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Department Applied Mathematics,
Biometrics and Process Control

The Usefulness of Models in Wastewater Engineering

Peter A. Vanrolleghem
January 18th 2001

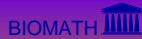
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Overview

- **Models**
 - What are they?
 - How do I build them ?
- **Application of Models**
 - Understanding / Education / Training
 - Experimental Design
 - Intelligent Sensors
 - Model-based Control
 - Decision support (System Design)

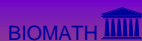
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Definitions

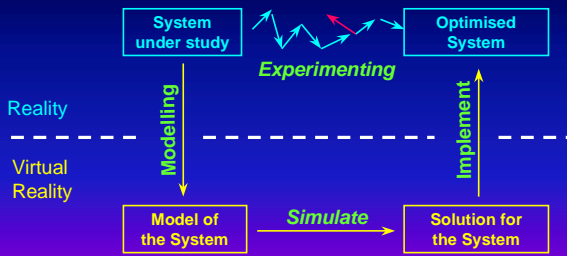
- **System**
Part of reality that is separated from its environment on the basis of a purpose defined by the researcher
- **Model**
An approximate description of a part of reality considering only those aspects of interest
- **Simulation**
= Virtual Experimentation: Manipulation of a model to gain insight in the "behaviour" of the real system

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Why Modelling ?

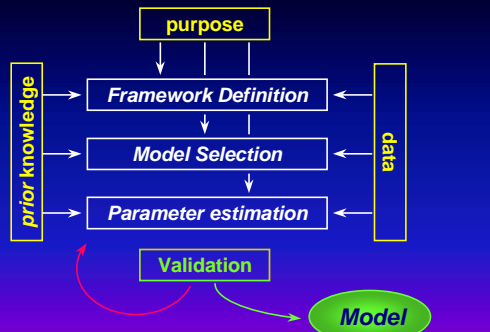
Solving Problems for complex systems



Model building: Starting points

- **Purpose of the model**
 - Increasing understanding of a system (Think tank)
 - Summary of knowledge/data (Communication)
 - Prediction of future behaviour (Control)
- **Prior knowledge**
 - Experience
 - Existing models
 - Literature (facts, phenomena, theories, ...)
- **Data**
 - Existing data
 - New data collected in view of model building

Model building: Subtasks



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Models to the General Public

$$E = mc^2$$

Models to the General Public



Weather Forecasting



(Reading, UK)

Models in Wastewater Treatment

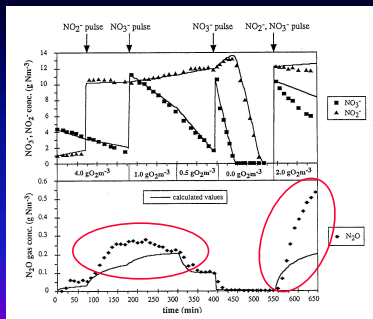
Only two types of application:

- Describing the past ($E=mc^2$)
 - Understanding (research - education - training)
 - Summary of knowledge
- Prediction of the future (*Weather*)
 - Forecasting the future state of an existing system
 - Forecasting the future behaviour of a changed system

Models for understanding

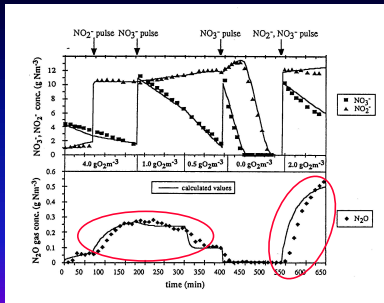
- Hypothesis is generated on the basis of
 - data as such (apple falls off a tree -> model)
 - discrepancy of data with an existing model
 - New insight is acquired when the new model is accepted by the scientific community
- ... until the next (better) data set comes along...

Understanding N_2O emissions



Model is insufficiently "flexible"

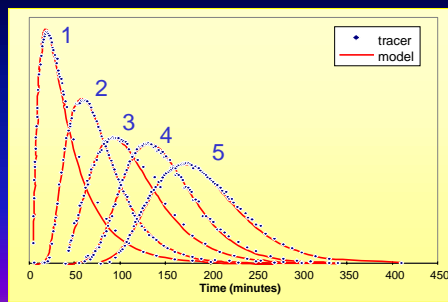
Understanding N₂O emissions



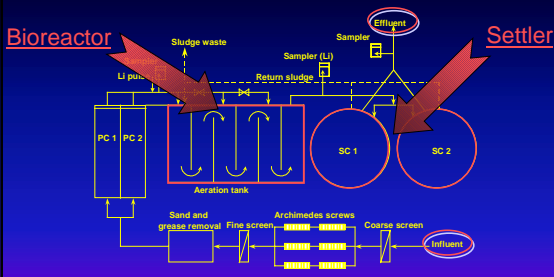
Model is much better !

