

# Applying a framework for calibrating a biofilm reactor model: a full-scale, moving-bed biofilm reactor active in nitrification

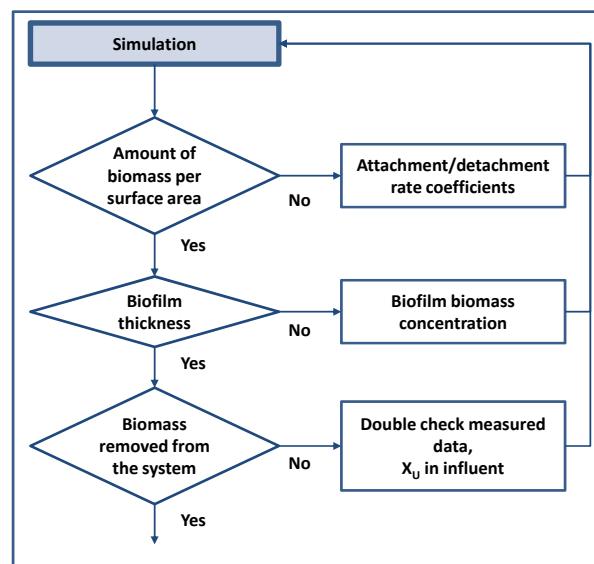
Brockmann, Boltz, Morgenroth,  
Daigger, Henze, Rittmann, Sørensen,  
Takács, Vanrolleghem, van Loosdrecht

INRA (FR)  
CH2M HILL (US)  
ETH Zürich/Eawag (CH)  
CH2M HILL (US)  
TU Denmark (DK)  
Arizona State University (US)  
WABAG (F/CH)  
Dynamita (FR)  
modelEAU (CA)  
TU Delft (NL)

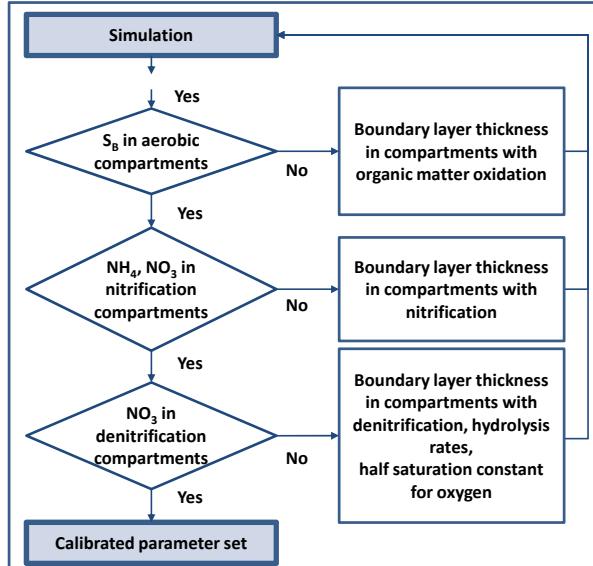
9<sup>th</sup> International Conference on Biofilm Reactors / Paris, France, May 28-31, 2013

29/05/2013

## Workshop result: calibration framework



## Workshop result: calibration framework



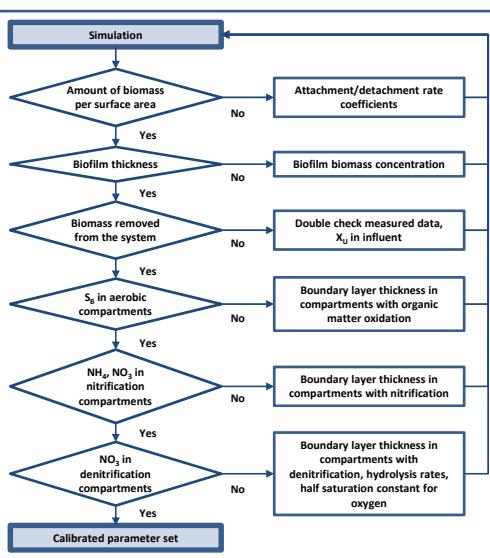
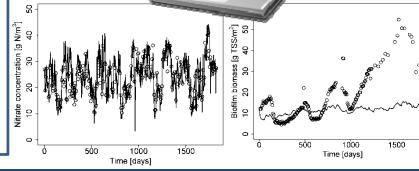
Brockmann et al. / IWA Biofilm Paris 2013

