

European Geosciences Union General Assembly 2010

Vienna, Austria, 5 May 2010

Session HS7.2: Hydrogeophysics in subsurface hydrology

Use of MODFLOW as an interpolation method

E. Rozos and D. Koutsoyiannis

Department of Water Resources and Environmental Engineering
National Technical University of Athens

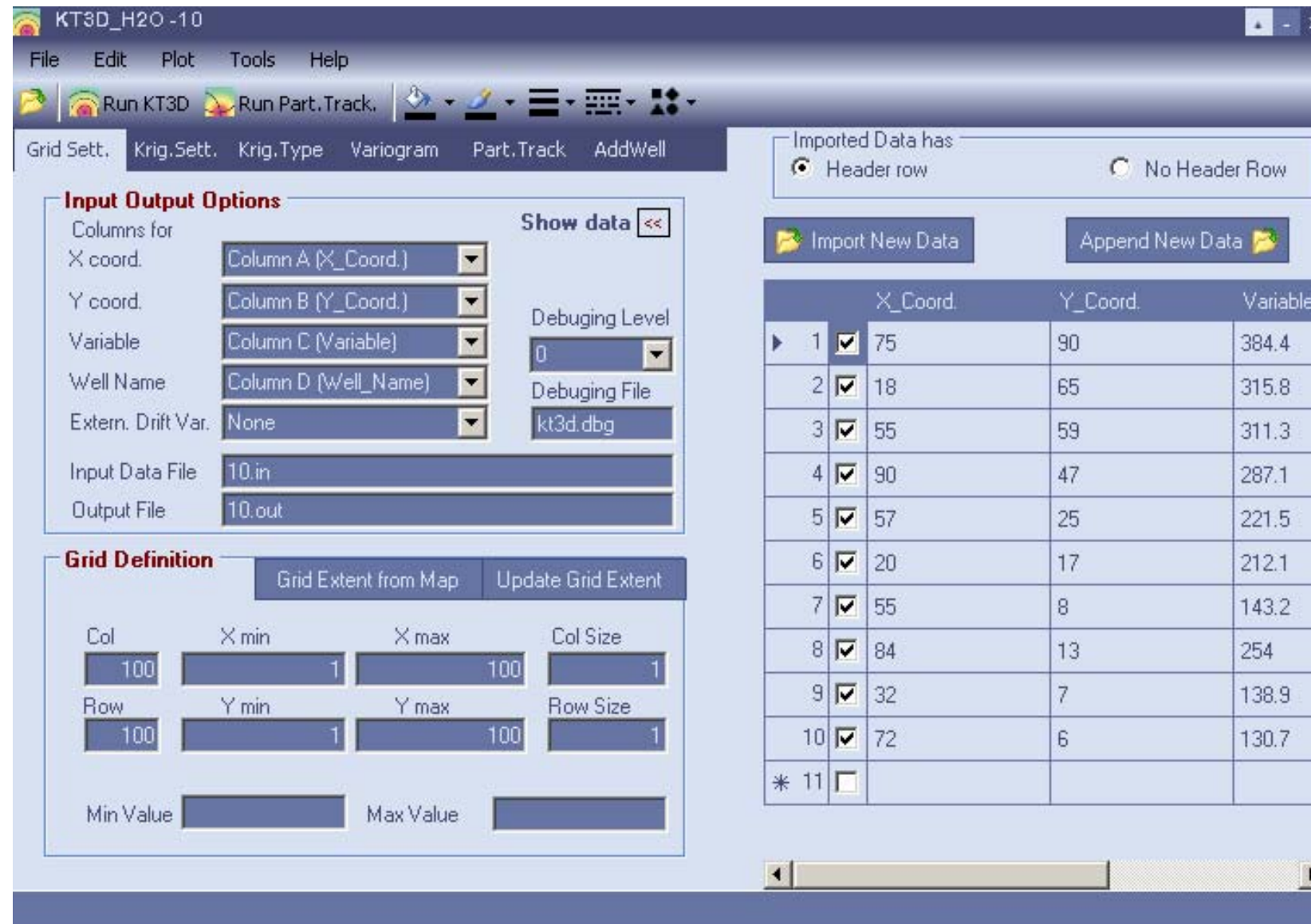
(www.itia.ntua.gr)

1. Introduction

Kriging is the most common method used for interpolations in groundwater applications. This pure statistical approach has the disadvantage that it does not guarantee that the values of the interpolated hydraulic heads are consistent with the groundwater flow physics (Rivest et al., 2008). This weakness is mitigated in the Universal Kriging (UK) method with the use of the so-called drifts. In this study a method based on the use of MODFLOW is proposed as an alternative to the UK method. The two methods are tested on a synthetic aquifer with steady state stresses. Two hypothetical observation networks, with 68 and 10 measurement points, provide the required data for the interpolations.

