Benchmarking of FEHM Control Volume Finite Element Solver

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SOILVISION INNOVATIVE GEO-MODELING SOFTWARE

Outline

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   – FEHM solver
   – SVOFFICE™5/WR
2. **Benchmarking**
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   – Non-isothermal geothermal modeling
   – Reactive solute transport modeling
3. **Ability to model field-scale systems**
4. **Summary**
5. **References**

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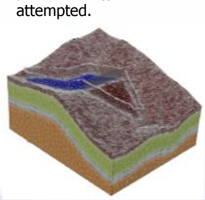
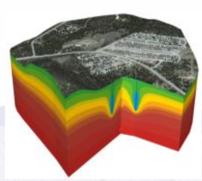
1. Introduction

– Numerical modeling of groundwater, contaminant transport, subsidence, and geothermal problems has expanded in the past few years due to the increase in computational power and software.
– Problems with larger numbers of total nodes, with complex geology involving faulting, as well as coupling of multiple physical processes (geothermal, CO_2 sequestration) are now being attempted.

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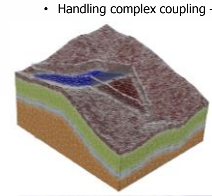
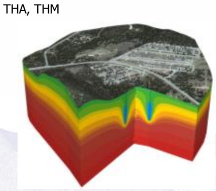
1. Introduction

– Barriers encountered in current commercial software
  • Current difficulties with complex geometry (including faults), unstructured meshes, and pinchouts
  • Difficulties in integrating with slope stability software (geotechnical)
  • Difficult to model reactive transport
  • Unsaturated solutions difficulties (formulation & solution times)
  • Thin layer issues
  • Handling complex coupling – TH, THA, THM

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1. Introduction

FEHM solver

• Developed by Los Alamos National Laboratory (LANL) over past 30 years.
• Capabilities*
  ✓Control Volume Finite Element (CVFE) method
  ✓Fully implicit, fully coupled Newton Raphson solution of nonlinear equations
  ✓3D complex geometries with unstructured grids.
  ✓Saturated and unsaturated media
  ✓Non-isothermal multi-phase flow of air, water
  ✓Double porosity/Double permeability capabilities for fractured reservoir
  ✓Simulation of geothermal reservoirs
  ✓Multiple chemically reactive and sorbing tracers
  ✓50 man-years of effort invested

* https://fehm.lanl.gov/

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1. Introduction

SVOFFICE™5/WR

• LANL and SoilVision Systems Ltd. have combined efforts to offer groundwater and geothermal numerical modeling solutions of larger and more complex systems.

SVOFFICE™ 5/WR POWERFUL • FLEXIBLE • EFFICIENT FEHM

SVDESIGNER – 3D CONCEPTUAL MODELING AND VISUALIZATION
SVSOILS – A KNOWLEDGE-BASED DATABASE SYSTEM FOR SATURATED / UNSATURATED SOIL PROPERTIES
SVSLOPE – 2D / 3D LIMIT EQUILIBRIUM SLOPE STABILITY ANALYSIS
SVFLUX WR – 2D / 3D SATURATED / UNSATURATED CVFE GROUNDWATER SEEPAGE MODELING
SVHEAT WR – 2D / 3D SATURATED / UNSATURATED CVFE GEOTHERMAL MODELING
SVCHEM WR* – 2D / 3D SATURATED / UNSATURATED CVFE CONTAMINANT TRANSPORT MODELING

*Under development

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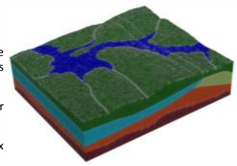
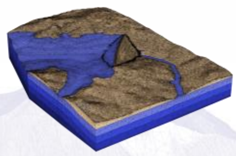
1. Introduction

SVOFFICE™5/WR key features

- Large Regional Models: Efficiently create and analyze large regional numerical groundwater flow models with millions of nodes.
- Nonlinear Analysis: Stable analysis of nonlinear unsaturated models.
- Handle Complex Geometry: Model complex geometry including pinch-outs.
- NEW SVDESIGNER™ Conceptual Modeling Module
- Automatic Mesh Generation and Manual Refinement.
- Easy to Use: Featuring a familiar user interface with easy to understand functions and redesigned icons.
- Import soil properties from the SVSOILS™ database of over 6200 soils.





