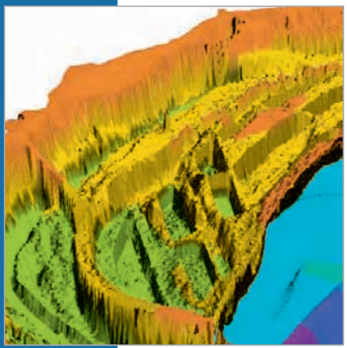
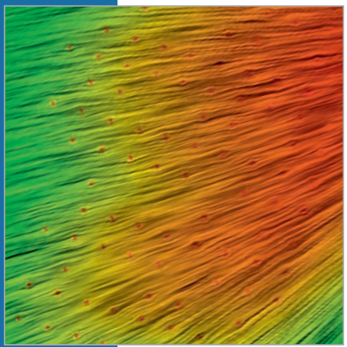
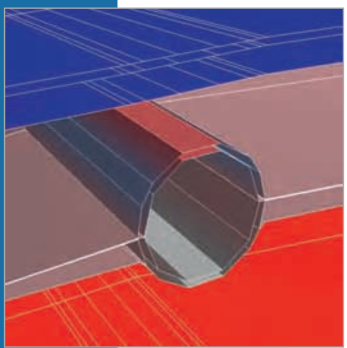
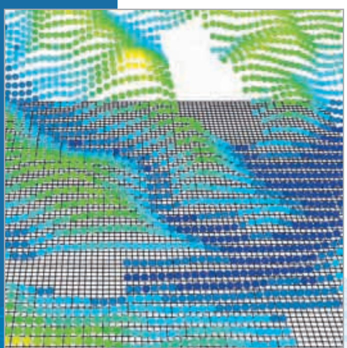






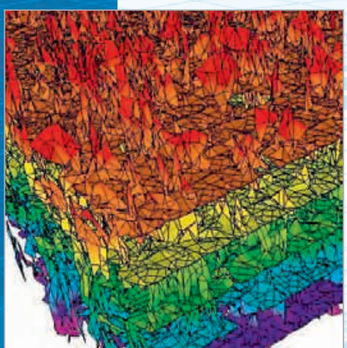
SPRING

Simulation of Processes in Groundwater



Professional Water Systems Modelling Software.

- **Groundwater flow modelling**
- **Contaminant transport modelling**
- **Heat transport modelling**



SPRING – Brought to you by the Engineering Consulting Firm delta h Ltd.

Flexible and Realistic Modelling of Hydrological Systems – using **SPRING**.

SPRING – Brought to you by the Engineering Consulting Firm delta h Ltd.

From underground mining to water supply, groundwater remediation and geothermics: **SPRING's** innovative software system provides optimal support for all your planning and consulting projects. Whether you want to simulate groundwater flow, heat flux, contaminant transport processes, or surface-groundwater interaction – **SPRING** offers intuitive support for the development of three-dimensional models accomodating all essential information using the Finite Element method – flexible, precise and realistic.

Up To Date with Science.

SPRING is continuously updated to account for the latest developments in hydrological system modelling. Originally developed at the Ruhr-University in Bochum, Germany by hydrologists, mathematicians and civil engineers, the software is continuously optimised in close cooperation with hydrological professionals and institutions of higher education and research. SPRING therefore reflects the state of the science in computational, model development and visualisation methods.

SPRING: Software Packages to Suit your Requirements.

SPRING is available in different packages, from a basic but powerful package for localised problems to a premium package for comprehensive watershed modelling. For maximum flexibility, **SPRING** can be updated at any time with additional packages.

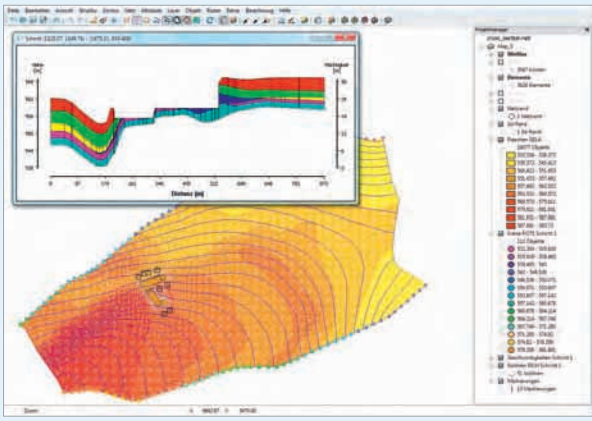
SPRING is exclusively distributed by the engineering consulting firm **delta h Ltd.**, whose experienced team of experts also offer introductory and advanced training in **SPRING**.

Getting to know SPRING's key features:

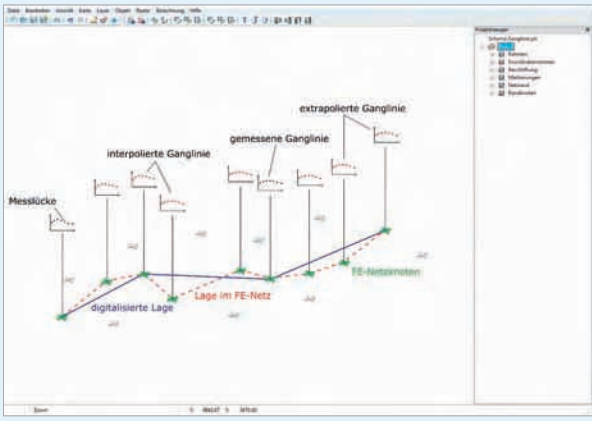
SPRING's Graphical User Interface – Simple Control, and Efficient Visualisation of Results.

A user-friendly graphical interface for importing data, model development, visualisation and evaluation of results ensures an intuitive control of all modelling steps. The graphical interface can be easily customised to suit your personal requirements.

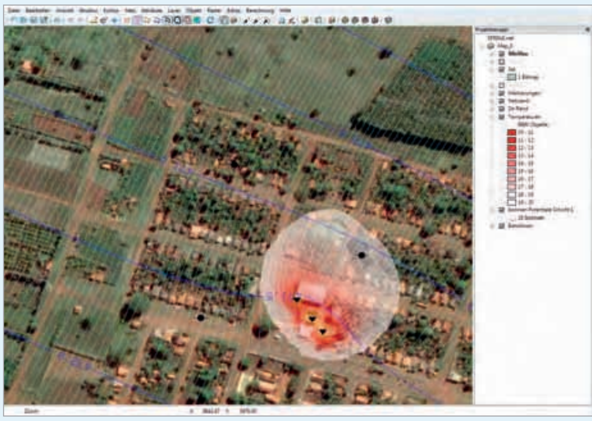
Numerous powerful visualisation options simplify the workflow. For example, layered strata can be vividly depicted using transparency effects, and 3-D views of the model and interim results can be visualised during transient calculations.



Cross-sections: SPRING allows sections to be drawn through the model during model development.

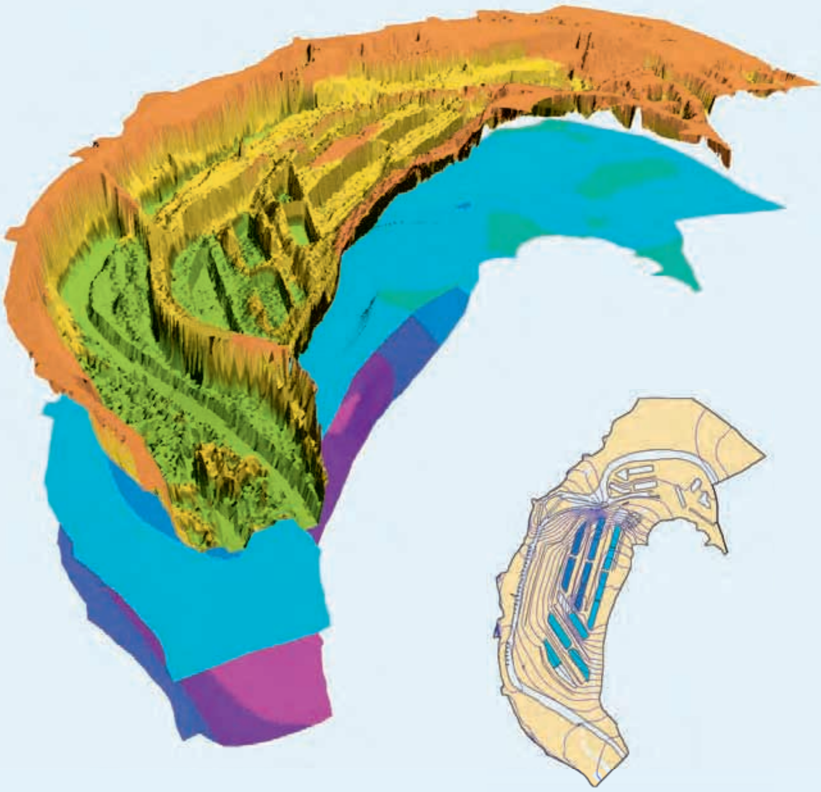


Transient Results: Real-time Visualisation of Transient Results.

