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Contribution of control and modeling for an integrated approach of water reuse to favour circular economy of nutrients

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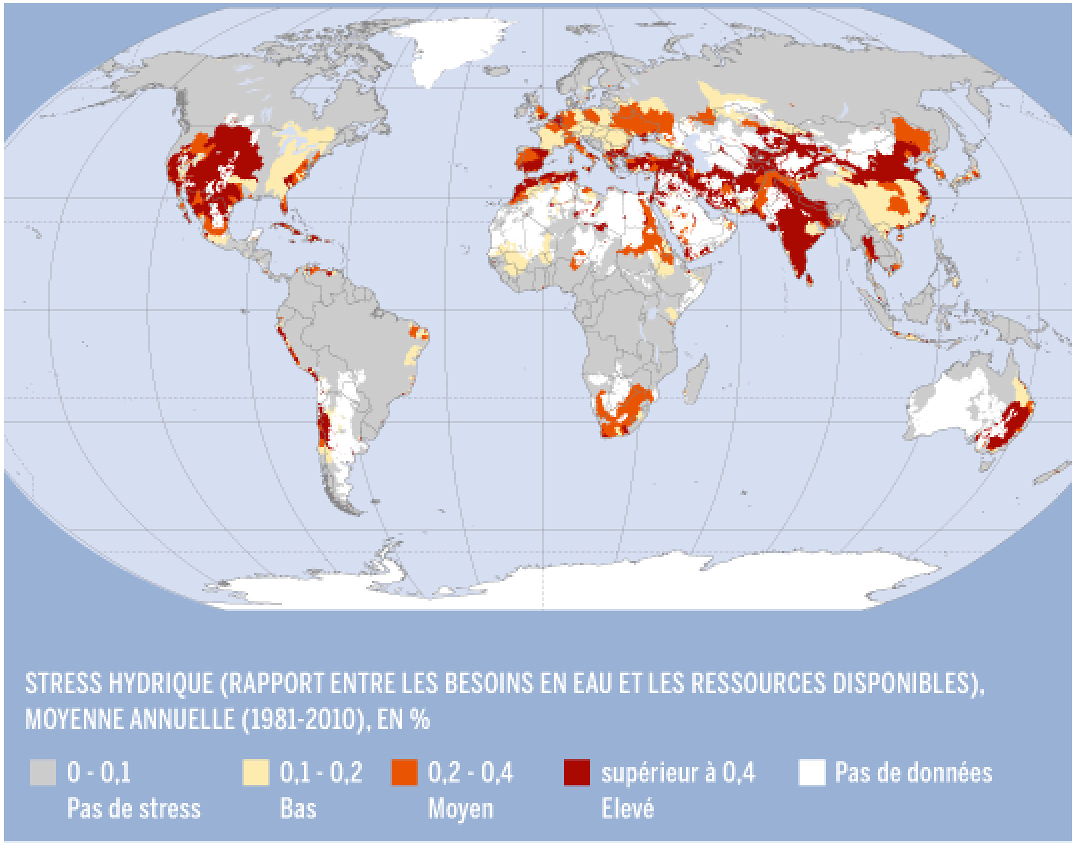
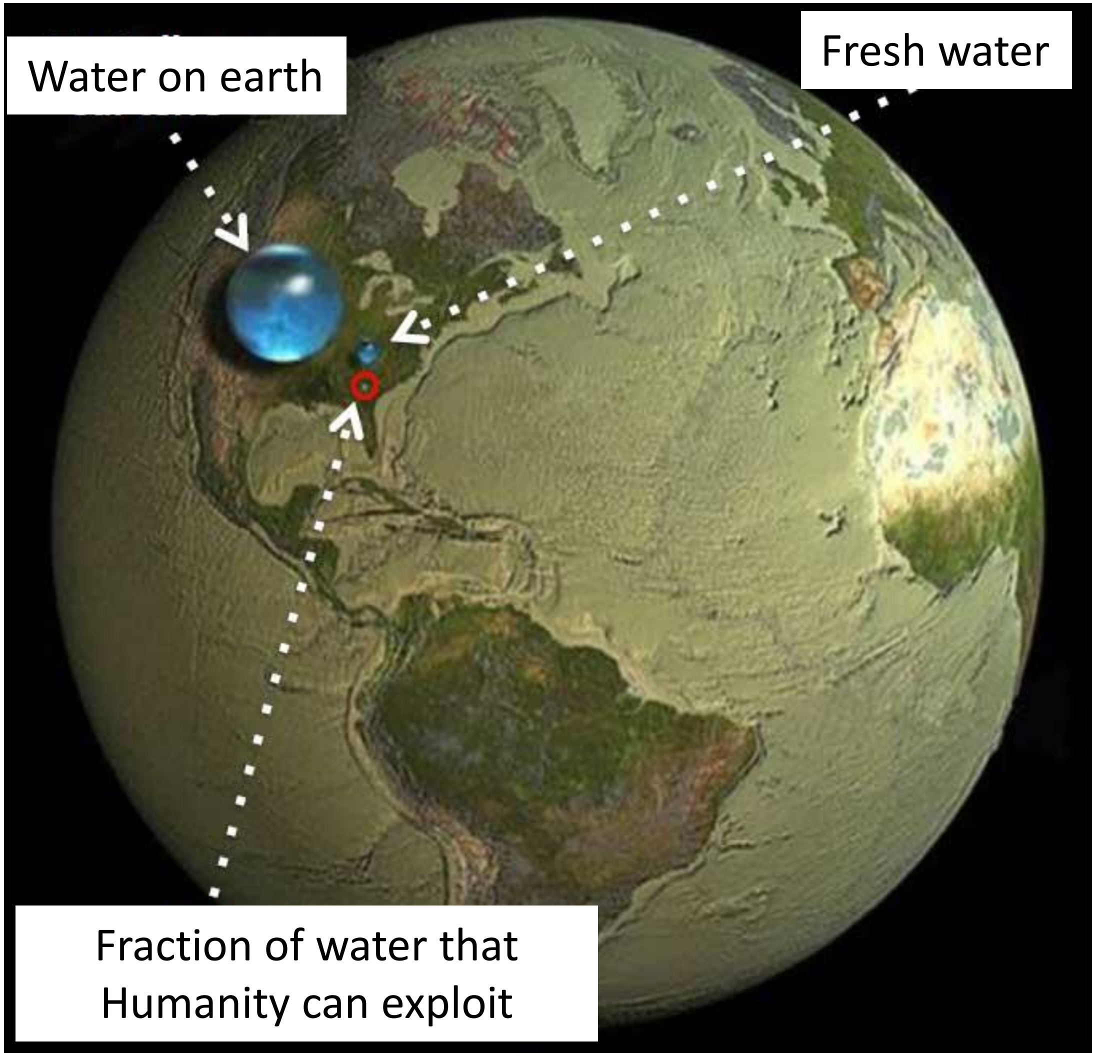
Facts...



ONU report on water (2015)

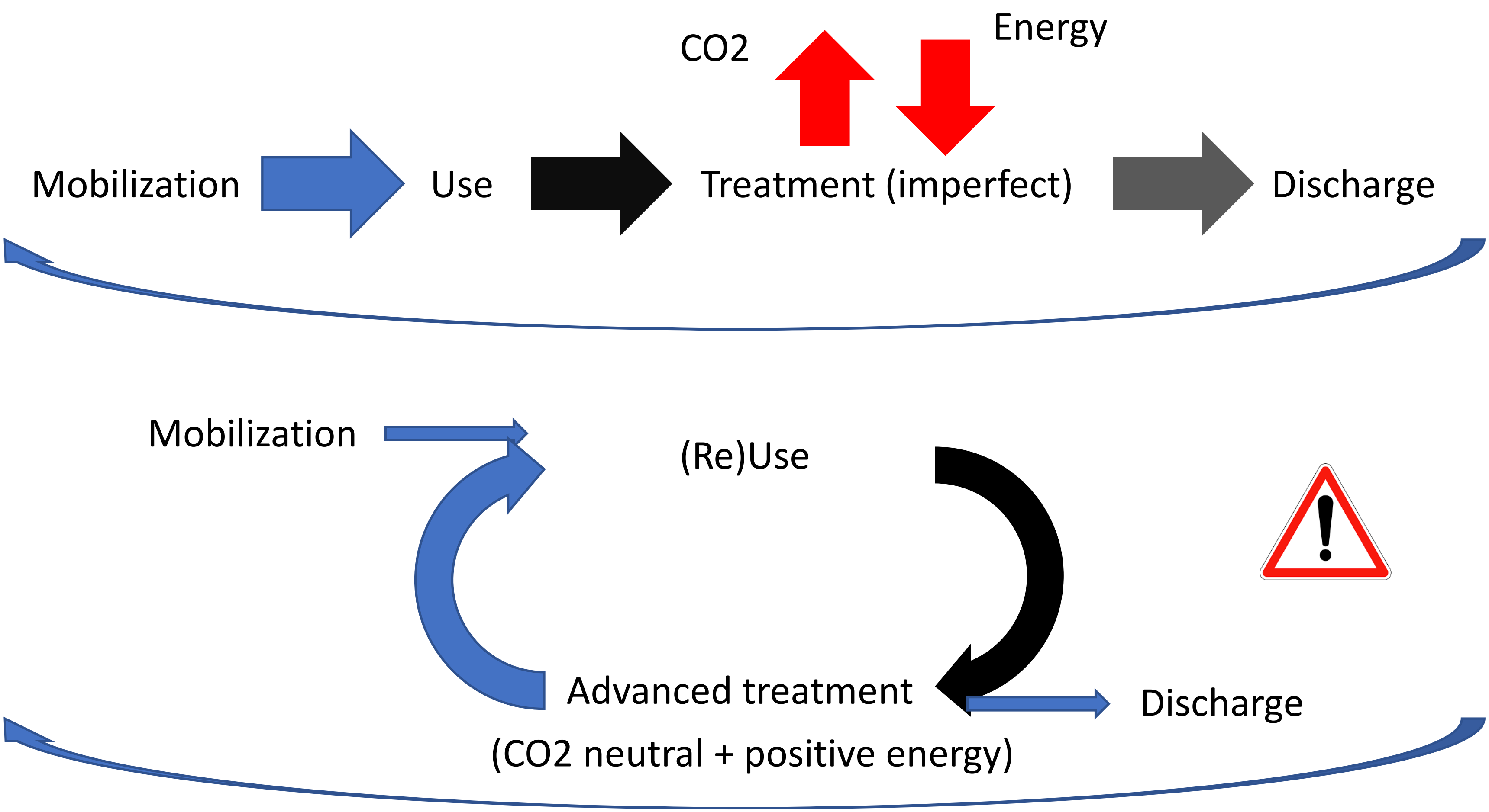
Facts…



Water on earth
Fresh water
Fraction of water that
Humanity can exploit

Why not reusing water in a virtuous cycle?

