UNIVERSITÀ DEGLI STUDI DI MILANO

Facoltà di Scienze e Tecnologie

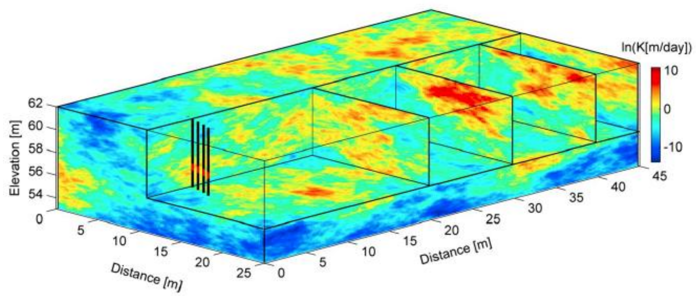
Dipartimento di Scienze della Terra " A. Desio"

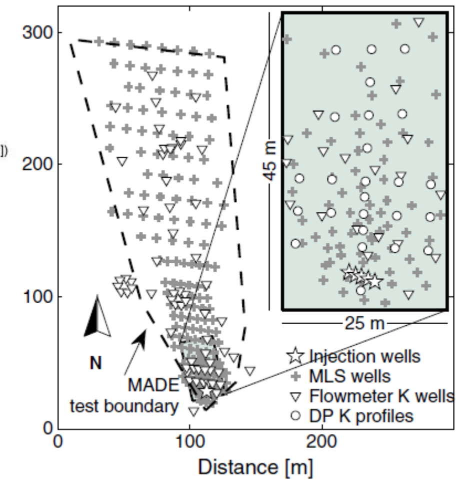
Should we collect more K data or more aquifer samples for effective subsurface characterization? A comparative study based on reproducibility of flow and transport modelling results

J. Terrenghi[(1)], M. Bianchi[(2)], G.P. Beretta[(1)]

(1) Università degli studi di Milano (2) British Geological Survey, Keyworth

Introduction



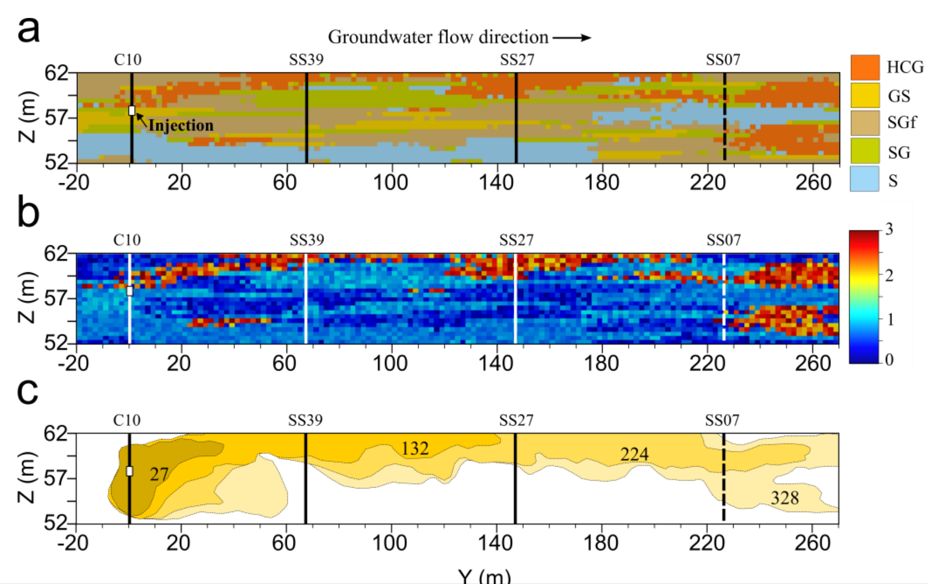


«[…] the classical ADE can predict complex pollution plume behaviour […] when <u>high-resolution K data</u> are collected…»

Dogan et al. (2014)

"Site-scale transport behaviour […] was effectively reproduced with a relatively simple, local ADE-based model. The physical aquifer heterogeneity was conceptualized and represented by the <u>spatial distribution of lithofacies</u> […]»

Bianchi and Zheng (2016)



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jacopo.terrenghi@unimi.it

Objective

Analyse the sensitivity of the results from numerical simulations of groundwater flow and advective transport with respect to the amount of available data

Two approaches for modelling aquifer heterogeneity:

Geological approach (GA)

-Based on lithological data;

-Modelling of hydrofacies distribution;

Hydrological approach (HA)

-Based on K data;

-Modelling K distribution;

