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Introduction

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Karst is the term used to describe the hydrological and geomorphological systems that develop on and in rocks of greater than normal solubility in meteoric waters. Carbonates are the commonest rocks in this group and carbonate karsts are the subject of this volume. As the hydrology of carbonate karsts is largely beneath the surface it is not well understood, or studied, by surface water hydrologists. Groundwater hydrologists also find karst terrains problematic because many karst aquifers contain a complex plumbing system which is not amenable to accurate analysis by the conventional methods applied to granular and fissure aquifers which use variants of the Darcy flow or diffusion equations. Indeed, a surface stream with a roof provides a better conceptualization for water movement in some karst aquifers although others are less heterogeneous and may be treated as fracture or double porosity aquifers.

For many years karst was treated as a scientific oddity, outside of the mainstream, and possibly not even subject to the "normal" laws of, hydrology, hydrogeology and geomorphology. This was unfortunate, because it seriously limited understanding of an extremely important resource and resulted in many environmental problems and unwise developments. Carbonate rocks occupy some 10% of the earth's surface but around 25% of the earth's population are largely or entirely dependent upon karst aquifers for their drinking water, and water for agricultural and industrial use. The largest such area is in southern China where a population of around 100 million people live in a bare karst area which covers some 900 000 km^2. In this area about 20% of the population live below the poverty line and 10% of the population have insufficient drinking water. In contrast to the bare karsts, many carbonate rocks are covered by productive soils and this is one reason for their high population. In the United States around 40% of the land to the east of the Mississippi River is karstic and in the European Alps important cities like Grenoble, Vienna and Innsbruck are supplied entirely by karst water. Around the Mediterranean Sea, in Europe, the Middle East and North Africa, karst aquifers are of fundamental importance for water supply both for human consumption and for agriculture which often depends on irrigation water. At the regional scale, karst water is often the only water resource.

Clearly the *sustainable management* of karst water resources is absolutely essential and in order to do this it is necessary to understand, and to be able to model and predict with some level of accuracy, the hydrology/hydrogeology of karst terrains. However, the scientific challenges present in the study of karst systems are many. For each karst hydrogeological system, the following major elements must be analysed: the structure of the system, the boundaries of the system and the boundary conditions of the system. The structure of the system is generally connected with the type and degree of aquifer porosity. Probably the most difficult task in karst hydrogeology is to define the hydrodynamic laws of groundwater flow given the range of possible types of porosity usually present in a karst aquifer. Two types of system boundary can be identified: inner boundary discontinuities such as low permeable fault zones and lithological changes between strata, and outer boundary discontinuities such as contacts between karst aquifers and other less permeable geological formations. The boundary conditions of the system are expressed both in terms of inputs such as infiltration of allogenic water, sinking of surface streams, seepage from other aquifers and artificial recharge, and outputs such as evapotranspiration, discharge into surface streams or other aquifers and spring discharges.

Several different approaches and methods have been used in the process of quantitatively defining karst hydrogeological systems. These include:

(a) interpretation of tracer experiments using both natural and artificial tracers,
(b) hydrograph recession analysis,
(c) water balance studies,
(d) regression analysis between one dependent variable and independent variables which are known to have a significant influence on the first one,
(e) hydrograph component separation.

In highly karstified aquifers, it is sometimes very difficult to adopt a "physically consistent" model using the discrete or continuum approaches and the REV (Representative Elementary Volume) or geostatistical theories. The main reason is that there is always insufficient knowledge of the way that karst systems really function and a general lack of accurate topological and geometrical data concerning the main karst conduits. In this case, simulations of the whole karstic system are usually realized by calibrating "black-box" models. These models are used to assess the transient behaviour of the karstic system in terms of water quantity. When solute transport is considered, for example to assess the protection zones, the transport is conceptualized as being highly dominated by convection (all other processes are neglected). Many "black-box" models simulate the whole karstic system including the unsaturated zone. Kernel functions are used to predict transient flow/transport behaviour of the karstic system. Interpretation of tracer tests using convolution treatments can also be realized. "Precipitation–runoff" models can be used at a regional scale for water quantity predictions. Multi-reservoir "black-box" models can be used and sometimes coupled to a model simulating the amount of water provided by the snowmelt on basis of different time scale.

In addition to the problems of modelling water quantity, the structure of most karstic aquifers makes them highly vulnerable to pollution. This structure is characterized by a high degree of heterogeneity, consisting on the one hand of high permeability in the conduits in contrast with low permeability in the encasing blocks, and on the other hand, of both dispersed and concentrated water infiltration. This duality produces a particular hydrodynamic behaviour: the floods caused by important infiltrations concentrated in very permeable areas are swift and violent, and consequently the filtration or the autopurification processes do not have time to develop as they do in porous media. Confident predictions on contaminant spreading and the probability of pollution are very difficult to make and have to be based on reliable and extensive data.

In general, karst aquifers are also very vulnerable to degradation and the related contamination by activities such as mining. Due to the high porosity, and consequently high transmissivity, once contaminants have entered the system they spread quickly and affect the quality of large bodies of fresh water. Therefore, exploitation of the water resources in regions with karstic aquifers requires prudence and a good understanding of the hydraulic links between the surface and the underground hydrological cycle.

Water management in karst regions requires special methods of investigation and regional planning because of the heterogeneity and vulnerability of karst aquifers. This need is even more pronounced in semiarid and arid environments. Tracer methods, involving the use of both artificial and natural tracers, are of special importance in research and prospecting. Often they are the only experimental tool for the direct evaluation of karst hydrological systems and aquifer parameters. The derived information is then used as the input for hydrological models. Although advanced methods such as the use of isotope tracer techniques are available in Morocco and in most of the North African countries, natural hydrochemical tracers are an indispensable tool for karst hydrologists.

During the 1990s, many countries and regions have promulgated regulations on protection zones in the vicinity of drinking water supply wells and springs in an effort to maintain, or to restore, the quality of groundwater. However, despite the fact that the authorities have often consulted the scientific community for assistance in the designation of the areas and the choice of the appropriate general regulations to be prescribed, it is still very difficult in many cases to determine, on a rigorous and scientific basis, the effective zones which are to be specially protected from any accidental pollution. The problem is particularly difficult in karstified aquifers where enlarged fissures, fractures and conduits carry the main portion of the groundwater flow. In these conditions, the groundwater network consists mainly of series of conduits and enlarged caves. The permeability and storage conditions are physically very different to those in a porous medium and thus the transit times, and degree of dilution, of pollutants are affected. Consequently, it appears that even if regulations exist, they are very often not followed, not applied or misunderstood, due to insufficient knowledge of the actual groundwater conditions; especially with regard to aquifer heterogeneity and the complex processes of contaminant transport in a karstified medium.

The papers, and the associated workshop discussions, in this volume will contribute to an improved understanding of karst hydrology and to water resource management in karst areas by addressing problems related to the modelling of flow and transport in karst aquifers, recharge processes of karst aquifers and the high vulnerability of karst water systems.