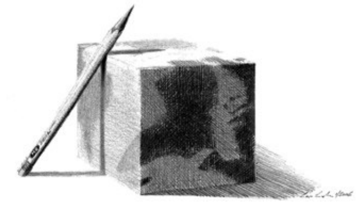
Associazione Monte Porzio Cultura and Comune Monte Porzio
in partnership with
Dipartimento di Geotecnologie per l’Ambiente e il Territorio
Università “*G. d’Annunzio*” di Chieti

www.GIScience.it



Advanced course

Applied groundwater flow and transport modelling

Groundwater management at regional scale for water supply policies assessment and at local scale for environmental remediation of contaminated sites

“*It is a capital mistake to theories before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts*”

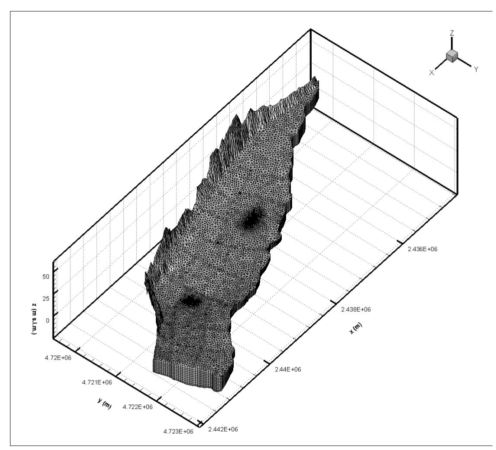
In Anderson and Woessner, after Sherlock Holmes in “*Scandal in Bohemia*”

Course scope

The course aims to introduce to groundwater modelling, in the framework of water supply and environmental protection and remediation projects.

The course covers fundamental of flow and transport groundwater modelling, including density-dependent behaviour so relevant to coastal areas where, particularly in Italy, most relevant urban and industrial settings are concentrated.

Based on theroretical flow modelling foundations (Darcy and continuità equations), density-dependent numerical formulation and contaminant transport processes (advection, decay and adsorption) are investigated, focusing on both analytical and numerical solutions with a specific focus on finite difference and finite elements methods. The course focuses on main steps of groundwater modelling development protocol, in the attempt to highlight major bottlenecks and critical issues.



3D discretization mesh Feflow FM3

Initial conceptual model validation and simulation of future scenarios both play a major role in groundwater modelling, demanding for high quality in documenting calibration process and final output. Surfing through this difficult path and balancing technical, ethical and communication issues, the guidelines of a best-practice application protocol are sketched. Focusing on data quality, documentation (metadata) and processing (lineage), fundamentals of applied design, development and management of groundwater GIS software platforms coupled with modelling software is reviewed. Geodatabases devoted to surface water and groundwater data management, namely the Hydro Data Model for ArcGIS™ 8/9 after **CRWR (C**onsortium for **R**esearch in **W**ater **R**esources, Austin, Texas), and the key role of geological, structural and hydrogeological interpretation are also considered.

Groundwater modelling learning path is generally a steep one, demanding for a strong multisciplinar approach involving such different application fields as geology, hydrogeology, spatial statistics, numerical analysis, software engineering and development. Despite all these issues, the course is still introductory, not demanding for previous in-depth experience but trying to put light on relevant bottlenecks and more common errors affecting output quality of modelling tasks.