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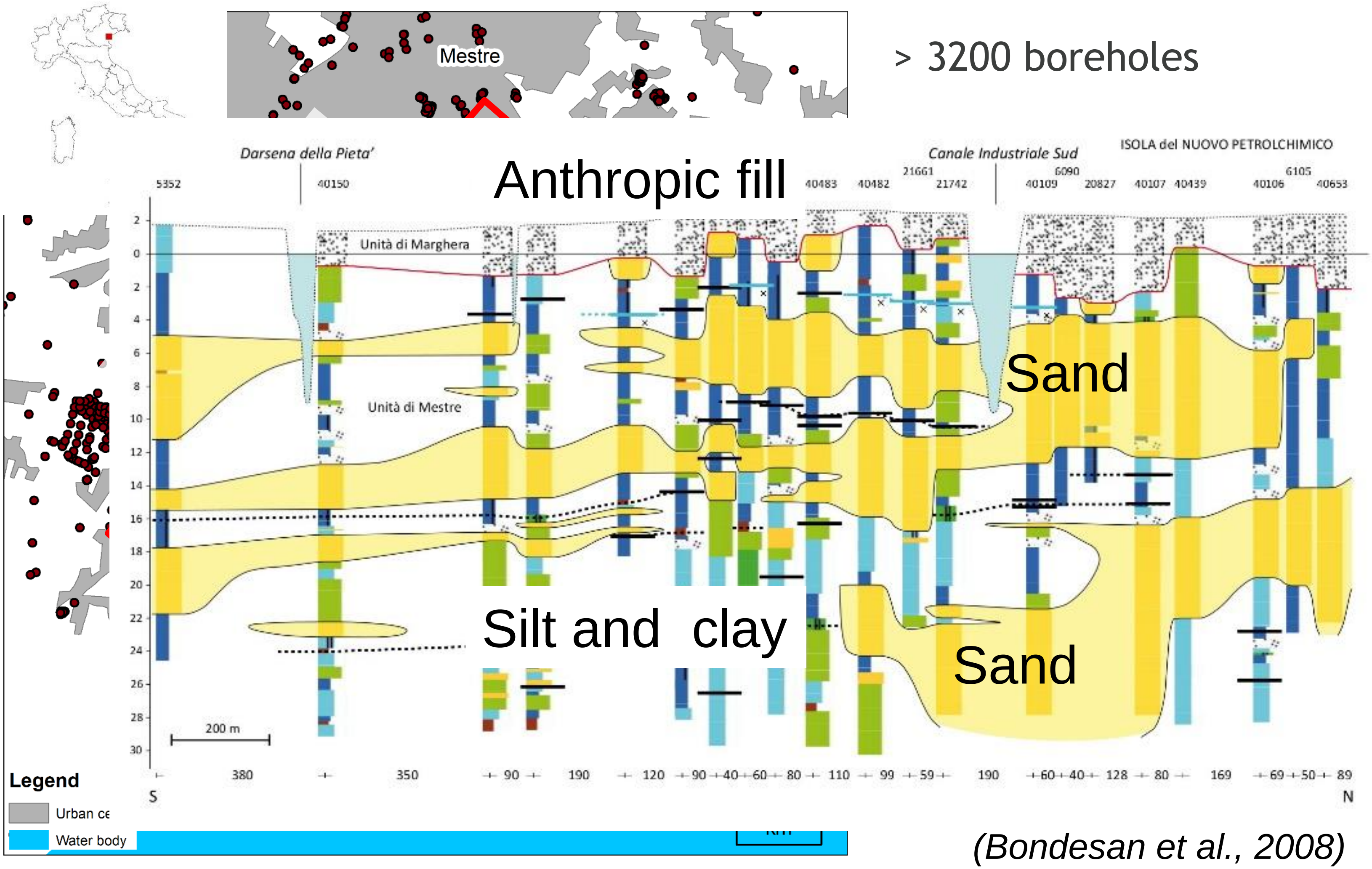
Data

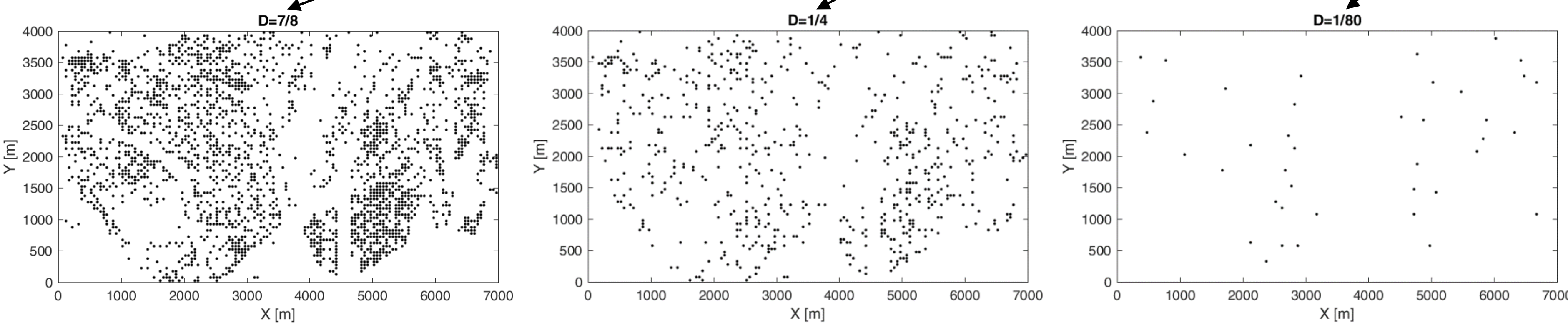


> 3200 boreholes

(Bondesan et al., 2008)

Scenarios of data density (D)

Scenario	Dmax	D=7/8	D=3/4	D=1/2	D=1/4	D=1/8	D=1/16	D=1/80
D	1/1	7/8	3/4	1/2	1/4	1/8	1/16	1/80
Data used	100%	87%	75%	56%	28%	14%	7%	1%