3

## From theory



## to practice

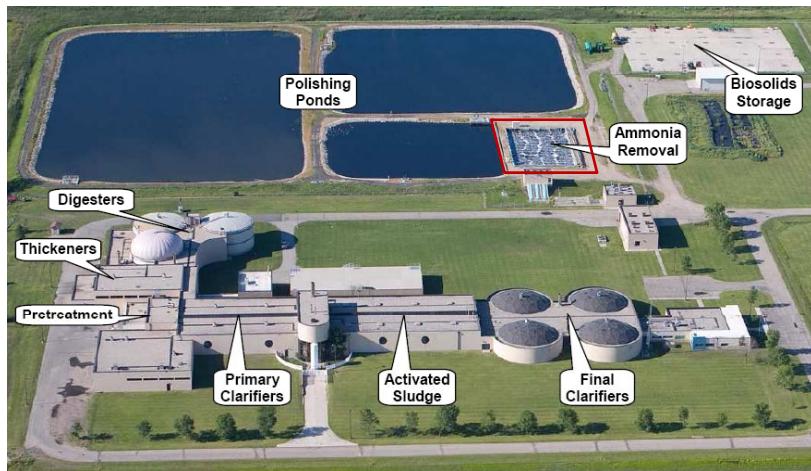
SIAAP Paris Achères Wastewater Treatment Plant,  
from: iwabiofilm2013.com

Brockmann et al. / IWA Biofilm Paris 2013

4

## Full-scale tertiary nitrification MBBR

Moorhead, Minnesota Wastewater Treatment Facility (MN, USA)



from: City of Moorhead (2012). Moorhead Minnesota Wastewater Treatment Facility.pdf

Brockmann et al. / IWA Biofilm Paris 2013

5

## Reactor and carrier material



from: maps.google.com

### Reactor

In operation since 2003

Design flow rate, m<sup>3</sup>/d 22,710

Basin dimensions (L x W x D), m 42 x 24 x 2.9

Basin volume, m<sup>3</sup> 2,970

Media volume, m<sup>3</sup> 938

Media volume, % fill 32



from: headworksinternational.com

### Hydroxyl ActiveCell 450 biofilm carriers

Effective specific surface area

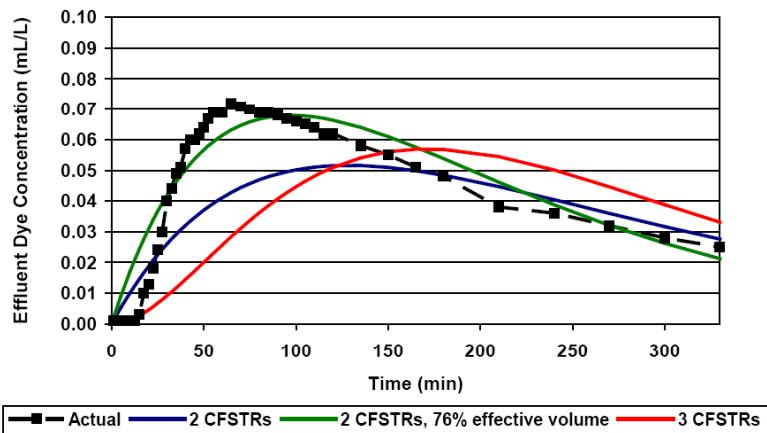
388 m<sup>2</sup> per m<sup>3</sup> of filled volume

