Approaches for Modelling Transient Unsaturated-Saturated Groundwater Flow During and After Construction

Matt White, Jordi Guimera,
Hiroshi Kosaka, Takuya Ohyama,
Peter Robinson and Hiromitsu Saegusa

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Transient Groundwater Flow in Geological Disposal of Radioactive Waste

- Development of a geological disposal facility has a significant affect on groundwater flow which can impact all phases of the project
- The construction and operation phases of the facility will last for many decades
  - Groundwater will flow into the excavations
  - There will be a reduction in groundwater heads, drawdown in the water table and desaturation of rock around the excavations
  - Groundwater flows affect the engineering design (e.g. grouting, design of water treatment facilities).
- Transient groundwater will affect the post-closure performance
  - For example, saturation (and swelling) of bentonite buffers

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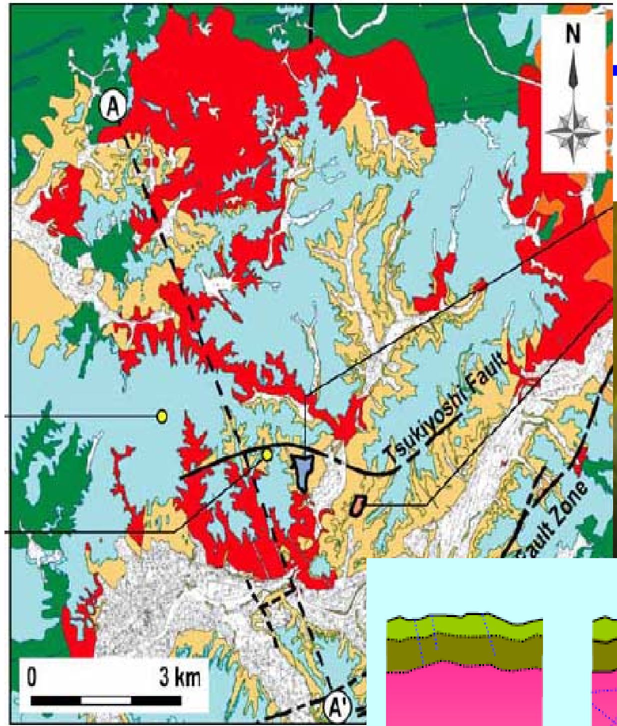
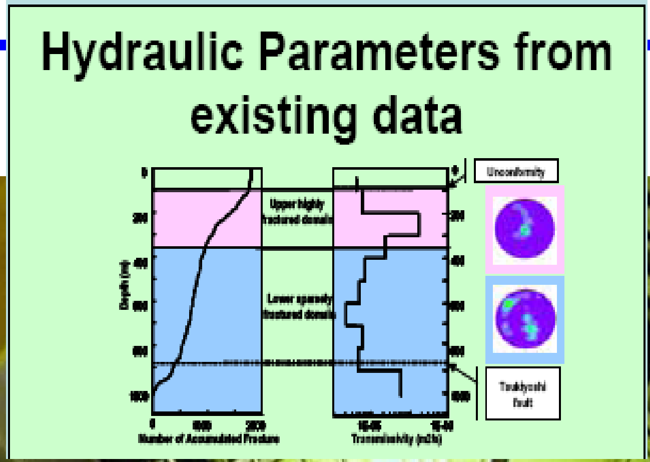
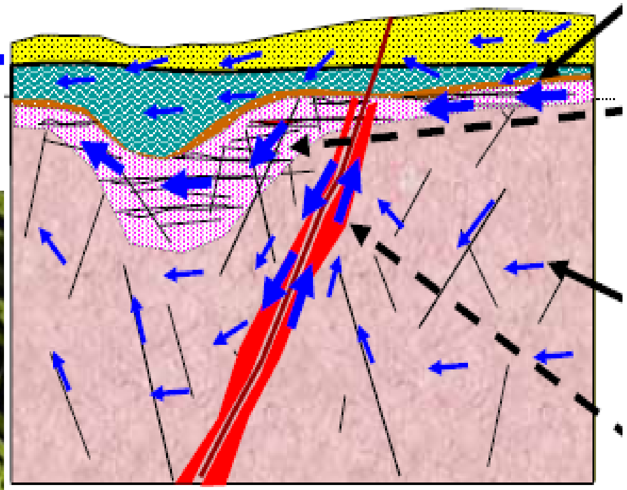
Presentation Objectives

- Describe approaches to modelling transient unsaturated-saturated groundwater flow in the Tono Area, Japan
- Identify key problems for modelling transient unsaturated-saturated groundwater flow in geological disposal projects
- Present an analysis of different approaches to mitigating these problems through application of appropriate conceptual models (reducing model complexity)
- Demonstrate the effect of reducing model complexity through application of a series of test models

