Key Features in Groundwater Simulation Codes

FEFLOW® is offered in *six* feature levels:

Symbol	Hierarchical level of feature extent	FEFLOW license ident
⓪	Flow 2D	F2
①	⓪ + Mass 2D	FM2
②	① + Heat 2D + Flow 3D	F3
③	② + Mass 3D	FM3
④	② + Heat 3D	FH3
⑤	③ + Heat 3D	FMH3

Any level includes all the features of all lower levels. Accordingly, license pricing increases with feature level. Symbols indicate the lowest level at which the respective feature is available. For example, the symbol ② denotes features that are available at levels ②, ③, ④ and ⑤. Features available at *all* levels are indicated by the symbol ⓪.

1 Basics

	FEFLOW
Integrated pre- and postprocessing	⓪
Interactive graphics	⓪
Data interfacing to GIS	⓪
Data interfacing to CAD	⓪
Programming interface (C, C++)	⓪
No internal software limits	⓪
Microsoft windows platforms	⓪
LINUX/UNIX platforms	⓪
64-bit technology	⓪

2 Physics

	FEFLOW
Darcy fluid flow in porous media	⓪
Variably saturated porous media	⓪
Free surface (phreatic) flow	⓪
Single-species mass transport	①
Multi-species reactive mass transport	①
Multi-phase flow and transport	
Heat (nonisothermal) transport	②
Variable-density transport	①
Thermohaline flow	②
Multi-diffusive convection	①

Key Features in Groundwater Simulation Codes

2 *Continued from* Physics

	FEFLOW
Fracture flow	0
Fracture mass transport	1
Fracture heat transport	2
Transient problems	0
Steady problems	0

3 Mathematics

	FEFLOW
Finite element method (FEM)	0
Finite difference method (FDM)	
Finite volume method (FVM)	
Discrete feature elements (fracs)	0
Adaptive time stepping (ATS)	0
Adaptive mesh refinement (AMR)	0

4 Dimensions

	FEFLOW
Three dimensions (3D)	2
Quasi three dimensions (Q3)	
Two-dimensional vertical plane (2V)	0
Two-dimensional horizontal plane (2H)	0

4 *Continued from* Dimensions

	FEFLOW
Axisymmetric (meridional) plane (2X)	0
One dimension (1D)	

5 Meshing

	FEFLOW
Prismatic elements in 3D	2
Tetrahedral elements in 3D	
Unstructured triangular meshes	0
Structured quadrilateral meshes	0
Delaunay meshes	0
Using add-ins in mesh generation	0
Refinement techniques	0
Derefinement (encoarsening) techniques	0
Node movement	0
Element edge flipping	0
Element deletion	0
Mesh reflection	0
Mesh coordinates transformation	0
Moving mesh for 3D free-surface problems	2

Key Features in Groundwater Simulation Codes

6 Maps

	FEFLOW
Loading background maps	⓪
Use maps for mesh design	⓪
Joining maps for direct data assignment	⓪
Use maps in 3D drawings	⓪

7 Data Support

	FEFLOW
Direct Read of Vector Data	
ESRI Shapefiles	⓪
ESRI coverages	⓪
ASCII	⓪
Internal binary interchange format (PLX)	⓪
Direct Read of CAD Data	
AutoCAD DXF	⓪
Direct Read of Raster Data	
Tagged image file format (TIFF)	⓪
JPEG file interchange format (JFIF)	
Exporting Vector Data	
ESRI Shapefiles	⓪
ASCII	⓪

7 *Continued from* Data Support

	FEFLOW
Internal binary interchange format (PLX)	⓪
Exporting CAD Data	
AutoCAD DXF	⓪
Exporting Raster Data	
ESRI ASCII grids	⓪
Surfer grids	⓪

8 Data Management

	FEFLOW
Direct linkage to dBase IV tables	⓪
Direct linkage to ASCII tables	⓪
Direct linkage to ESRI INFO databases	⓪

9 Data Regionalization

	FEFLOW
Akima interpolation	⓪
Inverse distance weighting (IDW)	⓪
Kriging	⓪
Customized data mapping techniques	⓪
Polygon-related regionalization (joining)	⓪

Key Features in Groundwater Simulation Codes

9 *Continued from* Data

	FEFLOW
Interpolation of time-varying 1D functions	0
Interpolation of time-varying 2D functions	0