124 m<sup>2</sup> per m<sup>3</sup> of reactor volume

Brockmann et al. / IWA Biofilm Paris 2013

6

## In-basin hydraulics



from: Zimmerman et al., WEFTEC 2005

Brockmann et al. / IWA Biofilm Paris 2013

7

## Monitoring data

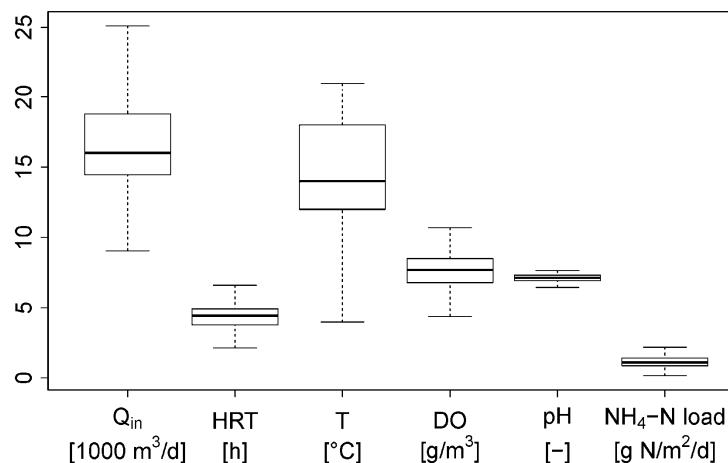
Frequency	Parameter
Daily	Effluent flow rate, air flow rate, air pressure
Three times a week (influent and effluent)	Temperature, pH, dissolved oxygen (DO), NH <sub>3</sub> -N
Once a week (influent and effluent)	Total carb. BOD <sub>5</sub> , soluble carb. BOD <sub>5</sub> <sup>(*)</sup> , TKN, NO <sub>2</sub> -N, NO <sub>3</sub> -N, alkalinity, TSS, biofilm biomass on carriers <small>(*) only influent</small>

Period: 2007-2011

Brockmann et al. / IWA Biofilm Paris 2013

8

## Operating conditions (2007-2011)



Brockmann et al. / IWA Biofilm Paris 2013

9

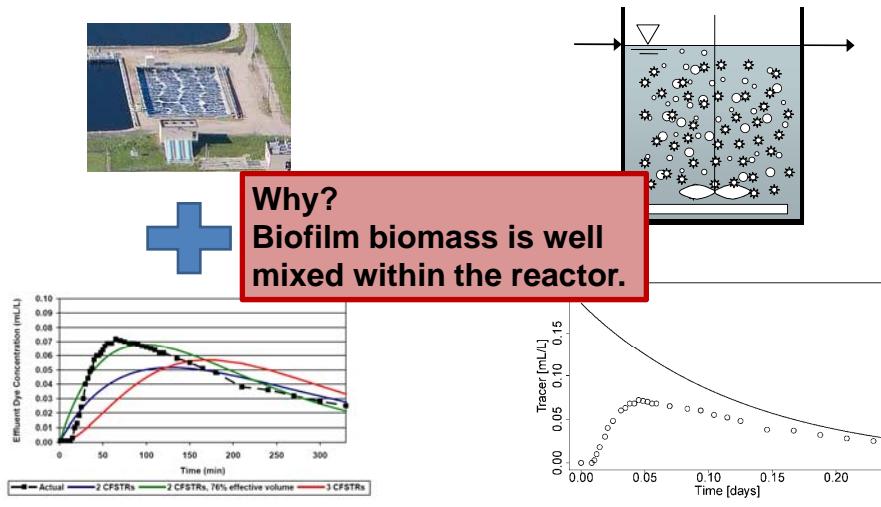
## Wastewater characteristics (2007-2011)

Parameter	Average ( $\pm$ std. dev.)
$Q_{in}$ , $\text{m}^3/\text{d}$	17,691 ( $\pm$ 6,056)
Carb. BOD <sub>5</sub> , g BOD/ $\text{m}^3$	6.8 ( $\pm$ 3.5)
sol. carb. BOD <sub>5</sub> , g BOD/ $\text{m}^3$	4.0 ( $\pm$ 2.0)
TSS, g TSS/ $\text{m}^3$	6.8 ( $\pm$ 3.2)
TKN, g N/ $\text{m}^3$	27.0 ( $\pm$ 9.8)
NH <sub>3</sub> -N, g N/ $\text{m}^3$	25.2 ( $\pm$ 9.4)
NO <sub>2</sub> -N, g N/ $\text{m}^3$	0.9 ( $\pm$ 1.1)
NO <sub>3</sub> -N, g N/ $\text{m}^3$	1.7 ( $\pm$ 0.8)
Alkalinity, mol $\text{HCO}_3^-/\text{m}^3$	6.5 ( $\pm$ 1.4)