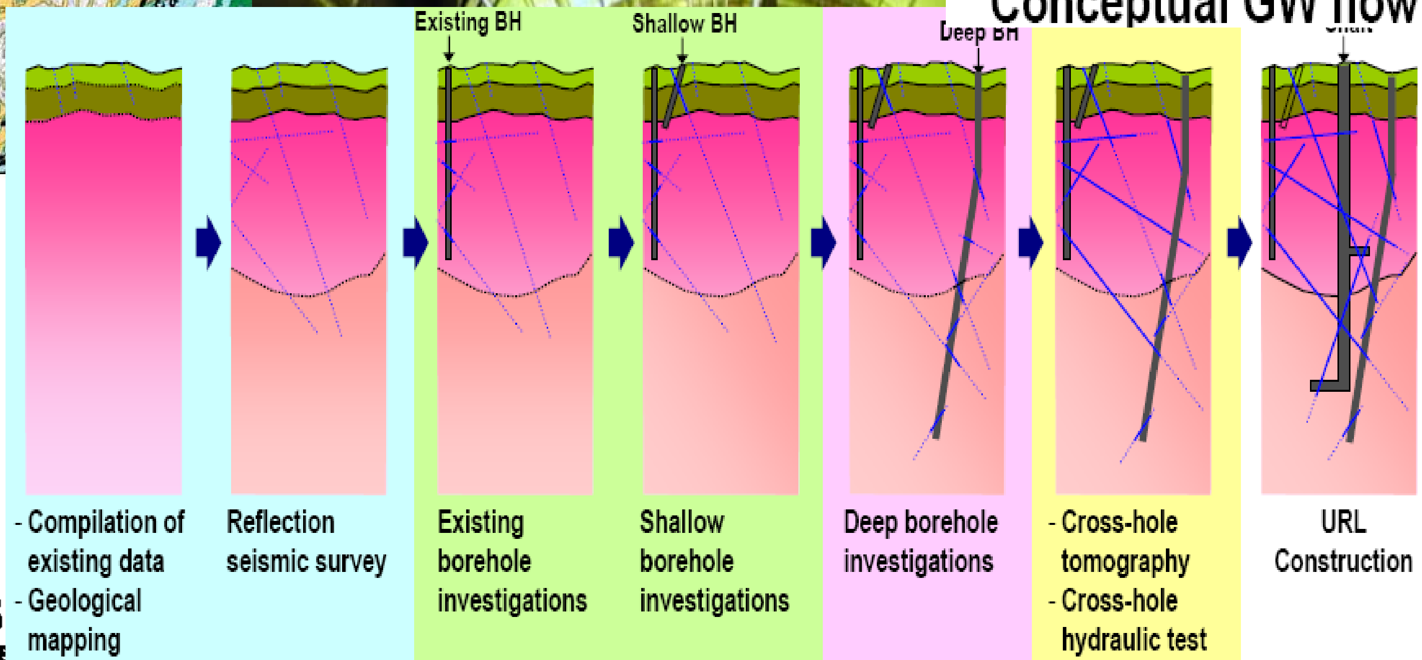
Investigations in the Tono Area







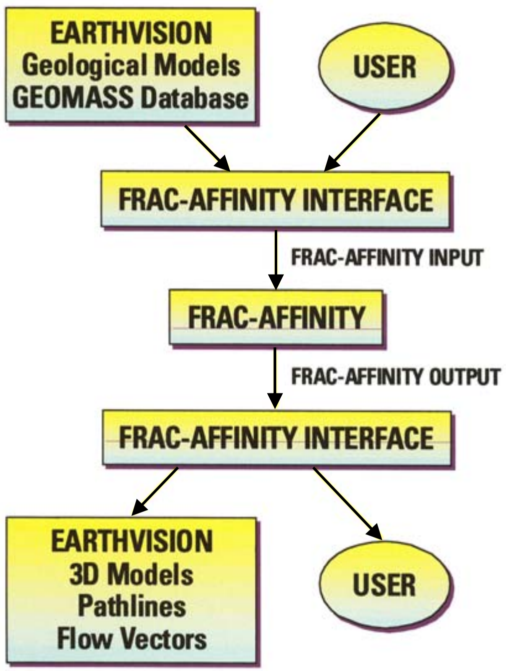
Conceptual GW flow model

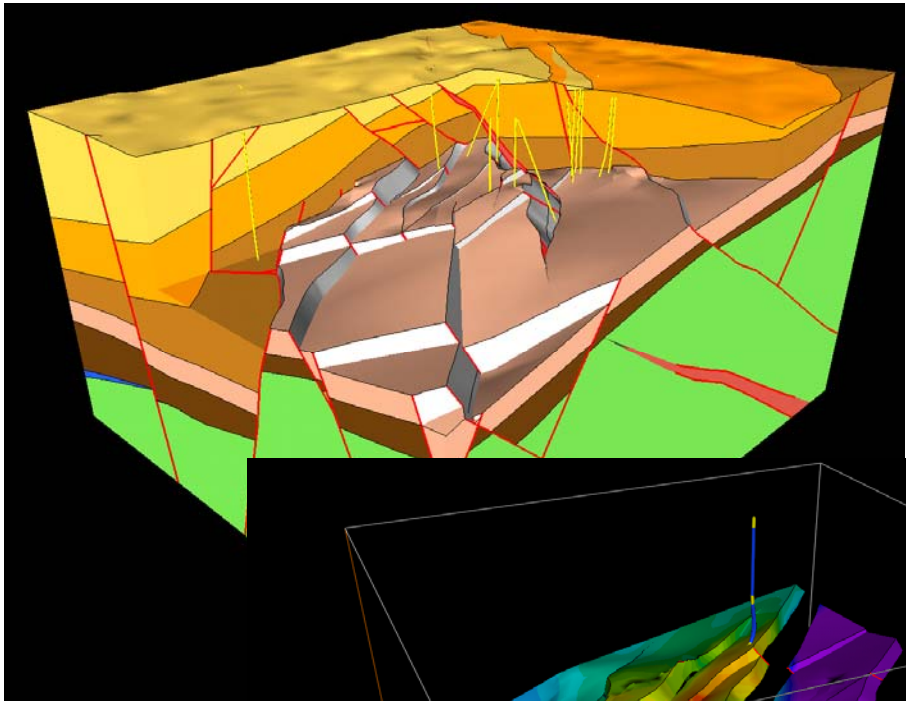


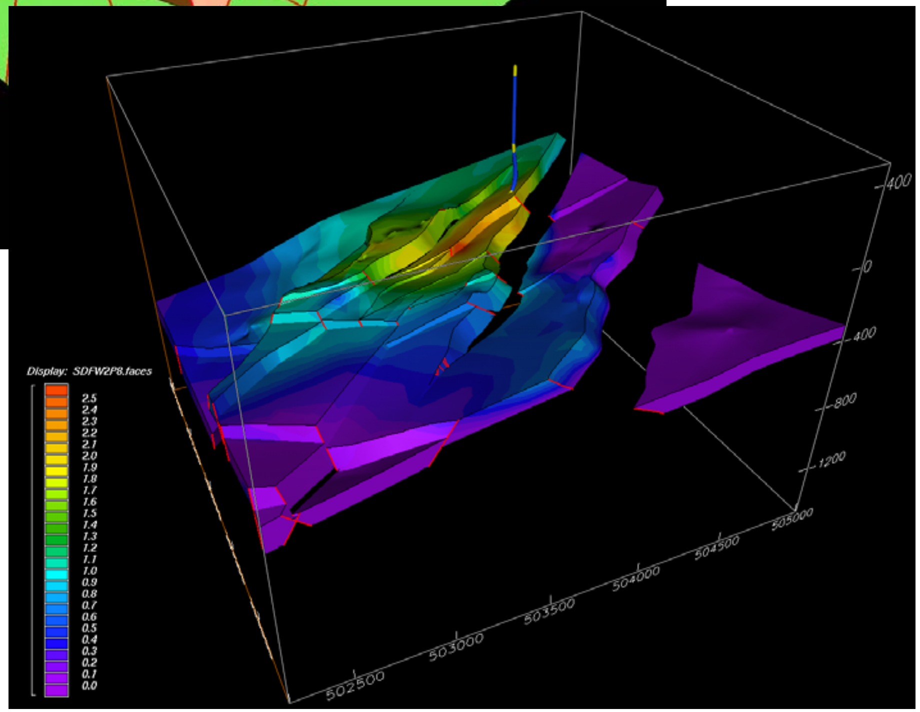
Tono Hydrogeological Investigations - Objectives

- Estimating groundwater flows into the Mizunami Underground Research Laboratory (MIU) shafts and galleries
- Modelling the response of the water table to excavation of the MIU
- Modelling heads at, and flows into, regional boreholes
- Development of an approach to site characterisation

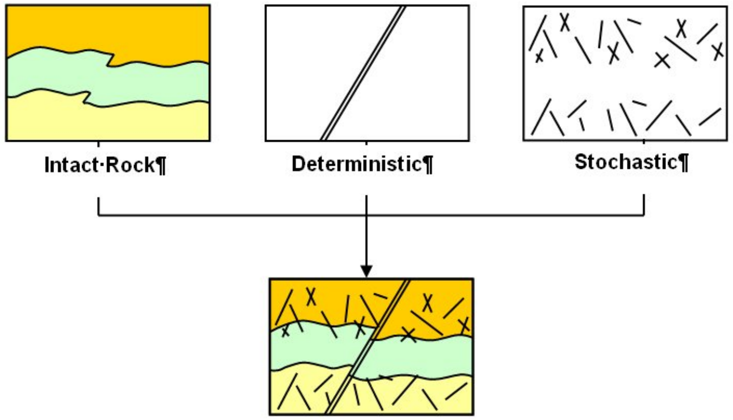
GEOMASS: Integrated Geological and Hydrogeological Modelling

