UNIVERSITEIT GENT

BIOMATH

Department Applied Mathematics, Biometrics and Process Control

The Usefulness of Models in Wastewater Engineering

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November 14th 2000

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Models in Control...

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 (Risk Assessment - System Design)

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

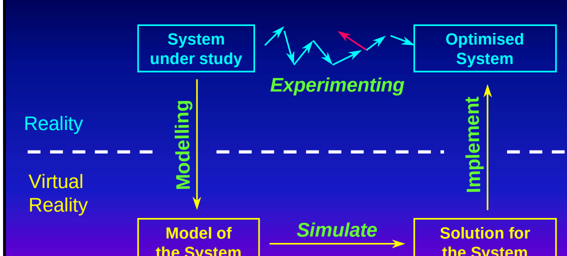
  = Virtual Experimentation: Manipulation of a model to gain insight in the "behaviour" of the real system

Types of Models

- Mental models (ideas, concepts, ...)
- Verbal models ("description in words")
- Scale models ("house in cardbord")
- Computer models ("house in AutoCad")
- Mathematical models ("equations")

Why Modelling ?

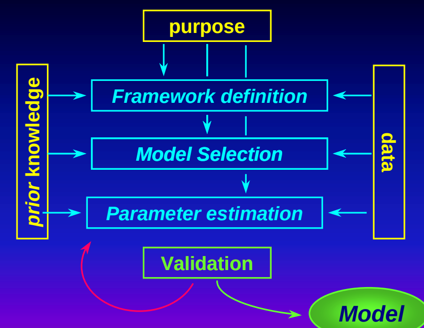
Solving Problems for complex systems



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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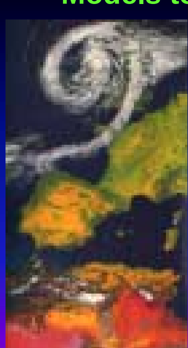
Models to the General Public

$$E = mc^2$$

Models to the General Public



Weather Forecasting

(Reading, UK)

Models in Environmental Engineering

Only two types of application:

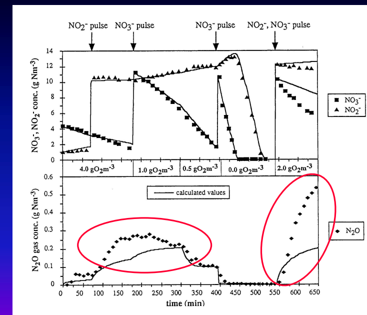
- Describing the past (*E=mc*^{2})
  - Understanding (research - education - training)
  - Summary of knowledge
- Prediction of the future (*Weather*)
  - Forecasting the future state of an existing system
  - Forecasting the future behaviour of a changed system

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

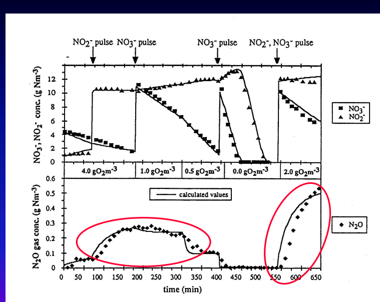
... until the next (better) data set comes along...

Understanding N_2O emissions



Model is insufficiently “flexible”

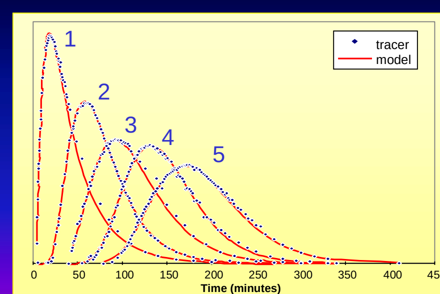
Understanding N_2O emissions



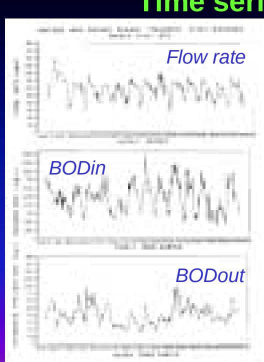
Model is much better !

Models for description/summary

Mixing behaviour in a river (only 5 numbers !)



