New Advances in Process Control and Modeling for WWTPs/WRRFs

Metropolitan Water Reclamation District of Greater Chicago

Chicago, IL

24 JUN 2016

Peter VANROLLEGHEM

Canada Research Chair in Water Quality Modelling

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Content of the seminar

- Three recent and ongoing developments on modeling and control in my research team

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Content of the seminar

- Three developments on modeling and control in my research team:
  - Modeling and control of the integrated urban wastewater system (sewer, treatment plant and receiving water body)
  - Modeling and control of greenhouse gas emissions and the impact of climate change on WWTPs
  - Modeling and control of resource recovery in WRRFs (water resource recovery facilities)

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Water quality-based control evaluation by means of an integrated urban wastewater model

Sovanna Tik, Thibaud Maruéjouls, Paul Lessard, Peter Vanrolleghem

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Introduction

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Introduction – Context

- CSO
  - Major source of pollution of urban rivers
  - Insufficient evaluation in practice
    - Quantity (on occasion – rudimentary)
    - Quality (rare)
- Real Time Control (RTC)
  - Cost ? → instrumentation VS construction
  - Effectiveness ? → modelling…

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Introduction – Challenges

- Many discharge points
- Challenging conditions
  - Installation
  - Cleaning
  - Maintenance

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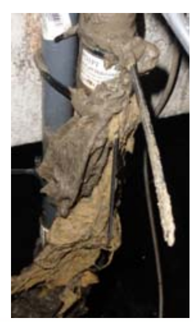

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Objectives

- Evaluate the global impact of an urban wastewater system on the receiving water
  - →Integrated model
  - →Focus on particulate pollution
- Show the interest of developing water quality based control strategies
  - →Quantity- VS quality-based control

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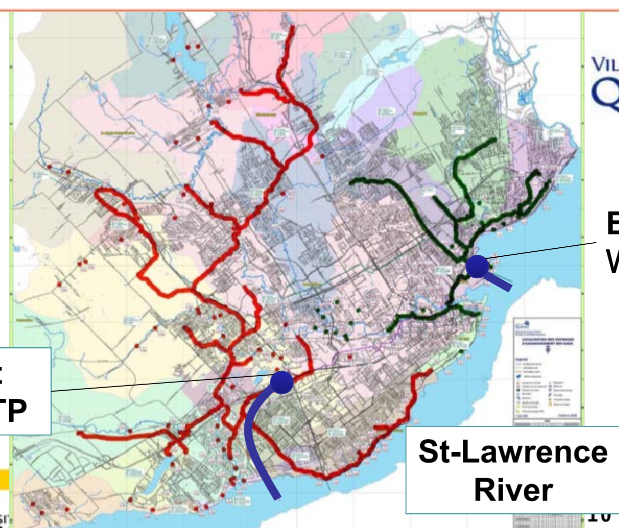
Methods – Case study Québec

VILLE DE QUÉBEC



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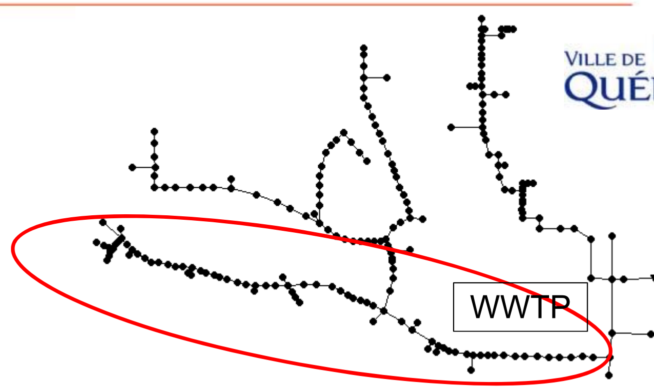
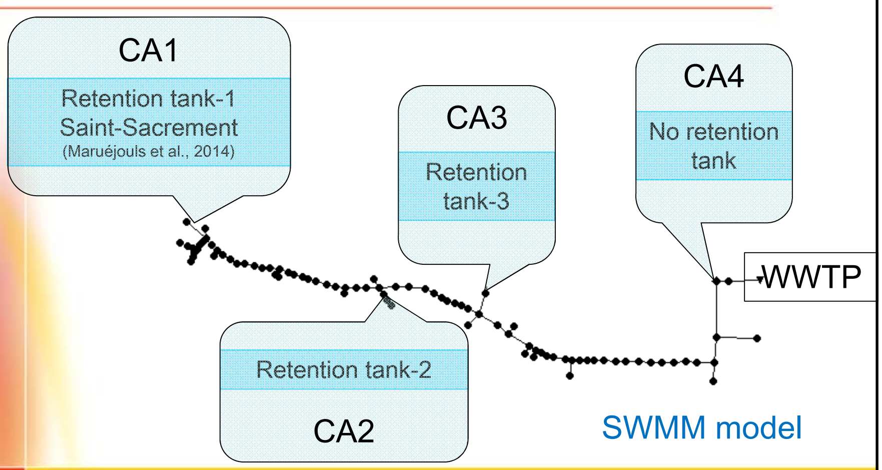
Methods – Case study Québec



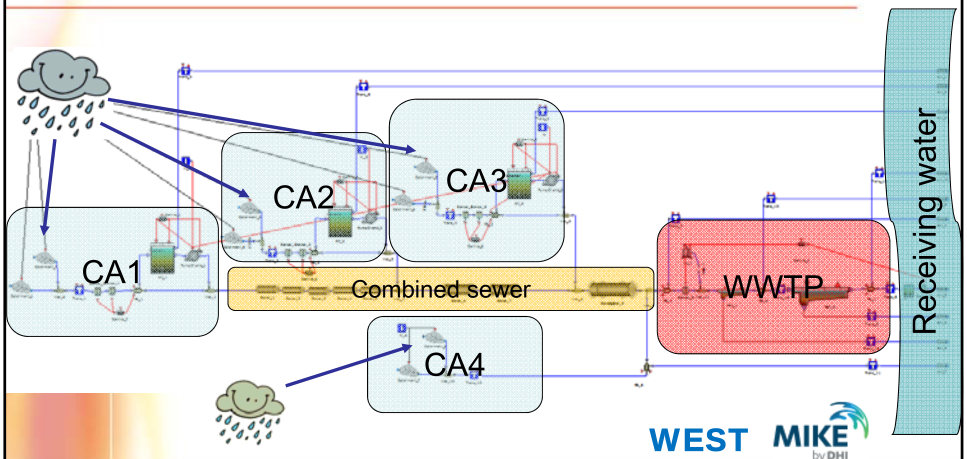
Methods – Québec case study



SWMM model

Reference : Maruéjouls, Lessard and Vanrolleghem (2014) – *Urban Water Journal*

Methods – Integrated model



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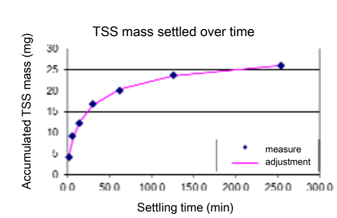
Methods – ViCAs