Brockmann et al. / IWA Biofilm Paris 2013

10

## 1. Calibration attempt: reactor model



Brockmann et al. / IWA Biofilm Paris 2013

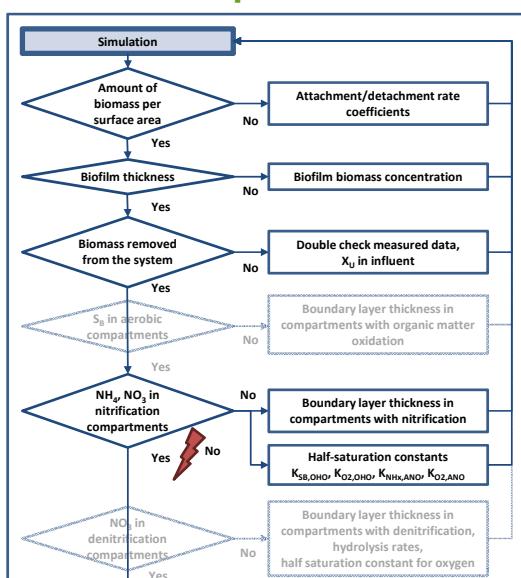
11

## 1. Calibration attempt: calibration

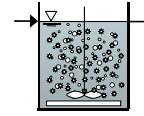
### Steady state calibration

Brockmann et al.

12



## Good agreement between model results and measured data



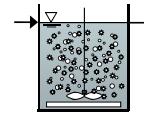
Parameter	Unit	Measured (*)	Model	Error
Ammonium	g N/m <sup>3</sup>	0.4	0.4	0.0%
Nitrate	g N/m <sup>3</sup>	24.0	27.0	12.5%
TSS	g TSS/m <sup>3</sup>	9.8	10.3	2.0%
Biofilm biomass	g TSS/m <sup>2</sup>	14.0	14.5	3.6%

(\*) median

Brockmann et al. / IWA Biofilm Paris 2013

13

## Unreasonable low $L_L$ and modification of kinetic parameters necessary

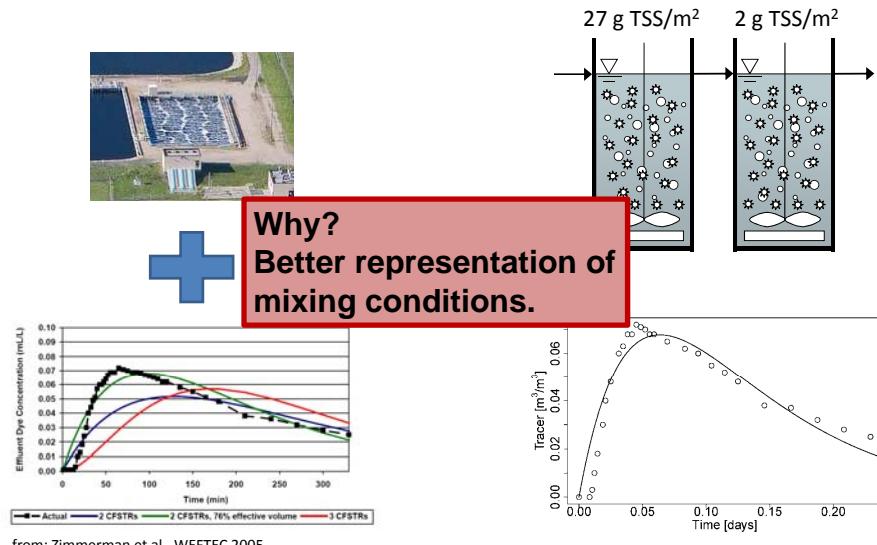


Symbol	Unit	Initial	Calibrated	Standard error absolute	Standard error relative
<b>System specific parameters</b>					
$k_{detach}$	d <sup>-1</sup>	0.2	0.013	$\pm 0.003$	0.25
BBC	g COD/m <sup>3</sup>	50,000	100,000	$\pm 7.9e^{-8}$	$7.9e^{-13}$
$L_L$	μm	100	30	$\pm 99$	3.3
<b>Kinetic parameters</b>					
$K_{SB,OHO}$	g COD/m <sup>3</sup>	4	0.1	$\pm 0.023$	0.23
$K_{O_2,OHO}$	g O <sub>2</sub> /m <sup>3</sup>	0.1	0.05	$\pm 2.0e^{-4}$	0.004
$K_{NHx,ANO}$	g N/m <sup>3</sup>	0.7	0.05	$\pm 0.16$	3.29
$K_{O_2,ANO}$	g O <sub>2</sub> /m <sup>3</sup>	0.8	0.05	$\pm 0.001$	0.021

Brockmann et al. / IWA Biofilm Paris 2013

14

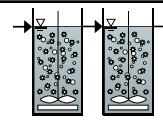
## 2. Calibration attempt: reactor model



