

SPECIAL ISSUE: ANALYTIC ELEMENT MODELING

MODFLOW 2001 and Other Modeling Odysseys Golden, CO, USA, September 11-14, 2001

This conference brings together users and developers of MODFLOW, related, and alternative modeling programs to present innovations capabilities, limitations, and explore future developments in groundwater modeling. Featured speakers include:

- Arlen Harbaugh**, United States Geological Survey (USGS): Directions for Ground-Water Model Development by the USGS
- Mary Anderson**, University of Wisconsin: Modeling Groundwater Fluxes at Interfaces: Is MODFLOW up to the Challenge?
- William Woessner**, University of Montana: New Lessons from Post-Audits?
- Michael McDonald**, McDonald-Morrissey Associates: Some Thoughts on the Logic of Modeling
- Frank Schwartz**, Ohio State University: Analysis of Research Impacts in Hydrology and Ground-Water Modeling
- Tom Prickett**, Thomas A, Prickett & Associates: MODFLOW in Court - Experiences of an Expert Witness
- Keith Beven**, Lancaster University, United Kingdom: Model Uncertainty as Landscape to Model Space Mapping
- John Doherty**, Watermark Computing, Australia: Parameterizing a Groundwater Model - Space Age Technology or Science Fiction?
- Wolfgang Kinzelbach**, Swiss Federal Inst. of Technology: Uncertainty in groundwater modeling - do we oversell models?
- David Steward**, Kansas State University: Developing Understanding of Horizontal Wells Using an Analytic Model
- Theo Olsthoorn**, Amsterdam Water Supply, Netherlands: Some MODFLOW Experiences and Odysseys
- Mary Hill**, USGS: **Darcy Lecture**, Guidelines for Effective Model Calibration (Any Model!)

- David Parkhurst**, USGS: Reaction-transport Modeling of a Sewage Plume at Cape Cod Massachusetts: A Convergence of Research Themes
- Chunmiao Zheng**, University of Alabama: Applied Contaminant Transport Modeling: A Historical Perspective and A View to the Future
- Graham Fogg**, University of California, Davis: Future Directions in Transport Modeling: Thoughts on Assessment of Vulnerability and Remediation
- John McCray**, Colorado School of Mines: Quantifying the Uncertainties Associated with Traditional Analytical Model Approximations in Vapor-Phase Pump-Test Analysis
- Rien van Genuchten**, USDA Salinity Laboratory: Rosetta: A Hierarchical Pedotransfer Model to Predict the Unsaturated Soil Hydraulic Properties from Soil Texture and Related Data
- Eileen Poeter**, IGWMC, Estimating Initial Conditions, From Finish to Start?
The registration fee is \$595 (US), including proceedings, receptions, lunches, and breaks. Many courses are associated with the conference (see back cover). For information contact IGWMC at 303/273-3103, fax 303/384-2037, igwmc@mines.edu. For registration, contact: CSM-SPACE at 303/273-3321, fax 303/273-3314, space@mines.edu. Corporate support of conference events will be publicly acknowledged, please direct inquiries to IGWMC. The schedule is outlined below.

ModelCARE 2002

CALIBRATION AND RELIABILITY IN GROUNDWATER MODELLING: A few steps closer to reality Prague, Czech Republic, June 17-20, 2002

ModelCARE'2002 follows the successful conferences ModelCARE'90 (the Netherlands), ModelCARE'96 (USA), and ModelCARE'99 (Switzerland). The conference provides an international forum for state-of-the-art presentations on relevant (continued page2)