Vitesse de Chute en Assainissement (ViCAs)

=

Sewage settling velocity



Reference : Chebbo and Gromaire (2009) – *Journal of Environmental Engineering*

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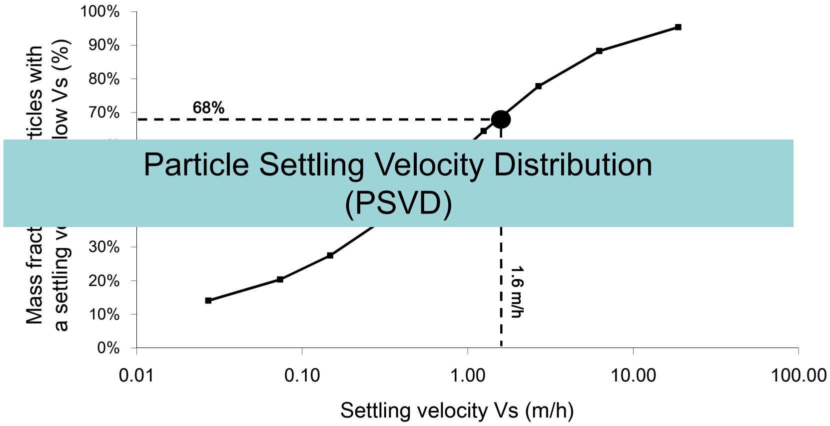
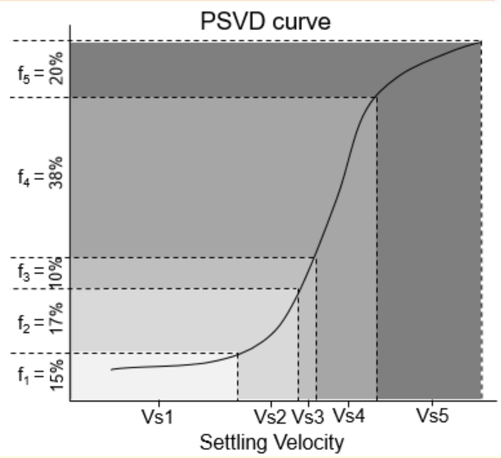
Methods – ViCAs

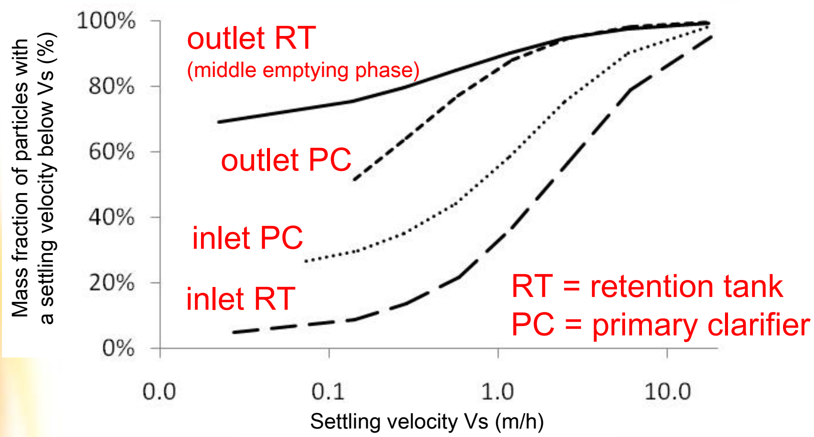


Reference : Chebbo and Gromaire (2009) – *Journal of Environmental Engineering*

Methods – PSVD



Methods – Typical PSVD



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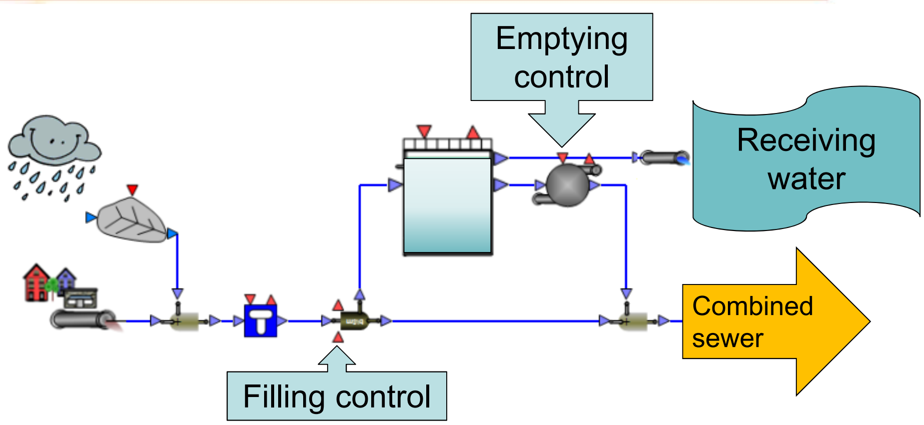
Methods – CA and RT sub-system



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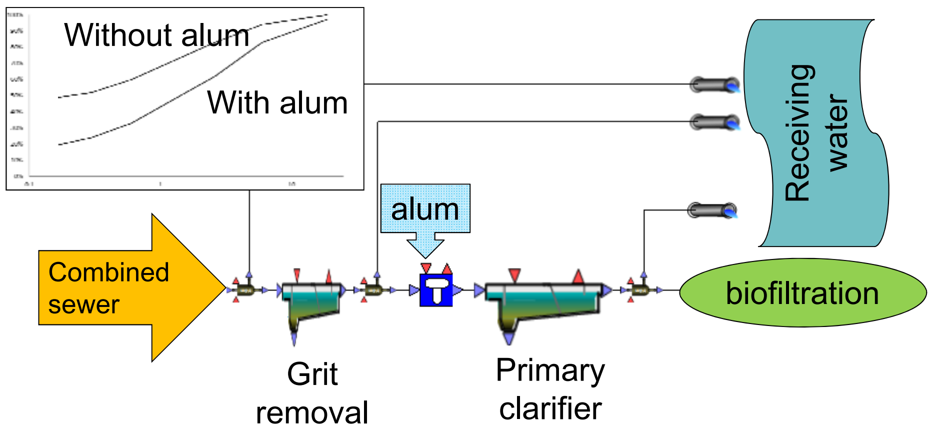
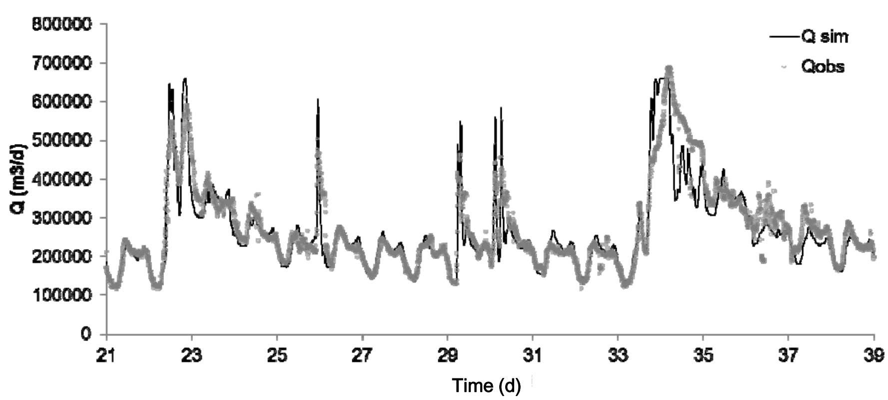
Methods – WWTP sub-system



