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PRESENT AND FUTURE DIRECTIONS IN KARST HYDROGEOLOGY

by

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(2 figures)

RESUME. - Voies actuelles et futures de l'hydrogéologie karstique.
La classification binaire classique distingue l'écoulement turbulent et localisé, dans de grands conduits, et d'autre part l'écoulement diffus et laminaire, conforme à la loi de Darcy, dans des fractures et des joints de stratification et entre les grains. On propose ici une classification en 3 catégories (fig. 1), qui comprend, outre les deux circulations précitées, celle qui se fait dans des fissures karstiques, c'est-à-dire par un réseau de joints élargis à environ 10 cm par la dissolution. Cependant, la difficulté de mesurer, et même seulement d'estimer, les proportions des trois types d'écoulement karstique reste très grande.

Besoins de la recherche fondamentale.

Le but le plus immédiat devrait être d'améliorer la connaissance des paramètres de base des systèmes d'écoulement en conduits, en fissures, et diffus. Des progrès ont été réalisés en élaborant des modèles mathématiques d'aquifères karstiques. Mais leur réalisme dépend d'une représentation adéquate des interactions entre les trois types d'écoulement, qui est difficile si l'on ne dispose pas des données de terrain nécessaires.

Applications aux ressources en eau.

L'application la plus importante de l'hydrogéologie karstique est la mise en valeur des ressources en eau. Un problème fondamental est, une fois encore, d'évaluer l'importance relative des écoulements en conduits, en fissures, et diffus, pour prévoir les disponibilités en eau et les risques de contamination. Depuis longtemps, on considère que des propriétés hydrochimiques plus variables indiquent un écoulement en conduits. Plus récemment, les isotopes stables se sont avérés de bons traceurs pour l'eau circulant dans des conduits. Une autre technique prometteuse est la mesure de la variabilité de l'activité du radon pour en déduire l'importance de l'écoulement en fissures. De nombreuses études décrivent le rapport entre la pollution des aquifères karstiques et l'utilisation du sol et les conséquences sur les eaux souterraines de la pollution industrielle, agricole ou due aux dépôts d'immondices. Un deuxième secteur de préoccupations est le tassement ou l'effondrement provoqués par les pompages dans les nappes.

Rapports entre karstologues et ingénieurs.

Les fruits des recherches des karstologues sont souvent ignorés par les ingénieurs, ce qui a parfois des conséquences désastreuses. Le meilleur remède à cette situation serait que les spécialistes du karst publient des articles ou fassent des conférences à l'intention des milieux professionnels concernés.

INTRODUCTION

These remarks attempt to summarise the current position of research into the hydrogeology of karst aquifers, as it appears to the writer, and to point out some directions in which future research might profitably go.

CONCEPTUAL CLASSIFICATION OF KARST AQUIFERS

We may take as a starting point the fundamental concept of karst aquifers as comprising bimodal flow media. The conduit flow in phreatic cave systems is physically embedded within a three-dimensional diffuse flow located within fractures, bedding planes, joints and intergranular pores. In general the conduit flow is localised and turbulent whereas the diffuse flow is laminar and obeys Darcy's Law. This dichotomy of flow types was first used by White (1969, 1977) in a conceptual classification of karst aquifers. Later it was shown by Atkinson (1977) that both types of flow could be demonstrated in field examples, and their relative importance could be crudely assessed by hydrological analysis. Study of a wider range of karstic and semi-karstic aquifers led Atkinson and Smart (1979) to

