Automatic calibration of groundwater flow parameters for an unconfined aquifer northeast of Vienna

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Abstract A calibration algorithm has been developed for the two-dimensional finite element groundwater flow model HPP-GMS. The calibration of the parameters for unconfined flow can produce strongly nonlinear problems. A Newton-Raphson scheme and a mixed Picard-Newton Raphson scheme have been used to improve the solution of the nonlinear unconfined flow problem. The calibration algorithm uses the adjoint state method for the calculation of the gradients associated with a Quasi-Newton minimization procedure. To reduce the number of parameters to be estimated different types of parameterization are used (downscaling approach for the hydraulic conductivities, zonation technique for recharge, parameterization for aquifer-river leakage, etc.) This calibration algorithm is applied with success to an unconfined aquifer northeast of Vienna.

INTRODUCTION

In the past decades, physically-based distributed parameter models (finite element, finite difference) have become a key tool in groundwater system analysis. The knowledge of the parameters used in the partial differential equation is one of the most difficult aspects in groundwater modelling. These parameters are not directly measurable and the knowledge on their spatial distribution is very incomplete. The model calibration (inverse problem) is the optimal determination of these parameters by observing the dependent variable collected in the spatial and time domains. Much work has been done in the field of automated flow model calibration. Detailed reviews are presented in Yeh (1986), Carrera (1988), Ginn & Cushman (1990) and more recently, Sun (1994). The calibration procedure is based on:

- the formulation of an objective function which is usually the sum of the quadratic difference between measured and calculated piezometric heads;
- the parameterization which reduces the number of parameters to be identified, in order to stabilize the inverse problem;
- a minimization algorithm which updates iteratively the initial parameter set.

The purpose of this paper is to present the automatic calibration procedure developed for the HPP-GMS groundwater flow model and its application to the Marchfeld aquifer.
THE CALIBRATION ALGORITHM

The calibration algorithm has been developed for the two-dimensional groundwater flow model HPP-GMS (Blaschke & Blöschl, 1992). This model is based on the classical finite element method. The calibration procedure works for unconfined and confined aquifers. Particularly, attention is given to the solution of the nonlinear unconfined flow equation. Calibration of parameters can produce strongly nonlinear problems. The classical Picard method has been known to either fail or converge slowly for such problems. A Newton-Raphson scheme and a mixed Picard-Newton Raphson (Paniconi & Putti, 1994) scheme have been developed to improve the solution of the nonlinear unconfined flow problem. The calibration procedure is based on the minimization of the objective function which is equal to the sum of the quadratic difference between observed and computed piezometric heads. This procedure uses a Quasi-Newton minimization algorithm (Byrd et al., 1995) which requires the calculation of the gradient of this objective function with respect to the parameters. These gradients are determined with the adjoint state method (Chavent, 1974). The computation of these gradients needs only the solution of the flow

Fig. 1 Downscaling approach.
system and its associated adjoint system. This method is particularly well adapted when a large number of parameters is to be determined with an acceptable computation time compared to classical methods (sensitivity method and finite differences method). Different types of parameterizations are used to reduce the number of parameters to be
BOUNDARY CONDITIONS

FLOW

- noflow
- constant head
- leakage
- wells
- control nodes

Fig. 4 Aquifer discretization and the boundary conditions.

Fig. 5 Initial downscaling mesh.
estimated. This step is the most important in the calibration procedure. The reliability of the simulations are highly dependent on the quality of the parameterization (Yeh & Yoon, 1981). A downscaling parameterization has been developed for the hydraulic conductivities and the porosities (Siegel, 1995). The parameter space is discretized in a triangular finite element mesh with a linear interpolation in each cell. The model calibration consists of estimating the parameters at the node of this mesh. The parameter at measured points are introduced in the mesh and are not estimated. The downscaling approach is defined by successive "parameter mesh" refinement (Fig. 1). With this approach the discretization level of the space parameter will be adapted to the quantity and quality of the observations. A classical zonation technique is used for the recharge parameters. An original parameterization has been introduced for the calibration of the aquifer-river leakage. The water flux exchange $Q$ between the unconfined aquifer and river is defined as follows (Fig. 2):

$$Q = \lambda (hs - hr) \text{ if } h < hr \text{ and } Q = \lambda (hs - h) \text{ if } h > hr$$

(1)

The calibration procedure can estimate the leakage coefficient $\lambda$ and the free water surface level $hs$. The leakage coefficient is considered as constant for each river. The free water surface level is estimated once per river if the river has a constant level. Otherwise, we estimated one water surface level per node of the river taking into account the river flow direction. Figure 3 shows the calibration procedure.

APPLICATION OF THE CALIBRATION PROCEDURE TO A REAL CASE STUDY

The field application of the calibration procedure is the Marchfeld aquifer northeast of Vienna. This unconfined aquifer, consisting of sand and gravel deposits, is characterized...
by substantial interactions between the aquifer and the streams as well as cut off stream sections of the Danube. In this area it is planned to establish an national-park "Donau-Auen". From the water resources point of view it is important to save the drinking water resources of this region. Therefore an interdisciplinary group describes the possibilities for extracting groundwater under the restriction of a national park. A steady-state groundwater model has been developed to give answers about the quantity and location of extraction-wells under the limitation of an maximum drawdown of 30 cm near the wells.

Figure 4 shows the discretization and the boundary conditions of the modelling area with a strong mesh refinement in the area of the national park. The model includes 26 cut off stream sections which discharges groundwater. The recharge is divided in nine areas which are defined in further studies (Blaschke et al., 1991) and will not be calibrated.

The initial downscaling mesh in Fig. 5 includes 19 measured hydraulic conductivities. For the calibration, 268 piezometric heads over the whole area are used. The estimated parameters are the hydraulic conductivities, the water fluxes at the boundaries (Neuman boundary condition) and the free water surface of the rivers (aquifer-river leakage).

For a more reliable result we calibrated two steady-state situations in one step (January 1985 and December 1987). Figure 6 shows the calibration result of the hydraulic conductivity. An overview of the differences between the measured and simulated piezometric heads are given in Fig. 7 for January 1985, and in Fig. 8 for December 1987. With an average value of the errors of 9 cm in both cases the result is very good.

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Fig. 7 Differences between measured and simulated piezometric heads for January 1985.
CONCLUSION

A calibration procedure using a downscaling parameterization is presented. With this parameterization, the discretization level of the space parameter will be adapted to the quantity and quality of the observations. The relatively short time to calibrate the model allows to vary the model boundary conditions and the constraints to the parameters. This gives more reliability in the final model calibration and predictions. To obtain more reliability a calibration of two steady-state situations are done in one step. The results for both cases look very good and allow a sensible estimation of the quantity of the groundwater extraction under "national park" conditions. The drawdowns obtained after a pumping test simulation using the calibrated parameters are consistent with the observed drawdowns.

REFERENCES


