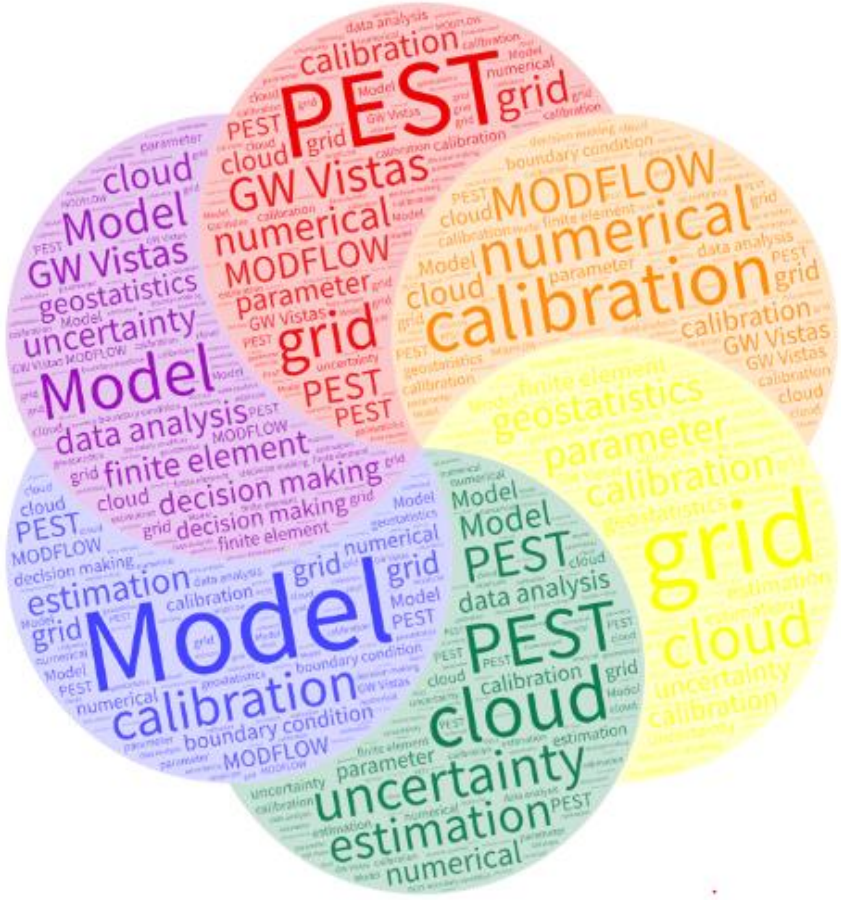


Modular Course

THIRD CIRCULAR – May 2019

Groundwater Numerical Models and How to Make them Useful

ON-LINE SESSIONS
13 & 20 September 2019
4 & 11 October 2019
Unicam e-learning platform

ON-SITE SESSION
9-10 December 2019
Milan, Italy
Venue to be confirmed

Initiative with the recognition of the
International Association of Hydrogeologists (IAH)

Info: **formazione@kataclima.com**

THE MODULAR COURSE

The object of the course is building and calibration of groundwater numerical models with the application of uncertainty analysis through different methods, available through the PEST and PEST++ suites. The course structure will be modular, with the possibility of participating in one or more modules independently. Participation in all modules will entitle participants a 20% discount.

Course Presentation

The course covers a wide range of topics, from GIS data processing to the most advanced modelling and model-based data-assimilation techniques. The target audience are those who develop, calibrate, deploy and rely on models to support environmental decision-making. Nevertheless, the discussion will be extremely interesting also for those who use models, such as managers, stakeholder groups and anyone who wishes to better understand what modelling can, and cannot, offer to the decision-making process.

In order to allow participants to understand and discuss important concepts, the course is distributed over a sufficiently long time-frame to be "fruitfully intense" while not "intensive". It is divided into three modules of progressively increasing complexity:

- The **first module (on-line)** deals with data processing, geostatistics and the basics of modelling, introducing the first concepts of model calibration – both manual and automated through PEST.
- The **second module (on-line)** focuses entirely on model calibration. It is intended for those who are already familiar with modelling. In this module, model calibration will be undertaken using both PEST and the new ensemble smoother available through the PEST++ suite. These programs will be used from both the command line and from the Groundwater Vistas Graphical User Interface. Instruction will be provided on use of command line; this can be useful for many modelling tasks. PEST support utilities will be demonstrated.
- The **third module (on-line AND on-site)** will be delivered in a classroom setting (with a streaming connection for those who cannot attend in person). However, it will differ from traditional classroom settings by:
  - Adopting an informal, conversational approach;
  - Attempting, within constraints set by time and resources, to meet the specific needs of participants, using their own modelling experiences as starting points for discussions.

