Risk management with probabilistic advective-dispersive well vulnerability criteria

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Challenges in Water Supply Systems

„Drinking-water quality is an issue of concern for human health in developing and developed countries world-wide.“

WHO 3rd edition, Guidelines for Drinking Water Quality, 2004, Introduction

„The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a **comprehensive risk assessment** and **risk management approach** that encompasses all steps in water supply from catchment to consumer.“

WHO 3rd edition, Guidelines for Drinking Water Quality, 2004, Chapter 4 Water Safety Plans

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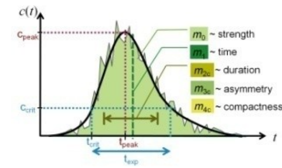
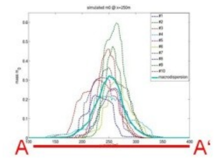
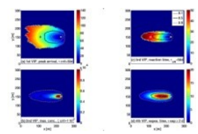
Outline



1. What kind of information is needed for risk management?

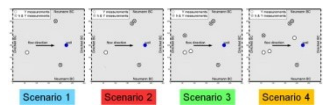


2. Why probabilistic risk assessment approaches?



3. Our probabilistic risk assessment approach!

4. Risk management under financial constraints?
   - Uncertainty reduction
   - Alternative risk treatment costs



5. Conclusions

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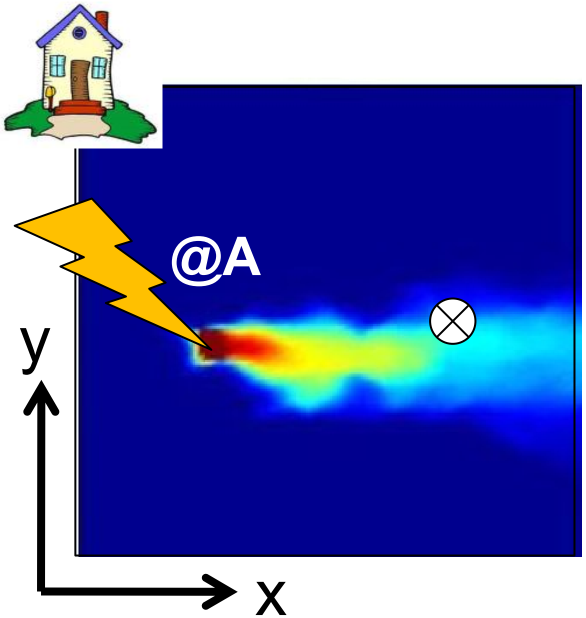
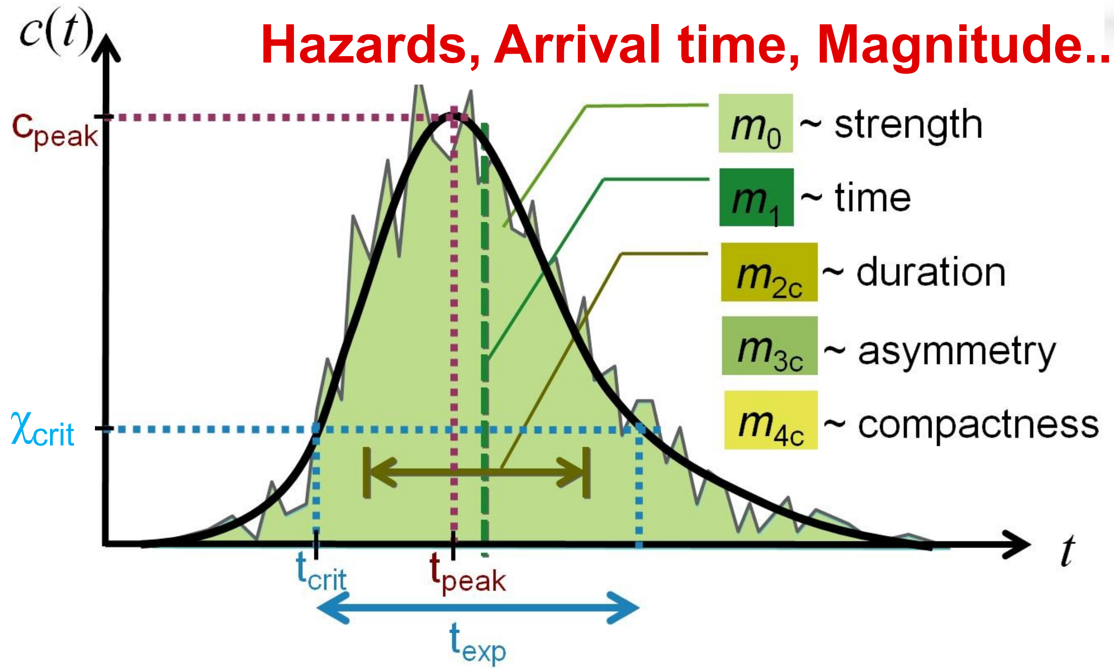
Well Vulnerability Criteria (WVC)