Time series of data



Summary of data:

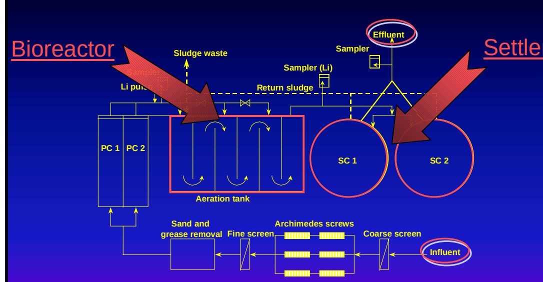
Time series models:

Bout(t) =

0.55 Bout(t-1) + 0.3 Bout(t-7)
+0.49 Bin(t) - 0.12 Bin(t-1)
-25 dt(t) + 32.5 dt(t-1) - 6.7dt(t-7)
-0.3 SSin(t-1) +0.22 SS(t-2)
+N(t)

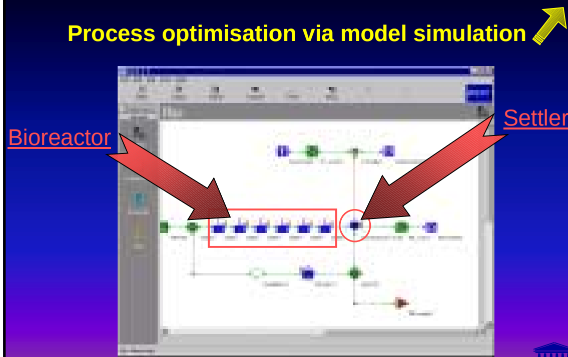
The whole data series is condensed into a few numbers (only 9)!

Use of models in plant design



Use of models in plant design (cont'd)

Process optimisation via model simulation



Use of models for Optimal Experimental Design (OED)

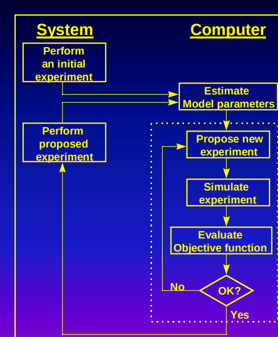
- Purpose of experimental design:
  create experimental conditions such that data allow
  - model selection
  - accurate parameter estimation
  - validation of a model

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 ?

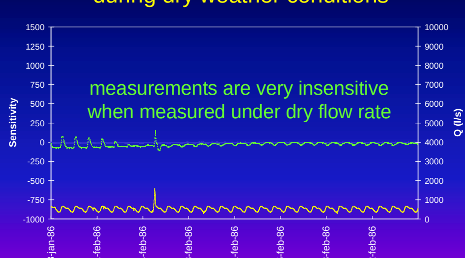
Quantified in an Objective Function
to be optimised by the OED algorithm

Model based Experimental Design



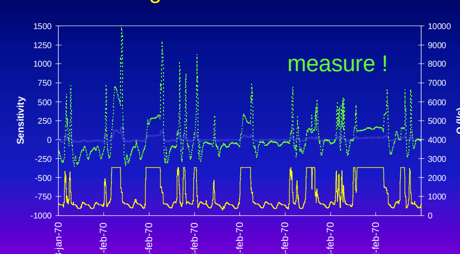
Application of OED

Calculated sensitivity to a settling parameter
during dry weather conditions



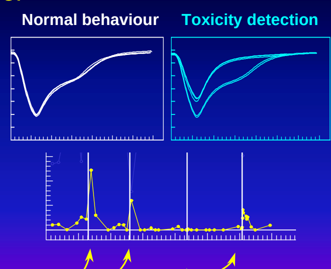
Application of OED

Calculated sensitivity to a settling parameter
during wet weather conditions



Intelligent sensors

- Raw data + Model



No action leads to pollution

Control prevents pollution

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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

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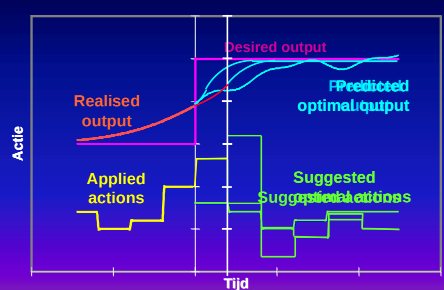
Model-based Control: MBPC (Model Based Predictive Control)



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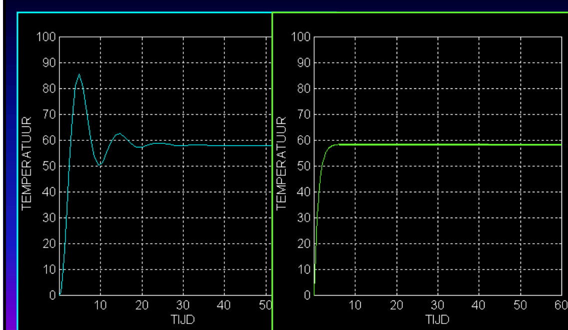
Controller tuning