  The focus of the two-day course is on model-value-adding software, and on its importance to decision-support modelling; appropriate software from the PEST and PEST++ suites will be demonstrated and used as examples. The first day focusses on the "**how**" of model value adding software, with the major focus being on calibration and uncertainty analysis. As such, it is a sequel to the second module, but using more sophisticated tools and techniques. Practical exercises will start from the model that was calibrated in the second module. The second day focusses on "**why**" such software should be used if modelling is to achieve its full potential in decision-support. The day will start with a description of model-value-adding tools that are available for assistance in decision-support modelling. This will be followed by practical examples and case histories. The day will finish with a discussion and exchange of ideas.
- A **final session (on-line)** will be devoted to supporting participants in their personal applications of the skills acquired during the course.

THE DARCY LECTURE

Each year, a panel of scientists and engineers invites an outstanding groundwater professional to share his or her work with their peers and students through this lecture series throughout the world. The 2019 Darcy Lecturer is **John Doherty**, presenting "STARTING FROM THE PROBLEM AND WORKING BACKWARDS".

Many groundwater models are commissioned and built under the premise that real world systems can be accurately simulated on a computer - especially if the simulator has been "calibrated" against historical behaviour of that system. This premise ignores the fact that natural processes are complex at every level, and that the properties of systems that host them are heterogeneous at every scale. Models are, in fact, defective simulators of natural processes. Furthermore, the information content of datasets against which they are calibrated is generally low.

The laws of uncertainty tell us that a model cannot tell us what will happen in the future. It can only tell us what will NOT happen in the future. The ability of a model to accomplish even this task is compromised by a myriad of imperfections that accompany all attempts to simulate natural systems, regardless of the superficial complexity with which a model is endowed. This does not preclude the use of groundwater models in decision-support. However it does require smarter use of models than that which prevails at the present time.

Modelers must be educated in the mathematics and practice of inversion, uncertainty analysis, data processing, management optimization, and other numerical methodologies so that they can design and implement modeling strategies that process environmental data in the service of optimal environmental management.

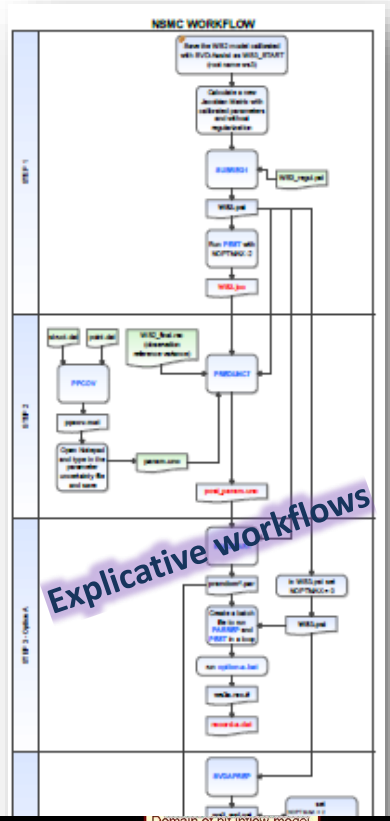
The Darcy lecture, organized by Ivana La Licata and Luca Alberti of the Geosciences group of DICA, will be held at Politecnico di Milano on Dec 11th