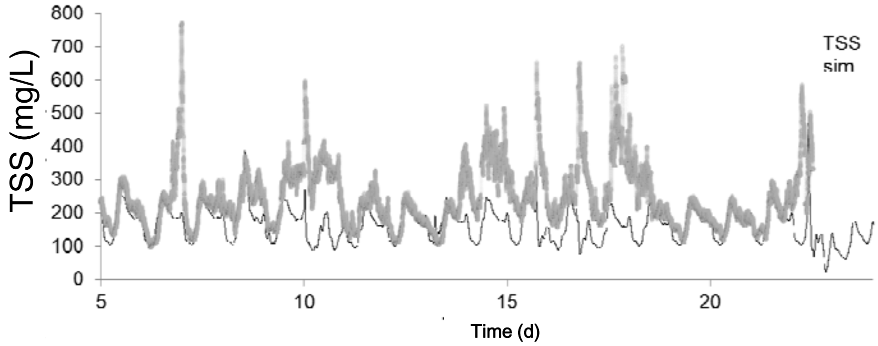
Methods – Model calibration

- Flow at the inlet of the WWTP



Methods – Model calibration

- TSS at inlet of primary clarifiers



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Methods – RTC comparison

- Wastewater discharges in receiving water without primary treatment
  - Volume of water discharged
  - Load of TSS discharged
- Retention tanks usage time
- Amount of alum added

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Results

- Two rain events evaluated in detail
  - Average intensity (20 mm in 24h)
  - High intensity (58 mm in 19h)
- Reduction by WQ-based RTC of the WW discharges not receiving primary treatment

Rain intensity	Volume	TSS-load
Average	-32%	-40%
High	-18%	-25%

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Results

- At the retention tanks

	Rain intensity	Max volume	Usage time
Quantity-based	Average	42%	32h
	High	100%	36h
Quality-based	Average	58%	35h
	High	100%	43h

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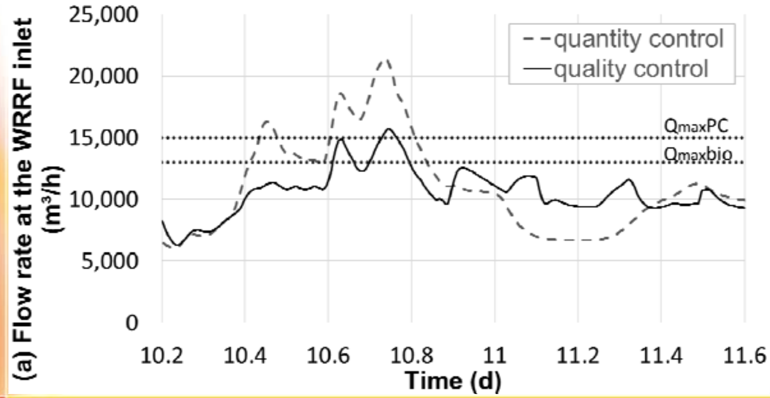
Results

- At the WWTP inlet (flow rate – average rain)



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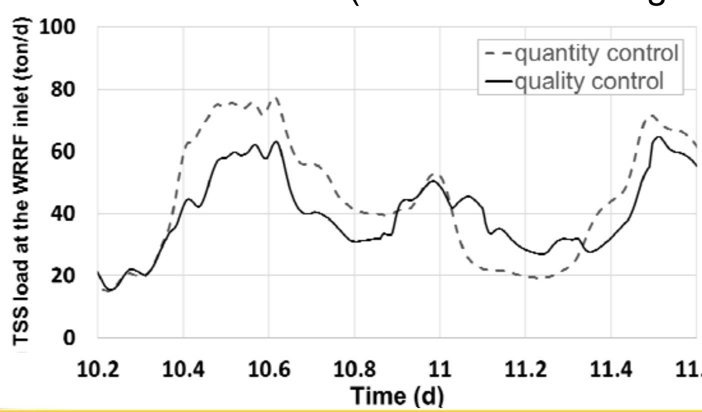
Results

- At the WWTP inlet (TSS load – average rain)



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Results

- Increase of alum consumption

Rain intensity	Injection time	Amount of alum used
Average	+43%	+35%
High	+41%	+36%

Take home

- Advantages
  - Reduction of discharges into receiving water
    - Volume (+)
    - Load (++)
  - Biofilter clogging is expected to be reduced
- Disadvantages
  - Higher retention tanks usage time
  - Higher alum addition

Acknowledgements – Integrated RTC

Ville de Québec

leLYRE

CRSNG NSERC

Fonds de recherche sur la nature et les technologies Québec

Climate change and wastewater management – a two-way street

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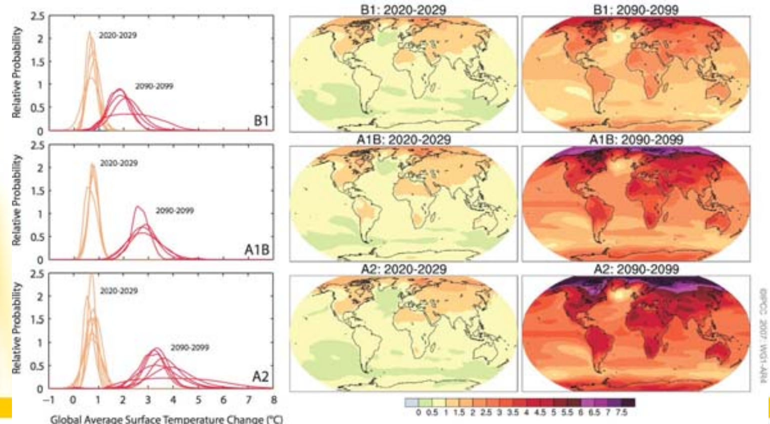
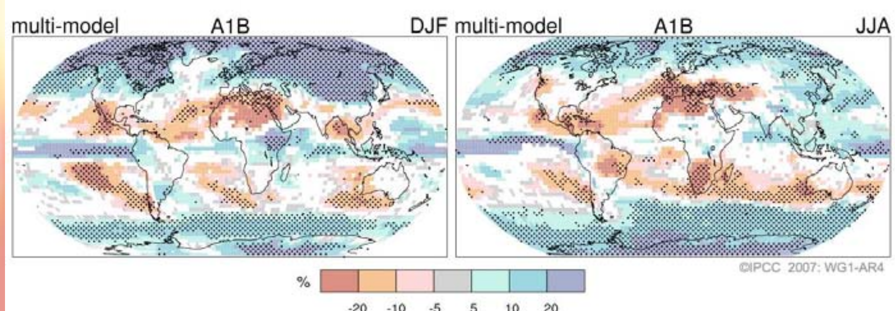
Climate change