Methods

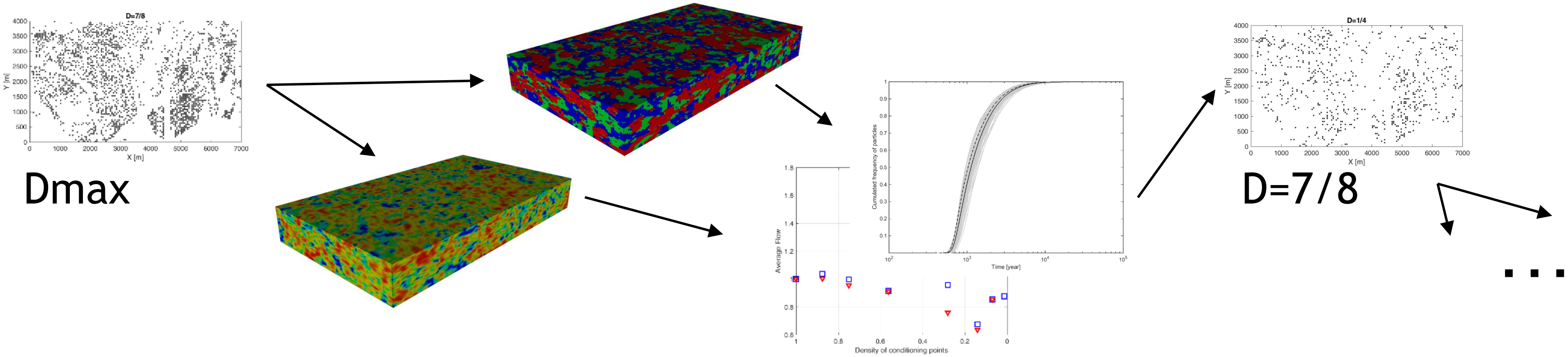
For each scenario:

1. Stochastic modelling of aquifer heterogeneity (GA and HA)

2. Simulations of groundwater flow and advective transport

3. Calculation of average flow, connectivity index, breakthrough curves (BTCs) and moments analysis

4. Comparisons with scenario with 100% data



Modelling aquifer heterogenity

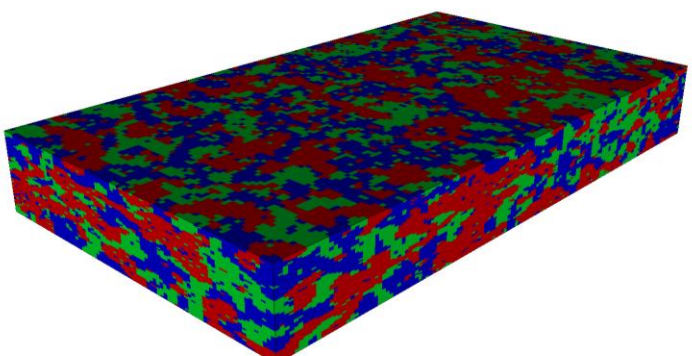
Geostatistical models developed for each scenario of data density

100 Monte Carlo conditional simulations

Geological approach (GA)

T-PROGS (Carle, 1999): Transition probability based and Markov chain model

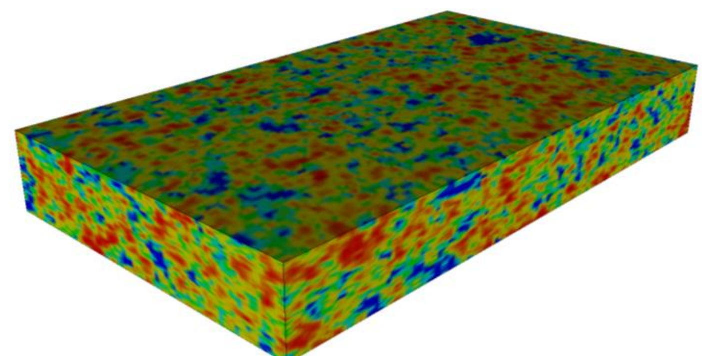
K is a discrete random variable

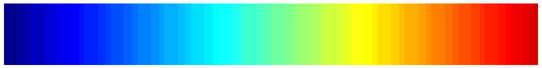


Hydrological approach (HA)

