International Association of Hydrogeologists

Wilhelm F. Struckmeier
Jean Margat

Hydrogeological Maps
A Guide and a Standard Legend

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Hydrogeological Maps

A Guide and a Standard Legend

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Page

CONTENTS

Page

PART II

Page

FIGURES (Part I)

FOREWORD

Before the middle of this century the increasing demand for water, particularly in the industrialized countries, called for a rational planning of water resources to serve for agriculture, industry and public supply. Hydrogeological maps were considered useful basic documents in this development and, consequently, compilation of hydrogeological maps at various scales and for various purposes commenced by 1940. Since then, more and more areas in more and more countries were covered by hydrogeological maps, but still large land surfaces of the Earth have not yet undergone detailed and systematic hydrogeological mapping.

A striking feature of hydrogeological maps prepared up to 1960 is their great variety of content and representation, as revealed from an exhibition held in Helsinki in 1961 during the General Assembly of the International Association of Hydrological Sciences (IAHS), where approximately 200 hydrological and hydrogeological maps were displayed. Owing to the complexity of hydrogeology at the interface between geology and hydrology, the variety of features presented on the maps is justified. However, the differences in representation which made it difficult to compare the hydrogeological conditions of different, even neighbouring, areas was criticized. Already in 1960 and 1961, the International Association of Hydrogeologists (IAH) attempted a survey of the techniques used in the preparation of such maps by circulating a questionnaire to hydrogeologists in many countries. The replies revealed that there was a complete lack of uniformity, whereby a symbol, an ornament or a colour would not have the same hydrogeological significance on whatever map it might appear. There were few maps with a regional rather than a parochial outlook, and there was no consensus of opinion as to what hydrogeological features should be portrayed on maps. Moreover most of the concepts reflected rather theoretical considerations which altogether ignored the practical difficulties of expressing such matters on a two-dimensional map.

Two basic requirements had become clear, the necessity for co-ordination on an international basis on the methods of presenting hydrogeological information in map form, and agreement, again on an international basis, on which hydrogeological features were of sufficient importance to require depiction upon a map wherever and whenever they occurred within the area covered.

Two international scientific bodies in particular, IAH and IAHS, concerned themselves with these problems. After many discussions, IAH had established in 1959 the Commission for Hydrogeological Maps with a remit first to prepare a Legend of recommended symbols, ornaments and colours, and secondly to plan the production of a series of small scale maps to cover the whole of Europe as a practical model. Contacts were established with UNESCO, FAO, the Commission for the Geological Map of the World (CGMW), and interested parties of many nationalities; agreement was reached on a draft legend for hydrogeological maps which was published by UNESCO (Anon, 1963).

The European international small-scale hydrogeological map project was mainly designed to harmonise hydrogeological representations for test purposes but also to promote mapping activities worldwide. Not only for cost reasons, but also to permit easy comparison, the map in question was to be compiled at the same scale (1 : 1,500,000) as the Geological Map of Europe, with the same grid of map sheets, topographic detail and projection.

To work out the new concept and the new legend, an area characterised by a high degree of hydrogeological complexity was selected and the decision was made to elaborate models of Sheet C5 (Bern) in order to test the legend and guidelines for representation. Hydrogeologists from Austria, Czechoslovakia, the Federal Republic of Germany, France, Italy, Switzerland and Yugoslavia were involved in the compilation of this map from 1962 to 1964.

Four versions of the map sheet were prepared, printed and discussed, reflecting with their legend and representational concepts the development from largely geological to hydrogeological thinking, where the hydrogeological character of rock bodies is expressed by colour on the map. On Model 4 of the sheet, which was accepted as the prototype of the European series, aquifers are shown by two tones of blue (intergranular aquifers) and green (fissured aquifers), and brown colour is used for rocks with local groundwater resources (light brown) or little or no usable groundwater (dark brown). Meanwhile the series of 30 sheets and explanatory notes of the International Hydrogeological Map of Europe is nearing completion. It is published jointly by the Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany, and UNESCO, Paris.

The practical work on the four versions of Sheet C5 resulted in numerous additions and modifications to the draft legend of 1963, so that a new legend for hydrogeological maps was published, in 1970, by the Institute of Geological Sciences (London), IAHS, IAH and UNESCO (Anon, 1970). The publication was in colour, and the text was printed in English, French, Spanish and Russian.