- Global warming… (3 scenarios)



Climate change (cont'd)

- … and precipitation (winter - summer)



Potential effects of climate change

- Higher temperatures

  => Faster reaction rates

  - More important algae growth
  - Increased biodegradation activity
  - Faster oxygen depletion

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Potential effects of climate change

- More intense rains
  - More important erosion, more run-off
  - Higher flow rate in (combined & storm) sewers
    - Resuspension and transport of sediments
    - Increased number/volume of overflows

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Copenhagen
Lyngbyvej
16 Aug. 2010
Photo: Bente Schou

Potential effects of climate change

- More intense rains
  - More important erosion, more run-off
  - Higher flow rate in (combined & storm) sewers
    - Resuspension and transport of sediments
    - Increased number/volume of overflows
    - Overloads on treatment plants (wet weather operation)
  - Higher flow rate in rivers
    - Resuspension and transport of sediments
    - Hydromorphology affected, « eco-hydraulics »

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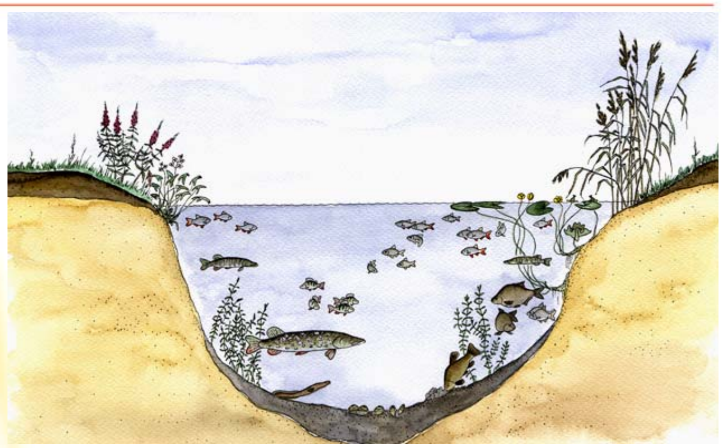
Potential effects of climate change



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Potential effects of climate change

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Questions to be answered:

- How to manage infrastructures that have a lifetime of 30 years (wastewater treatment), or even 100 years (storm and combined sewers)?
- What characteristics of these infrastructures must we focus on and develop <u>now</u> in view of the changes (climate and others) we anticipate?
- What can we do?

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What can we do? Retention!

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What can we do? Flexible retention!

- RTC = Real-time Control
- Improved combined sewer retention tank operation

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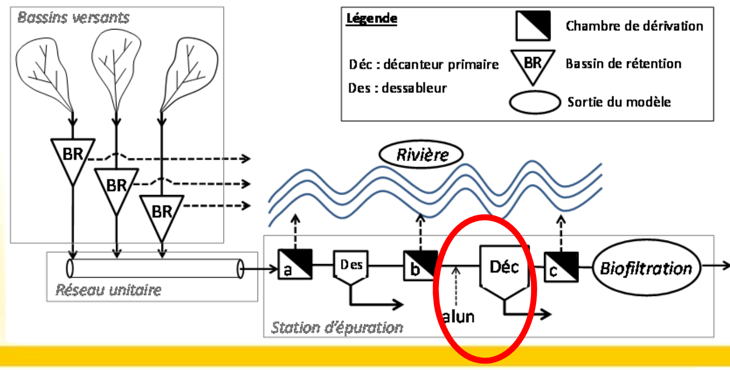
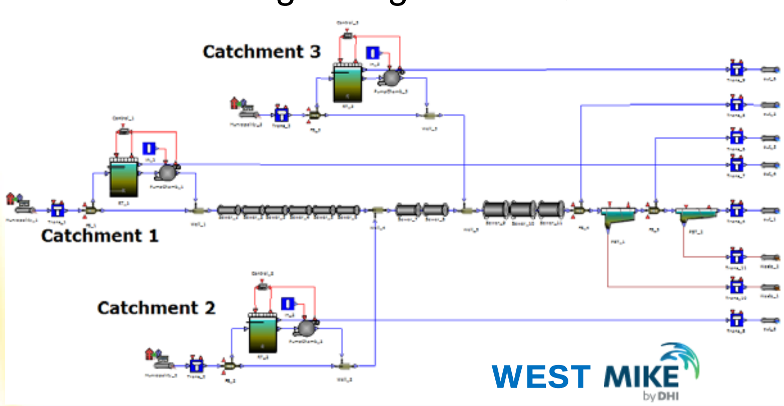
What can we do? RTC!

- Improved retention tank operation to minimize WWTP overload

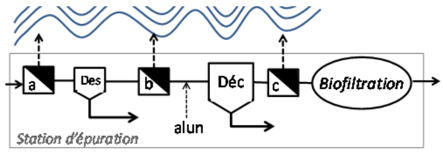


What can we do? RTC!

- Evaluation through integrated WQ simulation



What can we do?



- Discharges for different operating scenarios
  - Optimal emptying scenario depends on
    - Weather forecast
    - Current treatment capacity

	Location of overflow	*Scenario* 0	1	2	3	4	5	6	7	8
Discharged Volume (m³)	a	2430	2430	2430	0	0	0	0	0	0
	b	2038	2038	2038	1943	1943	1943	0	0	0
	c	8041	8041	4394	8997	8997	4777	9691	9691	5187
	Total	12509	12509	8862	10940	10940	6720	9691	9691	5187
Discharged Solds (kg)	a	259	259	259	0	0	0	0	0	0
	b	211	211	211	188	188	188	0	0	0
	c	441	136	68	478	147	71	500	154	76
	Total	911	606	538	666	335	259	500	154	76

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Climate change and wastewater management – a two-way street (Part II)

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Wastewater utility GHG

- Greenhouse gases in wastewater systems:
  - CO_2 (Biodeg., energy, chemicals) 1 CO_{2eq}
  - CH_4 (Anaerobic digestion) 34 CO_{2eq}
  - N_2O (Nitrogen removal) 265 CO_{2eq}

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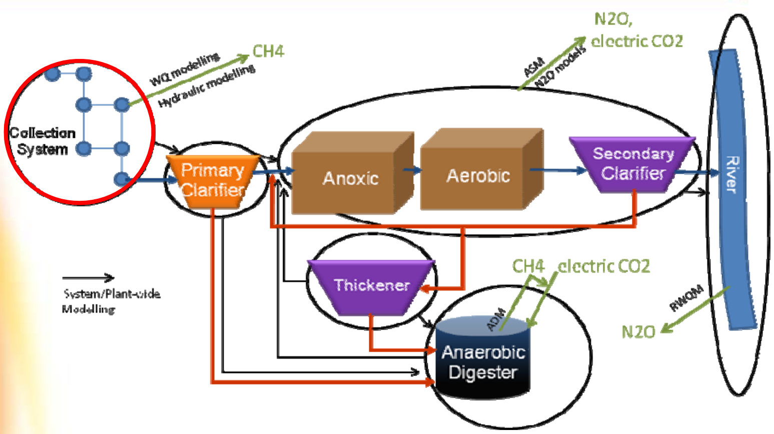
Wastewater utility GHG