SCHEDULE: MODFLOW 2001 and Other Modeling Odysseys

Tuesday 9/11 Lobby	Wednesday 9/12 Metals Hall	Wednesday 9/12 Petroleum Hall	Thursday 9/13 Metals Hall	Thursday 9/13 Petroleum Hall	Friday 9/14 Metals Hall	Friday 9/14 Petroleum Hall
Featured Talks	Harbaugh		Beven		Parkhurst	
Featured Talks	Anderson		Doherty		Zheng	
Sessions	Surface-Water / Ground-Water	Typical Problems & Solutions	Calibration / Parameter Est.	GUIs/Visualization/ GIS/Databases	Management / Remediation	Contaminant / Reactive Trnsprt
Featured Talks	Woessner		Kinzelbach		Fogg	
Sessions	Surface-Water / Ground-Water	Typical Problems & Solutions	Calibration / Parameter Est.	GUIs/Visualization/ GIS/Databases	Management / Remediation	Contaminant / Reactive Trnsprt
Freidhoff Hall GUIs @ lunch	Public Domain USGS GUI	ARGUS	Visual MODFLOW	Groundwater Vistas	PM Win	GMS
Featured Talks	McDonald		Steward		McCray	
Sessions	Surface-Water / Ground-Water	MF2000	Calibration / Parameter Est.	Constraining with Hydrogeology	Unsaturated / Multiphase Flow	Variable Density Flow
Featured Talks	Schwartz		Olsthoorn		van Genuchten	
Sessions	Fracture Flow	MF2000/ Education Issues	Case Histories / Unusual Apps	Stochastic Approaches	Unsaturated / Multiphase Flow	Variable Density Flow
Featured Talks	Prickett		Hill Darcy Lecture		Poeter	
ICE-BREAKER	Computer Demo Happy Hour		Poster Session Happy Hour		Closing	

ModelCARE 2002 (continued from page 1) methodologies and techniques, and identifies needs for development. The conference illustrates the applicability of various innovative techniques through case studies. Though the conference covers the entire field of groundwater modeling, two special areas of focus have been selected, namely (1) "Conceptual Model Uncertainty and Scale" and (2) "Calibration and Reliable Prediction: Journeys and Lessons". **Abstract Due: September 30, 2001** <http://www.guarant.cz/ModelCARE2002/>

Overview of AEM

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The Analytic Element Method (AEM) was developed for the mathematical modeling of groundwater flow and was originally intended for problems of regional flow. The method is numerical, providing an approximate solution. It is based on the superposition of analytic functions, called Analytic Elements, and might be considered as an extension of classical models of regional flow based on the superposition of elementary functions, for example the Thiem and Theis solutions for wells, and the potential for uniform flow. Analytic elements are mathematical functions that differ from the many existing classical solutions in that they are not restricted to a single boundary value problem, but rather possess degrees of freedom that allow their combination. Refer to the Special Issue of the Journal of Hydrology [1] for a description of the method as well as a number of papers on its application.

The AEM can model both transient and steady state flow in heterogeneous systems of aquifers separated by leaky layers. In fact, there are no theoretical limitations of the method. The main disadvantage, as compared to discrete numerical methods, such as the Finite Difference or Finite Element Method, is the significant effort required to develop and implement new analytic elements. The advantages of the method outweigh this drawback, however. The advantages of the analytic element method are as follows:

An AE Model is independent of scale; a regional model that may cover part of a country, such as the Dutch National Groundwater Model NAGROM [2] or the Metro model of the Twin Cities Metropolitan Area [3] can be used for detailed studies, without the need to create a new model.

The size of a model that uses the super-block approach [4] does not affect computational speed; local studies of capture zones, for example, can be carried out without the need to reduce the model size.

Particle tracking can be accomplished with a high degree of precision because analytic expressions for the velocity are used, rather than velocity components computed by interpolation from discrete points.

The speed of models based on the super-block approach is such that modeling can be done in real time.

An AE Model can be constructed solely by entering the features of the aquifer system that control flow; the effect of these features is translated in the appropriate mathematical expressions which are then superimposed.

References

- [1] Special Issue of the Journal of Hydrology. 226, Nos. 3-4.
 - [2] De Lange, W.J., 1996. NAGROM, a groundwater model for national groundwater management and regional and local studies. EWPC 6 (5), 63-67.
 - [3] <http://www.pca.state.mn.us/water/groundwater/metroadel.html>
 - [4] Strack, O.D.L., I. Jankovic, and R. Barnes, 1999, The superblock approach for the analytic element method. J. Hydrol. 226, 179-187.
- See also: <http://www.ce.umn.edu/AEMGroundwater/>
<http://www.groundwater.buffalo.edu/>
<http://www.strackconsulting.com>, and
<http://www.indiana.edu/~grwater/index.html>

Publication of articles describing software in this newsletter does not indicate that the software has been tested by igwmc. If you use the software, your critiques are welcome.

