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Simulation of Non-point Source Contamination Based on Adaptive Mesh Refinement

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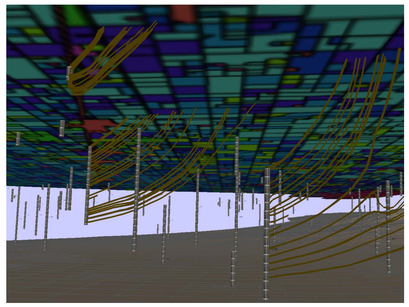
Motivation

Introduction: Non-point source pollution takes place in large agricultural basins where thousands of discharge surfaces (e.g. wells, streams) and contaminant discharges occur simultaneously in a highly heterogeneous spatial and temporal pattern.



Goal: Development of an efficient Non-Point Source Assesment Toolbox for the simulation and prediction of contaminant breakthrough curves in agricultural groundwater basins.

Methods & Challenges

Methods: We adopted the streamline transport approach:

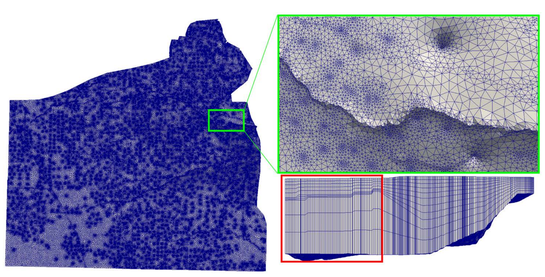
1. Steady state groundwater flow simulation.
2. Identification of contaminant pathways from pollution sources to affected discharge surfaces.
3. Derivation of unit response functions along contaminant pathways.

Challenges:

- Highly detailed resolution is needed to account for the spatial heterogeneity of sources, sinks and hydrogeology in agricultural basins.
- Optimal mesh generation is critical in large scale modeling.
- Use of the state of the art numerical libraries that enable parallel simulation.

Mesh Generation

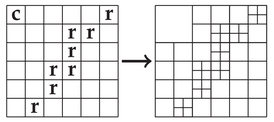
Theory: We need higher mesh density where we expect greater gradient changes of the variable being solved.
Practice:
Mesh generation tools have limited capabilities.



Adaptive Mesh Refinement

Key Idea: Let the simulation drive the discretization.

1. Start with a coarse mesh
2. Assemble & solve
3. Estimate error
4. Refine and go to 2

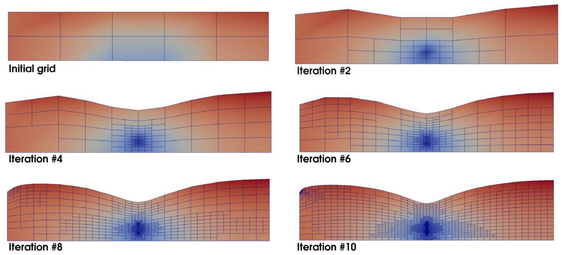


Adaptive Mesh Refinement seems to increase the computational cost. However, for non-linear problems, e.g., unconfined flow simulation, iterative solutions due to non-linearity can be solved simultaneously with AMR, thus reducing computional cost.

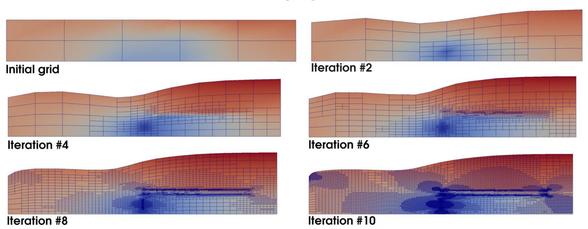
Blending AMR with unconfined flow simulation

1. Generate coarse mesh
2. Assemble & solve
3. Modify mesh to follow the water table based on the previous solution
4. Refine mesh
5. Repeat 2.-4. until stopping criteria are met

