SIMSTEP SEINE AVAL

A comprehensive biofiltration model and its calibration and validation for a large-scale nitrifying WRRF under upgrade

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americana

MOCOPÉE

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  - Upgrade of the Seine Aval WRRF
  - Nitrifying biofilter
- Aims of the modelling work
- Modelling of the Biofiltration stage
  - Model descriptions
  - Calibration and validation of the nitrifying stage
  - Results and discussions
- Conclusions

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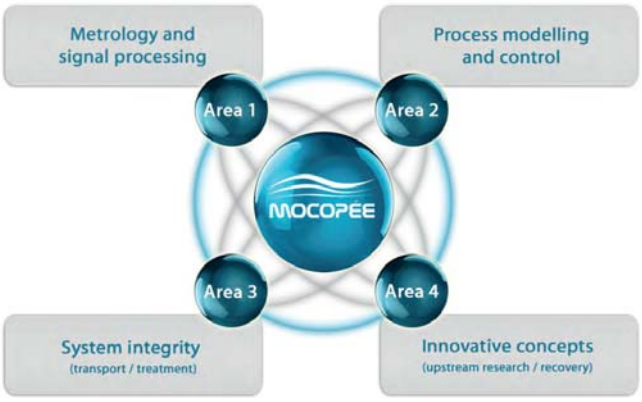
MOCOPEE – The Project

Modelling, control and optimization of wastewater treatment processes

- Research program launched in 2014
  2nd five-year phase started in 2018
- About the program
  - Four applied research axes
  - Budget 1-2 M€/yr
  - Around 30 research teams involved
  - 11 PhD students since 2014
- Supported by the Greater Paris Sanitation Authority (France)

SIAAP
Service public de l'assainissement francilien



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Upgrade of Seine Aval WRRF

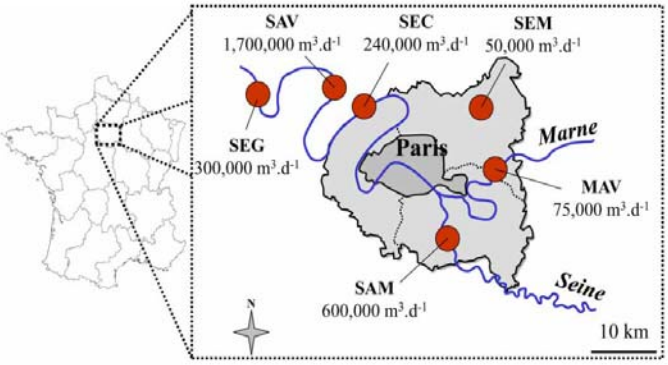

Figure 2: SIAAP's water resource recovery facilities.

- 6 water resource recovery facilities in the Paris region
- 2,5 million m^3 of wastewater treated each day
- 9 million inhabitants

Figure 3: Seine Aval (SAV) WRRF

- Nominal flow designed : 1,7 million m^3/d
- 5 million inhabitants

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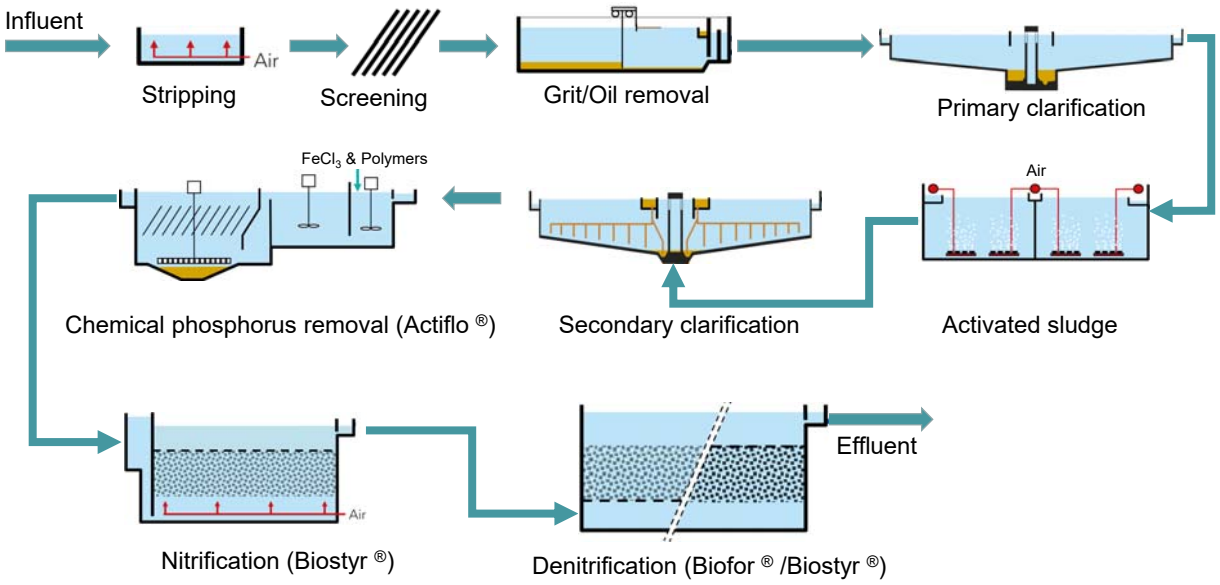
The Seine Aval WRRF flow scheme before upgrade