Write Your Own Analytical Element Model Right Now with MATLAB

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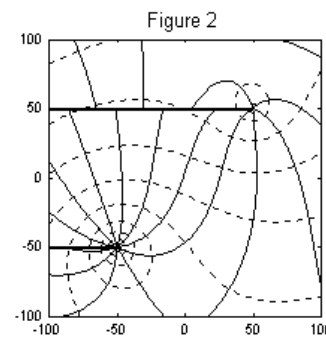
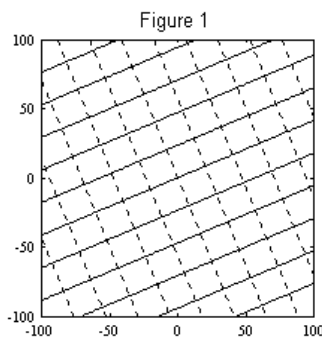
Analytic Element Modeling is the art of combining available solutions to the differential equation of groundwater flow, so their sum satisfies the groundwater head or flux in prescribed points. In basic form, analytic elements are functions of a complex variable $z = x + iy$. Such functions come in pairs, and their isolines are perpendicular, just like streamlines and equipotential lines.

Many useful analytic elements exist, and their number is growing. They are easy to visualize in MATLAB. A MATLAB exercise in Analytic Elements starts by defining z on an x,y plane, for instance by: $x = -100:100$; $y = -100:100$; $[X,Y] = \text{meshgrid}(x,y)$; $z = X + i*Y$. This generates a grid of 201 by 201 points, and z has a value at each point. (Type these commands in the MATLAB command window, which appears at startup). To see the grid, type: `close all; contour(x,y,real(z),'b',11); hold; contour(x,y,imag(z),'r',11); axis square`. There are 11 isolines of $\text{real}(z)$ and 11 isolines of $\text{imag}(z)$. z is actually an analytic element, called uniform flow. In MATLAB, the equipotential lines are blue and the streamlines lines are red although that cannot be seen in this black and white figure. If you want flow at an angle $\pi/8$, try: `close all; contour(x,y,real(z*exp(-i*pi/8)),11,'b');` `hold; contour(x,y,imag(z*exp(-i*pi/8)),11,'r');` `axis square` (figure 1). For uniform flow twice as strong, multiply z by 2.

The most versatile analytic element is the well: $f(z) = \ln(z)$. Try: `close all; contour(x,y,real(log(z)),11,'b');` `hold; contour(x,y,imag(log(z)),11,'r');` `axis square`, and see what happens. In this case, the streamlines are clearly those that intersect the wells while the others are equipotential lines. The fat line that extends from the well to minus infinity is the notorious "branchcut." It appears to be a nuisance, but it paves the way to modeling heterogeneous media.

Just two elements already allow for quite intriguing flow patterns, like: $u = z^2 \exp(i*pi/4)$; $w1 = \log(z-50-50i)$; $w2 = \log(z+50+50i)$; $f = .02*u + w1 - 2*w2$; `close all; contour(x,y,real(f),11,'b');` `hold; contour(x,y,imag(f),11,'r');` `axis square` (figure 2). In this example, the strengths of the elements were tuned by a multiplicative factor. In application, frequently some of the elements' strengths are not given a priori. They must be determined such that certain groundwater head conditions are met at prescribed points of observation. This raises a set of equations to be solved. Given a set of equations $Ax = y$, MATLAB solves it by the command $x = A \setminus y$, no matter if the number of unknowns matches the number of equations.

By now you may want to leave MATLAB's command window and enter the M-file editor. If you do, you are on the verge of writing your own Analytic Element code. Beware! Analytic Elements and MATLAB are an addictive blend.



Government agencies are no longer supporting entities such as the IGWMC. Yet, if many groundwater oriented professionals and companies maintain a membership in the center, the IGWMC can continue to provide valuable advising, teaching, information dissemination, software distribution and research services to the profession. Maintaining a membership in IGWMC provides stable support to ensure that IGWMC services are there when you want them, assists groundwater students, and provides you with reduced rates. see pgs 3&4.

Tim: Analytic Element Code You Can Modify

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It seems to happen all the time: You are using a software package to build a groundwater model and it cannot do what you want it to do. Or you come up with a great way of modeling a special phenomena, but you cannot link it to the software package that you like to use. What you really need is a computer program that you can modify yourself. And preferably one that is well structured and well documented so that modifications can be made easily. And wouldn't it be nice if the developers were actually interested in adding the features you developed to the program and make it freely available to all other users?