Work upon the European hydrogeological map series and developments in hydrogeological mapping elsewhere in the world have shown up a number of inadequacies in the 1970 legend, which was out of print by the late seventies.

To satisfy the demand for a modern international legend for hydrogeological maps, the IAH Commission on Hydrogeological Maps (COHYM), in co-operation with IAHS and UNESCO therefore prepared a low cost revised edition of the legend, published as a UNESCO Technical Paper in Hydrology (ANON, 1983). It was intended as an interim publication, which was to be replaced, after several years of practical use, by a fully revised international legend, to be published in colour and with a multi-lingual text. There is no doubt that the European map has become an enormous incentive for mapping activities elsewhere in the world and the legends of 1970 and 1983 have greatly contributed to a more uniform approach. Knowledge of the philosophy and technology of hydrogeological mapping, however, appeared restricted to a limited group of scientists working on programmes of UNESCO, the IAHS and the IAH. The need was evident to spread this knowledge to more hydrologists, hydrogeologists, geologists and engineers. UNESCO's International Hydrological Decade (IHD, 1965 - 1974) turned out to be the appropriate vehicle and several working groups and expert panels worked on methodological guidance material. In 1974, UNESCO published a specialized, quadrilingual supplement to the 1970 legend, entitled "Legends for geohydrochemical maps" which contained not only the recommended ornaments but also explained their uses and relevance (Anon, 1975).

A further important step was an IHD-publication entitled "Hydrological Maps" compiled by a working group and published jointly by UNESCO and the World Meteorological Organisation (WMO) in 1977 (Anon, 1977). This guidebook "Hydrological Maps" contained descriptive, narrative material on all fields of hydrological mapping and one chapter of 55 pages was devoted to groundwater maps. It introduced the philosophy of hydrogeological mapping to general-purpose and special-purpose maps and related them to the already existing international legend. Thus the seventies saw a broad thematic coverage of hydrogeological mapping. Finally, the spreading of knowledge on hydrogeological maps to students, graduate and university teachers led to the inclusion of an explanatory chapter and a model map in the UNESCO publication "Teaching aids in hydrology" (Anon, 1985).

The European map, the above mentioned guidebook and legends greatly helped to meet a pronounced demand for small-scale maps in other continents. Mapping activities were reported from a number of the larger countries and an appreciable number of regional or even continental maps were initiated. Remarkable examples are the hydrogeological maps of Africa, a number of South American countries, the Caribbean, Arab Countries, Australia, North America, South East Asia and, with other aims than the above European map, the countries of the European Economic Community and the (former) Socialist Countries. These regional maps, in turn, awoke national mapping activities (mostly at larger scales) in countries within these regions. Most of the maps are based on the principles developed within the framework of the IAH/UNESCO European map and on the legend developed within this context.

While these small-scale maps basically can be considered general hydrogeological maps or maps of occurrence or flow of groundwater, many medium- and large-scale special purpose maps have been developed at national level or, for selected areas, within countries. It would go beyond the scope of this foreword to describe all variations known to the authors. Hence, a list of maps brought to the attention of COHYM is included as Annex A, to show the broad variety of hydrogeological maps existing. A striking feature, however, is the universal applicability of the UNESCO legend which with some extensions could be used even for very difficult and specialized cases (Grimmelmann et al., 1986).

The mid-eighties brought a new momentum. An international symposium "Hydrogeological Maps as tools for economic and social development" was held at Hannover (Fed. Rep. of Germany) in May 1989 and the proceedings revealed a broad spectrum for compiling and applying hydrogeological maps. The symposium provided the impetus for new initiatives for preparing adequate, modern and updated guidance material, and this for two reasons. Firstly, stocks of the 1977 publication "Hydrological maps" were exhausted, and secondly, the progress in hydrogeological mapping was so evident that new guidance material was needed. Already in the preparatory phase of the symposium an expert group had started work on a new guidebook, meeting in Hannover in January 1986. Work however slowed down and was resumed only much later during the fourth phase of the International Hydrological Programme (IHP, 1990 - 1995).

Already prior to the Hannover symposium work had started on a revised version of "Hydrological Maps" restricted however to groundwater mapping. Preparations were initiated during meetings in Cambridge 1985, Karlovy Vary 1986 and Duisburg 1988.