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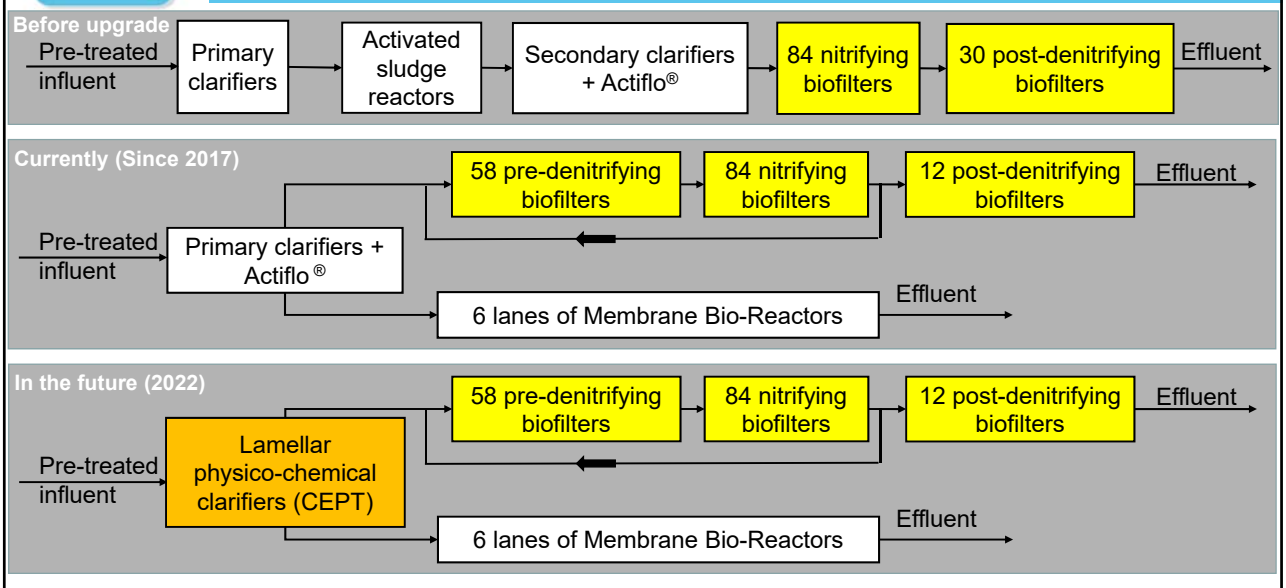
Upgrade of Seine Aval WRRF



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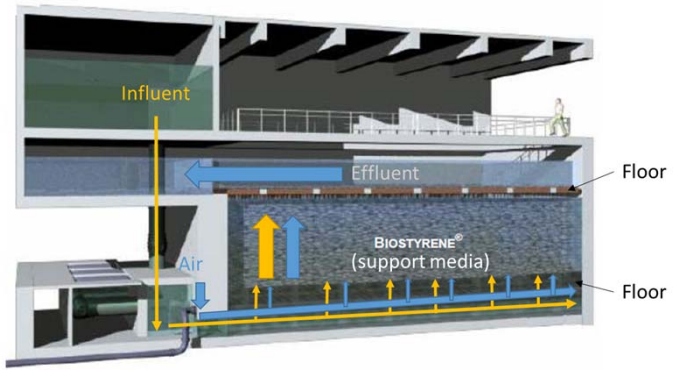
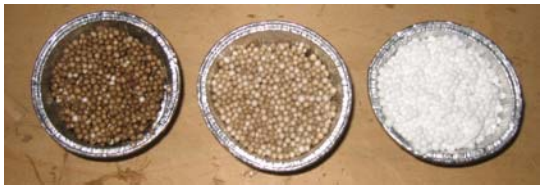
Nitrification → Biostyr®





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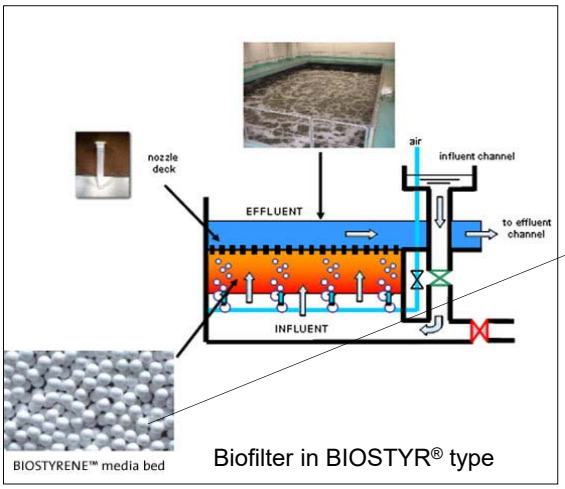
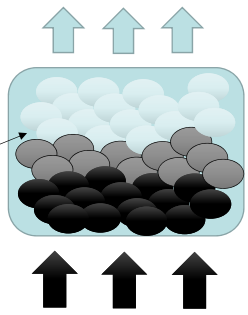
Nitrification → Biostyr®



