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Towards a paradigm shift: introducing explicit uncertainty evaluations in model based design

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- WERF Nutrient Challenge Program
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Overview

- Motivation
- Conventional and Model Based Design
- Uncertainty and Variability
- Making Risk and Reliability Explicit
- Probabilistic Design
- Summary

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Motivation

- Safety factors have not changed for decades
- Towards a paradigm shift:
  - increased use of simulators for design and optimization
  - simulator approach lacks reliability evaluation
  - need for scientific approach to balance risk/benefits
- Why now?
  - simulators are everywhere
  - conventional design paired with model based design
  - strict effluent guidelines & increased energy efficiency
  - awareness among practitioners

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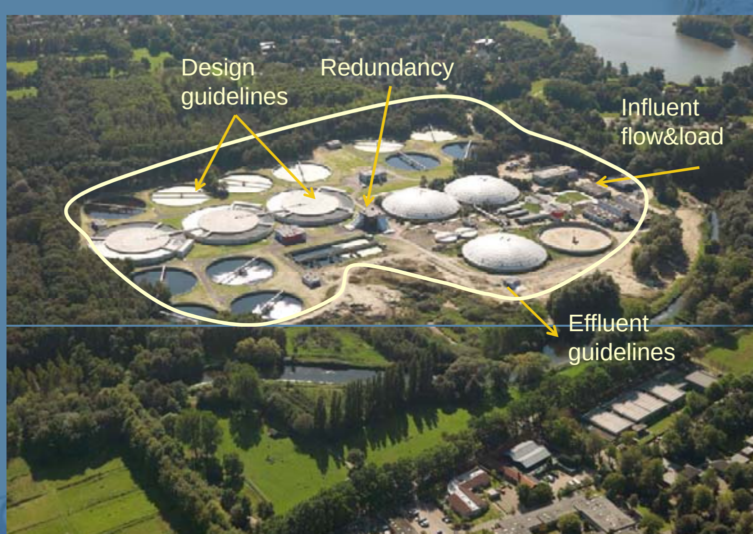
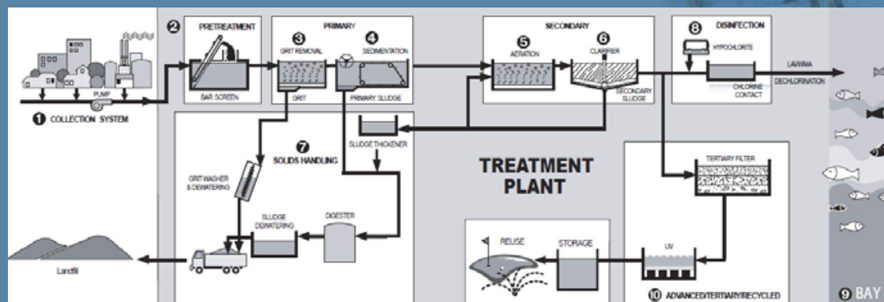
Motivation

- To make the paradigm shift complete we need to incorporate explicit uncertainty evaluations in our model based design and operations