The fourth IHP phase was marked by a desire to contribute to the rational management of water resources and to their protection. One project therefore was the compilation of a "Guidebook on mapping the vulnerability of aquifers". A joint IHP/IAH working group in two meetings (Tampa/USA, 1991; Torino/Italy, 1992) elaborated the text while a special group in Oegstgeest/The Netherlands, 1993, worked on a special legend for vulnerability maps. This work was carried out under the responsibilitiy of the IAH Commission on Groundwater Protection simultaneously and in close coordination with another group of IAH/IHP concerned with a new look at hydrogeological mapping. From the start, the two publications were planned as twin, fully complementary volumes; moreover compatibility was ensured by partial common authorship. The vulnerability guidebook was published as a special IAH publication with the support of UNESCO, in 1994, thus slightly preceeding the present guidebook on hydrogeological mapping.

As mentioned above, work on the successor book of "Hydrological Maps" was conducted within the framework of preparing, holding and evaluating the Hannover Symposium of 1989. With the financial assistance of UNESCO, a meeting took place in Hannover in January 1988 with Day, Engelen, Gilbrich, Margat, Romijn, Sarin and Struckmeier participating. The meeting reached a preliminary concept and assigned authors for chapters. A subgroup (Engelen, Khouri, Krásny, Romijn, Sarin, Struckmeier) subsequently met in Duisburg, Germany, in April 1988. The Hannover symposium in 1989 enabled a first exchange of drafts but it also provided new ideas and doubtless fertilized the further compilation of the draft text. Work slowed during the following years for reasons beyond the control of the authors but thanks to initiatives from the IAH and from UNESCO was resumed in 1993. A draft was circulated in winter 1993/94 to a larger number of hydrogeologists and map makers and the draft was subsequently reviewed during a meeting of editors (Rinteln/Germany, 15 - 17 June 1994) involving Messrs. Gilbrich, Margat, Romijn and Struckmeier. Mr. Day undertook scientific and linguistic revision during the second half of 1994 and publication became possible in 1995, thanks to financial aid from the German National Committee for the IHP/OHP, the IAH and UNESCO. As stated above, this volume is intended to be a guide for hydrogeologists involved in mapping or using maps and the publication should also be considered a twin of the guide on mapping the vulnerability of aquifers.

The authors, the sponsors and the publisher would appreciate wide diffusion of the guidebook so as to enable a worldwide up-swing of hydrogeological mapping.

The purpose of this book is not only to promote hydrogeological mapping but also to introduce this 'art' to a broad spectrum of users, ranging from practising hydrogeologists, water engineers and resource managers, to land and town planners, decision-makers and politicians, but not forgetting the general public. This can best be achieved by encouraging and assisting map makers to apply clearly understandable, logical approaches which make full use of agreed symbols and cartographic techniques and which illustrate hydrogeological systems with the utmost clarity. This book is intended to contribute towards better understanding of hydrogeological phenomena through visual presentation in the most appropriate way as required by differing circumstances: in other words, investigation and understanding, throughout the world, of hydrogeological systems when shown in thematic form.

Finally, the authors wish to gratefully acknowledge the efforts of past generations of hydrogeologists who paved the way towards today's understanding and knowledge.

W.F. Struckmeier W.H. Gilbrich J.B.W. Day

Part I
Chapter 1.
INTRODUCTION

Hydrogeology as a modern science has strongly expanded over the past three decades and growing emphasis is put on all aspects of the quantity and quality of water resources, surface water and groundwater, including the protection of the natural environment.

As a consequence, hydrogeological maps as synoptic representations of all kinds of earth- and water-related data have attained the utmost importance, since maps are particularly useful tools in describing static situations and dynamic processes in the subsurface as related to water. With the boom of computer assisted techniques (CAD = computer aided design and GIS = geo-information system) their significance is ever increasing.

In developing the present guidebook, the authors are aware of the long historical evolution from geology-oriented map types to the modern concept of visualisation of groundwater related features on maps. To achieve this goal the book will briefly discuss salient pecularities of groundwater, basic requirements for maps, types and classifications of maps and then introduce the techniques of map compilation.

PURPOSE OF THE GUIDEBOOK

This guidebook aims at a systematic presentation of the concepts and graphical representations valid for hydrogeological maps. Thus it provides information on a wide range of hydrogeological maps in the broad sense (see Annex A), assists the hydrogeologist to choose the most appropriate type of map for his purposes and thus leads to desired results in the most efficient way. It should assist the hydrogeological map maker to identify the type of hydrogeological map and the kind of representation that best corresponds to the purpose the map is intended to serve, as well as to point out constraints. Owing to the considerable variation of information depicted on a hydrogeological map, depending upon e.g. purpose (type), scale, reliability of information, cost or other factors, it would be unrealistic to believe that only one map type could satisfy all requirements.