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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
- Environmental Risk Assessment of
  “down-the-drain” chemicals ==> GREAT-ER

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MoSS-CC project

Model based **S**imulation **S**ystem for **C**ost **C**alculation

- 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:

$$COST = \Theta(Process\ Size)^n$$

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

Operating Cost Relationships

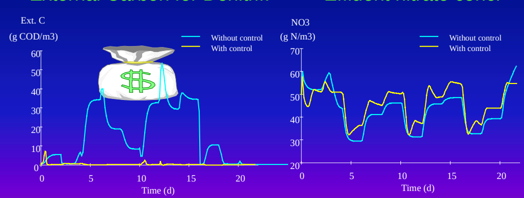
- Maintenance costs ==> proportional to investment
- Sludge treatment/disposal costs
- Pumping energy
- Aeration energy
- Mixing energy
- Effluent taxes

SIMULATION

Example of Cost Reduction

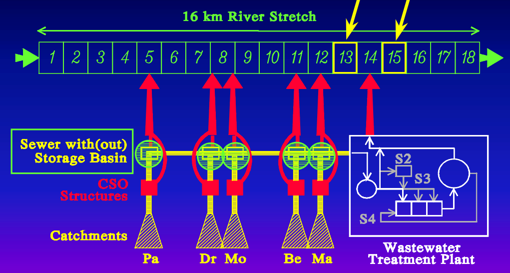
- Industrial plant with nitrogen problem:
  Question: Include automatic control or not ?

External Carbon for Denitrif. Effluent nitrate conc.

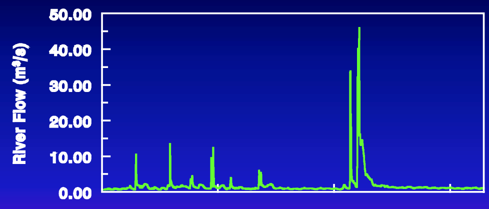


Integrated Urban Water Management

The Brussels case study...



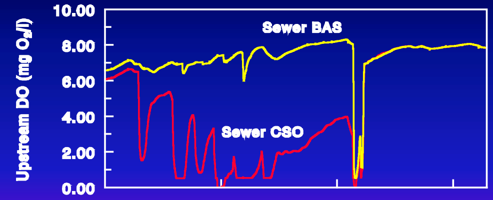
Effect of 2 design options (BAS/CSO) on River Water Quality



One big and several small rain events in summer '86

River Water Quality (oxygen)

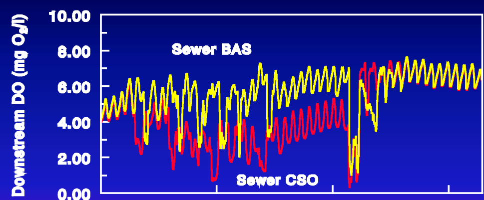
Downstream of CSO, Upstream of WWTP



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

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

GREAT-ER project

Geography-referenced Regional Exposure Assessment Tool for European Rivers

- prediction of the fate of specific **"down-the-drain" chemicals** in **surface water**
- using **Geographical Information Systems** (GIS)
- for use within **Environmental Risk Assessment**

Environmental Risk Assessment

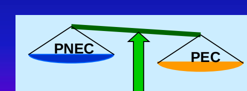
- Aim = **assess** the probability and severeness of negative **effects** on ecosystems after exposure to **chemicals**
- steps:
  - exposure: Predicted Environmental Concentration **(PEC)**

    → how much ends up in the environment ? where ?
  - effects: Predicted No Effects Concentration **(PNEC)**

    → how toxic / dangerous is the chemical for the environment ?

