



SVEUČILIŠTE U SPLITU  
FAKULTET GRAĐEVINARSTVA,  
ARHITEKTURE I GEODEZIJE

UNIVERSITY OF SPLIT  
FACULTY OF CIVIL ENGINEERING,  
ARCHITECTURE AND GEODESY

# Groundwater flow and solute transport modeling in aquifers

2017



University of Split

Spend your summer at  
SPLIT SUMMER SCHOOL for students  
of Civil Engineering, Architecture & Geodesy  
CROATIA / Split

## Welcome to Split Summer School!

### The Course: Groundwater flow and solute transport modeling in aquifers



Groundwater flow and solute transport modelling in aquifers covers many important engineering applications such as analysis of irrigation systems, pumping and tracer tests, remediation, groundwater age or contaminant pollution. This course will give comprehensive review of modelling in three basic subsurface structures: porous media, fractured media and karst. The course will provide participants with skills to learn about basic physical approaches as well as "state of the art" modelling steps in order to analyse mentioned engineering problems.

We would like to introduce you to the people organising the course and to the lecturers.

#### Organising committee

<p>Boris Trogrlić</p> <p>Ph.D. Dean, Associate professor <a href="mailto:btroglic@gradst.hr">btroglic@gradst.hr</a></p>	<p>Mirela Galić</p> <p>Ph.D. Vice Dean for Int. Cooperation, Associate professor <a href="mailto:mgalic@gradst.hr">mgalic@gradst.hr</a></p>	<p>Ana Jeličić</p> <p>Mag. ing. aedif. Academic Associate <a href="mailto:ana.jelicic@gradst.hr">ana.jelicic@gradst.hr</a></p>
		

#### Lecturers

<p>Hrvoje Gotovac</p> <p>Ph.D. Associate Professor <a href="mailto:hgotovac@gradst.hr">hgotovac@gradst.hr</a></p>	<p>Liangchao Zou</p> <p>Ph.D. PostDoc <a href="mailto:lzo@kth.se">lzo@kth.se</a></p>
	

**Team members:** Veljko Srzić, Ivo Andrić, Luka Malenica, Grgo Kamber, Ivan Lovrinović



## Program structure

### Sunday, 3/9 Faculty Entry hall

19.30-21.00	Registration
20.30 - ...	Welcome and address by Organising Committee

### Monday, 4/9 Classroom C2, Basement

9.00 – 9.30	Introduction (to the course, the participants and the lecturers)
09.30 - 10.30	Lecture: Basic principles of flow and solute transport in heterogeneous porous media (Darcy Law, heterogeneity, Flow equation, Advection-Dispersion equation, boundary and initial conditions)
10.30 - 11.00	Coffee break: cafeteria, -1 <sup>st</sup> floor
11.00 - 12.30	Lecture: Introduction to modelling of flow and solute transport in porous media (Modflow and Finite element flow solvers, Euler-Lagrangian transport models)
12.30 - 13.30	Lunch break: student restaurant, -1 <sup>st</sup> floor
13.30 - 15.15	Computational exercise: Modeling of tracer tests in heterogeneous porous media using "the state of the art" modeling tools and GUI interface

### Tuesday, 5/9 Classroom C2, Basement

09.00 – 10.30	Lecture: Physical systems of fluid flow in fracture-matrix systems (introduce the physical processes and governing equations)
10.30 - 11.00	Coffee break: cafeteria, -1 <sup>st</sup> floor
11.00 - 12.30	Lecture: Physical systems of solute transport in fracture-matrix systems (introduce the physical processes and governing equations)
12.30 - 13.30	Lunch break: student restaurant, -1 <sup>st</sup> floor
13.30 - 15.15	Computational exercise: Deriving of analytical flow and transport solutions in MATLAB



### Wednesday, 6/9 Classroom C2, Basement

09.00 – 10.30	Lecture: Introduction to modelling of flow in fractured media (Finite element flow solvers and codes)
10.30 - 11.00	Coffee break: cafeteria, -1 <sup>st</sup> floor
11.00 - 12.30	Lecture: Introduction to modelling of solute transport in fractured media (Finite element solvers and codes)
12.30 - 13.30	Lunch break: student restaurant, -1 <sup>st</sup> floor
13.30 - 15.15	Computational exercise: Modeling of flow and transport in fractured media (Finite element method: skills & codes)