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1. Introduction

This presentation

- Presents the results of benchmarks created to test the performance of the new groundwater and geothermal modeling system.
- Performance of the system is discussed as well as challenges and hurdles encountered in the collaboration.
  - It is difficult to find enough benchmarks in 3D
  - SVOFFICE supports multiple solvers (FlexPDE, SVCORE, FEHM)
  - Benchmarks are comprised of Journal papers and models run in multiple solvers
  - Solution matches were compared in terms of matches in pore-water pressures and flow volumes
- The ability of the system to scale up to model field-scale systems will be discussed.

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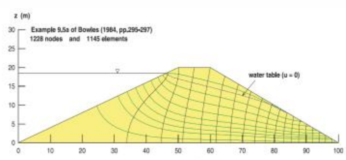
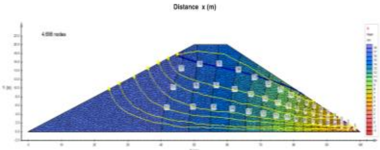
2. Benchmarking – Flow Through a Dam



Total head (*h*) result from Chapuis *et al.* (2001)



Total head (*h*) result from SVFLUX WR

Flux rate difference between WR/GE = 3.5%

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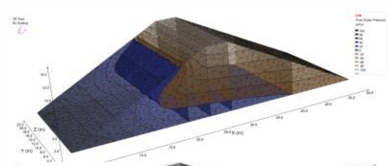
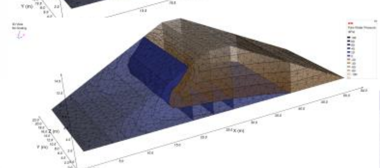
2. Benchmarking – Rapid Filling



Total head (*h*) result from SVFLUX WR



Total head (*h*) result from SVFLUX GT

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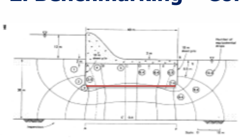
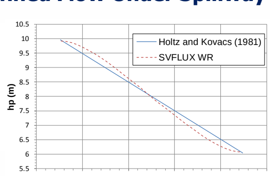
2. Benchmarking – Confined Flow Under Spillway

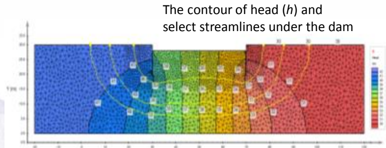


Description of the example model from Holtz and Kovacs (1981)



The contour of head (*h*) and select streamlines under the dam

Flux rate difference between WR/GE = 4.51%



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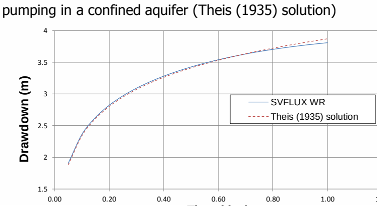
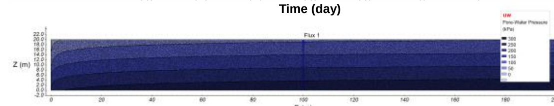
2. Benchmarking – Axisymmetric Confined Aquifer

- Well pumping in a confined aquifer (Theis (1935) solution)





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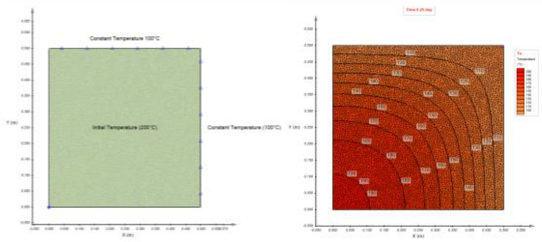
2. Benchmarking – 2D Heat Conduction

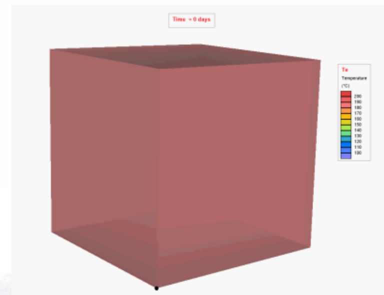
Non-isothermal geothermal modeling

- Results compared to analytical solutions from Carslaw and Jaeger (1959)



2. Benchmarking – 3D Heat Conduction

Non-isothermal geothermal modeling

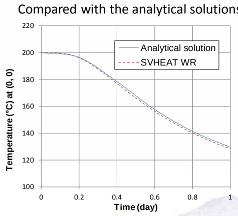


2. Benchmarking

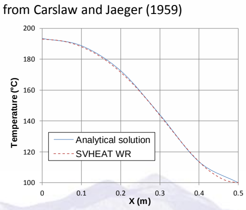
Non-isothermal geothermal modeling

- 2D and 3D Heat Conduction

Compared with the analytical solutions from Carslaw and Jaeger (1959)



Temperature change versus time at (0, 0).