SGSIM (Deutsch and Journel, 1992): variogram based

K is a continuous random variable





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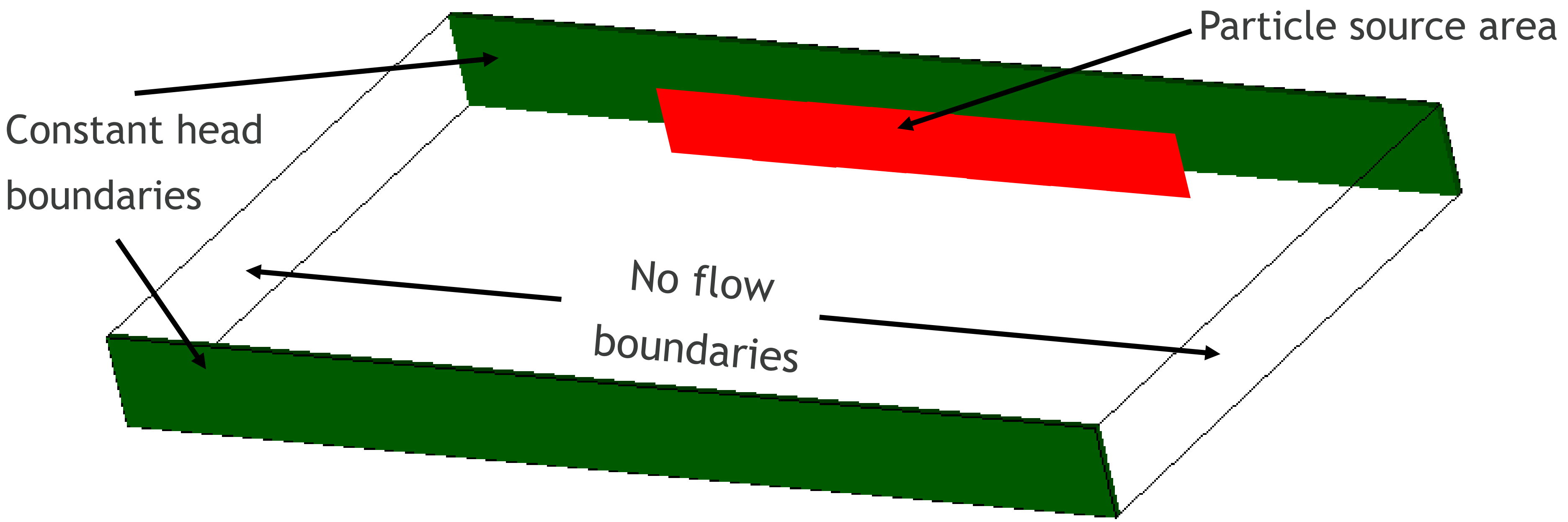
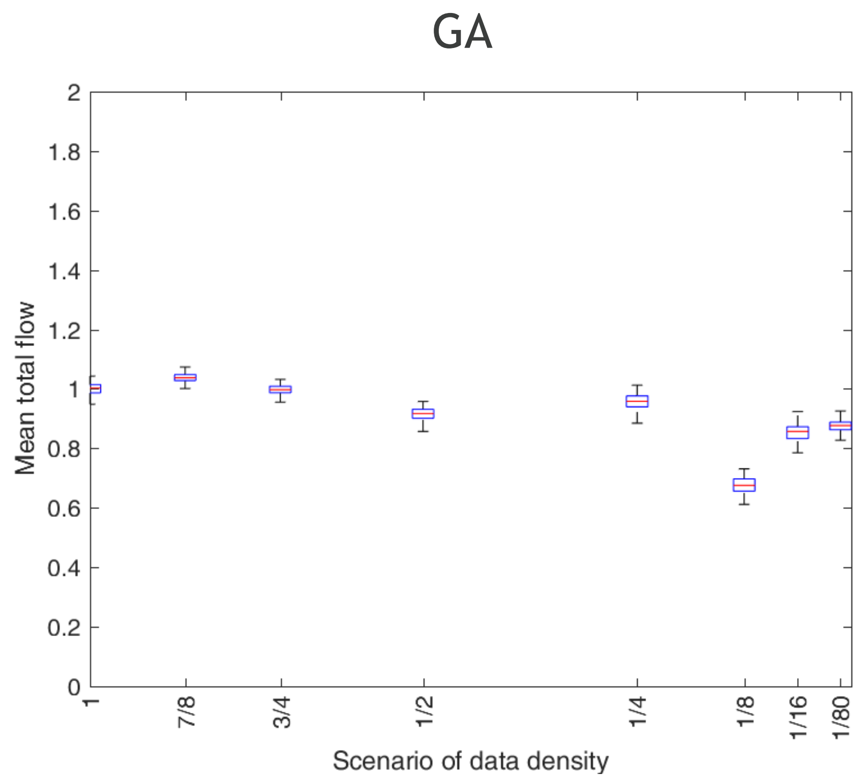
Simulation of groundwater flow and particle tracking

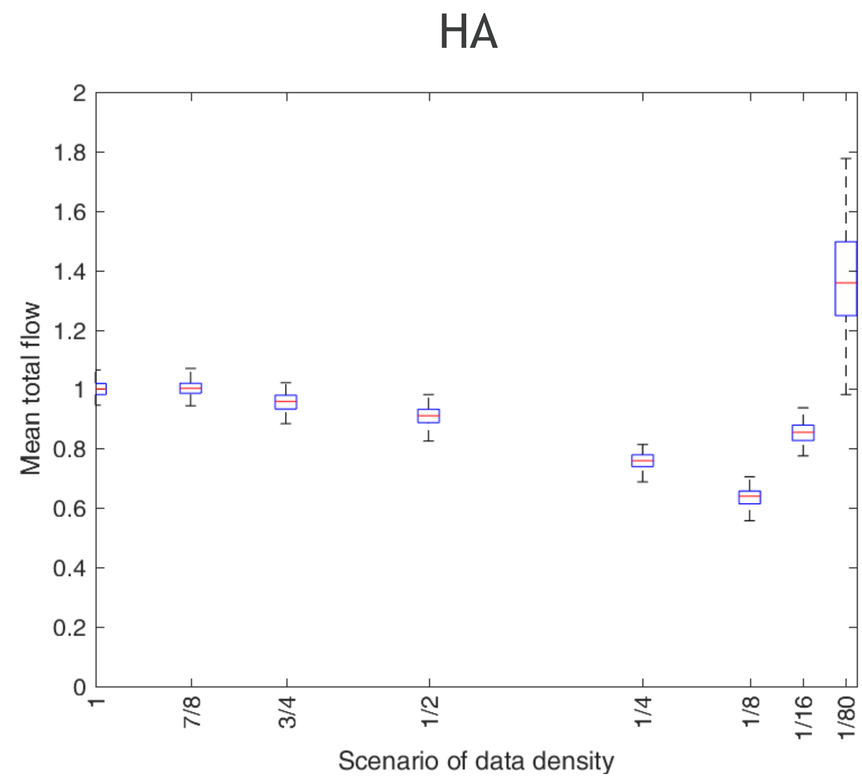
Steady state flow (MODFLOW) (Harbaugh,2005)