1) Time of peak arrival: t_{peak}
2) Max. concentration: c_{peak}
3) Time to react: t_{crit} (threshold level χ_{crit})
4) Exposure time: t_{exp}

(Frind et al.,2006)

Probabilistic Risk Framework

(Enzenhöfer et al.,2010)

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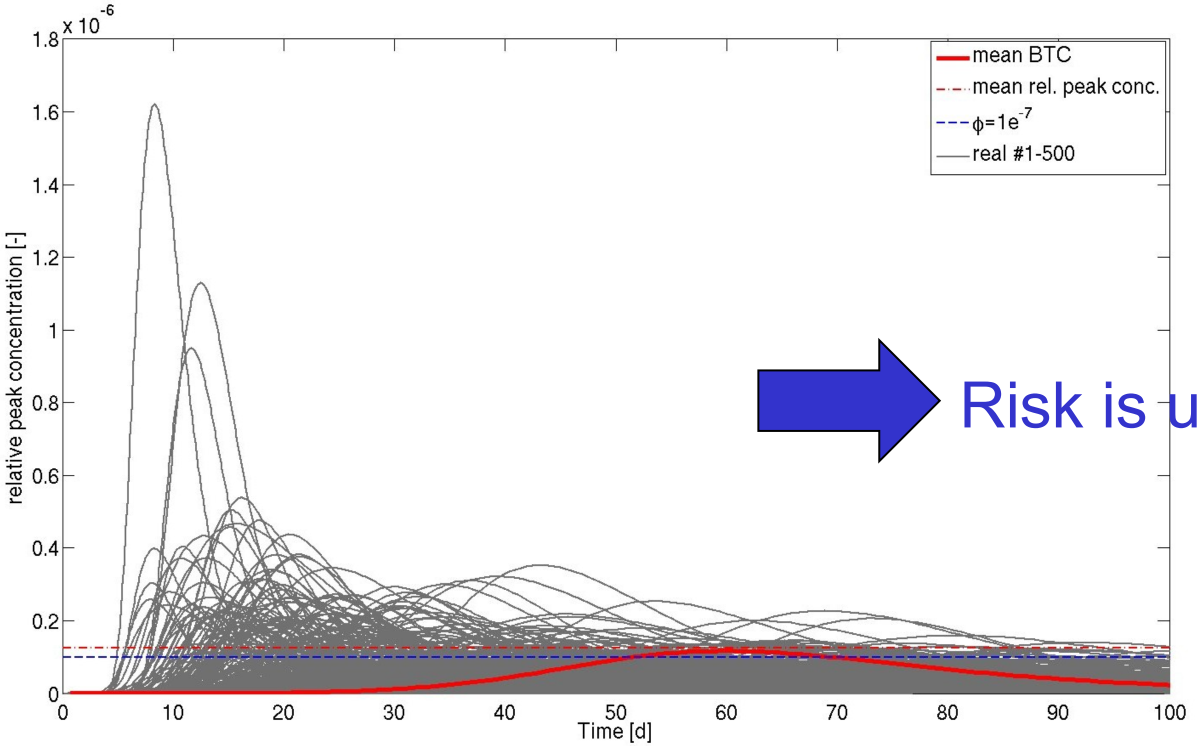
Why probabilistic risk assessment I