These were thoughts that led to the 'Tim' project. Tim is an analytic element program for the modeling of groundwater flow. The program has a full object-oriented design that was developed with the input from a large group of analytic element developers. Tim is an open-source computer program, which means that the source code is freely available and the users can make any modifications they like. Furthermore, when users develop features that may be useful for other users, they are supposed to give their developments back to the Tim project so that they can be included in the official release. The object-oriented design of Tim is basic, but flexible, so it is easy to learn how the program is structured and to make changes or additions.

Tim is written in Python. Python is an interpreted, interactive, object-oriented programming language. The advantages of the use of Python are numerous. Python is powerful yet the syntax is surprisingly clear (it is very easy to learn). Python runs on virtually any operating system, including Unix, Linux, Mac, and Windows. Python is open-source, so you can download it for free from the web. Use of Python is taking off, as evidenced by the fast growing number of Python books available in the bookstores. Oh, and Python was named after Monty Python's Flying Circus; who doesn't remember 'Tim the Enchanter' in Monty Python and the Holy Grail?

The beta version of Tim is available on the web. It is a basic, steady-state, analytic element program that includes wells, line-sinks, and circular area sinks. An extensive manual includes a Python tutorial, specifically geared towards analytic element developers and a detailed description of the design of the program and the implementation in the code. (The manual assumes that the user knows basic Python commands. You want to learn? Download a free tutorial from the Python website.) Current developments are carried out by Vic Kelson, Willem Jan Zaadnoordijk and Mark Bakker. A new release is planned for this summer and will include 3D particle tracking and transient analytic elements.

The Python website is at <http://www.python.org/> Download Tim from <http://www.engr.uga.edu/~mbakker/tim.html>

AEM Codes for 2D & 3D Groundwater Flow

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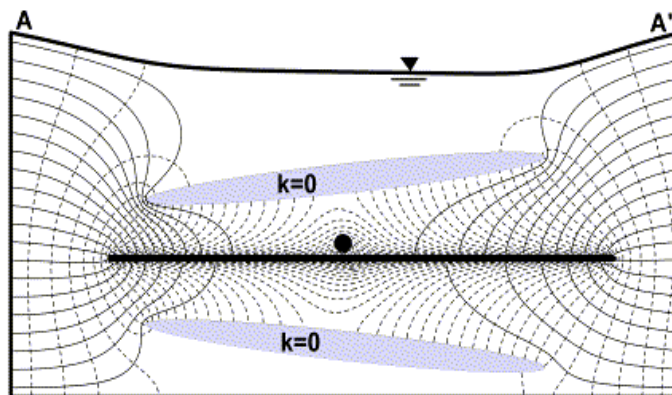
Split is a program for analytic modeling of single-layer groundwater flow in heterogeneous aquifers. Split includes particle tracking, capture-zone delineation, and parameter estimation. Split supports modeling of inhomogeneities bounded by polygons, spatially variable recharge, rivers and lakes with bed resistance, discharge- and head-specified boundaries, and many other features. The only inputs are hydrogeologic features. The user is not required to make decisions that affect the numerics of the underlying computational engine.

ArcFlow is an ArcView extension that seamlessly connects the geographic modeling information to the Split groundwater flow model. ArcFlow takes point, line, and polygon features, generated by the modeler in ArcView, and creates the Split input file, then uses dialogue boxes for hydrogeologic and model input. Geographic information is read directly from active ArcView themes. Split is launched from ArcFlow and new themes with the model output (e.g. head contours, capture zones) are brought back into the ArcView project.

Relevant GIS coverages are immediately available to the modeler for the construction of the model elements and for comparison with results. For example, ArcFlow automatically provides elevations of streams and rivers through a query of, for example, a digital elevation model. ArcFlow shows stream gains, losses, and discharges, predicted by Split. Existing ArcView extensions and scripts can be included in the modeling process. New scripts and extensions can be created. Extensions have been created to manage image files, generate geologic cross-sections, and access well data bases. The result is an ArcView-based modeling system with an embedded groundwater model.

PhreFlow models 3D transient flow and advective transport in a domain bounded by an impermeable base, a phreatic surface with recharge, and head specified lateral boundaries. The domain may contain an arbitrary number of wells of any orientation and inhomogeneities shaped as rotational ellipsoids of arbitrary conductivity. The well discharges and recharge can vary with time. PhreFlow uses a combination of the analytic element method to account or spatial distribution of heads and discharges and a finite difference method to account for transient conditions. PhreFlow outputs include heads, particle pathlines and capture zones.

