Stochastic modelling of geological heterogeneity and propagation of uncertainty: examples of application and open issues

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Plan

• Case study 1: nuclear waste (F)
  - Objective
  - Model
  - Results
  - Open issues

• Case study 2: nuclear waste (CH)
  ...

• Case study 3: hazardous waste (CH)
  ...

• Summary
Case 1: karst

Objectives

• Environmental impact assessment of the future surface facilities associated with the underground laboratory ANDRA

• Study of the system response in case of accidental contamination on site
Case 1: karst

Karstic aquifers: extreme heterogeneity
Case 1: karst

Random walk approach

Karst networks resulting from complex physical processes
→ **exact location of conduits is unpredictable**

Simulation of their **probable** location

Spatio-temporal process → **random walk**

Image of the geometry of karst networks
Case 1: karst

Stochastic modelling

- **Complex phenomenology:** coupled physical processes (transfer+dissolution)

- **Stochastic approach:** simplified description of the formation of karst networks

- **Reinforced random walk:** non-linear equation of Langevin

\[
\frac{dX(t)}{dt} = v(X(t), t) + \Theta(X(t), t) \xi(t)
\]
Stochastic modelling

- **Simulation**: 2D stochastic simulation of karstic networks

- **Lattice gas method**: discrete simulation on square grid

\[
\Delta X_{i,k} = \nu(X_{i,k}, t_i) \cdot \Delta t_i + \Theta \cdot \Delta W_{i,t,s} \cdot D(\alpha, \lambda)
\]

- Displacement of particles according to local rules = simulation of geometry at regional scale
Case 1: karst

Stochastic geometry + numerical modelling for groundwater flow and particle tracking

Histogramme des temps de parcours des particules sortant par les rivières

- Rivers: 43% < 10 a
- Springs (site): 32% < 1 a
- Springs (North): 27% < 100 a
Case 1: karst

Open issues

- Conditional random walk
- Improving physics of coupled effects
- Stabilisation of the simulated networks
Objective

- Evaluation of host rock storage capabilities
Case 2: marl

Geostatistical modelling
Case 2: marl

Monte Carlo Approach

- Borehole data and related information
- Geostatistical model of K
- Conditional simulation of K
- Transient groundwater flow model
- Distribution of performance criteria (fluxes, travel times, ...)
- Uncertainty of modelling results
Results

- Volumetric flow through repository
Open issues

- Classical Monte Carlo: lack of realisations
- Convergence of results (rare events)
- Alternatives
  - direct methods
  - quasi-Monte Carlo methods
  - ...
Case 3: molasse

Objectives

• Application of Plurigaussian simulation method (oil industry) to a hazardous waste landfill

• Characterisation of lithofacies for numerical modelling of contaminant transfer
**Plurigaussian approach**

1. $Y(x) < y_c$
2. $Y(x) > y_c$ and $Z(x) < z_c$
3. $Y(x) > y_c$ and $Z(x) > z_c$

**Case 3: molasse**
Case 3: molasse

Geostatistical modelling

Cross-Section in the Simulated Volume

LithoType
- Meanderbelt sand
- Levee sandstone
- Crevasse sand
- Mud Palaeosols
- Overbank sand
- Lacustrine silt

22 Novembre 2002, Paris
Open issues

• Operational (fast) techniques of upscaling transfer properties for large unstructured and heterogeneous grids (presence of faults)

• Inverse methods for selecting realisations of geostatistical models
Summary of open issues

• Conditional random walk (with memory)

• Random walk for physical processes with coupled effects

• Efficient methods for propagating uncertainty of geological and transfer properties into numerical modelling results