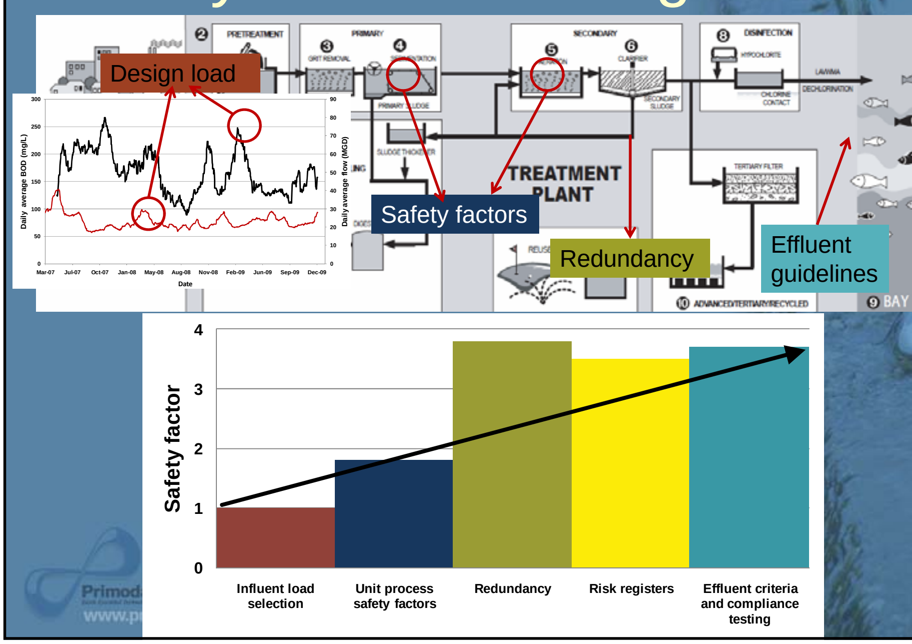
Eindhoven WWTP



Safety factors in design

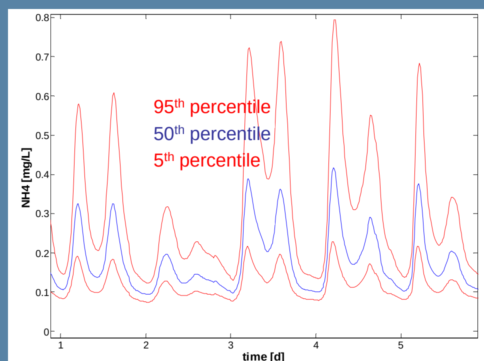


Safety factors in design



Why all this?

Variability ⟺ Uncertainty



in blue:
temporal variability due to influent variability

in red: uncertainty band due to parameter uncertainty

Vanrolleghem, P.A. (2010) Principles of Uncertainty Evaluations. Workshop 203: How Will Your Wastewater Plant Really Run? Evaluating Risk in Design and Operation WEFTEC, October 3, 2010, New Orleans.

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A Motivating Example

Input Uncertainty	Model Simulation	Output Risk	Decision Analysis
Select key sources of uncertainty	Run model with selected input parameters	Model predicted variation in effluent concentrations	Select design volume and add (or not) additional safety factors
Consultant No 1: Low process uncertainty	optimistic denitrification rates	Model predicted effluent concentrations	Design volume **X m³**
Consultant No 2: Some process and operational uncertainty	conservative denitrification rates and clarifier loading rates	Model predicted effluent concentrations	Design volume **2X m³**
Consultant No 3: High uncertainty associated with influent	conservative influent combination	Model predicted effluent concentrations	Design volume **4X m³**

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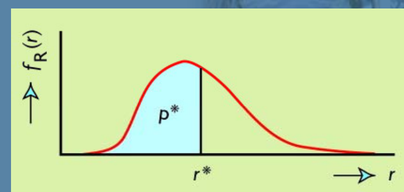
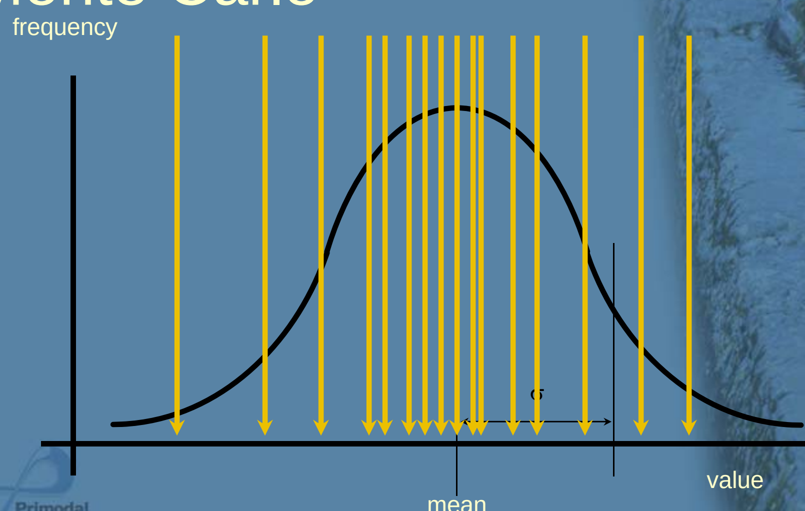
How can we do better?