Brockmann et al. / IWA Biofilm Paris 2013

15

## Only calibration of system specific parameters

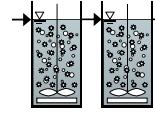


Symbol	Unit	Initial	Calibrated	Standard error	
				absolute	relative
$k_{\text{detach}}$	$\text{d}^{-1}$	0.2	0.012	$\pm 0.003$	0.25
BBC	$\text{g COD/m}^3$	50,000	100,000	$\pm 2.3\text{e}^{-11}$	$2.3\text{e}^{-16}$
$L_L$	$\mu\text{m}$	100	100	$\pm 81$	0.81

Brockmann et al. / IWA Biofilm Paris 2013

16

## Good agreement between model outputs and measured data



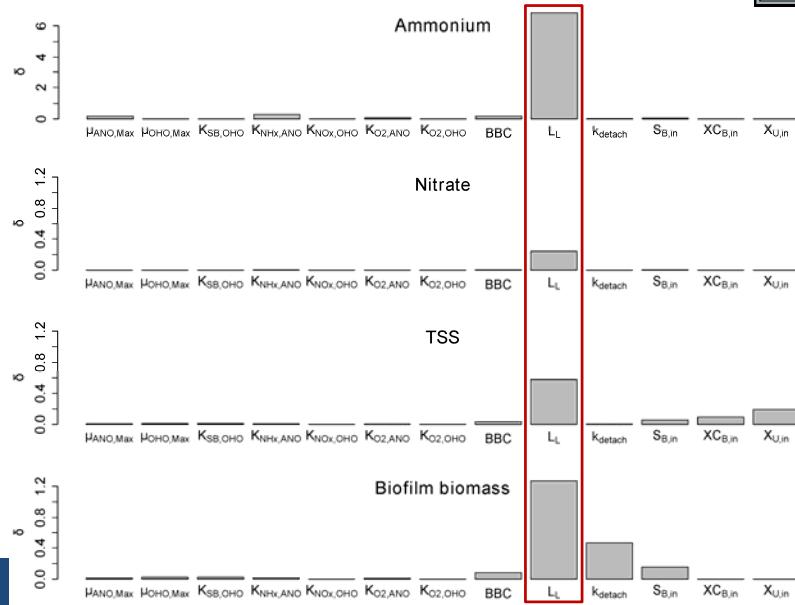
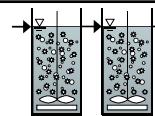
Parameter	Unit	Measured		Model	Error
		mean (*)	median		
Ammonium	g N/m <sup>3</sup>	2.1 ( $\pm 3.7$ )	0.4	0.4	0.0 %
Nitrate	g N/m <sup>3</sup>	23.5 ( $\pm 6.4$ )	24.0	26.8	11.7 %
TSS	g TSS/m <sup>3</sup>	10.5 ( $\pm 4.3$ )	9.8	10.9	11.2 %
Biofilm biomass	g TSS/m <sup>2</sup>	16.8 ( $\pm 10.7$ )	14.0	14.3	2.1 %

(\*) ( $\pm$  std.dev.)