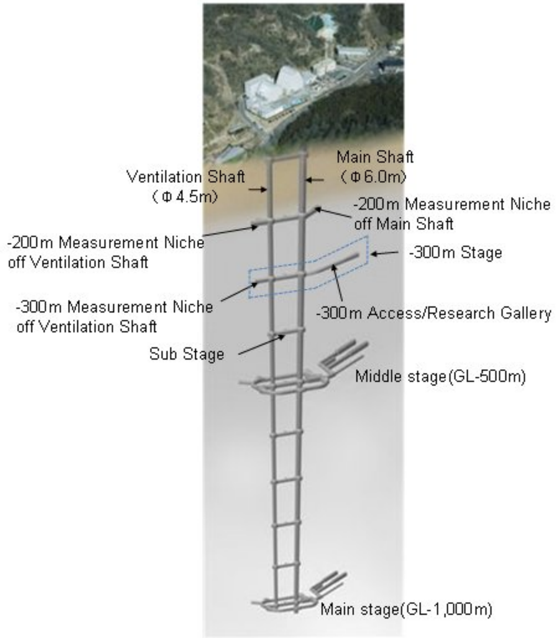


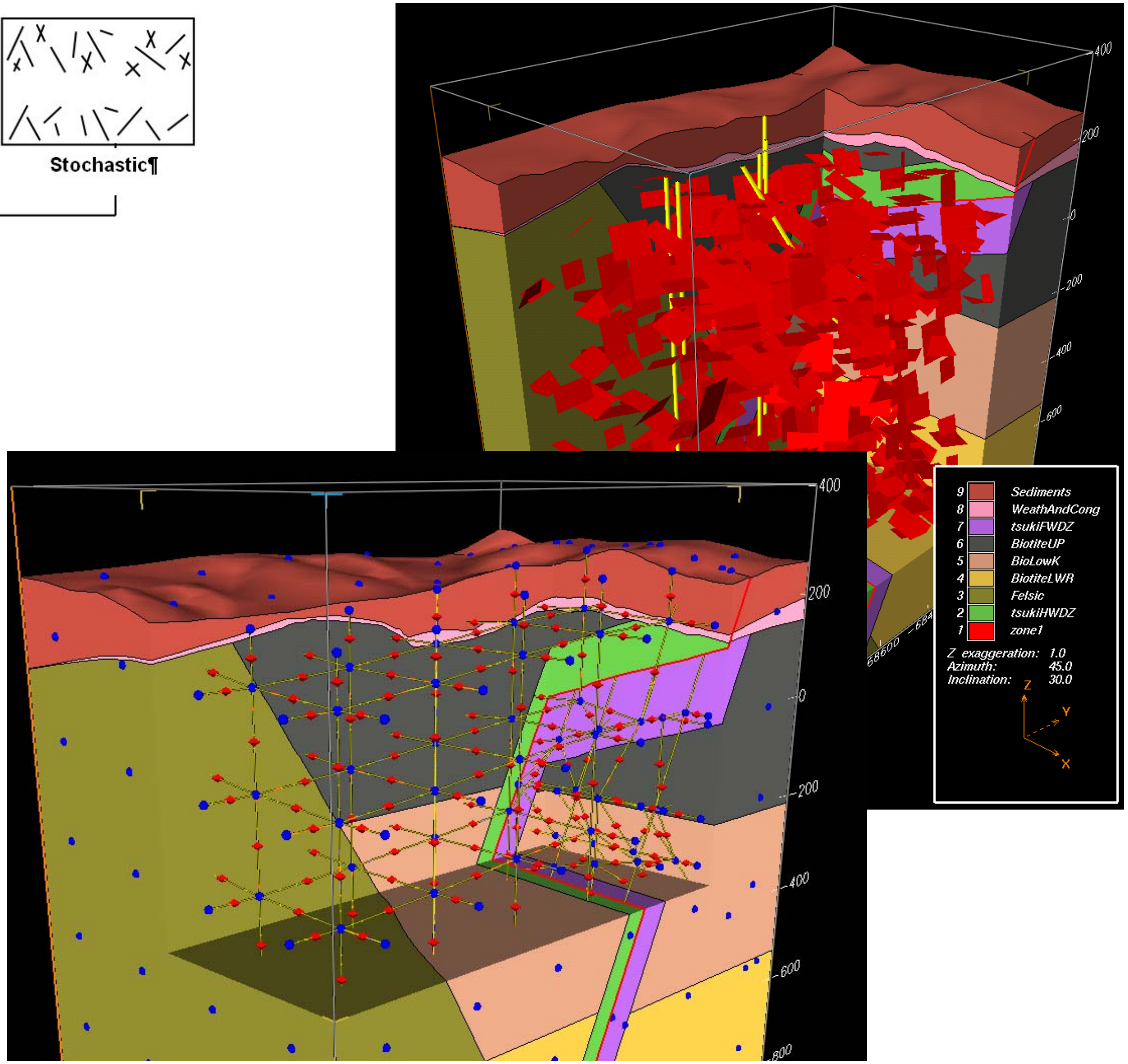




FracAffinity Groundwater Flow Modelling using a Hybrid Medium

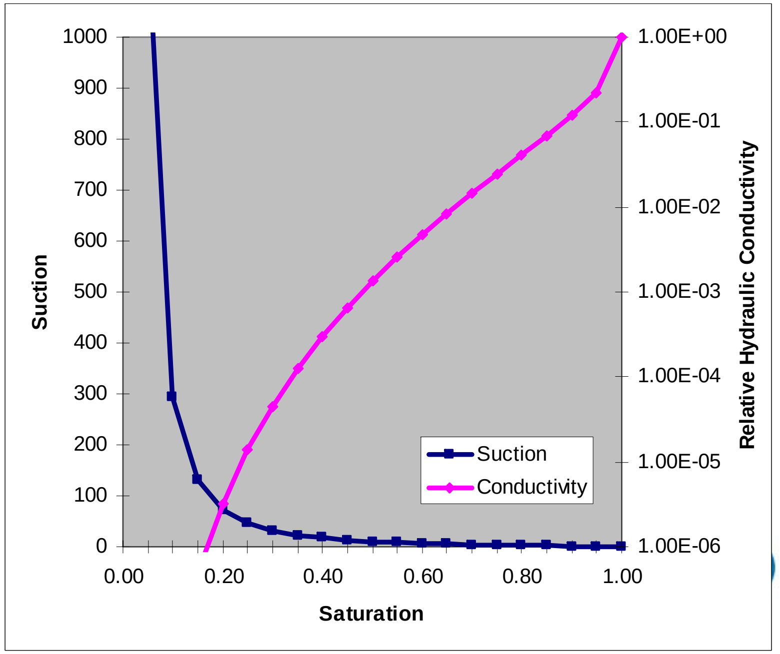


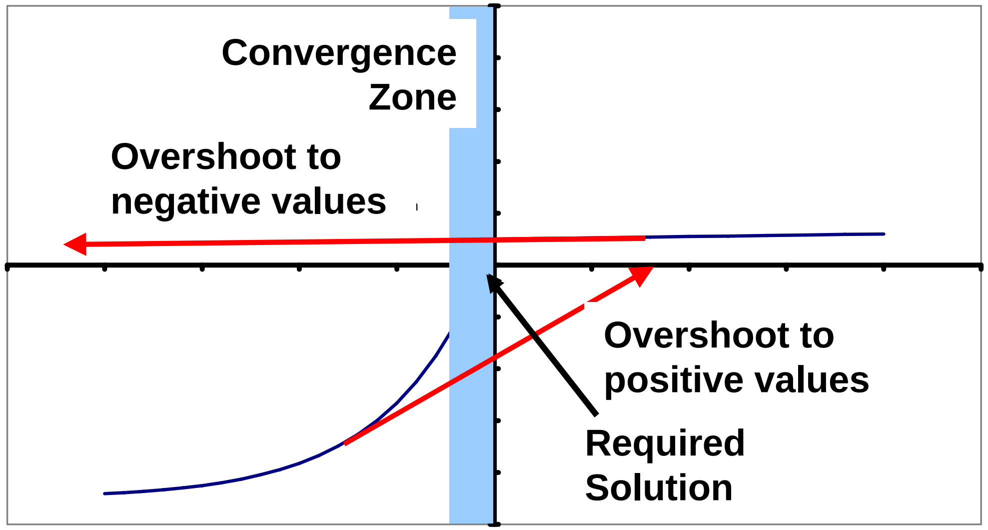




FracAffinity Linearity / Non-linearity

- Steady-state Saturated Flow: Linear
- Steady-state Unsaturated Flow: Non-linear due to dependence of conductance on saturation
- Transient Flow: Non-linear solution solved through a predictor-corrector approach





Summary of Issues

- Calculation time insufficient for practicable solution times
  - Practicable solution time target for iterative modelling is 24 hours
  - Practicable solution times particularly difficult to achieve for shaft excavation models – pressure field is constantly changing
- Change in pressure across water table transition is significant requiring consideration of this region
- Modelling possible with detailed grids but would exceed limits of computing capability for GEOMASS approach
- There is a need for appropriate models

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Potential Modelling Approaches

- Use saturated solver
  - Flows into boreholes will be below water table
- Estimate using steady-state conditions
  - Possible approach for estimating effect at certain times – period and extent of transient behaviour must be understood
- Simplify water retention models
  - Focus on saturated or unsaturated zones, not transition
- Develop appropriate gridding approaches
  - What are the limits to grid spacing for appropriate calculations?