2. Method 1: Universal Kriging (UK)

For the interpolations based on UK the MapWindow plugin KT3D_H2O (SSP&A, 2008) is used. KT3D_H2O interpolates the water level data using the technique of the hydrological drift terms (Tonkin and Larson, 2002).



The screenshot displays the KT3D_H2O software interface. The window title is "KT3D_H2O -10". The menu bar includes File, Edit, Plot, Tools, and Help. The toolbar contains icons for Run KT3D, Run Part.Track, and other functions. The interface is divided into several sections:

- Input Output Options:** Contains dropdown menus for X coord. (Column A [X_Coord.]), Y coord. (Column B [Y_Coord.]), Variable (Column C [Variable]), and Well Name (Column D [Well_Name]). It also includes a text field for Input Data File (10.in) and Output File (10.out), a Debugging Level dropdown (0), and a Debugging File text field (kt3d.dbg).
- Grid Definition:** Includes a "Grid Extent from Map" button and an "Update Grid Extent" button. It features input fields for Col (100), X min (1), X max (100), Col Size (1), Row (100), Y min (1), Y max (100), Row Size (1), Min Value, and Max Value.
- Imported Data:** A section with radio buttons for "Header row" (selected) and "No Header Row". It includes "Import New Data" and "Append New Data" buttons.
- Data Table:** A table with columns X_Coord., Y_Coord., and Variable. It lists 11 rows of data, with the 11th row marked with an asterisk and an unchecked checkbox.

	X_Coord.	Y_Coord.	Variable
▶ 1	75	90	384.4
2	18	65	315.8
3	55	59	311.3
4	90	47	287.1
5	57	25	221.5
6	20	17	212.1
7	55	8	143.2
8	84	13	254
9	32	7	138.9
10	72	6	130.7
* 11			

