

Comparative analysis of existing disinfection models

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International
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Introduction

- One of the major advantages of WSP:
Efficient bacteria removal
(Removal efficiencies: 1 to 4 log units)
- Main disinfection mechanisms :
Sunlight radiation, sedimentation and predation
- The most important cause of disinfection:
Sunlight exposure

Introduction

- Disinfection mechanism by sunlight exposure
(Davies-Colley *et al.*, 1999)

Mechanism 1:

UVB radiation  damage to cellular DNA

Disinfection mechanism independent of DO and pH

Mechanism 2 (Davies-Colley *et al.*, 1999):

Photo-oxidation by reactive oxygen species

Catalyst: Endogenous photo-sensitisers absorbing solar UVB

 Damage to internal structures of micro-organisms

Disinfection mechanism independent of pH

Introduction

Mechanism 3 (Curtis *et al.*, 1992 ; Davies-Colley *et al.*, 1999) : Photo-oxidation by reactive oxygen species

Catalyst: Exogenous photo-sensitisers absorbing a wide range of λ in sunlight

→ Damage to external structures of micro-organisms
Elevated pH acting in synergy with DO on disinfection mechanism

Disinfection models : $\frac{dN}{dt} = -k(t)N$ (Chick's Law)

with general empirical or semi-empirical formulae of k :

$$k = k_d + k_s \cdot I \quad \text{or} \quad k = k'_d \cdot e^{\chi \cdot I}$$

Introduction

To make suggestions to improve disinfection modelling in WSP :

Comparative analysis of existing models

- ▶ Explanatory variables (driving factors)
- ▶ Looking at the dynamic of the process (Assuming that solar radiation as a main disinfection mechanism)

Materials and methods

- Virtual pond characteristics:

Depth: 1m Volume: 30000 m³

Influent flow rate: 3000 m³.d⁻¹ RTD : 10 days

Initial No value 10⁵ /100 mL

- Models predictions: Solutions of the equation $\frac{dN}{dt} = -k(t)N$

$$\text{SBR: } N(t_n) = N(t_0) \cdot e^{-k_1 \cdot (t_1 - t_0) - k_2 \cdot (t_2 - t_1) - \dots - k_n \cdot (t_n - t_{n-1})}$$

$$\text{PFR: } N_E(t_n) = N_I(t_0) \cdot e^{-k_1 \cdot (t_1 - t_0) - k_2 \cdot (t_2 - t_1) - \dots - k_n \cdot (t_n - t_{n-1})}$$

$$\text{with } t_n = t_0 - \tau$$

$$\text{CSR: } \frac{N_E(t_n) - N_E(t_{n-1})}{\Delta t} = \frac{Q}{V} N_I(t_n) - \frac{Q}{V} N_E(t_n) - k_n \cdot N_E(t_n)$$

Materials and methods

- Models studied

- Daily models

1) $k = k_d + k_s \cdot I$			
Authors	k_d (d ⁻¹)	k_s	
Marais (1974)	$2.6 \times 1.19^{(T-20)}$		
Mayo (1989)	0.108	$\frac{5.79 \times 10^{-4}}{Z}$	*
Auer et Niehaus (1993)	$0.73 + \frac{v}{Z}$	$\frac{0.00824(1 - e^{-KZ})}{KZ}$	*
Mayo (1995)	0.135 pH	$\frac{5.67 \times 10^{-4}}{Z}$	*
Fallowfield <i>et al.</i> (1995)	$1.404 - 0.026Z$	0.002	**
$v = 1.38 \text{ m.j}^{-1}$	$K = 0.64 \text{ SS} + 24.09$ with $\text{SS} = 70 \text{ mg.L}^{-1}$ (Xu <i>et al.</i> , 2001)		

