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Information for Customers and Interested Persons

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Editorial

FEFLOW in a Generational Change

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Director of GMC

*This issue of DHI-WASY Aktuell exclusively focuses on FEFLOW, our finite-element simulation system for 3D and 2D flow, mass and heat transport in porous and fractured media. We are announcing the beginning of a new generation of FEFLOW, called **FEFLOW 6**. It delivers a compelling advancement in what modelers in the field of groundwater and porous media have, until now, only envisioned – best-in-class simulation capabilities assembled into a comprehensive and flexible simulation environment. FEFLOW 6 is a notable milestone in FEFLOW's 30-year history. FEFLOW was born in 1979 as a fragile and modest child, made its first steps in an academic well-sheltered kindergarten, grew continuously and became autonomous and successful in business. It was a development that required many hands and contributions. However, the advancements of FEFLOW notwithstanding, the journey is not (perhaps will never be) complete. To address the modeling challenges on the horizon, DHI-WASY will continue to reinvest in development and research and to explore new technologies for FEFLOW. In providing FEFLOW 6, we feel suitably prepared to cope with the future challenges in subsurface and porous media modeling. The future begins now.*

Content

FEFLOW 6

A New Working Environment

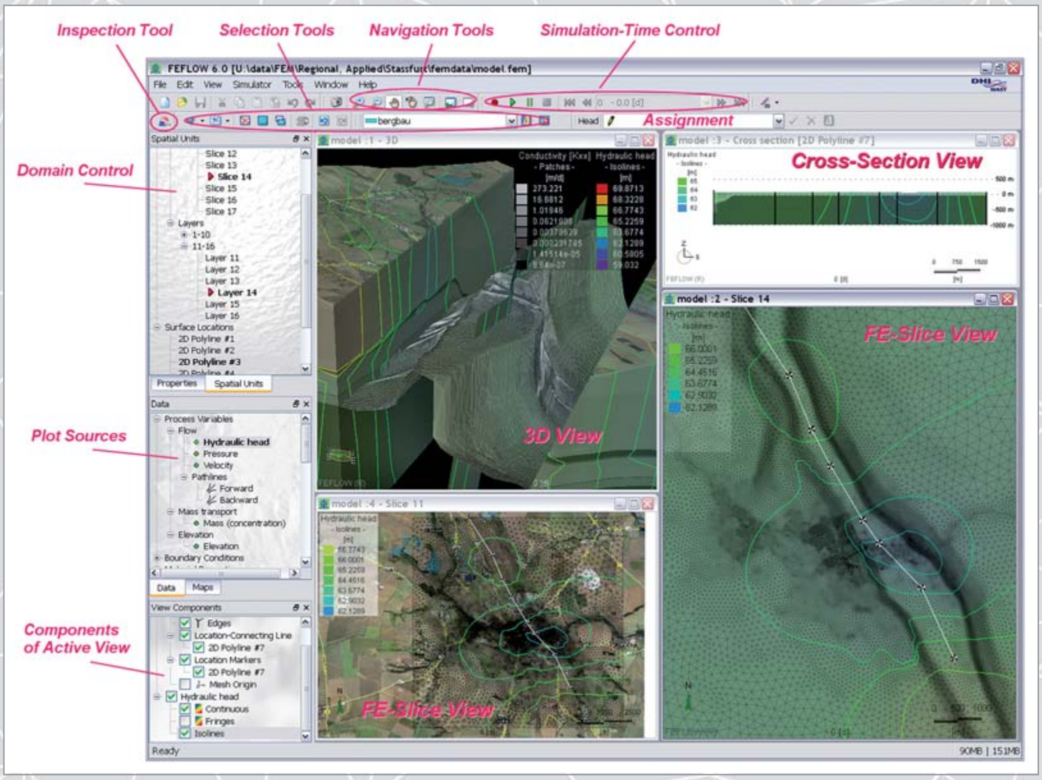


Fig. 1: The FEFLOW 6 user interface with multiple simultaneous views of the model

Volker Clausnitzer

One, perhaps the essential, motivation for the development of FEFLOW has been to facilitate efficient iterations of the modeling cycle from model set-up to simulation to visual and quantitative output of the results. It is probably fair to say that, in the process, FEFLOW pioneered the fully integrated graphical user interface for subsurface modeling software. Over the course of three decades, its computation capabilities have evolved to allow successful application to an increasing variety of problems. This is true in terms of physical processes as well as concerning the spatial and temporal scales, now spanning a range from millimeters to several hundred kilometers, and from fractions of a second to thousands of years, respectively.

Along the way, a persisting tenet has been to "keep the simulation honest" between input and output: Given a particular discretization, an oscillating solution may just be a mathematical consequence and will in such a case indeed be shown, foregoing any hidden internal fudging (really, changing) of user-specified input or intermediate results aimed at "nice-looking" results. While well-defined smoothing methods are available in FEFLOW, they are subject to user control and never invoked by default. This still applies fully to the most recent release, FEFLOW 6. Utilizing current GUI toolkit and graphics technology, FEFLOW 6 does however represent a break with the FEFLOW appearance that has become familiar to many users over the years. The likely most striking contrast in the user interface reflects the change away from a strictly hierarchical menu structure implying a serial workflow with a comparatively fixed sequence of operations. Instead, the new design keeps all functionality accessible whenever possible to ensure maximum flexibility and efficiency for the user.

Essentially, FEFLOW 6 gives the modeler more degrees of freedom together with the accompanying means of control. Figure 1 shows an example layout of the user interface with the basic toolbars (labeled on top), the key control panels (labeled on the left), and a set of views showing different aspects of the current state of the model. The docking feature of toolbars and panels makes the user interface truly customizable.

Another, less apparent yet fundamental change with respect to all previous FEFLOW versions is found in the workflow philosophy itself: the selection process has been completely separated from any assignment (or other model-modifying) operation. Specifically, element or node selections can be created by using any one, or a combination, of the available selection tools, including various mouse tools and intersection of map polygons. At any time, the current (volatile) selection can be made persistent (internally stored) for later use. All assignments or modifications are automatically directed at the current selection of nodes or elements. Changes in the model state due to user input or simulation progress are immediately reflected by all open views in which the respective parameter has been activated for plotting.

Besides a **Supermesh view** for supermesh design, there are three types of window for finite-element problems:

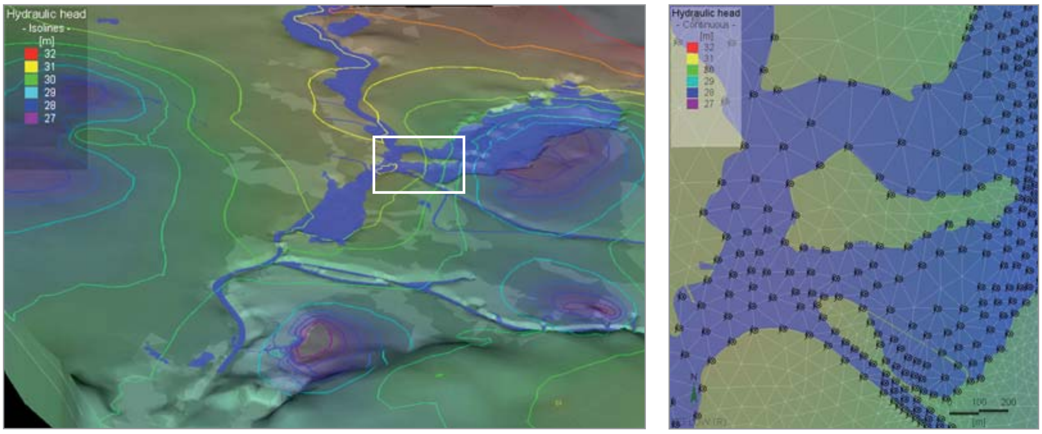


Fig. 2: Surface-water bodies and their representation as map and boundary conditions

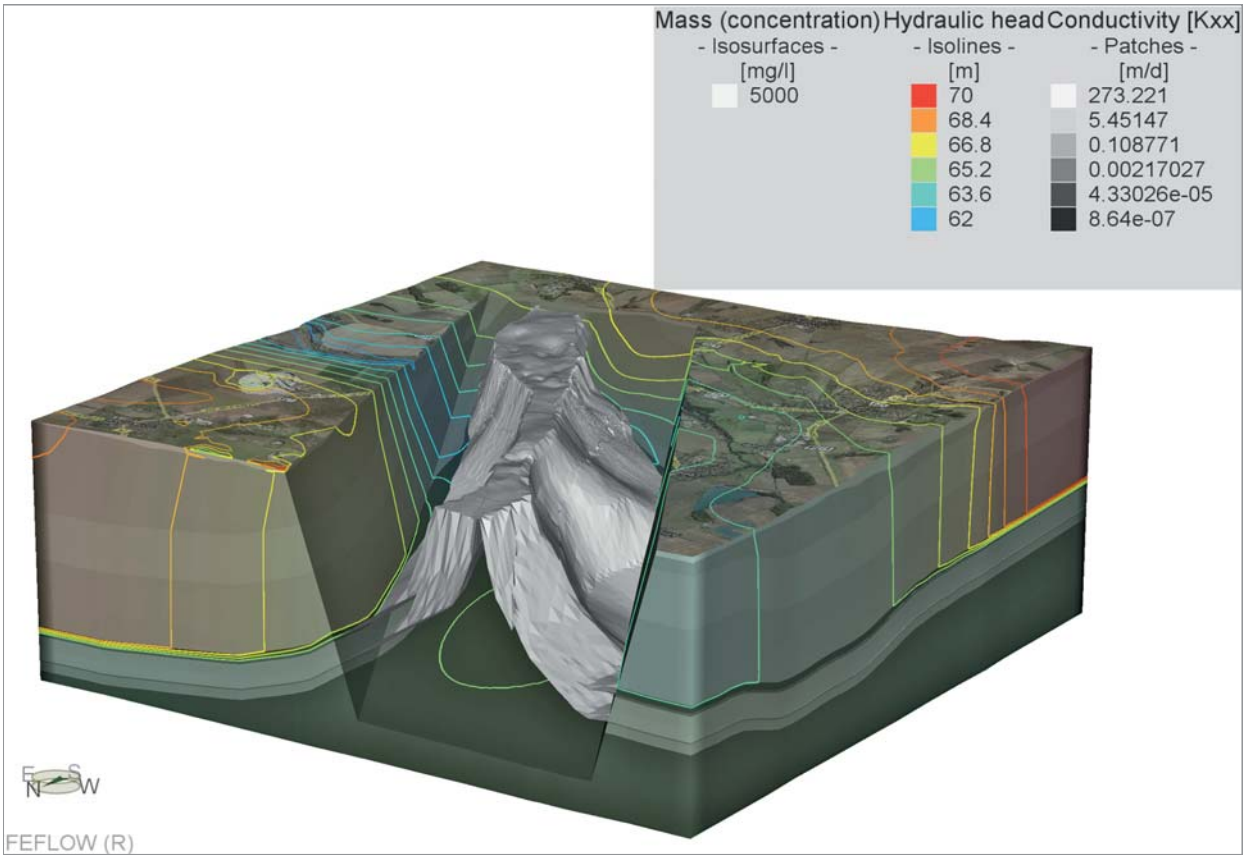


Fig. 3: A combination of data plots on a partially carved-out model domain (salt diapir in a sedimentary basin, 5x vertical exaggeration)

- **FE-slice view**, showing a 2D representation of a particular slice of the FE-mesh (a more flexible version of the main working area known from previous versions)
- **Cross-section view** for vertical, multi-segmented cross-sections of three-dimensional FE-problems
- **3D view** for three-dimensional FE-problems

The new capability of multiple simultaneous views of the same problem will benefit both model set-up and visualization of results. For example, several views of the vicinity of a cross-sectional line are shown in Figure 1, together with a view of the corresponding vertical cross section itself. Figure 2 presents plots of surface water bodies as surface maps in 3D and 2D views, the latter also showing a representation of the associated boundary conditions. While view-related memory is dynamically released whenever appropriate, a practical limit on the number of simultaneous views possible will be imposed by the available RAM on a given workstation.