Models for description/summary

Mixing behaviour in a river (only 5 numbers !)

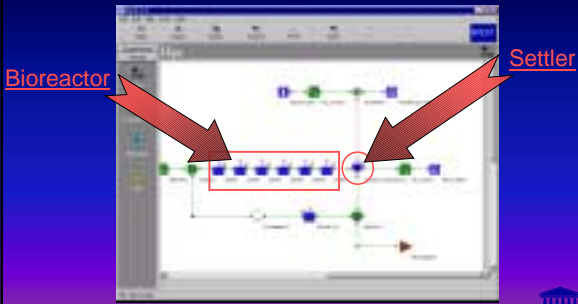


Use of models in plant design



Use of models in plant design (cont'd)

Process optimisation via model simulation ↗



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Use of models for Optimal Experimental Design (OED)

- Purpose of experimental design:
create experimental conditions such that data allow
 - model selection
 - accurate parameter estimation
 - validation of a model

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Questions to be answered by Experimental Design

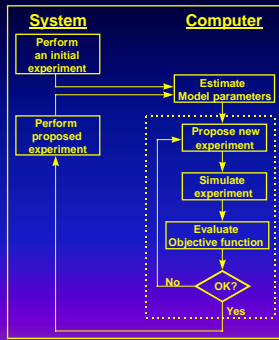
- What variables should we measure ?
- What is the required accuracy ?
- Over what period should be measured ?
- At what frequency are the data to be collected ?
- At what location should the measurements be done ?

Quantified in an Objective Function
to be optimised by the OED algorithm

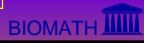
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Model based Experimental Design

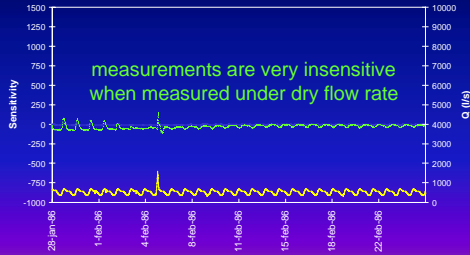


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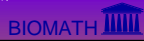


Application of OED

Calculated sensitivity to a settling parameter during dry weather conditions

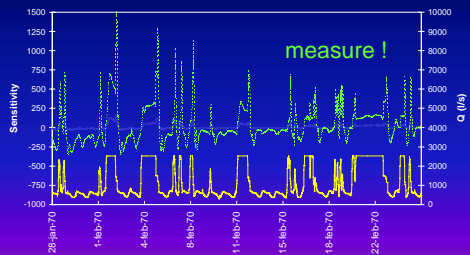


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Application of OED

Calculated sensitivity to a settling parameter during wet weather conditions

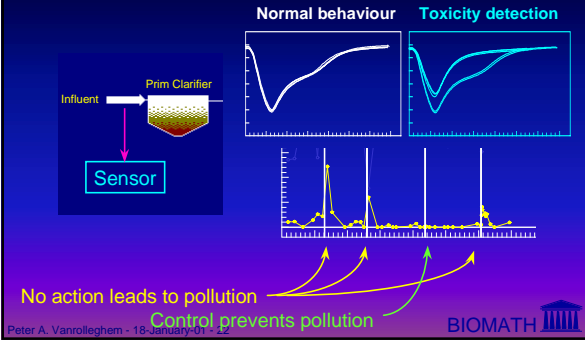


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Intelligent sensors

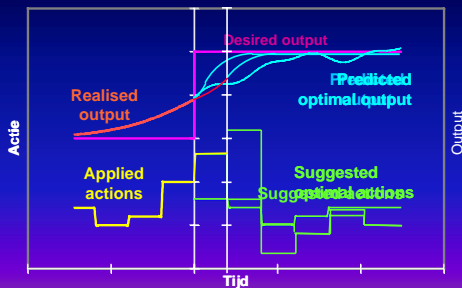
- Raw data + Model



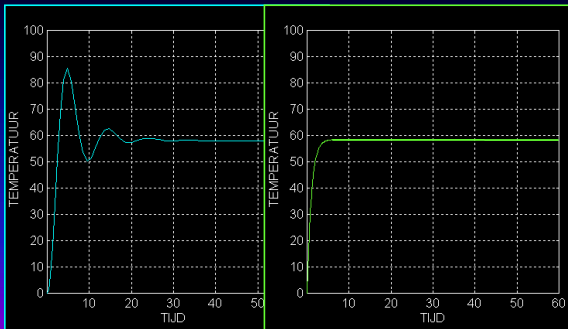
Use of Models in Process Control

- Controllers with built-in model
eg. Model based predictive control
- Support during the design of the control structure
Choice of actuators, sensors, control laws
- Support during the tuning of controllers
eg. Tuning the parameters of a PID-controller
- Prediction of disturbances
eg. Rain - runoff / diurnal waste flow pattern

