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Rational risk-based decision support for drinking water well managers by optimized monitoring designs

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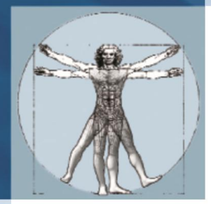
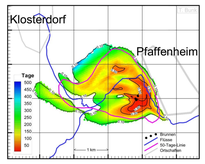


Motivation

The Water Safety Plan asks drinking water managers to implement full risk management schemes:

(1) What kind of hazards exist within the catchment,
(2) how these hazards can be controlled and
(3) knowing that they are controlled.



Thus stakeholders are often challenged to offer increasing safety levels by larger protection zones, but manage risk with low additional costs. Therefore optimal allocation of resources for improved monitoring is needed to perform risk-aware, cost-reduced and effective decisions in well-head delineation (WHP). Managers are thus challenged to know:

RQ-I: How many measurements are needed,
RQ-II: How well has the sampling quality to be and
RQ-III: Where to sample for optimal data worth?

Approach

First, we provide a probabilistic risk management (RM) approach for actively managed well catchments that quantifies uncertainty based on probabilistic intrinsic transport-based well vulnerability criteria: *Pdf of …*

a) … peak arrival time from source to well,
b) … possible peak concentration levels at the well,
c) … response time, exceeding a threshold level, and
d) … well down time (exposure time).

Secondly we provide answers to research questions *RQ-I* and *RQ-II* by optimizing the RM concept with improved monitoring for pre-defined designs (*RQ-III*). Our optimization goal is to minimize excess WHP area.

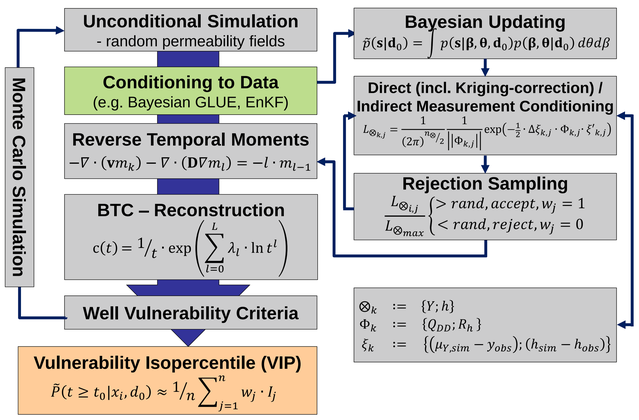


Fig. 1: Methodology to determine probabilistic intrinsic well vulnerability criteria, supporting rational risk management decisions.

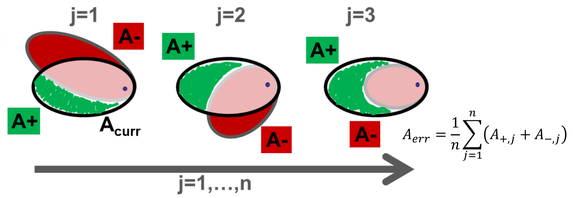
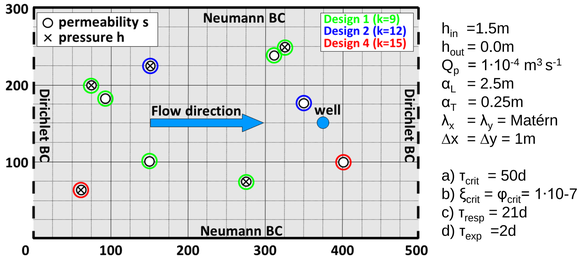


Fig. 2: Showing the utility concept of total wrongly-delineated area (A_{err}) between actual delineation (black ellipse) and uncertain catchment zones ($t \leq 50days$) due to epistemic uncertainty (dark grey ellipses).

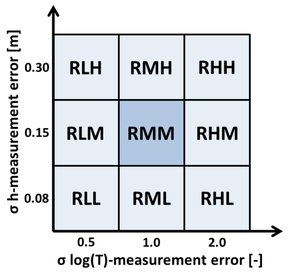
Synthetic Case Study



h_{in} =1.5m
h_{out} = 0.0m
Q_p = 1·10^{-4} m^3 s^{-1}
α_L = 2.5m
α_T = 0.25m
λ_x = λ_y = Matérn
Δx = Δy = 1m

a) τ_{crit} = 50d
b) ξ_{crit} = φ_{crit}= 1·10-7
c) τ_{resp} = 21d
d) τ_{exp} =2d

Fig. 3: Illustrative example, showing location of measurements (RQ-III) for three design cases (9, 12, 15 samples) and modeling parameters with given critical exceedance value t_0 for a) to d).



	Value	Unit
μ_Y	[-7.5 -5.5]	[-]
σ_Y	[1 3]	[-]
λ_x	[10 25]	[-]
λ_y	[5 15]	[-]
q_{rg}	120	[mm a^{-1}]
σ_{rg}	10	[mm a^{-1}]

Fig. 4: Showing the measurement quality matrix (*RQ-II*, left) with pre-defined standard deviation $\sigma_\otimes$ and the uncertain model parameters (right).

