Importance and effects of model couplings in hydrogeology

W. GOSSEL & P. WYCISK

Institute for Geosciences, Dept. Hydrogeology and Environmental Geology, Martin Luther University Halle, V.-Seckendorff Platz 3, D-06120 Halle, Germany

wolfgang.gossel@geo.uni-halle.de

Abstract Hydrogeological models depend in most case studies on geological and hydrological input data, e.g. geological structures, groundwater recharge, and surface water hydrographs. For two case study areas in Bitterfeld (Germany) and Northeast Africa the influence of couplings of modelling systems is investigated. The modelling systems were used for geology, hydrology, unsaturated zone and saturated zone flow and transport modelling approaches. The results show a high sensitivity not only to the numerical and geometrical but also to the coupling parameters and techniques.

Keywords modelling systems; couplings; Bitterfeld area; Nubian Aquifer System

INTRODUCTION AND BACKGROUND INFORMATION

Complex modelling approaches and research tasks depend on a lot of input data that are difficult to get from field experiments. Therefore it is very tempting to substitute the input data by another additional model. To connect the modelling systems e.g. for unsaturated and saturated flow modelling diverse strategies can be developped. A few of these strategies were investigated in two case studies.

For the Bitterfeld Megasite (Germany) the effects of open pit lignite mining and the fate of hazardous substances in the groundwater were investigated by coupling modelling systems for the geology, the unsaturated zone, the boundary condition of the river Mulde, the groundwater recharge and solute transport reactions to a regional groundwater flow model (Gossel *et al.*, 2009). The geological models were developped with different resolutions, for different parts of the total area and with different modelling concepts to compare the influence on the groundwater flow model (Wycisk *et al.* 2006). A long term groundwater recharge model, an unsaturated zone modelling approach and a model for surface water levels were coupled to substitute the direct parameterization. After the setup, calibration and scenario calculation of the groundwater flow model a transport model for an ideal tracer was coupled to the complex flow model.