The guidebook conceptualises the preparation of hydrogeological maps, whereby step by step different levels of information are compiled, superimposed and finally integrated. The ultimate aim is to develop a profound grasp of the complex hydrogeological situation and to portray it in a clear and easily readable manner on a map, eventually supported by section or diagram. For practical implementation, a standard legend is also included (see Part II).

Whilst the predecessors of this guidebook merely presented a list of symbols, ornaments and colours, the present guidebook is orientated towards systematic descriptions of the concepts and types of hydrogeological maps in the broad sense. A knowledge of these concepts is considered essential for every map author, to optimize map preparation. Moreover, useful hints on the practical aspects of hydrogeological map preparation are also provided.

The methodology here proposed requires a phase of careful evaluation of the hydrogeological problem, the definition of the task to be carried out and the preparation of an appropriate map concept. The methodology then leads to preparing a suitable base map and studying auxiliary information, eventually followed by additional hydrogeological field work, interpreting the collected data and information, redefining and adjusting the map concept, including the representational system, and, finally, drawing the map manuscripts which are then further processed by a cartographic draughtsman for printing a publication. The ultimate aim is to translate the hydrogeological setting into an optical language which can be understood without error and bias by the map user. Hence, the map making hydrogeologist will choose his means so as to best satisfy the intended readership which may range from specialists over the general public to politicians and decision makers.

The recommendations proposed here, in particular the standard legend (Part II), have been successfully applied worldwide for several decades. However, they are neither binding, nor can they substitute for the scientific initiative of the map maker who has to decide upon the appropriate representation as a function of the purpose of the map, the possible user, the levels of information, funds and personnel allocated, the time framework, etc.

It should be mentioned here that hydrogeological maps may be designed at two markedly different levels, i.e.
- as a product of a hydrogeological mapping project (optical result of data capture) or
- as a thematic synthesis of already existing data, maps and reports.

The main difference lies in the different objectives. Whilst the maps comprising a mapping programme are self-sufficient, general, basic public information, the thematic synthesis maps are usually tailored to serve a particular purpose or to answer a specific question or problem.

DEFINING THE SCOPE OF HYDROGEOLOGICAL MAPS

Position in geoscience and water science

Within the family of earth sciences hydrogeology is the link between geoscience and water science. Hydrogeological maps reflect this transitional character, as they encompass a huge variety of earth- and water-related parameters which they may portray. With their ambivalent nature they can be regarded as a subgroup of both hydrological or geological maps, (Figure 1) neither classification covering their full range (Anon, 1977).

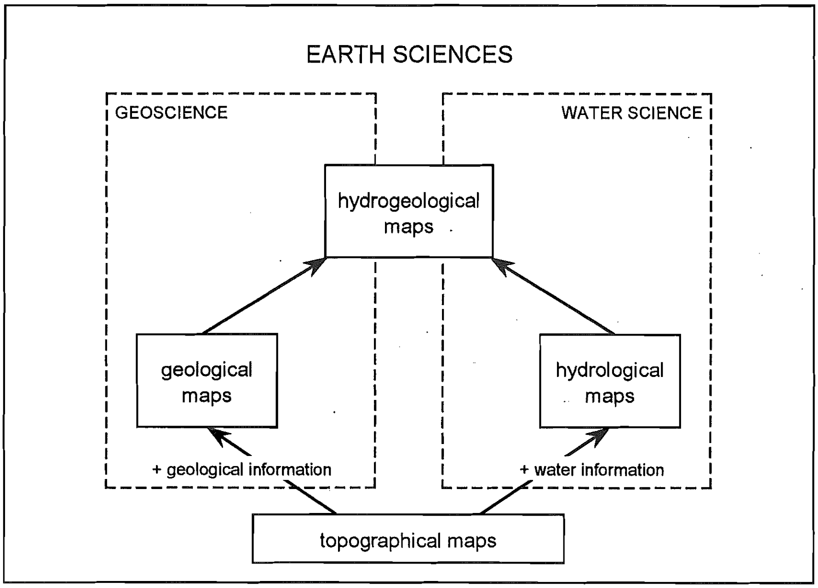


Figure 1. Hydrogeological maps in the system of earth sciences maps.