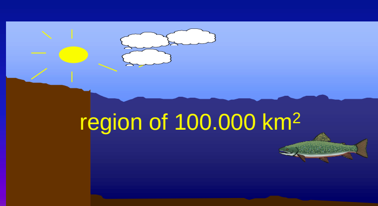
Environmental Risk Assessment

- Aim = **assess** the probability and severeness of negative **effects** on ecosystems after exposure to **chemicals**
- steps:
  - exposure: Predicted Environmental Concentration **(PEC)**
  - effects: Predicted No Effects Concentration **(PNEC)**
  - risk ratio: $\frac{\textbf{PEC}}{\textbf{PNEC}}$ **< 1 ?**



Environmental exposure assessment

- **Current methods** (advised in EU legislation):
  - **multimedia fate models**

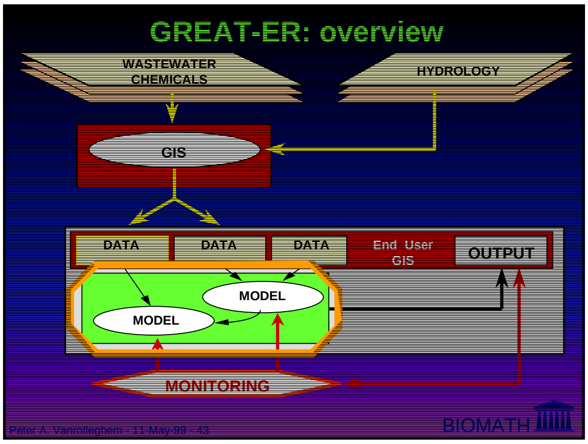


Environmental exposure assessment

- **Current methods**:
  - **multimedia fate models**
  - no spatial nor temporal variability considered

    → limited accuracy **FACTOR > 100-1000 !**
- **GREAT-ER: refine PEC calculations**
  - 'real' **geo-referenced** data
  - **variability**
  - geo-referenced → **validation** is possible