Biofilter in BIOSTYR® type

Filtration

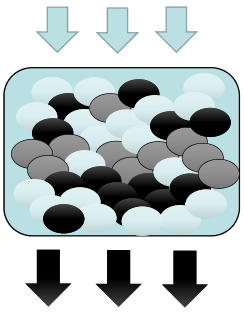
Treated water



Wastewater with large particles

Backwash

Washing water flux



Detached biofilm

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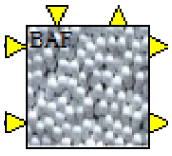
Aims of the modelling work

1. Develop models for each treatment process, simulate their performances and evaluate economic and environmental impacts.
2. Develop and use models as decision support tools for the distribution of the influent between the different processes.
3. Develop and use models for process control and optimization.

Trickling Filter model



Submerged biofilter model

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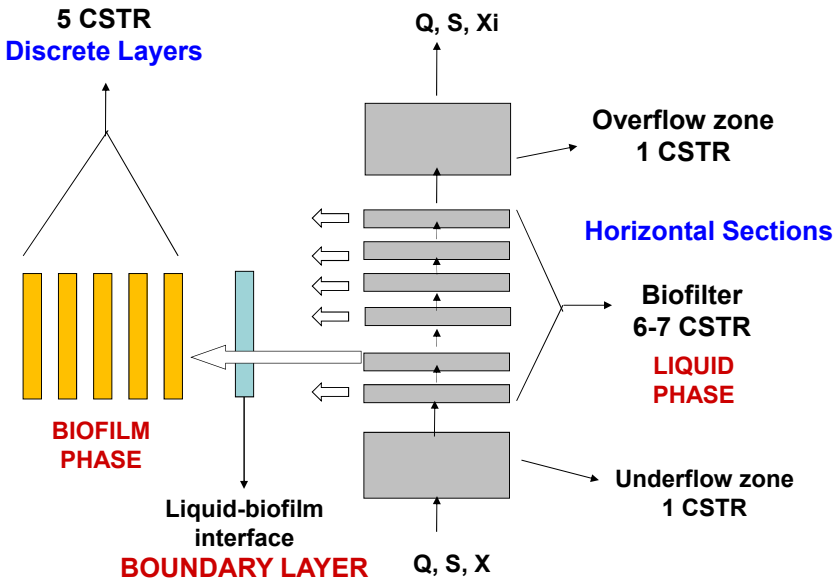
Biofilm system modelling approach

- Vigne et al. (2010)
- GPS-X



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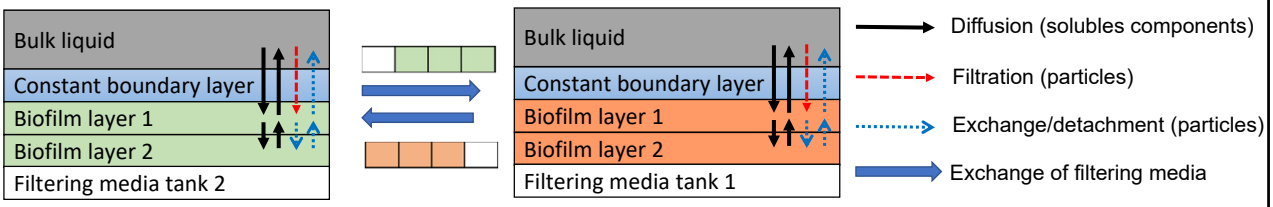
Model development work on Biofiltration stage

Model description I – Original model (Bernier et al., 2014)

1. 6-7 reactor tanks-in-series (vertical tanks, each 0.5 m of media bed)
2. 4 principal submodels : biofilter hydraulics, mass transport, 2-layer biofilm model and biological reactions.
3. Mass transport : diffusion, filtration, exchange and detachment
4. Biological reactions : Modified ASM1 (2-step nitrification/denitrification)
5. Backwash process (1/day) with media exchange between vertical tanks



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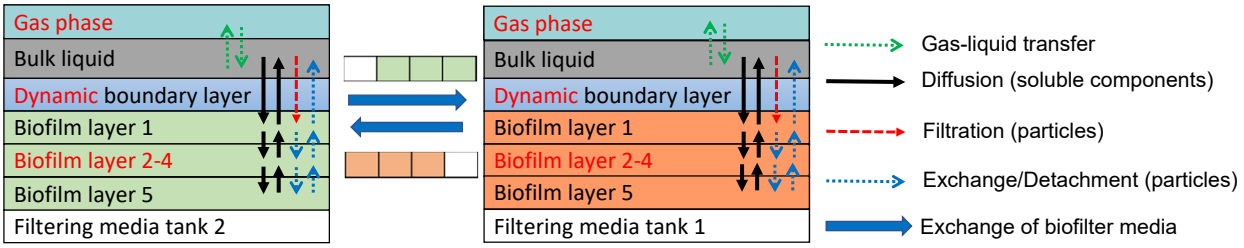
Model development work on Biofiltration stage