Full mouse- and panel-controlled navigation is available in all view-window types, including zooming in or out at a particular point (all view types), panning (all view types), and rotation (2D in FE-slice views, 3D in 3D-views). Notably, the view windows remain interactive and their settings accessible even during simulation computations. The **mesh inspector**, trusted companion through many FEFLOW releases, has been augmented by a sensitivity to element- and node-assigned data in 3D views.

As the plots of hydraulic conductivity, head isolines and a solute-concentration isosurface in Figure 3 illustrate, multiple parameters can be represented in the same view by choosing contrasting color sequences and different plotting styles. Element-based (material) parameters are always shown as noninterpolated patches while nodal scalar data can be plotted either in a continuously interpolated manner or at user-specified levels as fringes or as isolines/isosurfaces.

Velocity fields (nodal vector data) require representation of both direction and magnitude. Magnitude alone can be plotted similar to any other scalar parameter. The standard 2D and 3D arrow plots use arrow length to express magnitude (Figure 4). In addition, FEFLOW 6 provides a vector plot style that avoids arrow heads and instead indicates direction by increasing opacity, and a bullets style that represents magnitude by color rather than size and is thus especially useful for the visualization of low-velocity regions (Figure 5). As an alternative to vector plotting, pathlines provide spatial and travel-time information for virtual particles released at user-specified locations (Figure 6).

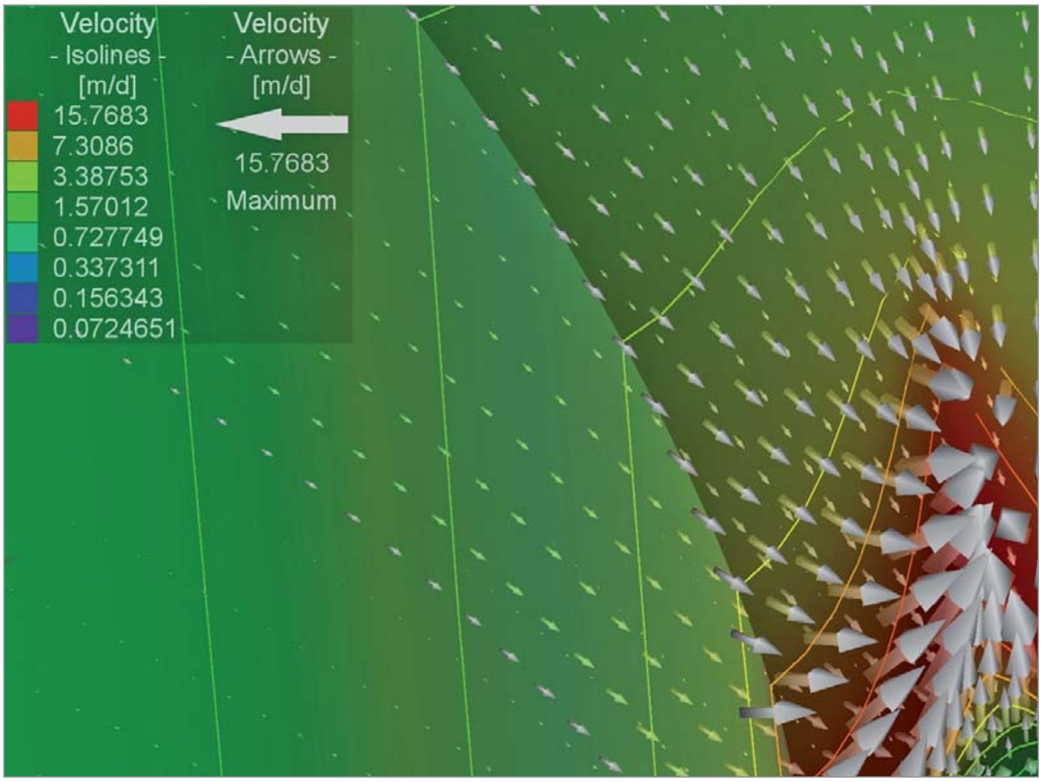
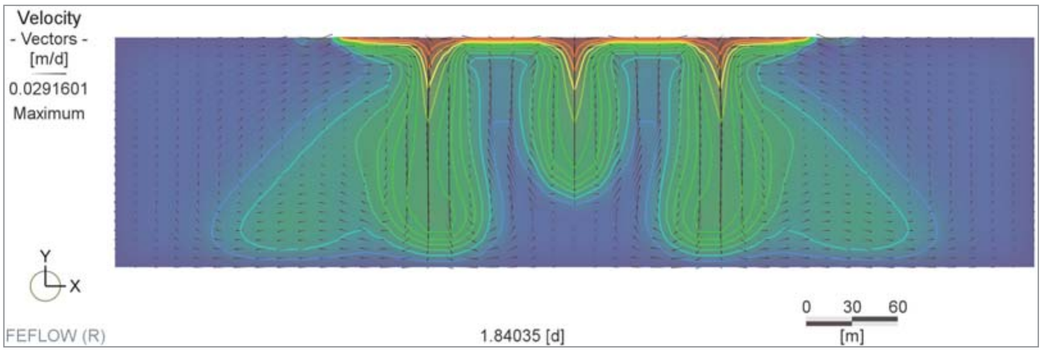


Fig. 4: Three-dimensional velocity-field visualization via arrows and translucent color plots



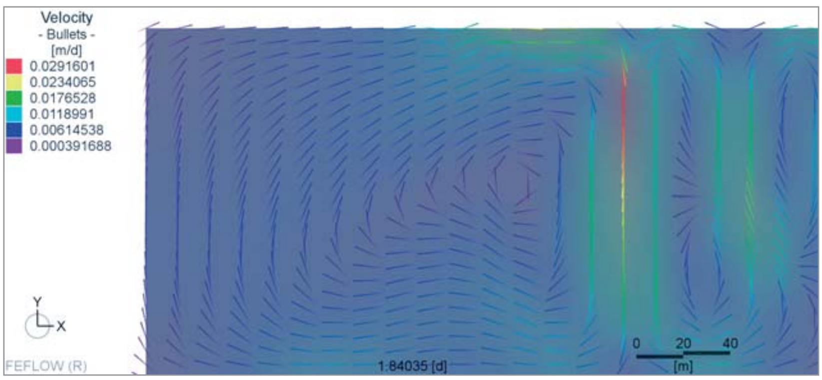
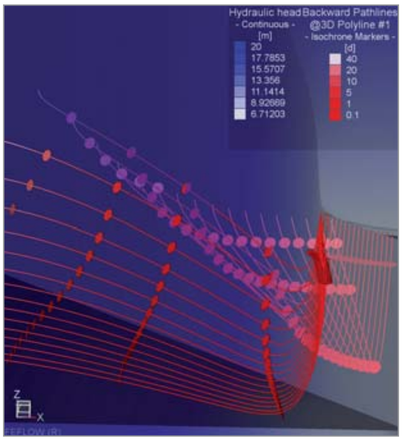


Fig. 5: Velocity-field visualization for the two-dimensional Elder problem via vector lines (top) and bullets (bottom)

Flexible and powerful means of visualization require effective control of the various view components, especially in a 3D view where any individual slice and layer can potentially be shown together with cross sections, isosurface plots and the possibly clipped or carved model domain. A dedicated tree control makes all individual components of a view window accessible. Individual properties such as colors, opacity, plot ranges and isolevels are controlled via property panels. Since all settings of each open view are stored together with the finite-element problem, identical views will be restored the next time the respective problem file is opened.



While individual data plots can be exported as scalable vector graphics for use in external plotting software, there is also the possibility to obtain "snapshots" of a complete view window where all view components are rendered at a user-specified resolution up to pixel numbers that are suitable for poster printing.

Fig. 6: Pathlines and isochrone markers

The FEFLOW 6 Architecture

Rainer Gründler

In the transition from manual to industrial software development, the software architecture of an application achieves a special importance. Monolithic applications such as FEFLOW 5.4 (2009), which has more than two million instructions are being replaced by framework applications with mainly reusable components that communicate only via well-defined interfaces – either directly in memory or via standard communication networks. This way, several coworkers can be coordinated independently for fixed subtasks.

The design of components and their communication, both among themselves and in relationship with the framework application, plays a central role. Apart from proprietary protocols there exist a number of market-established standards that pursue different priorities. With respect to the special demands of FEFLOW regarding performance and memory management, standard architectures are only conditionally suitable. A compromise had to be found that ensures reliability of components but also preserves the freedom for the programmers to influence code generation and control of memory release. It is a major development goal to be able to handle and solve finite-element models with meshes containing up to 10^7 nodes on standard desktop computers. This can be realized only by employing 64-bit technology and parallel processing (multi-threading).

Up to Version 5.x, FEFLOW was a monolithic application with closely intertwined simulation kernel and graphical user interface (GUI). This strong coupling comes with a number of major disadvantages:

- A graphical environment (X11) must be active to perform simulations even in batch mode.
- The program startup time is dominated by the GUI.
- Maintenance of the program code is complicated.
- Time-consuming training and multi-field ability required for new co-programmers.

The design of FEFLOW 6 strictly separates numerical code (simulation kernel) and accompanying code (GUI and tools). Based on a set of interfaces, different clients can use the kernel for obtaining/modifying model data and/or performing simulations. On local machines, the data are shared completely in memory so that any overhead is avoided.

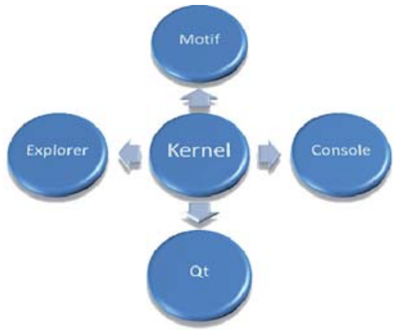


Fig. 1: FEFLOW kernel based client applications

Currently, four different clients are implemented on top of the FEFLOW kernel service:

- X11/Motif based GUI – compatible with FEFLOW 5.x. Stable version – no major development.
- Qt-based GUI – new multi-window application. Main target platform for development.
- Console client – graphicless, text-only simulation framework. Python interpreter to be included in near-term future releases.
- FEFLOW Explorer – Microsoft Foundation Classes (MFC) based visualization client.

Additionally, specialized client applications for customers with limited user interaction can be easily created and maintained.

The FEFLOW kernel interfaces are designed for speed and effectiveness to handle very large models comfortably and with excellent performance. The encapsulation of the data transfer between clients and kernel allows automated marshalling, a fundamental prerequisite so that in a future version client applications and the FEFLOW kernel may run on different computers. This way, a distributed FEFLOW version can be realized by providing only some additional marshalling and proxy code but without changing the source code of either client applications or simulation kernel.