AIM = FACTOR < 3-5


GREAT-ER: overview
WASTEWATER CHEMICALS
HYDROLOGY
GIS
DATA
DATA
DATA
End User GIS
OUTPUT
MODEL
MODEL
MONITORING
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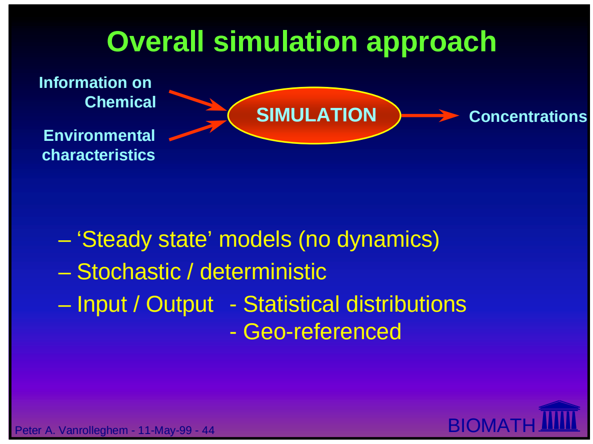
Overall simulation approach
Information on Chemical
Environmental characteristics
SIMULATION
Concentrations
– 'Steady state' models (no dynamics)
– Stochastic / deterministic
– Input / Output - Statistical distributions
- Geo-referenced
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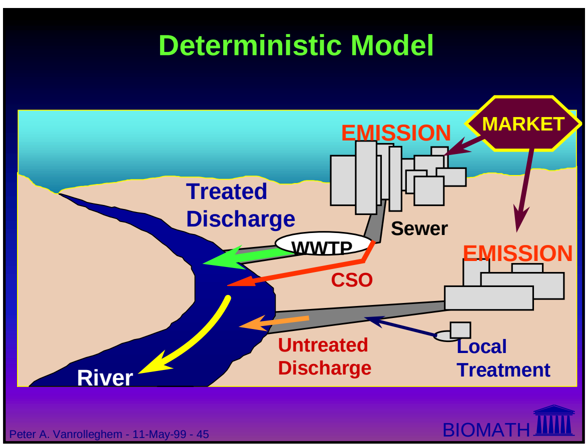
Deterministic Model
EMISSION
MARKET
Treated Discharge
Sewer
WWTP
EMISSION
CSO
Untreated Discharge
Local Treatment
River
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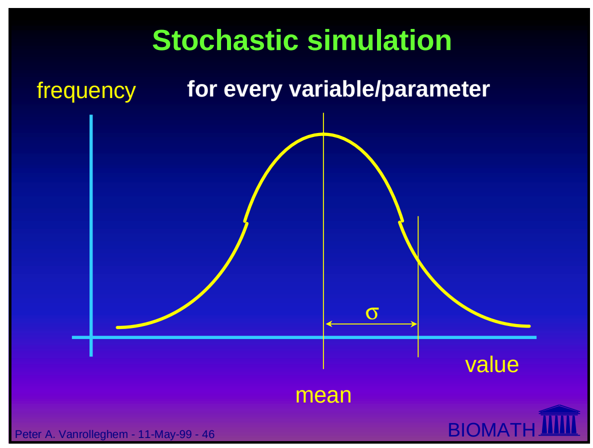
Stochastic simulation
frequency
for every variable/parameter
σ
value
mean
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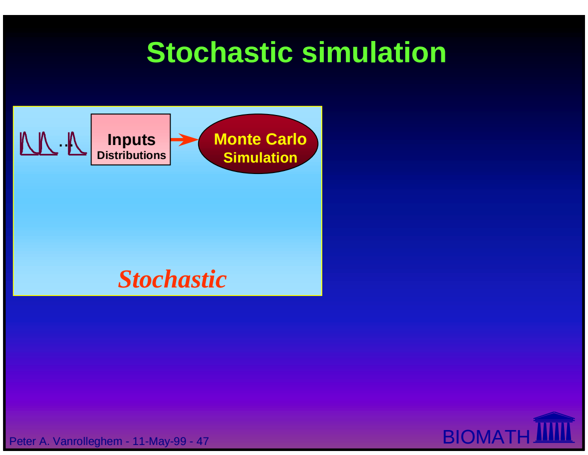
Stochastic simulation
Inputs Distributions
Monte Carlo Simulation
Stochastic
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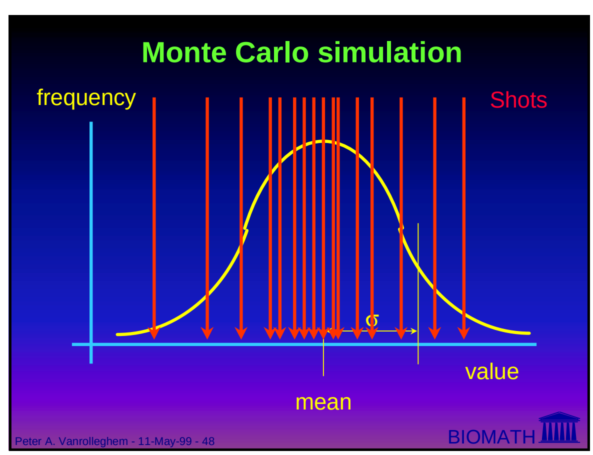
Monte Carlo simulation
frequency
Shots
σ
value
mean
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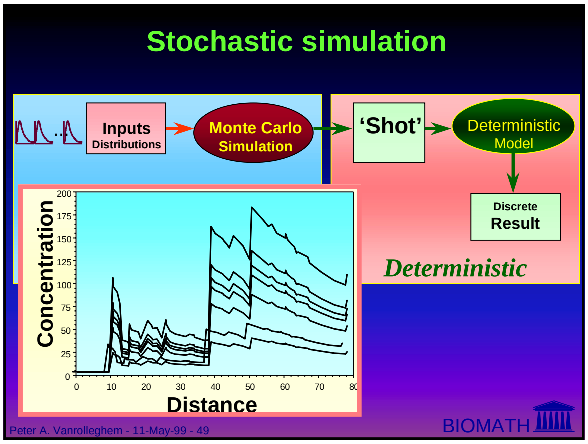
Stochastic simulation
Inputs
Distributions
Monte Carlo
Simulation
'Shot'
Deterministic
Model
Discrete
Result
Deterministic
Concentration
Distance