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suggest that an intermediate size of void, the karst fissure, was important in some aquifers. In karst fissure aquifers, turbulent or non-Darcian flows occur in a reticulate network of joints and bedding planes widened by solution to dimensions of ~ 10 cm. Atkinson & Smart (1979) suggested that a useful conceptual classification of karst aquifers might be along a two end-member spectrum from 100 °/o conduit to 100 °/o diffuse flow. More recent experience, and especially the great wealth of karst hydrogeological data now becoming available from China (Yuan, 1981, 1983), suggest that a three end-member spectrum may be more appropriate, as shown in Figure 1. Despite the obvious potential of such a classification in providing a framework for describing individual karst aquifers and the differences in their behaviour, its practical usefulness is limited. The actual properties to be used in specifying the end-members have not been defined. We could use the proportions of flow transmitted through the different types of void system, but this is extremely difficult to measure or even estimate. More easily measured parameters, such as contribution to void-space or to storativity, give a distorted picture of the dominant role played by a few large voids in transmitting groundwater. On the other hand, the concepts of hydraulic conductivity and transmissivity cannot be easily applied to the turbulent, non-Darcian flows characteristic of the conduit system, although Babushkin *et al.,* (1975) have suggested the use of a universal flow law to cover both laminar and turbulent regimes in fissured media. Perhaps the most feasible approach at present is that of Atkinson (1977) who attempted to determine the relative proportions of flow through normative cross-sections of a cavernous aquifer, basing his calculations on hydrologically-derived estimates of conduit frequency, roughness and diameter, and diffuse flow conductivity and storativity.

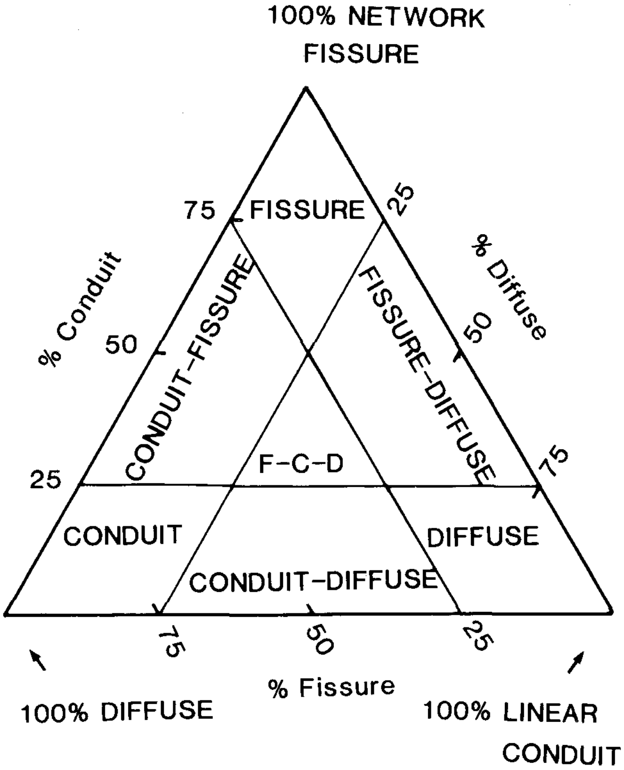

Figure 1. - Conceptual classification of karst aquifers

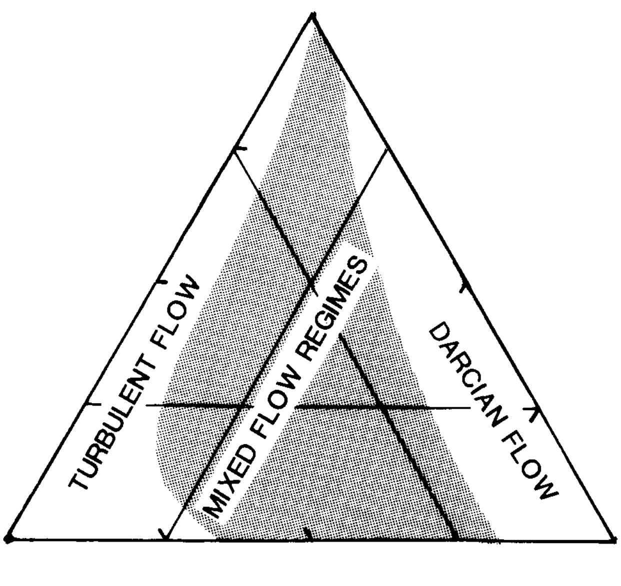

Figure 2. - Presumed relationship to predominant flow regime.