* cal⁻¹.cm²

** W⁻¹.m²

Materials and methods - Daily models

$$2) \quad k = k'_d \cdot e^{\alpha \cdot \bar{I}}$$

Authors	k'_d (d ⁻¹)	\mathcal{X} (J ⁻¹ .cm ²)
*Xu_1 <i>et al.</i> (2001)	$0.019 \times 0.915^{(T-20)}$	$\frac{0.170(1 - e^{-KZ})}{KZ}$
**Xu_2 <i>et al.</i> (2001)	$0.065 \times 0.915^{(T-20)}$	$\frac{0.191(1 - e^{-KZ})}{KZ}$

*Xu_1 kinetic/ Field monitoring data in first tertiary pond

**Xu_2 kinetic/ Field monitoring data in second tertiary pond

- Average values chosen for:

$$\text{pH} = 8.3; \quad \text{DO} = 4.6 \text{ mg.L}^{-1}$$

$$\text{T} = 15.0^\circ\text{C}; \quad \text{I} = 86.0 \text{ J.cm}^{-2}.\text{h}^{-1}$$

Materials and methods: Hourly models

► Hourly models

$$k = k_d + k_s \cdot I$$

Authors	k_d (h ⁻¹)	k_s
Curtis et al. (1992)	$-6.355 + 0.7437 \text{ pH} + 0.163 [\text{O}_2]$	0.001027 **
Craggs et al. (2004)	0.020 – 0.023	0.056 – 0.114 ***

**W⁻¹.m²

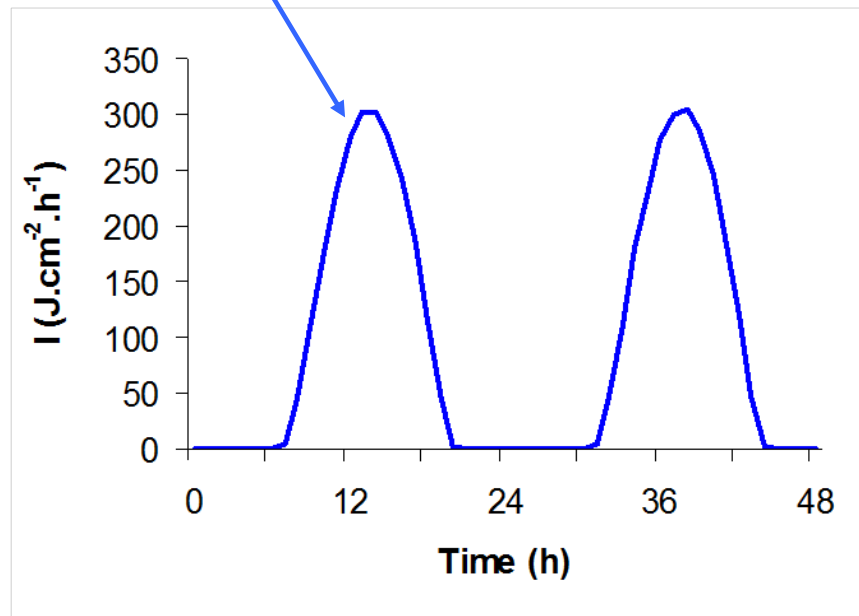
***MJ⁻¹.m²

- Daily variations of I, pH, [O₂] and T
≈
Sinusoidal functions

Materials and methods: Hourly models

Daily variations of I:

$$I = \frac{269.572}{2} \cdot \left[\sin\left(\frac{t}{3.812} + 4.354\right) + \left| \sin\left(\frac{t}{3.812} + 4.354\right) \right| \right]$$