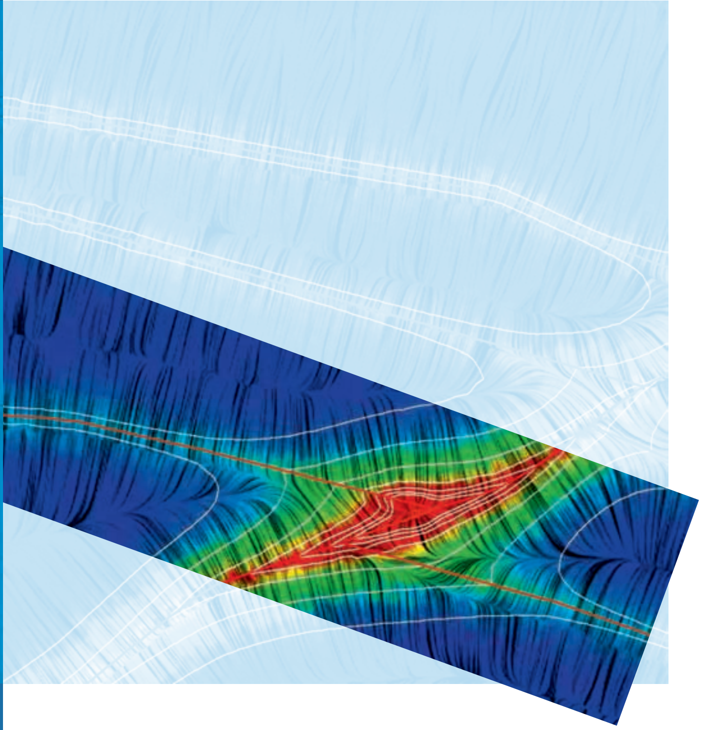


SPRING's Transparency Capability:
Graphical layers can be overlapped or removed, showing underlying layers and allowing different situations to be contrasted.

3-D Visualisation: SPRING supports a variety of 3-D views to assist in the model development.



Deep Geothermics

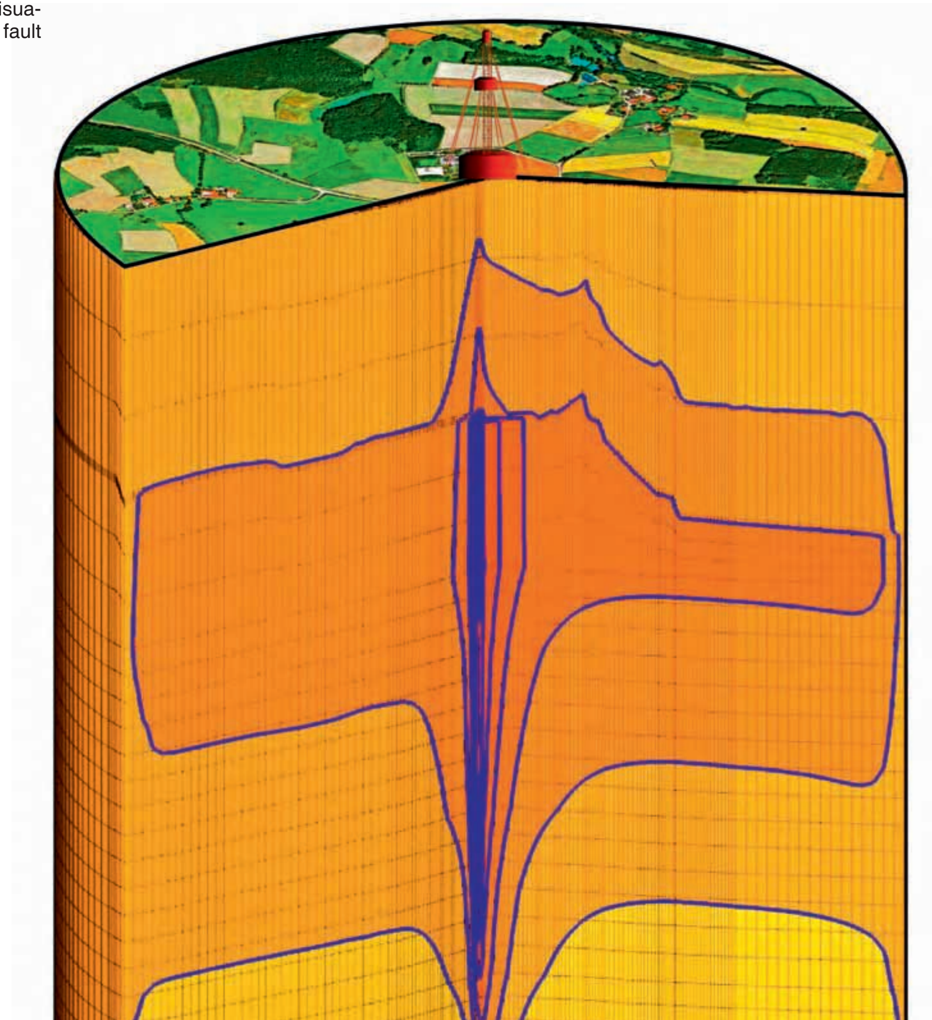


Simulation of Heat Transport in Deep Geological Strata

Understanding heat transport during the planning of large geothermal plants is complicated by heterogeneities in the subsurface and cyclical plant loads. **SPRING** offers numerous helpful features enabling reliable numerical calculation and prediction of a geothermal plant's physical environment.

Apart from the evaluation of geothermal potential, the software can assess the impacts of potential groundwater pumping. Monitoring programs can be developed and competing demands on the groundwater resource evaluated.

Deep geothermal project in the Molasse Basin, southern Germany (up to to 5000 m below surface): Visualisation of numerically modelled temperatures in a fault zone.

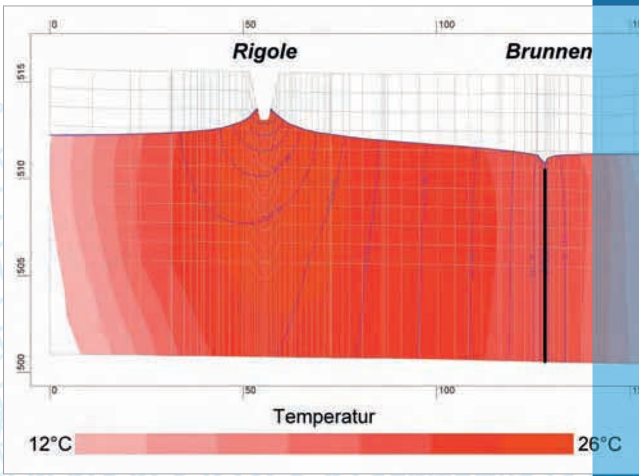


Cross-section through a deep geothermic model: Visualisation of finite-element mesh and calculated temperatures.

