Uncertainties in water system models – Breaking down the water discipline silos

Watermatex2011

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Spain

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Introduction

- Workshop on Uncertainty in Water System Models

Introduction

Workshop: Uncertainties in Water System Models

Thursday 11 – Friday 12 November

- Collaborative effort of:
  - IWA/WEF Design and Operations Uncertainty Task Group
  - International Working Group on Data and Models
    (under the Joint IWA/IAHR Committee of Urban Drainage)

Introduction

- IWA/WEF Design & Operations Uncertainty TG:
  - Current management of uncertainty in practice (A0)
  - Terminology and communication of uncertainty (A1)
  - Compilation of sources of uncertainty (A2)
  - Review of academic research on uncertainty in WWTP modelling (A3)
  - Identify gaps and define future research topics (A4)
  - Assess transferability of methods from other fields (A5)
  - Compile Scientific and Technical Report (A6)

Participants

- Ana Deletic
  Monash Univ. (AUS)
- Rebekah Brown
  Monash Univ. (AUS)
- Barry Croke
  Australian Nat. Univ. (AUS)
- John Doherty
  Watermark Num. Comp. (AUS)
- George Kuczera
  Univ. Newcastle (AUS)
- David McCarthy
  Monash Univ. (AUS)
- Peter Vanrolleghem
  Univ. Laval (CAN)
- Zoran Kapelan
  Centre for Water Systems (UK)
- Manfred Kleindorfer
  Univ. Innsbruck (A)
- Jean-Luc Bertrand-Krajewski
  INSA-Lyon (F)
- Peter Steen Mikkelsen
  Technical Univ. Denmark (DK)
- Wolfgang Rauch
  Univ. Innsbruck (A)
- Jens-Christian Refsgaard
  GEUS (DK)

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Participants

- Ana Deletic
  Urban Drainage
- Rebekah Brown
  Social modelling of water systems
- Barry Croke
  Hydrology
- John Doherty
  Hydrology
- George Kuczera
  Hydrology
- David McCarthy
  Urban Drainage
- Peter Vanrolleghem
  Wastewater
- Zoran Kapelan
  Drinking Water
- Manfred Kleindorfer
  Integrated Wastewater Systems
- Jean-Luc Bertrand-Krajewski
  Urban Drainage
- Peter Steen Mikkelsen
  Urban Drainage
- Wolfgang Rauch
  Integrated Wastewater Systems
- Jens-Christian Refsgaard
  Groundwater

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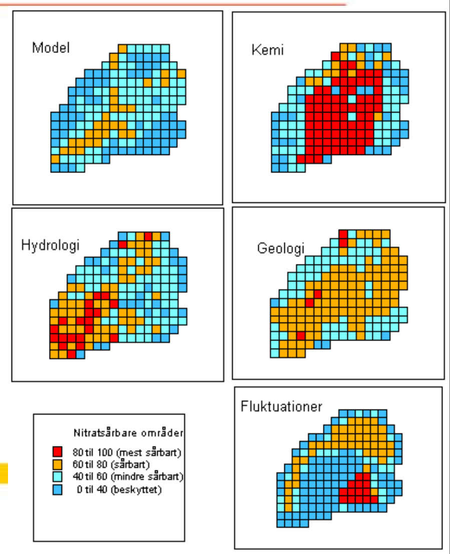
Lessons

- <u>Lesson 1</u>
  Jens-Christian Refsgaard:

Copenhagen County project on identification of suitable methods for assessing groundwater vulnerability (2000)

Assessments from five consultants on areas vulnerable to nitrate pollution from diffuse sources



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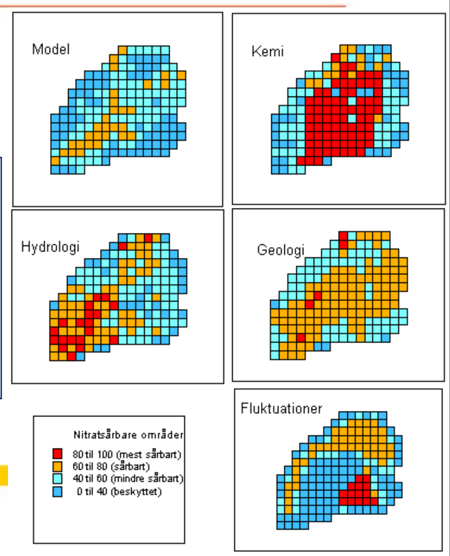
Lessons

- <u>Lesson 1</u>
  Jens-Christian Refsgaard:

Prediction uncertainty due to

- data interpretations
- model parameter values
- models (process equations)
- problem framing



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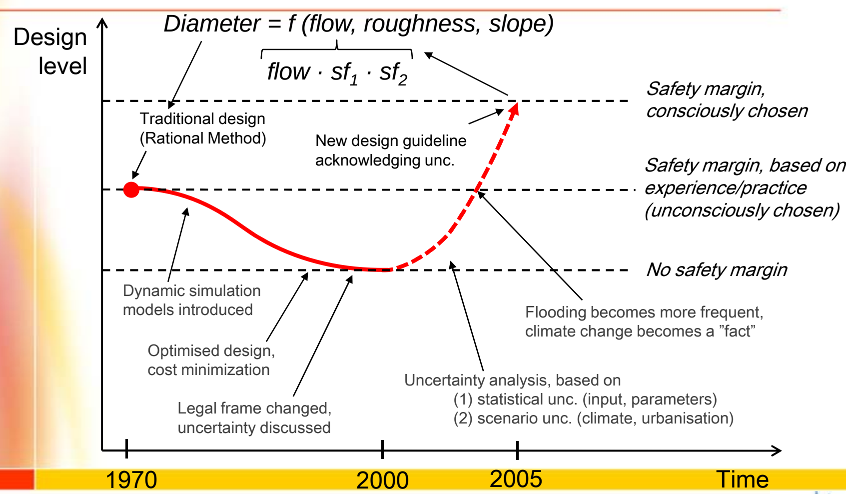
Lessons

- <u>Lesson 2:</u>
  Peter Steen Mikkelsen:

  Temporal evolution of safety margin in sewer design in Denmark over the last 40 years

Lessons



Lessons

- Exactly the same evolution takes place in WWTP design approaches
  - Simplified design models with
    - Worst case inputs
    - Safety factors
  - Process models with
    - Default parameters and influent characterization
    - Reduced safety factors
  - Process models with
    - Explicit uncertainty consideration

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Need for sharing developments

- Major methodological developments take place in hydrology
- Transferable/desired in other water fields

- Many uncertainty-related methods around!
- Too many?
- Meta-guidance by van der Keur et al. (2010) (a guidance on available guidances!) to navigate through the wealth of tools

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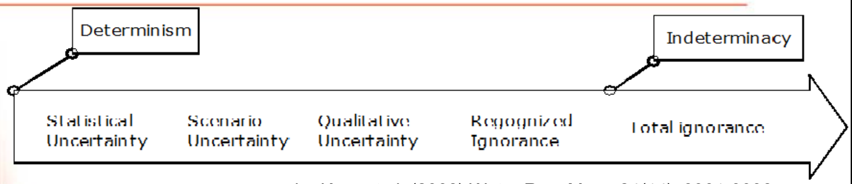
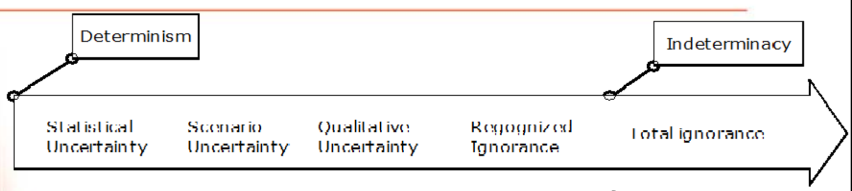
Agreement 1



van der Keur et al. (2008) Water Res. Man., 24(14), 3901-3938.

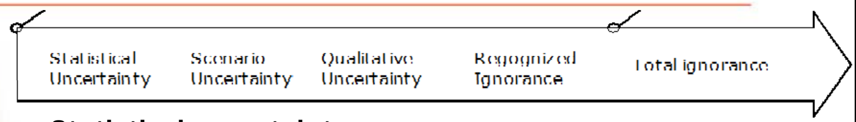
Agreement 1



Donald Rumsfeld

As we know, there are known knowns.
There are things we know we know.
We also know there are known unknowns.
That is to say :
We know there are some things we do not know.
But there are also unknown unknowns,
the ones we don't know we don't know.