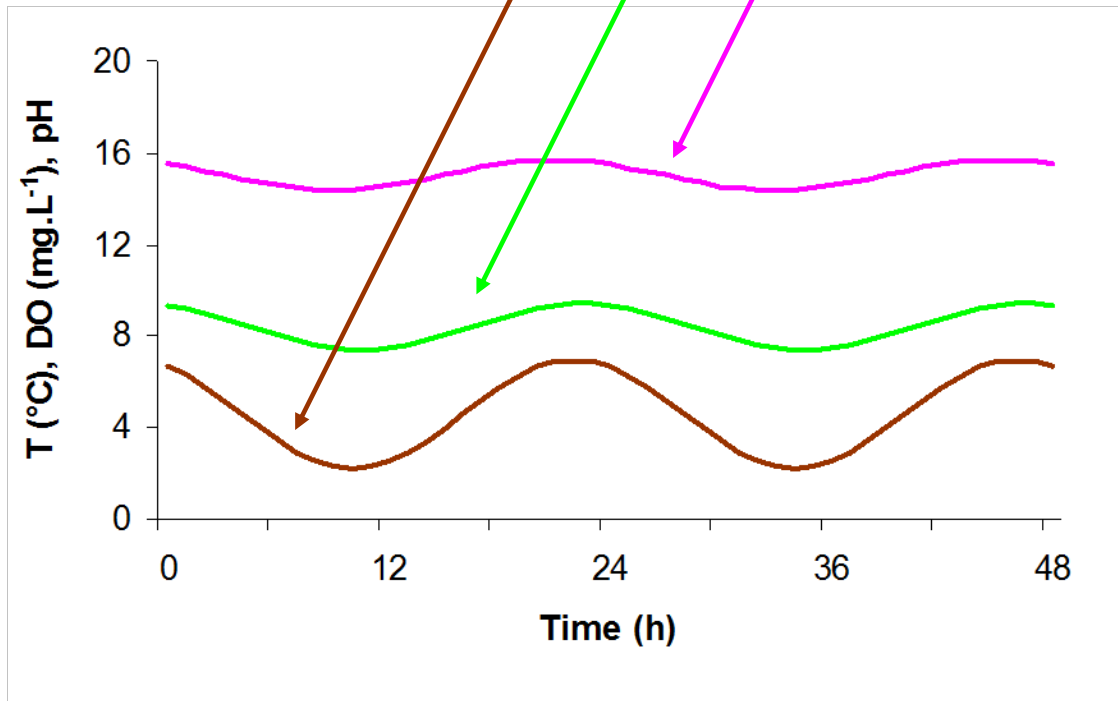
Materials and methods: Hourly models

Daily variations for :
O₂, pH and T

$$DO = 2.363 \cdot \sin\left(\frac{t}{3.812} + 2.064\right) + 4.574$$

