Universität Stuttgart
Institute of Hydraulic Engineering (IWS)

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GLOWA Danube

TRANSPORT MODELLING IN GROUNDWATER ON A VERY LARGE SCALE WITHIN THE FRAMEWORK OF INTEGRATED WATER RESOURCES MANAGEMENT MODELS

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Motivation

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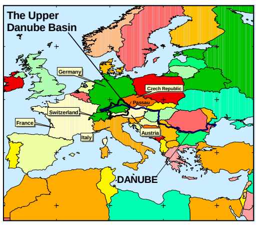
- Long-term change in light of global climatic change
- Modeled area 77 000 km^2
- Spatial discretisation: (1000x1000 m)
- FDM as numerical scheme (MODFLOW)
- Problem with numerical dispersion in groundwater transport model



Motivation

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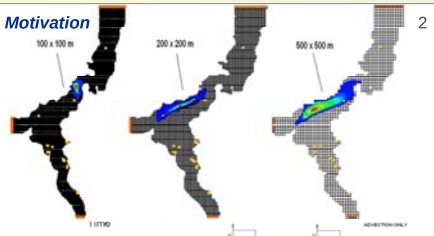

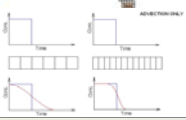

Effects of numerical dispersion depending on the grid size

Objectives and Approach

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- Avoid numerical dispersion on a coarse grid
- Determine the influence of the grid size
- Find out which numerical scheme is the most appropriate for the given task
- Find out which numerical scheme can approximate analytical solution the best

Selected numerical schemes

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Criteria:

- Fast technique
- Not to technically demanding
- Advection part solved with Lagrangian approach with explicite scheme
- Dispersive part solved with Eulerian approach with implicite scheme

Chosen schemes:

- ULTIMATE (Zheng and Bennet, 2002)
- Random Walk (RW)
- Method of Characteristics (MOC)
- Modified Method of Characteristics (MMOC)
- Hybrid Method of Characteristics (HMOC)

Multi-dimensional transport

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$$\frac{\partial c}{\partial t} + v \cdot \nabla c - \nabla \cdot (D \nabla c) = r + \frac{q_{in}}{n_e}(c_{in} - c)$$

- Advection
- Diffusion
- Dispersion
- Chemical reactions
  - Sorption
  - Decay

Analytical solutions

- 2-D transport in uniform flow field by Wilson and Miller (1978)
- A Recharge/ Recovery Single Well by Gelhar and Collins (1971)

Analytical solution used as reference for simple case studies

Test cases and application (1)

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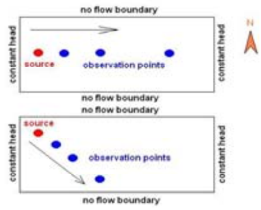

- 2-D transport in a uniform flow field
- 2-D transport in a diagonal flow field
- Leutkircher Heide and Aitrachtal (Rojanschi, 2001)

Test cases and application (2)

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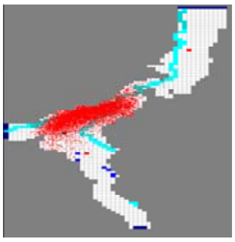

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2-D transport in uniform flow field

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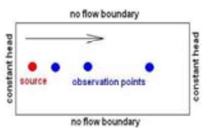

PROPERTY	VALUE	UNIT
Dimensions of the field	46000 x 31000	m
Layer thickness	100	m
Hydraulic conductivity	1150	m/day
Porosity	0.3	——
Longitudinal dispersivity	500	m
Ratio of transverse and longitudinal dispersivity	0.3	——
Volumetric injection rate	100	m^3/day
Concentration of the injected water	100	mg/l
Simulation time	730	day
Type of the aquifer	Confined	——
Type of injection	Continuous	——

- Grid 1000 x 1000 m, Pe = 10
- Grid 333 x 333 m, Pe = 3.33
- Grid 200 x 200 m, Pe = 2

Advection dominated flow !!!

2-D transport in uniform flow field

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Compared parameters:

- Concentration through observation points for the given time
- Breakthrough curves are compared with an appropriate analytical solution by calculating the relative error:

$$\varepsilon = \frac{c - c_{an}}{c_{an}}$$

- The affected area by means of relative error:

$$\delta(c_{cr}) = \frac{A(c_{cr}) - A_{an}(c_{cr})}{A_{an}(c_{cr})}$$

- The movement of the plume's center of gravity by means of zeroth and first spatial moments.

2-D transport in a uniform flow field

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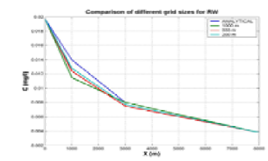

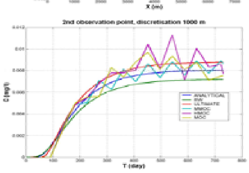

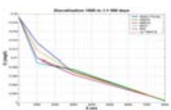

2-D transport in diagonal flow field

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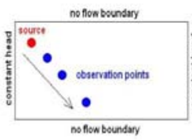

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Ratio of transverse and longitudinal dispersivity	0.3	——
Volumetric injection rate	100	m^3/day
Concentration of the injected water	100	mg/l
Simulation time	730	day
Type of the aquifer	Confined	——
Type of injection	Continuous	——

- Grid 1000 x 1000 m, Pe = 15
- Grid 333 x 333 m, Pe = 5
- Grid 200 x 200 m, Pe = 3

Advection dominated flow !!!

2-D transport in diagonal flow field

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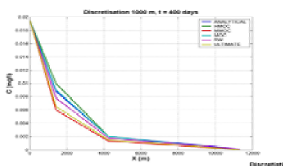

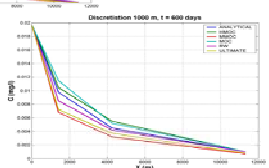

Intermediate Conclusions (Test Cases 1 and 2)

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- RW, MMOC and ULTIMATE showed the best results with respect to:
  - Relative error for breakthrough curves
  - Affected ared
  - First spatial moments
- Random walk – the best results, but hard to model
- Compare ULTIMATE and RW on the application

Application: Leutkircher Heide and Aitrachtal

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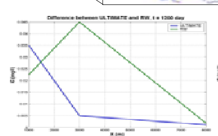

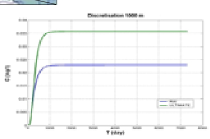

Final Conclusions

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- Apart from Random Walk and ULTIMATE the tested numerical schemes (MOC, HMOC, MMOC) show very large influences of numerical dispersion on coarse grids even in simple flow situations;
- ULTIMATE is suitable for simple flow fields but seems not to be appropriate on coarse grids with heterogeneous flow fields;
- Random Walk gives the best results compared to analytical solutions and other numerical schemes;
- At the moment, no ready for use code for the Random Walk code is available that could be applied for large scale regional models.