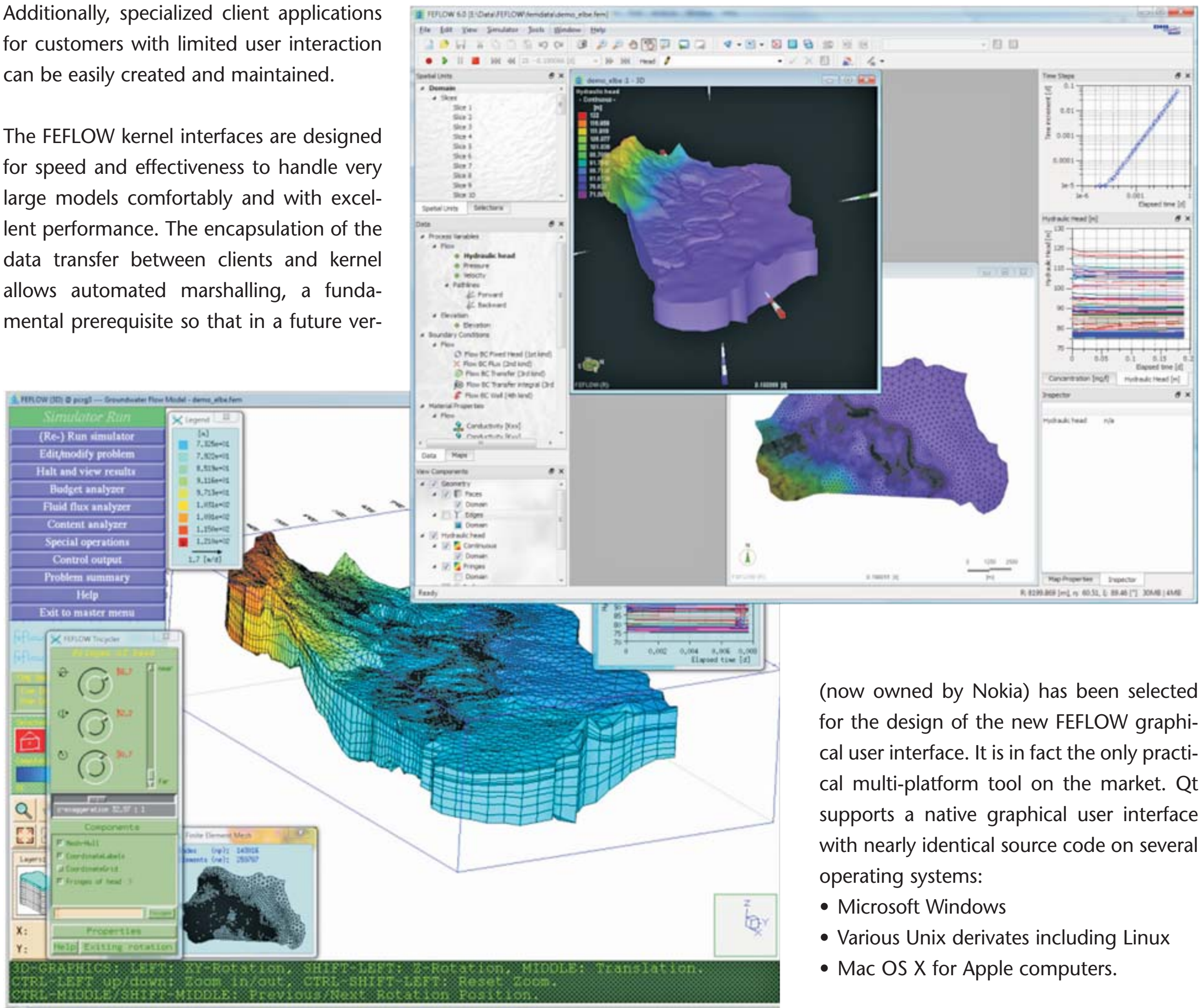


Fig. 2: Qt versus Motif based GUI

Given the raw simulator functionality of the new FEFLOW kernel, the integration of FEFLOW into combined and complex modeling packages becomes much easier. FEFLOW must no longer take the controller or master role but it can also run in slave mode. Public interfaces, such as OpenMI, can be easily implemented to complement the optimized internal FEFLOW interfaces.

Graphical User Interface based on Qt Toolkit

The graphical user interface of FEFLOW 5.x was subject to technical restrictions of the OSF/Motif standard. In particular, the following drawbacks motivated the development of a replacement:

- Missing modern GUI elements such as tree views, lists views with multiple columns, splitter windows, combo boxes, among other controls. No multi-document architecture (MDI).
- OSF/Motif has remained quasi-unchanged for more than 15 years and therefore looks accordingly “old-fashioned”. No support for “themed” controls.
- Unusual look and feel on Microsoft Windows platforms (file selection, etc.)
- Difficult internationalization and native-language support.
- Under Windows: dependent on an X-server as third-party product.

After a thorough evaluation period, the Qt toolkit of the Norwegian company Trolltech (now owned by Nokia) has been selected for the design of the new FEFLOW graphical user interface. It is in fact the only practical multi-platform tool on the market. Qt supports a native graphical user interface with nearly identical source code on several operating systems:

- Microsoft Windows
- Various Unix derivates including Linux
- Mac OS X for Apple computers.

Besides the multi-platform feature, the seamless integration of the 3D standard OpenGL was essential for the toolkit decision. Qt stores dialogs and other graphical resources in XML files, which implies good portability for future versions. HTML help, printing and internationalization support are also integrated in the toolkit.

The revised design incorporates dockable control elements and profits especially from flexible (and multiple, if desired) view windows that allowing simultaneous editing and monitoring of model data in multiple layers, particularly directly in 3D.

Model-View-Controller architecture

In contrast to previous (Motif-based) versions, the FEFLOW 6 design follows the Model-View-Controller (MVC) principle, which is essentially state-of-the-art in modern applications. This architecture strictly separates data retention and processing (model) from data visualization (view) and user interaction (controller).

This approach allows multiple views for a model, e.g., 2D and 3D views, as well as shared tools for data manipulation.

Selection-Operation paradigm

FEFLOW 6 introduces a new general workflow for editing parameters. First, nodes or elements have to be selected by one of, or a combination of several methods. These include single, rubberbox, polygon, lasso, border, map selection, or selection by a logical expression. Selections can be extended or shrunk by logical operations, such as union or intersection, and stored under a unique name. Based on a current selection

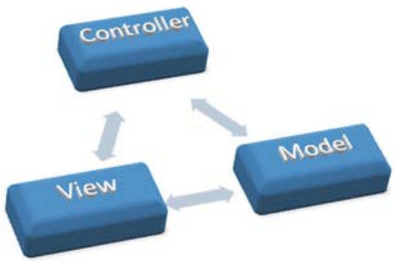


Fig. 3: Model-View-Controller architecture

it is possible to assign values from different sources, such as constant values, time series, lookup values, or mathematical expressions, or to perform other operations such as mesh refinement/derefinement or pathline computation. Since each selection method can be combined with any kind of operation FEFLOW 6 offers much more editing capabilities than any previous version.

Multi-threading

The new FEFLOW version uses multi-threading not only in the simulation kernel but also in the graphical user interface. By means of background processing the GUI remains responsive even during time-consuming tasks such as mesh generation or simulation run. This implies that the data model and its parameters can be analyzed even during simulation.

Multi-threading is also used to improve the performance of GUI-related tasks, such as parameter assignment, regionalization, map import, and also to accelerate the drawing routines. With these capabilities, very large models can be handled comfortably.

30 Years of FEFLOW

A Brief Historical Review

Hans-Jörg G. Diersch

The year 2009 marks the 30th anniversary of FEFLOW; the finite-element simulation system for 3D and 2D flow, mass and heat transport in porous and fractured media. It should give us the opportunity to reflect the history of its development in the preceding three decades. It started in a time when finite elements represented a recent and innovative modeling technology, which began to penetrate tentatively the flow modeling community with first single applications even in subsurface problems. So, FEFLOW was born at early days when finite elements were entering the field of groundwater and porous media worldwide. From the humble beginning as a simple one-man FORTRAN IV 2D program without any graphical features FEFLOW was continuously and independently developed and extended over a highly dynamic period characterized by innovations in computational methods and a revolution in hardware and information technologies. Today, FEFLOW wears a much different face compared to 1979. It has been established worldwide as a leading commercial software for modeling porous and fractured media. FEFLOW is at work in many companies, universities and research institutions around the globe. The benefits of deploying FEFLOW are obvious: applications in shorter times at higher quality and comprehension, and in an improved competitiveness. For FEFLOW customer success rests on providing a high-quality product that is easy to use, technically advanced, multiplatform-capable, compatible, and open to customization.

Predecessor

In 1973-1975 I developed the FINEL finite-element program termed for computing free-surface two-dimensional and axisymmetric potential flow at the department of hydrodynamics of the Technical University of Dresden, Germany, as part of my Ph. D. thesis. Bi-quadratic triangular elements were applied with a substructuring technique to reduce the effective number of equations to be solved. FINEL was able to compute up to 3,600 unknowns on a 32K-word mainframe computer equipped with punchcard input and hardcopy printed output. Applications referred to inviscid free-surface flows under sluice gates, over spillways and through valves. First attempts were performed to extend FINEL to steady-state advective and conductive heat transport in lakes.

The Very Beginning 1979

At the Research Centre for Soil Fertility of Müncheberg (Germany) I firstly turned to groundwater flow and mass transport and believed that porous media problems would only present an intermediate episode in my life. As a natural extension to potential flows, the FINEL programming framework was expanded for groundwater flow and mass transport applied to steady-state and transient 2D and axisymmetric problems. This groundwater extension required a new name, FEFLOW. The choice of the name was inspired by my basic intention of developing a general-purpose **finite-element** analysis program for a family of **flow** problems ranging from potential flow via groundwater flow up to Navier-Stokes flow. At the end, the plan stopped in the middle at porous media problems which have proven so manyfold, rich in details and attractive in many applications. However, the name FEFLOW has remained