$$pH = \sin\left(\frac{t}{3.812} + 1.931\right) + 8.384$$

$$T = 0.665 \cdot \sin\left(\frac{t}{3.812} + 2.338\right) + 15.016$$



Results and discussion

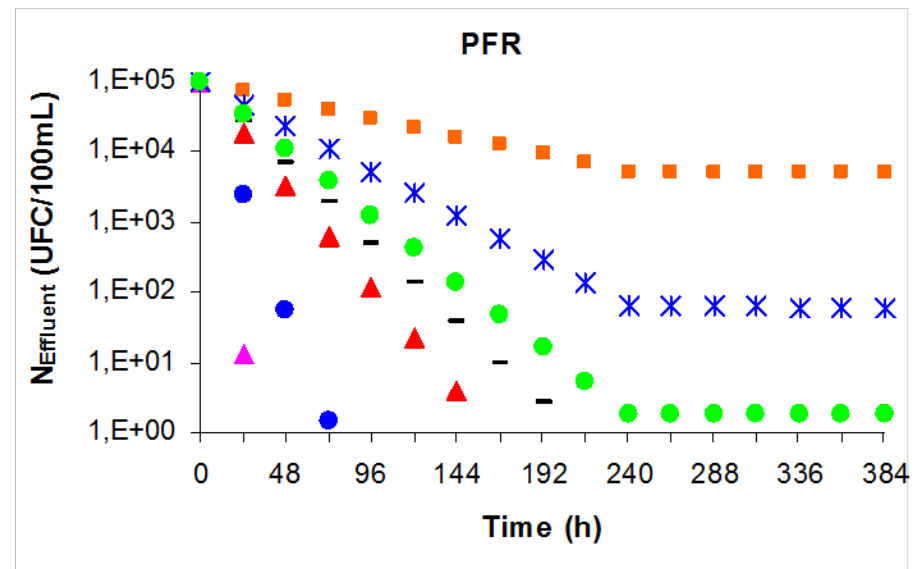
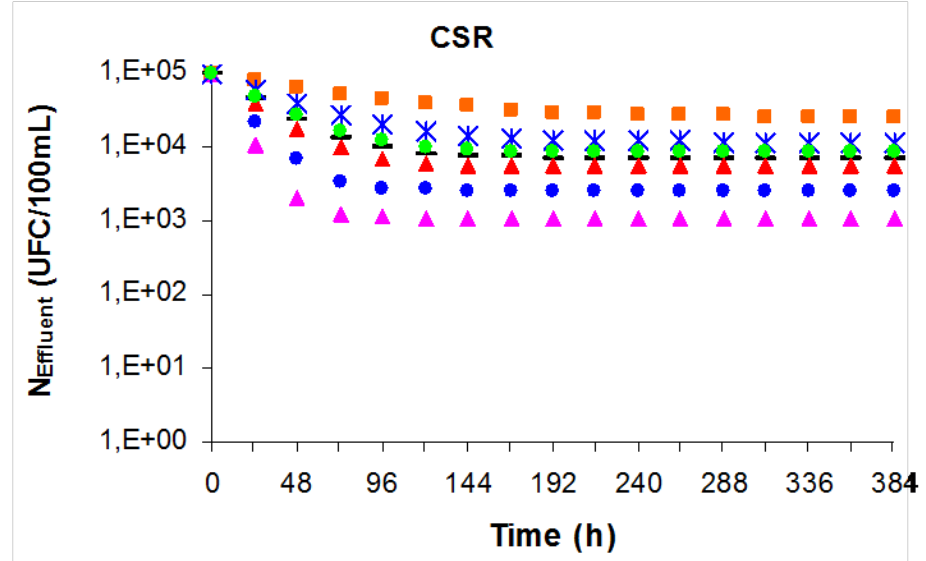
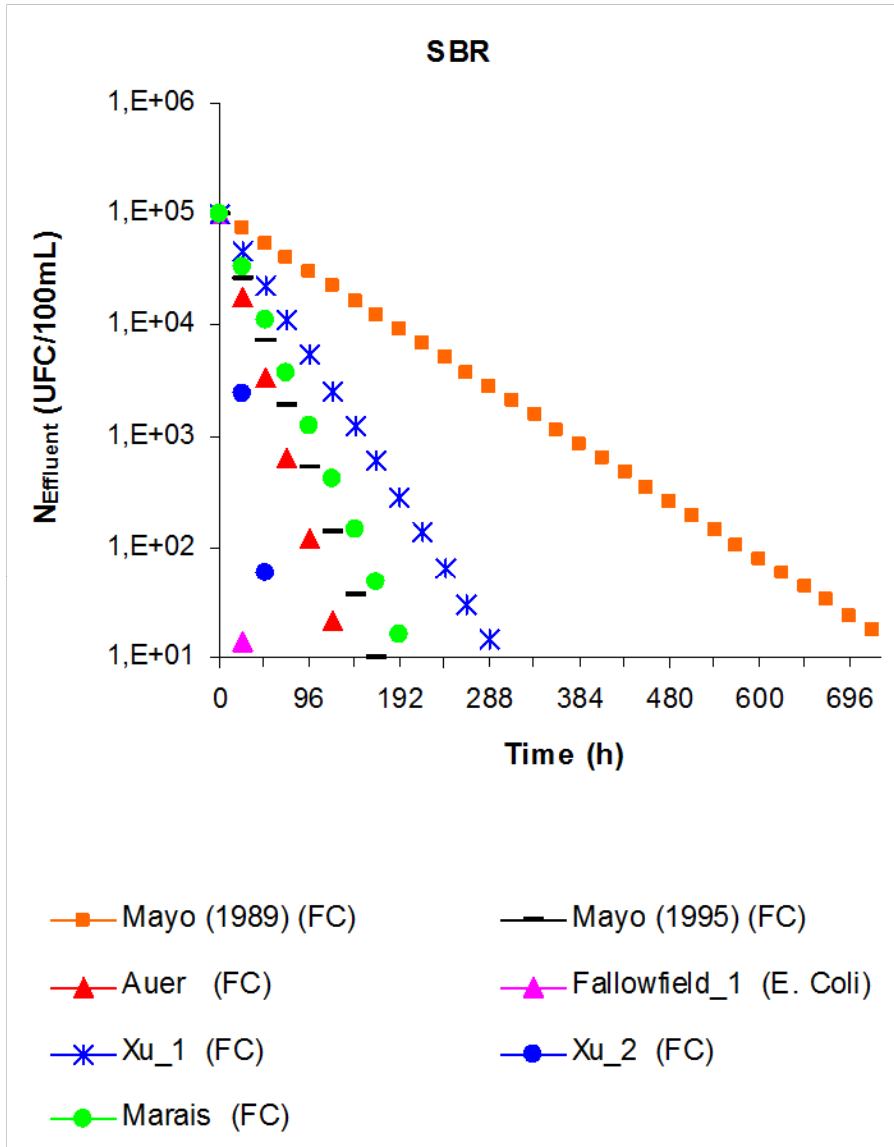
The effect on model predictions of :