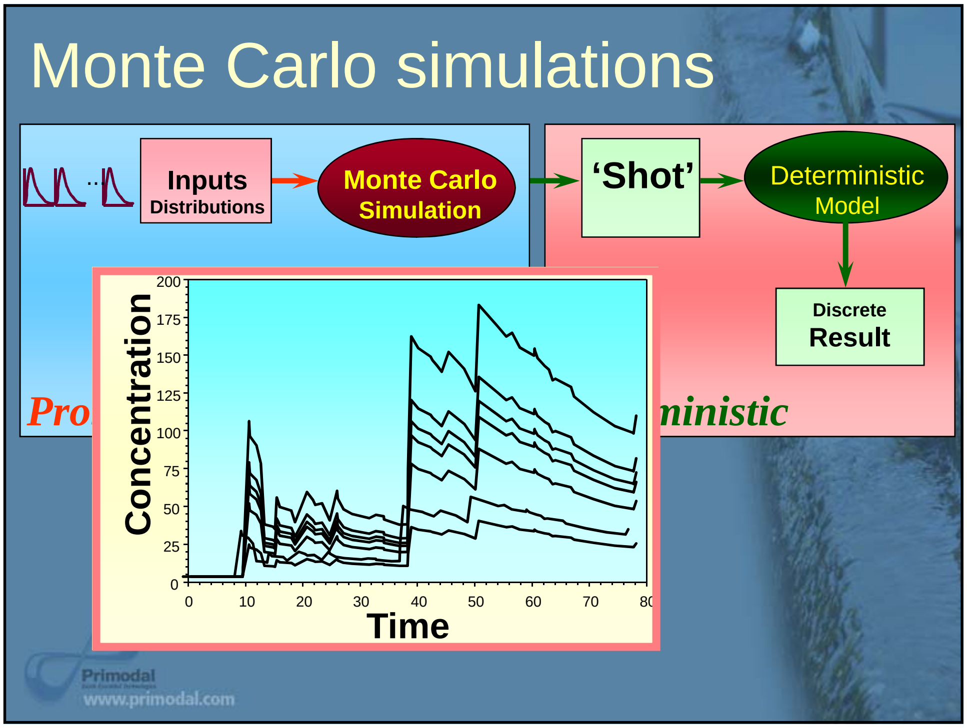
- Statistical description of variability / uncertainty
- Assessment and propagation are:



  - the basis for quantitative risk assessment
    - Risk of failure
    - Risk = [Probability of failure] * [Cost of failure]
  - essential for informed decision-making
  - the methods are there…so, why not?

Uncertainty Propagation: Monte Carlo




Monte Carlo simulations
Inputs
Distributions
Monte Carlo
Simulation
'Shot'
Deterministic
Model
Discrete
Result
Pro
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Concentration
Time
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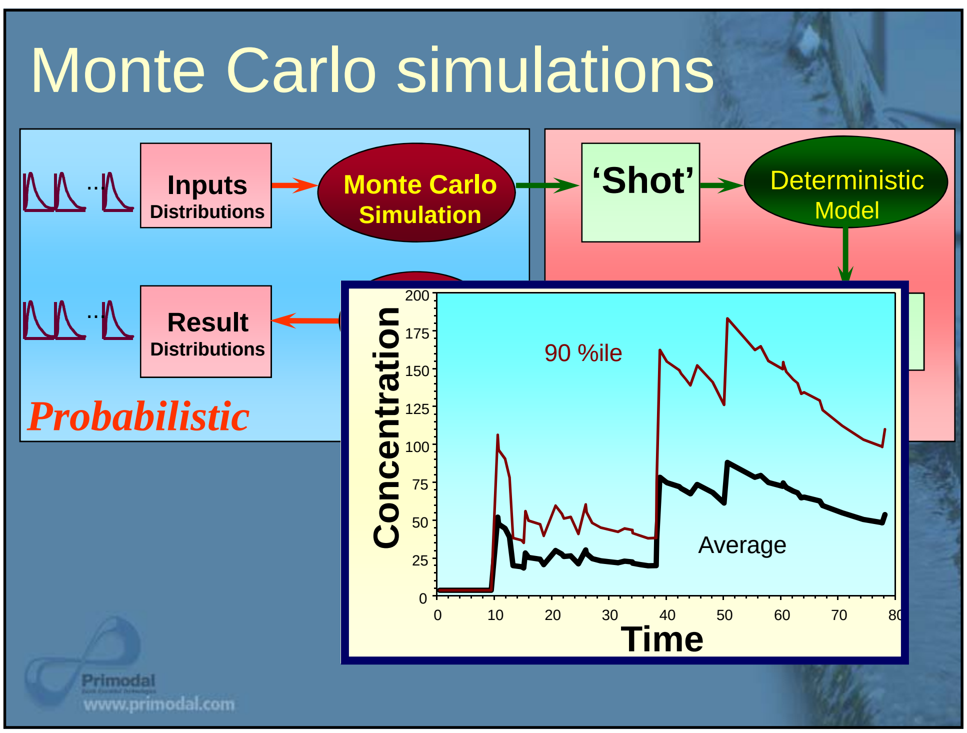
Monte Carlo simulations
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Average
Concentration
Time
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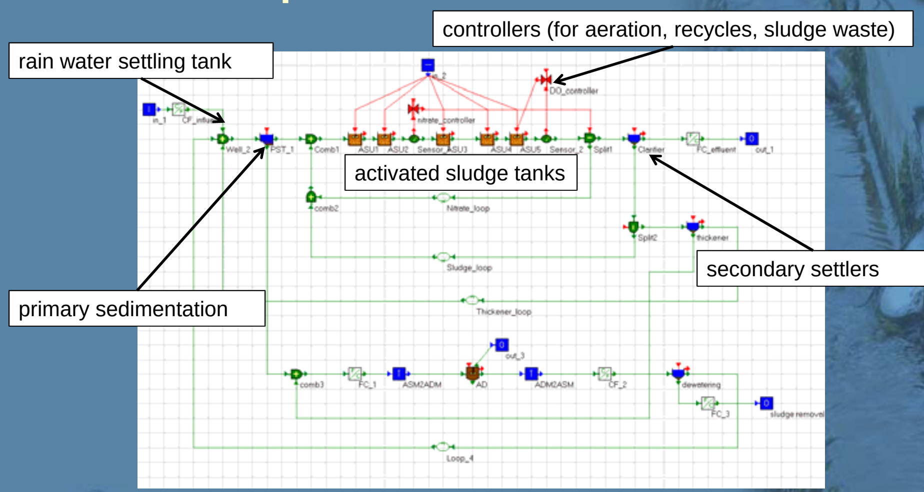
Eindhoven WWTP