Hydrogeological maps in the broad sense deal with the complex system "Water ⇔ rocks", their properties and interrelations (Figure 2). This system is three-dimensional, since it covers part of the earth's crust, and, in addition, it changes in time (particularly the water component). Hydrogeological maps, therefore, have to include the vertical dimension and they should have reference to a date. They may show mere parameters of a component of the system, a combination of parameters or comprehensive interpretations of hydrogeological data.

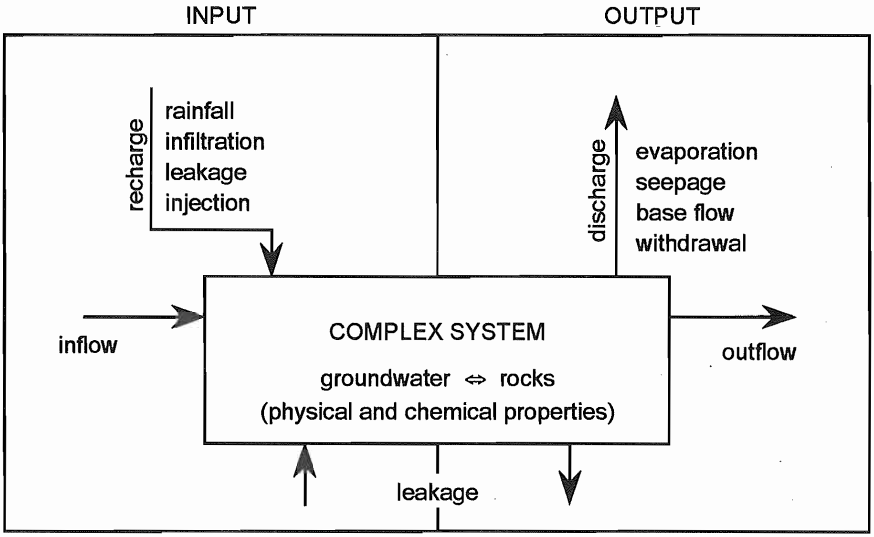


Figure 2. The complex system "Water ⇔ rocks", its input and output.

Hydrogeological mapping comprises all programmes and techniques that are suitable to collect, document, retrieve, plot, interpret and represent hydrogeological information in graphical form. Hydrogeological maps thus are the final product of the whole hydrogeological mapping procedure. The guidebook by virtue of its title will emphasize the compilation and drawing of maps.

Position in the field of graphical representation

Hydrogeological maps are part of the overall system of graphical representation used in earth sciences (Figure 3).

This publication chiefly deals with hydrogeological maps and vertical cross-sections, however, some notes on the usefulness of perspective diagrams are included. The most common graphical representations applied in geoscientific work, hydrogeological work included, are shown on Figure 4.

Maps and vertical sections are "representations, normally to scale and on a flat medium, of a selection of material or abstract features on, or in relation to, the surface (or subsurface) of the Earth" (Anon, 1973). On hydrogeological maps in the broad sense, these features represent data and information about groundwater and rocks, or derived information. In any case, on coloured hydrogeological maps colour must be attributed to true hydrogeological information, rather than to stratigraphy or rock type units.

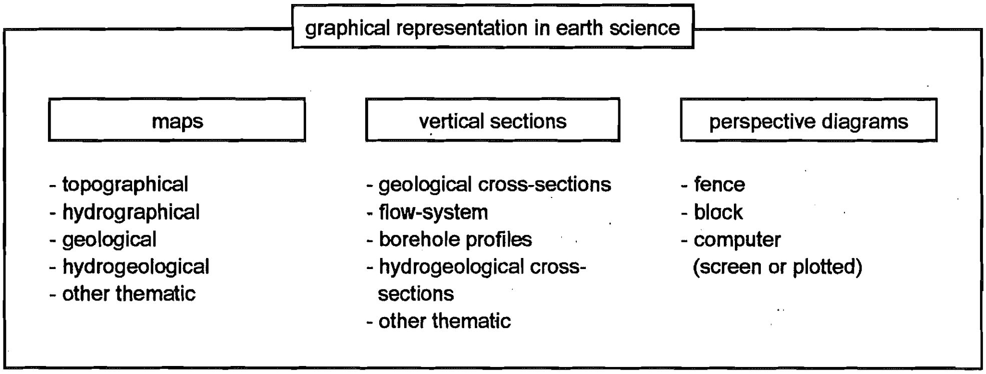


Figure 3. The system of graphical representation for use in the field of earth sciences.