- The choice of driving factors
- The use of average values of variables

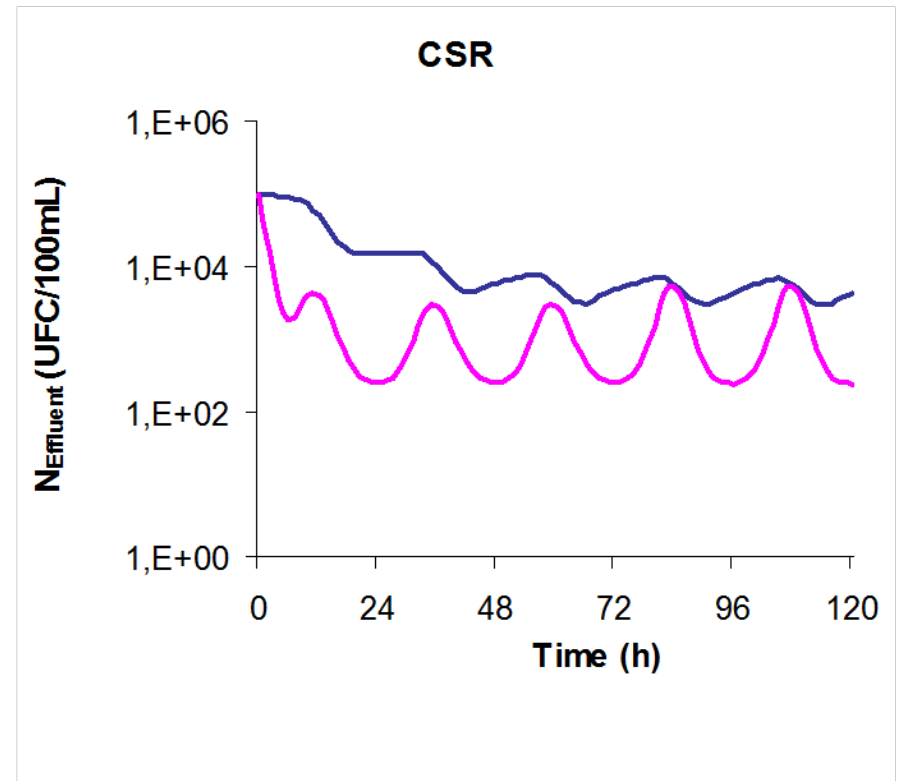
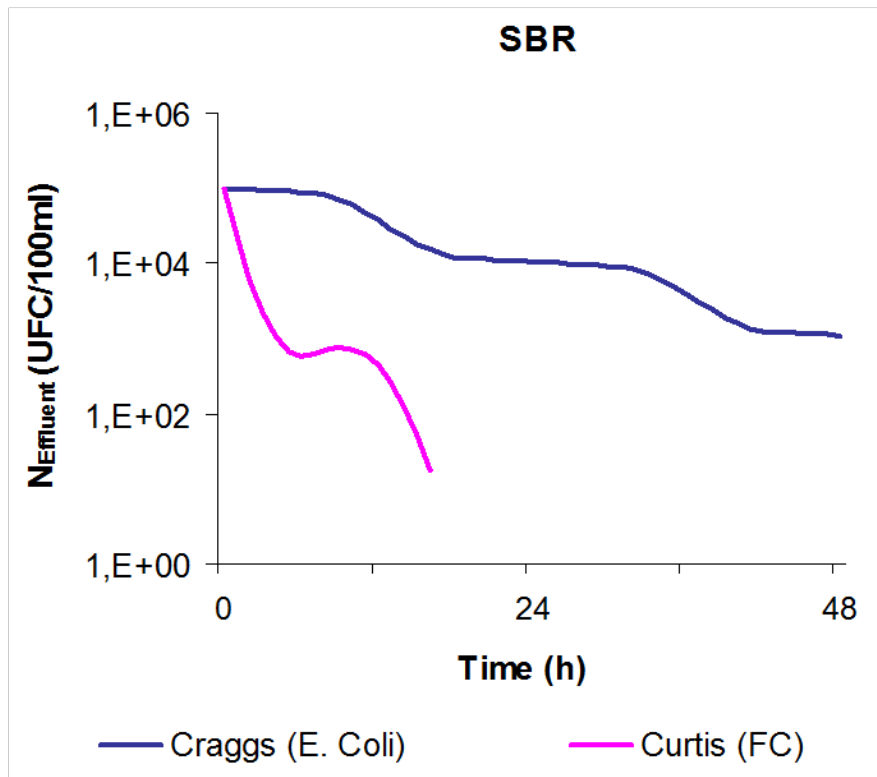
Results and discussion