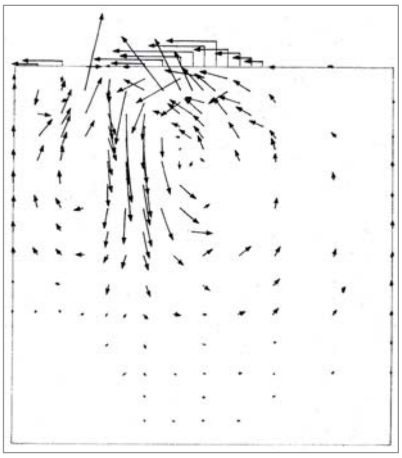
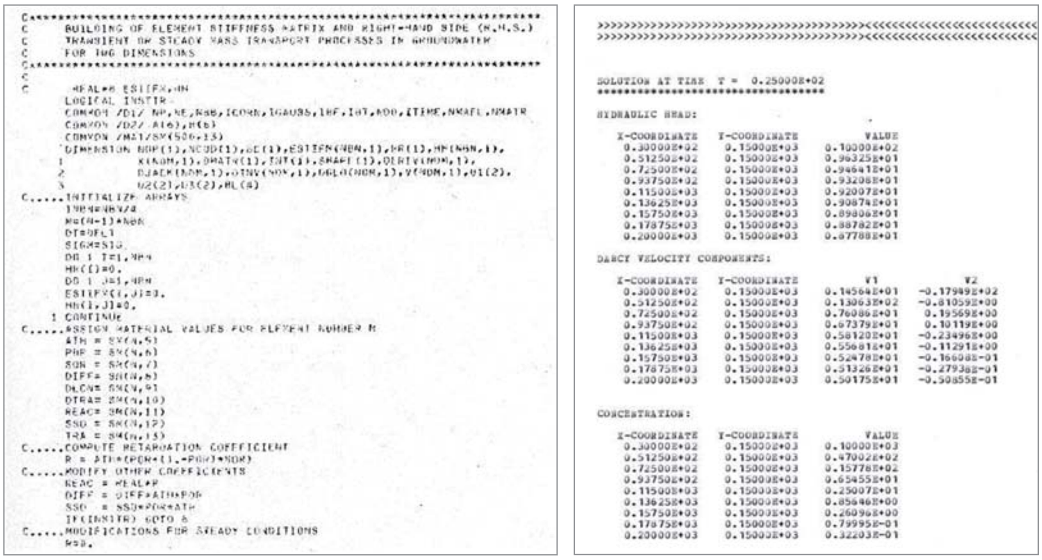


Fig. 1: Hand-plotted velocity field of the Elder problem, year 1980 (published in ZAMM 1981). Basically pencil drawn with ruler on millimeter paper and subsequently repainted by ink on parchment paper.