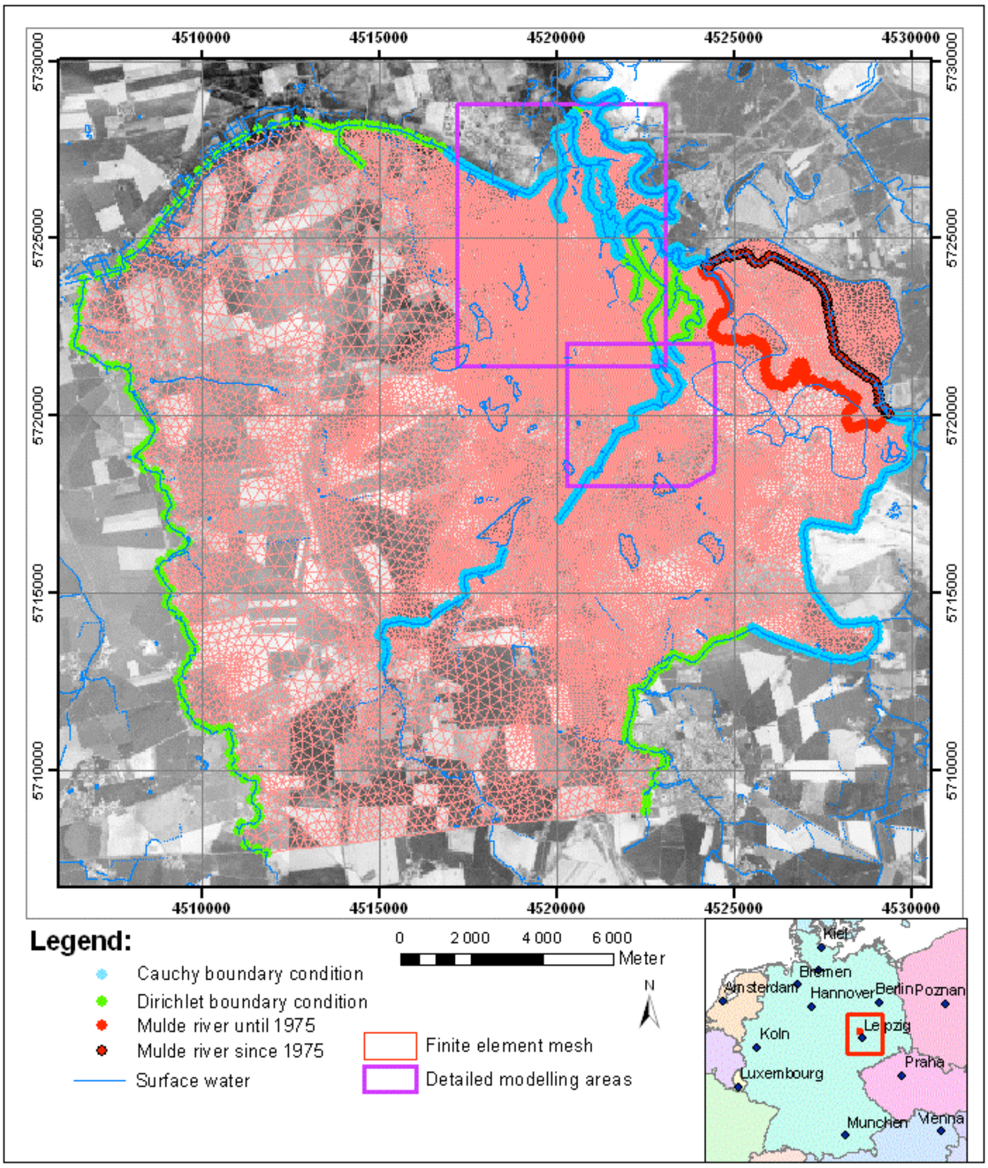

Fig. 1 Investigation area Bitterfeld with boundary conditions of the groundwater flow model

Another model area to test the coupling effects was the Nubian Aquifer System in North-Eastern Africa (Gossel *et al.*, 2010). Based on a former groundwater flow model (Sefelnasr, 2007; Gossel *et al.*, 2008), two major impacts had to be investigated by the enlarged model: 1.) The seawater levels of the Mediterranean Sea changed with a big amplitude in the last 140 000 years. 2.) The seawater intrusion in this time frame had to be investigated by a coupled solute transport and density driven model to find the reason for the recent outline of the interface between saltwater and freshwater. In this case study the integrated coupling of groundwater flow, transport and density driven processes was identified to be numerically unstable and sensitve to small changes of parameters and boundary conditions.