One particle per cell in an homogeneous conductivity area of 3200 cells. Simulations done with MODPATH (Pollock, 2012)



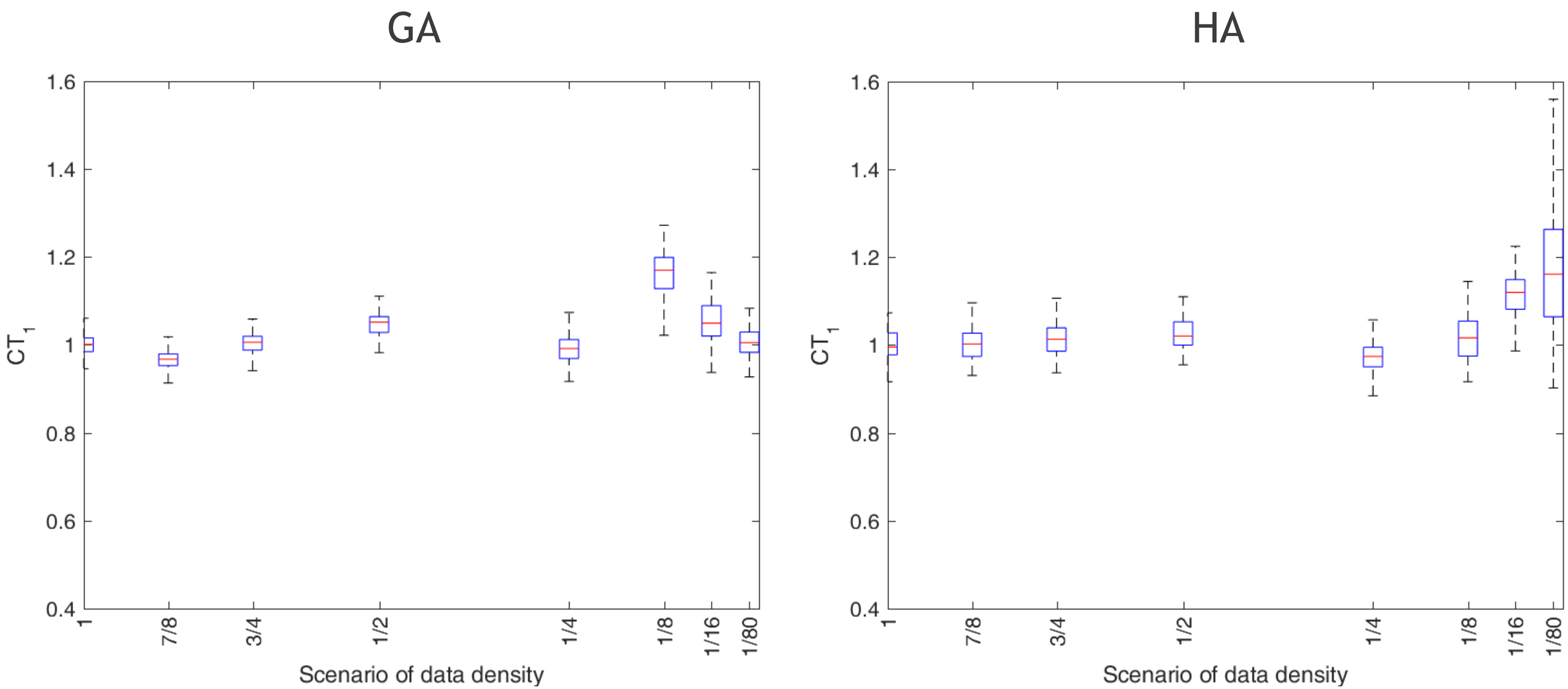
Results – Mean total flow





Results expressed as ratio between the value of the scenario and the value of the Dmax scenario of the same approach

Results - Connectivity index



$$CT_1 = \frac{t_{ave}}{t_{5\%}}$$

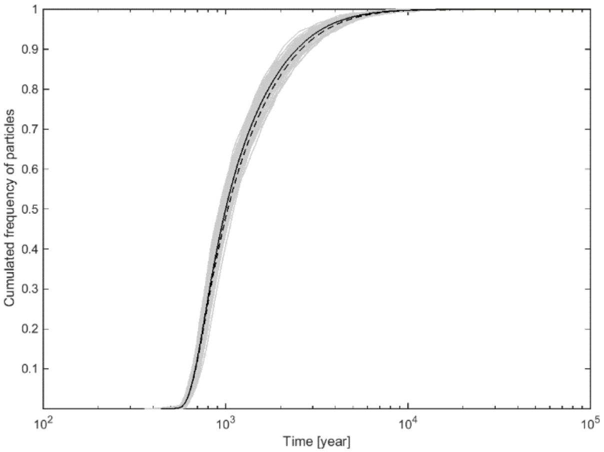
Knudby and Carrera (2005)