This handbook chiefly deals with maps as planar representations of hydrogeological data. The map sheet itself, however, is usually not only composed of the map face (the area represented on a thematic map) but it also contains a set of typical insets and explanations, to furnish clear and complete information to the map reader. The following main elements of a map are considered essential (see Figure 5):

- title expressing the theme and scale of a map - authorship
- map face providing thematic information in relation to a suitable and up-to-date topographic base
- legend explaining the graphical elements portrayed on the map
- cross-section to allow a pseudo-three-dimensional understanding of the hydrogeological setting
- inset maps to show additional information not contained on the map face, e.g. reliability of map information, climatologic information, index map to define the sheet location in the case of systematic map series
- date of the publication of the map
- date of map information (if differing from the publication date)
- place of issue
- copyright
- short citation (preferably at the right lower corner) to allow proper bibliographic citation and also for identification of the map when in storage.

Further cartographic principles are outlined in Chapter 3.

Role in the treatment and display of hydrogeological data

Graphic representations (maps in the broad sense including cross-sections and diagrams) in hydrogeology must be considered together with tables, data bases and mathematical models. These elements and their interrelations as well as the important role of data bases are shown in Figure 6.

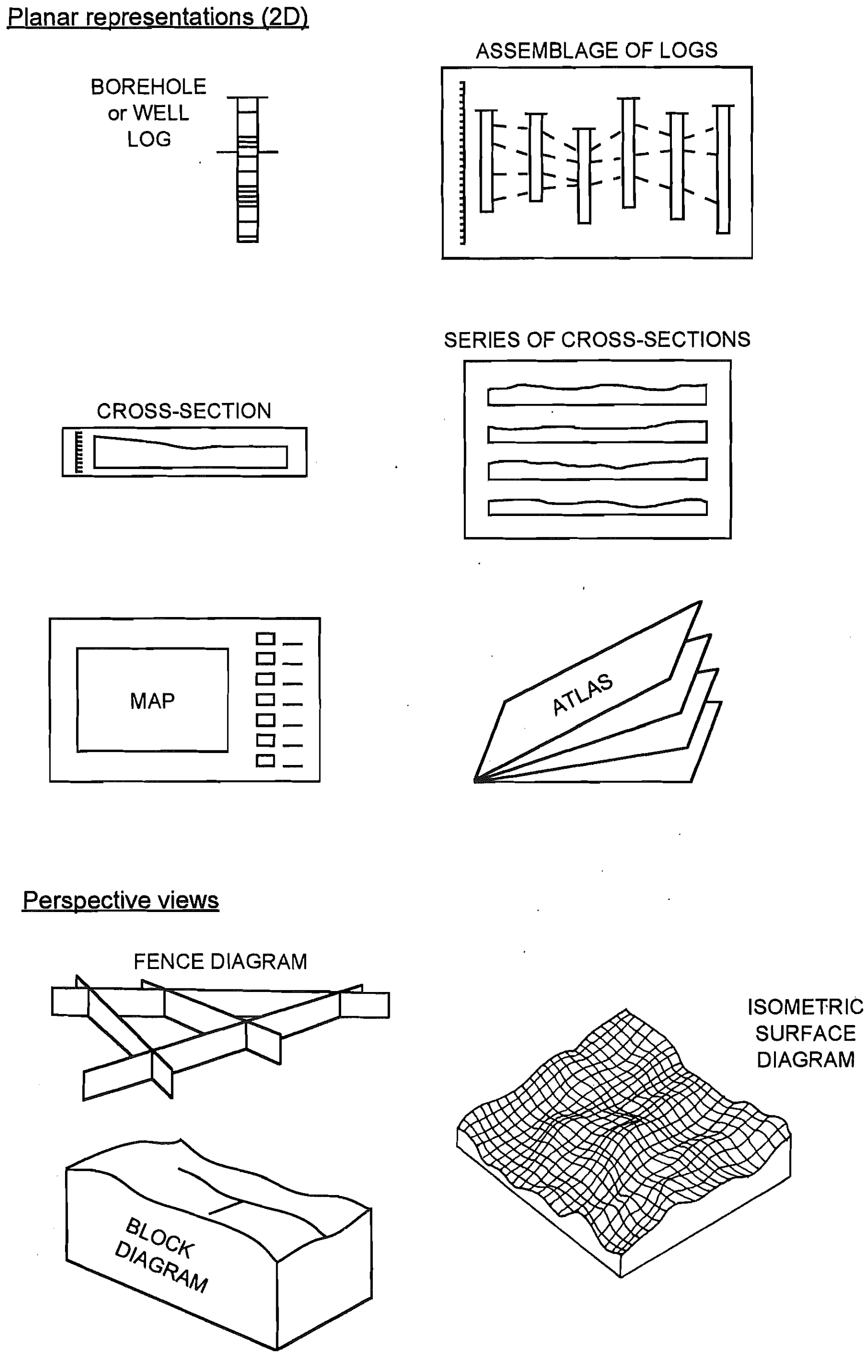


Figure 4. The most characteristic graphical representations in geoscience.

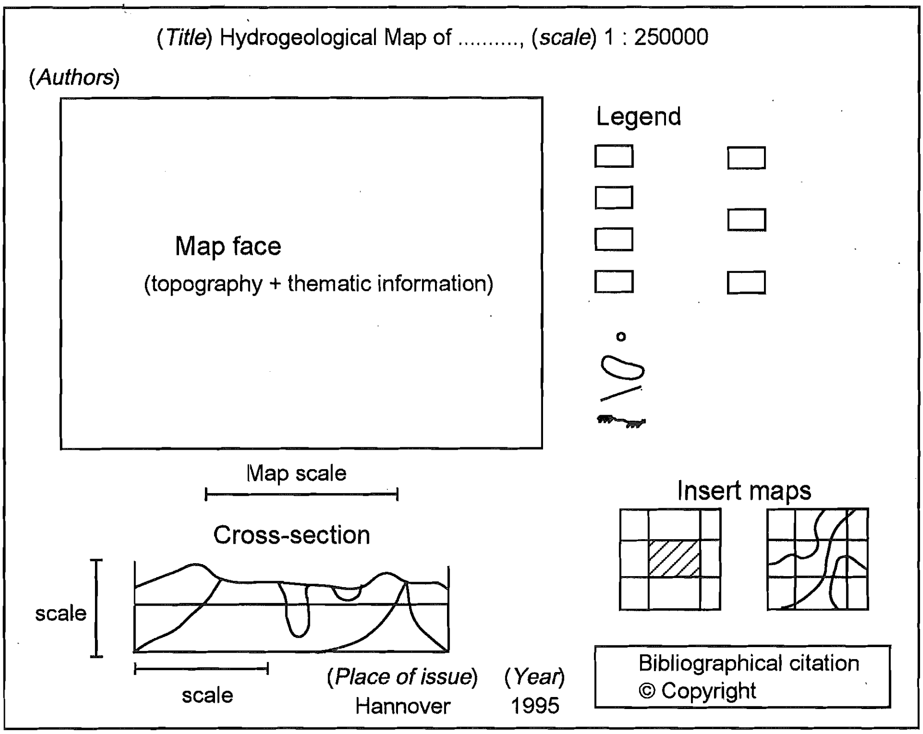