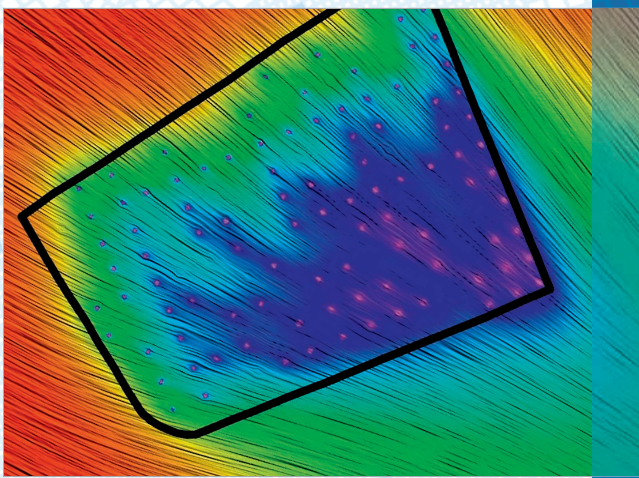
Near-Surface Geothermics

Geothermal heating

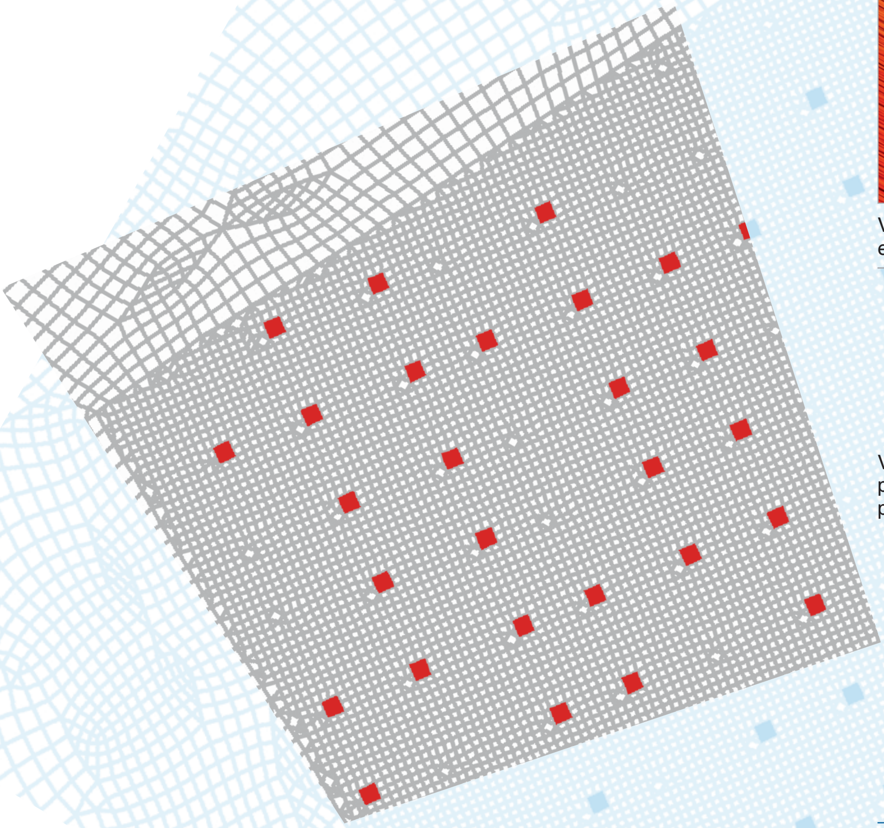
Regardless of whether wells, collectors or probes are used, **SPRING** offers specialised tools to evaluate a site for general suitability, competing utilisation interests and geothermal plant monitoring. **SPRING** enables the planning, dimensioning and optimisation of modern geothermal plants for heating or cooling – from a single family home to large-scale industrial plants.



Visualisation of simulation results for an injection-extraction cycle as part of a pumping test.

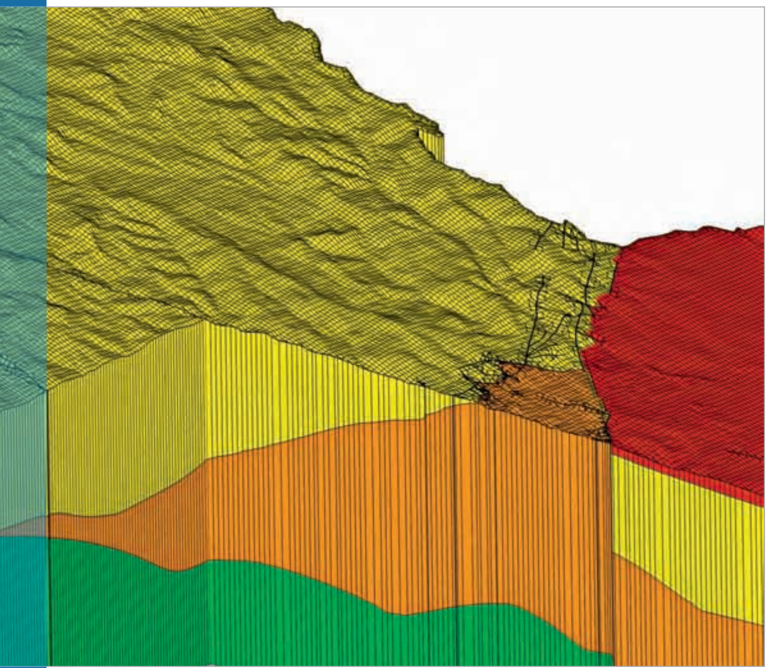


Visualisation of the spatial cooling effects as a result of earth probe field/heat exchanger



Visualised within the finite element mesh: Earth probes for cooling and/or heating of buildings as part of a near surface geothermal project.

Generation of Finite Element Mesh



Outcropping Geological Units

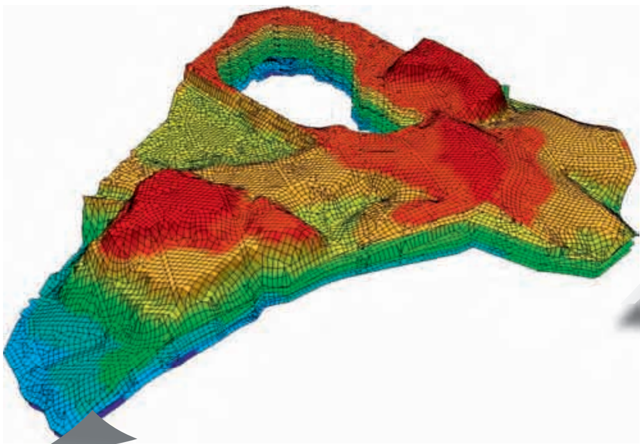
Outcropping geological units are supported by the automatic merging of finite element layers in (vertical) 2-D and 3-D models. This feature allows the accurate representation of complex geological and topographic features. A significant reduction in node and element numbers, especially in locally-refined mesh, ensures optimised CPU times whilst the merging of element layers maximises numerical stability.

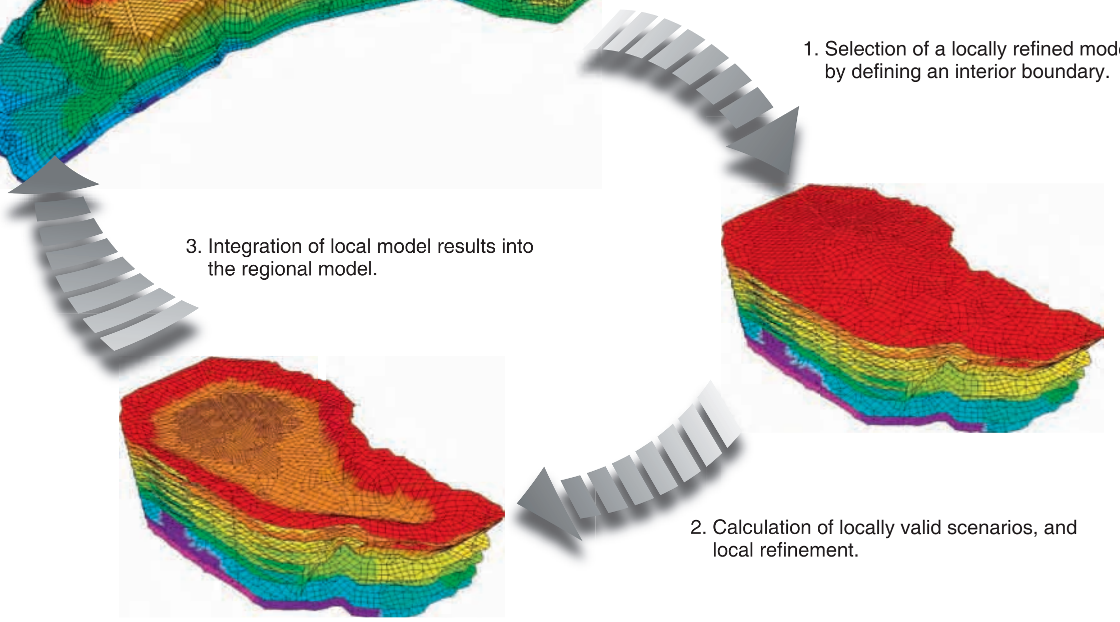
Geological unit

- Mittlerer Buntsandstein/Kreuznacher Schichten
- Rotliegendes/Karbon (Stefan)
- Karbon (Westfal)
- Devon

Coupling and De-Coupling of Local Mesh / Subdomains

SPRING can generate locally-refined models within a regional model to optimise updates, or to allow mesh refinement or scenario calculations.