Model description II – Model modifications (Mass transport)

1. Boundary layer with variable thickness (fluid and media properties)
2. More biofilm layers are considered (5 layers).
3. A gas phase and gas liquid transfer are introduced
4. Modification of particles mass transport
5. Improved media exchange between media tanks (to maintain biomass spatial organization)



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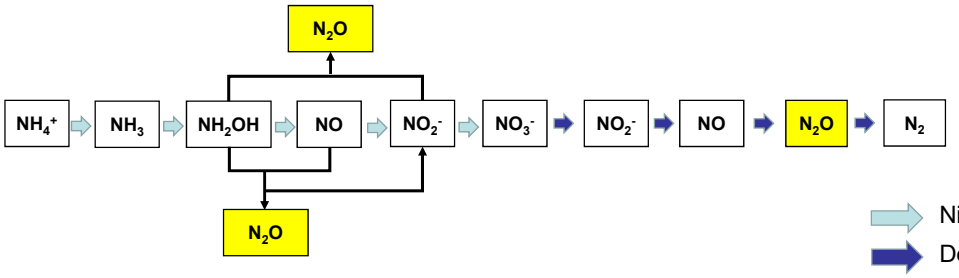
Model development work on Biofiltration stage

Model description III – Model modification (Biological reactions and energy comsumption)

Nitrification and denitrification in the modified model (Hiatt & Grady, 2008, Pocquet et *al.*, 2016**)**



Nitrification reactions

Denitrification reactions

N_2O emission reactions

limiting factors for biomass growth: [NH_4^+] and [PO_4^{3-}]

Pumping energy evaluation (According to Gernaey et *al.*, 2006**)**

Aeration energy evaluation (According to Wu et *al.*, 2005**)**

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Model development work on Biofiltration stage

Model description IV – Model modification (Energy consumption)

Aeration energy estimation (according to Wu et *al.*, 2005)

$$E_{aeration} = 0.024 \int \frac{Q_{air} * \Delta P}{\eta}$$

- Q_{air} is the air flow delivered by compressors to the stage (m^3/d)
- ΔP is the differential pressure (Pa)
- η is the overall efficiency of the compressors (-)

Pumping energy estimation (according to Gernaey et *al.*, 2006)

$$E_{pomp} = n * 0.024 \int \frac{\left(K' * Q_{fluid}^2 + H_{geo}\right) * Q_{fluid} * g * \rho}{\eta}$$

- n is the number of active pumps
- K' is the coefficient covering the friction headloss, minor losses and velocity head (d^2/m^5)
- H_{geo} is the geometric height (m) of the pump
- Q_{fluid} is the bulk liquid flow delivered by the pump (m^3/d)
- g is the gravity acceleration (m/s^2)
- ρ is the density of the fluid (kg/m^3)
- η is the overall efficiency of the pump

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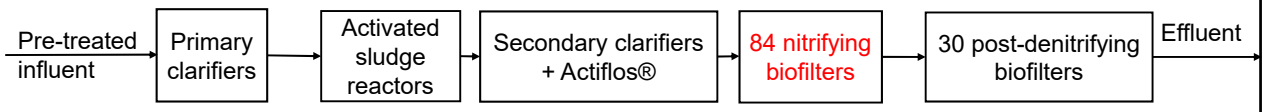
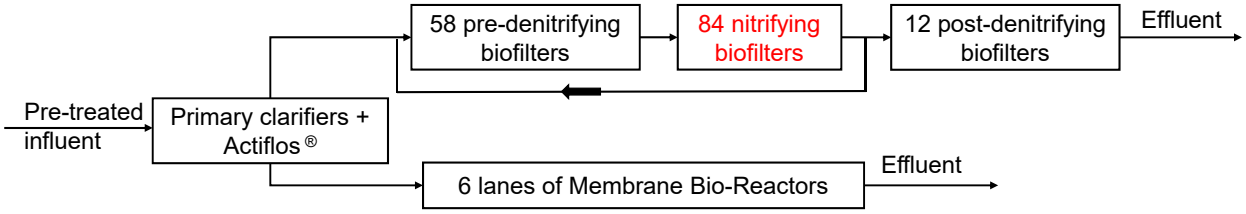
Calibration and validation of the nitrifying stage

Configuration before upgrade (for calibration)



Current configuration (Since 2017, for validation)



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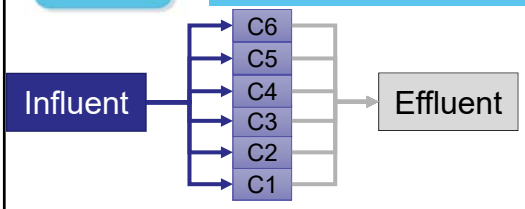
Calibration and validation of the nitrifying stage



C1 = 1 treatment cell (contains 14 biofilters)

Media bed height = 3,5 m

Daily average monitoring data	Sampler location
NO_3^-	Influent
TKN	Influent
Alkalinity	Influent
COD	Influent/Effluent
NO_2^-	Influent/Effluent
filtered COD*	Influent/Effluent
TSS	Influent/Effluent
NH_4^+	Influent/Effluent