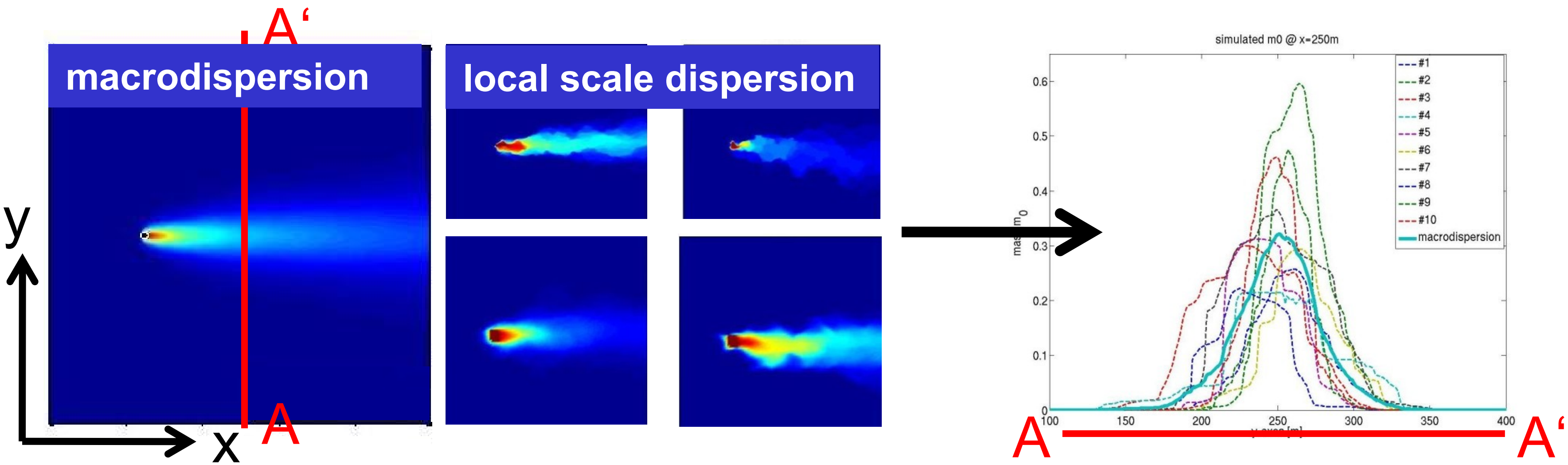
- Peak concentrations too small (averaging different peak times)
- Arrival of contamination is underestimated (uncertain first arrival)
-



Risk is underestimated !!!

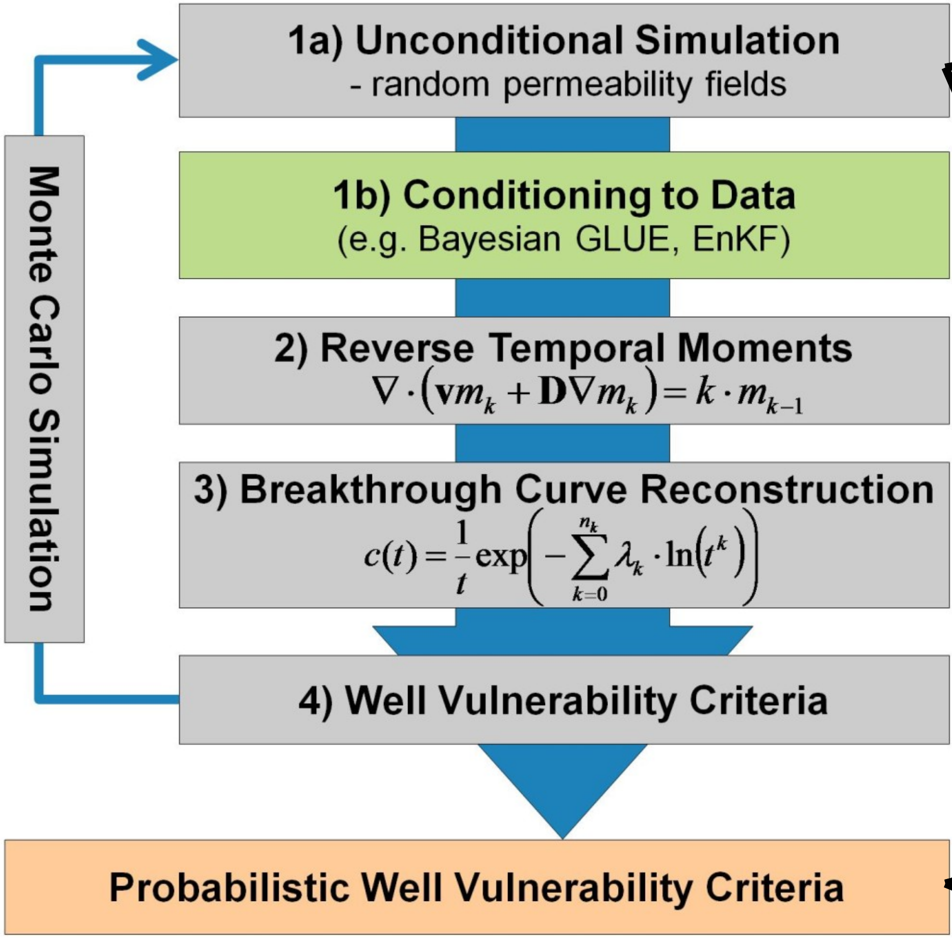
Why probabilistic risk assessment II

-
-
- Concentrations are assumed where there is none (variability in space)



Risk is underestimated

Our probabilistic risk concept



n = 500 realizations
Y = ln(μ)
μ = [-7.5 -5.5]
σ^2 = [1 3]
κ = [0.5 5] (Matérn)
λ_x = [10 25] m
λ_x = [5 15] m

$$P(t \geq t_0 \mid \mathbf{x} = \mathbf{x}_i) \approx \frac{1}{n} \sum_{j=1}^{n} w_j \cdot I_j(\mathbf{x}_i)$$