- The effect driving factors

► Daily models

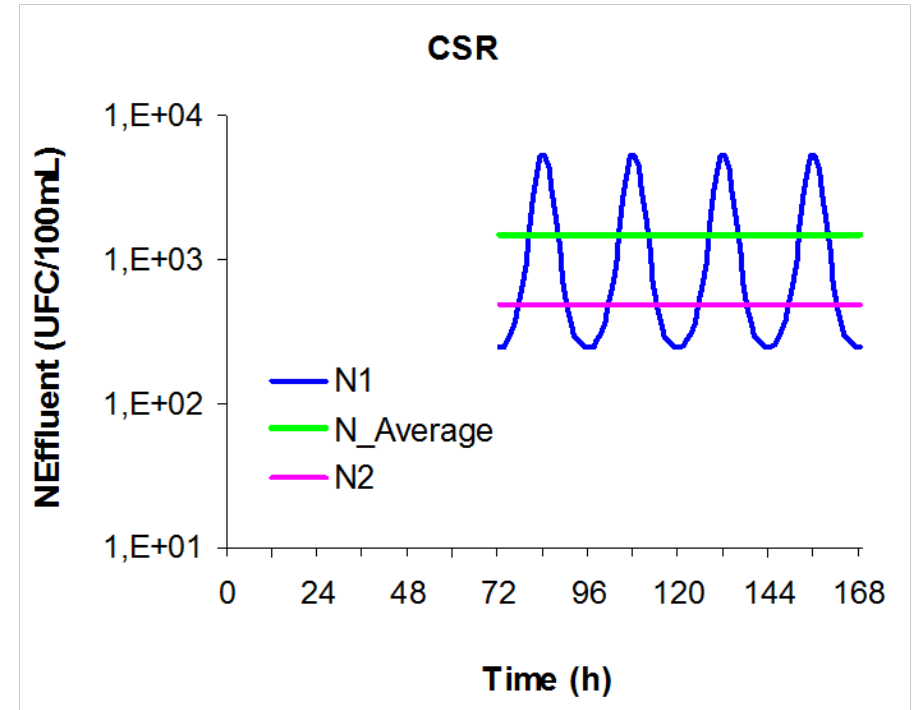
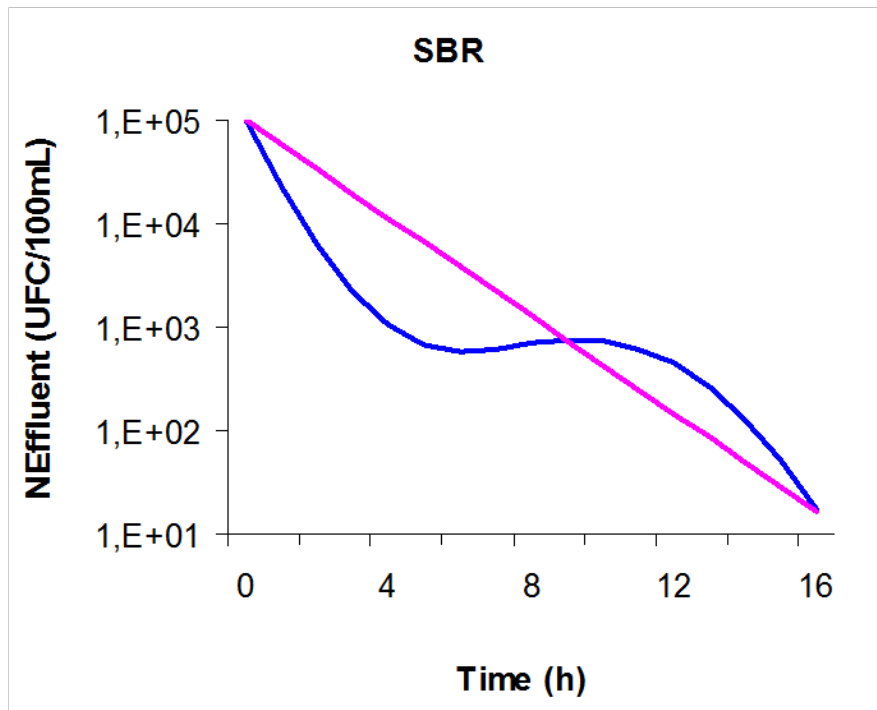


