SUBSURFACE FLOW SIMULATION WITH MODEL COUPLING

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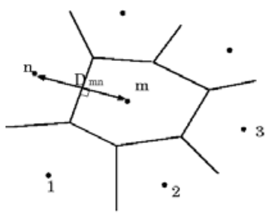
1. Abstract

The subsurface hydrology models are well known to be very time consuming and for that reason the modeler faces the dilemma to select between dense (good spatial representation) and sparse discretisation (low calculation time). The **MODFLOW** is considered as a standard ground water model and it is based on the finite differences method. The rectangular grid that is imposed by this method encumbers significantly the compromise between speed and representation. The **3dkflow** ground water flow model (Rozos et al., 2004; Rozos & Koutsoyiannis, 2006) is based on the integrated finite differences method (Narasimhan and Witherspoon, 1976) and discretises the flow domain using large non rectangular cells. The model is very fast and for that reason can be coupled easily with a global optimisation algorithm but it has the disadvantage that it needs as prior information the shape of the equipotential lines. The **coupling** of these two models has been proved to be very advantageous both in calibration and in application stages. The **MODFLOW** is used with a dense grid and a rough estimation of aquifer hydraulic parameters to simulate water flow and obtain the equipotentials. Hereupon the **3dkflow** is used in conjunction with the shuffled complex evolution algorithm to obtain reliable parameter estimates. These estimates may be subsequently used either with **MODFLOW** (solute transport, local impacts due to pumping, etc.) or **3dkflow** (stochastic forecast, water management decision programs, etc.) depending on the application type.

2. Design 3dkflow cells

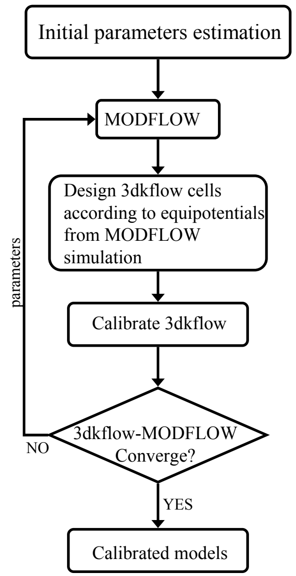
If the edges of the discretisation cells follow either the no-flow lines or the equipotential lines (**condition 1**), then the flow equation in the case of cell *m* surrounded by *N* cells is written as (Rozos & Koutsoyiannis, 2005):



$$G_m\, V_m + \sum_n K_{mn} \frac{h_n - h_m}{D_{mn}} A_{mn} = SS_m\, V_m \frac{\Delta h_m}{\Delta t}$$

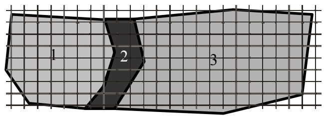
where A_{mn} is the area of interface between cells *m* and *n*, and D_{mn} is the distance of the centers of cells *m* and *n*. The (grad *h*) in above equation is approximated with $(h_n - h_m)/D_{mn}$. This approximation is accurate in the cases where the common edge of cells *m* and *n* is perpendicular to the line that connects the centers of the cells (**condition 2**).

3. 3dkflow-MODFLOW

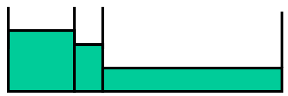


4. Difficulties

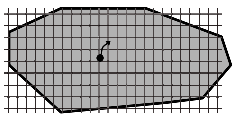
- Inter-block **transmissivities** between small cells of MODFLOW and large cells of 3dkflow are not mathematically equivalent.



- Coarse discretisation in 3dkflow, results in rough **profile** description.



- Coarse discretisation results in **misrepresentation** of connection of cells and springs.



5. Application

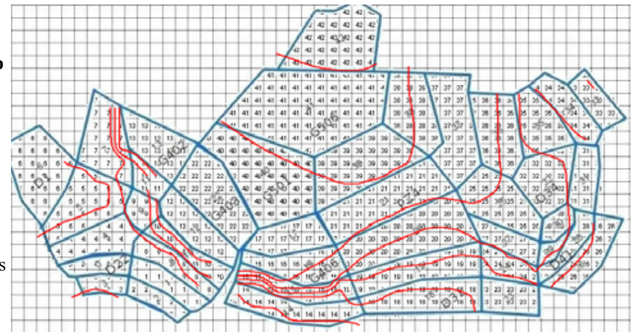
In this application MODFLOW and 3dkflow are used to simulate the water level fluctuation of the west Thessaly aquifer from October 1972 to September 1982.

The aquifer area is discretised with a 25x48 grid which is used for simulation with MODFLOW. This simulation produces a **map of equipotentials**.

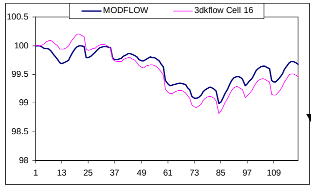
50 3dkflow cells are **designed** according to the two conditions described in § 2 and to the location of measurements.

3dkflow is **calibrated** (50 parameters for hydraulic conductivities, 1 parameter for specific yield) using water level measurements in 11 observation wells.

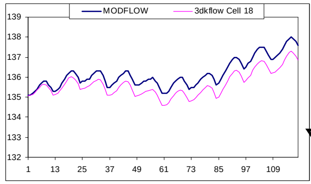
25x48 MODFLOW cells are grouped in 50 zones defined by 3dkflow cells. Calibrated conductivities with 3dkflow are **applied** to zones of MODFLOW. The aquifer is simulated again with MODFLOW.



50 3dkflow cells designed according to equipotentials (red lines) , 25x48 MODFLOW cells categorized in 50 zones.



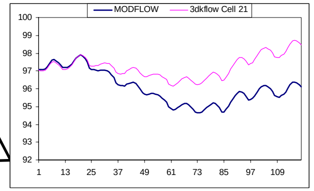
Simulated water level (monthly values) in 3dkflow cell 16 and MODFLOW cell (21,24).



Simulated water level (monthly values) in 3dkflow cell 18 and MODFLOW cell (23,34).

Budget report at the end of simulation with MODFLOW and 3dkflow.

Budget term	MODFLOW (hm^3)	3dkflow (hm^3)
Recharge	1889.4	1918.7
Drain out	1492.1	1492.6
Storage in-out	-397.3	-426.7



Simulated water level (monthly values) in 3dkflow cell 21 and MODFLOW cell (16,30) (cf. § 4 Difficulties).

References

•Narasimhan T.N. and P.A. Witherspoon, An Integrated Finite Difference Method for Analyzing Fluid Flow in Porous Media, WRR 12(1), 57-64, 1976.

•Rozos, E., and D. Koutsoyiannis, A multicell karstic aquifer model with alternative flow equations, Journal of Hydrology, 2006.

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•Rozos, E., A. Efstratiadis, I. Nalbantis, and D. Koutsoyiannis, Calibration of a semi-distributed model for conjunctive simulation of surface and groundwater flows, Hydrological Sciences Journal, 49(5), 819-842, 2004.

6. Conclusions

- MODFLOW is highly time consuming and for that reason it does not enable calibration by a global optimisation algorithm. 3dkflow **disadvantages** are the a priori need of equipotential lines and the rough description of water level profile.
- MODFLOW may be used to produce the map of **equipotentials** necessary to design 3dkflow cells. Hydraulic **parameters** obtained from 3dkflow calibration may be used in MODFLOW despite the different representation of the aquifer by the two models.