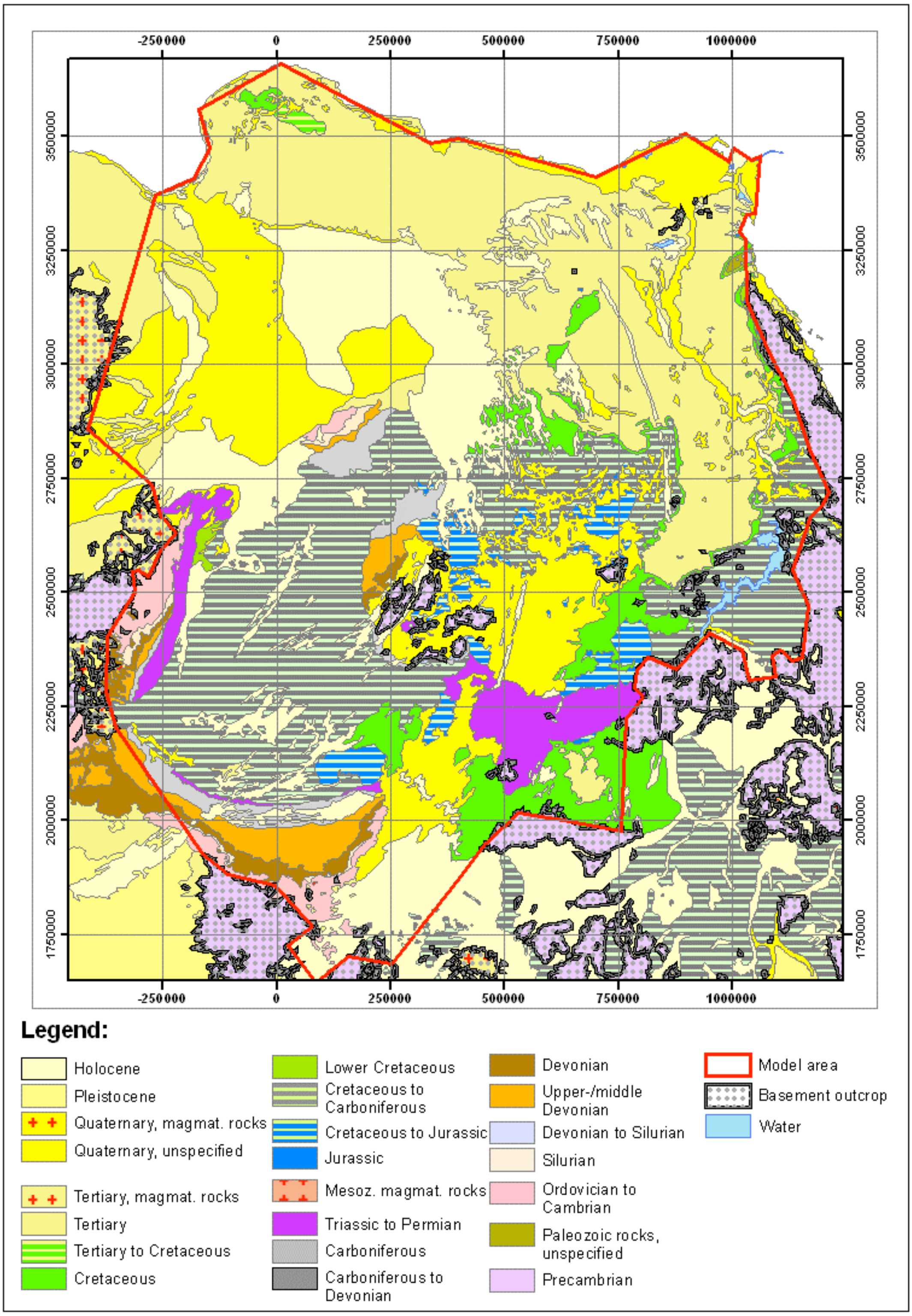

Fig. 2 Model area of the Nubian Aquifer System

SYSTEMATICAL APPROACH

The coupling of modelling systems such as groundwater flow and transport modelling systems, groundwater recharge and surface water modelling systems etc. was investigated considering systematical approaches in more detail. Technical or geometrical conditions as the Courrant- or Peclet number were not focussed in the investigation.

Diverse coupling techniques were investigated (Gossel, 2008) as shown in Fig. 3: At first horizontal coupling has to be differentiated from vertical coupling. Horizontal coupling means that the same modelling system is used to model with different resolutions, e.g. for a low resolution regional model and a high resolution local model. With the vertical coupling two different modelling systems are connected, e.g. a groundwater flow model and a groundwater recharge or a transport model. For these tasks different techniques exist. The geological model is coupled to a hydrogeological model by transfering structures and a parameterization. This “one way coupling” can be named a sequential coupling, i.e. a coupling without feedback. The same coupling method is used for setting the parameter groundwater recharge in a groundwater flow model, if the feedback of changing groundwater levels is neglected. The step of involving feedbacks can also be carried out in different ways. A serial coupling will set the depth to groundwater for the next time step of the groundwater flow model, a periodically synchronized solution would define certain time steps at which the depth to groundwater would be regarded and a fully iteratively coupled model for groundwater flow and recharge will do this for each time step. The last method is nearly always used for the coupling of groundwater flow and transport models so that this approach can be named an integrated coupling. The different methods are shown in Fig. 3.

The different coupling methods not only influence the technical options for data exchange, parallel computing etc. but especially the robustness or stability of the coupled models.