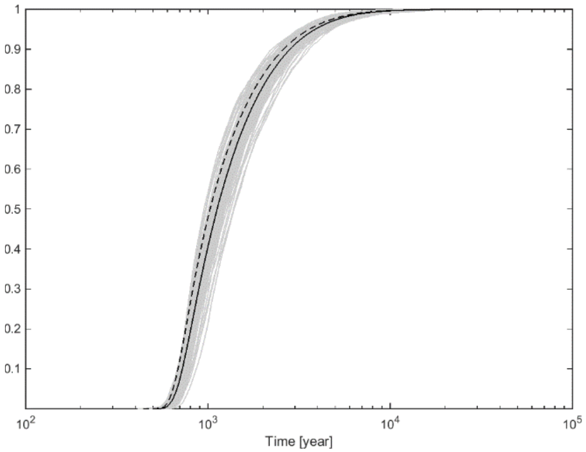
t_{ave} = average arrival time

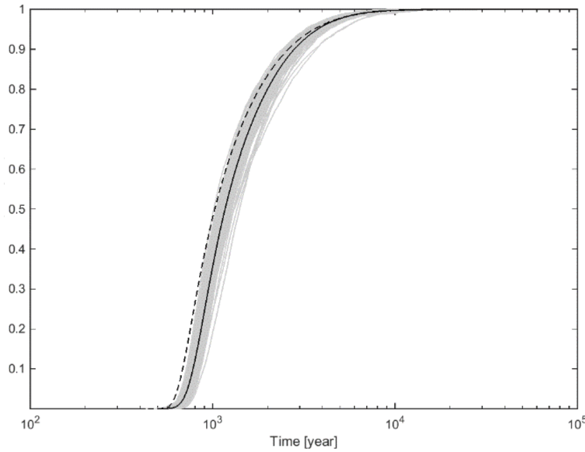
$t_{5\%}$ = time at which 5% of the solute has arrived at the outlet

Results expressed as ratio between the value of the scenario and the value of the Dmax scenario of the same approach