since. The first "official" reference to FEFLOW was in 1979 at a groundwater conference (Simulation of coupled transport, exchange and reaction processes in soil and groundwater) held at the Technical University of Dresden. At that time FEFLOW already provided an extended finite-element library (quadrilaterals and triangles of linear, quadratic or cubic type) and was able to compute transient groundwater flow and transport problems. Effort in modeling density-coupled problems was initiated.



```
C***********************************************************************
C     BUILDING OF ELEMENT STIFFNESS MATRIX AND RIGHT-HAND SIDE (R.H.S.)
C     TRANSIENT OR STEADY MASS TRANSPORT PROCESSES IN GROUNDWATER
C     FOR TWO DIMENSIONS
C***********************************************************************
C
C      REAL*8 ESTIFX,HN
      LOGICAL INSTIR
      COMMON /D1/ NP,NE,NBB,ICORN,IGAUSS,IHF,IHT,KOD,ITIME,NMATL,NMATR
      COMMON /D2/ A(6),H(6)
      COMMON /MA1/SM(506,13)
      DIMENSION NOP(1),NCOD(1),SE(1),ESTIFN(NBN,1),HR(1),HP(NBN,1),
     1          X(NOM,1),DMATR(1),INT(1),SHAPE(1),DERIV(NOM,1),
     2          DJACK(NOM,1),DINV(NOM,1),DGLO(NOM,1),V(NOM,1),U1(2),
     3          U2(2),U3(2),RL(4)
C.....INITIALIZE ARRAYS
      INBN=NBN/4
      M=(N-1)*NBN
      DT=DEL1
      SIGM=SIG
      DO 1 I=1,NBN
      HR(I)=0.
      DO 1 J=1,NBN
      ESTIFX(I,J)=0.
      HN(I,J)=0.
    1 CONTINUE
C.....ASSIGN MATERIAL VALUES FOR ELEMENT NUMBER N
      ATH = SM(N,5)
      POR = SM(N,6)
      SOR = SM(N,7)
      DIFF= SM(N,8)
      DLCN= SM(N,9)
      DTRA= SM(N,10)
      REAC= SM(N,11)
      SSO = SM(N,12)
      TRA = SM(N,13)
C.....COMPUTE RETARDATION COEFFICIENT
      R = ATH*(POR+(1.-POR)*SOR)
C.....MODIFY OTHER COEFFICIENTS
      REAC = REAL*R
      DIFF = DIFF*ATH*POR
      SSO  = SSO*POR*ATH
      IF(INSTIR) GOTO 6
C.....MODIFICATIONS FOR STEADY CONDITIONS
      R=0.
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SOLUTION AT TIME  T =  0.25000E+02
***********************************

HYDRAULIC HEAD:

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    0.51250E+02    0.15000E+03    0.96325E+01
    0.72500E+02    0.15000E+03    0.94641E+01
    0.93750E+02    0.15000E+03    0.93208E+01
    0.11500E+03    0.15000E+03    0.92007E+01
    0.13625E+03    0.15000E+03    0.90874E+01
    0.15750E+03    0.15000E+03    0.89806E+01
    0.17875E+03    0.15000E+03    0.88782E+01
    0.20000E+03    0.15000E+03    0.87788E+01

DARCY VELOCITY COMPONENTS:

   X-COORDINATE   Y-COORDINATE           V1             V2
    0.30000E+02    0.15000E+03    0.14564E+01   -0.17989E+02
    0.51250E+02    0.15000E+03    0.13063E+02   -0.81059E+00
    0.72500E+02    0.15000E+03    0.76086E+01    0.19569E+00
    0.93750E+02    0.15000E+03    0.67379E+01    0.10119E+00
    0.11500E+03    0.15000E+03    0.58120E+01   -0.23496E+00
    0.13625E+03    0.15000E+03    0.55681E+01   -0.11291E+00
    0.15750E+03    0.15000E+03    0.52478E+01   -0.16608E-01
    0.17875E+03    0.15000E+03    0.51326E+01   -0.27938E-01
    0.20000E+03    0.15000E+03    0.50175E+01   -0.50855E-01

CONCENTRATION:

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    0.51250E+02    0.15000E+03    0.47002E+02
    0.72500E+02    0.15000E+03    0.15778E+02
    0.93750E+02    0.15000E+03    0.65455E+01
    0.11500E+03    0.15000E+03    0.25007E+01
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    0.17875E+03    0.15000E+03    0.79995E-01
    0.20000E+03    0.15000E+03    0.32203E-01
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Fig. 2: Example of FEFLOW listings of FORTRAN IV source code (left) and printout (right), year 1984

FEFLOW Version 1 (1979-1986)

The project of building a general purpose finite-element program was consequently continued when I started to work at the Institute of Mechanics at the Academy of Sciences of (East-) Germany at Berlin in 1980. In a small working group FEFLOW was further completed and improved, e. g., by developing mesh generators, a command line input language, introducing upwind techniques as well as time-stepping strategies. FEFLOW was applied to subsurface problems in an increasing extent. Remarkable is the first Elder problem computation in 1980 (Fig. 1) long before this problem was recognized by others. For the Elder problem a mixed finite-element formulation was used in FEFLOW, where pressure, velocity components and concentration were handled as primary variables. At that time FEFLOW was a FORTRAN program with a limited pre- and post-processing, runnable on mainframe computers (Fig. 2).

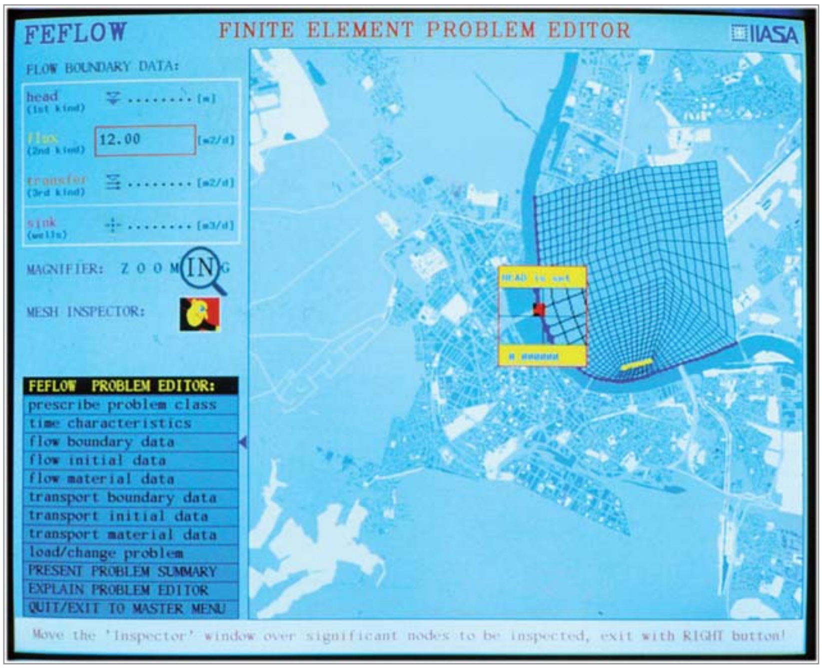


Fig. 3: FEFLOW problem editor in the SUN workstation implementation exhibiting already basic features (e. g., control panel, boundary condition input, mesh inspector, background map, meshing) similar in subsequent developments, year 1987. The proto typical implementation was done in the ACA group at IIASA Laxenburg (Austria).

FEFLOW Version 2 (1987-1990)

PC and microcomputers entered the market and began to revolve the software dramatically. Graphics became a significant component, not only for nicer plots and color rendering, but also for efficient data input and interaction. It was a chance to trash the old limited pre- and postprocessing tools and restart consequently on this new technology. The intention was the development of a fully graphics-based and interactive modeling package. There were no prototypes at that time and the new FEFLOW development had to start "from

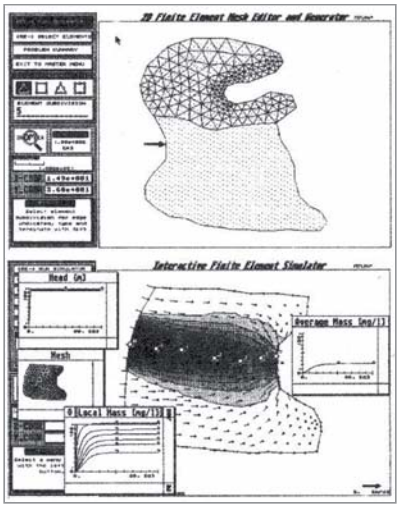


Fig. 4a: ATARI ST implementation showing interactive mesh generator (top) and simulator (bottom), year 1989. The monochrome graphical display had only a resolution of 640x400 pixels. The ATARI ST implementation was the first complete graphical simulation software in groundwater modeling containing mesh editor, mesh generators, problem attribute editor, simulation kernel and postprocessor. It already featured all basic properties of an interactive software system which we subsequently modified and extended in other implementations.

scratch". One challenge was finding efficient strategies for handling and controlling input and output data in the work flow (basic geometry –> mesh generation –> problem attribution –> simulation and computational control –> evaluation), while all nodal and elemental information remains hidden from the user. The code was completely rewritten from FORTRAN into C. The implementations were performed for SUN color graphics workstation (Fig. 3) and ATARI ST microcomputer with a simple monochrome monitor (Fig. 4a – b). Only primitive graphics libraries could be used in the absence of graphical standard tools at the time. FEFLOW became the first fully interactive and graphics-based finite-element simulator in groundwater.

Fig. 4b: ATARI ST microcomputer

FEFLOW Version 3 (1990-1992)

Graphical workstations conquered the computational market. The X window and OSF/Motif graphics style provided a new standard. FEFLOW was again adapted and extended. This effort was now done in a commercial environment. In 1990 I was one of the founders of WASY GmbH (the acronym WASY translates from German to Institute for Water Resources Planning and Systems Research) at Berlin and FEFLOW was developed further and marketed there on an increasing scale. A developing group was formed at WASY, which was enlarged stepwise in the subsequent years. FEFLOW became a registered trademark. From now, the X-Window/Motif outlook in blue-green-yellow colors was the typical GUI brand of FEFLOW (cf. Fig. 5).

