DHI WASY Software Training

Groundwater Modelling with FEFLOW 7.1

DHI Group

- Independent, self-governing not-for-profit research and consultancy organization
- Builds competence and promotes technological development relevant to water environments
- Total staff about 1200
DHI WASY

- Formerly
  - WASY Gesellschaft für Wasserwirtschaftliche Planung und Systemforschung mbH, founded in 1990
  - DHI Wasser und Umwelt GmbH, German branch of DHI Group, founded 2004
- Merged into DHI WASY GmbH in 2007
- About 85 permanent staff members in: Berlin (headquarter), Bremen, Hamburg, Munich
- Areas
  - Consulting
  - Software Solutions
  - Software Products

Groundwater Modelling Centre

- Specialized porous media simulation expertise within the DHI Group

- Staff: 10 people

- Three closely integrated main activities:
  - FEFLOW Development
  - FEFLOW Services
  - Groundwater Consulting
GMC – Groundwater Modelling Centre

“Internationally renowned scientists, software specialists and consulting professionals: The DHI Groundwater Modelling Centre (GMC) is designed to take up groundwater-modelling projects beyond the average — in all environments, in all countries”

Consultants GMC

<table>
<thead>
<tr>
<th>Abr.</th>
<th>Name</th>
<th>Remark</th>
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<tbody>
<tr>
<td>JLU</td>
<td>Junfeng Luo</td>
<td>Senior hydrogeologist, FEFLOW since more than 25 years, expert for density dependent flow, mining, capture zone analyses, Chinese</td>
</tr>
<tr>
<td>KEU</td>
<td>Katja Eulitz</td>
<td>Senior hydrogeologist, Groundwater modelling since 2001, expert for geological structural models, mining, groundwater flooding, capture zone analyses, Russian moderate</td>
</tr>
<tr>
<td>AKZ</td>
<td>Anna Zabel</td>
<td>Project Manager, experience in FEFLOW since 2011, Support and ACADEMY experience, also surface water capabilities, Portuguese, Spanish moderate</td>
</tr>
<tr>
<td>PSC</td>
<td>Peter Schützl</td>
<td>Global BAM porous media, geothermal applications, plug-in solutions, training, Spanish moderate</td>
</tr>
<tr>
<td>BMO</td>
<td>Bertram Manninkhoff</td>
<td>Senior Civil Engineer, BAM Groundwater Germany, FEFLOW since 1996, expert for coupled systems, plug-in solutions, Dutch</td>
</tr>
<tr>
<td>ARE</td>
<td>Alex Renz</td>
<td>Senior Engineer, expert for mine water management, stochastic and data-driven modelling, uncertainty analysis and machine learning, FEFLOW since more than 10 years.</td>
</tr>
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## Additional Experts GMC

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Name</th>
<th>Remark</th>
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<tbody>
<tr>
<td>BOK</td>
<td>Björn Kaiser</td>
<td>Support Team, density-dependent flow, geothermal applications, training, visualization</td>
</tr>
<tr>
<td>CVI</td>
<td>Carlos Rivera</td>
<td>Head of Support Team, automatic calibration and uncertainty analysis (PEST), unsaturated flow, mining, reactive transport, training, plug-in solutions, Spanish</td>
</tr>
<tr>
<td>PAK</td>
<td>Patrick Keilholz</td>
<td>BD-Team, expert for integrated water management, MIKE SHE, expert for arid regions</td>
</tr>
<tr>
<td>FJC</td>
<td>Fabien Comaton</td>
<td>Head of FEFLOW development, coupled interfaces, French, Spanish</td>
</tr>
<tr>
<td>JMR</td>
<td>Julia Mayer</td>
<td>Director Sales &amp; Support, Head of ACADEMY, unsaturated flow, French / Hebrew moderate</td>
</tr>
</tbody>
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## FEFLOW – More than Groundwater

More than „just“ groundwater:
- Subsurface Flow and Transport

FEFLOW handles groundwater flow and related processes in one software environment and one simulation model:
- Variably saturated flow
- Contaminant transport
- Heat transport
- Density-affected flow
- Chemical reactions
- And more...
FEFLOW – More than Groundwater

The software must be ...
- Easy-to-use and intuitive to quickly master everyday groundwater projects
- Powerful and comprehensive to model complex subsurface processes

Fields of Application
- Regional groundwater management
- Mine-water management
- Simulation of open-pit progress
- Groundwater management in construction and tunneling
- Geothermal energy (deep and near surface, both open-loop and closed-loop systems)
- Remediation / natural attenuation
- Seepage through dams and levees
- Groundwater – surface water interaction
- Capture-zone delineation and risk assessment
- Saltwater intrusion
- Industrial porous materials
- ... and many more
Flexible Meshes