VIP Results

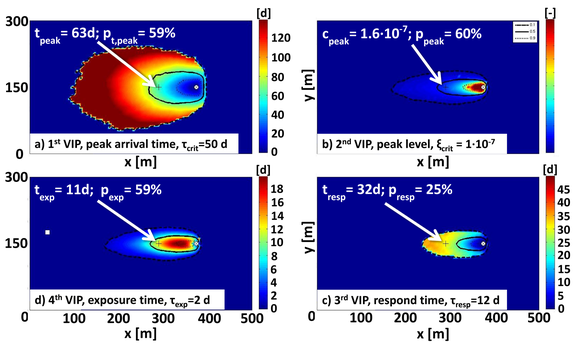


Fig. 5: Probabilistic isopercentiles [0.1, 0.5, 0.9] for intrinsic well vulnerability criteria a) - d) from n=1000 simulations (without additional data). Color-scale maps show the ensemble mean of the resp. well vulnerability criteria.

Improved Sampling Results

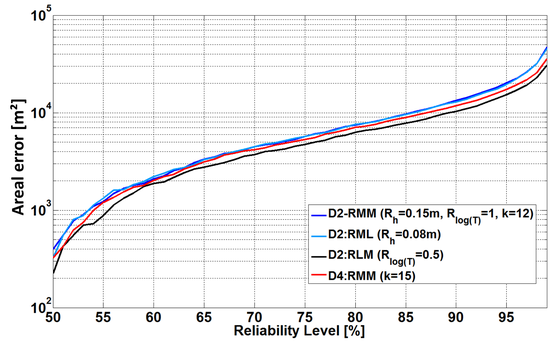


Fig. 6: Showing areal error dependency on risk acceptance level for reference case RMM (design 2 with 12 sampling locations and given standard deviation in head and log(T) error measurement) in comparison to amount of data (*RQ-I*, design 4) and data accuracy (*RQ-II*, RML and RLM).

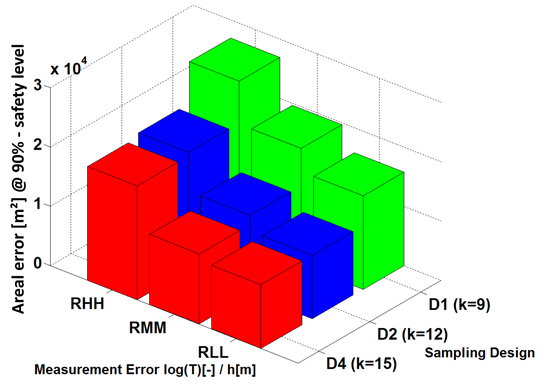


Fig. 7: Comparing measurement quantity (*RQ-I*) and quality (*RQ-II*) by showing utility value areal error A_{err} for three design cases (D1, D2, D4) and three measurement qualities from low (RHH) to high measurement accuracy in hydraulic transmissivity $\log(T)$ and piezometric head h (RLL).

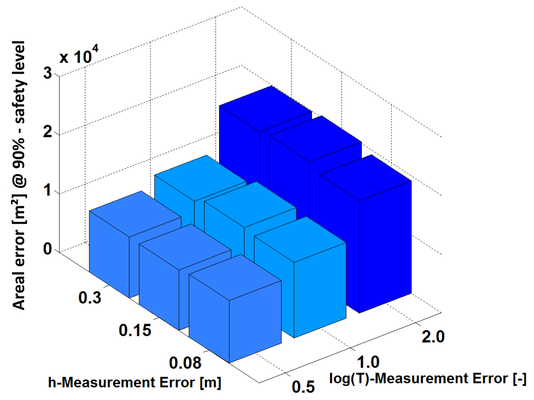


Fig. 8: Assessing for design 2 (k=12) the utility for doubling or halving the quality in head or conductivity measurements.

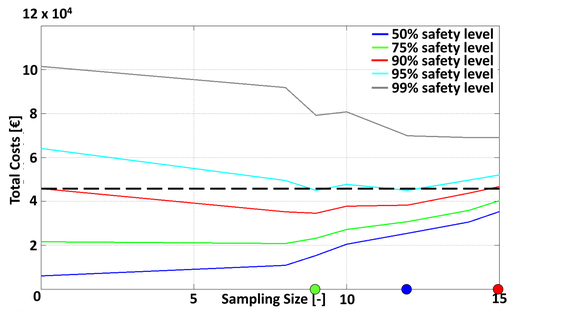


Fig. 9: Rational risk-based decision support towards sampling worth (*RQ I + III*). Here, showing for three given design cases (colored circles) system reliability depending on total costs for drilling (5000 €/well) and areal error (1€/m²) versus sampling size.

Conclusions

- VIP maps are easy to understand and support rational risk-informed decisions by the managers.
- Choice in risk acceptance level is most important for delineation costs.
- Sampling quality and quantity reduces costs.
- Sampling campaigns can pay for themselves.
- Here, the areal error follows a Weibull distribution.
- Sampling quality in $\log(T)$-measurements reduces areal error more than sampling piezometric heads.

Future Work

- Optimal positioning in sampling location with a tool called PreDia (*RQ-III*).
- Study effects of non-steady state flow conditions.
- Application towards a real test site.

References

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Acknowledgments

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