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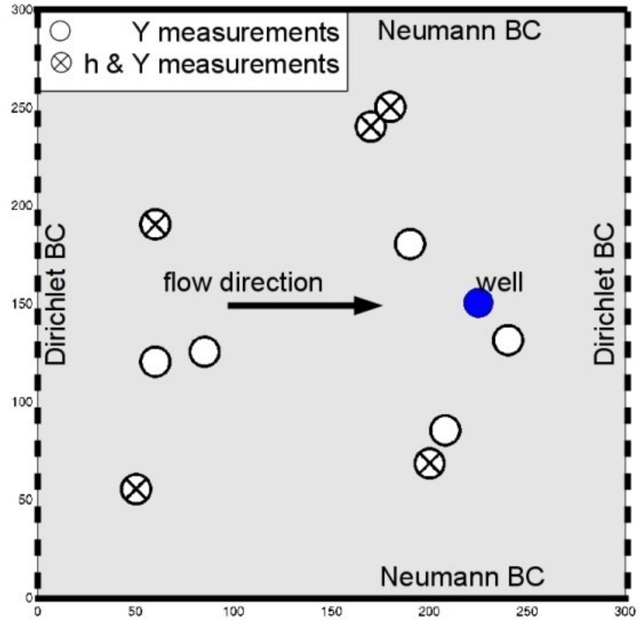
Conditioning on log(Y) and h



- Bayesian GLUE approach
- Synthetic truth ($\mathbf{d}_0$: 15measurements)
- Conditioned probabilistic WVC

$$\tilde{P}\left(t \geq t_0 \mid \mathbf{x}_i, \mathbf{d}_0\right) \approx \frac{1}{n} \sum_{j=1}^{n} w_j \cdot I_j(\mathbf{x}_i)$$

- Weight per realization j: $w_j = L_j / \sum L_j$

$$L\left(\mathbf{s}_j, \boldsymbol{\theta}_j, \boldsymbol{\beta}_j \mid \mathbf{d}_0\right) = \left(\frac{1}{2\pi \, \|\mathbf{R}\|} \cdot\right)^{m/2} \exp\left[-\frac{1}{2}\left(\mathbf{d}_0 - \mathbf{d}_{sim}(\mathbf{s}_j)\right)^T \mathbf{R}^{-1}\left(\mathbf{d}_0 - \mathbf{d}_{sim}(\mathbf{s}_j)\right)\right]$$

- **R**: error covariance matrix (e.g., measurement & model error)
- Fast Kriging-like conditioning of direct point-scale measurements
- Rejection Sampling $\frac{L_j}{L_{\max}} > r \begin{cases} true, & w_j = 1 \\ false, & w_j = 0 \end{cases}$

(Enzenhöfer et al., in Review)