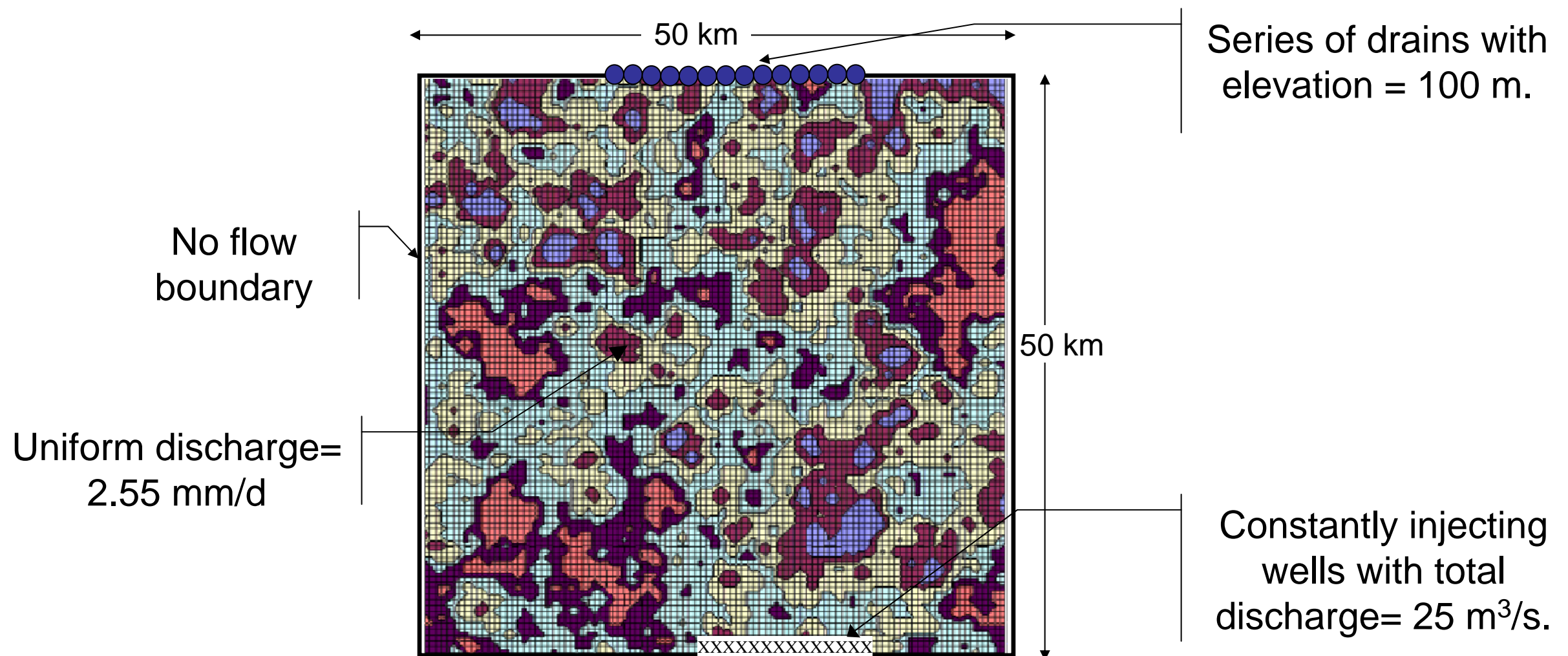
3. Method 2: MODFLOW

The idea explored is to use MODFLOW as an interpolation method to simulate the aquifer without the requirement to represent accurately the water budget. Instead, the MODFLOW parameters and stresses are calibrated to minimize the residuals between the simulated and observed hydraulic heads.

Consequently, the estimated parameters do not have a specific physical meaning (i.e. this is not an inverse modelling type of application) but are rather considered as the parameters of the MODFLOW-driven interpolation.

4. Synthetic aquifer

The synthetic values of conductivity are produced by a stochastic model that is an extension in two dimensions of the Symmetric Moving Average algorithmic scheme (Koutsoyiannis, 2000; Theodoratos, 2004), which is appropriate to simulate fields with long-range dependence (Hurst effect).



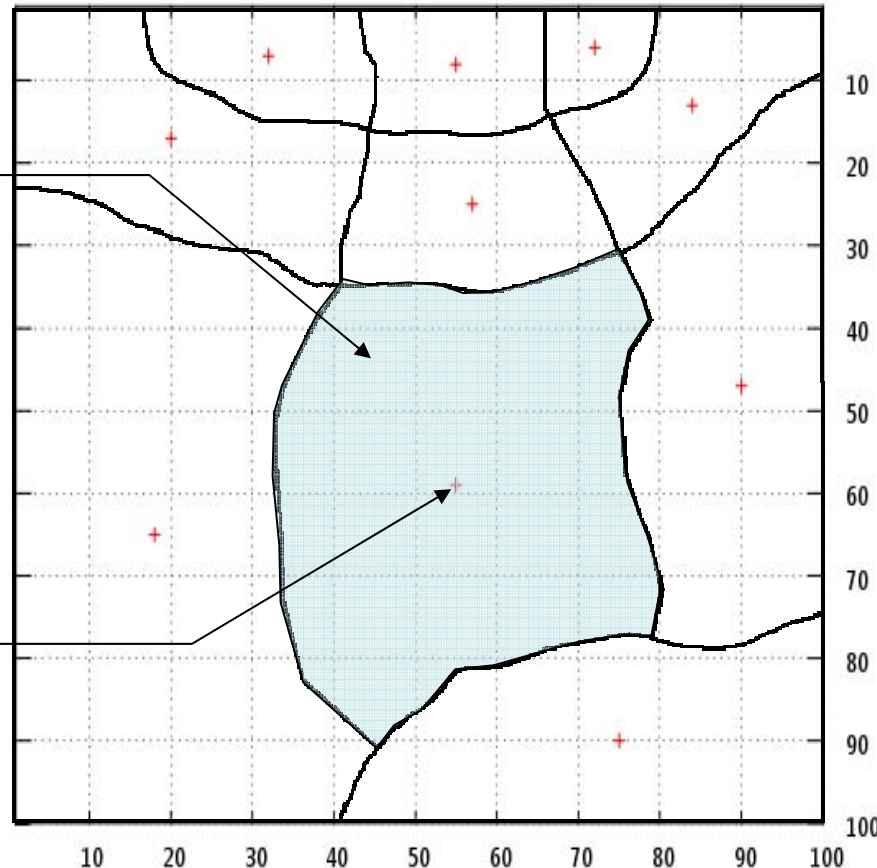
5. Observations – reference equipotentials

The steady state synthetic aquifer is simulated with MODFLOW. Hydraulic heads are recorded using two hypothetical observation networks, one with 10 and another with 68 measurement points. These observations are used as input data in the examined interpolation methods. The reference map of equipotential lines is also derived from this simulation. This map is used for accessing the efficiencies of the two interpolation methods.