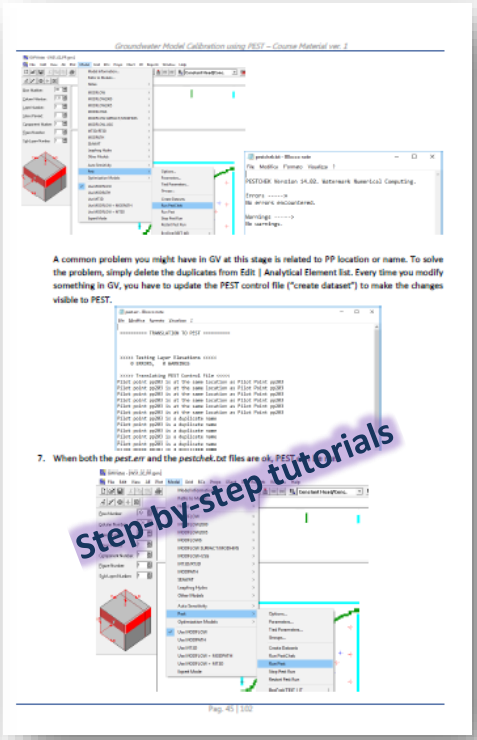
INSTRUCTORS

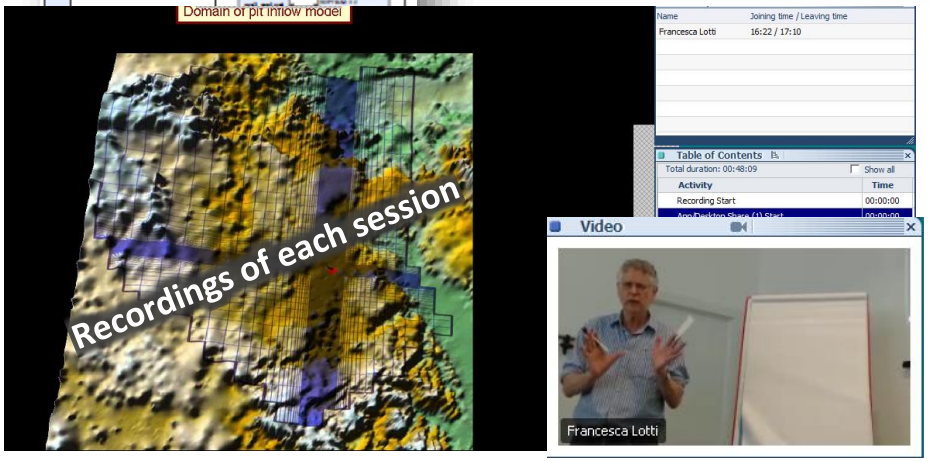
John Doherty, Ph.D, is the author of PEST and its supporting utility software suites. He is a self-employed consultant, who has also held positions with the National Centre for Groundwater Research and Training, Flinders University, Australia, and with University of Queensland, where he has undertaken research and supervised PhD students. He started his career as an exploration geophysicist, then moved to environmental modelling. He has since worked in the government, private and tertiary sectors. His research interests include the continued development of software and methodologies for solution of inverse problems using environmental models, quantification of model predictive uncertainty, and appropriate use of models in the decision-making context.

Francesca Lotti, Ph.D, is a consultant hydrogeologist and partner at Kataclima srl. She has 18 years of experience in field investigations and numerical modelling of contaminated sites, mines, geothermal systems, etc. She collaborates with research institutions and international companies. From 2001 to 2014 she was research fellow at the University of Tuscia, she is adjunct professor at the University of Camerino since 2008, supervisor of many students/PhD/interns, trainer at professional courses and lecturer at the II level Master "*Caratterizzazione e tecnologie per la bonifica dei siti inquinati*" at the University of Rome "Sapienza".

Giovanni Formentin is an environmental engineer and partner at Tethys srl. He has been working for 18 years as a consultant and researcher in the fields of hydrogeology and water management. He applies groundwater flow and transport models to water resources management and remediation of contaminated sites, in Italy and abroad.







COURSE PROGRAMME

Module 1 – Groundwater Numerical Modelling

- *Section A: insights of key topics (1h)*
  - Fundamental concepts of groundwater flow and transport: flow and transport equations, boundary conditions, pumping test interpretation, water balance calculation through map algebra
- *Section B: Geostatistical data processing (3h)*
  - Introduction to applied geostatistics.
  - ***Exercise***: analysis and processing of hydrogeological data-sets, semivariogram modelling, regionalization of field data, evaluation of the uncertainty of spatial distributions
- *Section C: Numerical Modeling (4h)*
  - Introduction to numerical modeling in groundwater: solution of flow equation through finite differences and finite elements, model assumptions and limits
  - ***Exercise***: creation of a simple numerical model with MODFLOW: setting of the grid, boundary conditions, properties, observation points.
- *Section D: Introduction to PEST (4h)*
  - Simplified theory behind one the most powerful software of inverse modelling available
  - ***Exercise***: Sensitivity analysis and calibration of parameters in the previously created model. Critical evaluation of results.