Objective : move from a recycling approach at the scale of large water cycle to an optimized management of the small water cycle.



The actual situation of REUSE in France

Less than 1% of TW is reused!

1. Loss of N, P

Sewage network

WWTP

Discharge

2. Potential diffuse pollution

Tertiary treatment

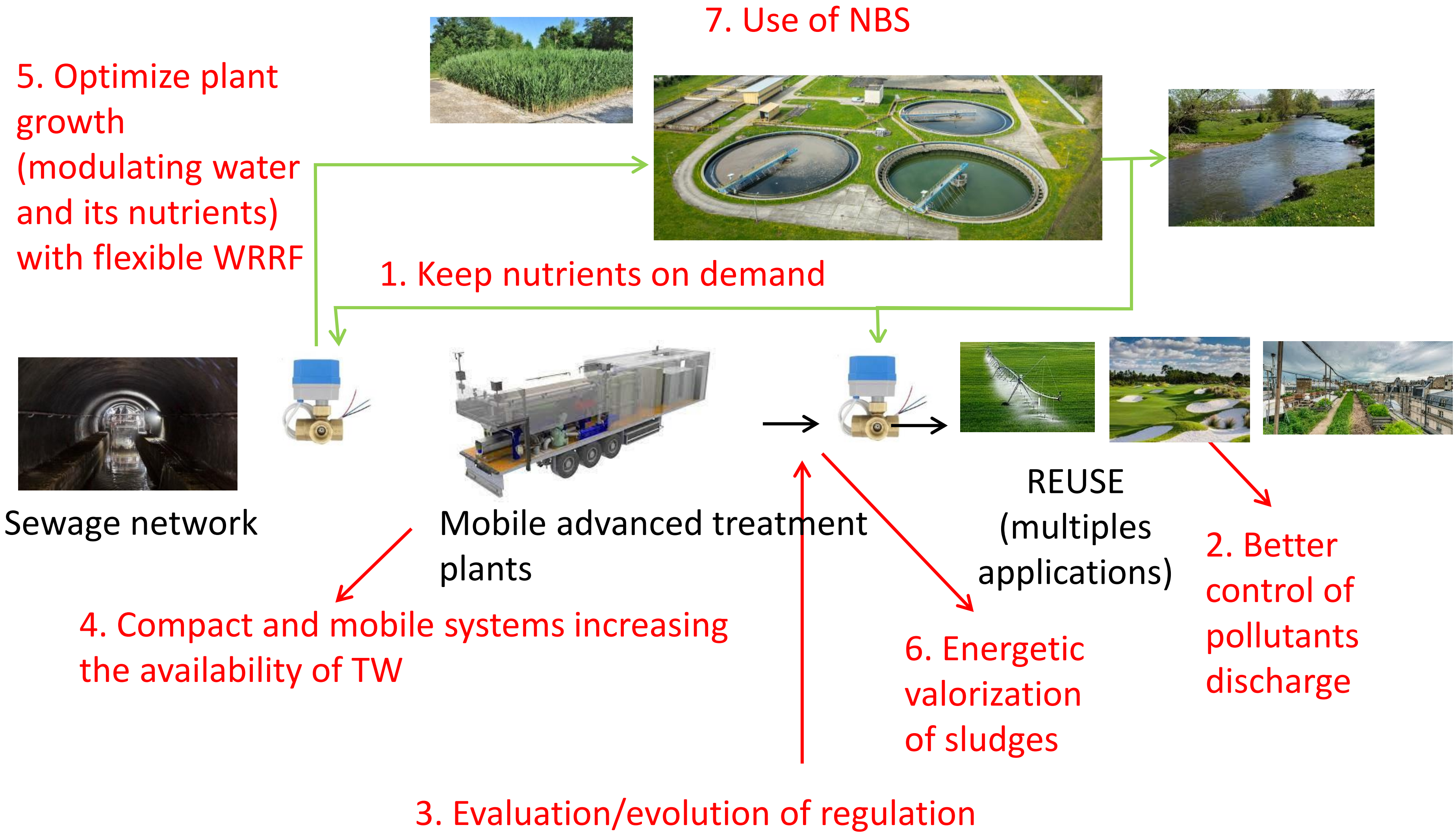
REUSE

4. Water only available in centralized systems

3. CODs, N, P smaller than normative constraints (costly treatments). Does not take into account the barriers of the soil neither the specific "needs" depending on usages

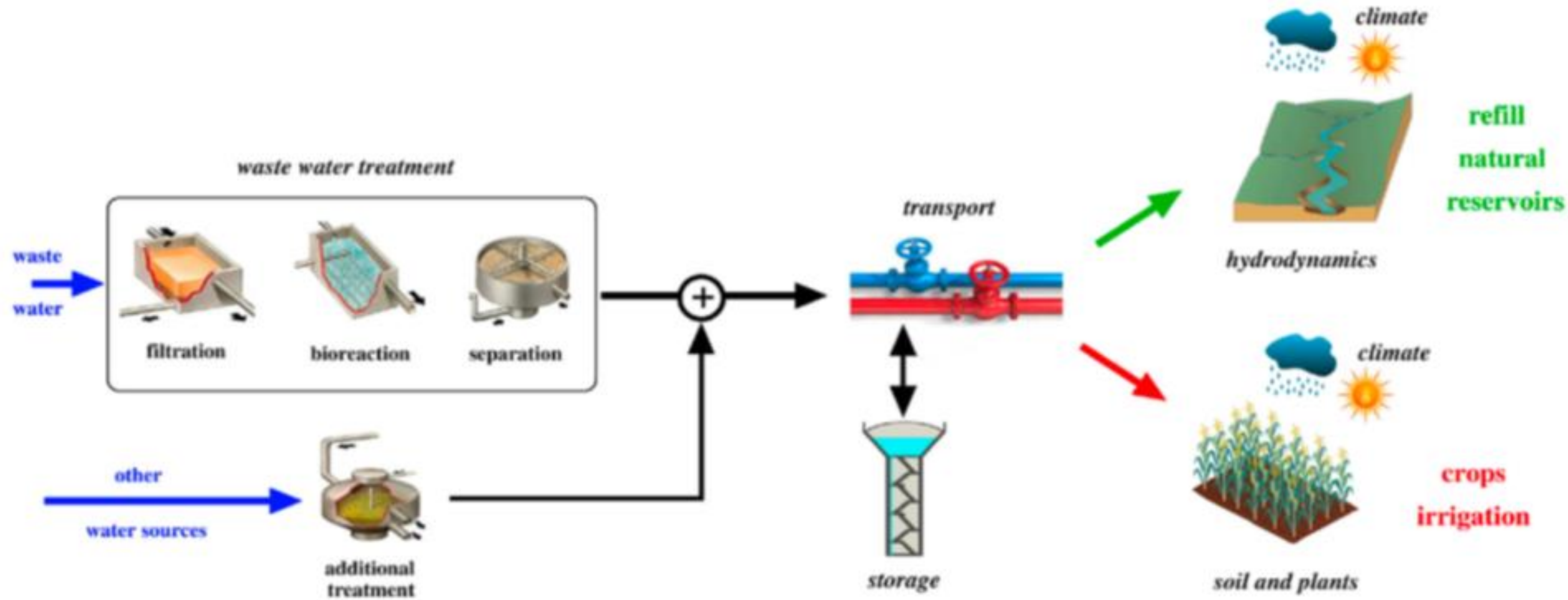
5. A limited number of usages

Promoting circular economy of water and nutrients



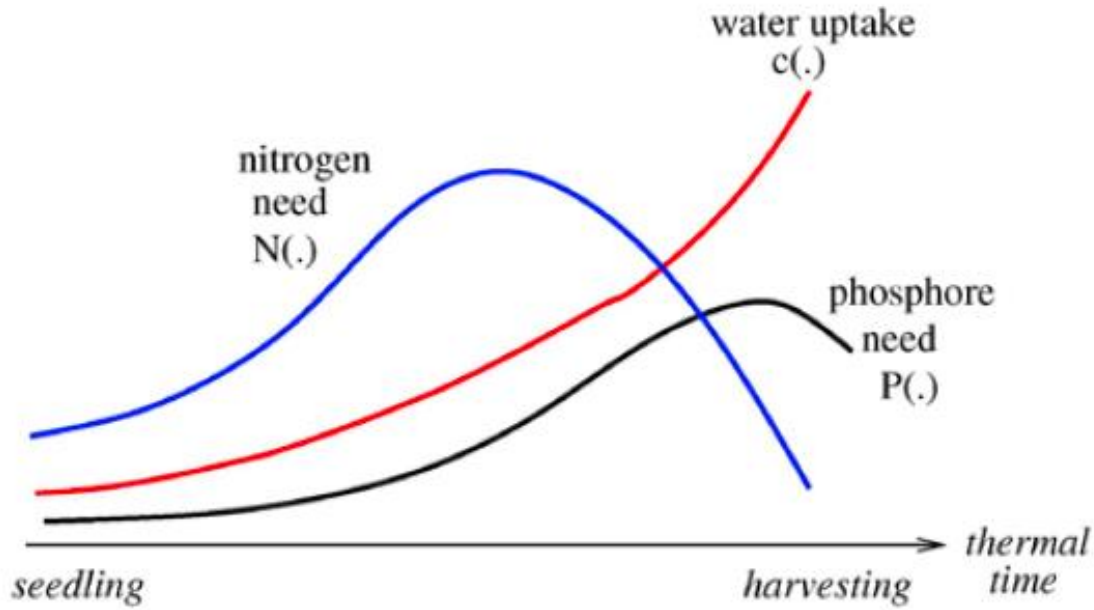
The "Water on demand" concept

Identifying the best levers for action



- The WWTP are obviously the best actuators of the small water cycles
- How moving from a WWTP to a WRRF?
- Which place for modeling and control?

How adapting the quality of water to plant needs?