Example with one well and uniform hydraulic conductivity



Example with one well and a low hydraulic conductivity zone

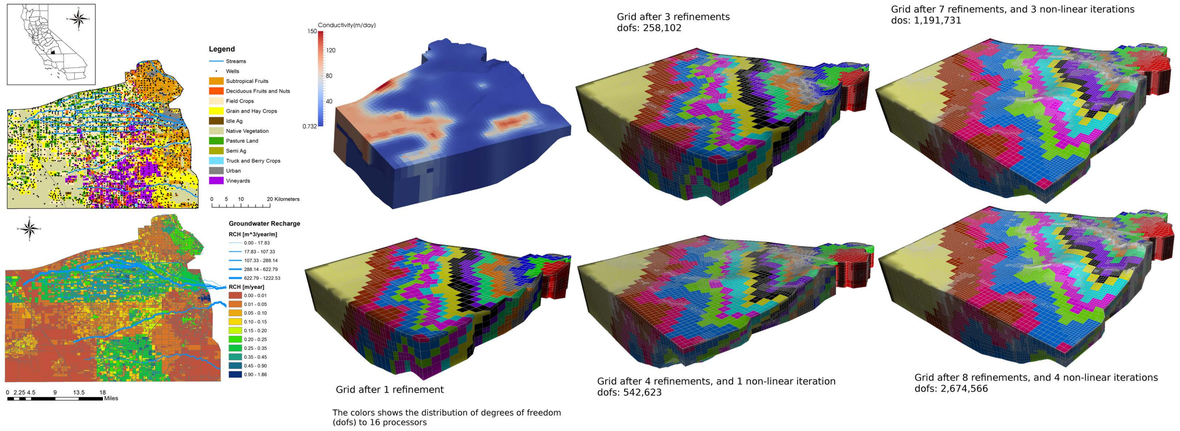


Libraries

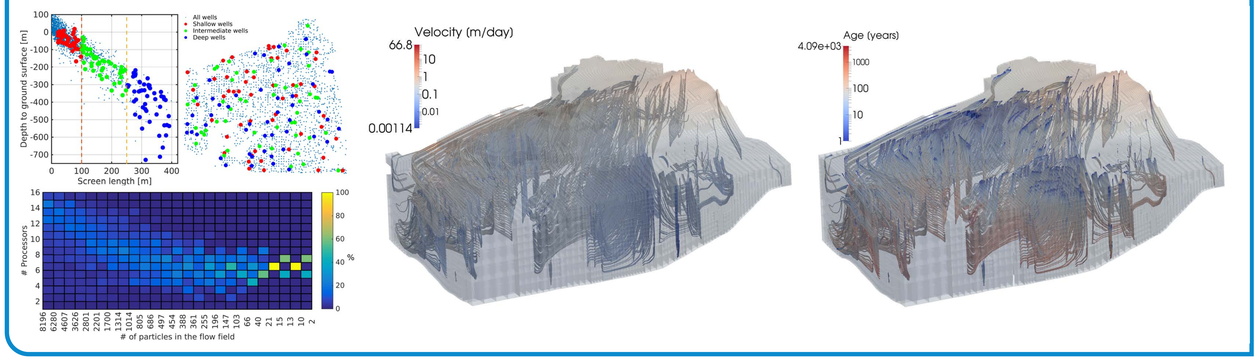
- **deal.II**: Support for finite element computations and adaptive mesh refinement (https://www.dealii.org/).
- **Trilinos**: Support for state of the art numerical solvers (http://trilinos.org/).
- **Computational Geometry Algorithms library (CGAL)**: Support for many types of spatial queries and efficient data structures (https://www.cgal.org/).
- **OpenSceneGraph**: Visualization library (http://www.openscenegraph.org/).

Application -Tule River Basin

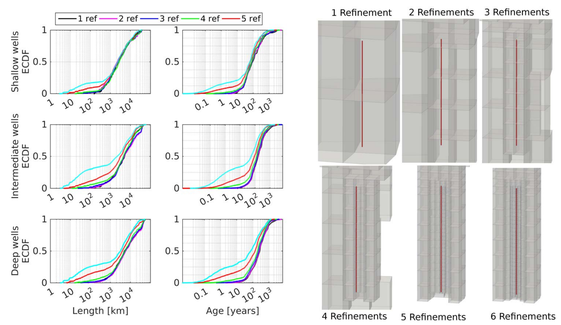
Simulation of groundwater flow



Particle Tracking



Grid Sensitivity



Conclusions

Conclusions:

- We combined AMR with nonlinear solver to simulatate non-point source contaminant transport.
- AMR generates optimal meshes.
- We use existing state of the art libraries to achieve parallel efficiency.
- Discretization around the sources/sinks is very critical.

Future research

- Extend the model capabilities
- Create a groundwater C++ API

References

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