Benedetti, L., *et al.* (2010) Wet-weather treatment upgrade scenarios with sensitivity and uncertainty analysis at the Eindhoven WWTP. In: *Proceedings of WEFTEC2010*, New Orleans, LA, USA, 2-6 October 2010.

Objectives

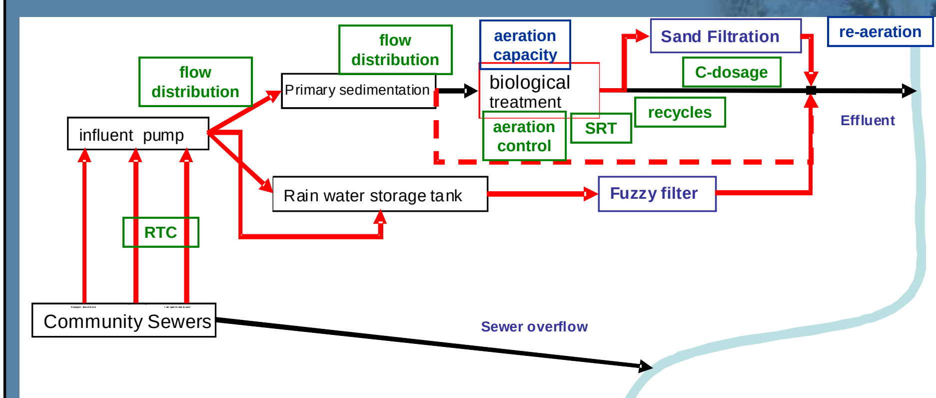
- EU Water Framework Directive: limit **peak discharges** into the receiving water
- **Model-based** analysis to **reduce** effluent NH_4, TSS and DO **dips**
- **Global sensitivity analysis (GSA):** identify the most important parameters for effluent peaks in wet weather
- **Monte Carlo (MC) scenario analysis:** identify the values for the operational parameters sets identified with the GSA
- **Uncertainty analysis (UA):** check the robustness of the best scenarios

Model implementation



WEST® simulator

Design and operation options



Global Sensitivity Analysis

- GSA on operational and bio-physico-chemical parameters (8-day input)
- Identify important parameters for plant performance
- Select sensitive operational parameters
- Optimization (MC)