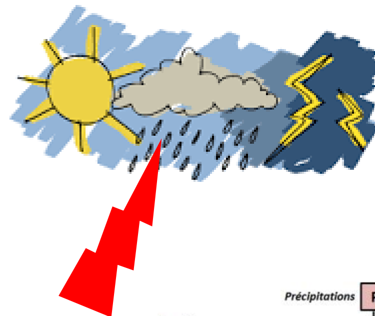


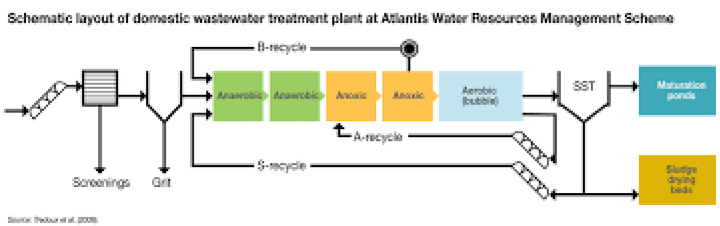
- The needs of plants are fundamentally dynamic
- They are subjected to weather disturbances
- Models are nonlinear, highly uncertain, noisy and partially observed

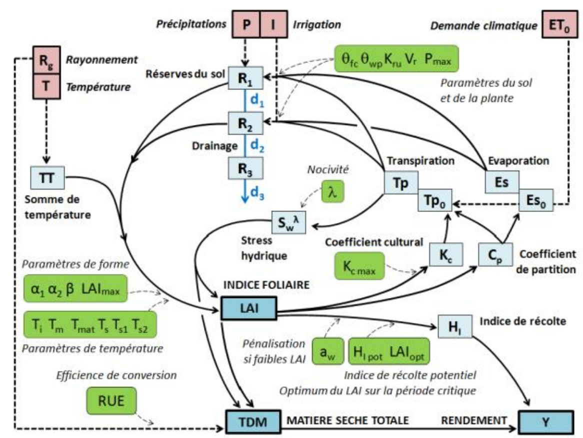
→ Give to the plants only (and all) what they need!

The ideal situation: coupling plant and WRRF models

Objective: maximizing biomass







Wastewater characteristics *w*

u

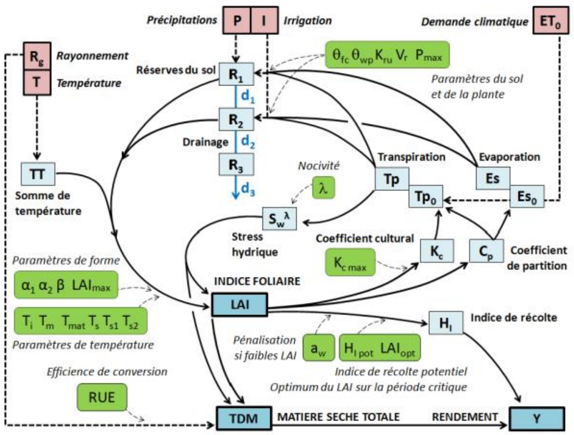
Biomass produced *B*

- Solve max(*B*) / *u* under the constraints *w*
- But models are difficult to couple (different timescales, different input-output configuration and variables, complex…)

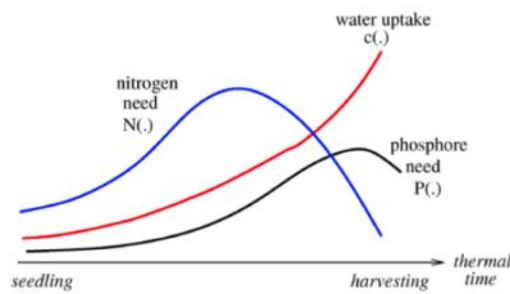
"Assembling" rather than "coupling" models

Plant models may be used to generate setpoints…

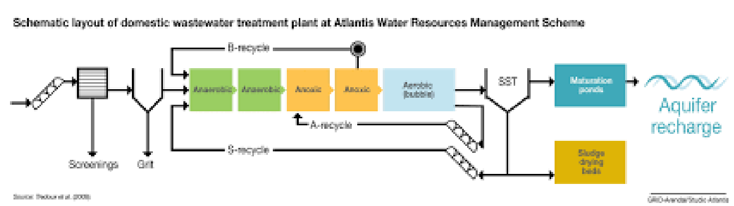
…that are used in WRRF models to deliver water with optimized characteristics



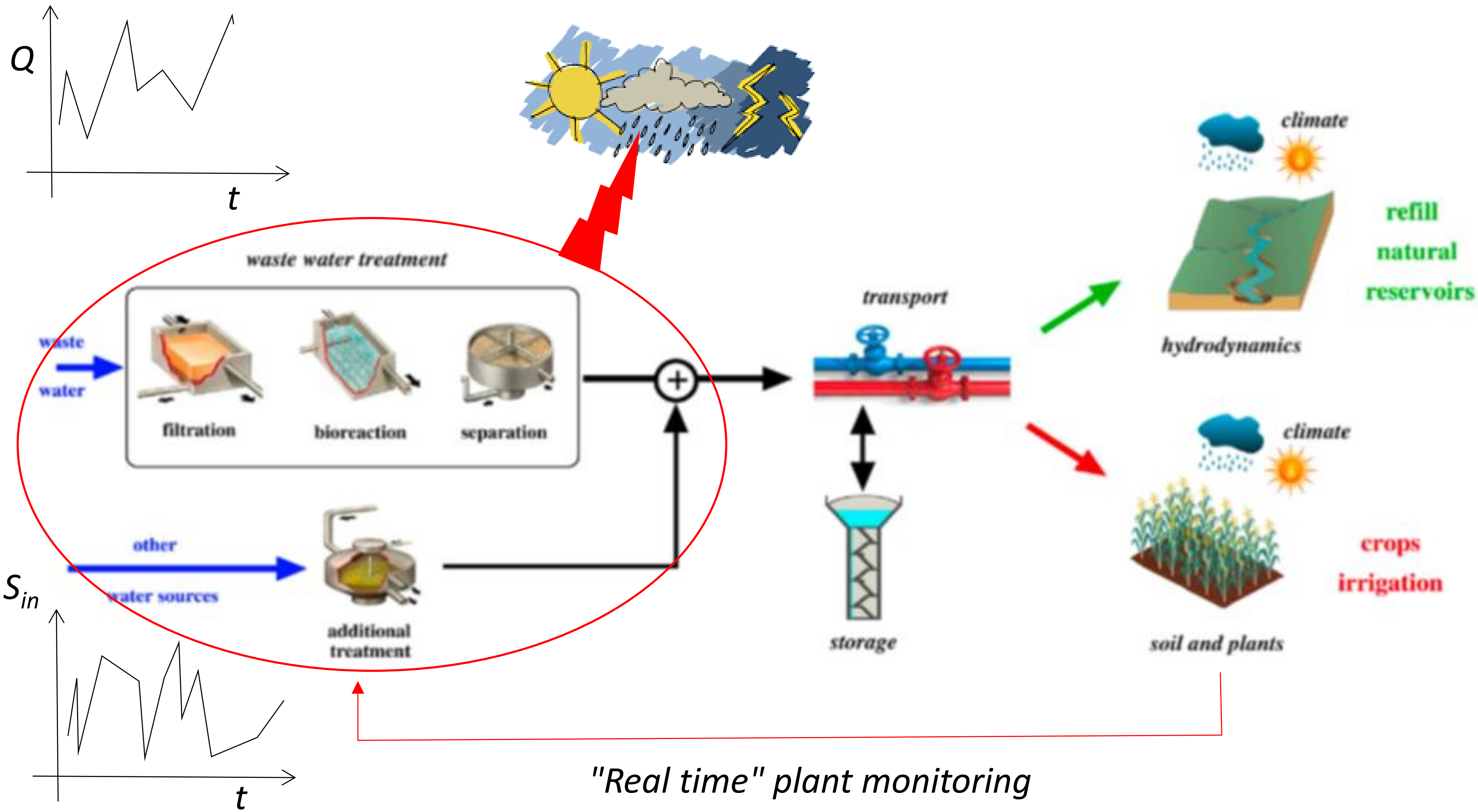
Which optimal needs?



Which flexible system to better deliver plant needs?



Putting these ideas in action: implementation



"Real time" plant monitoring

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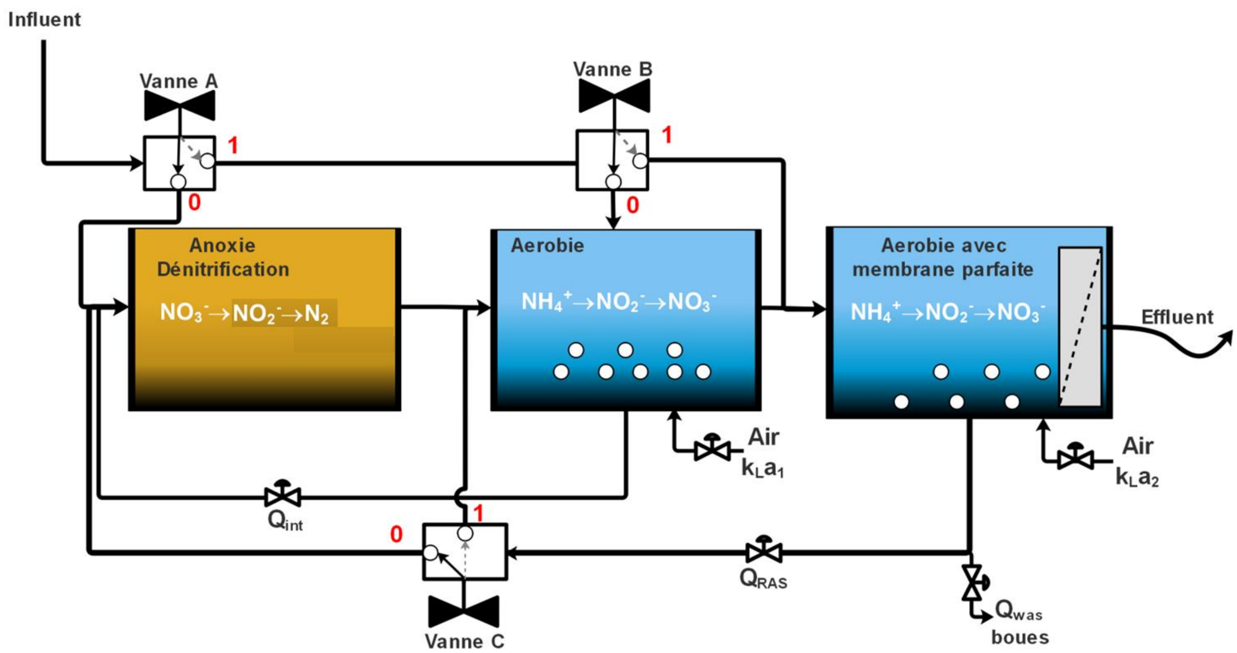
A flexible treatment system for REUSE (PhD thesis of Farouk Aichouche Control4Reuse project)

Which characteristics for a flexible treatment system?