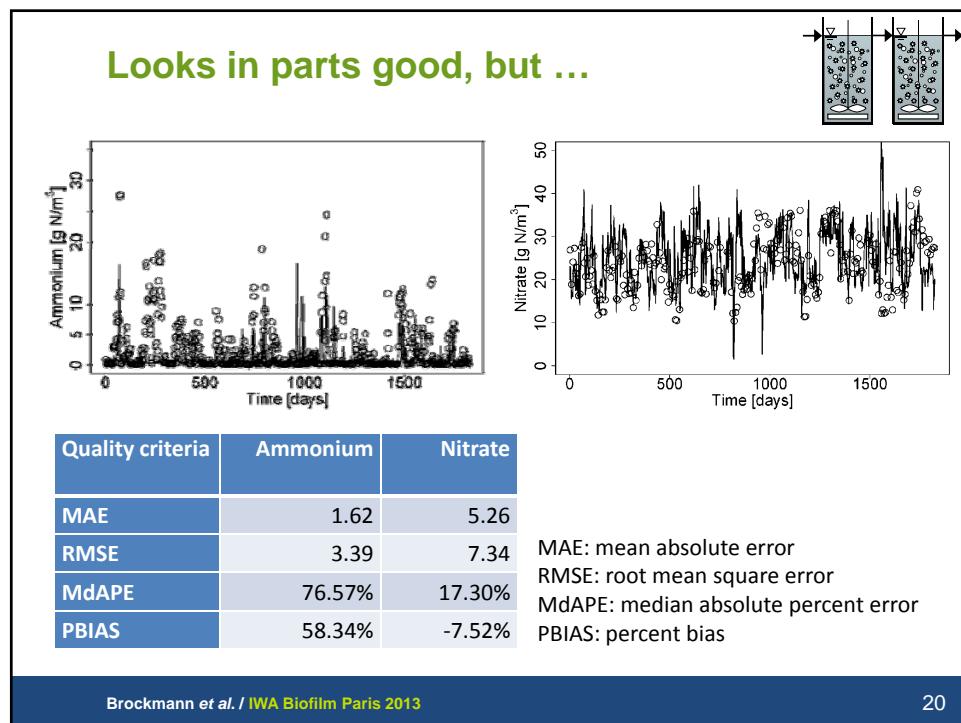
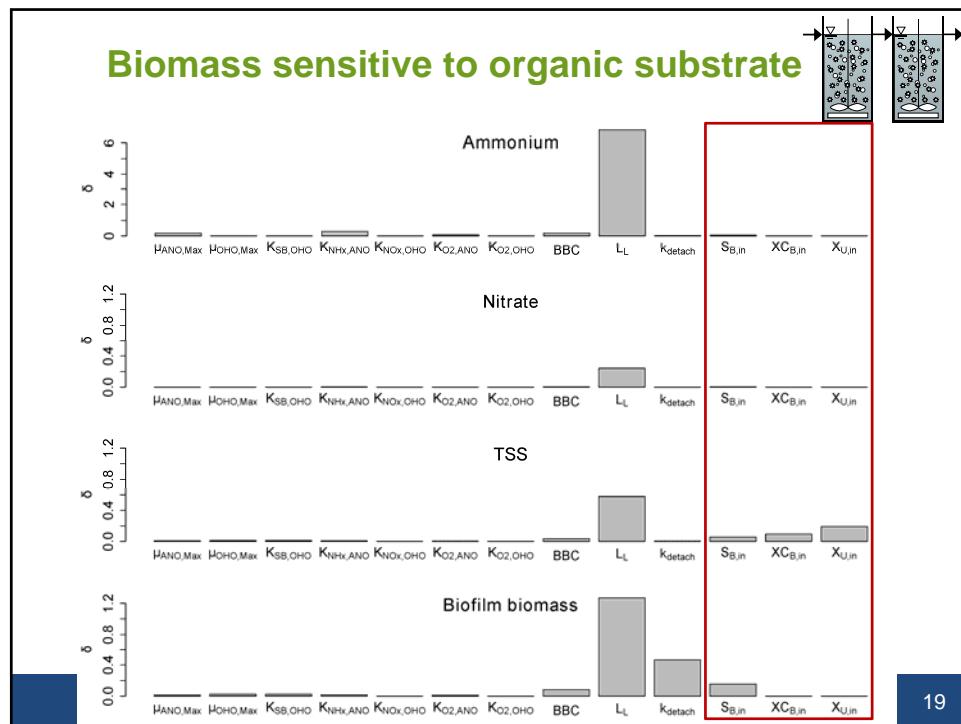
Brockmann et al. / IWA Biofilm Paris 2013