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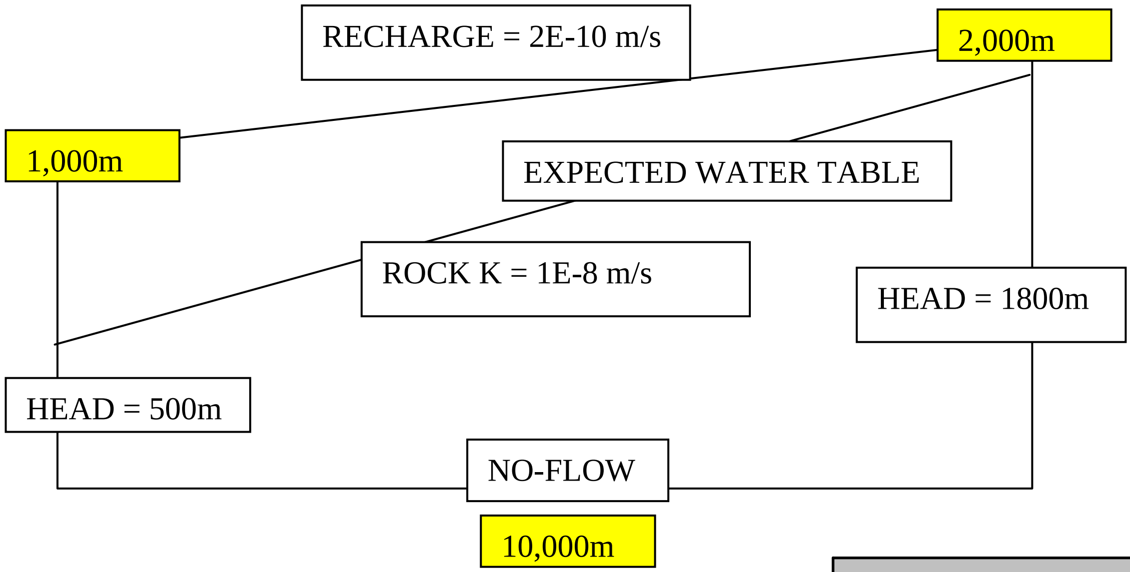
2D/3D Test Model: Geometry and Parameters



Parameter	Value
Porosity	10%
Specific Storage Coefficient	1e-05
Water Retention Model	Van Genuchten, A = 0.33, B = 0.2
Grid Size	X=50m, Y=1m, Z=50m