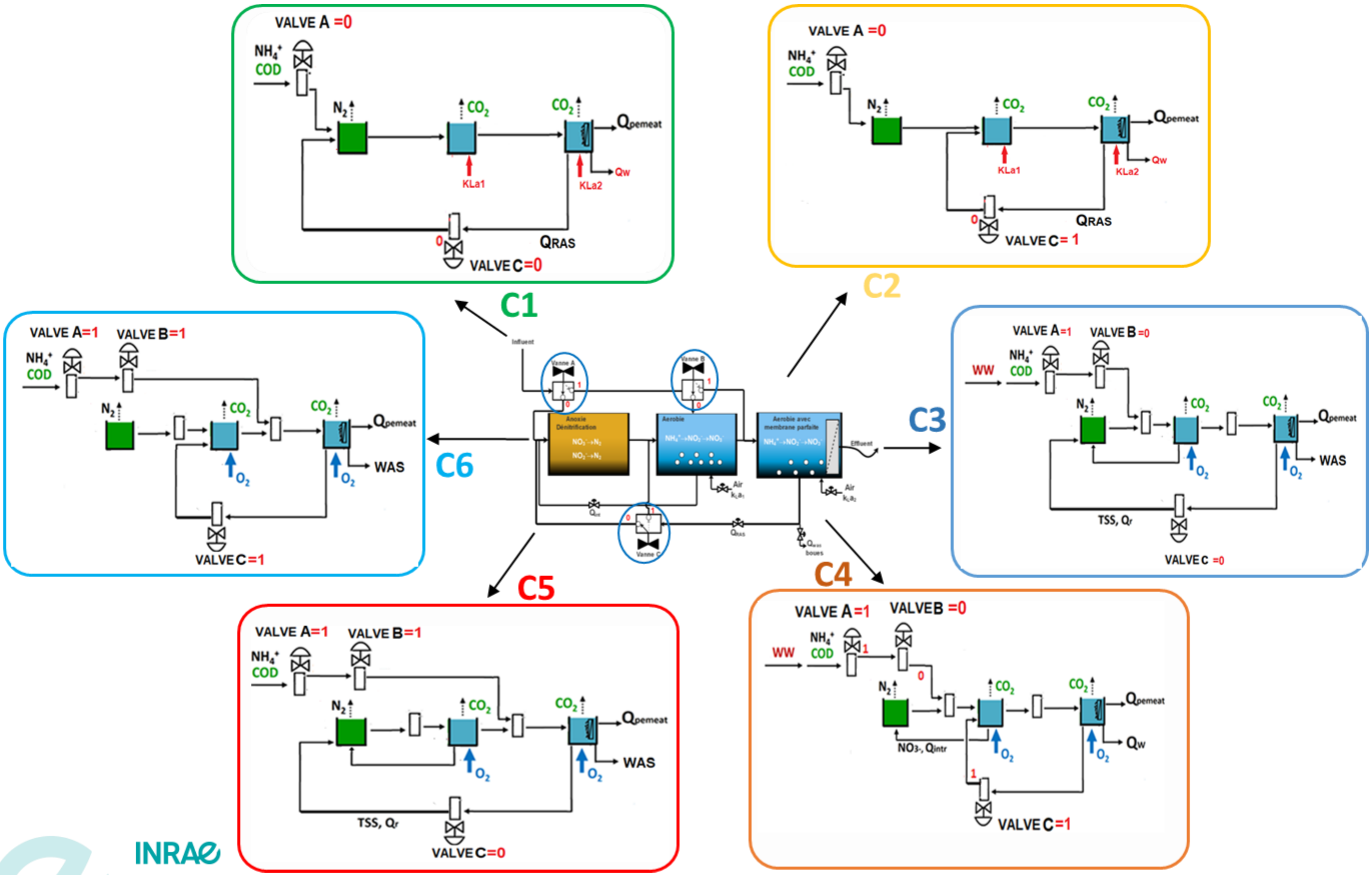
Let us concentrate on Nitrogen (because it is the main nutrient for plants contained in WW)…

- Must be able to deliver water complying with normative constraints when necessary (when no water is necessary for irrigation) => total nitrification and denitrification;
- Must be able to deliver a given level of nitrogen under its different possible forms (NH4 or NO3) and possibly a given quotient of them (NH4/NO3) => partial or total nitrification;
- Must prevent any sanitary risk => membrane based system;
- Must maximize flexibility => as many actuators as possible.

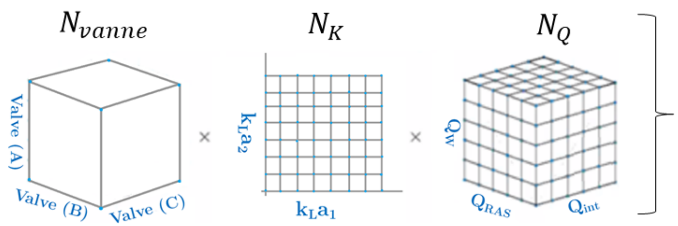
A flexible platform for REUSE



A flexible platform for REUSE

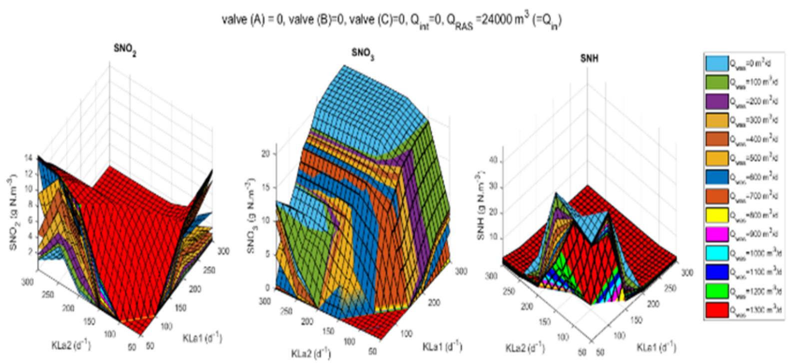


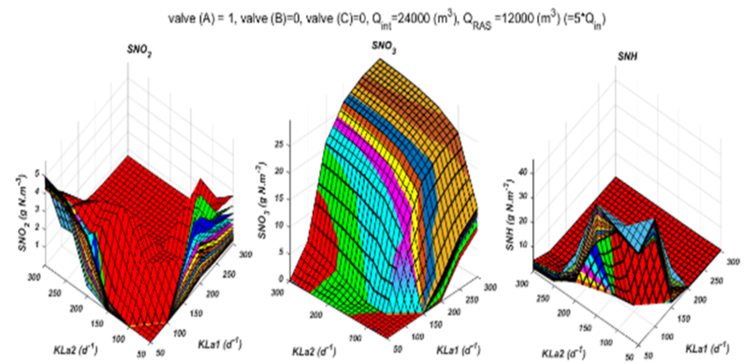
Static properties of the platform

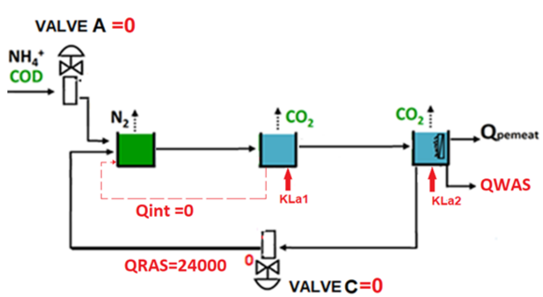


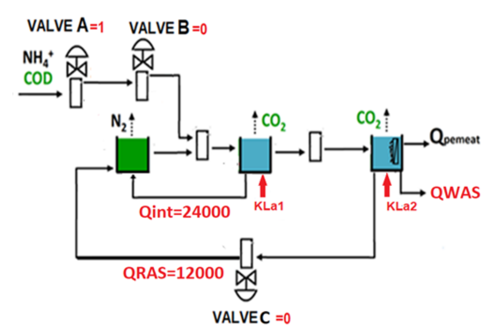
Nombre total d'états d'équilibre

$$N_{EE} = (N_{vanne})^3 \times (N_K)^2 \times (N_Q)^3 = 30240$$









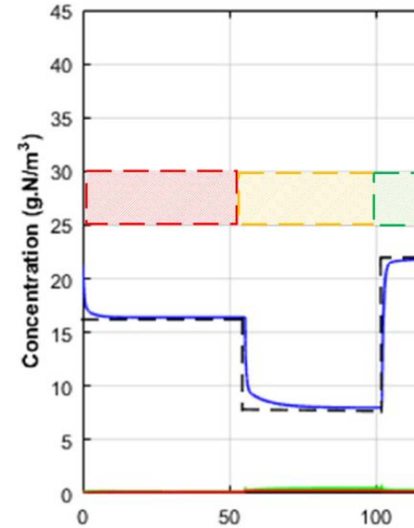
Open loop control of nitrate concentration

Algorithm:

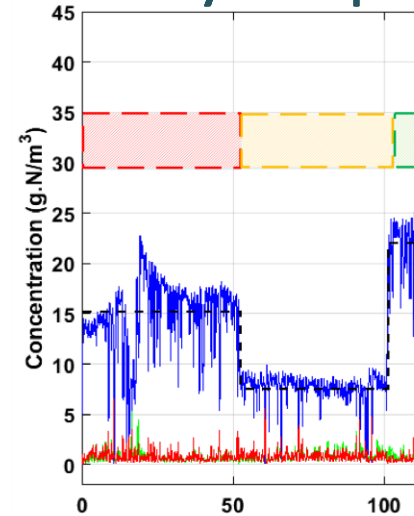
- *Fix SNO3* setpoint*
- *Find in the DB the closest steady state value*
- *Apply the associated configuration and control parameters to the FP*