Agreement 1



Statistical uncertainty
- All outcomes known
- All probabilities known

Scenario uncertainty
- Range of outcomes of plausible futures
- No probabilities known

Qualitative uncertainty
- Not all outcomes necessarily known
- Cannot be described statistically

Ignorance
- We are aware that there is something we do not know

Total ignorance
- We do not know that there is something we do not know

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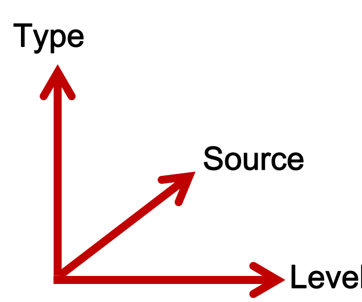
Agreement 2

- A draft framework for communicating about uncertainty
  - *"Any departure from the unachievable ideal of complete determinism"*
  - A 3-dimensional concept
    - Type: statistical, scenario
    - Source: inputs, parameters
    - Level: reducible/irreducible



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Agreement 3

- Representation of uncertainty in water system models:

  $Y(t) = f(X(t), \Theta \mid S)$

  - Y: model outputs
  - X: model inputs (forcing functions)
  - f: model structure
  - Θ: parameters (! ~~Time-varying parameters~~)
  - S: scenarios that are fully quantifiable

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Agreement 4

- Sources of uncertainty can be found in:
  - f: model structure uncertainty
  - X: input uncertainty
  - Θ: parameter uncertainty
  - S: scenarios uncertainty
- <u>Forward modelling problem (Unc. propagation):</u>
  - Uncertainty in Y as result of uncertainty in f, X, Θ, S
- <u>Inverse modelling problem (Unc. assessment):</u>
  - Uncertainty in Θ (and/or f) from residuals (Y – data) for given X and S (with their uncertainties)

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Agreement 5

- Forward modelling: a “No-problem”
  - Analytical (linear error propagation: *OK for mildly NL*)
  - Numerical (Monte Carlo)
- Transfer into practice is an issue:
  - Available compute power (Monte Carlo)
  - Training
- Monte Carlo sampling methods:
  - Mature
  - Suitable methods should be selected on case by case basis (e.g. correlations)

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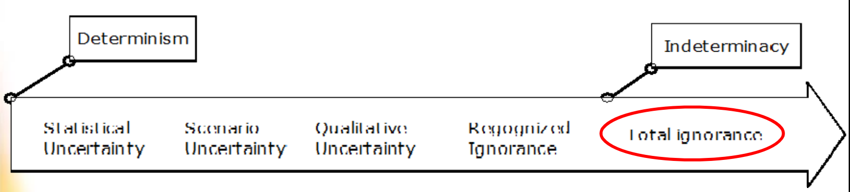
Agreement 6

- Inverse modelling: (Assess sources of uncertainty)



- Nothing can be said about total ignorance

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Disagreement 1

- <u>Inverse modelling:</u>
- Assessing recognized ignorance
  - Under full development !
- Assessing qualitative uncertainties
  - Social sciences: generate uncertainty profiles from key stakeholders
- Assessing scenario uncertainties:
  - Scenario-building methodologies focusing on relationship societal-biophysical systems

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Disagreement 2

- <u>Inverse modelling:</u>
- Assessing statistical uncertainties
  - Many methods available
  - Frequentists (typical water professionals) vs. Bayesians
  - Bayesian approach is <u>probably</u> the way to go
    - Statistical rigour – assumptions made can be scrutinized
    - Integrates all uncertainty sources (incl. observation system)
    - Prior knowledge can be used in a natural way
  - Problems remain:
    - Numerical load for complex models
    - Error models to work with

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Agreement 7

- Inverse modelling procedure for statistical unc. assessment:

Step 1
- Prepare the calibration problem
  - Define objectives, calibration data and methods

Step 2
- Parameter estimation
  - Bayesian approach
  - Optimisation approach
  - Trial and error approach

Step 3
- Diagnostic testing of hypotheses
  - Residuals analysis,
  - Singular Value Decomposition

Step 4
- Model validation
- Prediction intervals

Agreement 8

- Key challenges:
  1. Assess uncertainties in the absence of data
     - Ungauged systems
     - Future scenarios
  2. Critical importance of data sets (size/content) for inverse modelling
  3. Model structure unc. dominates statistical unc. and we are ill-equipped to actually deal with it
  4. Scenario analysis for exploring recognized ignorance

Agreement 8

- Key challenges:
  5. Reducing predictive uncertainty through better consideration of the different sources of uncertainty
  6. How to best utilise the quantified uncertainty in decision-making
  7. How to help decision-makers deal with qualitative and scenario uncertainty

Take home

- Twelve people from different "water silos" came together at Surfers Paradise
- The silo-effect is relatively small
  - More agreement (8) than disagreement (2)
- Hence, experiences should be shared
- Uncertainty becomes increasingly explicit
- Considerable challenges remain (7)