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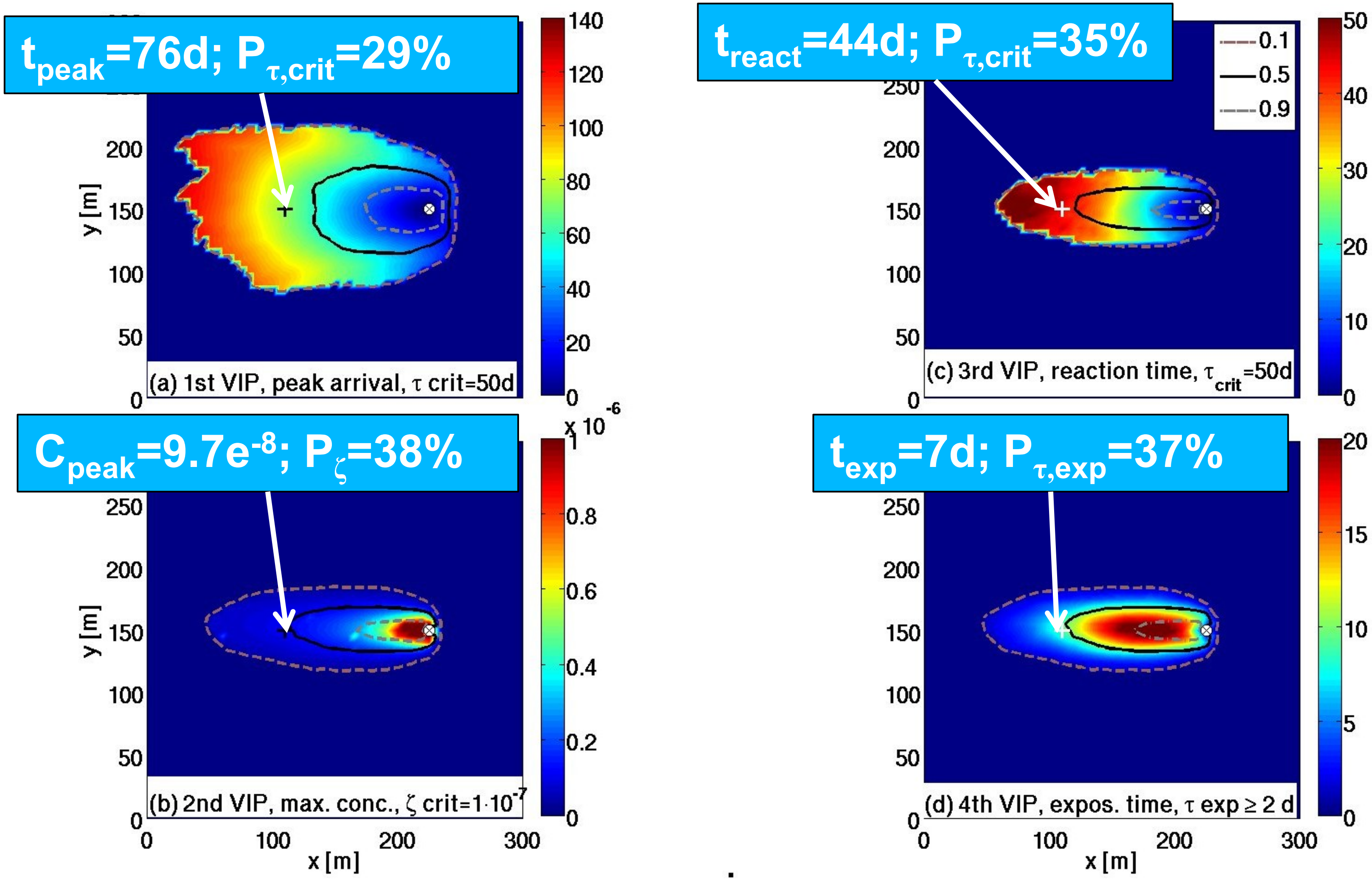
Risk mapping results (conditional)



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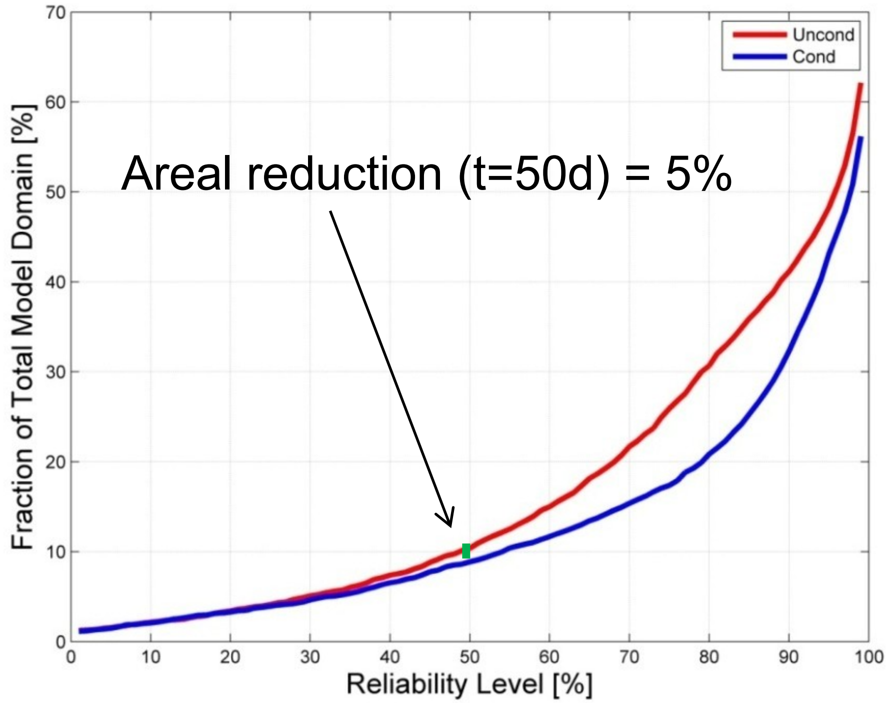
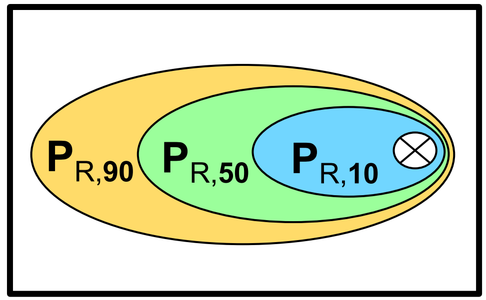
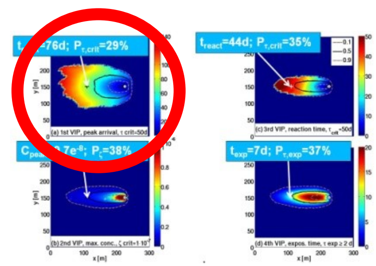
Probabilistic Risk Management by financial means