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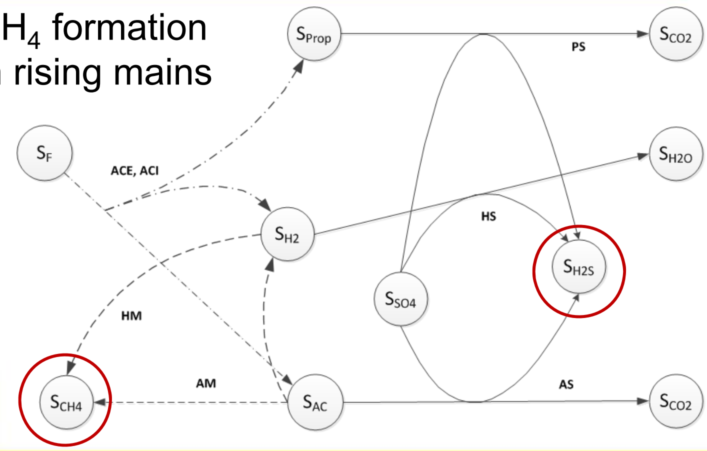
GHG in sewer systems

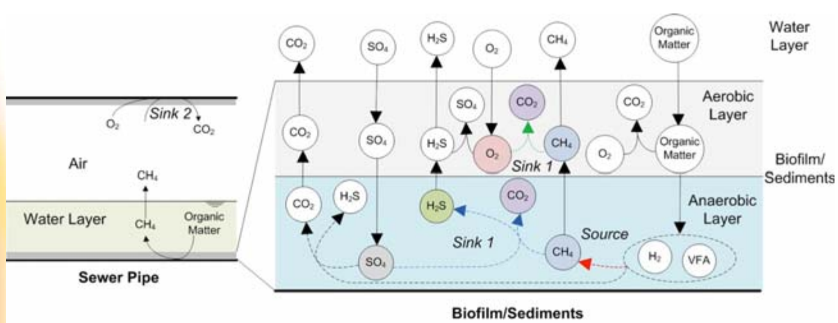
- CH_4 formation in rising mains



Guisasola et al. (2009) Water Res. 43: 2874-2884

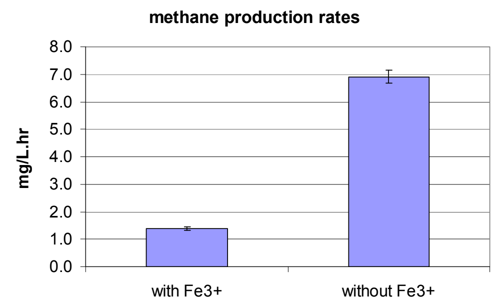
GHG in sewer systems

- CH_4 formation in gravity sewers (with O_2 transfer)



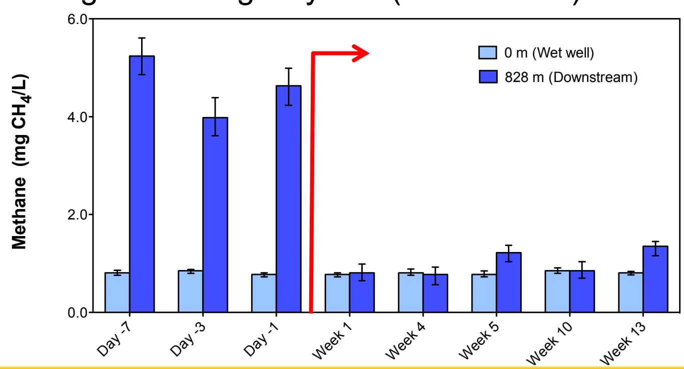
What can we do? Add chemicals!

- Chemicals used for sulfide control
  (Brisbane: 6 M$/yr repair → 1 M$/yr chemical addition)
  also reduce methane formation

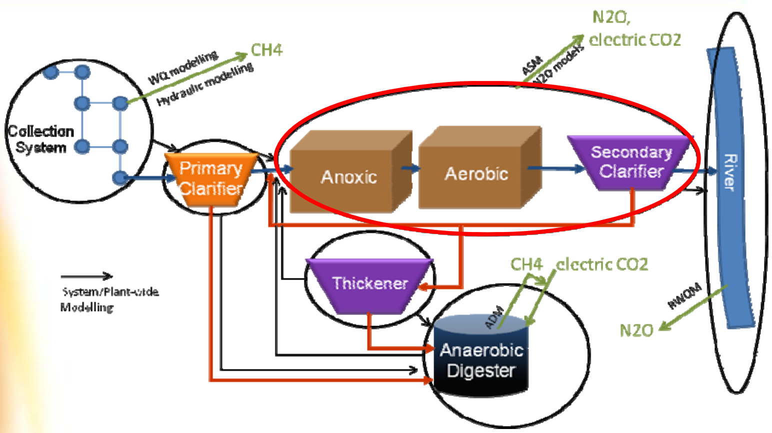


What can we do? Add chemicals!

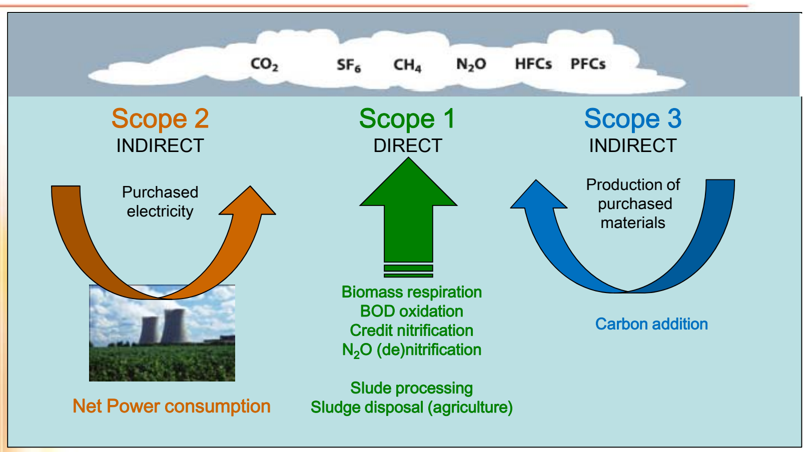
Acidified nitrite was added in the sewer intermittently at 100 mg N/L during Day 0–2 (for 33 hours)