Module 2 - Groundwater model Calibration

- *Section A: Getting familiar with the command line (3h)*
  - Windows settings to make things easier
  - ***Exercise***: execution of general tasks through the prompt line (exercise to check the proper settings of participants' computers and do a little practice)
- *Section B: Structure of files (1h)*
  - Modflow input/output files
  - PEST input/output files
- *Section C: Traditional Parameter Estimation (4h)*
  - Well-posed inverse problem
  - The Jacobian matrix – why it is needed and how to calculate it
  - How to define an objective function and reduce it
  - Observation weights
  - Prior information
  - Some important PEST settings
  - ***Exercise***: Traditional calibration of parameters applied to a pre-build model. Critical evaluation of results
- *Section D: Highly parameterized inversion (6h)*
  - Why do we need regularisation
  - Subspace regularisation – singular value decomposition
  - Tikhonov regularization
  - Measurement and regularization objective functions
  - Pilot points as a spatial parameterization device
  - Optimal pilot point emplacement
  - Pilot points and geostatistical regularization
  - ***Exercise***: pilot point calibration of parameters applied to a pre-build model. Critical evaluation of results.

Module 3 – Making the modelling appropriate for the problem: How and Why

First day - "How":

- *Session A: Uncertainty analysis (2h)*
  - Bayes equation
  - Linear uncertainty analysis
  - Null Space Monte Carlo
  - Ensemble Kalman smoother
- *Session B: Practical application I (2h)*
  - ***Exercise***: hands-on exercise on uncertainty analysis applied to a pre-calibrated model
- *Session C (2h)*
  - The difference between local and global sensitivity analysis
  - The difference between sensitivity analysis and uncertainty analysis
  - The role of model validation
  - When to calibrate and when not to calibrate
  - Complexity vs simplicity – the benefits and drawbacks of each
  - Direct predictive hypothesis-testing
- *Session D: Practical application II (2h)*
  - ***Exercise***: continuation of the exercise on uncertainty analysis

Second day - "Why":

- *Session A: Decisions and Modelling (2h)*
  - The role of modelling in risk assessment and risk reduction
  - Metrics through which decision-support modelling should be judged
  - Conveying uncertainty to regulators/managers
- *Session B: An overview of model-partner software provided through the PEST and PEST++ suites (2h)*
  - Global sensitivity analysis
  - Prior uncertainty analysis
  - Linear sensitivity, uncertainty and data-worth analysis
  - Post calibration uncertainty analysis – from null space Monte Carlo to Kalman ensemble methods
  - Global Optimizers
  - Optimization under uncertainty
- *Session C: Some Case Histories (2h)*

  These will focus not so much on modelling details, as on the relationship between modelling and management/decision-making. In all cases the question will be asked "was this the best type of modelling to support the decisions that needed to be made" and, "if it was not the best, what would have been better"
- *Session D: "Group Therapy" (2h)*

  Participants question the instructors and/or initiate discussions based on their own experiences in decision-support modelling. Questions and discussion topics can range from strictly application (for example "what weights should I use in PEST") to more philosophical (for example, "what is the best modelling approach to address this particular problem").

General Info:

- During the exercises, the following **software** will be used: Groundwater Vistas 7 (participants will be provided with a temporary 3 months license); PEST; PESTPP-IES; PEST support utilities; MLU for Windows; QGIS 2.18; QGIS plugins; SAGA GIS; MS Excel; Notepad++; Command line window.
- **Final on-line session:** Individual (or small groups) sessions will be organized starting from January 13 to discuss homework, troubleshooting, specific suggestions about the use of PEST on real participant's projects.

REGISTER ONLINE

Course schedule

Module	SEPT	OCT	DEC	JAN
MOD1	13, 20			
MOD2		4, 11		
MOD3			9-10	
Final Session (optional)				13

For any additional information and logistic enquiry, please write an email to **formazione@kataclima.com**

Early Registration fees UNTIL JUNE 28

(VAT not included, if applicable)

Participant	MOD1	MOD2	MOD3	**ALL**
Student	240,00 €	270,00 €	320,00 €	675,00 €
ECHN Member	240,00 €	270,00 €	320,00 €	675,00 €
IAH Member	270,00 €	330,00 €	360,00 €	765,00 €
Regular price	300,00 €	360,00 €	400,00 €	845,00 €

Registration fees AFTER JUNE 28

(VAT not included, if applicable)

Participant	MOD1	MOD2	MOD3	ALL
Student	290,00 €	320,00 €	370,00 €	780,00 €
ECHN Member	290,00 €	320,00 €	370,00 €	780,00 €
IAH Member	320,00 €	380,00 €	410,00 €	890,00 €
Regular price	350,00 €	410,00 €	450,00 €	970,00 €

Organizing committee

Francesca Lotti, Kataclima
Giovanni Formentin, Tethys
Vincenzo Piscopo, University of Tuscia
Eleonora Paris, University of Camerino

Contacts & Info

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Francesca Lotti (+39.338.4624787); Giovanni Formentin (+39.349.4173798)

Venue of ON-SITE Lessons in December

Milan – address to be communicated