1. Risk aversion
2. Uncertainty reduction by sampling
3. Alternative risk treatment methods
4. Areal demand costs in early-alert systems

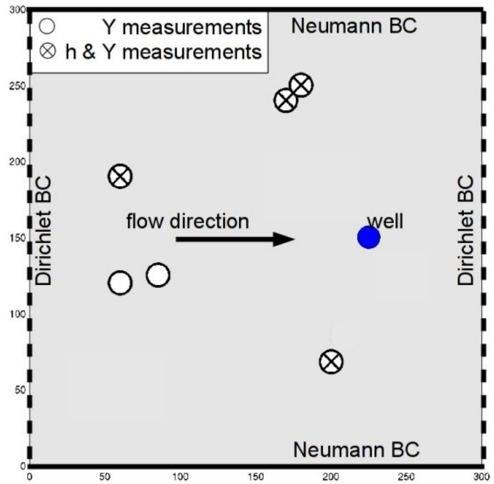


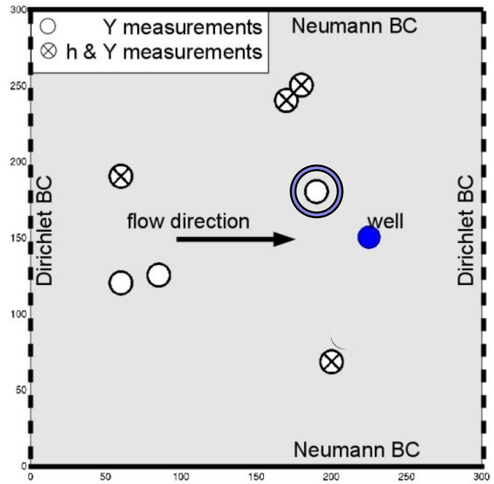




2) Cost reduction by areal uncertainty reduction

- Where to sample?
- How valuable is the investment?
- How many samples?