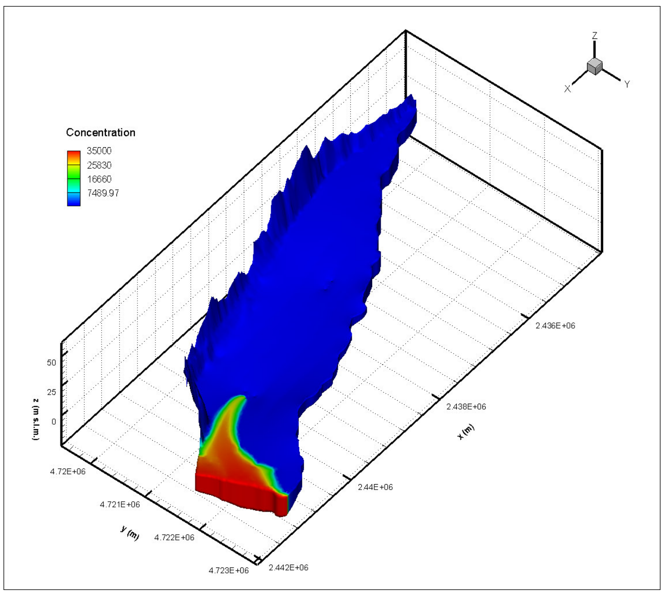
Foreword

Water resources historically played a key role worldwide. Large regions (i.e. Sahel, African horn and central-western Asia) have been traditionally affected by water supply shortages (UNEP, 1997) due to low precipitation and high evapotranspiration rates, demanding for increasing exploitation of fossile deep aquifers. The same quantity problems still affect most other regions worldwide, for example during summer time in. many touristic sites in Italy due to increased water demand.. Quality issues turn to be of major concern too, including extensive salinization phenomena along coastal areas, due to overexploitation policies. All the problems above and their impact on transboundary policies assessment and management are also well known at European level, increasingly demanding for actions contrasting desertification phenomena related to climate and land use modifications (EU, 2003).

Particularlly relevant to human use, quality problems emerge in both developed and developing countries, ranging from overuse of pesticides in agriculture, to industrial activities and lack of water sanitation (Tolba, 1992).

.Despite surface waters can locally play a major role as a source of water supply, face to both technical and cost-benefits considerations, groundwaters are still an extremely valuable protected resource and deeper aquifers are often expòloited to address both quantity and quality degradation issues. Relevant examples include Nubian Sandstones in sahelian region or Po plain multiaquifers system in north Italy.

Face to above issues, academic and applied hydrogeological and modelling research are well established disciplines, with wide relevance in environmental-oriented scientific journals and conferences. In this framework, GIScience also turns to play a major role, with emerging disciplines as Hydroinformatics, **GwGIS**s (**G**roundwater **G**eographical **I**nformation **S**ystems) development and groundwater flow and transport modelling, disciplines being central to current course.



Vomano valley
Salt water intrusion in coastal areas due to groundwater overexploitation

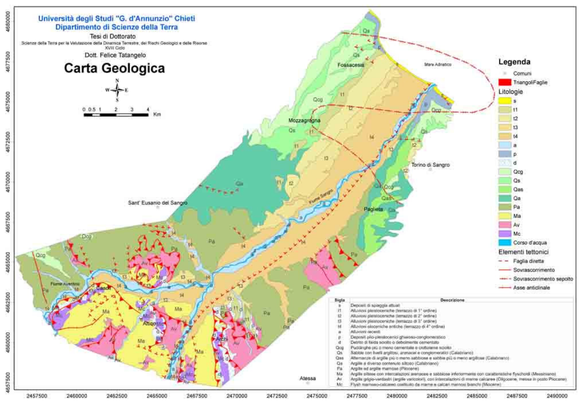
GwGIS definition can be properly focused after Cowen (1988) "*a decision support system integrating georeferenced spatial data in a problem-solving environment*", by including "*addressing groundwater management issues and policies*". GwGIS provides a technological and conceptual framework for both hydrological and hydrogeological data analysis, simulation numerical models development and, generally speaking, SDSSs development.

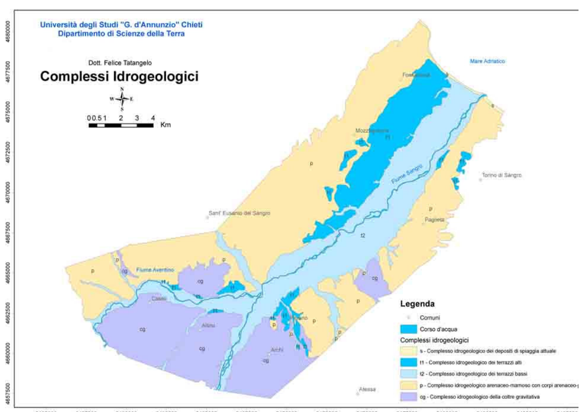
Today groundwater modelling is central to water management and protection policies assessment, particularly in the legislative framework of the 471/99 Law, in Italy, and the recent EU Water Directive. Validation of conceptual models and quantitative simulation of groundwater systems behaviour both contribute to proper design of environmental protection measures in contaminated sites and prove useful in water supply policies design on the medium-long time horizon. Fundamental to industry and increasingly requested by environmental protection authorities, groundwater modelling has turned to be a fundamental step in most environmental consulting.

Analysis of groundwater modelling development protocol and hands-on sessions, focusing on GMS (MODFLOW, MODPATH and MT3D finite difference codes) and on the finite elements 3D and density-dependent FEFLOW modelling environment, will contribute to highlight major relevant problems and risks related to calibration and simulation processes.

