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Evaluation of Risks Related to Ground Water Regime Changes

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Abstract

Due to changes in ground water flow regime as a result of extreme hydrological events such as floods or drafts, eventually water retention structures, the conditions in the ground environment change. It may threaten stability of ground itself, objects on streams, levees and buildings or objects situated directly behind the levees as well as wells, withdrawal structures or water resources in general. Determination of these changes in ground water flow should be an integral part of floodplain or water resource risk analysis. The main inputs to damage evaluation and risk analysis are based on ground water flow modelling. Uncertainties involved in modelling process due to incorrectness of accepted assumptions may be reduced by application of statistical method and mainly method of space depending random fields. The application of modelling tools is the way to assess factors that may cause damage. Risk analysis procedure then involves evaluation of these factors and definition of certain levels of risk caused by changes in ground water flow regime. The procedure of risk assessment was established with respect to problems related to ground water flow.

Keywords: Model; Stochastic; Random Fields; Risk.

Introduction

Problems of extreme flood events, quality of ground water, seepage under water structures, management of water resources and many others are far more often parts of assessment of possible risks and consequences of these phenomena. The models of ground environment are rarely based on sufficiently detailed description of geological condition. The base soils are usually complicated with respect to layer thickness, occurrence of anomalies and distribution of material properties. These uncertainties related to unknown material properties are in modelling procedure reflected in less reliable results. The way diminishing these uncertainties is to introduce the properties as random quantity. This can be done by application of statistical approach, for example spatially dependent random fields. Methods of random fields contrary to classical methods like Monte Carlo can take into account also space relations. The main difficulty in application of these methods is determination of correlation length.

Risk or thread was mainly evaluated as a rate of trespassing of certain level of crucial parameters such as level of water table or piezometric head, critical gradient value or concentration of certain matters in ground water.

Objectives

The paper deals with applicability of probabilistic and stochastic approaches respectively (especially space random fields generation) in ground water modelling and evaluation of threads and risks related to changes in ground water flow regime. Case studie was done in the area at conjunction of two rivers, the Svratka and the Svitava river, in town of Brno in Czech Republic. Another area of interest was situated in small town Chocen. The areas of interest are located in the south-east part and center of Czech Republic respectively. Character of rivers is changing from upper catchment to lowland. Fluvial sediments are found in wide range along the streams.

Chosen methods are used to generate an array of calculation parameters (e.g. hydraulic conductivity coefficients). Ground water heads resulting from application of different correlation lengths are compared.

Evaluation of threads was based on comparison of calculated level of ground water head (with respect to chosen hydrologic scenario) and critical levels posing threads on objects (buildings, structures, area with water intake).

Hydrogeology Data

Hydro-geologic survey shows that geological conditions along both rivers are similar. The impermeable bottom is created by neogen soils as mostly clay, diorites and grano-diorites (reach in river km 9,000 ÷ 11,000 of the Svitava river). Upon them the fluvial gravel and sandy gravelous sediments with subtle particles of clay with thickness of cca 2,0 ÷ 10,0 m with mid to good permeability. The surface layers consists of clayey loams or backfill with low permeability with thickness about 5,0 m. In urbanized areas there is paving or asphalt on the surface.

Coefficients of hydraulic conductivity are determined from laboratory tests, calculated from grading curves and locally based on pump tests.

Tab. 1. Values of Hydraulic conductivity coefficient used

Soil	Hydraulic conductivity coefficient k [m.s^{-1}]
Backfill with sand	~ 10^{-5} ÷ 10^{-6}
Backfill with loam and clay	~ 10^{-7}
Fluvial gravel and sandy-gravel	~ 10^{-4}
Neogen clay	~ 10^{-10}

Ground Water Flow Model

Ground water flow was solved in characteristic profiles along both rivers (2D vertical models) and as area defined by the Svratka and the Svitava and head race connecting both rivers (2D horizontal model and 3D model). The characteristic profiles were chosen to describe fully the flow regime in key location of the area. Totally there were 47 cross section profiles, among them 32 profiles on the Svratka river and 15 profiles on the Svitava. Figure 1 is showing modelled area with one set of boreholes.