*SNO3**	K_LA_1	K_La_2	V_A	V_B	V_C	Q_{WAS}	Q_{RAS}	Q_{int}
15,2	100	300	1	1	0	400	2×Qin	1×Qin
7,5	100	150	1	1	1	300	Qin	0
22	150	150	0	0	1	700	Qin	Qin
14,8	150	300	1	1	0	300	Qin	0
7	100	250	1	1	0	400	Qin	Qin
15,1	150	200	1	0	0	300	Qin	0

- **Cas statique inf**

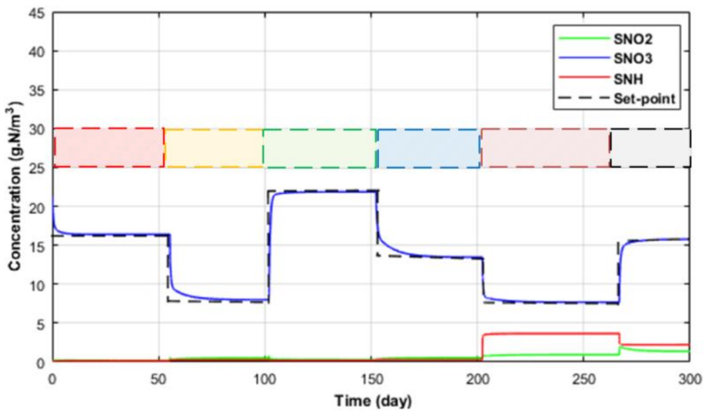


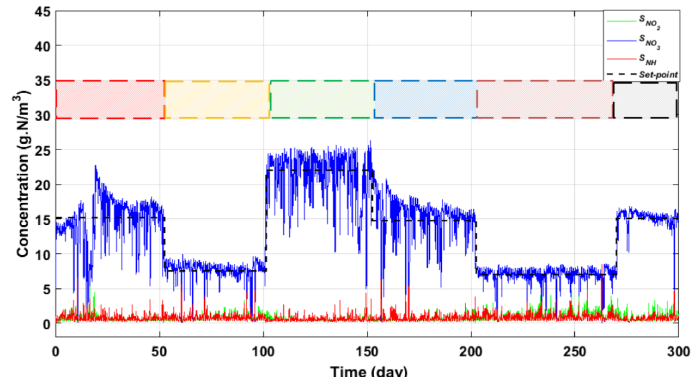
Cas dynamique



Open loop control of nitrate concentration

- *Works very well as long as inputs are close to those used to build the DB…*





- …but gives bad results if inputs are badly kown…

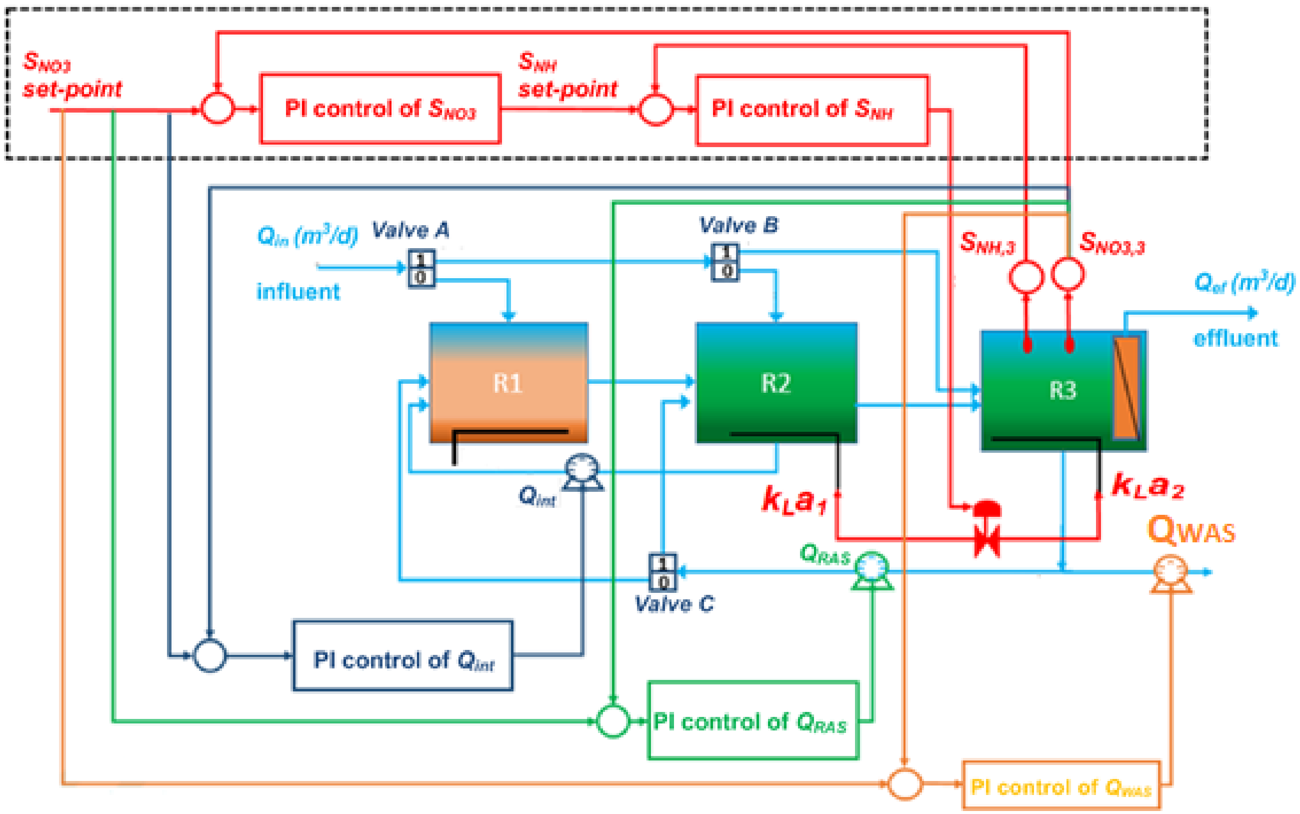
Closed loop control of nitrate concentration

Use of a "cascade" control loop

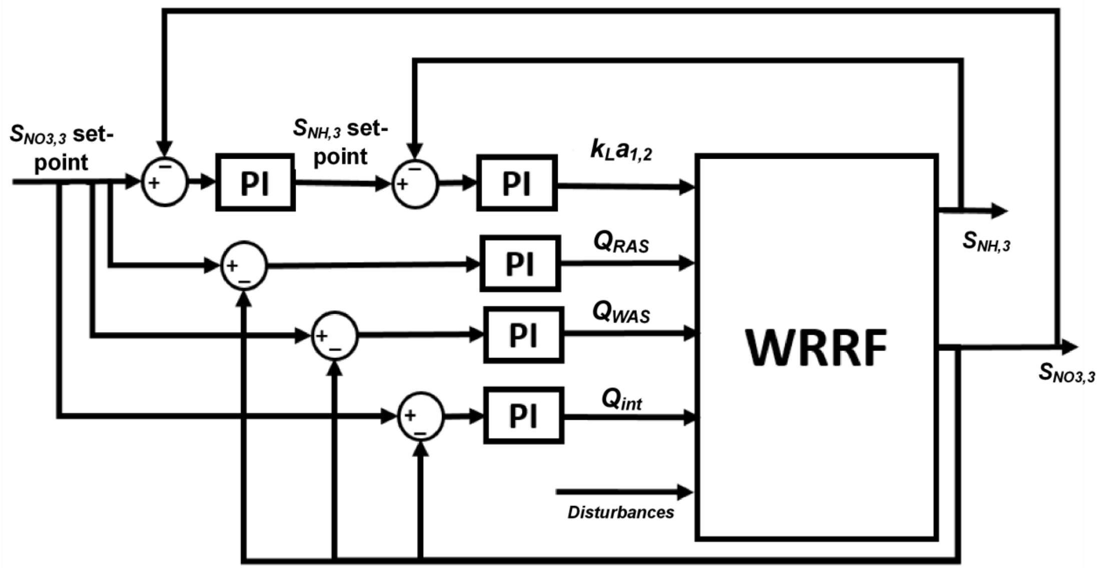
The oxygen is controlled using $k_L a_1$ and $k_L a_2$

Three loops of simple PI controllers

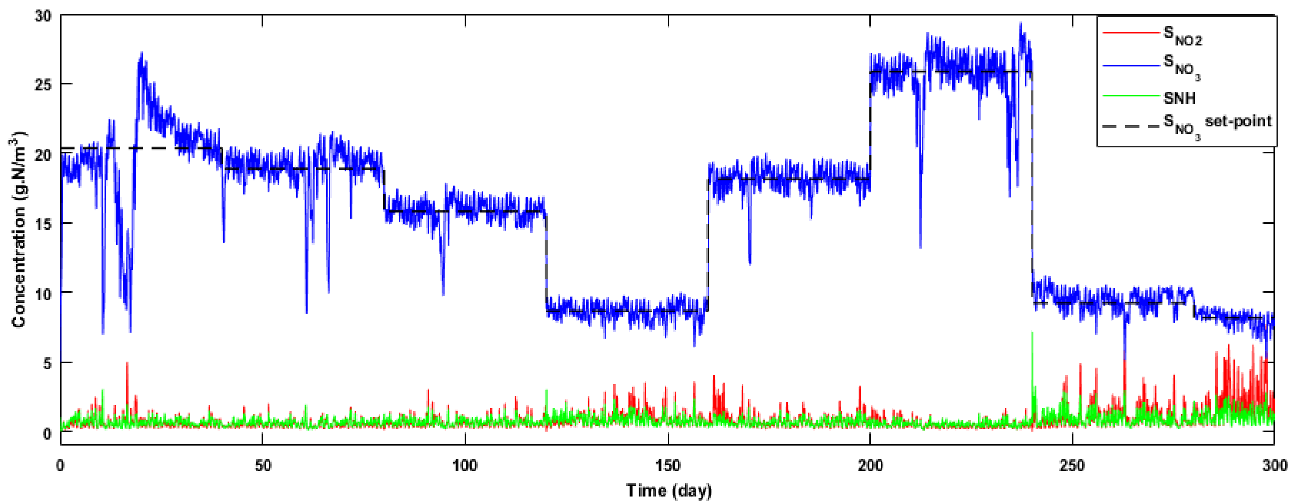
Allow the control of the recirculation rates Q_{int} and Q_{RAS} while the SRT in controlled using Q_{WAS}