The programs Split and PhreFlow have also been used to investigate macroscopic dispersion. Research versions of these programs allow for implementation of as many as 100,000 circular inhomogeneities in 2D (Split) and 10,000 inhomogeneities shaped as rotational ellipsoids in 3D (PhreFlow) with analytic accuracy. The programs, including examples, manuals, references and movies depicting the dispersion process, may be downloaded from www.groundwater.buffalo.edu. This figure shows intersections with constant head surface and projections of selected pathlines on vertical plane for a steady-state problem that includes two impermeable lenses and two nearly-horizontal wells.



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Source Water Area Delineation of Public Water Supply Wells using WhAEM2000

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WhAEM2000 is a public domain computer program that solves steady state ground-water flow and advective streamlines in homogeneous, single layer aquifers. The program was designed for capture zone delineation in support of protection of the source water area surrounding public water supply wells.

The computational engine within the software is based on the analytic element method, with point sinks for representing wells, line-sinks for rivers, no-flow line elements for impermeable boundaries, uniform flow functions to lump far-field boundaries, and a rainfall function for representing constant recharge. The development of WhAEM2000 has been a cooperative effort between the US Environmental Protection Agency Office of Research and Development, the EPA Office of Ground Water and Drinking Water, Indiana University, and the University of Minnesota.

WhAEM2000 is intended to support conceptual model development and testing in a step-wise approach. The EPA Report "Working with WhAEM2000" guides the user through a wellhead protection case study involving the wellfield of the city of Vincennes, Indiana, which is located in glacial valley fill. WhAEM2000 supports capture zone delineation based on: (1) calculated radius methods for wells in a flat piezometric field; (2) uniform flow methods where far field sources of water are lumped into a single function; and (3) geohydrologic modeling including the influence of hydrologic boundaries such as rivers and lakes. Protection areas are designed and overlaid upon electronic base maps. The base maps are based on US Geological Survey Digital Line Graph (DLG) or DXF sources. The release of streamlines from the well radius, backward into the gradient, of length related to residence time, provides the basis of the capture zone. Observed heads can be placed on the basemap as test points, and the difference between simulated heads to observed heads can be represented graphically with triangles that are sized based on the magnitude of residual, and colored and oriented based on the sign of the residual. WhAEM2000 has on-line help and tutorials.

The WhAEM2000 graphical user interface was written in Visual Basic by Vic Kelson. The Fortran solution engine is based on the code ModAEM by Vic Kelson. Access to Henk Haitjema's GFLOW solution engine, including resistance line-sinks and inhomogeneity elements, is planned in a future release.

WhAEM2000 software, user guide, and binary basemaps can be downloaded from the EPA Center for Exposure Assessment Modeling (<http://www.epa.gov/ceampub/whaemap.htm>) or the EPA Center for Subsurface Modeling Support (<http://www.epa.gov/ada/csmos/models/whaemwin.html>). Training courses in Source Water Delineation using WhAEM2000 will be offered through the EPA Drinking Water Academy (<http://www.epa.gov/safewater/dwa.html>).

The Analytic Element Model GFLOW

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The groundwater flow model GFLOW implements the analytic element method for steady state single aquifer flow. The newest (Windows) version, GFLOW 2000, supports domains with differing hydraulic conductivity, aquifer base elevation, porosity and aquifer recharge. In addition, it features fully and partially penetrating slurry walls and wells, and line-sinks with resistance to flow between the aquifer and the surface water features they represent. The program supports three-dimensional particle tracking and flux inspection lines, which are polygons across which the groundwater flow is reported. To facilitate model calibration, the GUI displays up and down arrows at test points (locations with measured heads), proportional to the difference in modeled and measured head. Conjunctive stream flow and groundwater flow solutions calculate steady state stream flow in a set of line-sink strings that form a stream network. Thickness of line-sinks is proportional to the local stream discharge.

In this diagram, a tributary to the East Fork of the White River is pumped dry by an expanded well field in Columbus, Indiana. The line-thickness of the tributary and the river is proportional to the stream flow. The dry section shows up as a thin gray line. A bundle of particle traces marks the capture zone for one of the wells. Polygons represent outwash areas with differing aquifer properties and recharge rates.