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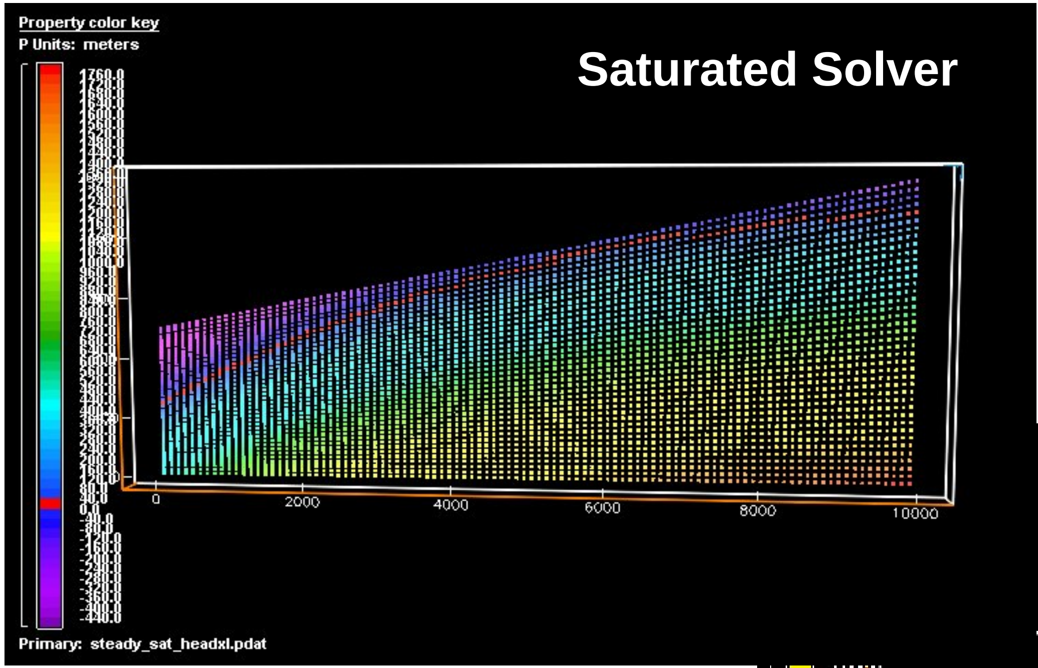
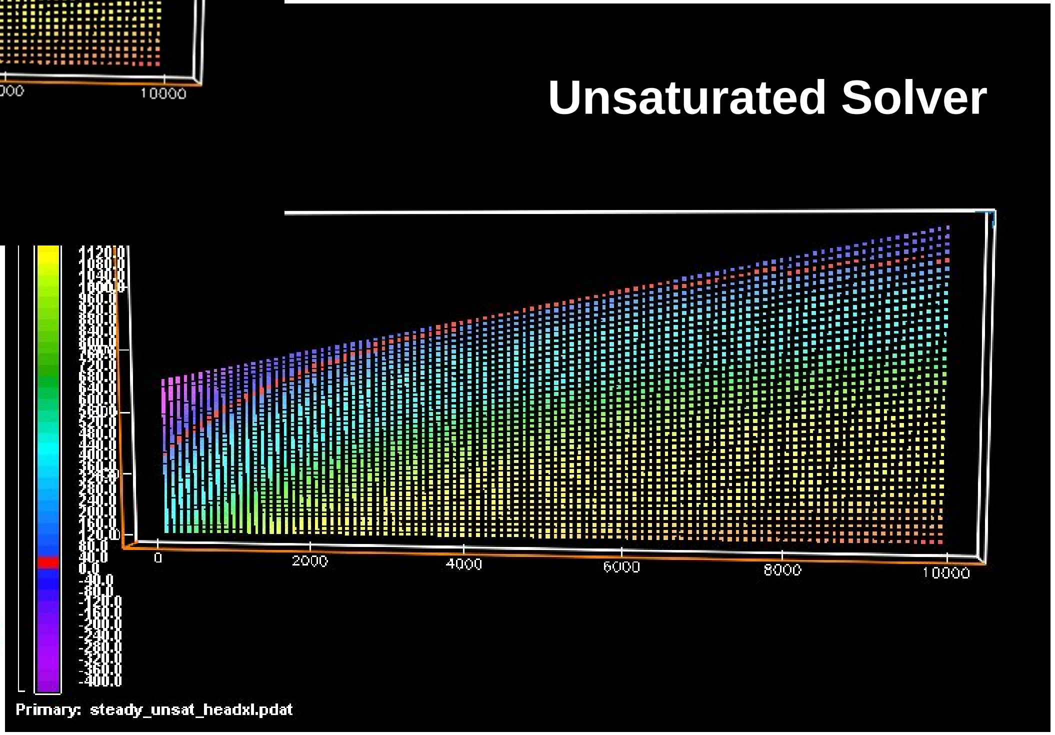
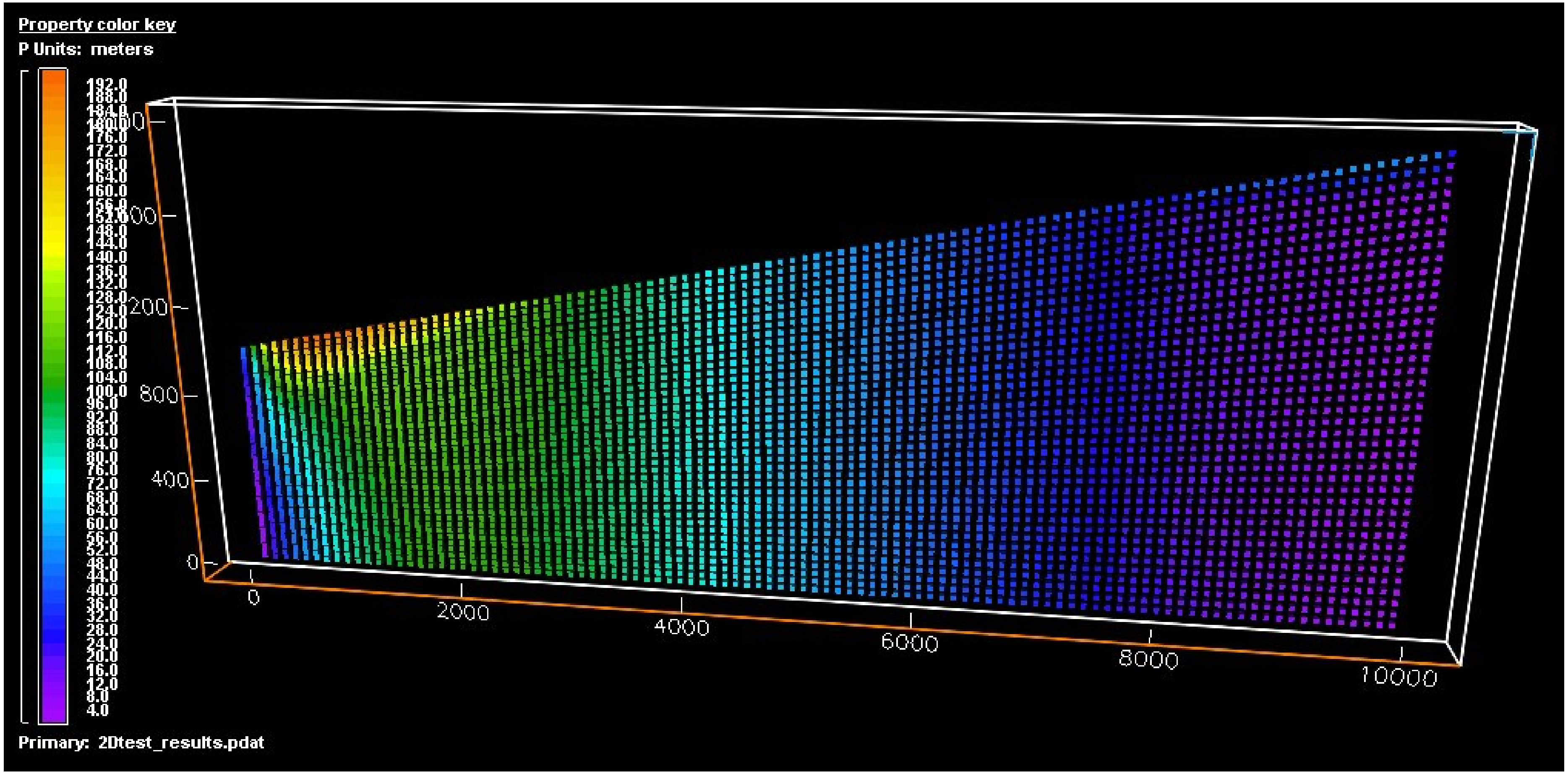
Comparison of Saturated/Unsaturated Solvers