10 Editing

	FEFLOW
Geometry Construction Tools Including	
Point-and-click location with mouse	0
X, Y coordinate input with mouse	0
Snap to vertex, endpoint, or along the edge	0
Undo/redo operations	0
Assign edges as parabolic segments	0
Assign edges as circular segments	0
Move, rotate, split, delete, copy, and paste operations	0
Intersection of two segments	0
Auto-close for polygons	0
Attribute Data Assigning Tools for Initial, Boundary and Material Conditions Including	
Mouse selection	0
Data mapping (regionalization)	0
Tools for data exploring and retrieval	0

10 *Continued from* Editing

	FEFLOW
Time-varying databases for 1D curves and 2D distributions	0
Copy, joining and debug operations	0
Data inheritance in mesh enrichment and layer (re-)configuration	0
Trimming layer thicknesses and distances	0

11 Boundary Conditions

	FEFLOW
Dirichlet-type	0
Neumann-type	0
Cauchy-type (leakage)	0
Well-type	0
All boundary conditions can be transient	0
All boundary conditions can be constrained	0
Specific Boundary Conditions	
Hydraulic head	0
Pressure	0
Seepage face	0
Saltwater head	1
Saturation	0
Moisture content	0

Key Features in Groundwater Simulation Codes

11 *Continued from* Boundary

	FEFLOW
Integral flux	2
Free drainage	0
Multi-layer well (well bore condition)	2
Borehole heat exchanger (BHE)	4
Total mass flux	1
Total heat flux	2
Dispersive mass flux	1
Conductive heat flux	2

12 Boundary Constraints

	FEFLOW
Neumann constraint for Dirichlet-type	0
Dirichlet constraint for Neumann-type	0
Neumann constraint for Cauchy-type	0
Dirichlet constraint for Cauchy-type	0
Dirichlet constraint well-type	0
All constraints can be transient	0

13 Material Data (General)

	FEFLOW
Time-constant distributions	0
Time-variable distributions	0
User-defined formula for sink/source relationships	0
Anisotropy of hydraulic conductivity in 2D	0
Axis-parallel anisotropy of hydraulic conductivity in 3D	2
Layer-oriented anisotropy of hydraulic conductivity in 3D	2
General (full) anisotropy of hydraulic conductivity in 3D	2
Anisotropy factor of solid heat conductivity in 3D	4

14 Unsaturated Material Data

	FEFLOW
Empirical Laws for Capillary Pressure and Relative Conductivity Relations	
van Genuchten - Mualem (α-*n* params)	0
van Genuchten - modified (α-*n*-*m* params) with regularization	0
Splines (cubic; monotonic, non-monotonic)	0
Brooks - Corey	0
Haverkamp	0
Exponential	0

14 *Continued from* Unsaturated

	FEFLOW
Linear	0
Hysteresis	0

15 Model Options for Variably Saturated Flow Problems

	FEFLOW
Standard Richards equation	0
Mixed (saturation-pressure) formulation	0
Primary variable substitution (switching)	0
Picard method	0
Newton method	0
Residual error control	0
Kirchhoff integral transformation in steady-state	0
Gravity direction setting	0

16 Free Surface (Phreatic) Conditions

	FEFLOW
Unconfined aquifers	0
Confined aquifers	0

16 *Continued from* Free Surface (Phreatic) Conditions

	FEFLOW
Moving (adaptive) mesh strategy	2
Fixed mesh strategy	2
Multiple free surfaces (perched water)	2
Control of partially-saturated cells/elements by a linear relation of the cell filling height	2
Control of dry cells/elements by a residual pseudo-saturation	2
Control of dry cells/elements by deletion	

17 Fracture Elements

	FEFLOW
Flow Laws	
Darcy	0
Hagen-Poiseuille	0
Manning-Strickler	0
Pipes (1D)	0
Faces (2D)	2
Horizontally placed	0
Vertically placed	2
Arbitrarily placed in 3D	
Variable-density flow and transport	1