The course is part of a wider learning project focused on GIScience and on development of **GIS**s (**G**eographical **I**nformation **S**ystems), relevant to most application areas, as urban planning and environmental protection, just to recall two of them. And the course is effectively focused on **EIS**s (**E**nvironmental **I**nformation **S**ystems) development and specific fields of spatial analysis and modelling applied to groundwaters.

Due to its main focus on applications and modelling protocol, Anderson and Woessner (1992), "*Applied Groundwater Modeling: Simulation of Flow and Advective Transport*", has been adopted as the reference textbook for the course.





Valle del Sangro
Geological and hydrogeological interpretation

References in text

Cowen D.J., 1988. GIS versus CAD versus DBMS: what are the differences?. Photogrammetric Engineering and Remote Sensing, 54, pp. 1551-1554

EU, 2003. Water policy in the European Union, available from: http://europa.eu.int/comm/environment/water/index.html

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UNEP, 1997. Global environment outlook. Published by the United Nations Environment Programme and distributed by Oxford University Press.

Course program

The course will be based on a theoretical and hands-on path, focusing on fundamental steps towards satisfactory model implementation. Following a review of FEFLOW fundamentals, a numerical flow and transport 2D/3D simulation environment in saturated, unsaturated, fractured and density-dependent conditions, application details will be explicitly addressed along practical sessions. Role of calibration choices, including extension of modelling area and proper selection of boundary and internatl conditions, will be reviewed, and issues relevant to coupling with external 3D and time-dependent geodatabase and GIS software platforms will be addressed in the framework of complex modelling approaches.

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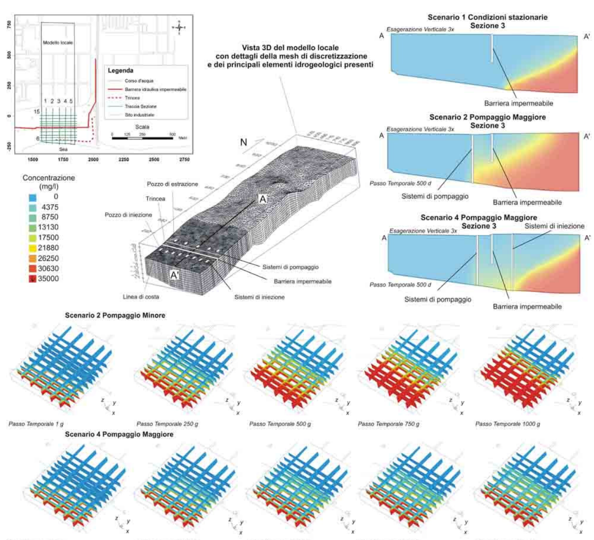
Introduction to numerical modelling and codes

This introduction focuses on basic theory, architecture of relevant numerical codes and state-of-the-art guidelines in applied groundwater modelling. Despite a deep knowledge of numerical formulation is not necessarily required in simpler applications, it definitely contributes to a correct approach to modelling tasks and turns to be fundamental in complex applications.

- ❑ Introduction to groundwater modelling: scope, objectives (prediction, interpretation and general) and implementation protocol (conceptual model, calibration, sensitività analysis, simulation and postaudit);
- ❑ Basic flow equations (*Darcy* and continuità)) and review of numerical formulation of finite difference method (space and time discretization, at local and global scale, computation matrices and steady-state solution with explicit and implicit methods, based on iterative approaches). Geometry, hydrogeological and hydrological properties, *sources* & *sinks*, boundary conditions (Dirichlet, Neumann and Robbins). Fundamentals of finite elements numerical method and comparison against finite difference. Transport equations;
- ❑ Flow and transport finite difference and finite elements numerical codes: Modflow/Modpath from USGS, /Mt3d and Feflow from WASY;
- ❑ Case studies of groundwater modelling for water management at large scale and environmental remediation in contaminated areas, with a specific focus on density-dependent conditions in coastal areas.