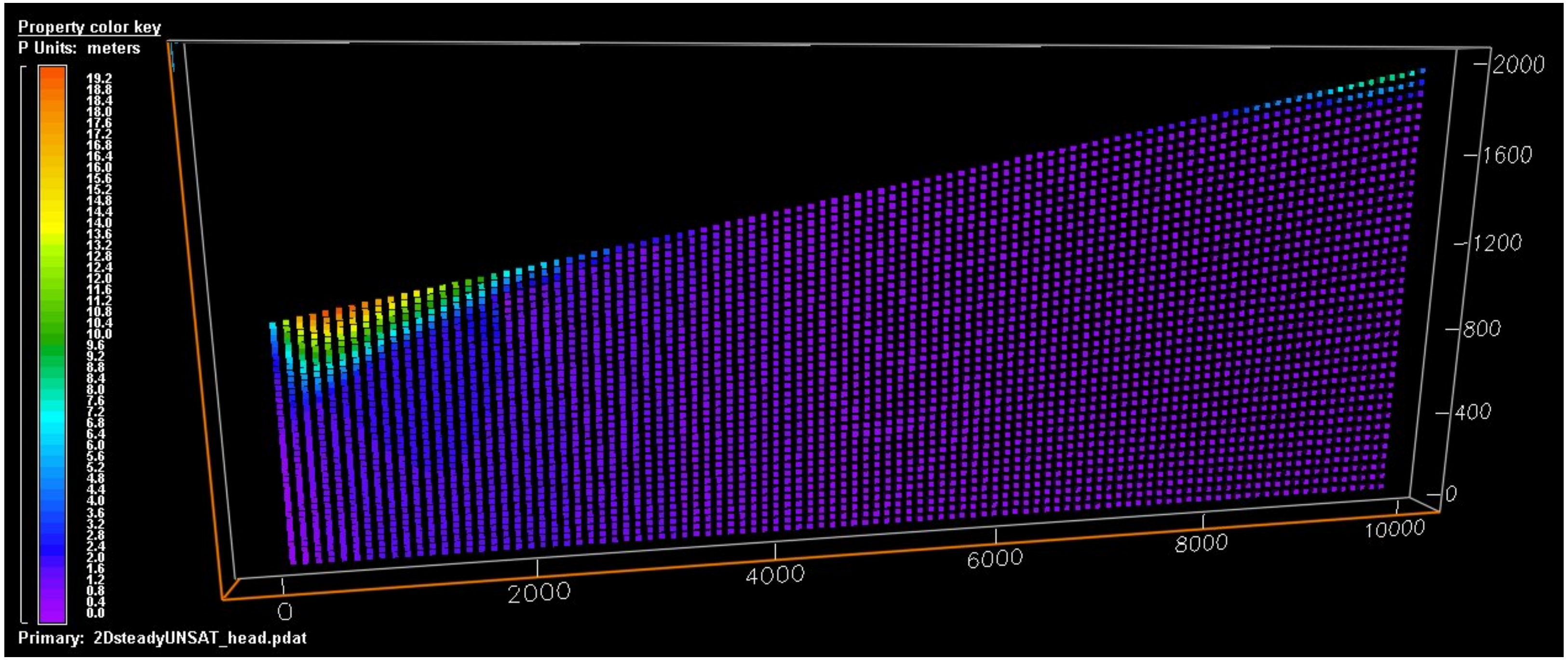


Saturated/Unsaturated Solvers – Head Comparison



Steady-state/Transient Unsaturated Solver

- Calculated boundary flows < 1% different
- Head differences < 2m in saturated zone



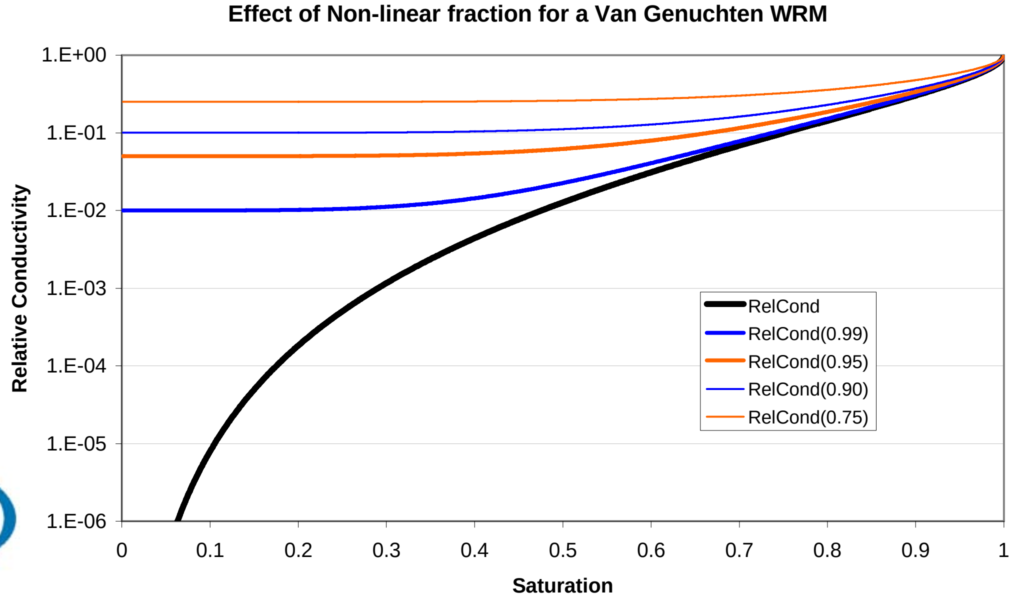
Water Retention Model Simplification

- A scaling factor – the Non-linear Fraction (NLF) was tested
- The NLF (f_{nl}) modifies the pressure-dependent conductivity ($K(p)$) as follows:

$$K(p; f_{nl}) = \frac{K_{sat}}{K_{red}}\left(f_{nl} + (1 - f_{nl})K_{red}\right)$$