Storativity coefficient used was derived from soil properties and water according to geological conditions. For permeable sandy gravel value of $S_p = 6.10^{-4}$ and $S_f = 0,22$ (gravelous soil) to $S_f = 0,07$ (loam soil).

Model boundary conditions were as follows:

- water level time variation in streams was derived from flood hydrograph,
- ground water level with respect to hydro-geological survey was adopted from map.

The initial conditions were derived by calculating steady state flow in time zero. The length of time step was assumed 1 hour according to length of flood episode.

Characteristics Generation Methods

Deterministic approach

Using software developed on Brno University of Technology (Institute of Water Structures) for ground water flow, the value of k and S are assigned as a single mean value derived on bases of geological survey. Using GMS a single value of characteristic was assigned to material specified in borehole sets.

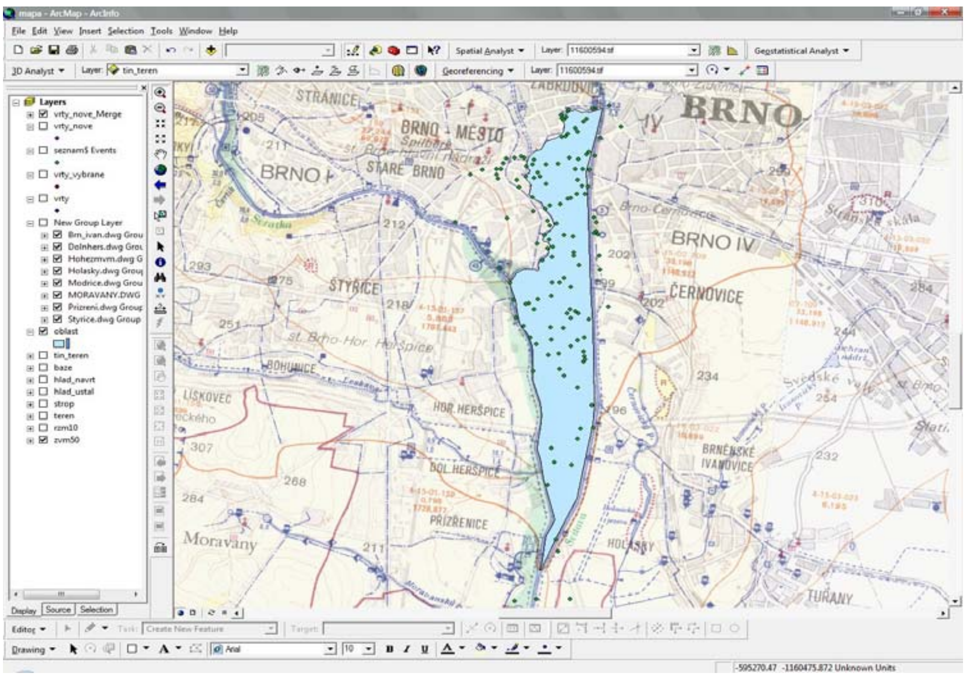


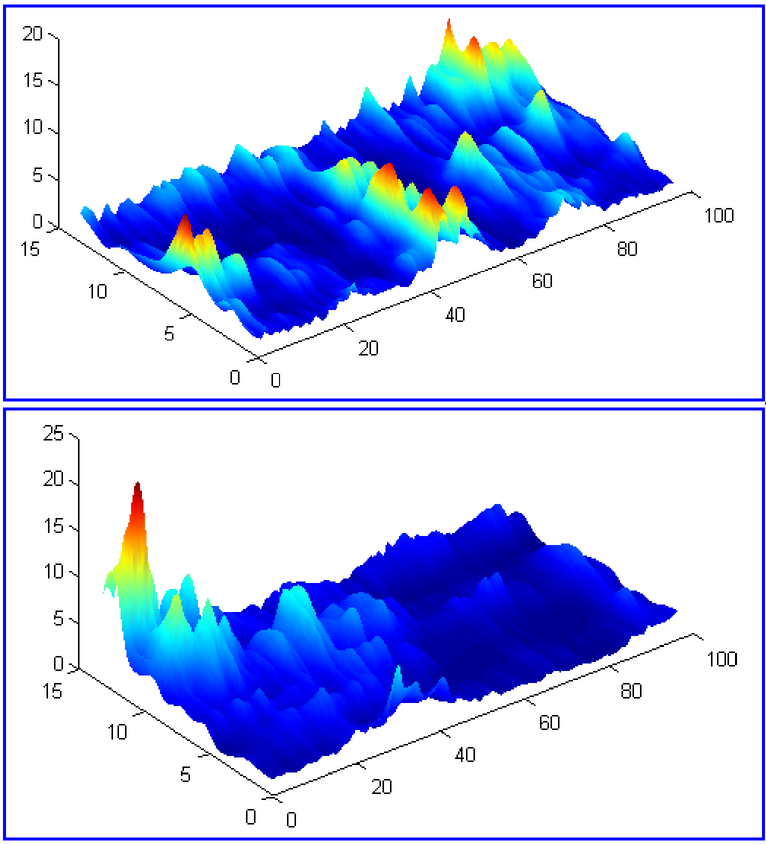
Fig. 1 Modelled area between the Svratka and the Svitava river

Stochastic approach

Stochastic approach to generation of soil characteristics was applied by using GMS software (stochastic analysis module) and as a separate procedure of random field generation. GMS determines hydraulic conductivity by using test well logs. The interpreted values for each layer are weighted according to layer thickness, and the weighted average value of k_x is then determined for each model layer at each test well location. A 2D data set s then created by interpolating the computed values. The 2D data set is then used to set the MODFLOW array of values for each layer.

Random field generation methods

Number of methods of random field generation exists. Not all of them are suitable for hydraulic conductivity coefficient generation. However, there are several methods applicable to generate random field of *k* coefficient. Among these are LAS, TBM and FFT methods (Fenton, 1990, Harter, 1994, Mensik, 2004). Figure 2 shows example of generated array of conductivity coefficients with different correlation lengths.



A

B

Fig. 2 Array of conductivity coefficient for correlation length
A - 10 m and B - 25 m (Mensik, 2005)

Applied Tools

The groundwater flow was calculated using two software tools. While applying deterministic approach the software HPV (developed in Institute of Water Structures) and GMS were used. The HPV is defining material properties on group of elements (i.e. macro-elements) as value of k in direction of x and y-axes. With GMS material properties were specified using two sets of boreholes (65 boreholes). In several locations the geological profile had to be slightly changed.

Figure 3 shows the procedure applied with stochastic approach. The model area was built with GMS interface. When the MODFLOW project was created the random field of conductivity coefficient was generated using ArcMAP GIS tools with help of Matlab software. This random field of hydraulic conductivity coefficients is applied within the MODFLOW model.