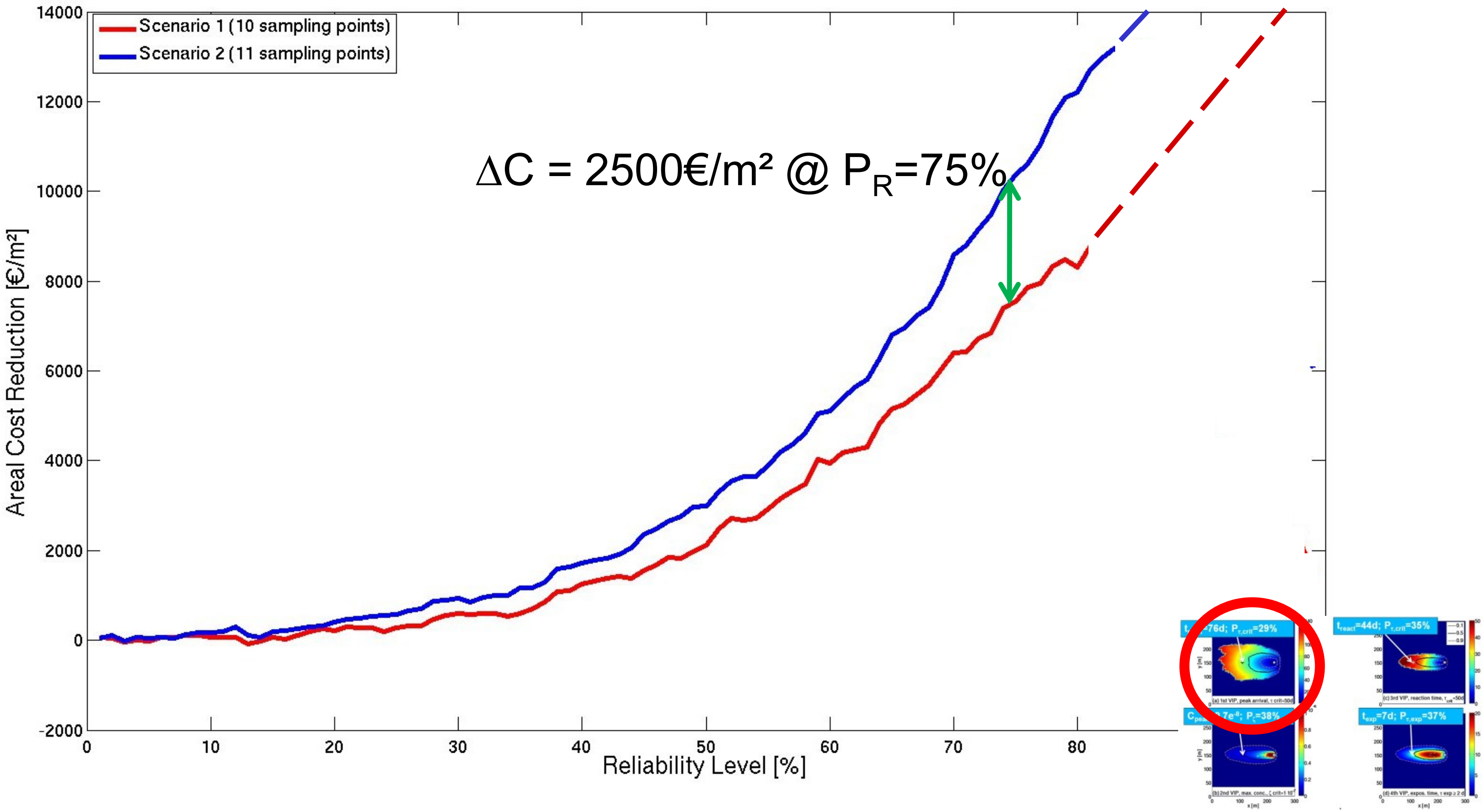
Design 1

10 samples
(6/4)

Design 2

11 samples
(7/4)

2) Areal Cost Reduction by sampling



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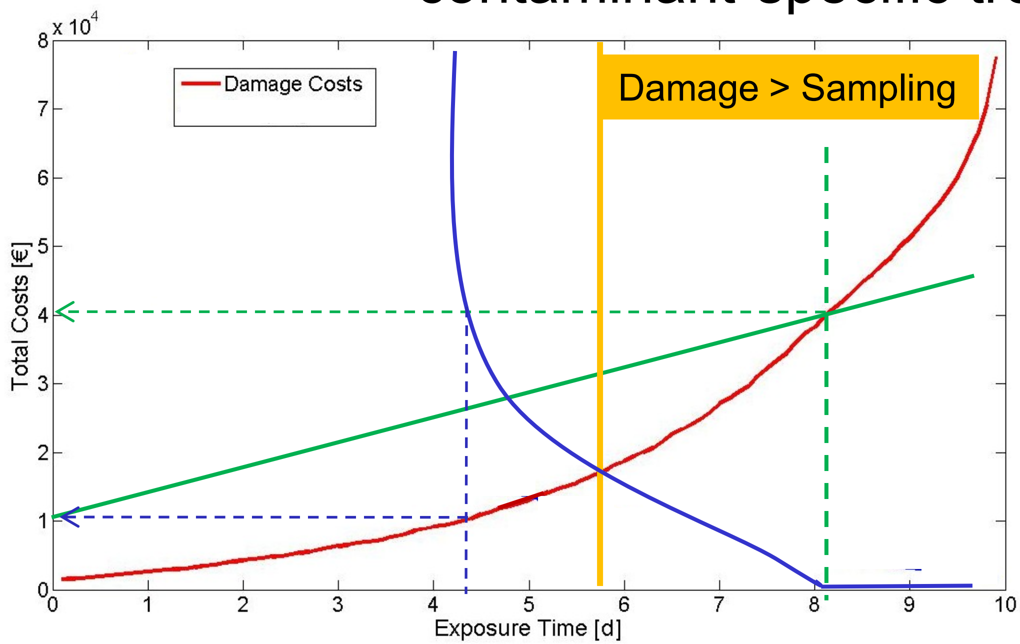
3) What is the Damage? – Choosing Alternatives

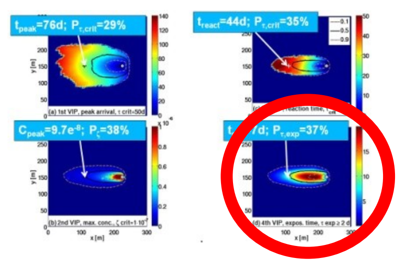
- Replacement Cost Method: Damage D_i [€]:

$$D_i = t_{\exp,i} \cdot Q_P \cdot \gamma_i$$

- γ = cost function (e.g., water price [1.30€] or contaminant-specific treatment costs)