- where K_{red} is the reduction factor for the full non-linear water retention model

$$K_{red} = \frac{K_{sat}}{K(p)}$$



Optimum Gridding Approaches

- Investigation of general effects of grid size, simple model:
  - 2D test model grid run with 50m, 10m and 1m grid size
  - Full transient unsaturated calculation
  - Model run time 4 minutes, 26 minutes and 32.5 hours
  - < 2% difference in flows into and out of the model
- However, more complex models required for “real-world” modelling in 3D
- Specialise gridding approaches in GEOMASS include:
  - Refinement of grid size in cuboid regions
  - Refinement of grid around boreholes
  - Refinement of grid around 2.5D features

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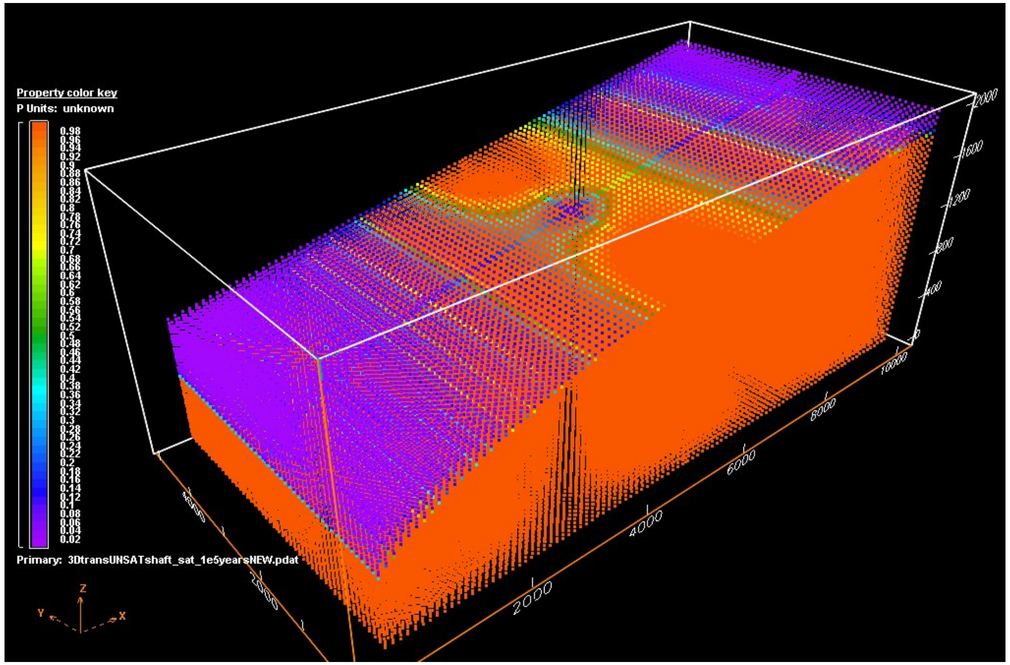
Developing a 3D Modelling Approach

- Comparison of steady-state and transient 3D model
  - Grid size 100x100x50, NLF 0.9
  - Flux into shaft 7×10^{-4} m^3/s (expected result)
  - Run-time: steady-state 14 minutes; transient 28.5 hours



Coarse Transient Model

- In order to investigate how the run-time could be reduced a coarse model was evaluated:
  - Grid-size 200x200x100m
  - NLF 0.75
  - Run-time: steady-state 1.7 minutes; transient 27 minutes
- For this model, the shaft inflows were 7 x 10^{-4} m^3/s
- Sensitivity tests were conducted to determine whether the grid size or the NLF had the greatest affect on shaft fluxes
- Hypothesis was that the NLF, which controls the conductivity of unsaturated zones (i.e. around the shaft) would have the greatest impact

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Results from Sensitivity Tests

MODEL ID	NLF	Grid Size	Shaft Inflow (m^3/s)	Run Time (minutes)
FINE	0.9	100x100x50	7.0e-4	14
COARSE	0.75	200x200x100	4.5e-4	1.7
COARSE A	0.8	200x200x100	4.5e-4	2
COARSE B	0.85	200x200x100	4.6e-4	23
COARSE C	0.9	200x200x100	NOT RUN	
FINE D	0.75	100x100x50	7.0e-4	14
FINE E	0.8	100x100x50	NOT RUN	
FINE F	0.85	100x100x50	NOT RUN	
COARSE LOCAL	0.9	200x200x100 with local grid size of 100x100x50 around shaft	6.8e-4	2

Specific Conclusions – Flow Modelling I

- Unsaturated flow processes typically occur at local scale and are therefore problematic to model at regional scale
- Introduction of the NLF and grid refinement techniques for transient modelling are particularly significant
- The choice of parameters is complex and requires testing for specific models

Specific Conclusions – Flow Modelling II

- For unsaturated conditions, the saturated solver can be used to give an approximation of the water table location
- Calculations of the steady state for unsaturated-saturated conditions are not affected by approach, i.e. use of transient or steady-state unsaturated solver
- Calculation of the fluxes at external boundaries and the topography of the water table are insensitive to grid spacing
- Introduction of the NLF for transient calculations allows complex unsaturated-saturated models to be calculated without significantly affecting the results
- Calculations of the fluxes into a shaft are affected by the grid spacing around the shaft

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General Conclusions – Geological Disposal

- Groundwater flow on regional and local scales is of primary significance to all phases of the development of a geological disposal facility (construction, operation, closure, post-closure)
- A range of groundwater modelling tools will be required for specific processes
- For regional modelling, it is important to consider transient saturated-unsaturated systems
- Methods are available for appropriate modelling of these systems, and the impacts of modelling approaches can be quantified

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