FEFLOW Version 4 (1992-2001)

This period was extremely productive and successful. FEFLOW was becoming well-known more and more and could be established on the international market. The causes of FEFLOW's success were manifold. In a highly qualified teamwork FEFLOW was significantly extended and improved: **1992-1995**, v. 4.0-4.4 (3D extensions, ther-

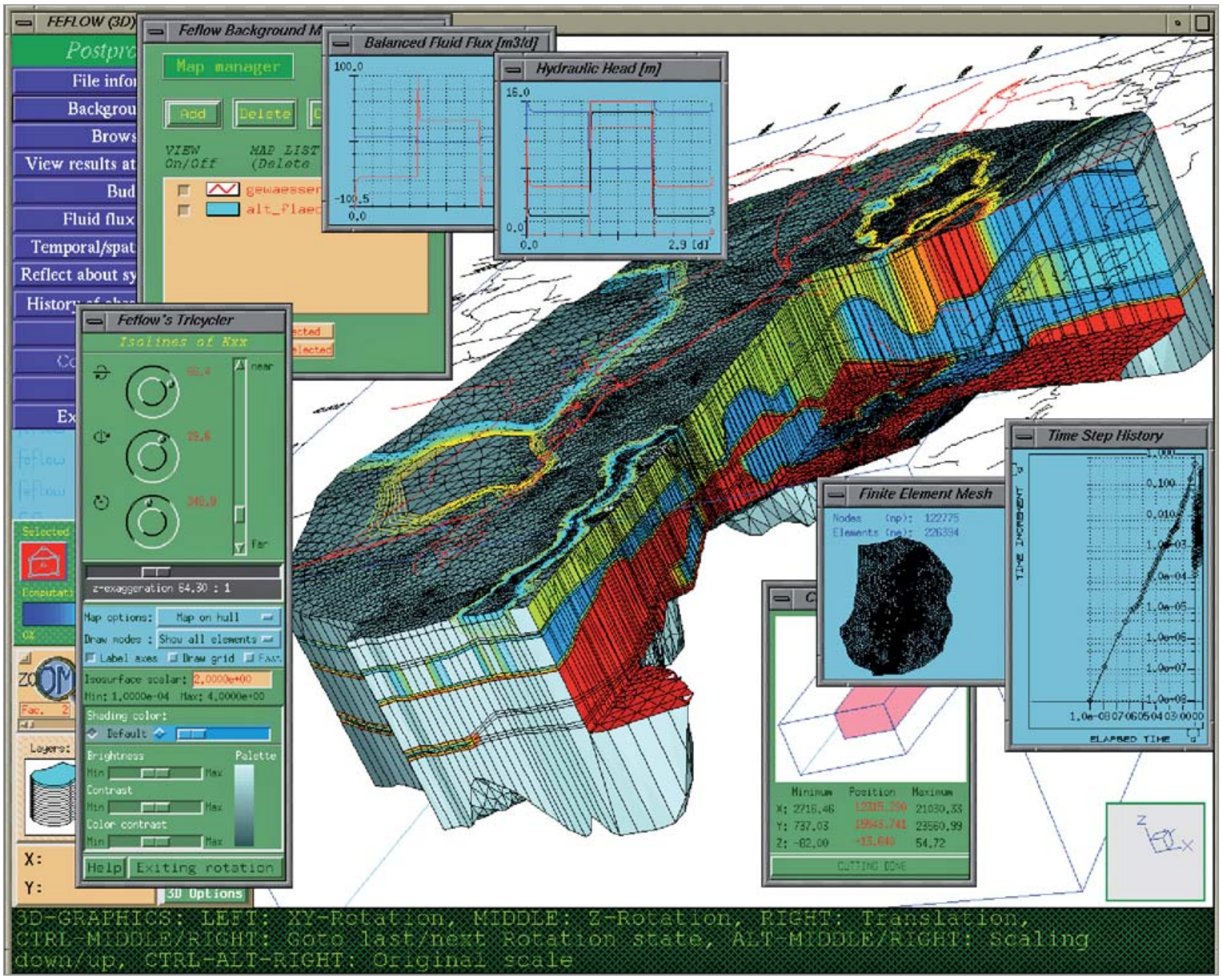


Fig. 5: FEFLOW's X window and Motif GUI style, year 1996

mohaline problems, 3D visualization, GIS interface extension); **1996-1997**, v. 4.5 (extended data interfaces, introducing data store manager DSM, map assistant, mesh refinement/derefinement); **1997-1998**, v. 4.6 (Windows 95/NT installation, TMESH mesh generator with add-ins, revision of budget analysis tools); **1998**, v. 4.7 (Interface manager IFM, unsaturated problems, extended interpolation techniques for time varying data, FEPLOT); **1999-2000**, v. 4.8 (PEST for parameter estimation, legend editor, improved map manager, reference distributions); **2001**, v. 4.9 (extended zooming tools, improved coordinate handling, new mesh editor, nonlinear dispersion, improved phreatic mode, new features in FEPLOT). In the extensions of the code object-oriented programming with C++ became increasingly present.

FEFLOW Version 5 (2002-2009)

The next steps in the development were: **2002**, v. 5.0 (discrete feature elements (1D/2D), extended possibilities for unsaturated flow, FE-LM² parameter fitting tool, true color implementation); **2003-2004**, v. 5.1 [extensions for density-variable transport (gravity-projected option), fast TRIANGLE mesh generator, algebraic multigrid (SAMG) equation solver]; **2005**, v. 5.2 (multispecies transport, parallel computing, FEMATHED reaction kinetics editor, transient pathline computations, FEFLOW Explorer for 3D visualization and animation); **2006-2007**, v. 5.3 (64-bit technology, variable-density multispecies multidiffusive transport, new mesh generator GRIDBUILDER, scatter plots, formula editor for sink/sources); **2008-2009**, v. 5.4 (borehole heat exchanger simulation, spline interpolation, improved parallelization, new SAMG solver). In 2007 the shares of WASY GmbH were purchased by DHI Group. The company has since been renamed to DHI-WASY GmbH and FEFLOW became part of the DHI Group software portfolio. Version 5.4 has already a specific feature, viz., the GUI is completely separated from the numerical kernel, so that an alternate GUI can be linked via existing interfaces. In fact, parallel to old GUI a new modern GUI has been developed and tested, however, up to now still hidden from the user.

FEFLOW Version 6 (2009-...)

The time of the classic X window and OSF/Motif GUI is now ending after a period of nearly 20 years. The old GUI is being displaced by the Qt graphical interface, which provides a modern and powerful environment for modeling and simulation with many new and interesting features (Fig. 6).

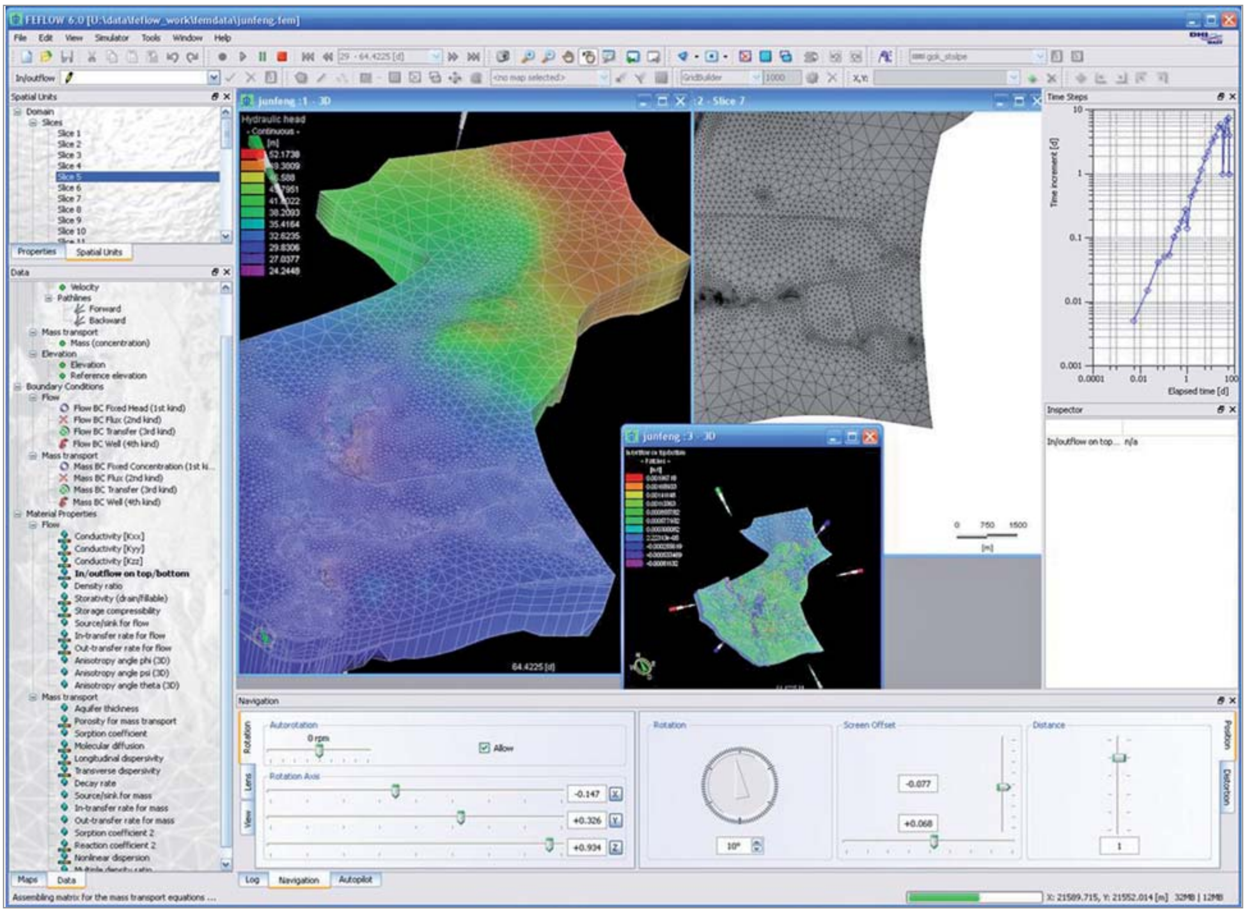
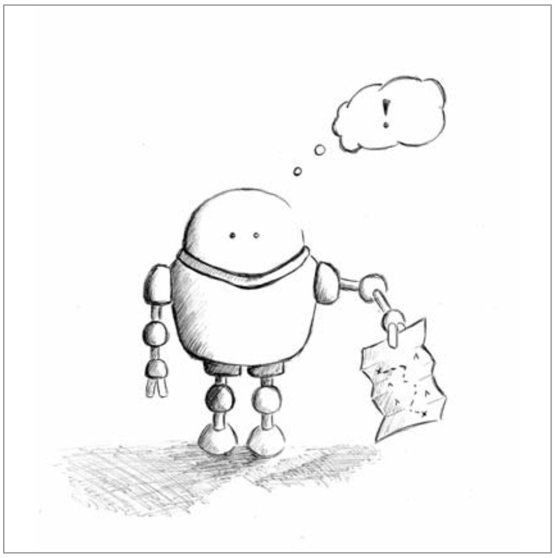


Fig. 6: FEFLOW 6 new development, year 2009

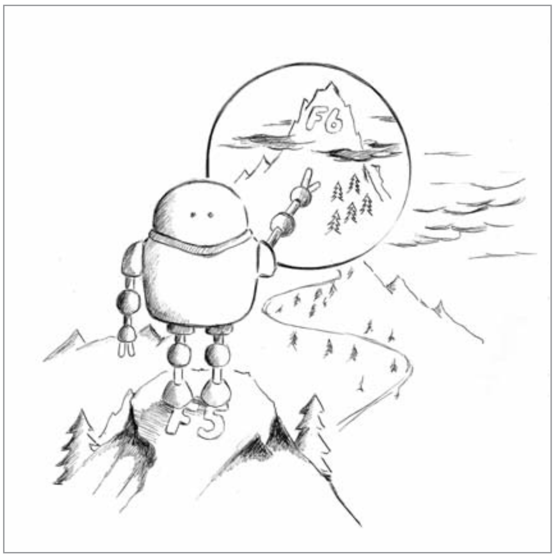
This new GUI combined with the improved software architecture, components and object-oriented programming will be the basis of FEFLOW's further success in the coming decades. More details can be found in the articles written by the responsible developers Rainer Gründler and Volker Clausnitzer.



Where Have all the Blue Buttons Gone?

Efficient Transition from FEFLOW 5.x to FEFLOW 6

Peter Schätzl & Alexander Renz



Although the handling of FEFLOW 6 is intended to be intuitive and easy to use, any software of FEFLOW's complexity is unlikely to be completely self-explanatory. In particular, the user interface based on toolbars and control panels provides a new degree of flexibility but may appear somewhat unfamiliar to users of FEFLOW 5.x who are accustomed to strictly hierarchical menu structures and serial workflows with a fixed sequence of operations.

So what are the main challenges for DHI-WASY in developing appropriate training material and course contents for the introduction to FEFLOW 6? In FEFLOW 5.x the hierarchical structure allows to align training and materials directly to this structure – providing a clear framework. In contrast, the user interface design of FEFLOW 6 keeps all functionality accessible whenever possible to ensure maximum flexibility and efficiency for the user. As a consequence, training will focus on explaining the philosophy and concepts of the user interface. Once the basic ideas have been put across, the application of these concepts onto all different kinds of models and model parameters is straightforward and mostly self-explanatory. Documentation and training therefore focus on two major parts:

1. The explanation of all components of the user interface (menus, toolbars, panels, views). In training courses and step-by-step examples this is done in an incremental approach, starting with the most basic ones, and then extending, using the components one by one.
2. The practice of important workflows as examples based on step-by-step descriptions or the guidance of a trainer.

Based on these ideas and challenges, DHI-WASY has developed a set of tools guiding the users towards the application of the new version.

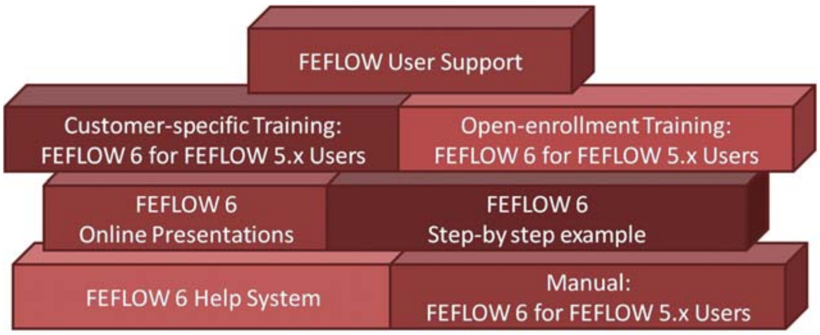
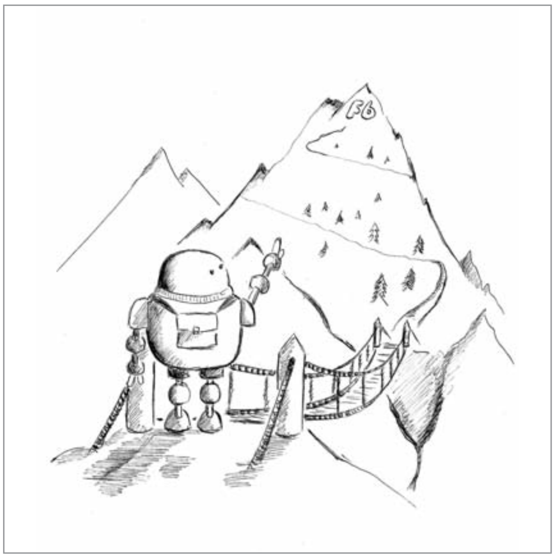


Fig. 7: Building blocks for an efficient transition to FEFLOW 6.



Having "climbed the mountain" of FEFLOW 5.x and feeling confident and safe on its top, for you as a user FEFLOW 6 might look like an unknown and far summit high up in the clouds. So you might ask whether it is really worth the effort climbing it. Of course we know it is. But rather than only talking about all the advantages of FEFLOW 6, we provide you with binoculars: By presenting the new user interface at the 2nd International FEFLOW Conference, at a number of regional user group meetings and in free online seminars, a close look at the far summit is offered – yet still without the effort of climbing it, i.e., without getting your hands on.

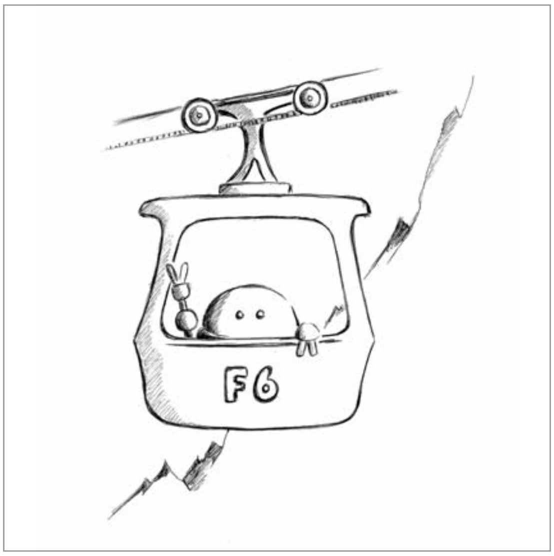


Fig. 8: Online Seminars

Topic	Time	Duration
FEFLOW 6 Online Seminar – english	October 1, 6:00 pm	1 hour 30 minutes
FEFLOW 6 Online Seminar – english	October 2, 8:00 am	1 hour 30 minutes
FEFLOW 6 Online Seminar – deutsch	October 8, 2:00 pm	1 hour 30 minutes
FEFLOW 6 Online Seminar – deutsch	October 26, 2:00 pm	1 hour 30 minutes
FEFLOW 6 Online Seminar – english	October 27, 6:00 pm	1 hour 30 minutes
FEFLOW 6 Online Seminar – english	October 28, 8:00 am	1 hour 30 minutes
FEFLOW 6 Online Seminar – english	November 24, 6:00 pm	1 hour 30 minutes
FEFLOW 6 Online Seminar – english	November 25, 8:00 am	1 hour 30 minutes

Please register via http://dhisoftware.webex.com (click on Register and search for FEFLOW 6).

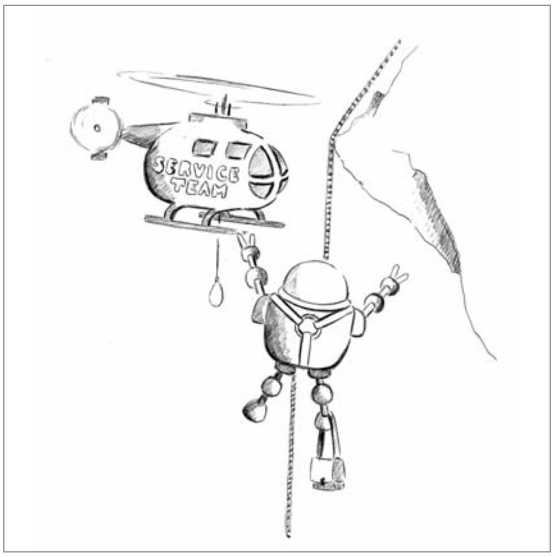


Fig. 9: Upcoming Courses