► Hourly models

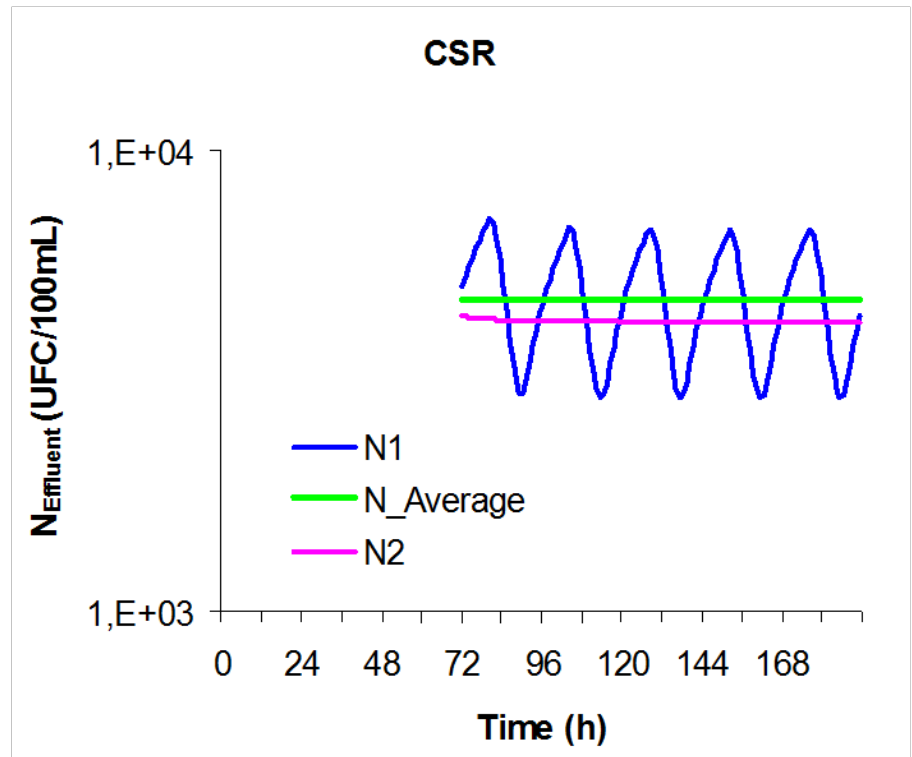
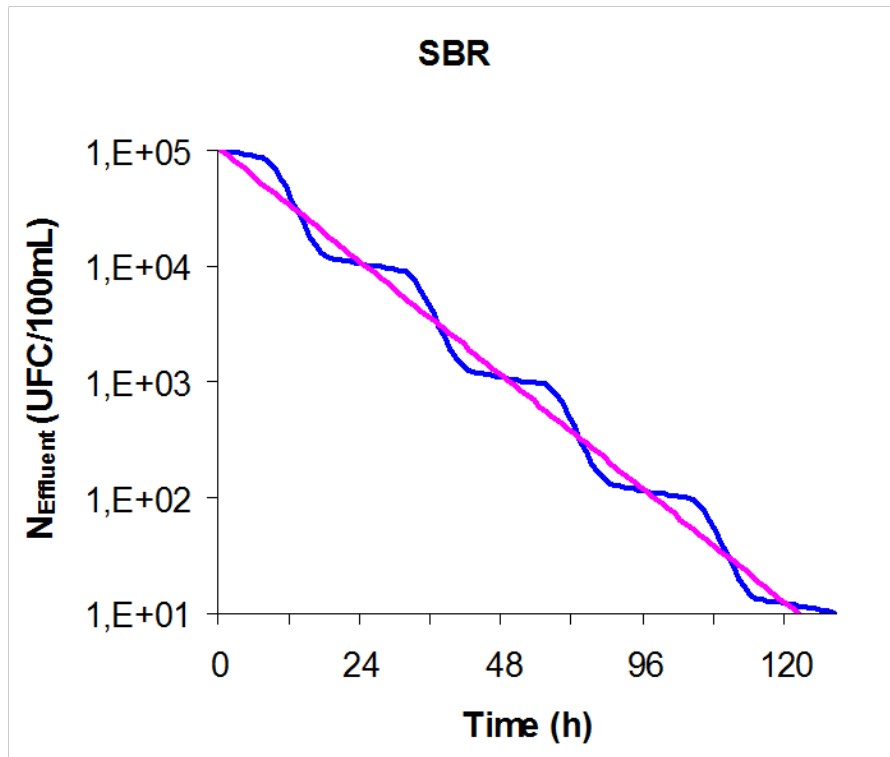


Results and discussion

- The effect of the use of the average of variables
 - ▶ Curtis *et al.* model



► Craggs *et al.* model



Conclusions

- Disinfection models:
 - ▶ Empirical or semi-empirical
 - ▶ Explanatory variables arbitrary chosen
 - ▶ Huge differences between predictions that are detrimental for a good design
- To improve disinfection modelling :
Enhance knowledge of mechanisms

Conclusion

If the most important of disinfection mechanisms is **sunlight**

We must take into account (and measure) daily variations of variables such as I, pH DO....and other meteorological data

- Very few data are available at an appropriate time scale
- Use of average values of such variables can lead to an overestimation of disinfection.
- Measurements have to be combined with a good knowledge of the hydrodynamic of the reactor.
- New measurement methodologies have to be developed : a transportable pilot plant is being designed

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