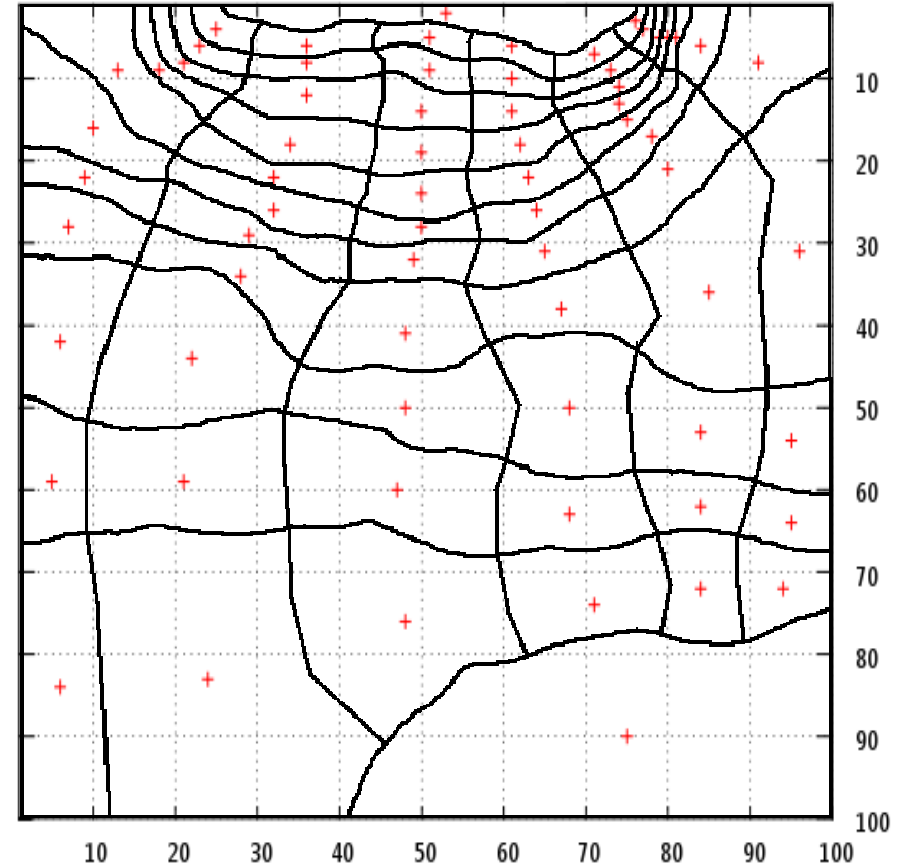
6. MODFLOW: Influence zones

- The first step for interpolating with MODFLOW is to define the influence zone for each measurement point. These zones are considered to be homogeneous areas. The shape of these zones should be based on the equipotential lines therefore a prior estimation of them is required.

