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source qui doit être utilisée pour toute référence à ce travail

Introduction to karst modelling

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According to DOTT (1998) we may use the terms *analytical* and *synthetic* science to highlight the distinction between two different approaches in investigating real systems: "The former stresses quantitative data and testable, predictive hypotheses, which inevitably oversimplify; in so doing, they impose an idealised order upon nature. Synthetic sciences rely chiefly upon qualitative, descriptive data with verbal and diagrammatic arguments, which strive to do justice to the great complexity of nature". To distinguish these two aspects within the earth sciences, LAUDAN (1987) chose the terms *causal* and *historical.* FRODMAN (1995) thinks, that geology is definitely an *hermeneutic* (interpretive) and *narrative* (historical) science. With the increasing use of numerical models in the earth sciences it seems, however, evident that geologists and hydrogeologists are somewhere between the two poles.

Since the beginning of karst research, early in this century, the interpretive and narrative approach prevailed in karst hydrogeology. During the last decades the scientific exchange between "narrative hydrogeology" and "quantitative hydrogeology" was intensified due to the fact that numerical models have been more widely accepted as a tool to test various hypotheses. A prominent example for such an intensified exchange are the recent developments in the field of speleogenesis. For more than 60 years researchers have been discussing whether caves form at shallow or deep levels below the outflow (or: outlet) of the system. With the use of models it could be shown that this question is not relevant because the depth at which caves are developing mainly depends on the parameter distribution, initial conditions and boundary conditions.

As it was pointed out by KLEMES (1986) and ORESKES *et al.* (1994), the increasing use of numerical simulation models had, unfortunately, a drawback: the misinterpretation of the simulated results (or the misuse of models) have not been infrequent in the last decades. In most cases the misinterpretation was due to the confusion between the concepts of "real system", "schematic representation of the real system" and "numerical model". To avoid the misinterpretation of the model studies presented in this volume and to help the reader to make the link between "descriptive hydrogeology" and "numerical modelling", we dedicate this preface to the relations between *real system, abstract scheme*, and *numerical model* (KIRALY 1994).

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Real systems, abstract scheme, numerical model

The reconstruction of a regional groundwater flow field, which is consistent with a given hydraulic conductivity field and with given boundary conditions, nearly always requires the use of numerical models.

A model is not the reality, it is only the realisation of a schematic and symbolic representation of the real system. The relations between *real system*, *abstract scheme* and *numerical model* are represented in figure 1, which also shows the principal problems in modelling groundwater flow.

Starting from incomplete information on the aquifer to be modelled, a schematic representation of the real system has to be worked out first. Generally, the flow of the goundwater is represented by differential equations, which may change depending on the type of problem to solve (saturated-unsaturated flow, constant or variable density flow, multiphase flow, etc.). The flow equations contain a few parameters depending on the aquifer properties (hydraulic conductivity, specific storativity, effective porosity, etc.) and the real medium will be represented by the field of these parameters, i.e. by giving a parameter value to each point of the modelled region, even there where we have never made any observation. As the available data on the hydraulic parameters are very limited, it appears clearly that indirect estimation of the parameters and interpolation or extrapolation of the measured values will be unavoidable when modelling real aquifers (figure 2). It must be emphasised that fractured and karstified media may present additional difficulties due to the strong local heterogeneity of the parameter fields. Finally, the imposed and initial conditions complete the scheme, sometimes also termed the "conceptual model".

The second problem is related to the realisation of a computer code based on numerical methods which allow to solve the equations defined in the abstract scheme. The problem is far from being simple for highly non-linear or hyperbolic differential equations in a heterogeneous 3-D space. As a matter of fact, the numerical model is only a more or less imperfect realisation of the abstract scheme.

The third, very important problem in modelling groundwater flow is the transfer of the simulated results onto the real system. Strictly speaking, the simulated results are not "valid" but in the highly simplified scheme or numerical model, and their meaningful transfer onto the real system requires that simplifying assumptions and uncertainties on the data explicitly do appear as uncertainties on the results. This could help to avoid such ridiculous situations as trying to simulate observed piezometric heads within a few centimetres, even though the schematised hydraulic conductivity field "ignores" the strong local heterogeneities existing in the real system.

In the authors' opinion many misunderstandings and unnecessary discussions about models could be avoided when keeping in mind the differences between real system, abstract scheme and numerical model, as well as some of the fundamental properties of a scheme (SUTER 1966):