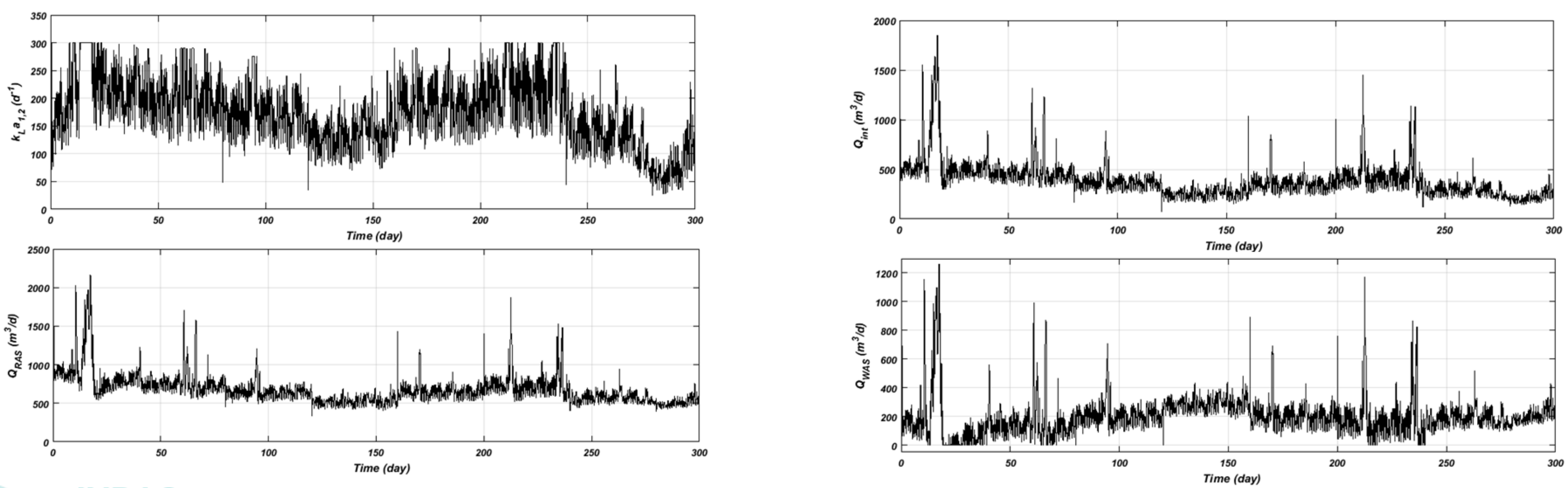


Closed loop control of nitrate concentration



Simulation results with input dynamic disturbances

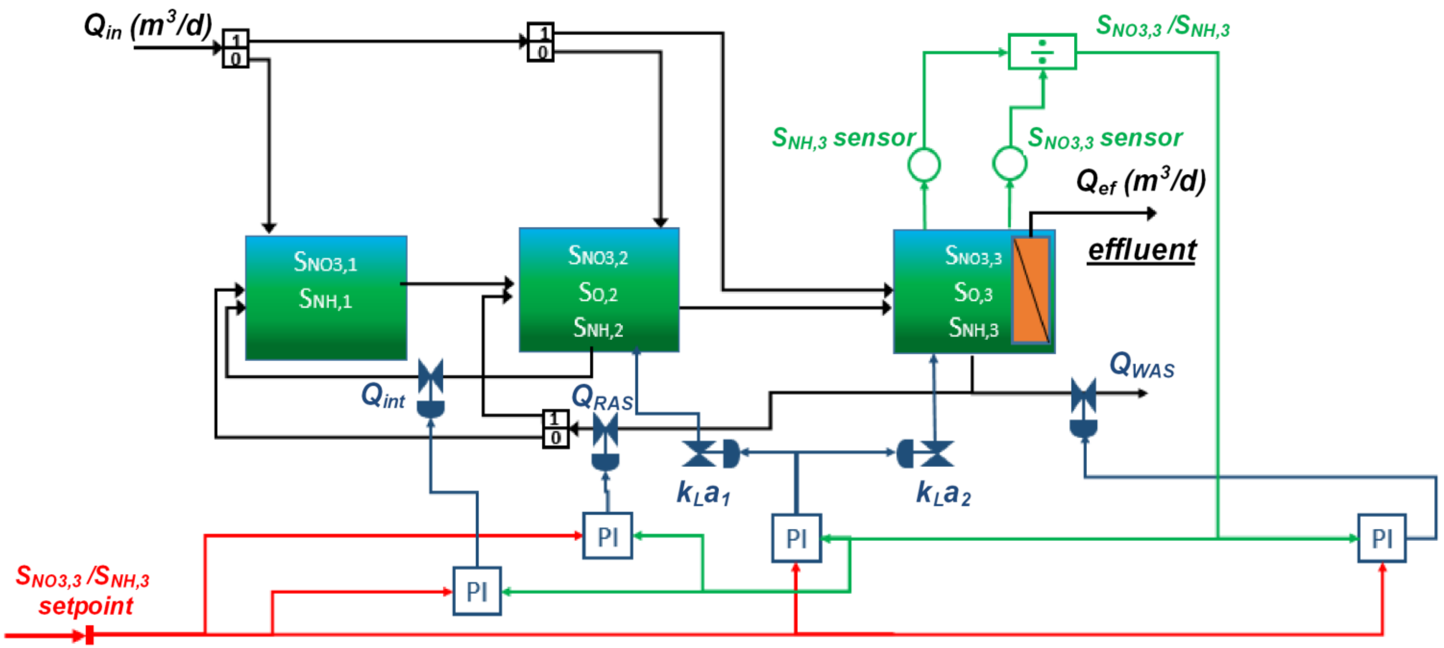




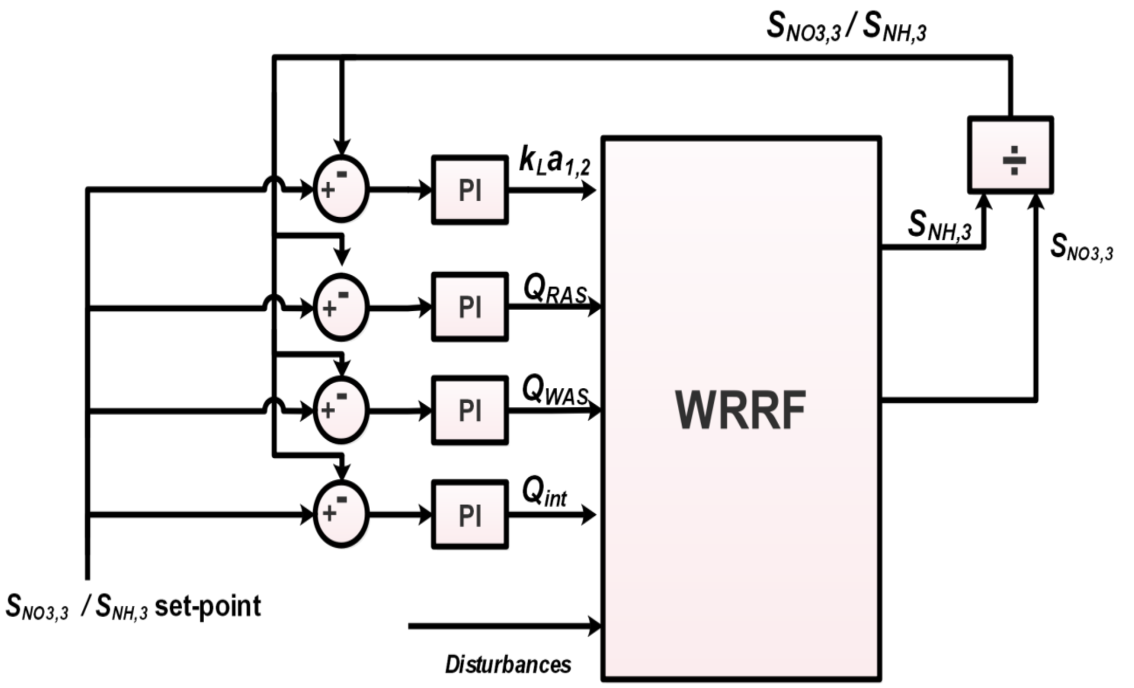
Closed loop control of the quotient NO3/NH4

Four simple PI controllers

Allow the control of the ratio using k_La_1 and k_La_2, the recirculations Q_{int} and Q_{RAS} and the SRT using Q_{WAS}



Closed loop control of the quotient NO3/NH4



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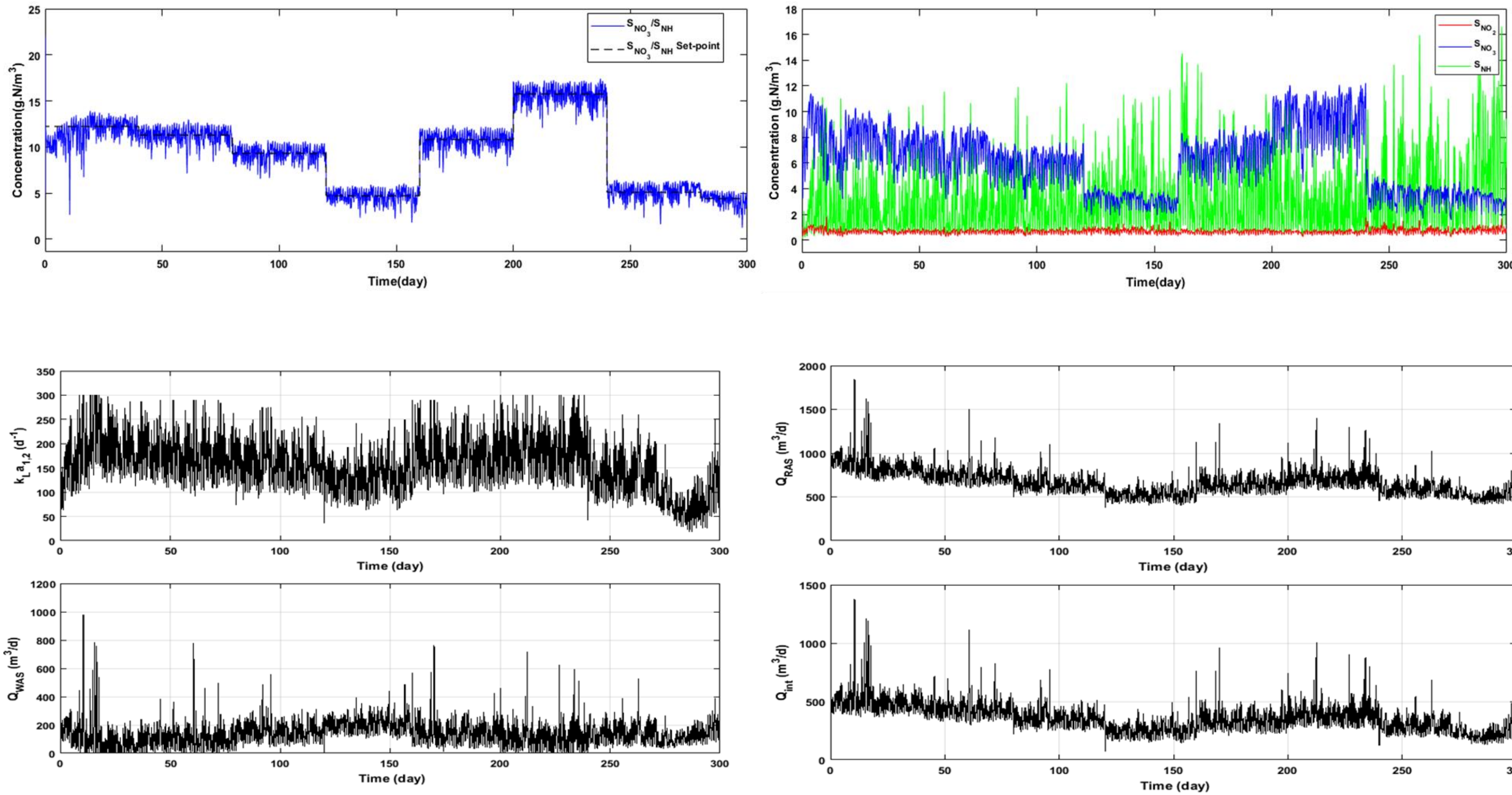