### Thursday, 7/9 Classroom C2, Basement

09.00 – 10:30	Lecture: Basic principles of flow and transport in karst aquifers (3-D porous matrix, 1-D conduits, exchange between matrix and conduits, boundary and initial conditions)
10.30 - 11.00	Coffee break: cafeteria, -1 <sup>st</sup> floor
11.00 – 12.30	Lecture: Introduction to modelling of flow and transport in karst aquifers (Finite volume flow solver, Modflow-CFP, Lagrangian transport models)
12.30 - 13.30	Lunch break: student restaurant, -1st floor
13.30 – 15.15	Computational exercise: Modeling of flow and transport in 3-D laboratory karst model (4*2.5*2 m)

### Friday, 8/9 Žrnovnica, Laboratory for hydraulics and hydrology

09.00 – 12.00	Laboratory exercise: Modeling of flow and transport in 3-D laboratory karst model (4*2.5*2 m) in Žrnovnica (5 km from Split)
12.00 - 12.30	Coffee break: Žrnovnica
12.30 – 14.00	Final projects presentations and discussions
14.00 – 19.00	Field trip with Lunch at Jadro and Žrnovnica catchment
18.30 - 19.30	Diploma awarding
19:30 -	Dinner at Faculty restaurant



## Learning materials

### E-learning

<http://cigla.gradst.hr/moodle26/>

### Books

Zheng C., Bennet G.D. *Applied contaminant transport modeling*, John Wiley & Sons; 2002.

White WB. *Groundwater flow in karstic aquifers*. In: Delleur JW (ed) The handbook of groundwater engineering, chap 21. CRC, Boca Raton, FL, 21.1–21.47, 2007

### Articles

Gotovac H, Andričević R., Gotovac B. Multi-resolution adaptive modeling of groundwater flow and transport problems. *Advances in Water Resources*. 30, 5; 1105-1126, 2007.

Gotovac H., Cvetković V., Andričević R. Adaptive Fup multi-resolution approach to flow and advective transport in highly heterogeneous porous media: Methodology, accuracy and convergence. *Advances in Water Resources*. 32, 6; 885-905, 2009.

Gotovac H., Cvetković V., Andričević R. Flow and travel time statistics in highly heterogeneous porous media. *Water Resources Research*. 45, 7402-1-7402-24, 2009.

Gotovac H., Cvetković V., Andričević R. Significance of higher moments for complete characterization of the travel time probability density function in heterogeneous porous media using the maximum entropy principle. *Water resources research*. 46, 05502-1-05502-14. 2010.

Srzić V., Cvetković V., Andričević R., Gotovac H. Impact of aquifer heterogeneity structure and local scale dispersion on solute concentration uncertainty. *Water Resources Research*. 49, 1-17, doi: 10.1002/wrcr.20314. 2013.

Cvetković V., Gotovac H, On the upscaling of chemical transport in fractured rock. *Water resources research*. 50, 7; 5797-5816, 2014.

Fiori A., Zarlenga A, Gotovac H., Janković I., Volpi E., Cvetković V., Dagan G. Advective transport in heterogeneous aquifers: Are proxy models predictive?. *Water resources research*. 51, 12, 9577-9594, 2015.

Király L. Karstification and groundwater flow. *Speleogenesis Evol Karst Aquifers* 1:1–26, 2003

Sauter M, Kovacs A, Geyer T, Teutsch G. Modellierung der hydraulik von karst grundwasserleiter: eine übersicht [Modeling of the hydraulics of karst aquifers: an overview]. *Grundwasser* 11(3):143–156, 2006.



Zou L., Jing L., Cvetkovic V. Assumptions of the analytical solution for solute transport in a fracture-matrix system, INTERNATIONAL JOURNAL OF ROCK MECHANICS AND MINING SCIENCES , 83, 211-217, 2016.

Zou L., Jing L., Cvetkovic V. Roughness decomposition and nonlinear fluid flow in a single rock fracture, International Journal of Rock mechanics and Mining Sciences, 75, 102-118, 2015.

Zou L., Jing L., Cvetkovic V. Modeling of Solute Transport in a 3D Rough-Walled Fracture-Matrix System, TRANSPORT IN POROUS MEDIA, 116, 3: 1005-1029, 2017.