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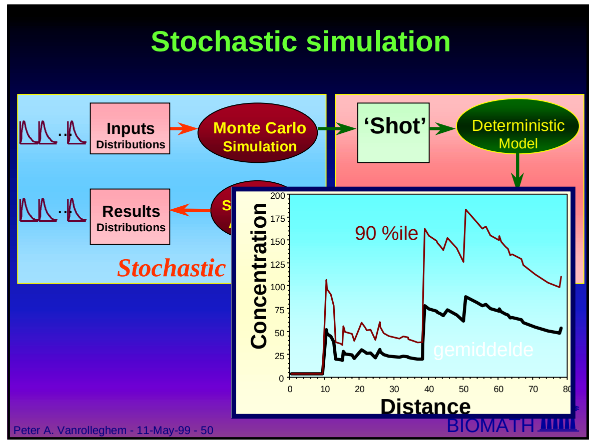
Stochastic simulation
Inputs
Distributions
Monte Carlo
Simulation
'Shot'
Deterministic
Model
Results
Distributions
Stochastic
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gemiddelde
Concentration
Distance
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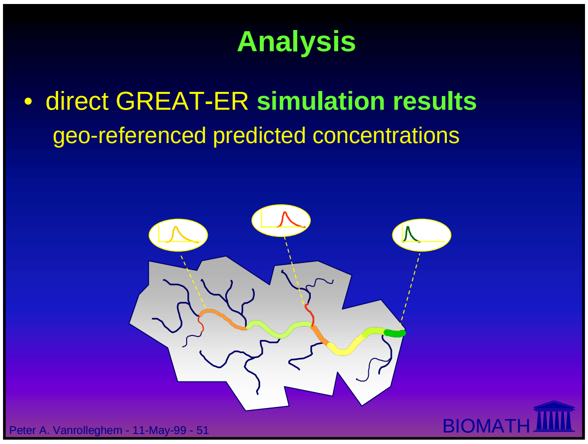
Analysis
• direct GREAT-ER simulation results
geo-referenced predicted concentrations
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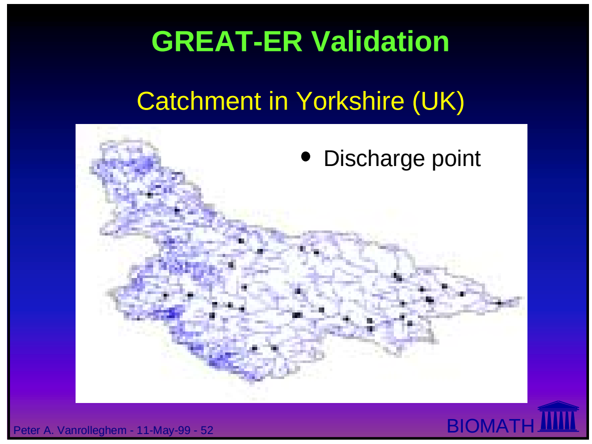
GREAT-ER Validation
Catchment in Yorkshire (UK)
• Discharge point
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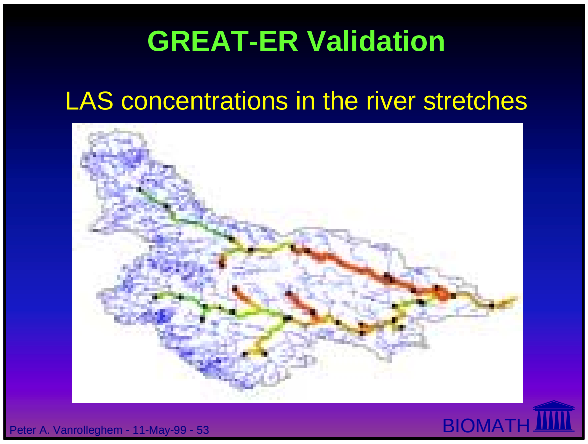
GREAT-ER Validation
LAS concentrations in the river stretches
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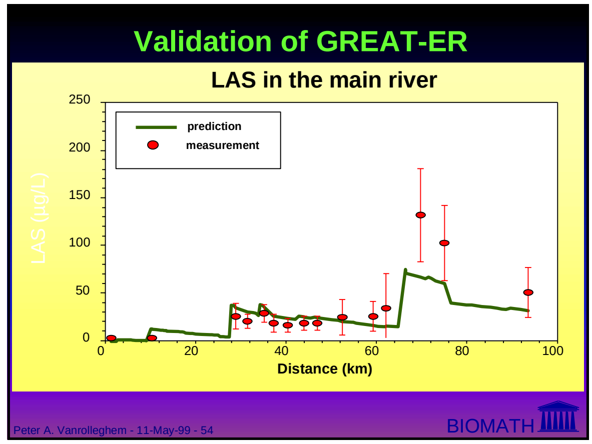
Validation of GREAT-ER
LAS in the main river
prediction
measurement
LAS (µg/L)
Distance (km)
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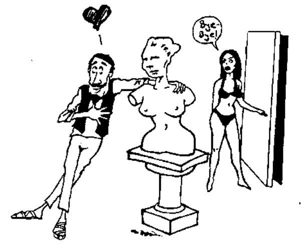
“Do not fall in love with your model”

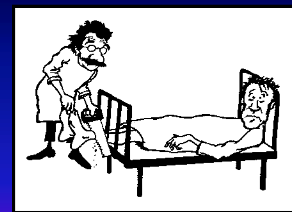


Pygmalion

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 !

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Arigato !

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November 14th 2000

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