FUNDAMENTAL RESEARCH NEEDS

The most immediate aim for fundamental research in karst hydrogeology should be to improve our knowledge of the range of values for basic aquifer parameters of the conduit, diffuse and fissure systems. Recent improvements in pumping test interpretation (Boulton & Streltsova, 1977) should help here, but there is still a surprising lack of such basic data as transmissivity and storativity from pumping tests in the diffuse flow (see Laurent, 1985; Biron, 1985, this volume). Tracer tests are a common technique for investigating conduit flow, but we still lack adequate models for describing tracer breakthrough curves in terms of the hydraulics of conduit flow, turbulent dispersion and exchange with the fissure system (or "system-annexe" of Mangin (1975). The literature contains almost no estimates of conduit flow resistance, a parameter of fundamental importance in predicting aquifer behaviour (Atkinson & Smart, 1979; Gale, 1984; Atkinson *et al.,* 1983).

Some progress has been made in recent years in devising numerical models of karst aquifers (Kiraly, 1977; Cullen & Lafleur, 1984; Rushton, 1978). However, the realism of such models depends upon an adequate representation of the interaction of conduit, fissure and diffuse flows, which will be difficult to realise without adequate field data.

APPLICATIONS TO WATER RESOURCES

The most important application of karst hydrogeology in the future is likely to be in assessment and development of water resources (Dodge, 1985; Waltham *et al.,* 1985, this volume). Here a fundamental problem is to appraise the relative importance of conduits, fissures and diffuse flow blocks in different individual aquifers, as a means of predicting availability of groundwater resources, and characterising the resources which may be at risk from contamination. Hydrochemical properties have long been thought of as indicators of conduit flow, especially the relative variability in spring water chemistry which is greatest in conduit systems and least in diffuse-fed systems (Schuster & White, 1971; Friederich & Smart, 1982). More recently, stable isotopes have shown great promise as tracers of conduit water, although isotopic mixing is often greater than might have been anticipated (Atkinson *et al.,* 1985, this volume; Bakalowicz *et al.,* 1974). Another very promising technique is to use the variability of natural radon (^{222}Rn) activity in groundwaters as a measure of the importance of fissure flow (Andrews & Wood, 1972; Smart, Andrews & Zereshki, unpublished work). All of these techniques need wider application, in conjunction with hydrologic and hydrogeologic analysis, across a range of aquifer types, so that their value in prediction and classification can be assessed.

Numerous case studies are now appearing describing the relation between karst aquifer pollution and land use (Delannoy, 1985; Gamez, 1985; this volume), as well as industrial, agricultural and waste disposal pollution (Gunn *et al.,* 1985, this volume; Smart, 1984, in press). A second area now attracting attention is land subsidence or collapse following pumping (Delattre, 1985; Laurent, 1985, this volume; Edmonds, 1983). The mechanics of this phenomenon are well understood, but its prediction remains difficult or impossible.

RELATIONS BETWEEN KARST SPECIALISTS AND ENGINEERING GEOLOGISTS

A final area of current concern, a least to karst specialists, is the relationship between their field and the wider disciplines of hydrogeology and engineering geology. It is a common feeling among the former that their contributions are often ignored by engineers, sometimes with disastrous consequences. A recent North American textbook of hydrogeology which has become a standard (Freeze & Cherry, 1979) describes karst in wholly non-quantitative terms in a few pages. This lack of contact is not prevalent in all countries, and in China especially very serious attention is given to karst in engineering geology institutes and organisations (Yuan, 1983; Freeze & Cherry, 1979). The best approach towards correcting this situation is for karst specialists to write and contribute to publications and conferences intended for non-karst professionals. Only in that way will awareness be increased of the special problems of karst landscapes and the existing range of knowledge and techniques for solving them.

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