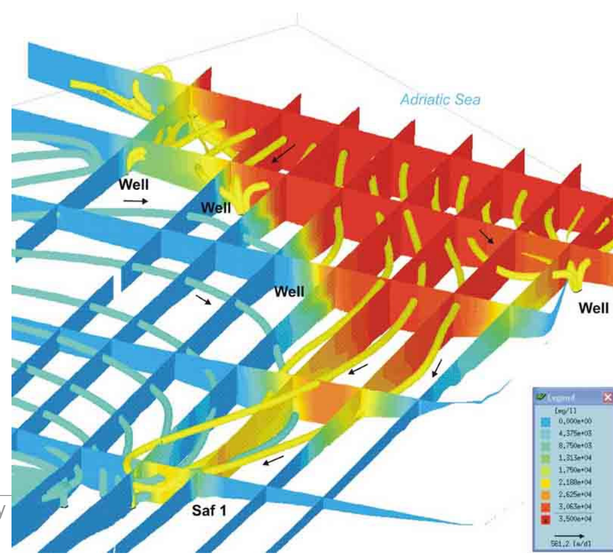


Density-dependent numerical analysis to assess groundwater data management policies in a coastal area

Conceptual model

Building a conceptual model of a hydrogeological system is a complex task. Geometry, hydrogeological and hydrological properties, estimation of their spatial distribution face to data quality and data density issues all play a relevant role in proper assessment of modelling scope and objectives.

- ❑ Basic data: recharge by rainfall and by leakage from human-made infrastructures, land use, system geometry and hydrogeological properties. Hydrogeological interpretation, spatial analysis and regionalization tasks (statistics, variography and Kriging). Major bottlenecks and critical issues in modelling tasks: and properties transfer to discretization grids and meshes.
- ❑ Conceptual modelling fundamentals: extension of modelling area, lithostratigraphic and hydrogeological units, flow balance and modelling strategies. 2D models in confined and phreatic conditions, vertical leakage in quasi 3D and 3D addressing multiaquifer systems conditions.
- ❑ Discretization grid/mesh design in 2D and 3D, to minimize risks of failure in



3D advanced visualisation of groundwater pathlines and saline concentration distribution in Feflow 5.2 FM3 numerical convergence and maximize efficiency of computation process.

Development and life of a numerical model: calibration, simulation and *postauditing*

Development and life of a numerical model has both technical and communication implications. While calibration is undoubtedly a fundamental step in modelling development, next steps often reveal the complexity of underground hidrology leading to consider more complex or totally new objectives, face to both technical and legal requirements. All the above steps, including calibration, simulation, model output verification (*postaudits*) and outcomes communication, are the major focus of current course.

- Calibration is the core activity in modelling protocol, often time-consuming and definitely critical to the next steps of the model life. Following a *trial and error* process, calibration aims to reproduce the observed behaviour of the groundwater system (i.e. spatial and temporal distribution of piezometric heads, contaminant concentrations). Different approaches to calibration risks and bottlenecks are reviewed in detail, face to scopes, objectives, investigation scales, application complexity (i.e. 2D vs. 3D, flow vs. transport, density dependent or fractured conditions), different geometries, hydrological and hydrogeological properties distribution, in the framework of spatial statistics targets.

- Simulation, focused on both conceptual analysis and prediction, is the final target of any modelling process. Face to different objectives and scales, simulations potentially address a wide range of questions, ranging from large scale groundwater exploitation policies assessment in the framework of a sustainable development approach to local scale analysis for environmental protection and remediation. Focusing on numerical assessment of time-dependent systems behaviour, simulation supports the definition of both general and local best-practice guidelines (i.e. exploitation policies, efficiency of wells barriers in capturing contaminated flow), in the framework of a cost-benefit analysis.

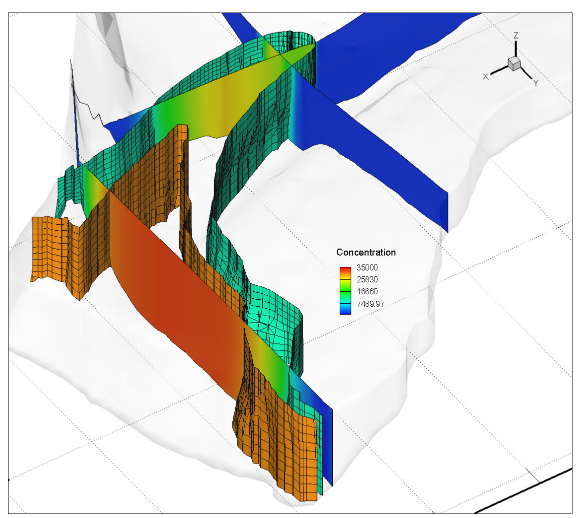
- Post-calibration assessment and modelling outcomes communication also play a major role, face to the discipline complexity, to the requirements of efficient technology transfer, proper assessment of modelling uncertainty and, last but not least, equilibrium in relationships with all stakeholders (industry, environmental agencies, population, etc..). Once new data are collected and new knowledge emerges, or new more complex objectives are focused on, further developments in the calibration process are generally required

Data output Management and visualization in advanced groundwater modelling applications

Efficient hydrological and hydrogeological data management and the availability of fully integrated modelling environments, following the principles of **ESDA** - **E**xploration **S**patial **D**ata **A**nalysis), and advanced 3D/time dependent visualisation play a key-role in supporting groundwater modelling activities. Available tools contribute to cut development times, while enhancing the overall efficiency of modelling process, otherwise not realistically feasible (i.e. complex 3D and fractured environments). Definitely they support a spatio-temporal integrated approach along all steps of groundwater modelling protocol.