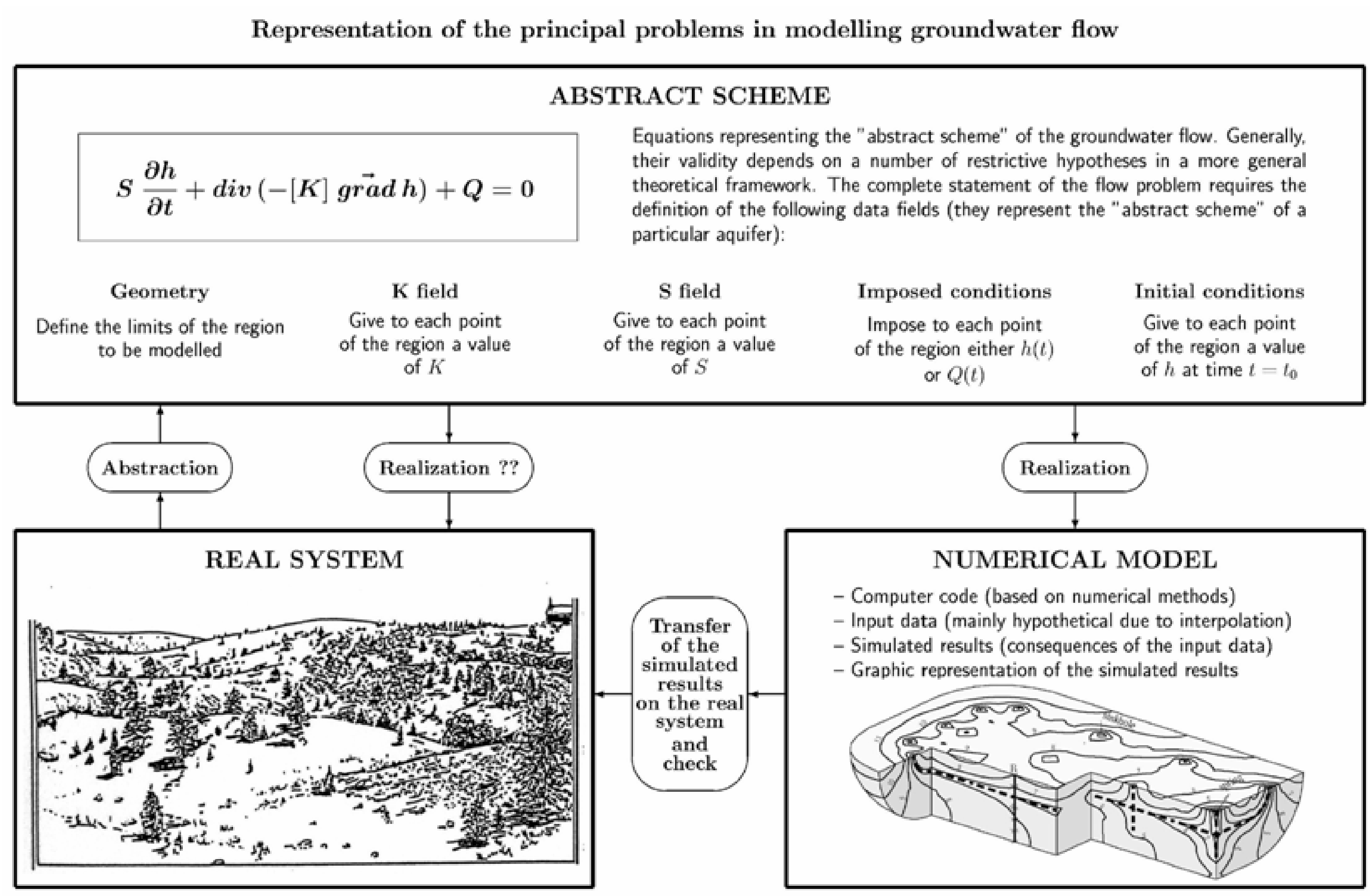

Figure 1: Relations between real system, schematic representation of the real system and numerical mode (after Kiraly 1994, modified).

- A scheme is established with a previously defined intention: to solve a problem. Depending on the problem to solve, the same real system may be represented by very different schemes.
- A scheme is summary, partial. Only certain elements of the real system are represented (generally by symbols) and only certain processes of the real system will be expressed by (generally quantitative) relations between these symbols.
- A scheme is always perfectible (by using more complicated equations and more detailed parameter fields), but it will never be identical (and it could never be identified) with the real system.
- Once established, the efficiency of a scheme must be judged with respect to the previously declared intention (aim). In itself, a scheme is neither "good", nor "bad". It becomes "good" or "bad" only when it is supposed to represent such and such real system or to solve such and such well defined problem.
- Each concrete realisation of an abstract scheme will be called "model". The numerical model, for example, is a realisation of the scheme (figure 1), but the real system, which motivated the creation of the schematic representation, ought to be a "model" of the abstract scheme, too.

The last proposition is somewhat unusual, but it simply shows the formal condition for the possibility to transfer the simulated results onto the real system: the transfer is possible only if both the numerical model and the real system may be considered as being, to some extent and from a certain point of view, the "models" of the same abstract scheme. In other words, we have to deduce the verifiable consequences of the proposed schematic representation (in most cases precisely by using numerical models) and we have to check, by direct or indirect experimental methods, whether the real system may (or may not) be considered as a realisation (a "model") of the proposed scheme. The central role played by the schematic representation may be surprising, but it is the only thing we actually and exactly know, because we have created it.

The usual model concept declares that something we exactly know (the schematic representation) is a model of something we do not know so well (the real system). The above proposed "upside-down" definition suggests an action: how to show, by direct or indirect experimental methods, that a system which we do not know exactly may (or may not) be considered as a realisation (a "model") of a schematic representation we have created from incomplete information. In the first case the battle takes place mainly in the abstract scheme, very often without any new information on the real system (see for example some of the papers published in the 1980's on flow and transport in fractured aquifers). In the second case we have to go back to the real system and look for new findings using direct or indirect experimental methods. And presently this is what we need the more.