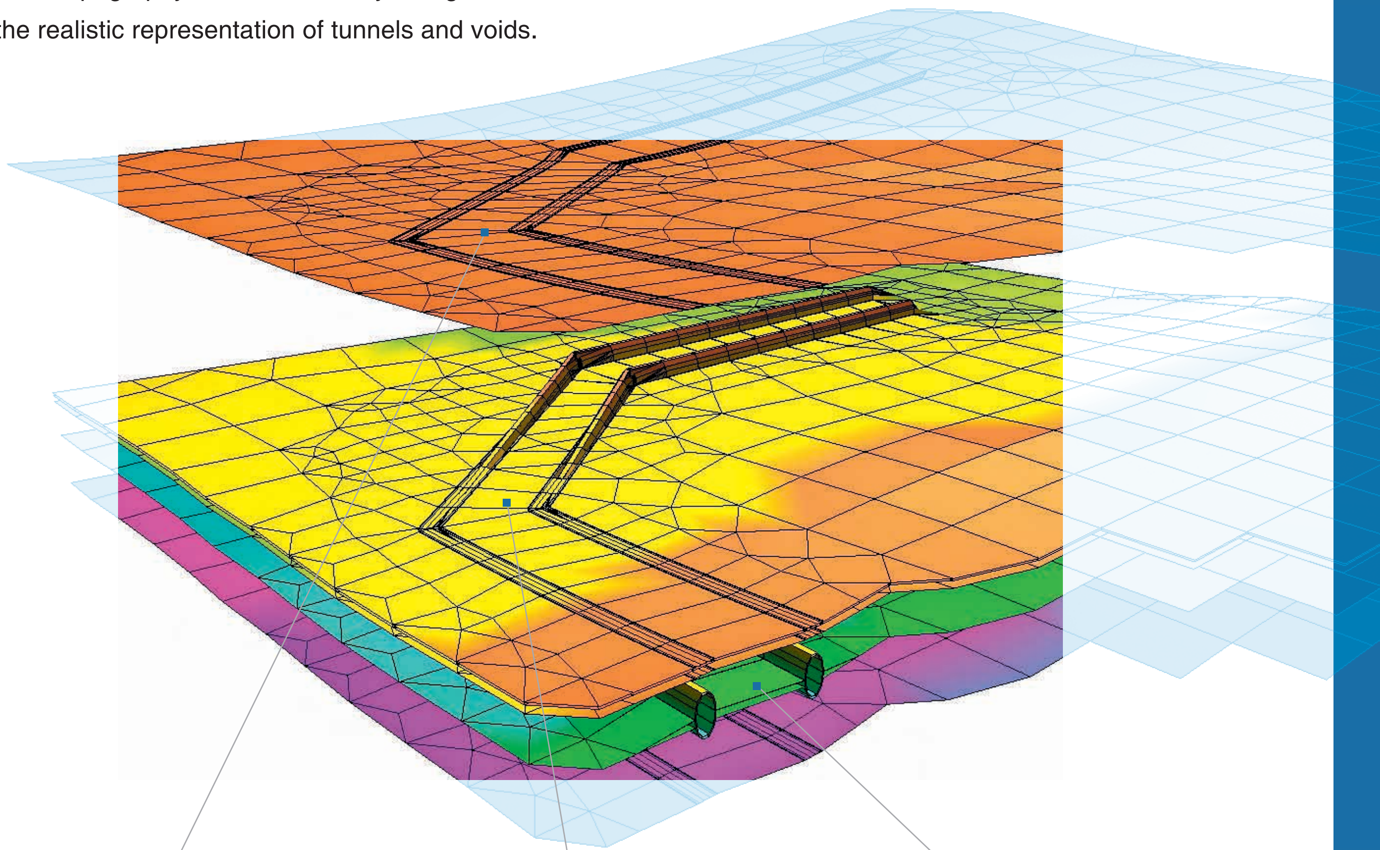


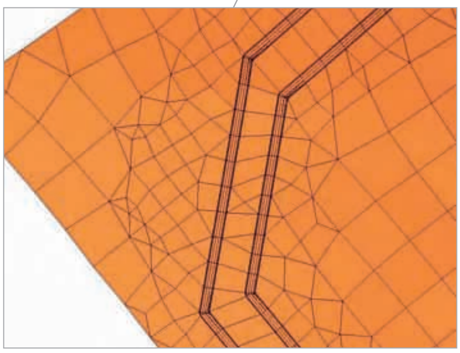


Generation of Finite Element Mesh

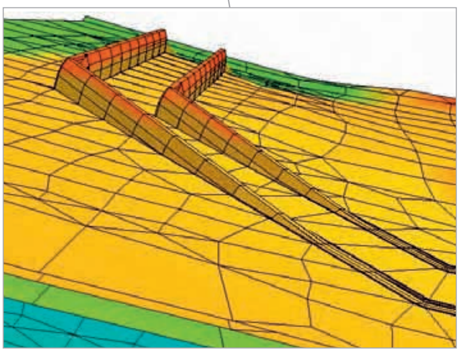
Integration of Tunnels and Mine Voids

A wizard allows tunnels and mine voids to be quickly and easily integrated into 3-D models. Potential changes in element layers or topography are automatically recognised, ensuring the realistic representation of tunnels and voids.

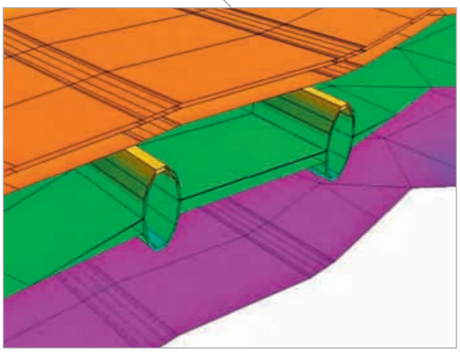




Simple integration into the Finite Element Mesh.

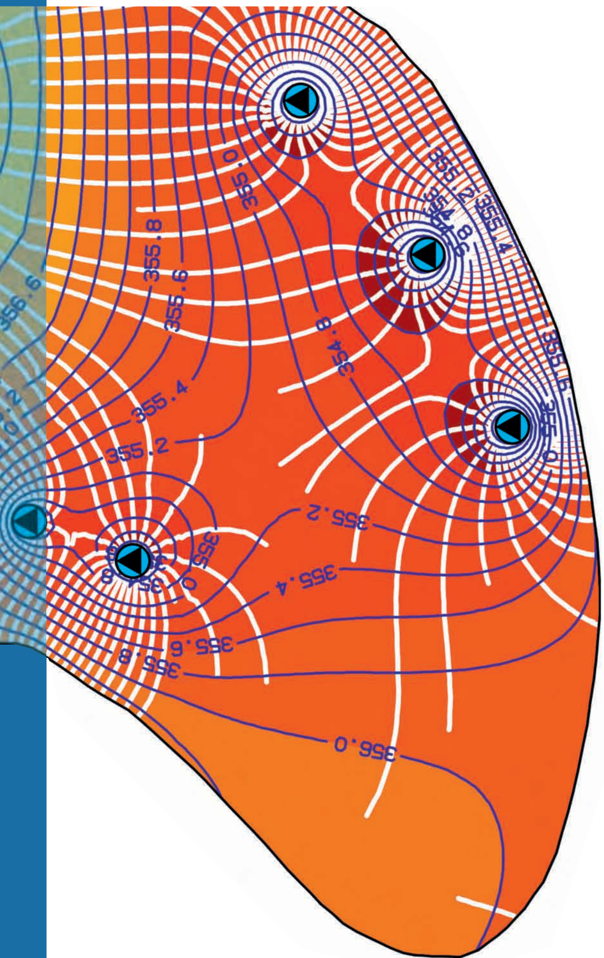


Realistic Representation of Tunnel and Mine Voids.



Tunnels dipping into deeper layers.

Determination of Catchment Areas



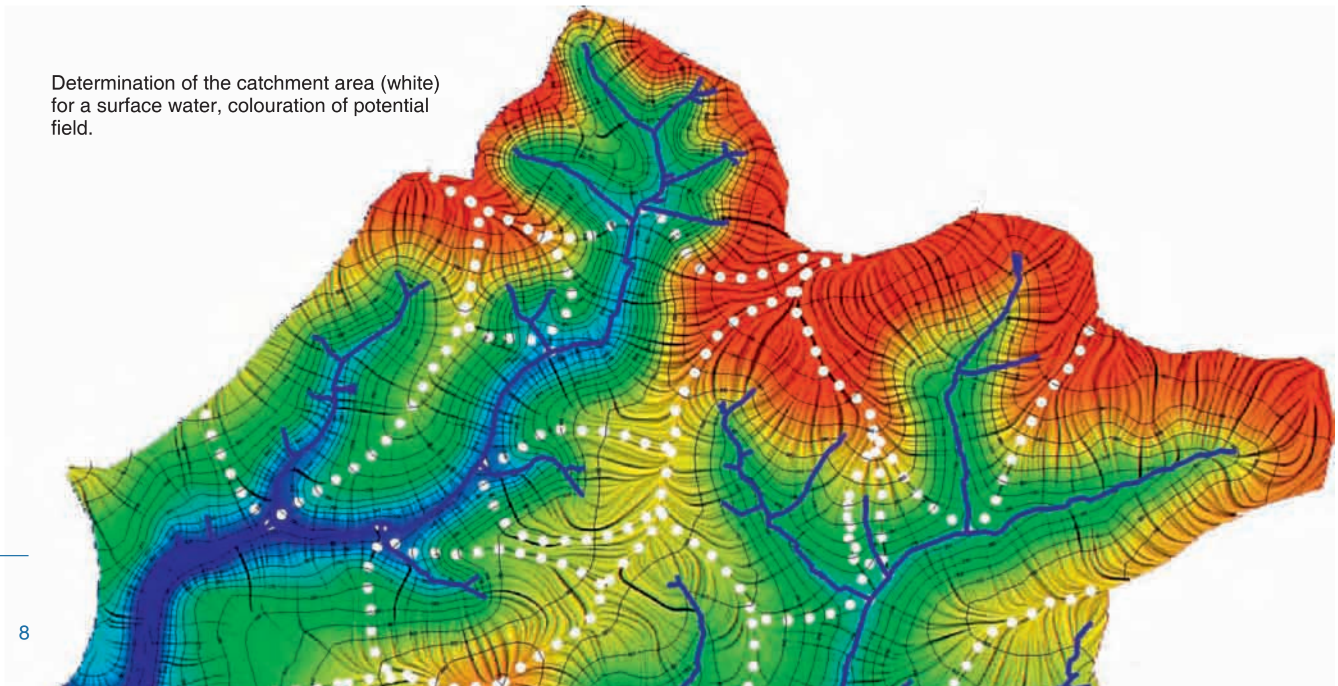
Example of mass fluxes for water supply from river bank filtration: Streamlines (white) and hydraulic heads (blue, with increasing red shading at lows).