- Finite Differences vs. Finite Elements

Flexible Meshing

- Triangular or quad elements (2D)
- Prisms, cuboids, tetrahedron (3D)
- 3D or 2D horizontal / vertical / axisymmetric projection
- 1D and 2D for fracture / pipe / borehole flow
Finite-Element Mesh Type Library

2D Model Projections

Horizontal projection

Vertical projection

Axisymmetric projection
Flexible Meshing

3D Geometry

...allows detailed models of complex geometrical structures

Temporal Element Deactivation

- Elements of the finite-element mesh can be temporarily deactivated and reactivated.
- Simulation of time-varying model domain geometry (e.g. open-pit simulation projects, long-term morphological changes, etc.).
Physics

Groundwater and vadose-zone flow
- Saturated flow (Darcy law)
- Unconfined conditions (different approaches)
- Unsaturated / variably saturated flow (Richards equation)
- Fracture flow
- Density- and viscosity-dependent flow

Physics

Transport
- Heat transport (advection-conduction equation)
- Solute transport (advection-diffusion equation)
- Groundwater age
- Combined solute/heat/age transport
- Sorption, decay
- Multispecies simulation
- Kinetic reaction systems
Ease of Use

- User interface for preprocessing, simulation, and postprocessing
- GIS/CAD/ASCII/Excel/Access interfaces for import and export
- 2D/3D map support
- Database support (ESRI, Oracle, PostgreSQL)
- Geological models (LeapFrog, GeoModeller, GOCAD)
- Advanced computational methods
  - Powerful mesh generators
  - Automatic time-stepping scheme
  - Algebraic multigrid solver
  - Parallelization

Visualization

- 2D top / cross-section / data-trace views
- 3D views
- 2D / 3D map support
- 3D clipping and carving
- Live, interactive visualization during simulation run
- Hardware acceleration via OpenGL
- 3D stereoscopic display/projector support
FePEST: Parameter Estimation with PEST

- Interface between FEFLOW and PEST
- Part of FEFLOW installation
- Calibration, optimisation, predictive analysis and sensitivity analysis
- Latest versions of PEST.exe and PLPROC.exe accessible
- Features:
  - Pilot-point method
  - Constant values within specified zones
  - 2D and 3D models
  - Steady state and transient models Tikhonov regularization, SVD, SVD-Assist
  - Parallel optimisation (BeoPEST)

Corporate Licenses

- Arbitrary number of FEFLOW instances possible for the same model (identical mesh and problem class) with only one license seat
- Running FEFLOW on remote servers
- Licenses accessible via network
- Benefits:
  - No additional costs for optimization / sensitivity analysis
  - Simultaneous editing of multiple scenarios of the same model
FEFLOW Viewer

- Free (no license required)
- Works with existing FEFLOW models
- Model and results files
- Visualization and analysis
- Export of figures and animations
- Use by modeler
  - No license necessary for postprocessing
  - Share your model with colleagues even if licenses are limited
- Use by consulting clients
  - No need to purchase an additional license
  - Deliver viewable model files to customers

Extensibility

- Open programming interface
  - Documented API interface
  - User can develop plug-ins for
    - Additional functionality
    - Workflow automation
- Application Examples
  - Groundwater / surface-water coupling
  - Integration of technical installations in geothermal modeling
  - Import of model properties
  - Export of model results
- Development Services
  - Plug-in development as a consulting service
User Support

• We help by
  o Giving advice on FEFLOW modeling
  o Analyzing possible model improvements
  o Explaining theoretical background and functionality

• In addition, we offer:
  o Training courses
  o Solutions
  o Software customization
  o Consulting in modeling projects
  o Model reviews

FEFLOW Services
- Support
- Training
- Plug-in solutions

Why FEFLOW

• Highly scalable software package
  o Different feature levels available

• Commercial software
  o DHI guarantees consistent services
  o Close contact to support staff
  o Software performance benchmarked and documented
  o Quality assurance
  o Ongoing development
Documentation

- Installation Guide and Demonstration Exercise
- User Manual
- FEFLOW Book
- White Papers Vol. I-V
- Help System

All manuals are available as pdf on the FEFLOW DVD (*.pdf) or for download on [www.feflow.com](http://www.feflow.com).

Licensing and Maintenance

Licensed via HASP hardware dongle and license manager software NetLM

- License types:
  - F2 2D flow
  - FM2 2D flow, mass and age transport
  - F3 2D/3D flow
  - FM3 2D/3D flow, mass and age transport
  - FH3 2D/3D flow and heat transport
  - FMH3 2D/3D flow, mass, age and heat transport
- Personal, Corporate or Subscription licenses
- License includes 1 year maintenance
- Research discounts and lab kits available