Wastewater utility GHG



GHG emissions from WWTP



Evaluation of GHG emissions

- Different approaches to estimate GHG emissions:
  - Empirical factors:
    - e.g. IPCC, 2006; LGO, 2008; NGER, 2008
  - Simple comprehensive models:
    - e.g. Cakir and Stenstrom, 2005; Monteith *et al.*, 2005; Bridle *et al.*, 2008; Foley *et al.*, 2009
  - Dynamic deterministic models:
    - ASMG1 (Guo & Vanrolleghem, 2014) → N_2O
    - ADM1 (Batstone et al., 2002) → CH_4

+ complexity

BSM2G benchmarking platform

Corominas et al. (2012)
Biotechnol. Bioeng., 109, 2854-2863

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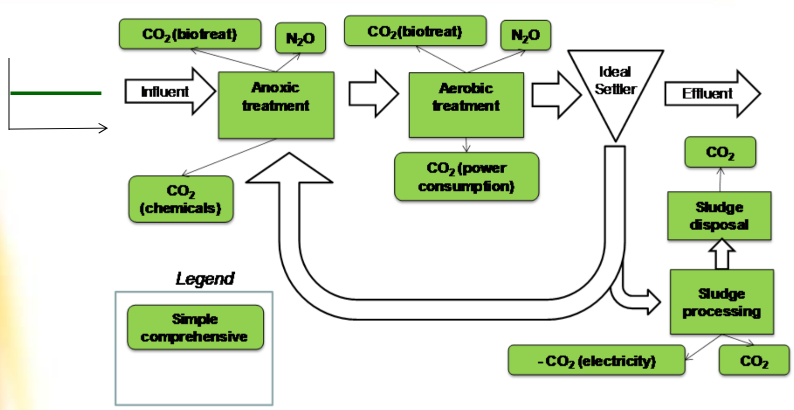
Evaluation of GHG emissions



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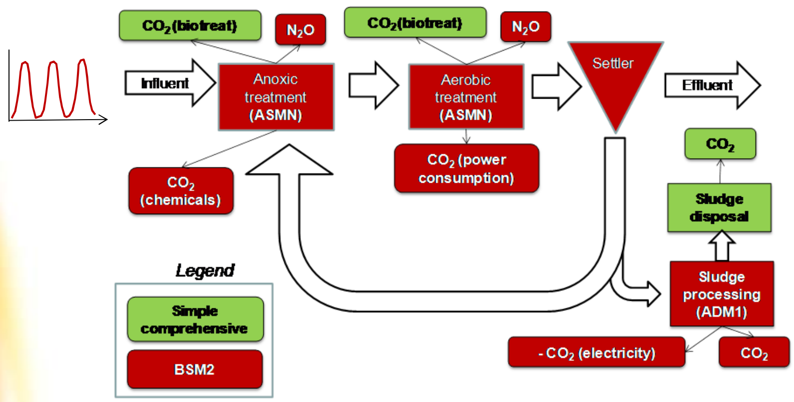
Evaluation of GHG emissions



Corominas et al. (2012)
Biotechnol. Bioeng., 109, 2854-2863

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What can we do? Control!

- Comparison of ***no control*** and ***yes control*** (DO control in aerobic reactors, DO = 2mg·L^{-1})

Breakdown of GHG emissions (kg CO_2e·m^{-3})	No control	Yes control	%
Bio-treatment GHG emissions	0.451	0.376	-17
Biomass respiration	0.179	0.178	-1
BOD oxidation	0.212	0.212	0
Credit nitrification	-0.168	-0.167	-1
N_2O emissions	0.228	0.152	-33
Sludge processing GHG emissions	0.231	0.231	0
Net power GHG emissions	0.000	-0.038	-
Power	0.311	0.272	-13
Credit power GHG emissions	-0.311	-0.310	0
Embedded GHG emissions from chemical use	0.099	0.099	0
Sludge disposal and reuse GHG emissions	0.193	0.193	0

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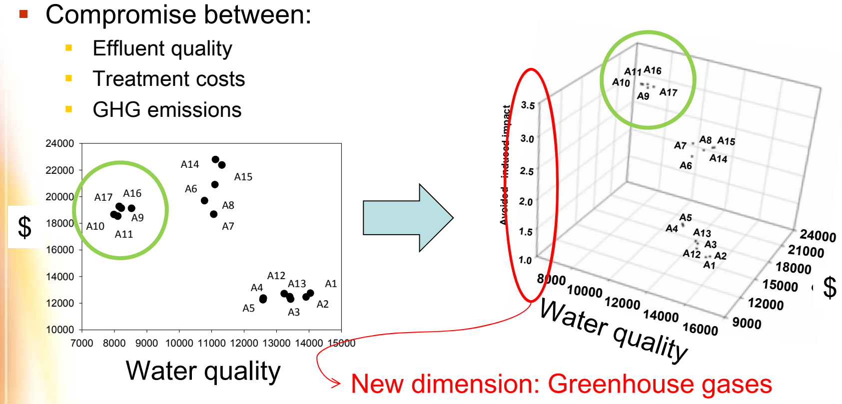
Benchmarking control strategies

- Overall result of our studies so far:
- Compromise between:
  - Effluent quality
  - Treatment costs
  - GHG emissions



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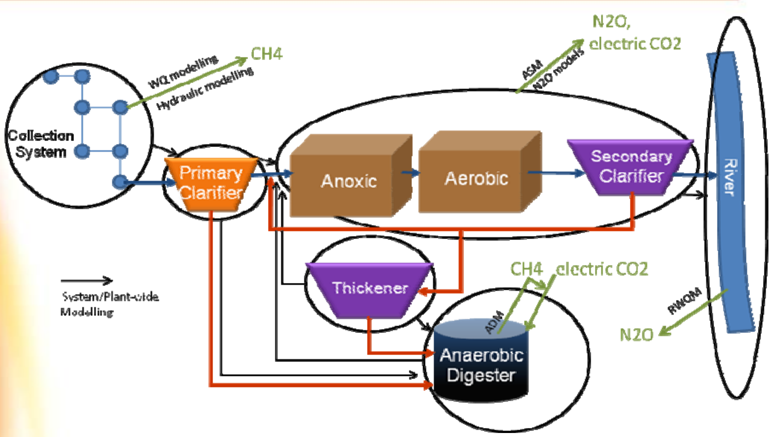
Wastewater utility GHG



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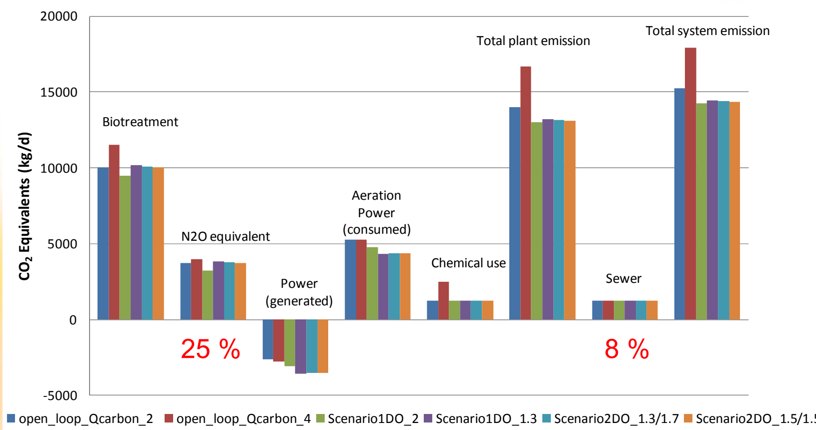
GHG emissions from a WW utility