10 observation points



68 observation points



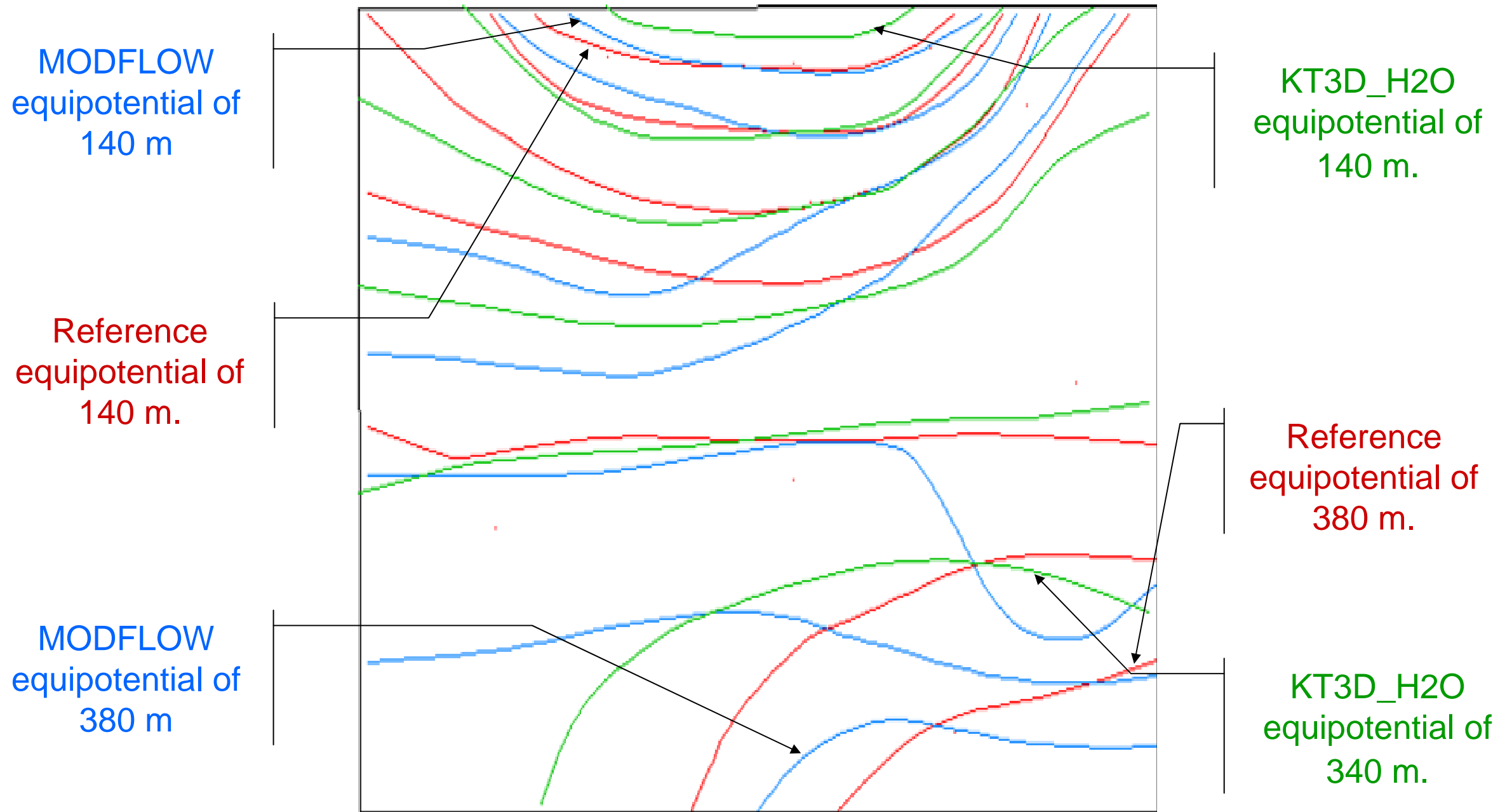
Influence zone of the measurement point characterized by homogeneous conductivity.