Model-based Control: MBPC (Model Based Predictive Control)



Controller tuning



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Use of Models in Decision Support

- Wastewater treatment plant design using Economic Cost calculations ==> MoSS-CC
- Integrated urban water management using sewer/WWT/river models ==> Brussels

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MoSS-CC project

Model based Simulation System for Cost Calculation

- Calculation of the investment cost of a new or upgrade WWTP design
- Calculation of the (fixed & variable) operating costs of a new or upgrade WWTP design

=> Better design

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Investment Cost Relationships

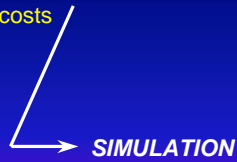
- Power laws are applied:

$$COST = \Theta(\text{Process Size})^n$$

- **Process size:** an easy to measure plant characteristic:
 - volume
 - area
 - length
 - design flow rate
 - pumping capacity
 - installed mechanical power

Operating Cost Relationships

- **Maintenance costs** ==> proportional to investment
- **Sludge treatment/disposal costs**
- **Pumping energy**
- **Aeration energy**
- **Mixing energy**
- **Effluent taxes**

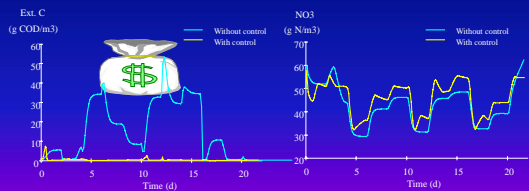


Example of Cost Reduction

- **Industrial plant with nitrogen problem:**
Question: Include automatic control or not ?

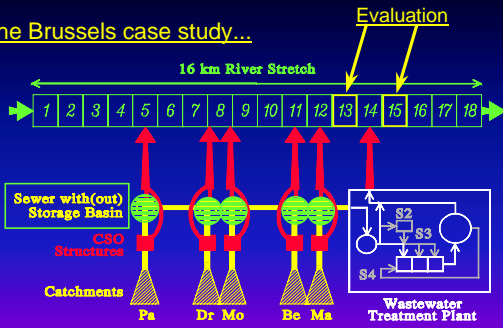
External Carbon for Denitrif.

Effluent nitrate conc.

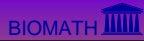


Integrated Urban Water Management

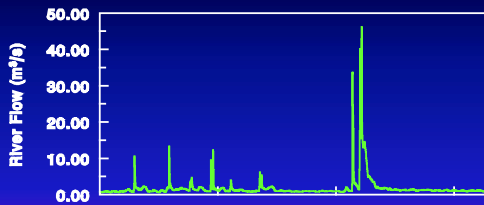
The Brussels case study...



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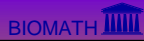


Effect of 2 design options (BAS/CSO) on River Water Quality

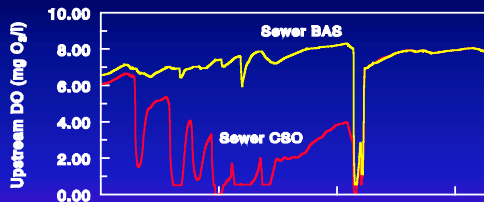


One big and several small rain events in summer '86

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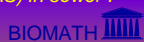


River Water Quality (oxygen) Downstream of CSO, Upstream of WWTP

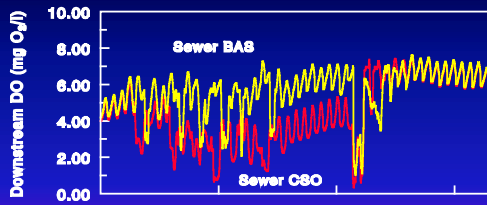


Clear beneficial effect of retention basins (BAS) in sewer!

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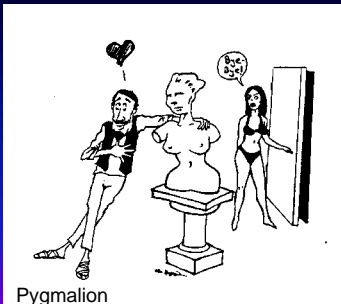


River Water Quality (oxygen) Downstream of CSO, Downstream of WWTP



Beneficial effect of basins is reduced due to lower efficiency of WWTP by increased loading from basins

“Do not fall in love with your model”

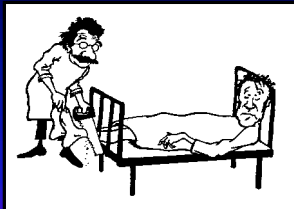


Pygmalion

Epilogue

Models are and can be very useful,
but they are only an approximate description of reality

Procrustes bed:
(Greek mythology)



*“Do not adjust reality
to the model”*

Modelling should be done
with knowledge in the field !