Calculation of Streamlines

Stationary and transient flow fields or fluxes can be visualised through the automatic calculation of streamlines by **SPRING**. The depiction of mass fluxes can be scaled by the user. Travel times can be optionally shown along with stream lines.

Visualisation of schlieren

Catchment areas of surface waters or abstraction boreholes can be determined quickly and reliably by showing “schlieren”. The flow paths are determined using flow velocities within the calculated groundwater potential field and visualised intuitively using schlieren. Using colouration of schlieren, an additional parameter like topography or temperature can be visualised.

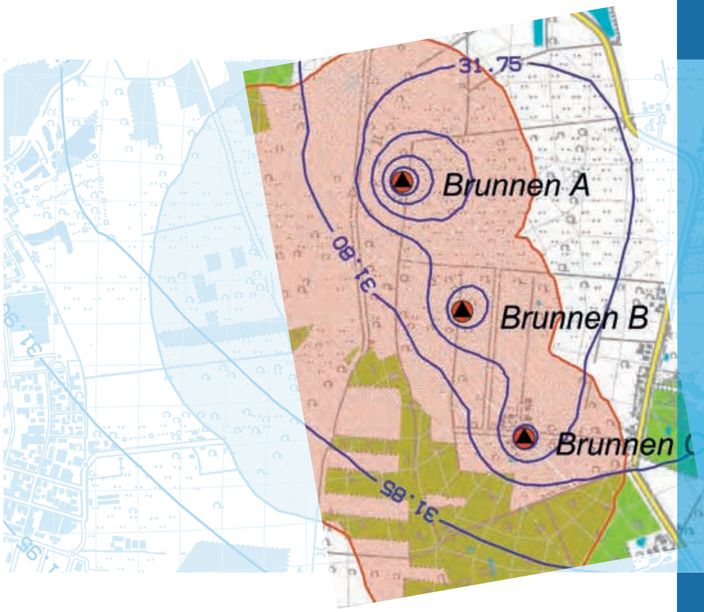


Determination of the catchment area (white) for a surface water, colouration of potential field.

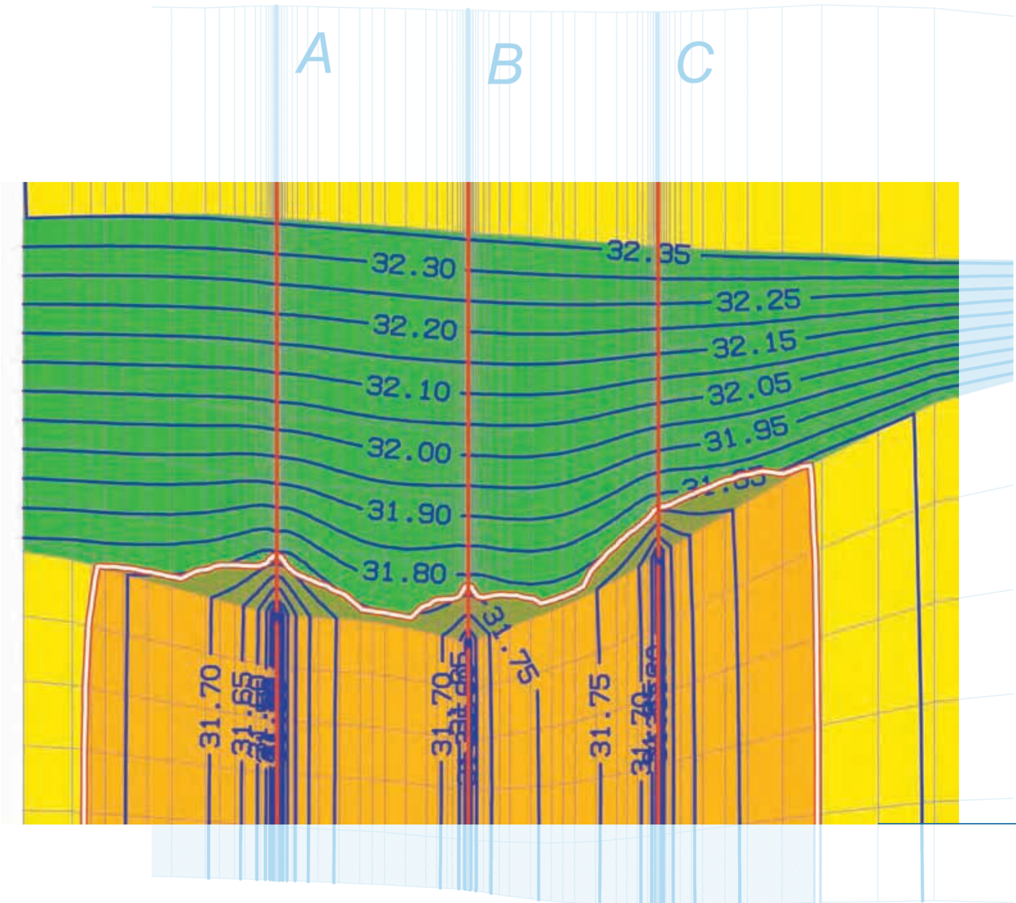
Determination of Catchment Areas

Transport calculations with inverted flow.

The calculation of contaminant transport utilising the inverted flow field allows the accurate determination of catchment areas under consideration of advective and dispersive-/diffusive- processes.
The applied methodology allows calculating the probability of a water particle arriving in an abstraction borehole or surface water. While conventional methods of velocity tracing do only partially (if at all) allow to reflect local heterogeneities, **SPRING's** dispersive term technique enables an accurate representation thereof.



Determined catchment areas
„50 day-area“



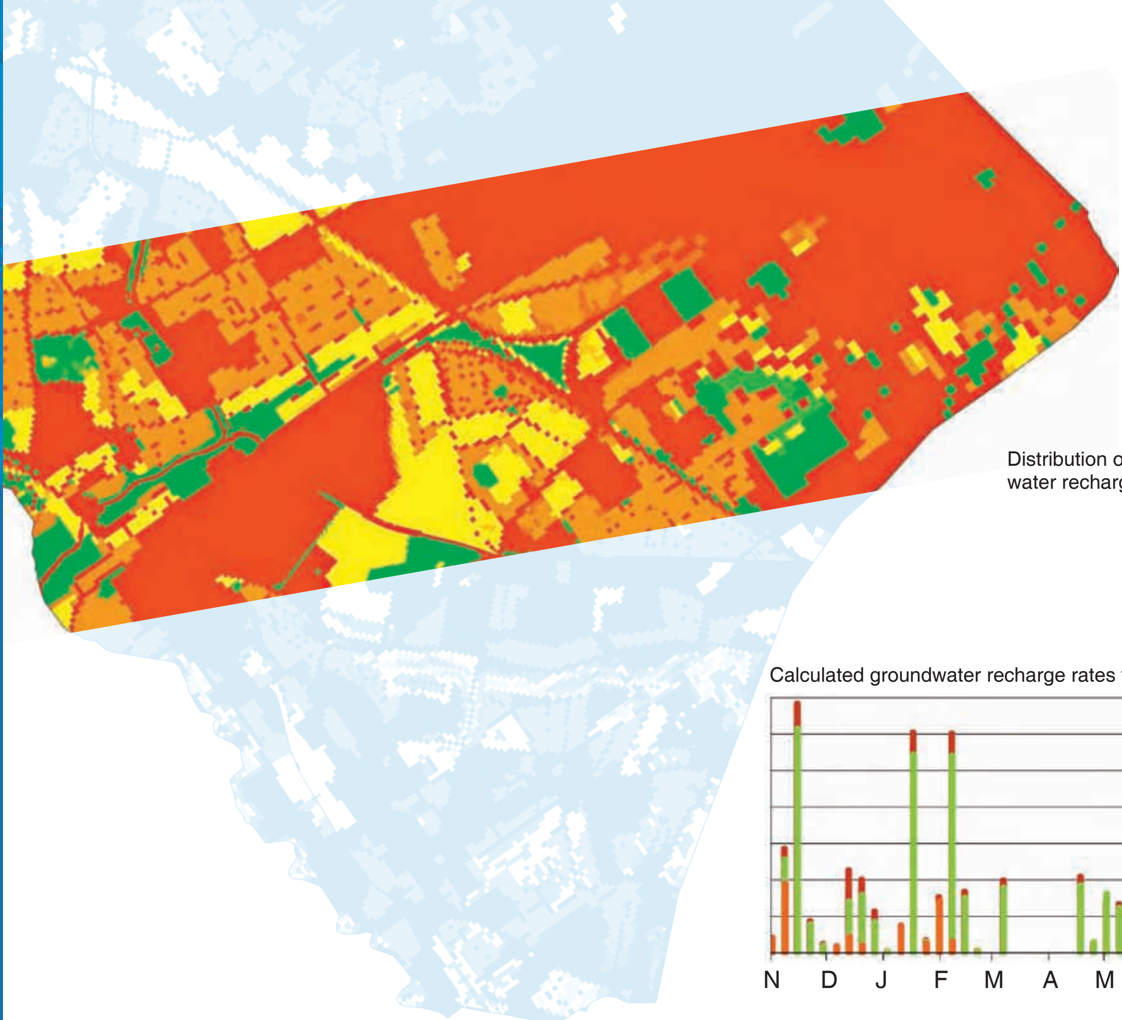
Cross section: Determined catchment areas
„50 day-area“
Aquifer
Aquiutard