Results - BTCs







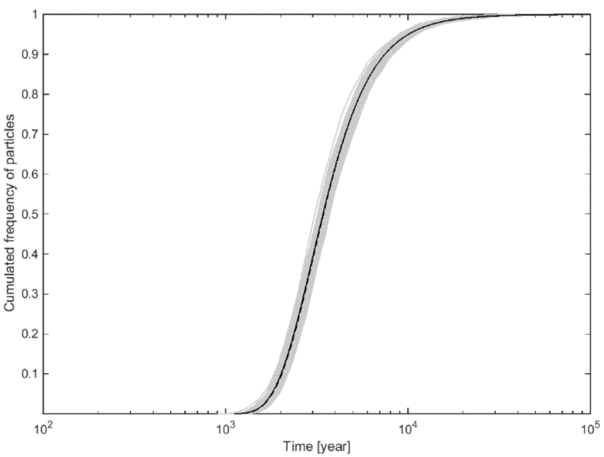
GA

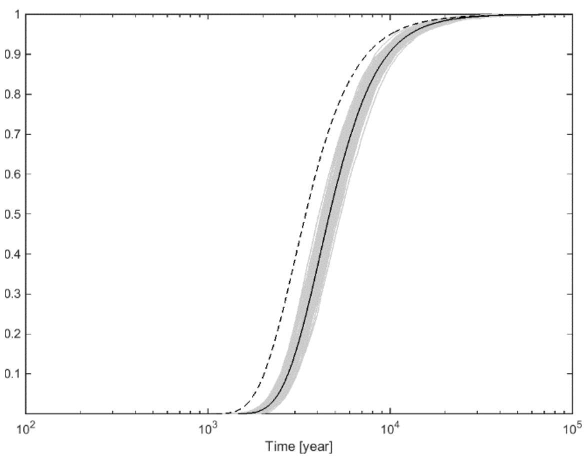
HA

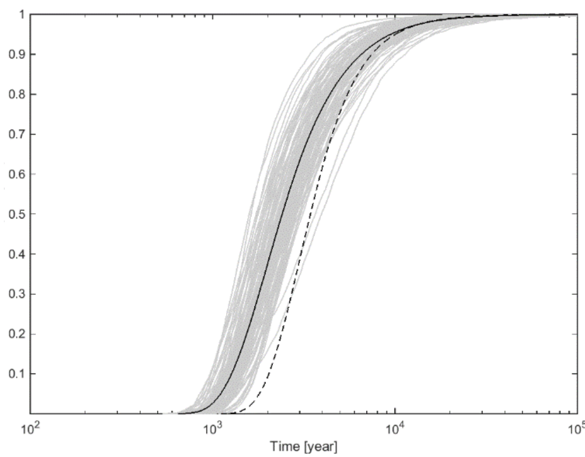
D=7/8

D=1/4

D=1/80







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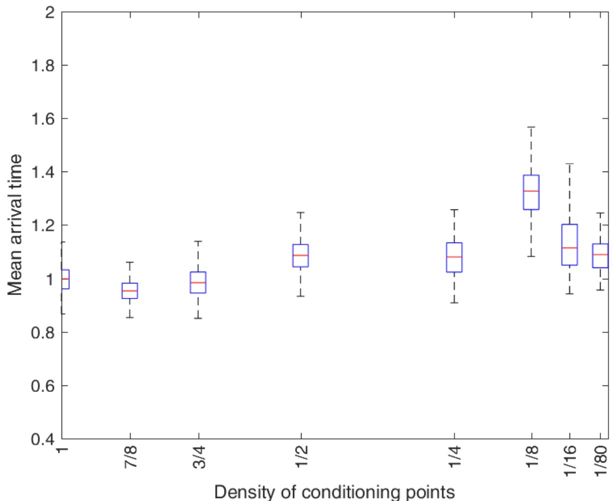
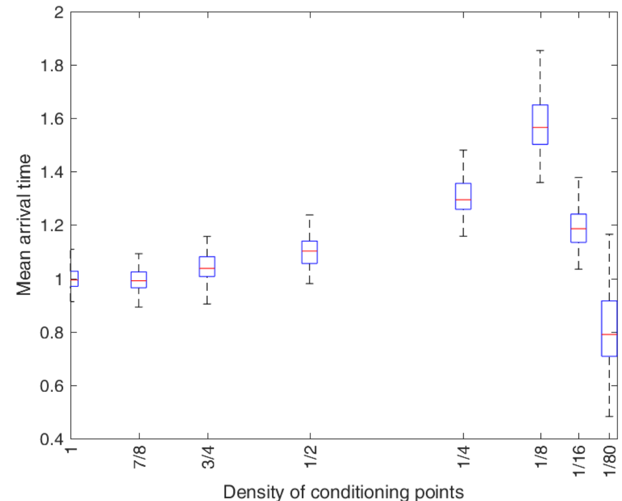
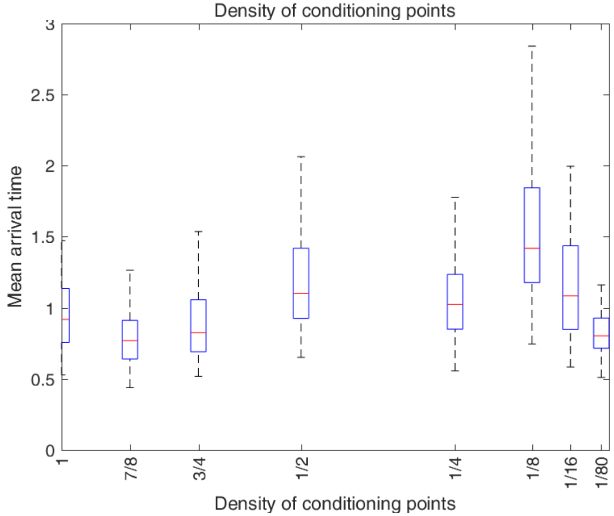
Results – Central moments

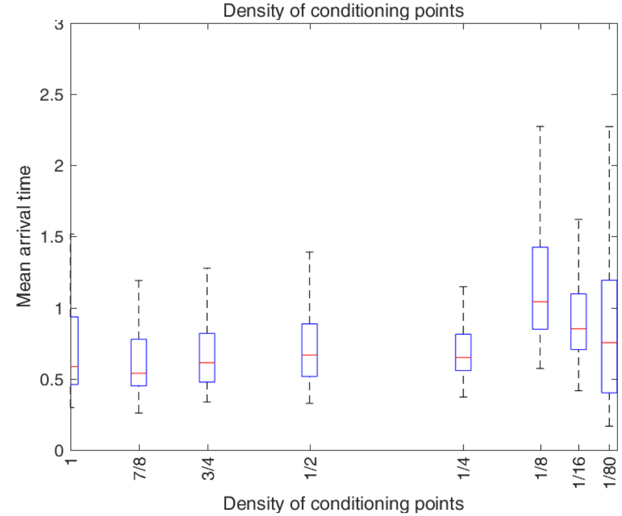
GA | HA





Arrival time of centre of mass based on first central moment





Spreading of arrival time based on second central moment

Results expressed as ratio between the value of the scenario and the value of the Dmax scenario of the same approach

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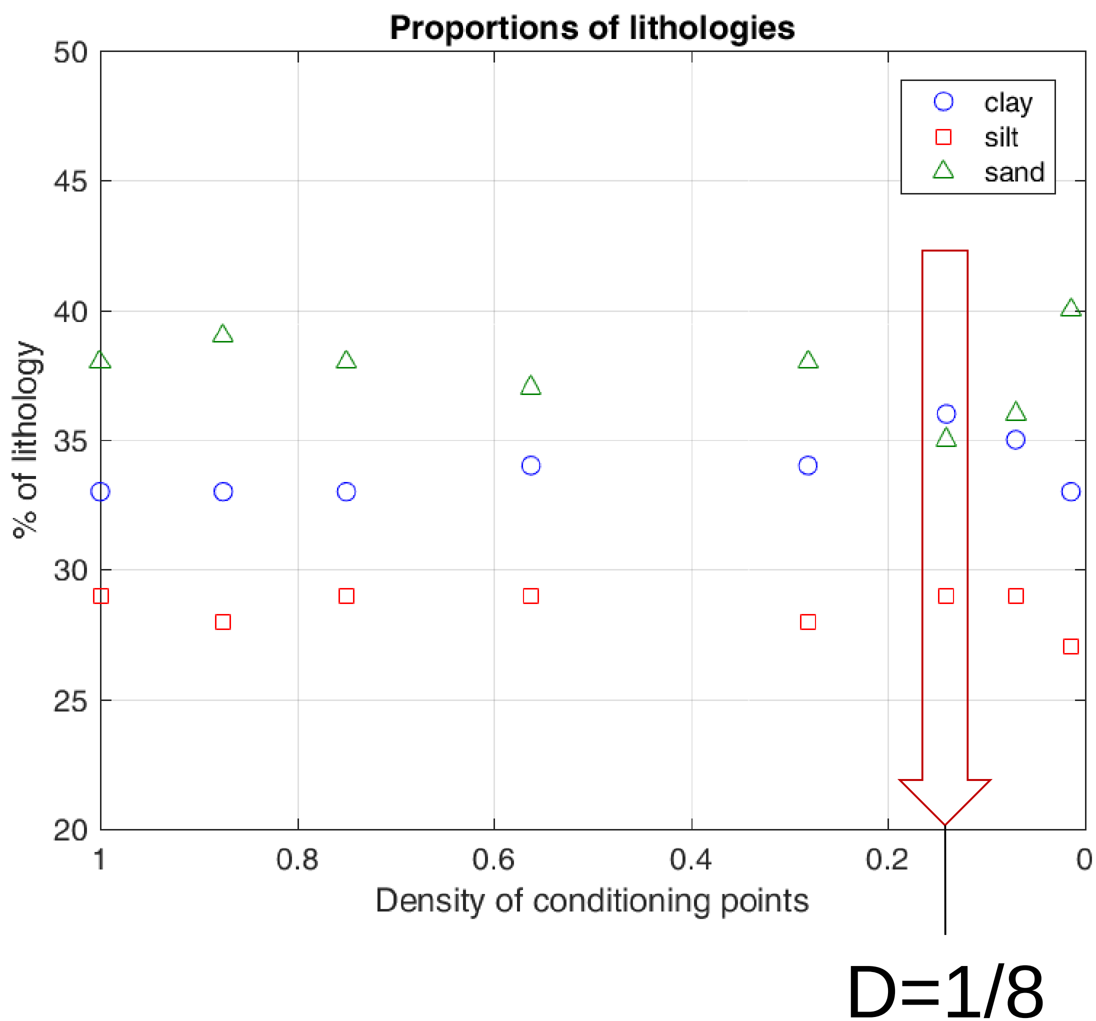
Proportions of lithologies