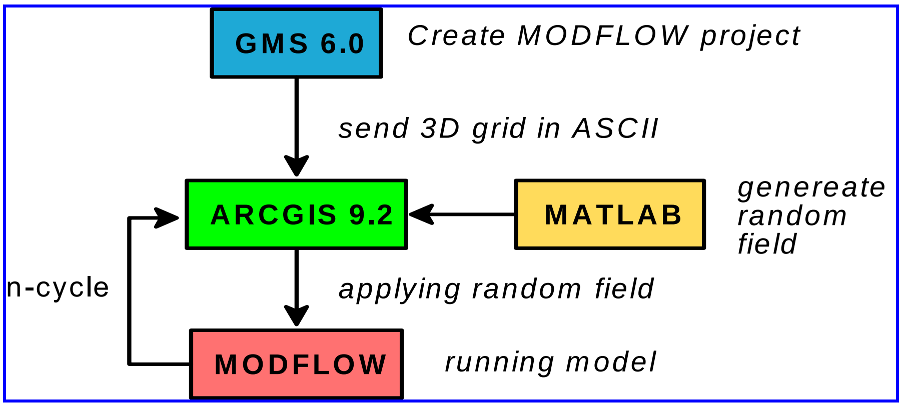


Fig. 3 Process scheme

Results

The results obtained from modelling tools was processed and visualized in the ArcGIS for the post-processing. This procedure was automatically repeated in n-cycles with change of correlation length (Fenton, 1994 and Harter, 1994) to derived the piezometric heads, velocities, gradients, etc. in form of interval of expected values. This way a set of results (e.g. piezometric heads) are obtained. Finally, visualizations were made for better presentation of geology and results, see Figure 4 and 5.

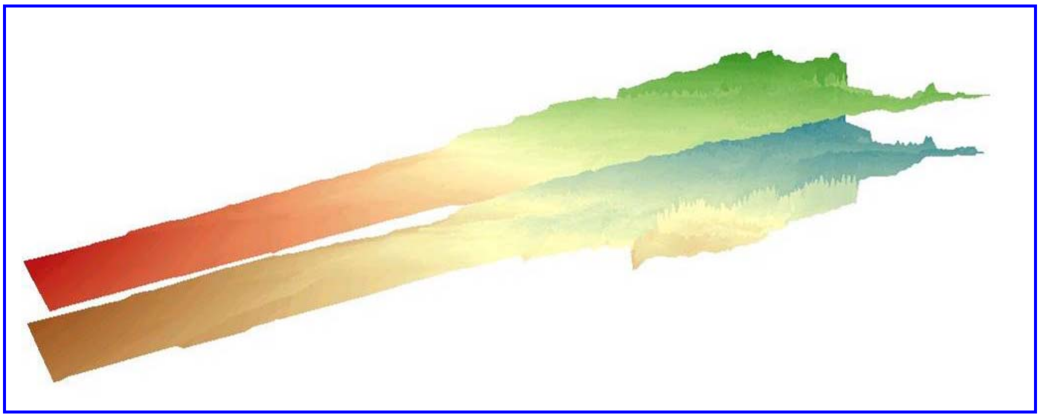


Fig. 4 Visualization of layer elevation in ARCScene

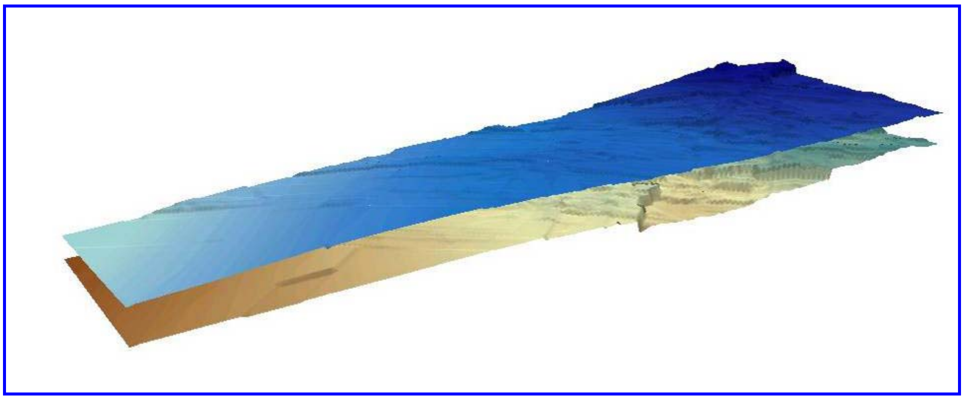


Fig. 5 Results in ARCScene

Possible threads were evaluated mainly by comparison of calculated values of piezometric head, velocities, gradients, etc. to defined critical limits. Attention was paid to problems of flooded areas as well as areas of water source. Assessment of threads was done by comparing difference between calculated water level and terrain or minimal water level necessary for intake. Illustrative map of calculated water level and terrain differences is shown in fig. 6. Risk then is described by risk matrix comparing probability of occurrence of the simulated event and ratio of danger caused by this situation.