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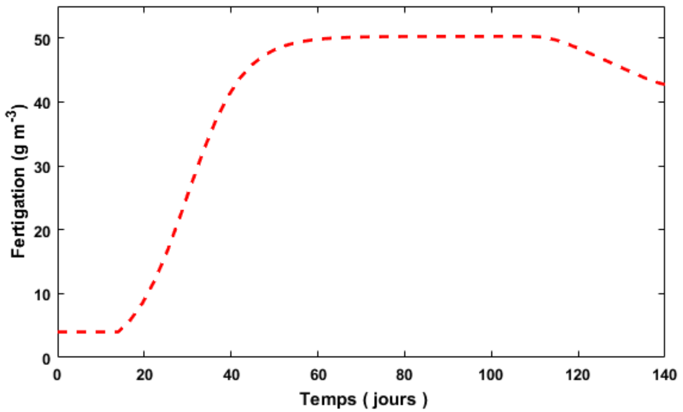
Assembling models (FP operated using setpoints generated using plant model)

Optimal setpoints generation

- Kenza Boumaza, Nesrine Kalboussi, Alain Rapaport, Sébastien Roux, Carole Sinfort. Optimal control of a crop irrigation model under water scarcity. Optimal Control Applications and Methods, Wiley, 2021, 20 p. ⟨10.1002/oca.2749⟩. ⟨hal-03226630⟩
- Nesrine Kalboussi, Alain Rapaport, Térence Bayen, Nihel Ben Amar, Fatma Ellouze, et al.. Optimal control of membrane filtration systems. IEEE Transactions on Automatic Control, 2019, 64 (5), pp.8704-8709. ⟨10.1109/TAC.2018.2866638⟩. ⟨hal-01854430⟩

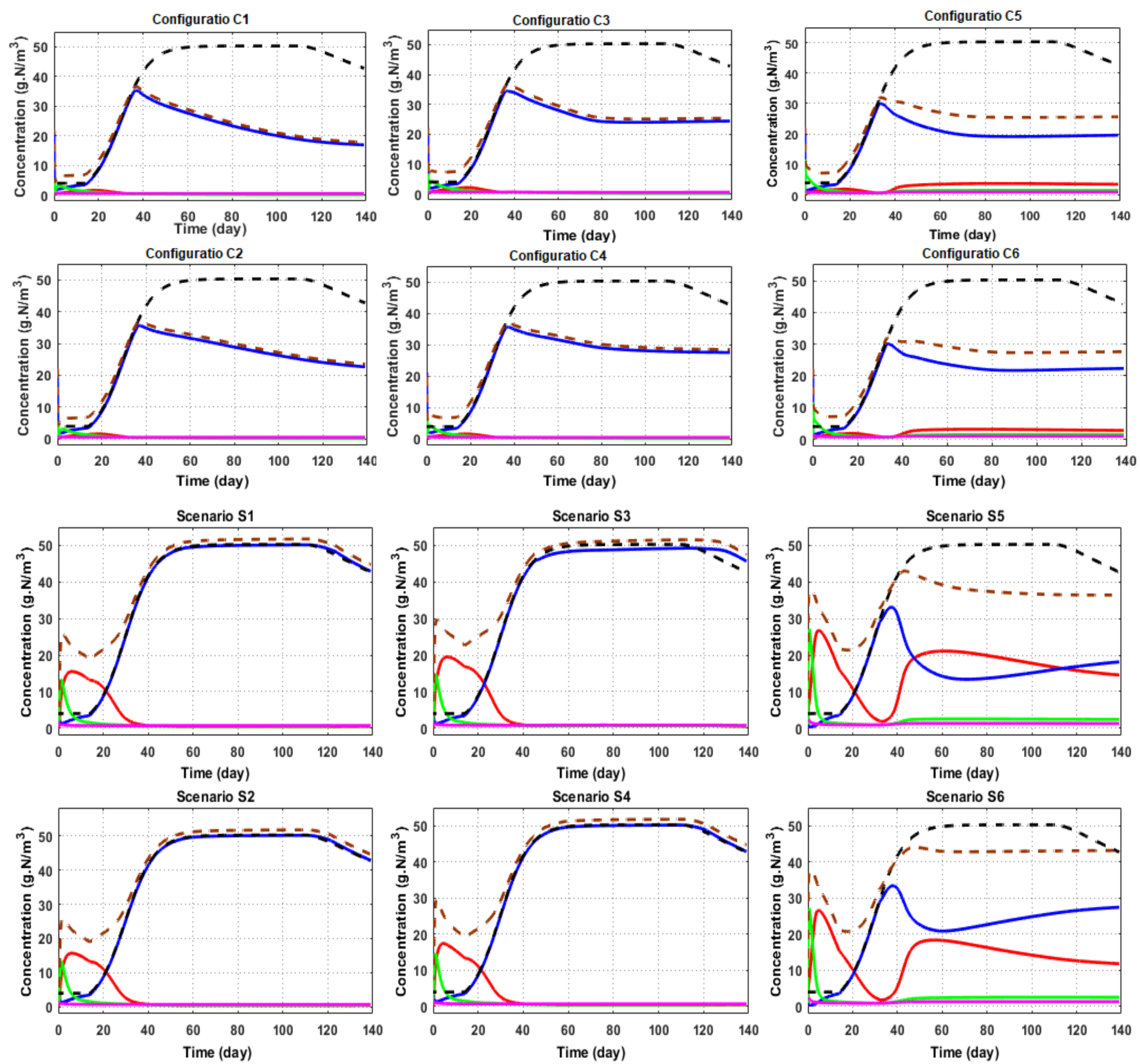


Results (nitrate control)

Nin=30 mg/l

Valve A	Valve B	Valve C	Configuration
0	0	0	C1
0	0	1	C2
1	0	0	C3
1	0	1	C4
1	1	0	C5
1	1	1	C6

Nin=50 mg/l



Indices for choosing the best configuration

Total nitrogen recovered= $\int_0^{T_{simulation}} N_{tot}(t)Q_{ef}(t)dt$

$$Pumping\ Energy = \frac{1}{T_{simulation}} \sum_{i=1}^{N} PF_i \int_0^{T_{simulation}} Q_i(t)dt$$

$$Aeration\ Energy = \frac{S_O^{sat}}{T_{simulation} \times \rho} \int_0^{T_{simulation}} V_{R2}K_La_1(t) + V_{R3}K_La_2(t)dt$$

$\boldsymbol{\rho}$: transfert efficacity [g] of oxygen per [kWh]

Indices for choosing the best configuration

	Complete treatment	C1	C2	C3	C4	C5	C6
ANTS [kg]	21720	49960	57730	57890	62860	58010	62070
ANTD [kg]	22089	72570	84810	80890	88970	78460	82880
PES $[KWh\ j^{-1}]$	2909.2	2639.6	2403.2	2889.2	2499.8	2873.2	2811.3
PED $[KWh\ j^{-1}]$	3714.2	3201.8	3003.2	3489.2	3299.8	3493.4	3425.1
AES $[KWh\ j^{-1}]$	13959.3	13799.8	13145.3	13656.1	13355.7	13822.7	13799.1
AED $[KWh\ j^{-1}]$	14681.3	14291.1	14055.2	13922.5	14009.8	14398.9	14299.0