Determination of groundwater recharge rates

Groundwater recharge rates

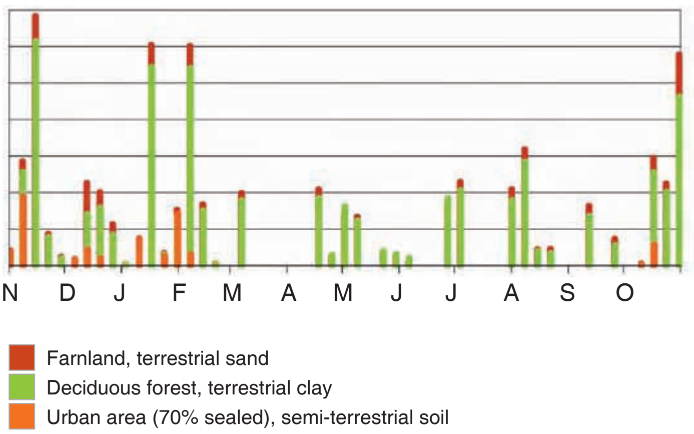
Groundwater recharge is a sensitive and significant parameter for any model calibration, which therefore requires special attention. **SPRING** offers a variety of approaches and methodologies to calculate stationary (steady-state) or transient groundwater recharge rates.

After definition of the input parameter – depending on the chosen method e.g. precipitation, climatic zone, soil type, land use or sealed surface area – the corresponding program module calculates the spatial and/or temporal distribution of groundwater recharge for the entire model domain or selected areas/zones.



Distribution of calculated average groundwater recharge rates.

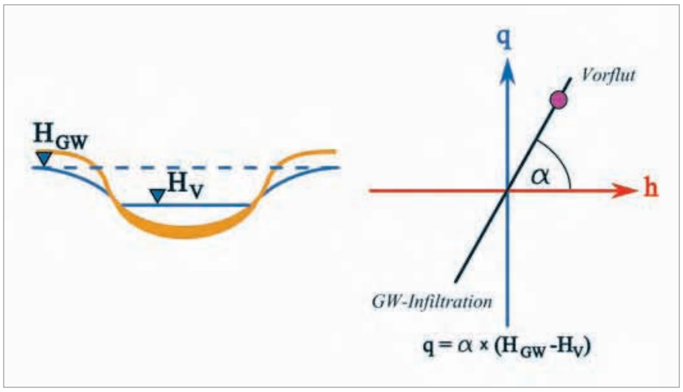
Calculated groundwater recharge rates for a zone (table).



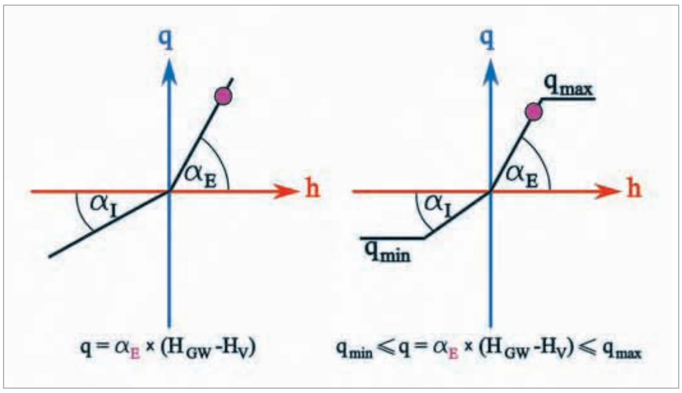
Surface-groundwater interaction

Surface-groundwater interaction via a leakage approach

SPRING determines the interaction between surface and groundwater using water levels and leakage coefficients. Additional parameter like the ratio of in-/ex-filtration capacity, limitations on minimal or maximum exchange volumes as well as the detachment of surface water bodies can be optionally considered to allow a more detailed description of the interaction.



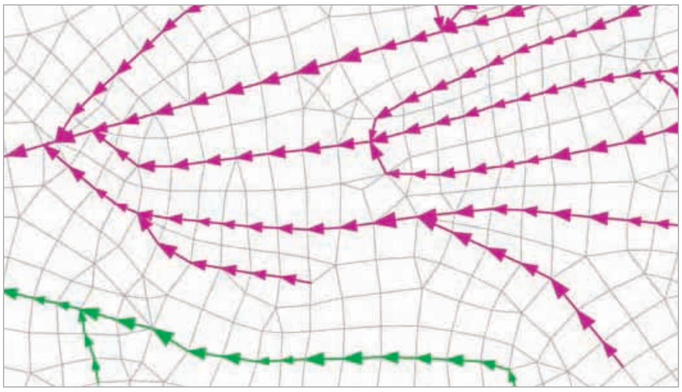
Parameterisation of surface-groundwater interaction using water levels and leakage coefficients.



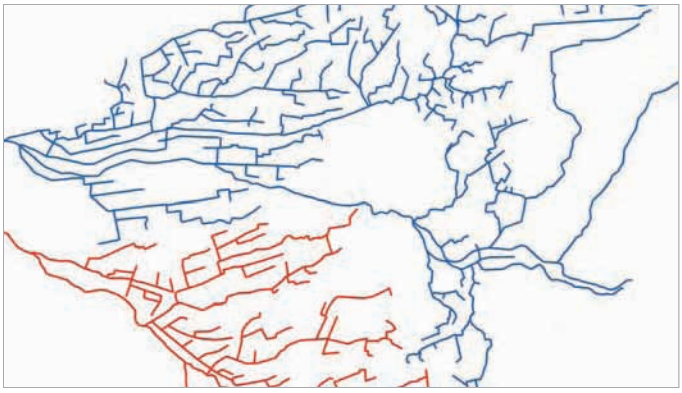
Calculation of leakage effects under consideration of ex- and infiltration ratios (left) and limitation of exchange volumes (right).

Coupling of ground and surface water flows

Using integrated waterway linkage (surface water coupling) **SPRING** allows yield balancing of exchange volumes between surface and groundwater. The approach limits the seepage volume for dry and non-perennial surface water stretches to the volume of water entering the stretch from upstream water courses or external discharges.

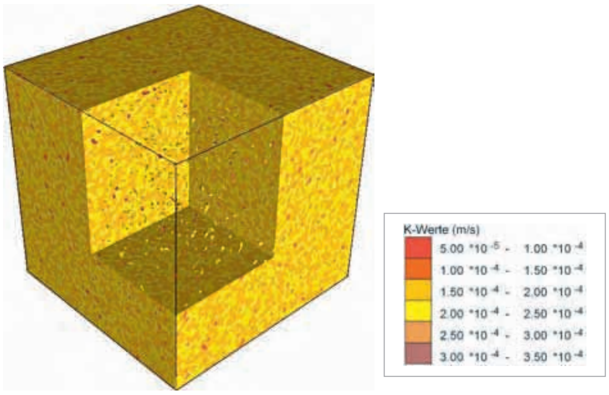


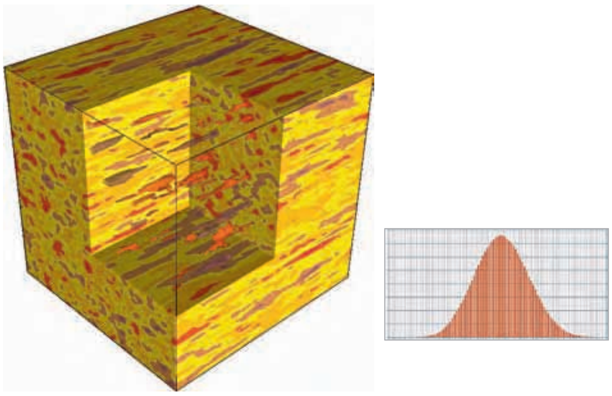
Automatic determination/checking of flow direction.



Automatic coupling of surface water branches/stretches.