Key Features in Groundwater Simulation Codes

17 *Continued from* Fracture Elements

	FEFLOW
Extended Oberbeck-Boussinesq approximation	1

18 Chemical Reactions

	FEFLOW
Equilibrium reaction (sorption)	
Henry	1
Freundlich	1
Langmuir	1
Nonequilibrium reaction	
1st order linear decay	1
Michaelis-Menten	1
Decay chains	1
Multi-species reaction kinetics	
Degradation	1
Arrhenius	1
Monod	1
User-specified type with an interactive **reaction kinetics editor** FEMATHED: Freely editable reactions using a fast formula interpreter, including conditional expressions	1

19 Variable Fluid Density

	FEFLOW
Default Oberbeck-Boussinesq approximation	1
Extended Oberbeck-Boussinesq approximation	1
Constant expansion	1
Variable (higher-order) expansion	2
Gravity direction setting	1
Viscosity dependency	1
User-defined formula for viscosity relationships	1
Non-Fickian (high-concentration) mass flux	1
Consistent velocity approximation	1
Variable fluid density in fractures	1

20 Time Stepping Methods

	FEFLOW
Constant time steps (user-predefined)	0
Variable time steps (user-predefined)	0
Adaptive error-controlled time steps	0
Implicit in time	0
Explicit in time	
Mixed, 2nd-order scheme (Crank-Nicolson)	0
Time step modifiers (maximum, increase limits)	0

Key Features in Groundwater Simulation Codes

21 Numerical Stabilization

	FEFLOW
Upstream weighting (unsaturated problems)	0
Streamline upwinding (SU)	1
Full upwinding (FU)	1
Shock capturing (SC)	1
Petrov-Galerkin least-square upwinding (PGLS)	1

22 Sparse Matrix Equation Solvers

	FEFLOW
Preconditioned conjugate gradient method (PCG)	0
Algebraic multigrid (AMG) with OMP extension	0
Restarted orthogonalization-minimization method (ORTHOMIN)	0
Restarted generalized minimal residual method (GMRES)	0
Conjugate gradient square method (CGS)	0
Bi-conjugate gradient stable method (BiCGSTAB)	0
Postconditioned bi-conjugate gradient stable method (BiCGSTABP)	0
Direct Gaussian equation solvers	0

22 *Continued from* Sparse Matrix Equation Solvers

	FEFLOW
Solver parameter settings (stop criteria, maximum iteration numbers, etc.)	0

23 Parallel Computing

	FEFLOW
Supports hyper-threading in processor units	0
Supports multiprocessor multicore hardware systems	0

24 Particle Tracking

	FEFLOW
Stationary	0
Transient	0
Isochrones	0
2D	0
3D	2
Forward	0
Backward	0
Methods	

24 Continued from Particle Tracking

	FEFLOW
Pollock	0
4th-order Runge-Kutta	0
Relevant area of influence (RAI)	2

25 Resulting Data Evaluation Tools

	FEFLOW
Diagrams for observation points and wells	0
Diagrams for balanced flux quantities	0
2D graphics	0
3D graphics	2
Budget analysis	0
Fluid flux analysis	0
Content analysis (volume, mass, energy)	0
Spatial operations (differences)	0
Temporal operations (difference, deviation, cumulative changes)	0
Creating 2D cross-sectional models from 3D	2
Reverse flow field analysis	0
Legend editing	0
Diagram editing	0

25 Continued from Resulting Data Evaluation Tools

	FEFLOW
Scatter plots for spatial and temporal data	0

26 Resulting Data Graphics

	FEFLOW
Isoline contouring (2D)	0
Isoline contouring (3D)	2
Fringes (2D)	0
Fringes (3D)	2
Vector plotting (2D)	0
Vector plotting (3D)	2
Visualization of vector fields by texture transport (2D)	
Visualization of vector fields by texture transport (3D)	
Pathlines (2D)	0
Pathlines (3D)	2
Isochrones (2D)	0
Isochrones (3D)	2
Streamlines (2D)	0
Isosurfaces (3D)	2
Cutting (3D)	2

26 *Continued from* Resulting Data

	FEFLOW
Map overlay (3D)	❷
Fences and cross-sections (3D)	❷
Animation, video creation (2D)	⓿
Animation, video creation (3D)	❷

27 Interface Modules

	FEFLOW
Parameter estimator (PEST), steady and unsteady	⓿
Coupling with the surface water model MIKE11†) (unsteady groundwater - river network simulation)	⓿

†) requires extra license