Sensor data (each 15 min)	Sensor location
Water flow rate	Influent
Air flow rate	Influent
TSS	Influent
PO_4^{3-}	Influent
Temperature	Influent
NH_4^+	Influent/Effluent
NO_3^-	Effluent
DO	Effluent

* Filtered COD was only available in 2017

Operational information: Aeration and pumping energy

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Calibration and validation of the nitrifying biofilter model

Global sensitivity analysis

- To identify influential parameters
- To reduce the number of parameters to be calibrated
  ⇒ Monte-Carlo approach for sensitivity analysis (Sin et al., 2011)

Calibration

- To identify the best parameter values
  ⇒ Monte-Carlo approach for calibration (Sin et al., 2008)
  ⇒ 30 days of data over summer holiday (2009)
  ⇒ Pollution load decreased in this period

Further tests and adjustments

- To test and improve model prediction performance for long term period
  ⇒ Test 1: 60 days of data after summer holiday (2009)
  ⇒ Test 2: Entire year of data for 2009
  ⇒ Manual adjustments for a few parameter values

Validation test

- To validate model performance under current treatment configuration
  ⇒ 180 days of data for year 2017
  ⇒ Only one aeration parameter value had to be changed (aging of aerators)

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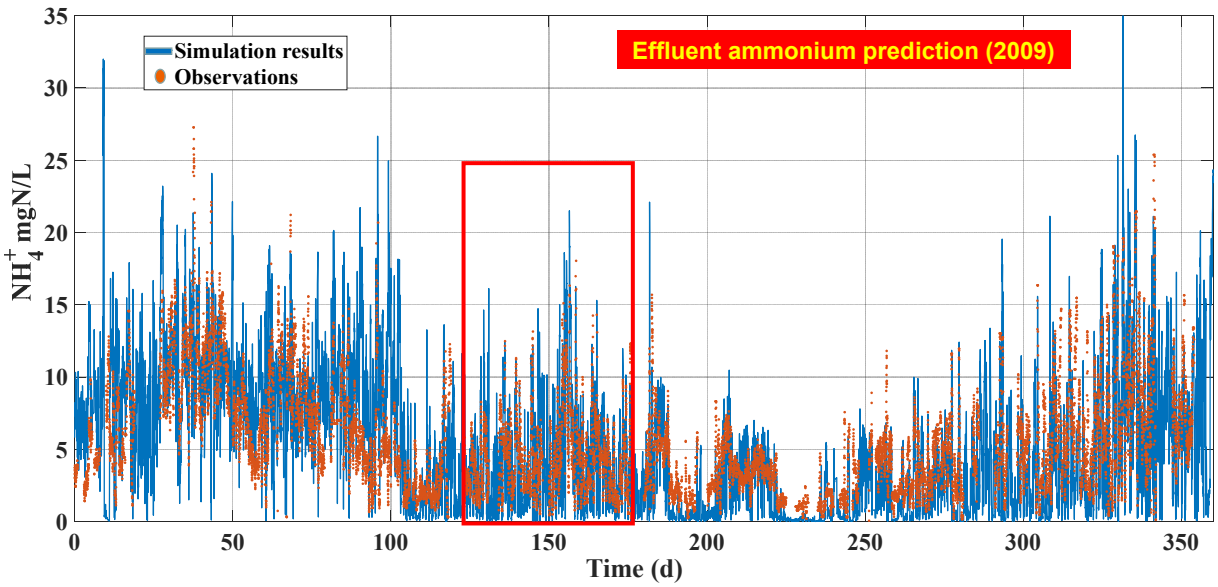
Calibration and validation results



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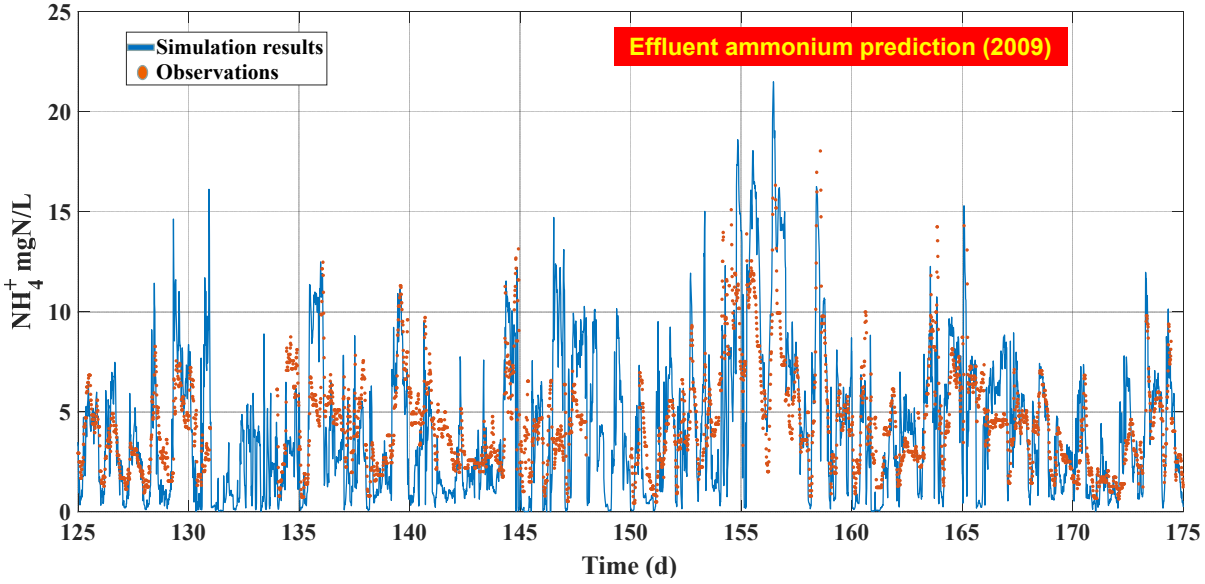
Calibration and validation results