GFLOW 2000 is used by students, government agencies, and consultants. The USGS in Wisconsin uses it as a screening tool and starting point for detailed MODFLOW models. The states of Wisconsin and Ohio as well as many consultants use it for capture zone delineation in the context of wellhead protection. In Nevada, GFLOW was used to model the impact of projected groundwater withdrawals on several springs in the desert north of Las Vegas. The USEPA uses it for large-scale regional aquifer modeling in the eastern part of the US.

GFLOW was developed by Henk Haitjema (beginning in 1985) at Indiana University as an educational tool for his groundwater modeling class. Several of his PhD students contributed to the further development. Dr. Steve Kraemer added a partially penetrating well function (1988); Dr. Sherry Mitchel-Bruker added steady state surface water solutions (1996); and Dr. Vic Kelson added code to automatically extract a local MODFLOW model out of a regional analytic element model. The DOS version of GFLOW consists of the solver GFLOW1 and the preprocessor GAEP (by Phil Dilavore and Vic Kelson) and has been available as a free educational code or a commercial code since 1994. GFLOW 2000 consists of an enhanced GFLOW1 solver and a GUI modeled after EPA's WhAEM program.

GFLOW 2000 is available as a public domain version, the educational version, and as proprietary software. The educational version is equally powerful as the proprietary version, but misses some of the export functions, including the export of a large MODFLOW model (it does support export of a small model). The program is equipped with a context sensitive Help System. The code may be downloaded from www.haitjema.com. The same web site also contains additional documentation. The novice analytic element modeler (and GFLOW user) may benefit from reading the text "Analytic Element Modeling of Groundwater Flow" by Henk Haitjema published by Academic Press in 1995, which offers an introduction to the theory and application of the analytic element method.

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3DFlow: A Public Domain Code for Modeling and Visualizing 3D Groundwater Flow

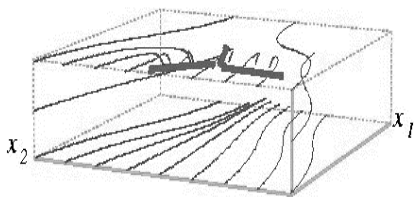
David R. Steward, Kansas State University, steward@ksu.edu

3DFlow is a public domain, interactive computer tool that models and visualizes 3D groundwater flow. This tool simulates steady flow to horizontal wells, partially penetrating wells and fully penetrating wells in a regional field of uniform flow. Aquifer features may be located in a horizontal aquifer bounded by two planes, in a semi-infinite aquifer bounded by one horizontal plane, or in an aquifer that is infinite in extent. 3DFlow provides an interactive learning environment with pull-down menus and projection of a 3D view region on the screen.

The analytic approach provides a continuous representation of groundwater head and velocity, enabling a boundary condition of uniform head to be accurately matched along horizontal wells. It also enables accurate prediction of streamlines and travel time.

An example illustrating 3DFlow is presented in figures showing streamlines near a horizontal radial collector well. Streamlines pass through a set of user specified lines, located along the edge of the view region at the lower limit of x_1 in this figure. A boundary condition of uniform head is matched along this well by distributing the flux into the well (pumping rate) with a non-uniform distribution that is computed by 3DFlow and illustrated in the graph. The interactive environment provided by 3DFlow enables evaluation of multiple well configurations.

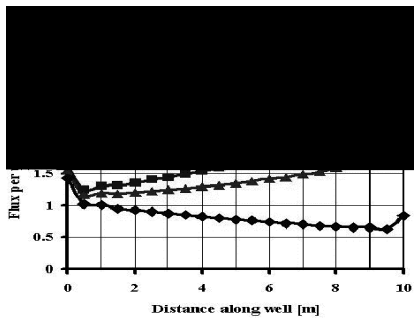
Horizontal radial collector well



Three-dimensional view
Flux into horizontal well



Plan view (normal to x_3 -axis)



3DFlow currently runs only under the DOS operating system, and requires 64MB of memory. Development of 3DFlow was partially supported by KIWA and RIZA in the Netherlands. For more information, visit: <http://www.groundwater.ce.ksu.edu>