Measurement point

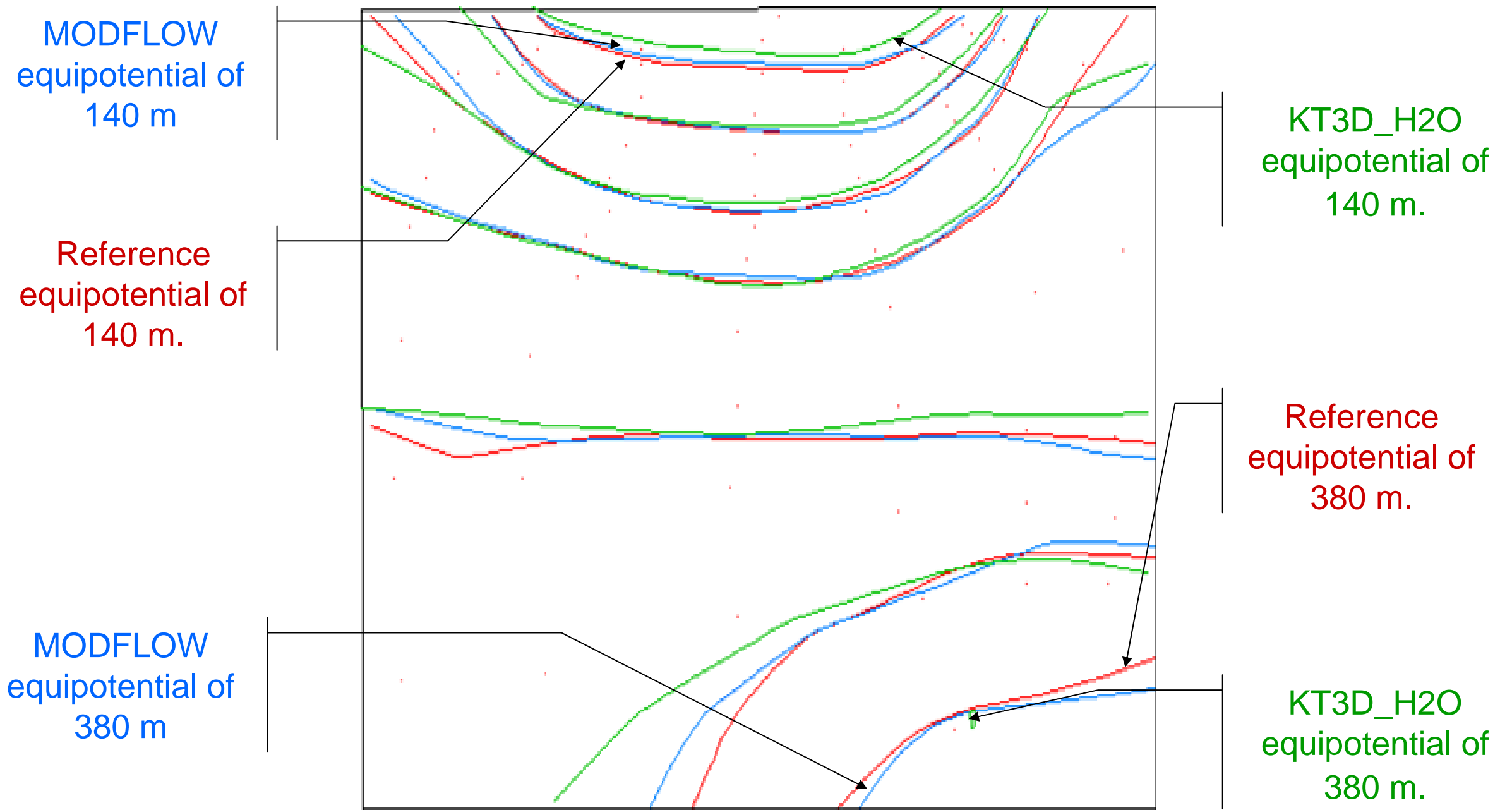
7. MODFLOW: Parameter optimization

The influence zones actually constitute a zone-based parameterization of the aquifer. At each zone a conductivity parameter is assigned. This type of parameterization, based on equipotential lines, introduces to the optimization procedure indirect information about the aquifer properties. One more parameter is used for the constant uniform recharge on the aquifer. The boundary conditions are identical with those of the synthetic aquifer except the injecting wells (these wells correspond to a type of recharge which typically is not directly measurable, like infiltration from mountainous areas, and hence unknown during the interpolation). The PEST algorithm (SSP&A, 2005) is used for the optimization of the parameters.

8. Results: 10 observation points



9. Results: 68 observation points



10. Methods comparison

	MODFLOW & PEST	KT3D_H2O
Speed	LOW	HIGH
Simplicity	LOW	HIGH
Reliability (limited measurements)	LOW	MEDIUM
Reliability (measurements abundance)	HIGH	HIGH

11. Conclusions

- KT3D_H2O performed satisfactory even with limited number of measurements.
- The use of MODFLOW as interpolation method has fallen short despite the indirect information introduced by the parameterization method. This interpolation method has also the disadvantage of requiring considerable preparative work.
- However MODFLOW can be used to achieve a better interpolation accuracy in cases where a dense network of measurement points is available, along with prior information about the functioning of the aquifer.
- Otherwise, we do not recommend the method we have tried!

12. References

- Koutsoyiannis, D. (2000) A generalized mathematical framework for stochastic simulation and forecast of hydrologic time series. *Water Resources Research*, 36(6), pp. 1519-1533.
- Rivest M., D. Marcotte and P. Pasquier (2008) Hydraulic head field estimation using kriging with an external drift: A way to consider conceptual model information, *Journal of Hydrology*, 361, pp. 349-361.
- SSP&A (2008) KT3D_H2O, A program for Kriging Water Level Data using Hydrologic Drift Terms. User manual, Beta Version 3.0. <http://www.sspa.com/Software/kt3d.shtml>
- SSP&A (2005) PEST, Model-Independent Parameter Estimation. User manual: 5th Edition. <http://www.pesthomepage.org>
- Theodoratos N. (2004) Stochastic simulation of two-dimensional random fields with preservation of persistence, thesis, Department of Water Resources, Hydraulic and Maritime Engineering - National Technical University of Athens, Athens.
- Tonkin M. J. and S. P. Larson (2002) Kriging water levels with a regional-linear and point-logarithmic drift, *Ground Water*, 40(2), pp. 185-193.