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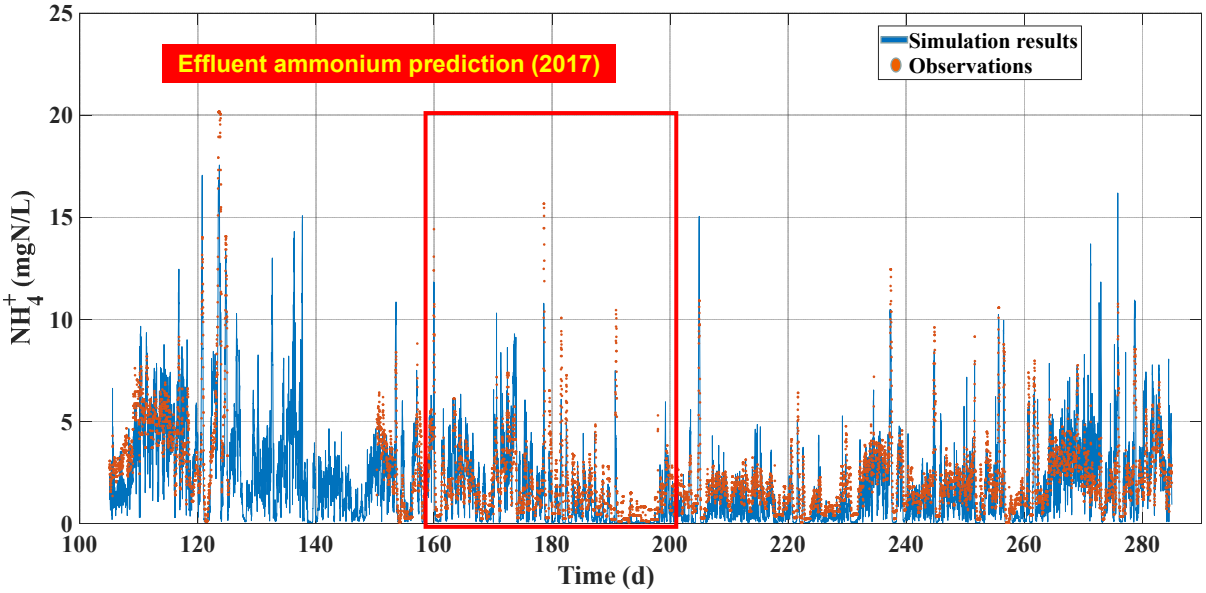
Calibration and validation results



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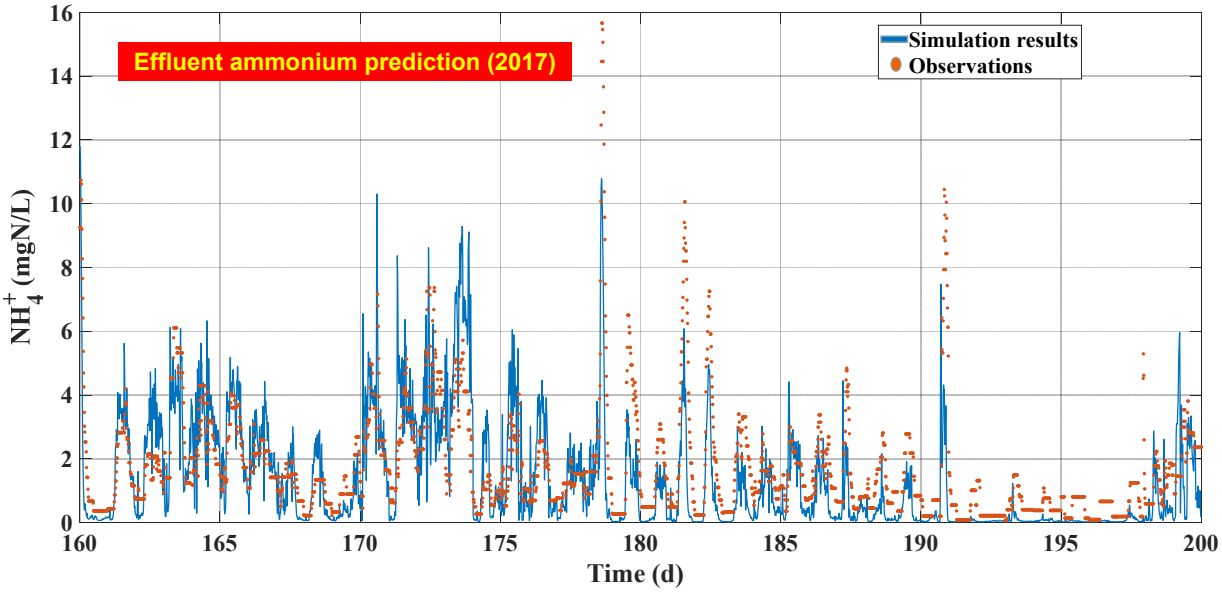
Calibration and validation results