Course Title	Date	Location, Organizer
FEFLOW 6 for FEFLOW 5.x Modelers	14/15 September	Berlin, Germany, DHI-WASY
Groundwater Modeling using FEFLOW	28-30 October	Johannesburg, South Africa DHI South Africa
Finite element modelling of flow, heat and solute transport with FEFLOW	3-5 November	Shrewsbury, UK, esi
Groundwater Modeling using FEFLOW	3-5 November	Cambridge ON, Canada DHI North America
Groundwater Modeling using FEFLOW	10-12 November	Denver CO, USA DHI North America
Introduction to FEFLOW	30 November – 4 December	Berlin, Germany, DHI-WASY
FEFLOW 6 für FEFLOW 5.x-Modellierer	7/8 December	Berlin, Germany, DHI-WASY
FEFLOW 6 for FEFLOW 5.x Modelers	9/10 December	Berlin, Germany, DHI-WASY

You have decided to take up the challenge? Running down Mount FEFLOW 5.x and ascending Mount FEFLOW 6 from the valley bottom doesn't seem to be the shortest possible way. Thus it is our job to offer the technical means to bridge the gap. As a first component, we have constructed a suspension bridge consisting of a thorough documentation (help system), a transition manual, and a step-by-step example model described for both FEFLOW 5.x and FEFLOW 6. These modules help, but you'd still have to climb on your own.

For the ones of you who prefer a more convenient and faster way, we have also constructed a funicular: Join us in a two-day "FEFLOW 6 for FEFLOW 5.x modelers" training, and we'll safely guide you to the new heights. The funicular operates on schedule, but also on demand: Besides open-enrollment courses we can also provide customized FEFLOW 6 introductory courses on-site.

You got lost on the way up to Mount FEFLOW 6? Our support team provides quick and first-class mountain rescue and guides you back onto the track.

We are confident that you will like the view from Mount FEFLOW 6 once you have stood on its summit – the one overtopping all the other ones around!

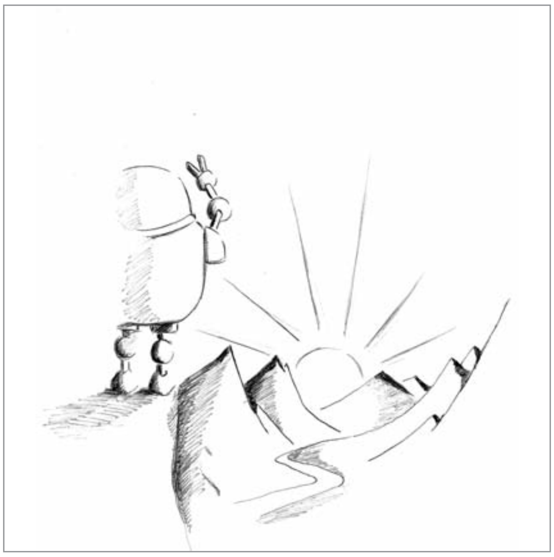


Fig. 1 – 6: © Cryptic 2009

Using Maps and Map Data with FEFLOW 6

Olaf Arndt

FEFLOW 6 introduces a new handling of maps and map data conforming to the new architecture (2D and 3D views) and employing standard techniques known from in Geographic Information Systems (GI Systems). Two basic map types can be distinguished:

- Georeferenced raster based maps (TIFF, PNG and JPEG) and
- Vector data (e.g. DXF, Shape data, ASCII formats), which in general are containing attribute data.

In addition, vector maps may contain either 2D or 3D coordinates. To meet this circumstance the map handling of each type has some communalities as well as distinctions.

In analogy to the organization of the FEFLOW data (process variables, material properties, etc.) maps are organized in a dockable tree structure, were a separate group per map format exists. This organization enables quick access to add, remove or configure specific maps or entire map groups. It provides also a context-menu based recent file list, one per supported file format. Up to the map file entry, the structure is common for each map type.

The further structure depends on the map as well as user-defined properties, which are described in the following sections.

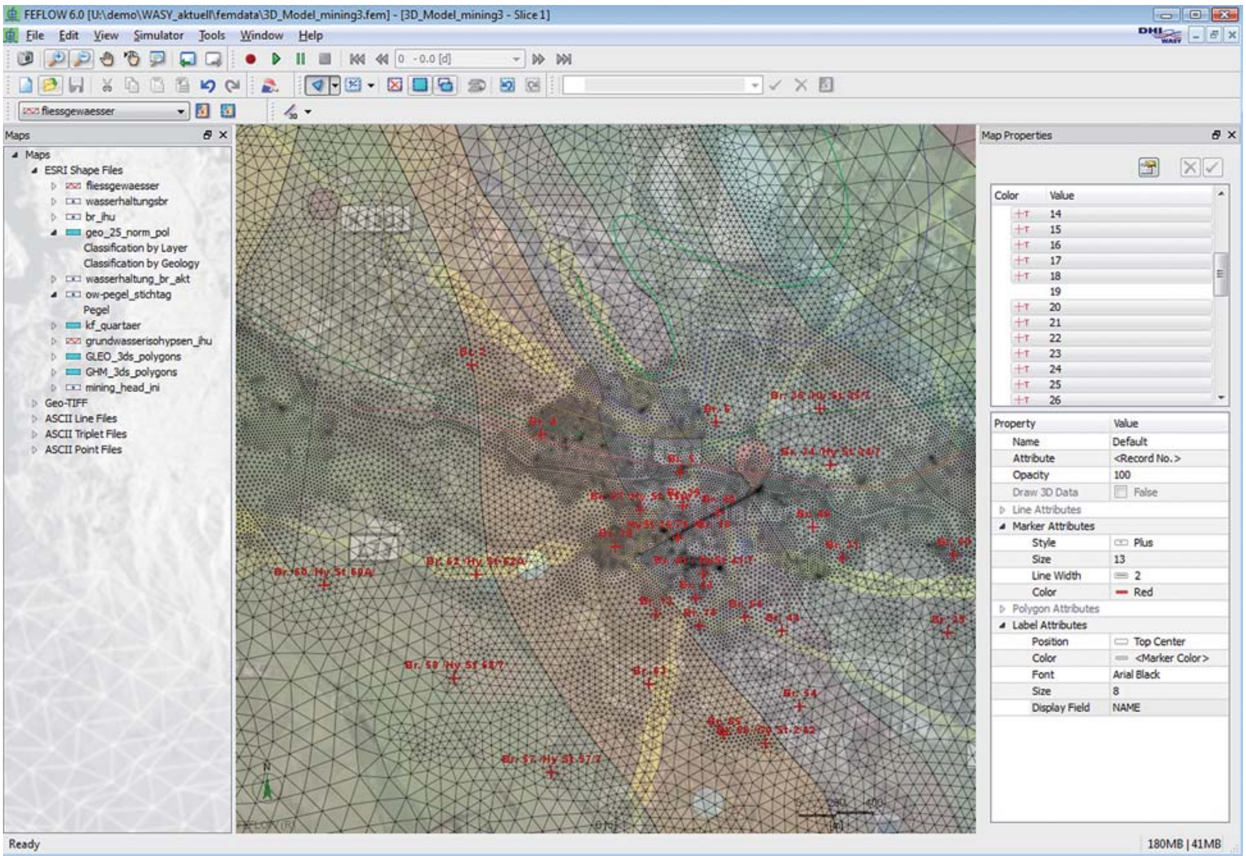


Fig. 1: Map configuration and usage with FEFLOW 6.

Raster-based maps

Beside the Tagged Image File Format (TIFF), FEFLOW 6 also supports the Portable Network Graphics format (PNG) and the JPEG File Exchange Format, where the maps have to be georeferenced. Due to missing attribute data, the raster-based maps can be used as background maps only. The visualization of raster maps in 2D views is analogous the visualization in previous FEFLOW versions, beside the fact that FEFLOW 6 supports a configurable transparency. This enables the user to use multiple maps simultaneously. In the case of 3D models FEFLOW 6 supports also 3D views. In this case, the visualization of raster-based

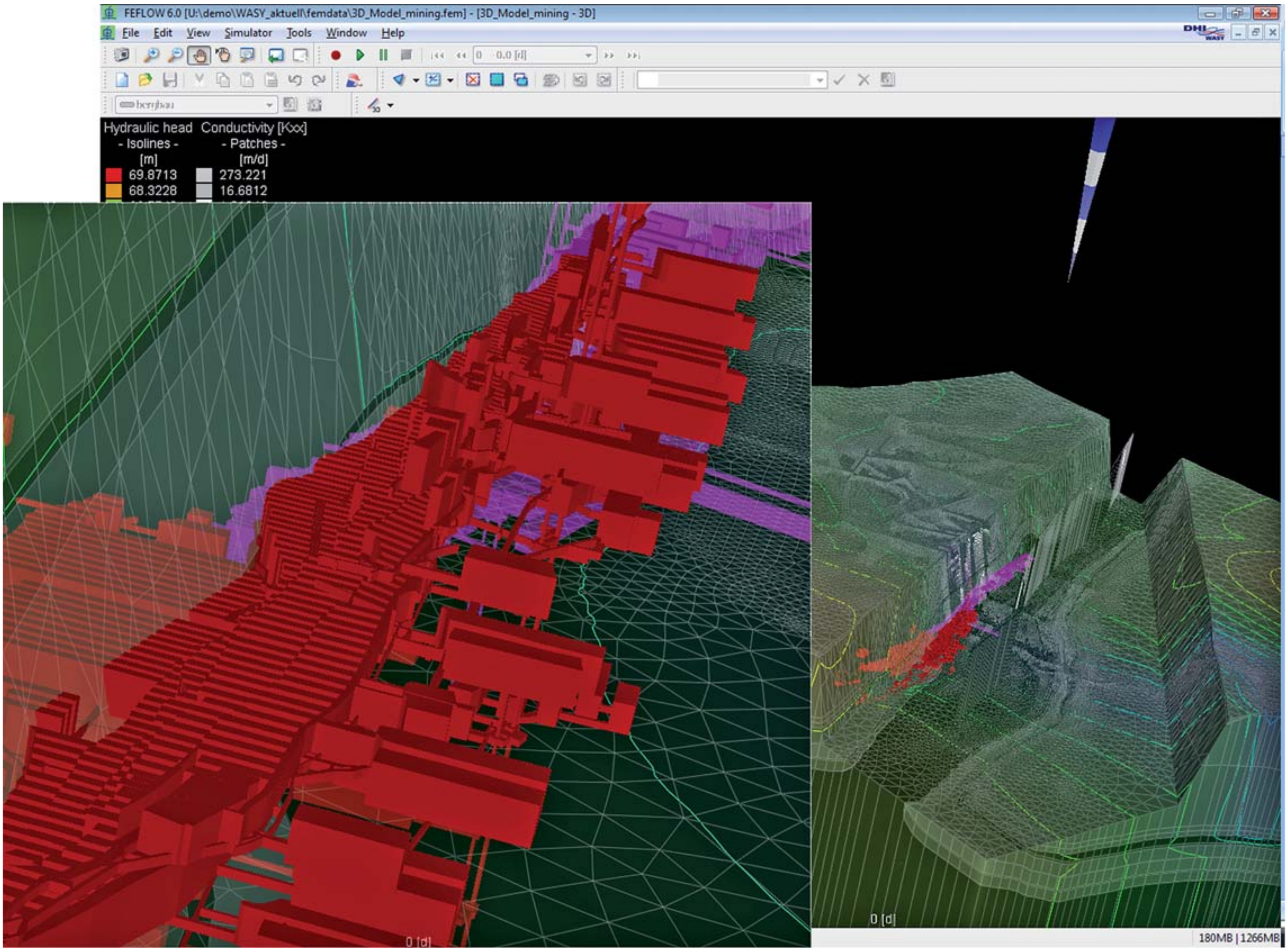


Fig. 2: Visualization of 3D mining data using the FEFLOW 3D view.

maps has to be handled in a different way. Since raster data lack Z-coordinate values FEFLOW 6 performs texture mapping, were the raster data are mapped on a 3D surface (the so-called spatial domain) which can be the model top boundary or a specific slice.

Vector maps

FEFLOW 6 supports multiple file formats of vector data, which can be added as map. Currently, supported formats are the ESRI Shape File Format, AutoCAD DXF files, and several ASCII formats. FEFLOW 6 is also capable to handle 2D or 3D vector data. Similar to modern GI Systems, a layer concept was introduced in FEFLOW 6. Here, it is possible to define several layers with different symbologies like variable colors or classifications. Each defined layer is added to the map tree structure and hence is available to different views. The layer definitions are stored in the Finite Element Model file (FEM file). To define the symbology of a layer FEFLOW 6 provides a map property panel, which is organized by groups according to the corresponding map data. The settings can be divided in general layer settings (layer name, classification attribute, or transparency) and settings of the respective record that depend on the record type (line, point, or polygon). The panel also provides a classification dialog. Using this dialog, it is possible to classify the map data by unique values or ranges based on predefined color palettes.

In addition to the drawing of 2D vector maps – which is similar to raster maps as described above – there is a special mode of drawing 3D vector data in 3D model views. Using this mode, the Z-coordinate is used to visualize the data instead of mapping the data on a surface. So, 3D objects can be shown directly inside the 3D model space at their real position.

Selection of Nodes and Elements

Compared to previous versions, FEFLOW 6 provides a slightly different concept of assigning data to the model. Now, data will be assigned to a selection of nodes or elements, thus before assigning data, a selection has to be defined. To do so, different methods are available to the user. Beside classical selection (like single, rectangular or polygonal selection), the selection by vector maps is also provided. Therefore, all available vector maps are added to the map selection combo box. By choosing the desired map, two map selection modes are available, either automatic selection by all map geometries or interactive selection. In the case of selecting elements by polygons, it is also possible to define the selection modes **element center in polygon, elements contained by polygon, or element intersects polygon**.

Assigning Data to Parameters

Based on an existing selection, data can be assigned to the selected nodes or elements of a parameter. After choosing the corresponding parameter for editing, several editing tools are available. The simplest way is to assign a constant value to the entire selection. This can be done by entering the value or selecting a previous value from a recent list. In general, each specified value will be treated as a value defined in the (parameter-specific) current user unit but it is also possible to specify the unit of the value, which causes a on-the-fly conversion as long as the unit belongs to the required category. Besides entering the value of the parameter, it is also possible to choose a predefined entry from the parameter lookup table. This makes it possible to define *named materials* with typical parameter values. While setting time-varying boundary conditions or constraints it is also possible to edit and assign time series. Finally, attribute values of vector maps can also be assigned.