Parameterisation options





Stochastic parameterisation

SPRING allows the stochastic generation of spatially correlated or non-correlated input parameters like hydraulic conductivity.

1. Stochastic generation of (spatially uncorrelated) data:

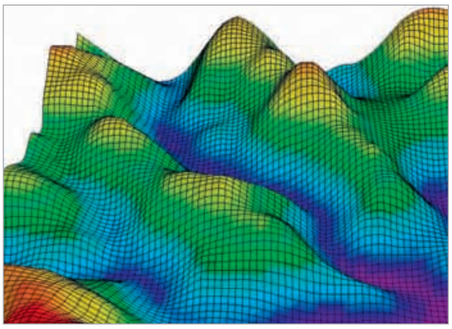
Stochastically generated parameter (following a defined function) are assigned to all or individual nodes respectively elements of a layer.

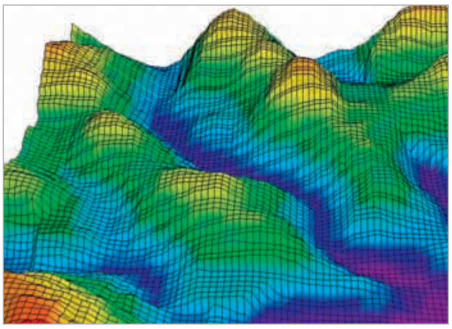
2. Stochastic generation of spatially correlated data:

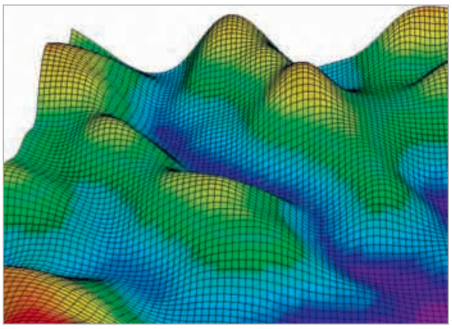
Spatially correlated data are generated using a “turning-band” algorithm (exponential approach). The interpolation accounts for the similarity of data as a function of their proximity and spatial correlation lengths may vary in three dimensions.

Interpolation of attributes

Following the mesh generation, geological, hydraulic and hydrologic data, which are in the best case only known locally or for limited areas, are entered. Flexible and customisable geostatistical, global and local interpolation functions interpolate attributes to nodes or elements of the model mesh beyond the known and defined areas.
A wizard allows parameterisation using adjustable geostatistical global and local interpolation functions.


Gauß´s interpolation


Inverse distance weighting (IDW)

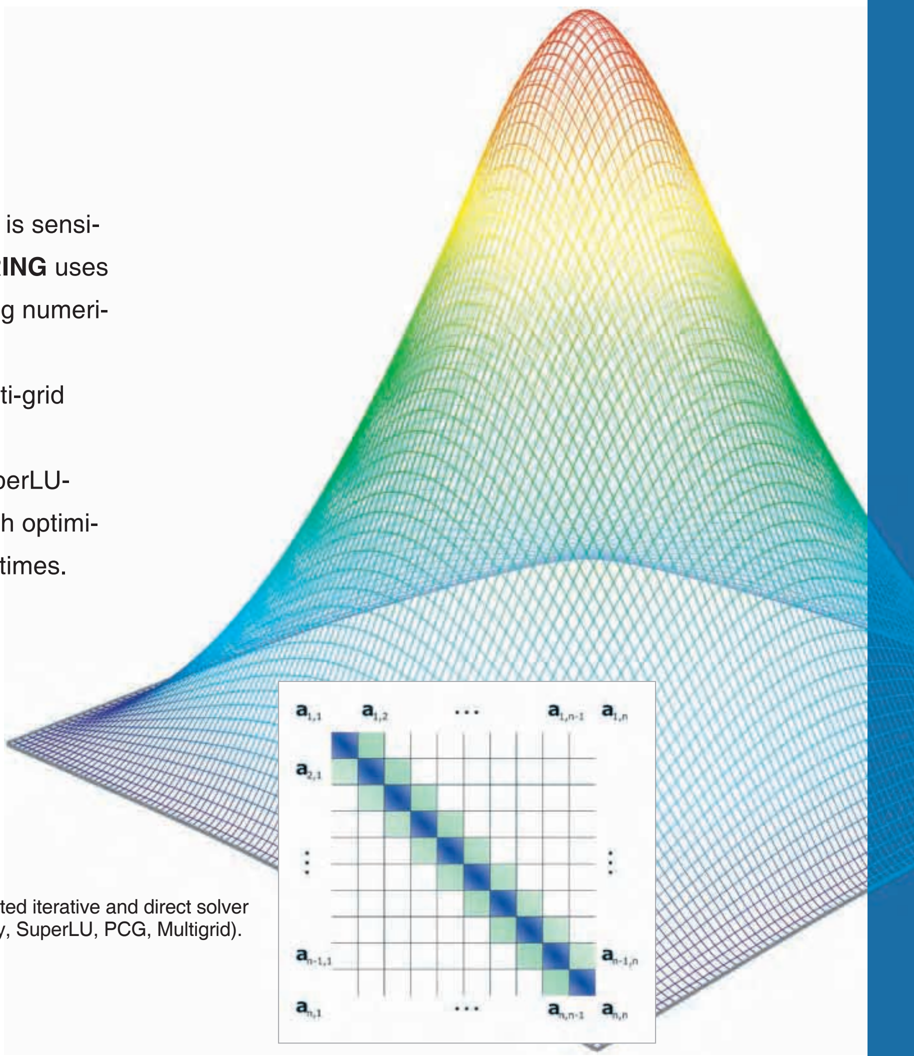

Kriging

Interpolation points

Numeric engine and hardware

Solver

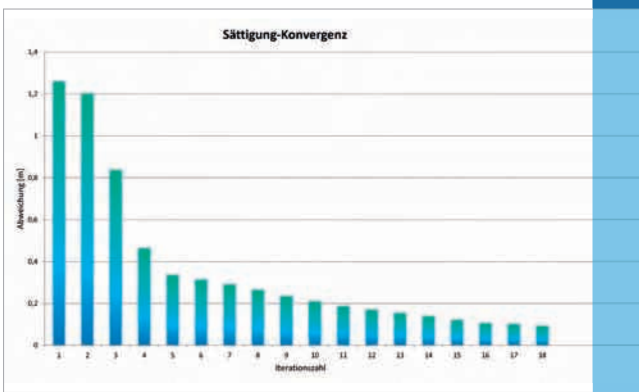
Numeric modelling of flow and transport processes is sensitive to discretisation and boundary conditions. **SPRING** uses solvers which are efficient and fast, with outstanding numerical stability.
CG-solvers with special pre-conditioning and a multi-grid solver are available for iterative solutions.
Available direct solvers use the “Cholesky-” or “SuperLU-algorithm” along with a specially adjusted bandwidth optimisation for efficient CPU usage and fast processing times.



Task-related iterative and direct solver (Cholesky, SuperLU, PCG, Multigrid).

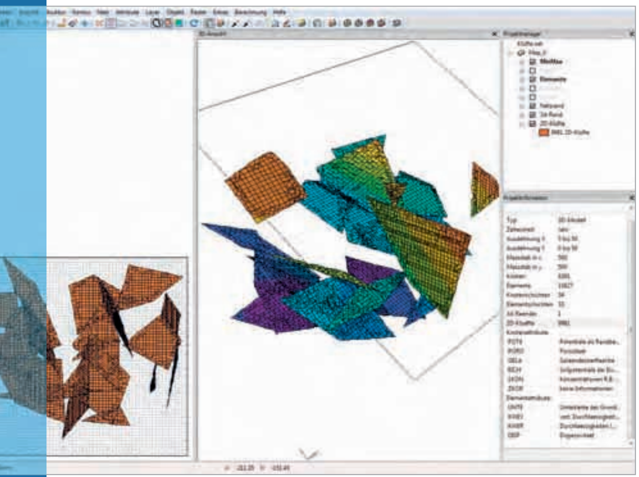
64-Bit support

The latest version of **SPRING** software is available for the 64-bit operating systems Microsoft Windows (Vista x64, Windows 7 x64) and Linux (e.g. SUSE x64, OpenSUSE x64), ensuring wide and efficient application of professional groundwater models with an essentially unlimited number of nodes.

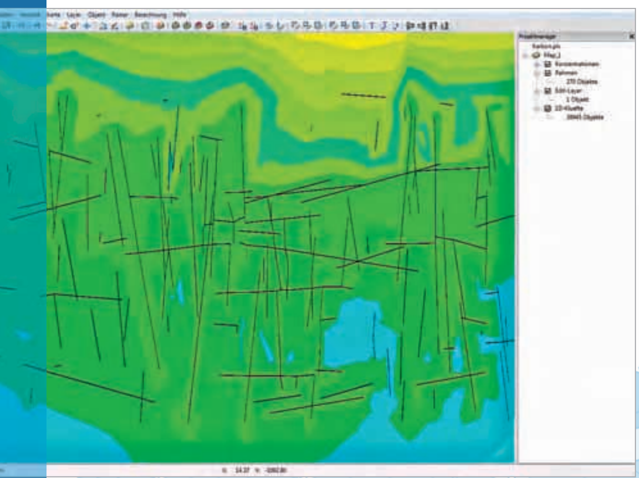


Convergence of saturation.