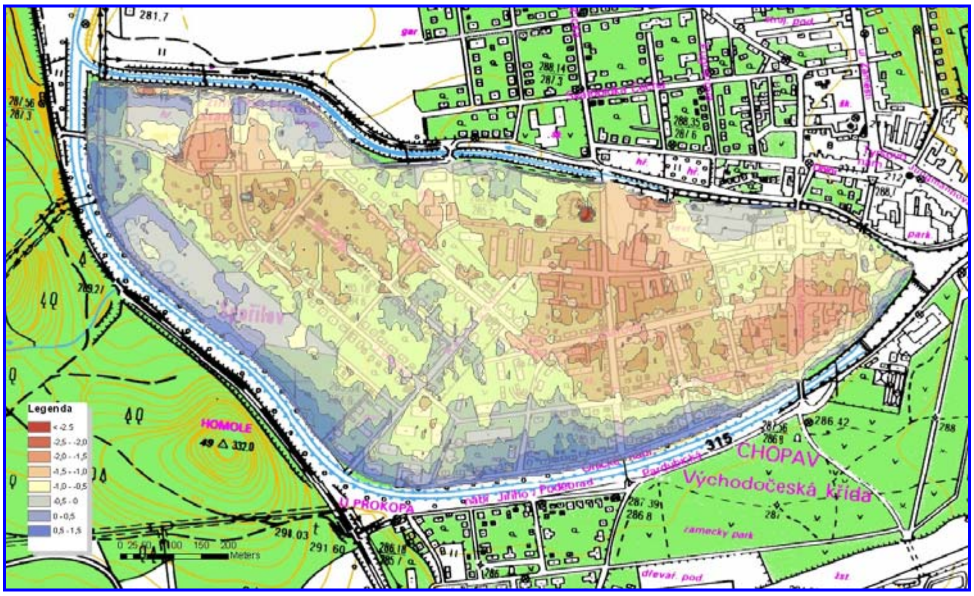


Fig. 6 Map of thread in form of transcendence of defined limits

Conclusions

There is a need for reliable inputs to modeling tools applied in evaluation of threads and risks resulting from changes in ground water flow regime. Conservative deterministic way to solve the problem is to assume constant condition in ground environment and calculate flow characteristics. Application of random fields is one possible way to decrease high level of uncertainty involved in approximation of soil environment properties. The main problem in random field generation applied in case studies is determination of correlation length and mainly very time consuming pre-processing. After application of sensitivity analysis we hope to get better in view to influence of correlation length to generated random filed of conductivity coefficient. Application of random field approach when generating coefficients of hydraulic conductivity is suitable in case of sufficient amount of data on hydraulic conductivity of soils. This requires dense enough set of boreholes. In locations with sufficient information about soil characteristics, the generation of random fields may describe the hydraulic conductivity in more details. However, the selection of interval is crucial for calculated result. With lack of information on soil properties it may be difficult to identify this interval correctly. In location with lack of data it is suitable to use interpolation method to generate the base for random field generation. For such interpolation the kriging may be used. This method uses dependence on distance between known values.

When calculating level of ground water there were clear difference between results with different interpolation method selected. The interpolation method appears to have in some cases greater influence on obtained results then generated random fields.

In procedure of risk evaluation the key role plays except ground water flow conditions also starting hydrological event (flood, draft) as well as state of influenced object (building, wells, etc.). These factors are significant when applying the calculated results to risk matrix. Hydrological conditions describe mainly the probability of occurrence. More subjective assessment is to determine ratio of danger posing by changes in ground water flow. This should be the theme of further study.

Acknowledgements

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