Conclusions

- Overall the reproducibility of the results with the geological approach is less affected by the loss of information
- Compared to HA, GA provides more accurate estimations with lower uncertainty
- With the GA, the reproducibility is dependent on the correct evaluation of the volumetric fractions of the hydrofacies (control on K distribution)
- Taking into account the geological structure in the definition of the K field is a cost-effective strategy for aquifer characterization to support flow and transport modelling

Thanks for your attention!

jacopo.terrenghi@unimi.it

References

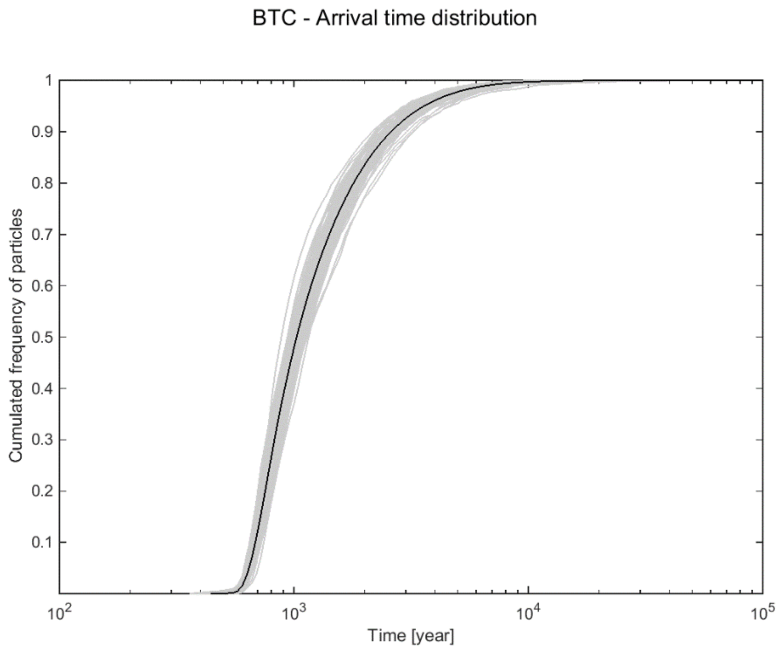
- Bianchi, M., and C. Zheng (2016), A lithofacies approach for modeling non-Fickian solute transport in a heterogeneous alluvial aquifer, Water Resour. Res., 52, 552–565, doi:10.1002/2015WR018186.
- Bondesan A., Primon S., Bassan V., and Vitturi A. (2008) (a cura di), Le unità geologiche della provincia di Venezia. Cierre Grafica, Caselle di Sommacampagna (VR)
- Carle, S. F. (1999), T-PROGS: Transition probability geostatistical software, version 2.1., Univ. of Calif., Davis.
- Deutsch C.V., and Journel A.G. (1992), Geostatistical software library and user's guide. Oxford University Press, New York.
- Dogan, M., R. L. Van Dam, G. Liu, M. M. Meerschaert, J. J. Butler Jr., G. C. Bohling, D. A. Benson, and D. W. Hyndman (2014), Predicting flow and transport in highly heterogeneous alluvial aquifers, Geophys. Res. Lett., 41, 7560–7565, doi:10.1002/2014GL061800.
- Harbaugh, A. W. (2005), MODFLOW-2005, the U.S. geological survey modular ground-water model—The ground-water flow process, U.S. Geol. Surv. Tech. Methods, 6-A16.
- Knudby C, and Carrera J. (2005), On the relationship between indicators of geostatistical, flow and transport connectivity. Adv Water Resour. doi:10.1016/j.advwatres.2004.09.001.
- McCallum, J.L., Herckenrath, D. and Simmons, C.T. (2014) Impact of Data Density and Geostatistical Simulation Technique on the Estimation of Residence Times in a Synthetic Two-dimensional Aquifer. Math Geosci 46: 539. doi:10.1007/s11004-013-9518-6.
- Pollock, D.W., 2012, User Guide for MODPATH Version 6 — A Particle Tracking Model for MODFLOW: U.S. Geological Survey Techniques and Methods 6 - A41, 58 p.

jacopo.terrenghi@unimi.it

Results - BTCs

Scenario Dmax

GA



HA