Additional specialised applications



Visualisation of fractures.

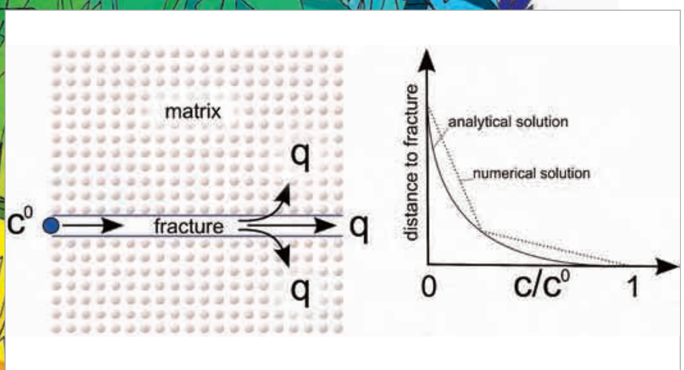


Contaminant transport in a fractured aquifer.

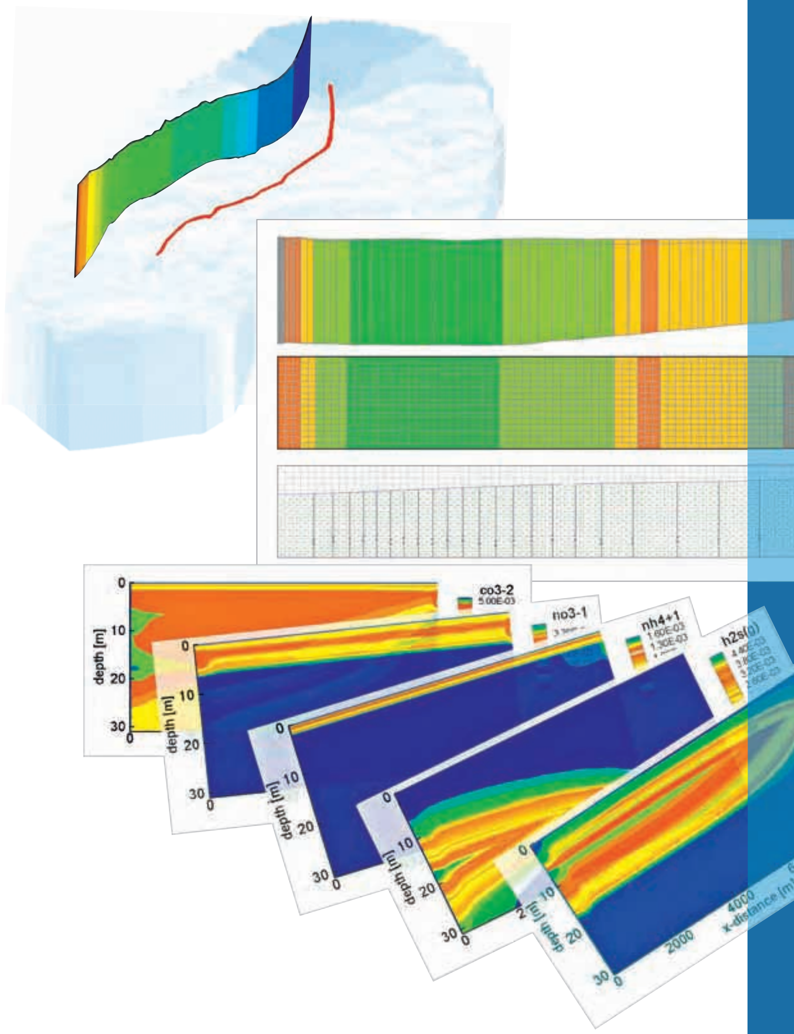
Stochastic generation of discrete fractures and faults

As a result of high flow velocities, fractures and faults are the dominant transport pathways for contaminant and heat transport in fractured rocks. **SPRING** uses matrix diffusion to couple the fast advective transport in the fractures and faults with the slow diffusive transport of solutes in the surrounding rock matrix.

SPRING offers a specialised function for the stochastic generation of discrete fractures. All fracture specific flow and transport processes are integrated into the model, and unlimited numbers of lithological layers with different fracture properties can be combined.



Additional specialised applications



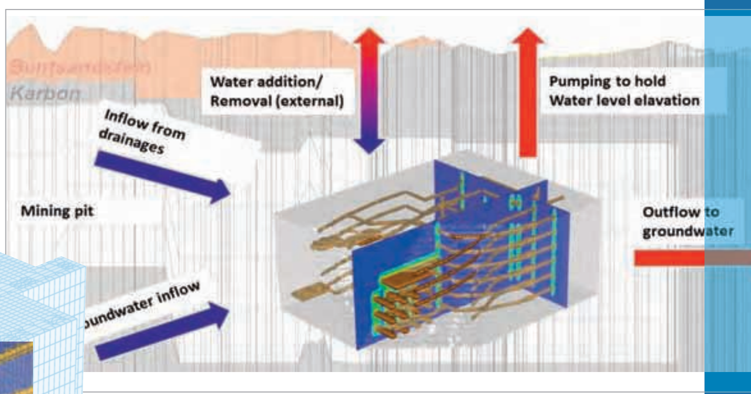
Reactive contaminant transport

SPRING offers an interface to the software program MIN3P to enable modelling of reactive contaminant transport in the unsaturated zone.

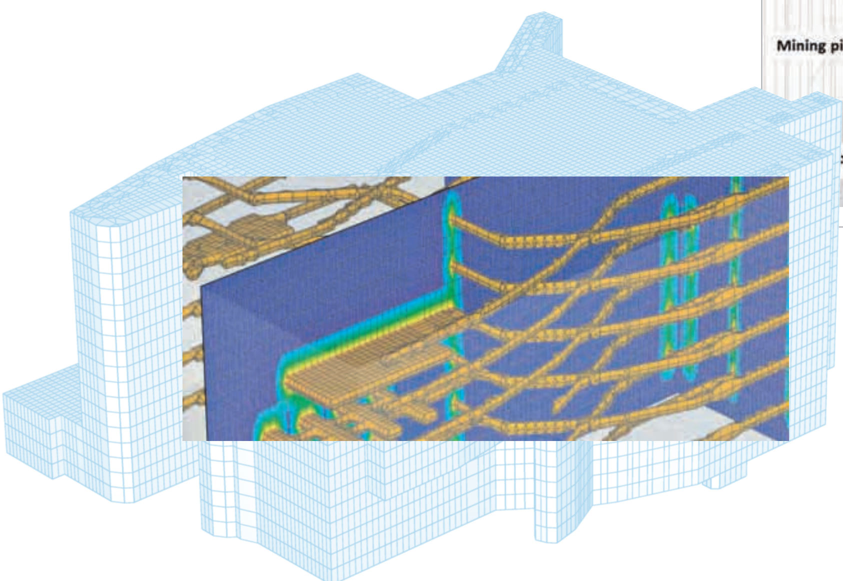
Example
1. Extraction of a vertical cross-section from a 3D-flow model
2. Transferring the vertical cross-section into MIN3P (Mayer 2010)
3. Geochemical reaction model
4. Calculation of reactive contaminant transport for a non-conservative solute within the aquifer
5. Modelling results

Mine flooding

The simulation of rebounding water tables in (for example) mine flooding problems poses special challenges to numerical models, which must accurately account for the physical interaction between the flooded voids and the surrounding aquifer. **SPRING** offers an integrated, powerful box-model for these problems, allowing simple and accurate parameterisation of flooded voids.



Simulation of mine and lake flooding using SPRING's integrated box model.

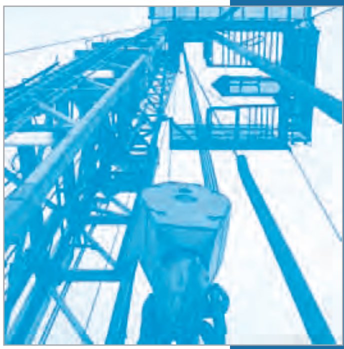


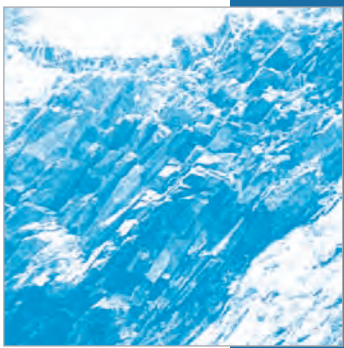
We are here for you!

Any questions regarding SPRING or specialised applications of the software?

Do you require individual training or advice?

Our team is ready to assist!





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