Assigning Data by Map

In FEFLOW 6 there are new facilities to assign map attributes to model parameters. To enable the assignment of map data to a selection set of nodes or elements as described in the previous section, the map data must be linked to the specific parameter in advance. For each vector map an arbitrary number of attributes can be linked to one or multiple parameters. For each link additional settings are available like source unit or regionalization method. The defined links are part of the model definition and therefore stored in the FEM file so that they can easily be modified and assignment can be repeated. In addition, it is possible to add the current selection of nodes or elements to a specific link, so all required information to repeat an assignment task is available.

Another improvement compared to previous FEFLOW versions is the fact, that FEFLOW 6 supports the visualization of an arbitrary number of model parameters while editing a specific one. So it is possible to

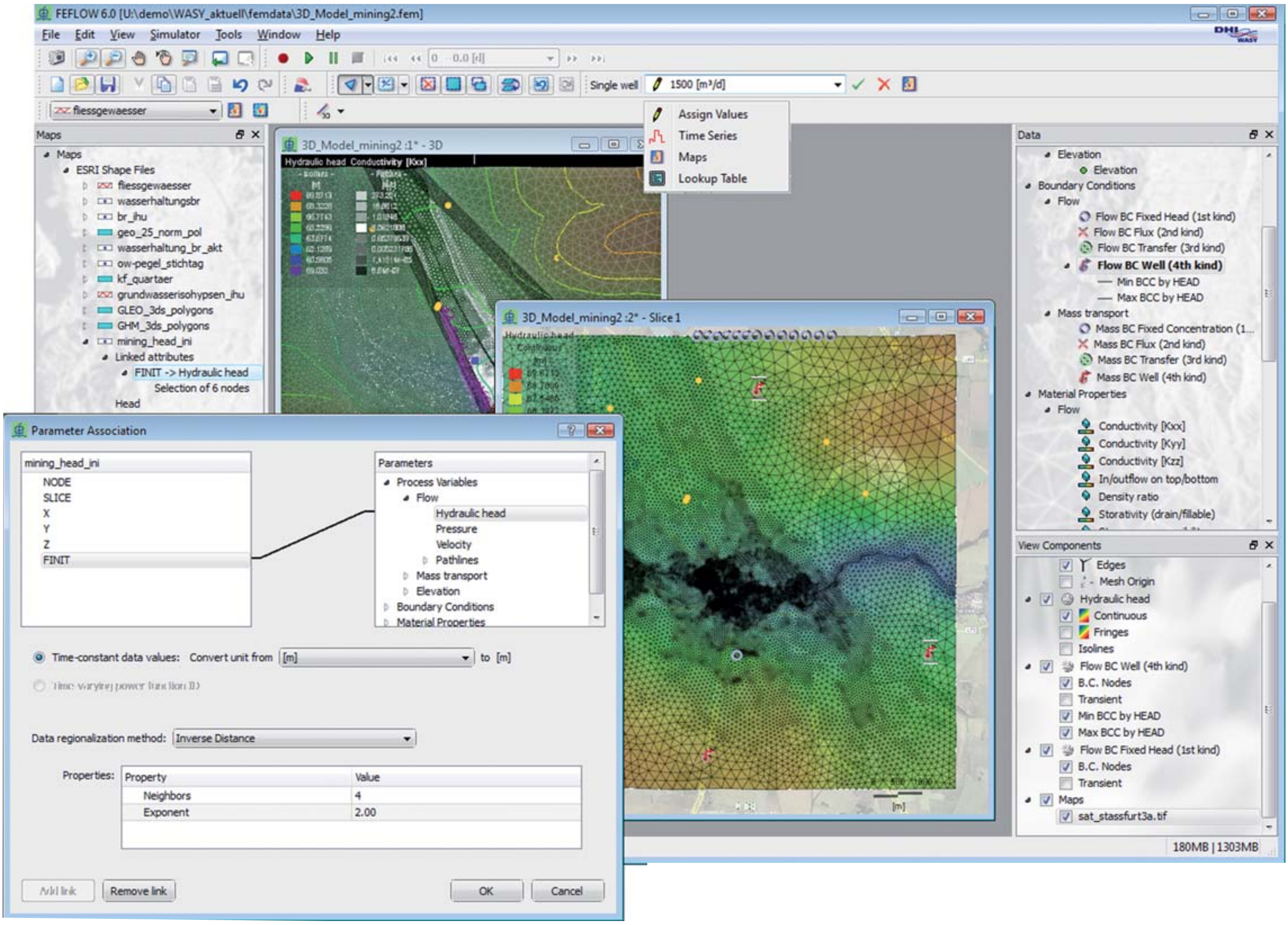


Fig. 3: FEFLOW 6 link configuration and editing tools.

display for example flow or material parameters while setting boundary conditions.

Exporting Data

In FEFLOW 6 there are also new export capabilities available. Besides exporting nodal and elemental parameters, aggregated fringes and isolines data can be exported which greatly simplifies the further external processing of the data in a GI System. Furthermore, given an existing 3D model and an appropriate file-format selection, it is now possible to export the parameters as 3D data.

Performance Issues

To improve performance with respect to continuously growing model size but also increasing core numbers of even desktop computer, many tasks in FEFLOW 6 are performed in parallel. This holds not only during model simulation but also during model design. So the user benefits from parallel architectures during map preparation, selection of nodes and elements, or assignment of data.

Splines for Approximation of Material Parameters

Volodymyr Myrnyy

The capillary retention properties encountered in soils research or in the development of artificial porous media are not always well described by the classic empirical relationships. The need for an alternative is exemplified in Figure 1 where a cubic spline graph fits measured retention data much better than the empirical van Genuchten relation. Splines are continuous, piecewise polynomial functions with certain requirements on smoothness. They represent a very flexible approach to data approximation. Moreover, splines offer a direct and fully automated way from the experimental data to the parametric curves used to describe capillary-pressure – saturation and saturation – conductivity dependencies for simulation of variably saturated flow problems.

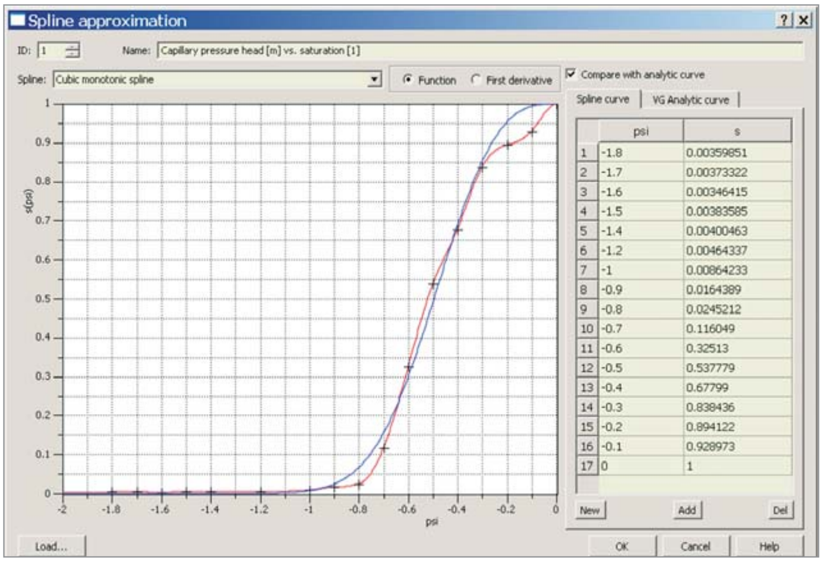


Fig. 1: Cubic monotonic spline and van Genuchten fits of capillary-pressure vs. saturation data

Cubic splines in FEFLOW

Having been introduced in FEFLOW 5.4, cubic interpolating splines can be found in the Problem Editor as an additional model for unsaturated flow material properties. The spline dialog (Fig. 1), accessible via the Edit button, provides graphical and table-based data representations and also the capability to change available spline properties and to compare a spline curve with a van Genuchten fit. Measurement values can be loaded from *.pow or *.txt files containing two-column data. Alternatively, data may be edited directly in the table. By default, the monotonic version of the cubic interpolating spline is used. This ensures that the first derivative always stays positive which is essential in the case of the capillary-pressure – saturation relation-ship where the first derivative represents the storage capacity. However, as a consequence of monotonicity, the spline function may become nonsmooth in some points.

Another option is the classical cubic spline with a smooth first derivative. Here the user should check visually whether the first derivative is indeed positive everywhere. This may require some expert work. While the saturation-conductivity curve is defined on the [0,1] interval, the capillary-pressure – saturation curve is be defined on the negative half-axis. The spline curve is extended to *minus infinity* by an exponential function smoothly connected to the first node of the spline. The final spline node should always be (0,1) where the first derivative is set to zero by a boundary condition on the spline function to enforce a smooth transition of the curve to fully saturated conditions.

The new splines model for unsaturated material properties is both powerful and sensitive. Unsuitable spline coefficients may lead to incorrect results or nonconvergence. Correctly used, the model opens the door to some exciting, previously inaccessible investigations in the field of unsaturated flow problems in porous media.

FEFLOW 6

Release Schedule

From now on, a beta version of FEFLOW 6 can be downloaded from www.feflow.info for testing. This beta version can be installed in parallel to FEFLOW 5.4 and brings both the 'old-style' Motif interface (version 5.5) and the new Qt interface. It is fully functional with a license for FEFLOW 5.4. As the beta version provided for download will be updated frequently during the testing period, the usage of each single downloaded version is limited to three months.

After intensive beta testing and further improvement, FEFLOW 6 will be released on DVD. The official release version will then require a new license. As in the past, the new license and installation package will be sent to all FEFLOW users with a current Service and Maintenance Agreement (SMA) automatically.

Latest releases of DHI-WASY software

Software	Release
FEFLOW®	5.4
FEFLOW®	6.0 beta
FEFLOW Explorer	3.0
SIWA on ArcView	1.1
WGEO®	5.0
Verm on ArcView	2.1
ProfleGG	1.0
ArcProfleGG	1.0
HQ-EX®	3.0
WBalMo®	3.1
GeoDAta eXchange	4.0
WISYS®	3.5

Latest releases of DHI software

MIKE by DHI: Release 2009 SP2

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News

New Staff

Julia Mayer for FEFLOW

Julia Mayer studied Environmental Engineering at the University of Stuttgart and at the Technion, Israel Institute of Technology in Haifa. Her university education focused on water resources management and groundwater modeling. During her Diploma thesis at the Dept. of Water Resources Management and Modeling of Hydrosystems of the Technische Universität Berlin she additionally developed profound knowledge of numerical modeling of flow in porous media. From September 1st 2009 Ms. Mayer has joined the Groundwater Modeling Centre (GMC) of DHI-WASY where she mainly will be involved in software support and training of FEFLOW users.

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