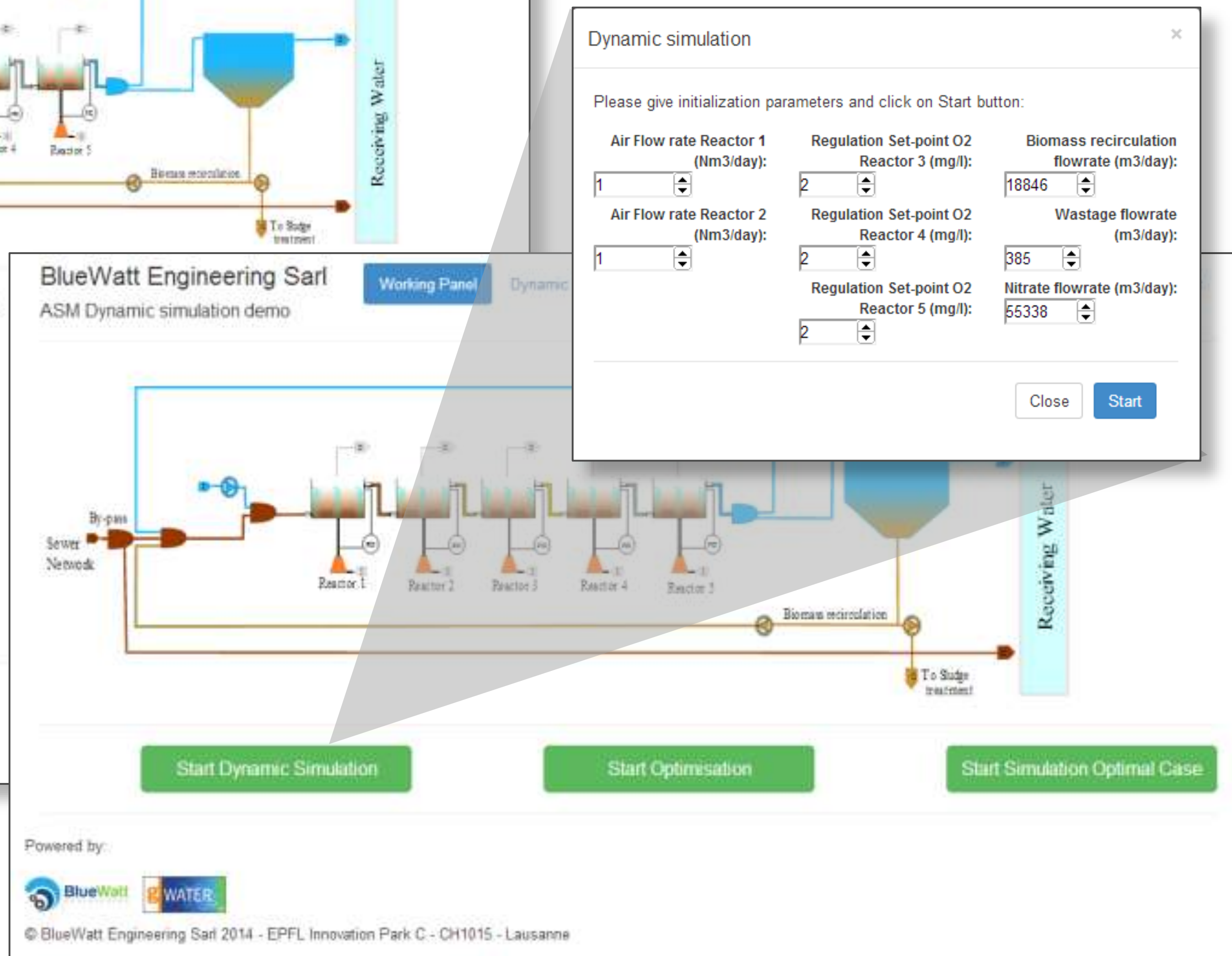
- Any gWATER model can be used in the same way
- Typical applications
  - Daily support for plant operation (off-line use)
  - Optimal and predictive control (on-line use)
  - Advanced monitoring of plants (connections with measurements)
  - Operator training / education tool

- Currently implemented for a lead customer in Switzerland
  - hosted in PSE Lausanne office
  - commissioned last week