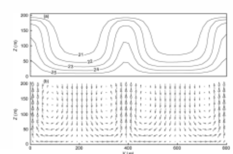


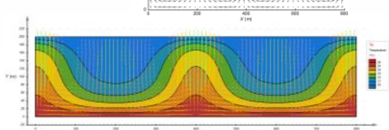
Temperature versus position ($x = y$) at 0.25 days.

2. Benchmarking - Non-isothermal geothermal modeling

- the effect of topography driven flow on the development of convection cells in a groundwater aquifer
- Free convection cells

Yang et al. (2000)



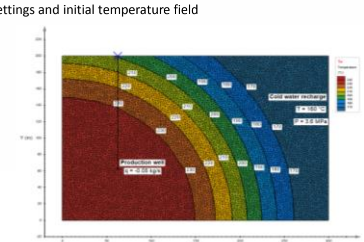


2. Benchmarking – Heat and Mass Transfer

Non-isothermal geothermal modeling

- Water-Vapor Multiphase Heat and Mass Transfer Problem

Model settings and initial temperature field



2. Benchmarking – Heat and Mass Transfer

Non-isothermal geothermal modeling

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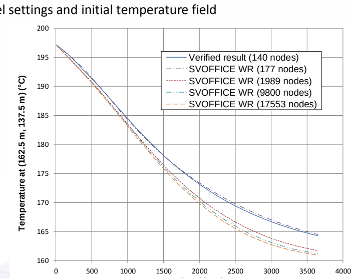
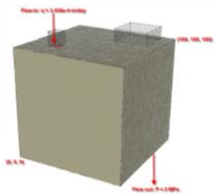
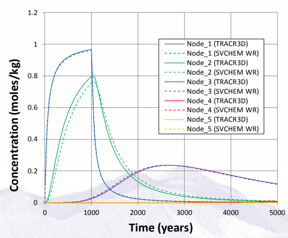


2. Benchmarking

Reactive solute transport modeling

- Three-Dimensional Radionuclide Transport





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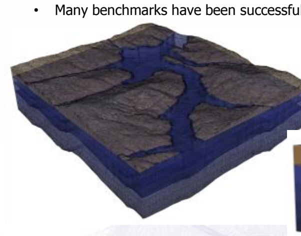
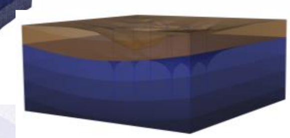
3. Ability to model field-scale systems

- Large models of 1-3M nodes have been solved
- Solution has been proven fast for unsaturated non-linear solutions
- Solutions of models with thin layers are improved
- Many benchmarks have been successfully solved to date





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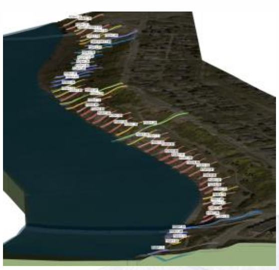
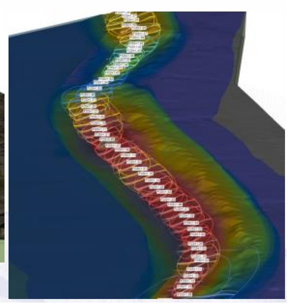
3. Ability to model field-scale systems

Coupling with Geotechnical Slope Stability





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4. Summary

- Interest in benchmarking the combined SVFLUX/SVHEAT + FEHM software
- Software has passed 2D, Axisymmetric, and 3D benchmarks
- Additional benchmarking has been performed by comparing solutions by running solutions in multiple solvers (FlexPDE, SVCORE, FEHM)
- Accuracy of the solver in terms of comparisons to pore-water pressure, and flow calculations has been reasonable to date
- Speed of the solver in terms of solving unsaturated flow problems has been exceptional
- Abilities of the solver related to solving thin-layer models has been improved over other solvers
- Opens the possibilities of solving models of increased complexity in the following areas
  - Complex unstructured meshes, double porosity / permeability, multi-component reactive contaminant species, improved speed in unsaturated flow problems

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Thank you…

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