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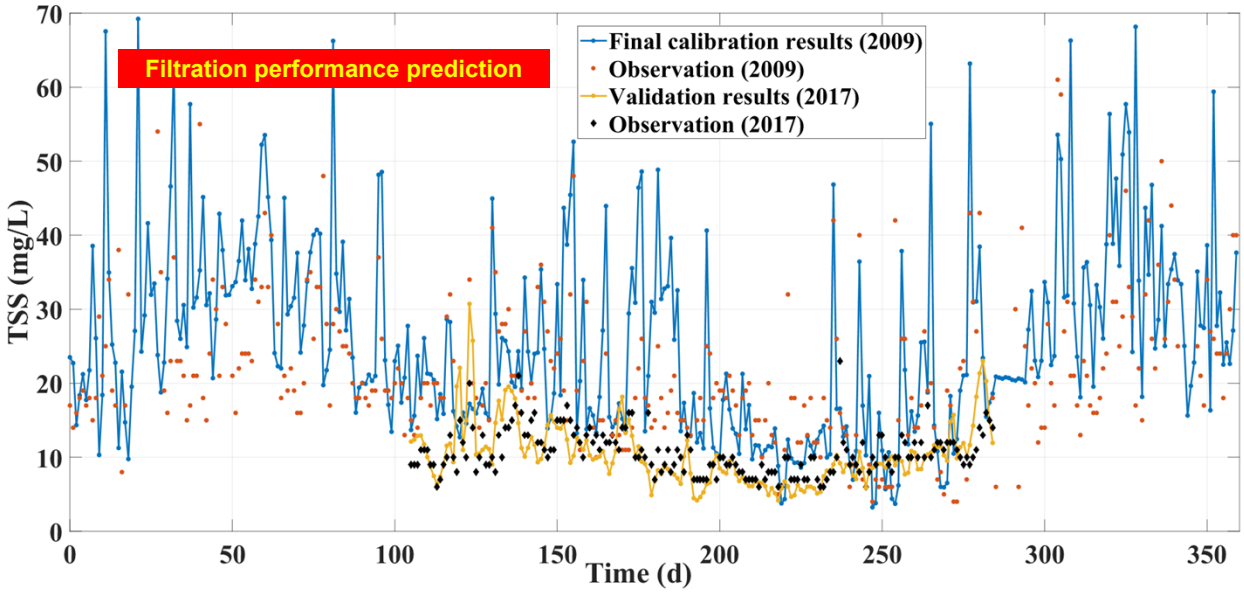
Calibration and validation of the nitrifying stage



Calibration and validation results

Summary of statistical scores

Scores for 2009 (calibration)	NH_4^+	NO_3^-	DO	NO_2^-	COD	TSS	PO_4^{3-}
Number of validated observations (n)	27048	34272	33313	329	331	332	329
Observed mean (mg/L)	5.55	34.04	6.63	0.78	62.27	21.58	0.39
Mean error (ME) (mg/L)	-0,32	2,19	-0,22	-0,13	-2,99	3,87	0,07
Root mean square error (RMSE) (mg/L)	3,58	4,55	0,79	0,56	15,08	11,83	0,16

Scores for 2017 (validation)	NH_4^+	NO_3^-	DO	NO_2^-	COD	TSS	PO_4^{3-}
Number of validated observations (n)	14841	14841	17226	178	180	180	180
Observed mean (mg/L)	2.30	19.12	6.40	0.77	41.52	10.68	0.76
Mean error (ME) (mg/L)	-0,33	1,35	-0,92	0,16	-0,52	-0,32	-0,12
Root mean square error (RMSE) (mg/L)	1,53	3,13	1,26	0,78	5,44	3,39	0,17