- Brief overview of relational databases and OO geodatabases, last-generation GIS platforms, personalization tools (i.e. VBA/ArcObjects for ArcGIS 8/9,), hydro extensions (*Hydro* and *Groundwater Data Model*) and advanced 3D/time dependent visualisation solutions (Tecplot).

- Integrated numerical modelling environments, with full pre- and post-processing features, supporting 2D/3D and time-dependent conditions, calibration process assessment (statistical measures and graphical display of obs. vs. comp.) and state-of-the-art visualisation



Salinity isosurfaces and concentration distribution over Sections, in Tecplot 9 after a Feflow FM3 simulation solutions (3D, *slicing*, animation). Philosophy and architecture of GMS groundwater modelling systems GMS (Brigham Un.) and FEFLOW (WASY) will be compared.

Hands-on sessions

All major steps in groundwater modelling development will be explicitly addressed in the hands-on session, focusing on the real case of the Vomano valley (north Abruzzo, Italy), addressing groundwater management and exploitation policies face to risks of overexploitation and salt water intrusion phenomena, as well as environmental protection and remediation issues..

Implementation of modern **GDI**s (**G**eographical **D**ata **I**nfrastructures) guarantees referential data integrity, efficient data querying and full access to data documentation (metadata), turning to play a major key role in supporting a consistent approach to groundwater data modelling tasks. New ArcGIS 8/9 geodatabase models for surface water and groundwater data management (Maidment, 2002; Strassberg & Maidment, 2004; **CRWR** - **C**entre for **R**esearch in **W**ater **R**esources) and the availability of mature GIS software platforms strongly contribute to effective modelling (conceptual models definition, spatial statistics analysis and calibration, mapping and 3D visualization).

Geodatabase and GIS are relevant to implementation of integrated modelling and management systems, starting from elementary loose coupling strategies, based on simple file transfer protocols, up to fully integrated (tight coupling) ones. 3D and time-dependent (transient state) conditions highly benefit from such a structured approach, making modelling tasks easier to control and more consistent with scope and objectives.

Hands-on sessions will cover preliminary analysis of conceptual models, including stratigraphic and hydrogeological units analysis, hydrological and hydrogeological properties distribution, internal and boundary conditions (heads, flows and concentrations). Sensitivity analysis addressing uncertainty issues and supporting further steps of hydrogeological process will be investigated in detail, further focusing on true scope and objectives face to complex projects.

The real case of the Vomano valley (Abruzzo), focused on optimization of pumping regimes at main well fields and related risks to induce salinization phenomena, will be reviewed from both a MODFLOW and a FEFLOW point of view, addressing future scenarios in medium-long term simulation perspective. The balanced role of recharge by direct infiltration and leakage from surface water bodies, the relevance of a major paleo-river and all the hydrogeological features revealing from stratigraphies and indirect geophysical information (geoelectrics) will be explicitly investigated face to calibration process requirements.

GIScience project

The course fits in the framework of a wider learning GIScience project. Supported by high-level professional and academic profiles focused on the fields of GIScience and Environmental protection and remediation, the project addresses introductory issues in the GIScience introduction course and in a seminar devoted to *Business Geographics & Geodemographics*, and more advanced topics in software engineering and programming in the two courses on VBA/ArcObjects for ArcGIS 8/9 and JAVA.

The new advanced courses on environmental project management and groundwater flow and transport modelling focus on the growing environmental market, with its demand for high specialization. These courses perfectly fit in the project framework, being focused on **EIS**s (***E**nvironmental **I**nformation **S**ystems*) design and development, including advanced issues as spatial statistics, modelling, **ESDA** (**E**xploratory **S**patial **D**ata **A**nalysis) and 3D/time-dependent visualization.

Following a complex and coherent learning path, after principles of traditional part-time and distance learning philosophy, and thanks to previous 2003-2005 editions experience, the course is based on both formal classes and self-learning, making course accessibility easier and final learning targets more realistic.