Conclusions and perspectives

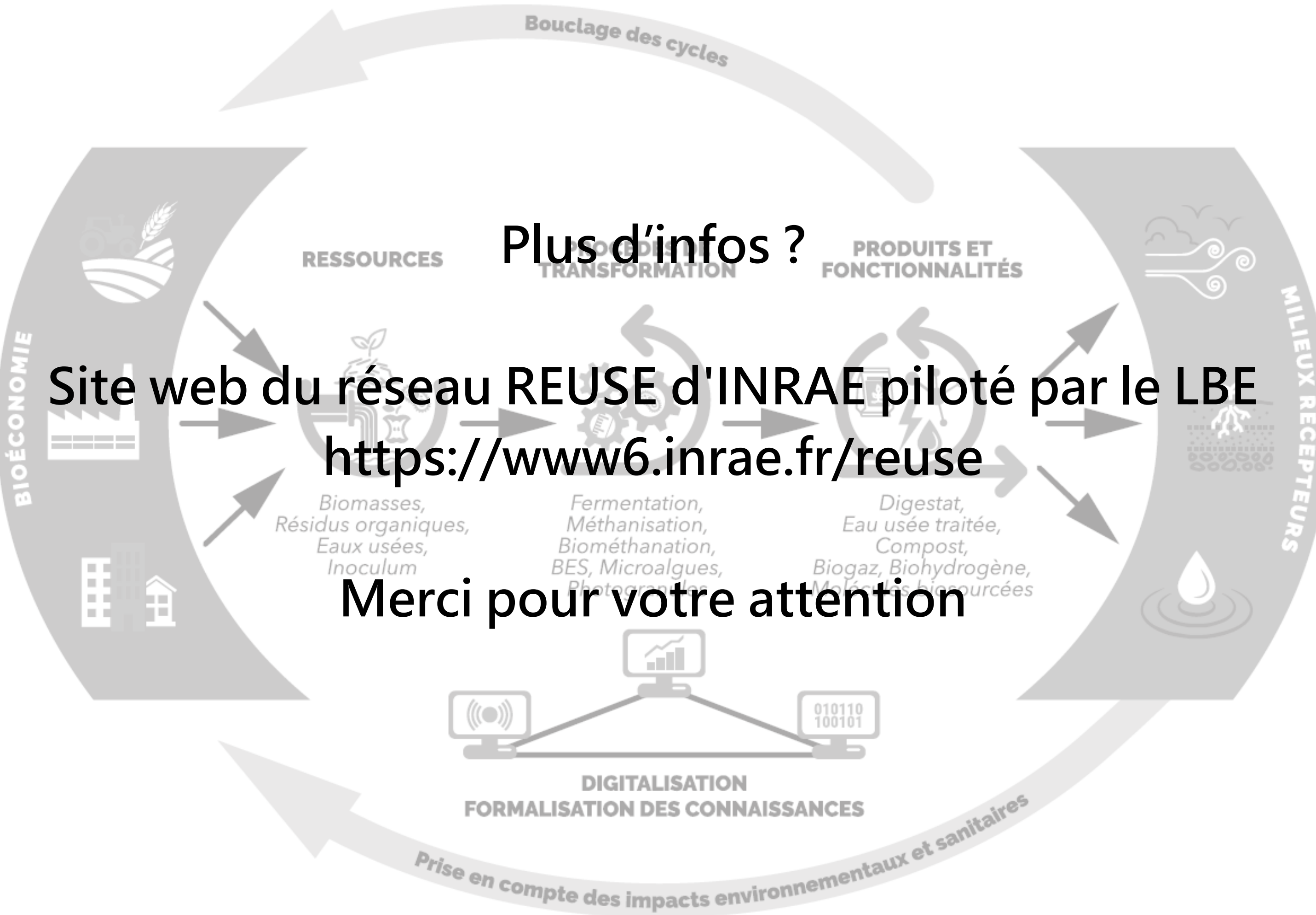
Conclusions and perspectives

- The appropriate control of a flexible platform allows to recover nitrogen from WW
- Using plant models allows to generate optimal setpoint for this platform
- Flexibility allows contributing to a better circular economy of water and nutrients
- Perspectives include:
    - Consider P and K
    - Include micropollutant dynamics
    - Implement other scenarios
    - Manage online mode switching
    - Implement more advanced controllers
    - …

Plus d’infos ?

Site web du réseau REUSE d'INRAE piloté par le LBE
https://www6.inrae.fr/reuse

Merci pour votre attention



Mes copains ne l'savent pas mais
je ne sais pas nager…
Par le plus grand des hasards,
aurais tu des bouées?

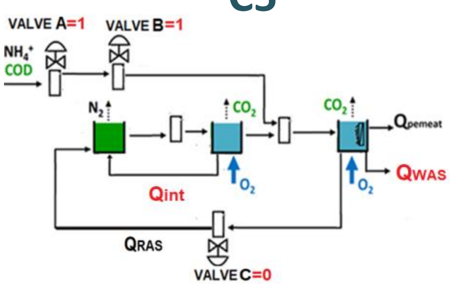
Managing transitions between different modes should be optimized: Example #1

1er transition à l'instant 100 jours

2ème transition à l'instant 200 jours

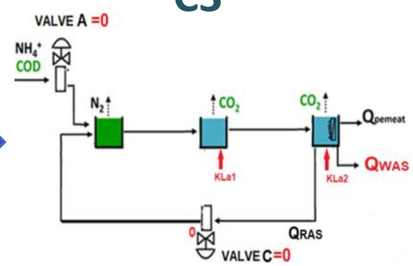
Mode NH4+

C5



Mode NO3-

C3



$V_1 = 56$ L ; $V_2 = 56$ L ; $V_3 = 40$ L

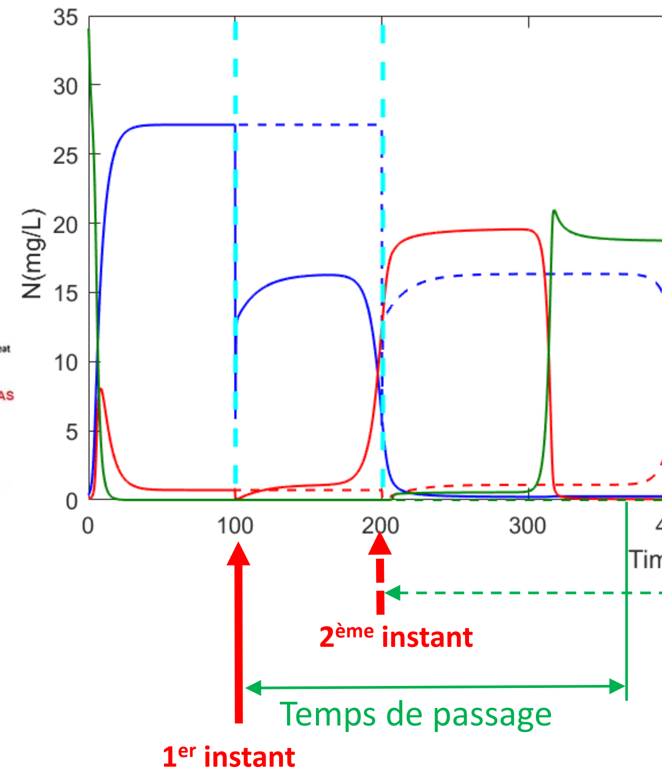
$Q_{Ras} = Q_{int} = 0$

$Q_{WAS} = 32{,}4$ L/jour

$Q_{Ras} = 270$ L/Jour

$Q_{WAS} = 1{,}4$ L/jour

Concentrations d'ammonium (ble… (rouge) pour la transition à 100 jo… jours (ligne pointillées)



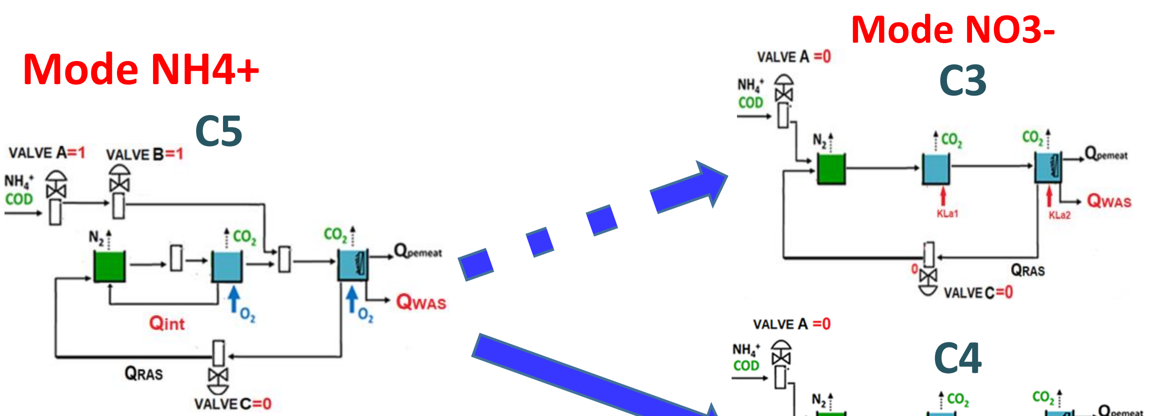
Les conditions initiales différentes des bactéries nitrifiants au mome… transition expliquent la différence observée dans le temps de répons…

Managing transitions between different modes should be optimized: Example #2

De C5 à C3 : lignes pointillées

De C5 à C4 : lignes continues

Dans C3, Q_{ras} est dirigé vers l'anoxie, tandis que dans le C4, le Q_{Ras} est dirigé vers l'aérobie.

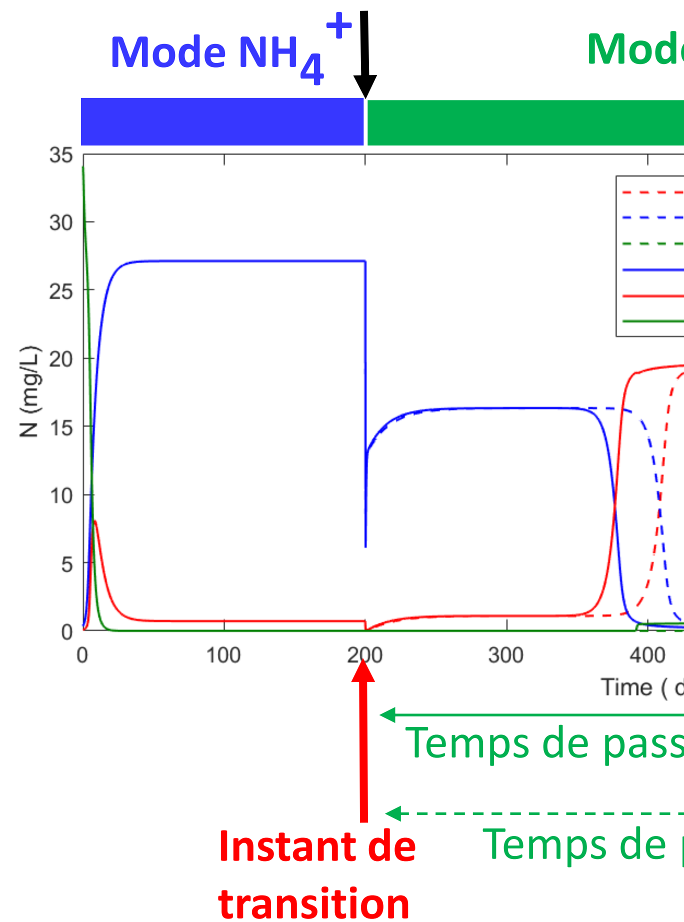


$Q_{Ras} = Q_{int} = 0$

$Q_{WAS} = 32{,}4$ L/jour

$Q_{Ras} = 270$

$Q_{WAS} = 1{,}4$ L/jour



La première transition (C5 à C3) est plus lente que la seconde (C5 à C4)