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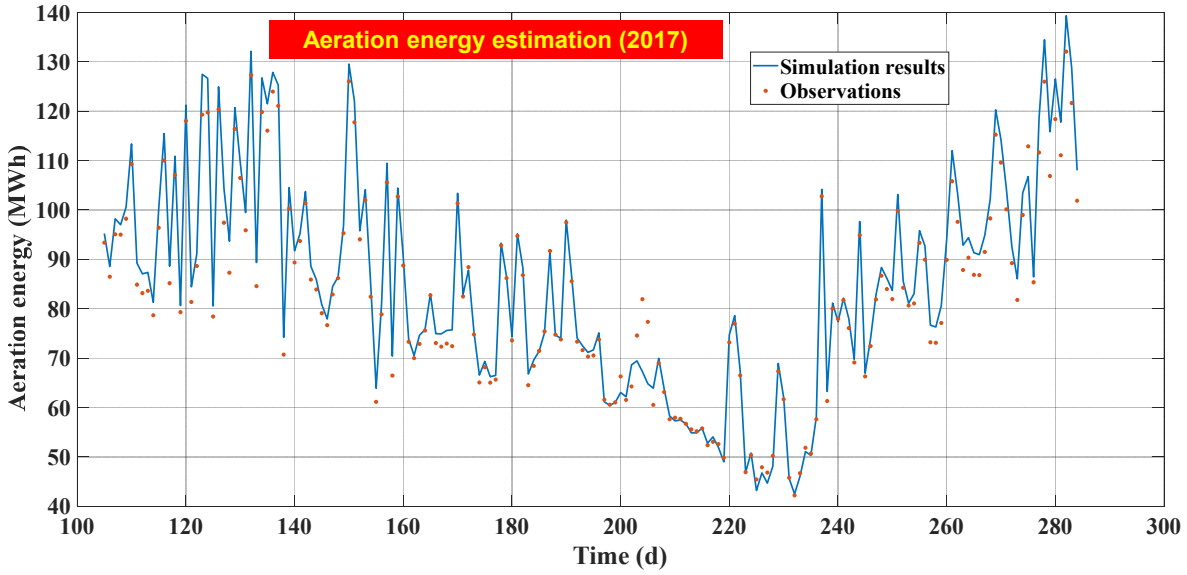
Energy consumption and N_2O emission estimations



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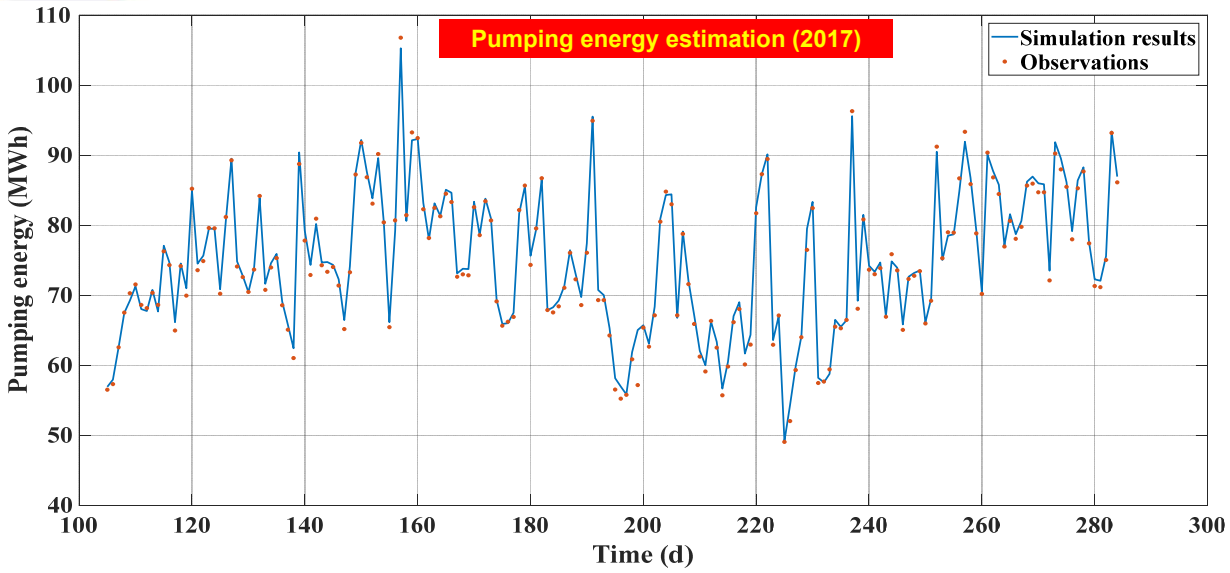

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Energy consumptions and N_2O emissions estimations

- N_2O emission factor (EF) (According to Bollon et al., 2016)

$$EF_{N_2O} = \frac{N_2O\ emitted}{NH_4^+\ removed} * 100\%$$

Daily N_2O emission factor (%)	Simulated (in 2009)	Observed (by Bollon et al., in 2016)
Summer period	3,03 ± 2,29 (n=60 days)	2,26 ± 0,46 (n=7 days)
Winter period	5,88 ± 2,69 (n=60 days)	4,86 ± 0,54 (n=14 days)

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Conclusions

- Modified multi-layer ASM1GHG biofilm model
  - N-species (NO_2)
  - Mass transport: Filtration, detachment, exchange of biofilm
  - Energy consumptions (aeration, pumping)
  - N_2O emissions
- Calibration and validation for the nitrifying stage (Biostyr®)
  - 2009, 2017 configurations
  - Good prediction performances
- Project progress and perspectives
  - Modelling of post-denitrification and CEPT (finished)
  - Modelling of pre-denitrification (in progress)

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