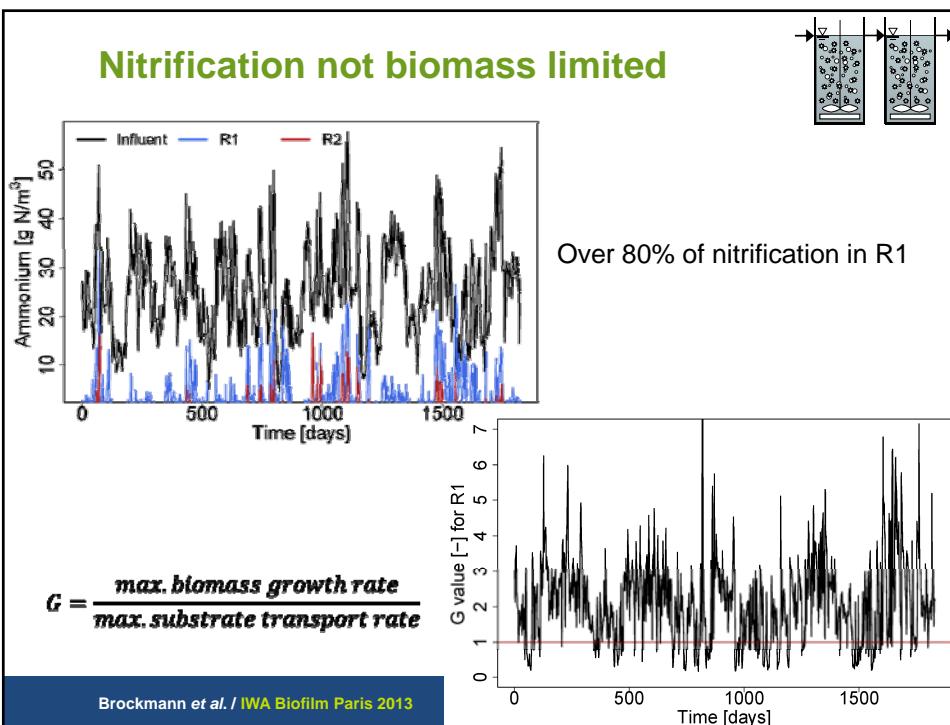
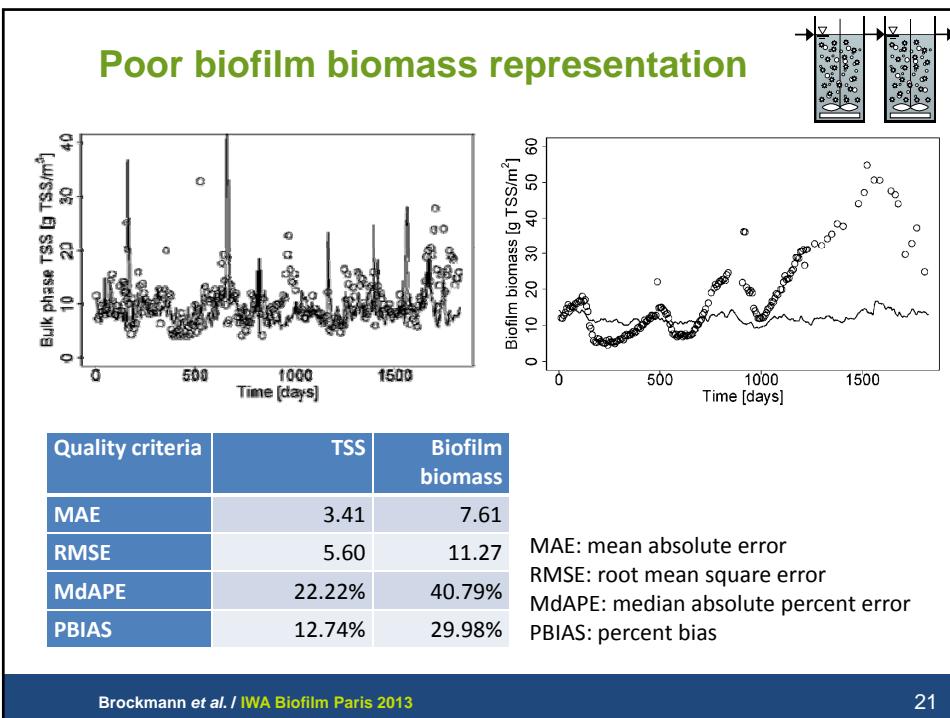
17

## High sensitivity to changes in $L_L$



18





## Conclusions

- Application of the calibration framework allowed steady state calibration of a biofilm reactor model for a full-scale tertiary nitrification MBBR.
- An adequate representation of the mixing conditions in the bulk liquid is important to obtain reasonable parameter values.
- Wastewater characterization with respect to organic substrate is also important for modeling nitrifying biofilm reactors.
- Dynamic simulation/calibration: Timely evolution of biofilm biomass may not be described mechanistically well enough by the biofilm model.

## Acknowledgements

The authors were able to meet and discuss at a workshop 10.-12. December 2011 in North Carolina (US) thanks to the financial contribution of

- World Water Works, Inc.
- Veolia, Inc.
- Dynamita, Inc.
- CH2M HILL, Inc.

Moorhead, Minnesota Wastewater Treatment Facility (MN, US) is greatly acknowledged for providing full-scale MBBR data.