State of the art in AEM modeling practice

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Three major advantages of AEM modeling techniques are (1) the inclusion of groundwater flow at any scale in one model, (2) the possibility to refine parts in a model without changing the model outside those parts and (3) the capability of coupling of existing models. Most of the advanced use of the techniques uses one or more of these advantages. An example of advantage (1) is the Yucca Mountain Model of Bakker et al. (1999), covering about an area of 300.000 km², including rivers at large distances, wells at their exact locations and variation of the aquifer transmissivity. An example of advantages (1), (2) and (3), is the Bethune-polder model of Moorman (1999), in which detailed 3D flowlines are computed in a polder area covering a part of two sub-models of the national model of the Netherlands, NAGROM (De Lange, 1991, 1996). The flowlines matched field conditions well. The model was built to show consequences of a possible future change of the polder back into a lake.

NAGROM was built as part of an integrated instrument for water management in the Netherlands (RIZA, 1996). NAGROM has served as a basic set of models for many studies in which it was used either as the "outside world around the local area of interest" (even for FDM and FEM models by delivering boundary conditions) or as a basis for regional studies on applied water management of major surface waters in the Netherlands (e.g. river Meuse, Lake IJsselmeer).

AEM is capable of handling: multi-aquifer flow, piecwise variation of aquifer conductivity, thickness and base, continuous variation of resistance of separating layers and of surface water levels on top of a model, three-dimensional continuous variation of the water density in a multi-aquifer system, transient behavior using elements for areal storage and multi-resistance/multi-surface-water-level boundary-condition e.g. for ditches or drains that may fall dry. All versions of the AEM provide three-dimensional particle tracing and most have a GUI and/or connections to GIS. Finally, most if not all AEM software will become open and compatible in an object oriented framework.

References

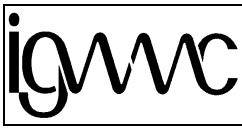
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STANMOD Version 2 for Windows - Analytical Solutions for Transport

STANMOD (STudio of Analytical MODels) is Windows-based software available through a Cooperative Research and Development Agreement (CRADA) between IGWMC and the U.S. Salinity Laboratory in Riverside, CA. All the codes are easy to use, efficient and provide accurate optimization. **CXTFIT2** [Toride et al., 1995] estimates solute transport parameters using nonlinear least-squares parameter optimization by fitting a variety solutions for the 1D advection-dispersion equation to experimental results and may also be used to solve the direct or forward problem, including: equilibrium transport; chemical or physical nonequilibrium transport; and stochastic stream tube transport assuming local-scale equilibrium or nonequilibrium. **CFITM** [van Genuchten, 1980], a simple alternative to CXTFIT2, uses analytical solutions for 1D equilibrium transport, considering semi-finite and finite media to determine transport parameters by optimizing observed breakthrough data. **CFITM** [van Genuchten, 1981] analyzes observed column effluent data using analytical solutions for 1D equilibrium or nonequilibrium transport in semi-finite columns; including: nonequilibrium, a dual-porosity flow model, and one- or two-site sorption models. **CHAIN** [van Genuchten, 1985] analyzes advective-dispersive transport of solutes involved in sequential first-order decay reactions with up to four species in a decay chain. **3DADE** [Leij and Bradford, 1994] evaluates analytical solutions for 2- and 3-D equilibrium transport in the subsurface, assuming steady unidirectional water flow and accounting for retardation, first-order decay, and zero-order production. 3DADE can solve the direct problem or the inverse problem. **N3DADE** [Leij and Toride, 1997] evaluates 2- and 3-D nonequilibrium solute transport in steady unidirectional flow fields, for systems of semi-infinite longitudinal length, and infinite transverse length, with nonequilibrium transfer between two domains in either the liquid phase (physical nonequilibrium) or the adsorbed phase (chemical nonequilibrium) accounting for retardation, first-order decay, and zero-order production.

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Applied Environmental Statistics ID # 01-1	Dennis Helsel Ed Gilroy	May 21, 2001 4 days	May 24 8am-5pm	\$1395 \$1495/May 11
Zero to Kriging in 30 Hours ID # 01-2	Isobel Clark Bill Harper	June 7, 2001 3.5 days	June 10 8am-5pm	\$1245 \$1445/May 24
MODFLOW: Introduction to Numerical Modeling ID # 01-3	Eileen Poeter Evan Anderman	September 8, 2001 4 days	September 11 8am-5pm	\$895 w/MODFLOW 2001, \$1095 w/o
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