Web interface – 1

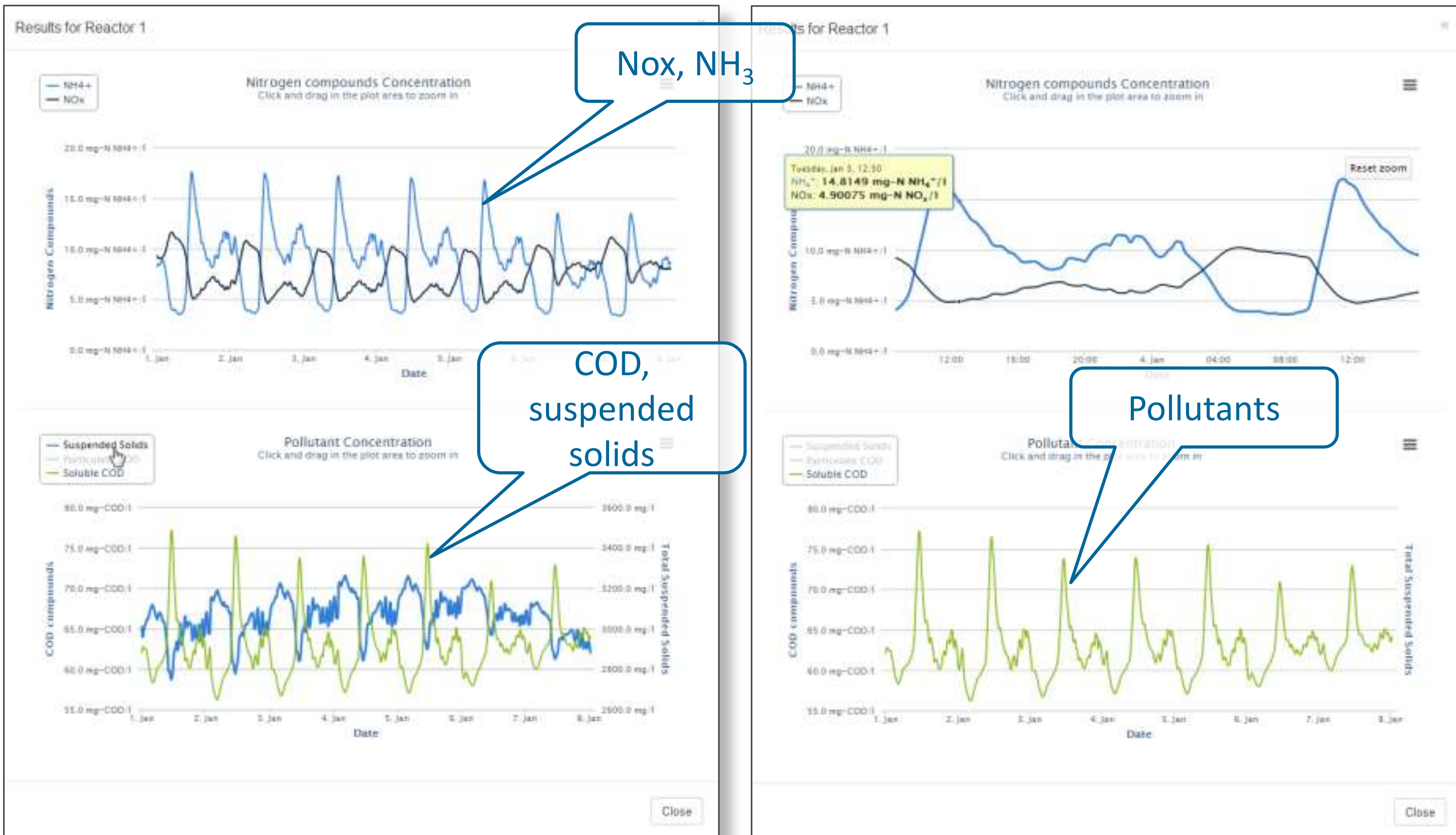
< Dashboard





Control >

Web interface – 2



Conclusion

- The combination of high-fidelity models and optimization technology can bring many benefits
  - reduce power consumption
  - optimize aeration rates
  - optimize process configuration (e.g. active cell numbers)
  - minimize investment costs
- As well as
  - reduce chemical consumption
  - reduce environmental impact (CO_2 emissions, others)
  - improve water quality (nitrification, P-removal,...)
  - benchmark process performance
  - provide effective and efficient troubleshooting
  - minimize need for trial-and-error analysis of scenarios

Conclusion

- Sophisticated models can now be delivered to plant personnel or Engineers via web interface

- gWATER is the framework that we use to deliver this
  - we are strongly investing in continuous improving of the model library and the web-based system
  - we are building academic and industrial collaborations for models development and validation

PSE sectors and products

General mathematical modelling
gMODEL
gPROMS ModelBuilder Advanced process modelling environment

Chemicals & Petrochemicals
gPROCESS
gPROMS ProcessBuilder Advanced process simulation environment
AML: GLC
AML: FBCR
Advanced model libraries for reaction and separation

Life Sciences, Food & Consumer goods, Specialty & Agrochemicals
gSOLIDS
Solids process optimisation
gCRYSTAL
Crystallization process optimisation
gCOAS
Oral absorption modelling

Wastewater Treatment
gWATER
Wastewater systems optimisation

Power & CCS
gCCS
CCS system modelling

Fuel Cells & Batteries
gFUELCELL
Fuel cell stack & system design

Oil & Gas
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BlueWatt ENGINEERING

gPROMS THE WORLD'S LEADING ADVANCED PROCESS MODELLING PLATFORM

FOR MORE INFORMATION OR TO ARRANGE A CALL CONTACT US AT

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Thank you