Software

MsOffice™, RDBMS MsAccess™ (www.microsoft.com) and Feflow FM3™ (WASY, www.wasy.de).

Who is it for?

Environmental and Earth sciences experts, ITC and GIS professionals, Water resources consulting companies and public authorities professionals working in the water resources sector.

It is required: a deep knowledge of PC/MsOffice™ environment, a basic knowledge of interpretation , management and analysis of hydrological and hydrogeological data. It is not required knowledge of design and development of relational databases, geotabases, GIS softwares, numeric modelling, even if a previous exeperience could be useful. The course book has a didactic and scientifica approach that allows a easier understanding of the topics covered.

Location & dates

The course will take place at the Environmental Education Centre Casa Archilei, located in Fano (PU) and easily accessible from major transport links. The course will have a duration of 40 hours, with 8 hours lessons on Saturdays, following a calendar balancing the needs for didactic continuity and in-depth learning requirements. Calendar details are available on www.giscience.it web site.

Registration

Registration forms are available at the Administration Office of Monte Porzio Cultura, they can be downloaded in PDF format or they can be requested via Email at info@giscience.it .

Course fees are 1050 € + VAT (20%) in a unique payment before course starting. For payments prior to 1/3/2007, a reduced fee of 1000 € + VAT (20%) will be applied.
Participants in previous GIScience courses promoted by the Association, students regularly enrolled in degree, post-degree and Phd courses at Italian or foreign universities at the moment of registration, as well as education Institutions, public and private companies enrolling more than one person will benefit of a 10% discount.

Fees must be payed by bank transfer to "Associazione Monte Porzio Cultura", Account # 000020111416, "BANCA SUASA – Credito Cooperativo, Filiale di Castelvecchio", Strada Cesanense, 137 – 61040 Castelvecchio (PU) - ABI 08839, CAB 68451, CIN J, with the clear statement "Participation in course Applied groundwater flow and transport modelling". If 10% discount conditions are satisfied, they must be explicitly reported on the registration. Both registration form and photocopy of bank transfer must be sent by fax to 0721-862724 at the attention of Ing. D. Guanciarossa.

Associazione Monte Porzio Cultura reservs the right to refuse registration or to withdraw the course, depènding upon maximum and minimum number of participants. In case of course withdraw, already paid registration fees will be remboursed.

Certificate

At the end of the course, participants attending at least 70% of the lessons will be awarded a Completion certificate.

Didactic material

The course book provided to each participant is:

Anderson, M.P. and Woessner W.W., 1992. *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*. Academic Press Inc., San Diego CA, USA.

For those interested in further documentation please refer to the following reference bibliography:

Bear, J. and Verruijt, A., 1987. *Modelling Groundwater Flow and Pollution*. Reidel, Dordrecht, Holland.

De Marsily. G., 1986. *Quantitative Hydrogeology. Groundwater Hydrology For Engineers*. Academic Press Inc., San Diego CA, USA.

Kinzelbach, W., 1986. *Groundwater Modelling. An Introduction With Sample Programs In Basic*. Elsevier, Amsterdam, Holland.

Maidment, D.R., 2002. *Arc Hydro: GIS for water resources*, ESRI Press, Redlands, CA, USA

Pinder, G.F., 2002. *Groundwater modelling using geographical information systems*. Wiley & Sons, ISBN : 0-471-08498-0, 248 p.

van Deursen W.P.A., 1995. *Geographical Information Systems and Dynamic Models*, Ph.D. thesis, Utrecht University, NGS Publication 190, 198 pp. Available from:
www.carthago.nl and http://www.geog.uu.nl/pcraster/thesisWvanDeursen.pdf

For GMS e FEFLOW documentation, check the following websites:

Ems-I, 2005. *Environmental Management Systems*. Inc. Web site: www.ems-i.com.

WASY Software, 2005. FEFLOW: Finite Element Subsurface Flow System. Fes Web site: http://www.wasy.de/english/produkte/feflow/index.html.

For those interested in the geodatabase "Hydro Data Model" and"Groundwater Hydro Data Model":

Ormsby T., Napoleon E., Burke R., Groessl C. e Feaster L., 2001. *Getting to know ArcGIS desktop: basics of ArcView, ArcEditor and ArcInfo*. ESRI Press (includes a CDROM with a 180 days trial copy of ArcGIS™)

Info

For further information, please refer to Ing. David Guanciarossa, President of "Associazione Monte Porzio Cultura", Email address info@giscience.it or go to the Contacts section of www.giscience.it website.