Alternativ II: Sampling @ location A, P_R = 90%



Alternativ I: Treatment

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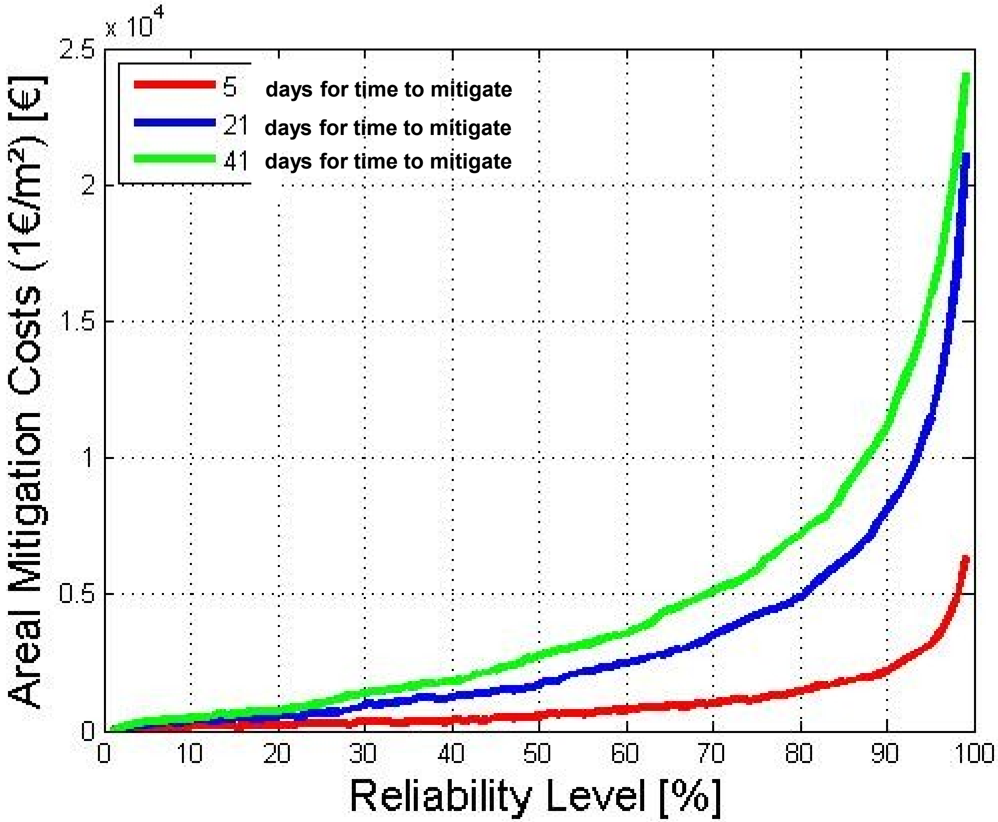
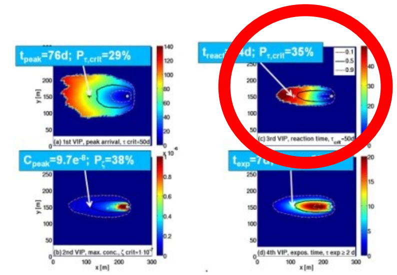
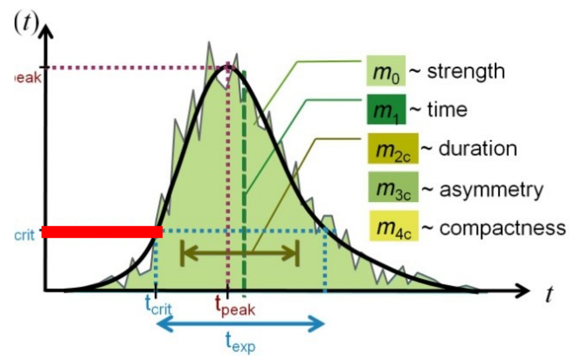
4) Areal costs until mitigation measures are installed





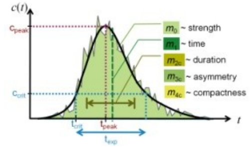


Reaction time

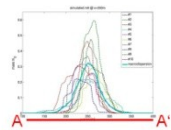
With increasing early-alert respond time the areal demand increases

Summary

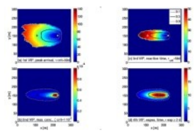
1 WVC are adequate for risk management



2 Seperation between dilution, location and uncertainty

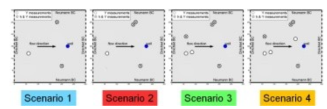


3 Indispensible information for risk management



4 The higher the risk aversion, the more expensive is RM

- Sampling and uncertainty reduction pays back
- Damage and alternative risk treatment
- Fast early-alert respond can pay itself



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Thanks to ...

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