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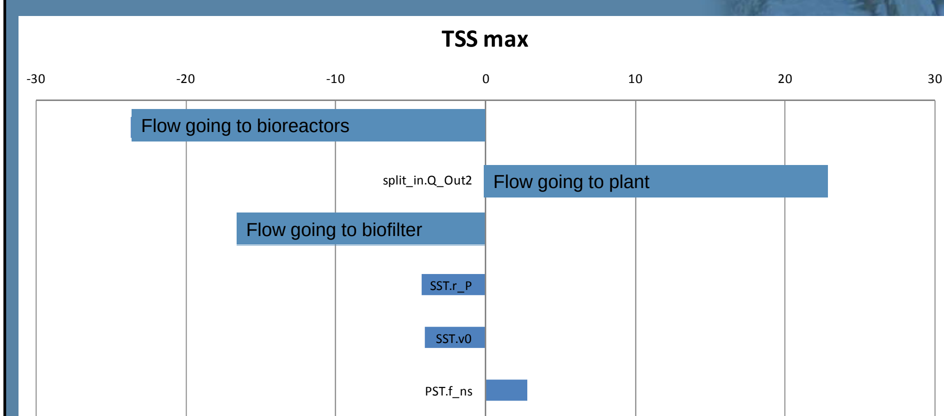
Sensitivity ranking

Most influential parameters: flow splitting and by-passes



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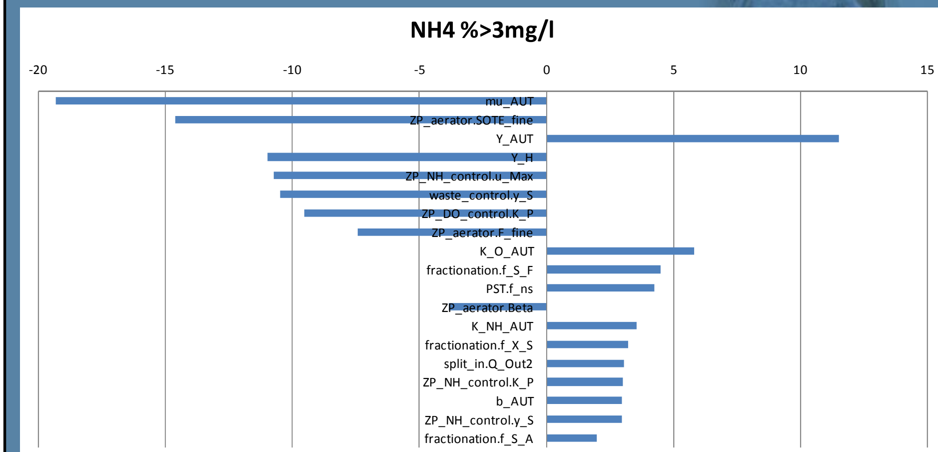
Sensitivity ranking



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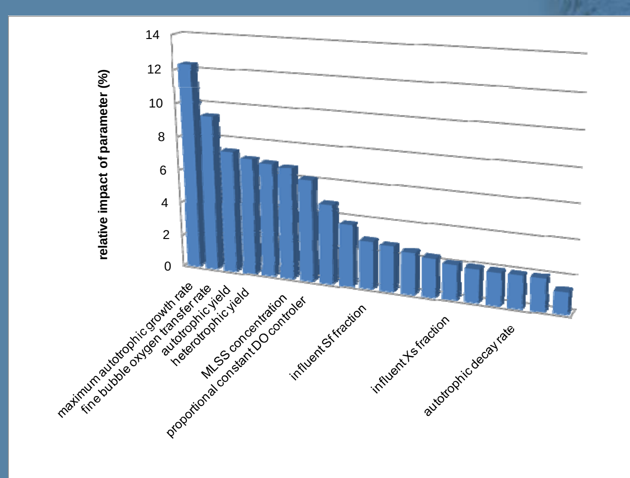
Sensitivity ranking



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The important operational settings

- Carbon source controller
- Cascade (NH_4-DO) aeration controller
- Recycle controllers
- Sludge wastage
- Flow splitters

Uncertainty analysis

Multi-criteria analysis

→

uncertainty analysis (UA)

Selection of best operational parameters

- Generation of scenarios with Monte Carlo varying the most important operational parameters
- Ranking of scenarios according to multiple criteria
- Selection of 5 best scenarios according to agreed criteria
- Uncertainty analysis with Monte Carlo varying the most important process model parameters

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Process parameters for UA (from the GSA)