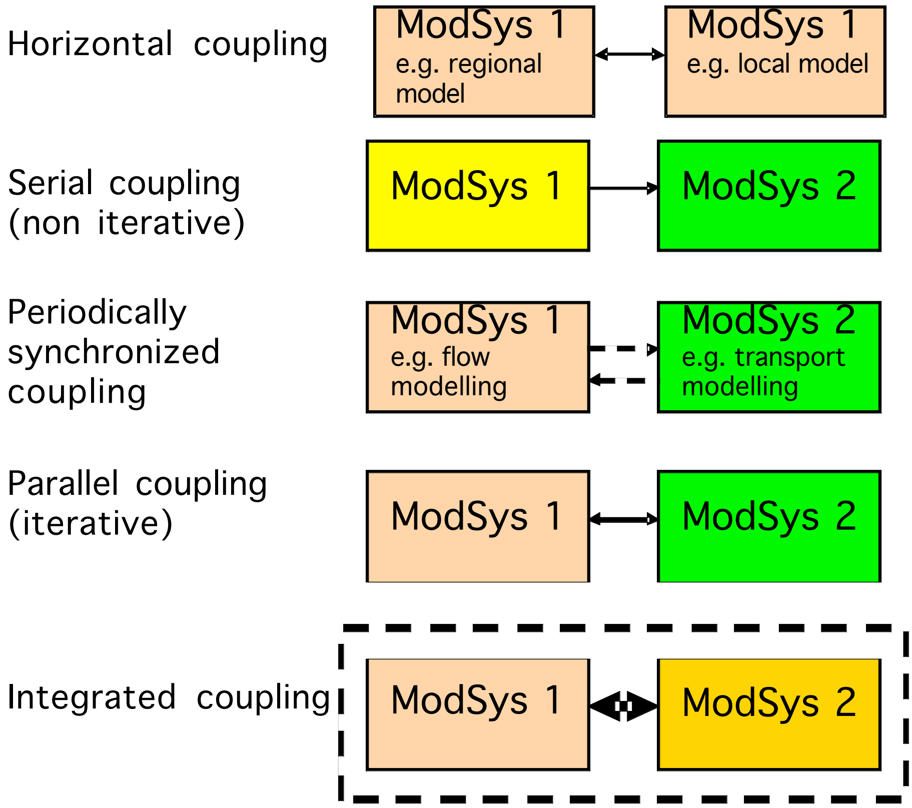

Fig. 3 Methods for coupling modelling systems (ModSys)

APPLICATIONS OF MODEL COUPLINGS

The coupling methods were used for different tasks in the modelling approaches. Geological models were always coupled sequentially to the hydrogeological models, in both case studies numerical groundwater models. The groundwater recharge was coupled in the model of the Nubian Aquifer System sequentially, in the Bitterfeld area with an infiltration model and in areas with a great depth to groundwater an unsaturated flow model. Iterative couplings were used for the transport modelling of the spreading of hazardous substances in the Bitterfeld area and the density driven flow and transport modelling of the development of the interface between saltwater and freshwater. Another sequential coupling in the Bitterfeld area was implemented for the coupling of the groundwater flow model to the pure statistical surface water level model.

RESULTS

Most important here are the views on the effects of the model couplings. The modelling results are not described in detail here but in Gossel *et al.* (2009) and Gossel *et al.* (2010).

The striking factor of an evaluation of model couplings is the stability of the resulting modelling approach. The stability must be considered under the aspects of numerical stability, geometrical stability and the stability of the coupling method. The sequential couplings of geological and hydrogeological model are stable whereas the iteratively coupled models are relatively unstable. This is due to the fact that in iteratively coupled models the factors causing instability seem to be added whereas in sequentially coupled models only the highest factor in each of the coupled modelling systems defines the instability of the whole modelling approach. The periodically synchronized modelling approaches as implemented for the coupling of infiltration water, unsaturated and saturated flow modelling systems is also very stable and has – compared to the sequential model coupling – additionally some advantages of the fully iterative approaches.

The influences of the method of model couplings on the results of the modelling approach itself are in most cases not so serious if the coupling is stable.

CONCLUSIONS

The methods for model couplings have a big influence on the stability of the complete modelling approach. The advantage of the substitution of an input parameterization by a complete model has to be very reasonable on the background of loosing model stability.

REFERENCES

Gossel, W. (2008) Schnittstellen bei der Kopplung von Modellierungssystemen der Hydrogeologie. Habilitation thesis available via http://sundoc.bibliothek.uni-halle.de/habil-online/08/08H031/habil.pdf

Gossel, W., Stollberg, R., Wycisk, P. (2009) Regionales Langzeitmodell zur Simulation von Grundwasserströmung und Stofftransport im Gebiet Untere Mulde/Fuhne. *Grundwasser* **14**, 47-60.

Gossel, W., Sefelnasr, A.M., Wycisk, P. (2010) Modelling of paleo-saltwater intrusion in the northern part of the Nubian Aquifer System, northeast Africa. DOI: 10.1007/s10040-010-0597-x

Sefelnasr, A.M. (2007) Development of groundwater flow model for water resources management in the development areas of the western desert, Egypt. Dissertation thesis available via http://sundoc.bibliothek.uni-halle.de/diss-online/07/07H178/index.htm

Wycisk, P., Gossel, W., Wollmann, A., Fabritius, H. & T. Hubert (2006): High resolution digital geological 3D-models as a base of hydrodynamic calculation in heterogeneous aq-uifers. In: Recharge systems for protecting and enhancing groundwater resources - Proceedings of the 5th International Symposium on Management of Aquifer Recharge, ISMAR5, Berlin, Germany, 11–16 June 2005, IHP-VI, Series on Groundwater No. 13, 455-460.