Take home

- Climate change and wastewater management - A two way street

Take home

- Wastewater systems emit greenhouse gases

The revenge …

Take home

- Climate change and wastewater management - A two way street:
  - Mitigation
  - Adaptation

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Take home

- Mitigation
  - Reduce GHG emissions
    - Sewer → chemical addition
    - WWTP → improved operation,
      but compromise with effluent quality
- Adaptation
  - Pursue flexibility in long-living WW systems
    - Sewer → Retention tank operation – RTC
    - WWTP → Wet weather handling – RTC

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Acknowledgements for GHG work

Canada Research Chair in Water Quality Modelling

Otto Mønsted

Développement économique, Innovation et Exportation Québec

Universiteit Gent

BIOMATH

TU Delft

Waterschap De Dommel

Nordea Fonden

Seventh Framework Programme

Resource Recovery from Wastewater and Sludge: Modelling and Control Challenges

Peter VANROLLEGHEM and Céline VANEECKHAUTE

Outline

- Water resource recovery
- Modelling challenges
- Control challenges
- Take home

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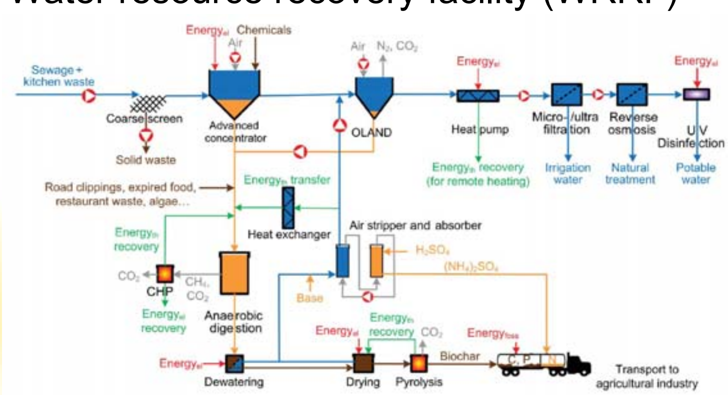
"Wurfs"

- Water resource recovery facility (WRRF)



Verstraete & Vlaeminck (2011)
Int. J. Sust. Dev. World Ecol., 18, 253-264.

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Resource recovery processes

- Stripping (NH_3, fatty acids)
- Air scrubbing (ammonium sulfate)
- Precipitation (struvite, Ca-phosphate)
- Filtering (paper fibers)
- Extraction (PHA)
- Ion exchange (NH_4^+)
- Reverse osmosis (H_2O, N-K concentrates)
- Phase separation (butanol)
- Pyrolysis, gasification, incineration (energy)
- Chemically enhanced primary treatment (COD)

All physico-chemical unit processes

Outline

- Water resource recovery
- Modelling challenges
- Control challenges
- Take home

Modelling physicochemical processes

- We've done it simply:
  - Aeration: Kla (C_{sat}-C)
  - pH: f(pKa, TAN, Alk, …)
  - Precipitation: MeOH/MeP
  - Membrane: $J = TMP/\mu.(R_m+R_f+R_c)$

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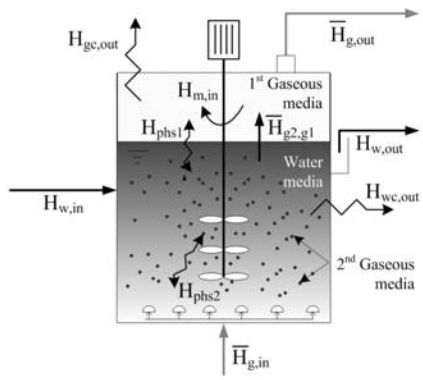
Modelling physicochemical processes

- We have to do it differently:

  Temperature:



Fernandez-Arevalo T., Lizarralde I., Grau P., Ayesa E. Water Res., 60, 141-155 (2014)

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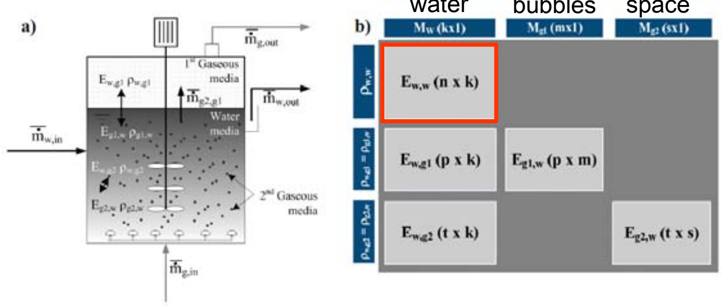
Modelling physicochemical processes

- We have to do it differently:

<u>Gas exchange:</u>

water bubbles head-space



Fernandez-Arevalo T., Lizarralde I., Grau P., Ayesa E.
Water Res., 60, 141-155 (2014)

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Modelling physicochemical processes

- We have to do it differently:

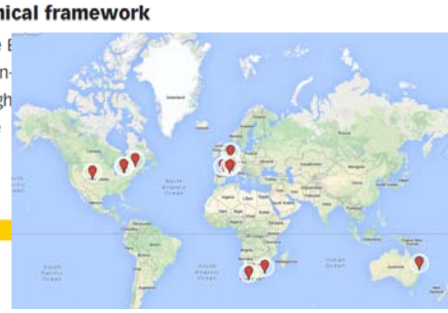
<u>Precipitation:</u>

1147 © IWA Publishing 2012 Water Science & Technology | 66.6 | 2012

Towards a generalized physicochemical framework

Damien J. Batstone, Youri Amerlinck, George E
Paloma Grau, Bruce Johnson, Ishin Kaya, Jean-
Stephan Tait, Imre Takács, Peter A. Vanrollegh
Christopher J. Brouckaert and Eveline Volcke

ABSTRACT



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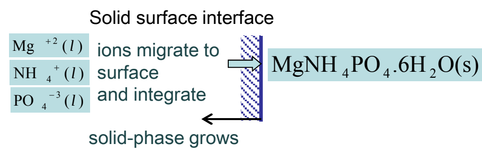
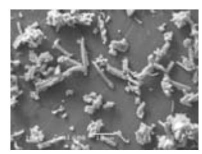
Modelling physicochemical processes

- We have to do it differently:

Precipitation:





Modelling physicochemical processes

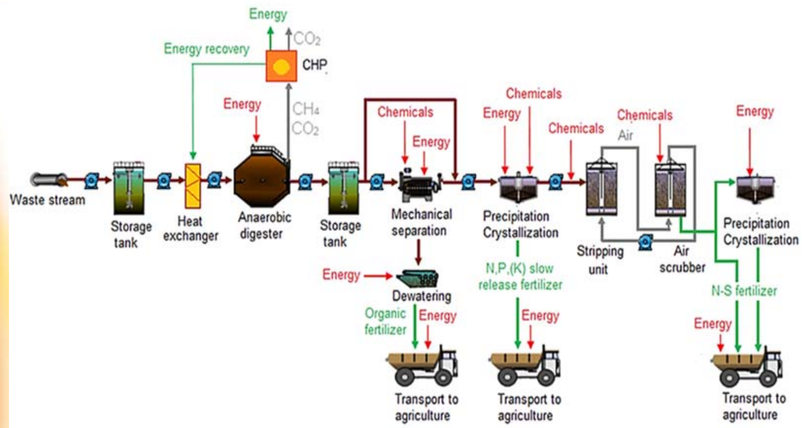
- We have to do it differently:

Precipitation:

It gets a little crowded in wastewater

Mg^{2+} HCO^{3-} $CaOH^+$ $NaHPO_4^-$ Ca^{2+} $MgHCO_3^+$ $CaHPO_4$ (aq) $MgH_2PO_4^+$ $CaAc^+$ Na^+ Cl^- $CaHCO_3^+$ Mg^{2+} $NaHCO_3$ (aq) SO_4^{2-} $NaCO_3^-$ $NaSO_4^-$ HPO_4^{2-} $MgSO_4$ (aq) $CaSO_4$ (aq) K^+ CO_3^{2-} Na^+ NaAc (aq) $CaCO_3$ (aq)

Model-based optimization of resource recovery trains in WRRFs



Céline Vaneeckhaute (2015)
PhD thesis, Université Laval

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Outline

- Water resource recovery
- Modelling challenges
- Control challenges
- Take home

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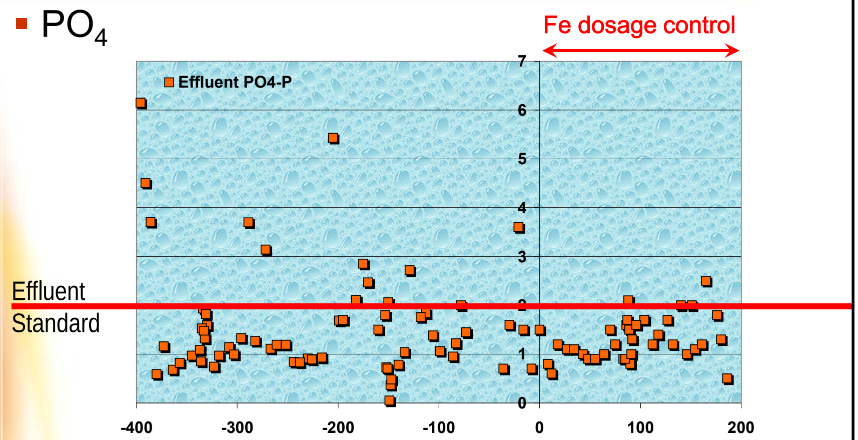
Successful control in WWTP

- PO_4



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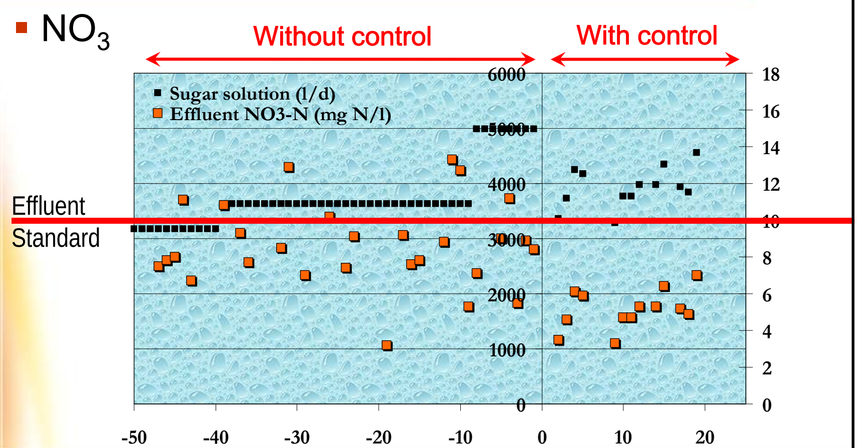
Successful control in WWTP

- NO_3



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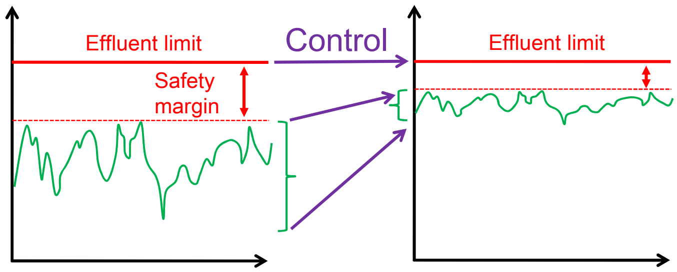
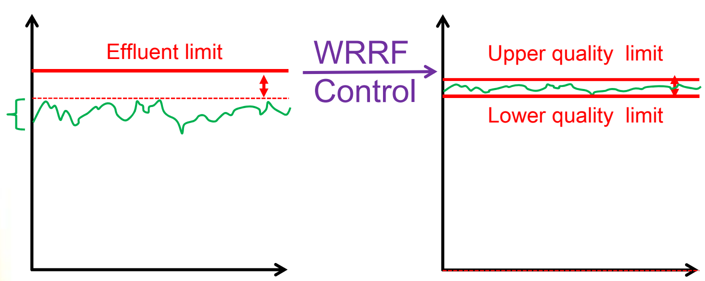
Control challenges

- Paradigm shift:



Control challenges

- Paradigm shift:



Control challenges

- Much stricter product specifications!

Control challenges

- No more forgiving client

Control challenges

- No selection of raw materials

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Outline

- Water resource recovery
- Modelling challenges
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Take home messages

- WWTPs → WRRFs !
- Physico-chemical processes !
- Modelling challenges are non-trivial
- Resource recovery products
  must compete with existing products
- Product specifications are strict
- Control is much more strict (upper & lower limit)
  (no more forgiveness!)

Acknowledgements on WRRFs

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New Advances in Process Control and Modeling for WWTPs/WRRFs

Metropolitan Water Reclamation District of Greater Chicago

Chicago, IL

24 JUN 2016

Peter VANROLLEGHEM

Canada Research Chair in Water Quality Modelling

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Content of the seminar

- Three recent and ongoing developments on modeling and control in my research team:
  - Modeling and control of the integrated urban wastewater system (sewer, treatment plant and receiving water body)
  - Modeling and control of greenhouse gas emissions and the impact of climate change on WWTPs
  - Modeling and control of resource recovery in WRRFs (water resource recovery facilities)


"That's all Folks!"
Stefano Marsili-Libelli