- Influent fractionation
- Autotrophic biomass
- Oxygen transfer
- Hydrolysis

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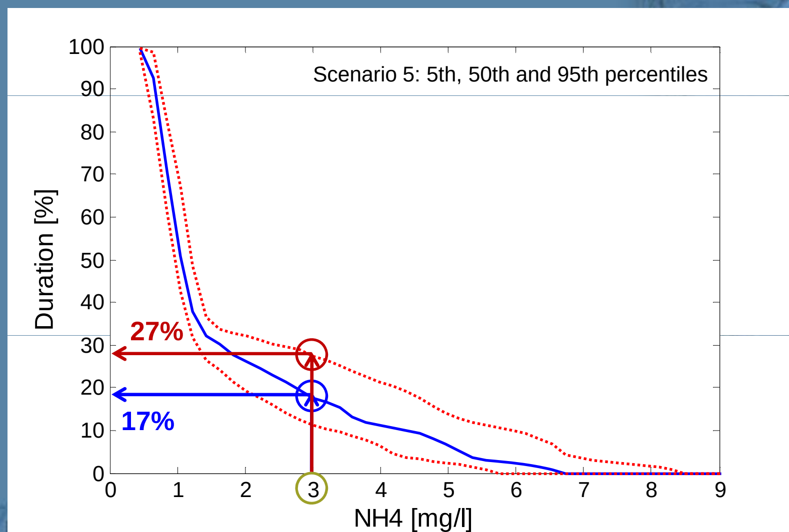
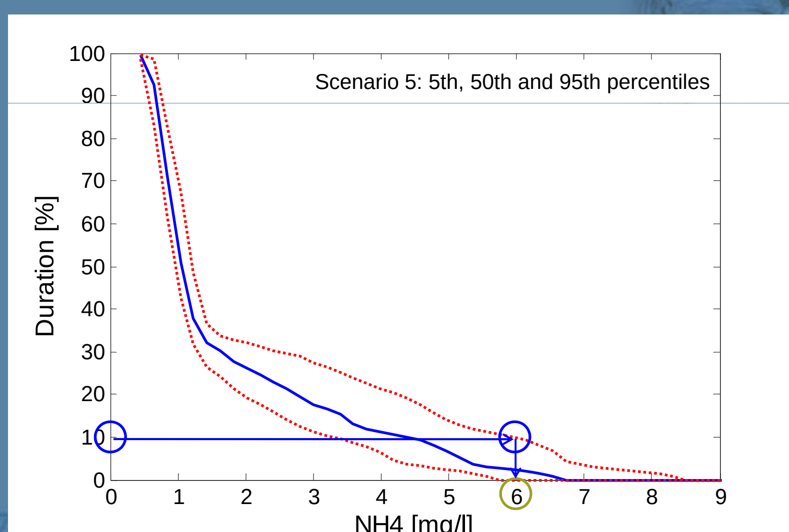
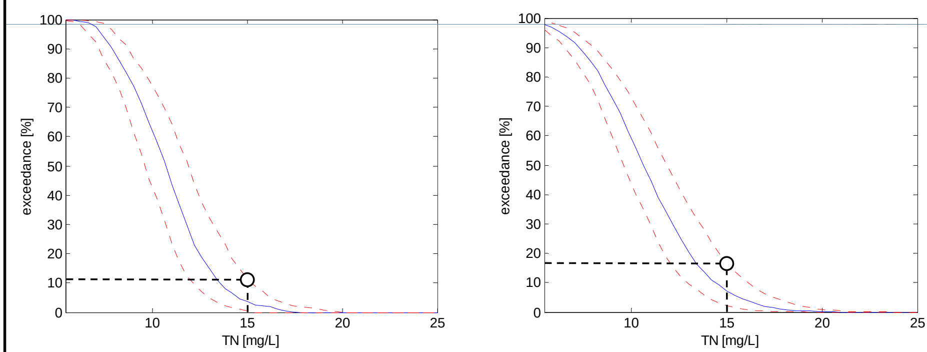
Results



Results



Results – variable averaging periods



CD curves: 24-hour (L) and 2-hour (R) averages.

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Conclusions

- A single snapshot does not provide quantifiable information about the reliability of a process design
- Statistical description of variability / uncertainty.
- Uncertainty analysis can provide "reality" to modeling results.
- Uncertainty results can be used to size a system with an "appropriate" level or risk

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Teams and Projects