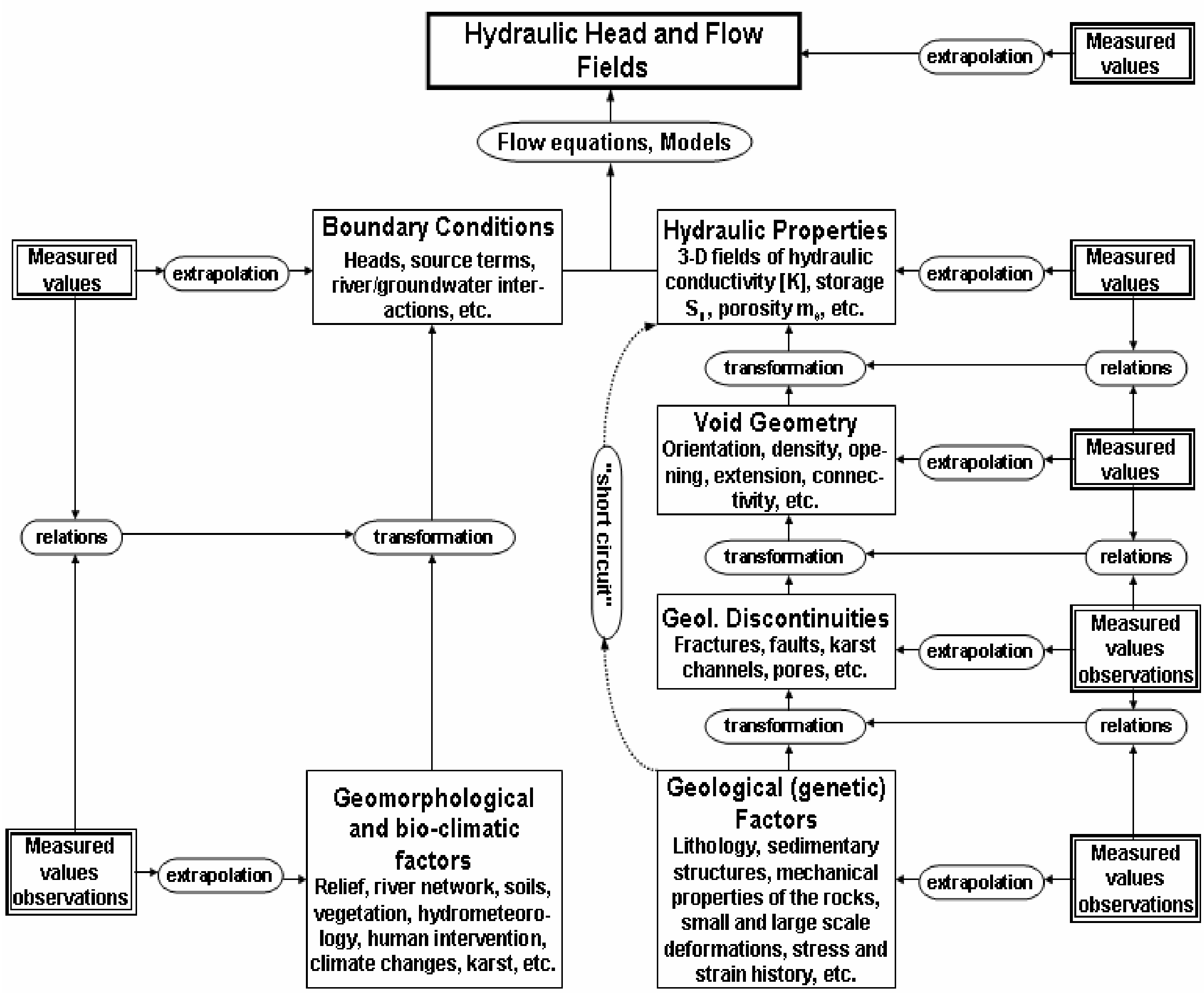

Figure 2: Problems related to the reconstruction of hydraulic parameter and flow fields (after Kiraly 1975, modified).

As a matter of fact, schematic representation of the real system, numerical modelling and experimental fieldwork should go hand in hand. The numerical models might be used from the very moment where the first hypotheses on geometry, hydraulic parameters and boundary conditions are explicitly formulated. Whatever may be the value of these hypotheses, the numerical model will give a "response", which represents the verifiable consequences of our inevitably hypothetical and schematic representation of the real system. Ultimately, it is the observed behaviour of the aquifer which will decide if our hypotheses are acceptable or not. It follows that models may be used to guide and assist our investigations step by step, that is, long before everything is ready for the "great and infallible final simulation".

Finally, it must be emphasised that modelling is not just curve-fitting. As it was pointed out by KLEMES (1986): "For a good mathematical model it is not enough to work well. It must work well for the right reasons. It must reflect, even if only in simplified form, the essential features of the physical prototype."

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