Figure 5. Elements of a thematic (hydrogeological) map.

Maps, data bases, tables and models are to be considered complementary modules in the systematic hydrogeological reconnaissance and mapping process, usually carried out e.g. by governmental and other public bodies. Data bases containing point and areal data are of prime importance to any service responsible for groundwater issues, whereby maps have a dual function both at the output and input side of the data bases. Sophisticated and true computer-based data bases able to handle both point and areal data are burgeoning (see Chapter 7). However, traditional data bases such as archives, lists, reports and especially maps on which particular data is registered are and are likely to remain very useful and must be considered extremely valuable elements in the hydrogeological knowledge building process.

JUSTIFICATION FOR HYDROGEOLOGICAL MAPS

In contrast to topographic and geographic maps which are generally well appreciated, the value of thematic maps (hydrogeological maps included) is often disputed. Even technicians, planners and administrators sometimes argue against maps, so that they are ignored, hampered or misused. On the other hand it is increasingly evident that even the general public will accept thematic maps in journals or newspapers, such as those related to population density, distribution of criminality, etc. Hydrogeological maps should make use of this trend. The chief problem seems to be that the map users do not find fast enough the particular information they expected or they are unable to grasp it due to poor design; in other words, the content and representation of the map do not meet the expectations of the map user. This problem may not necessarily be the fault of the map user but can result from poor map-making techniques.

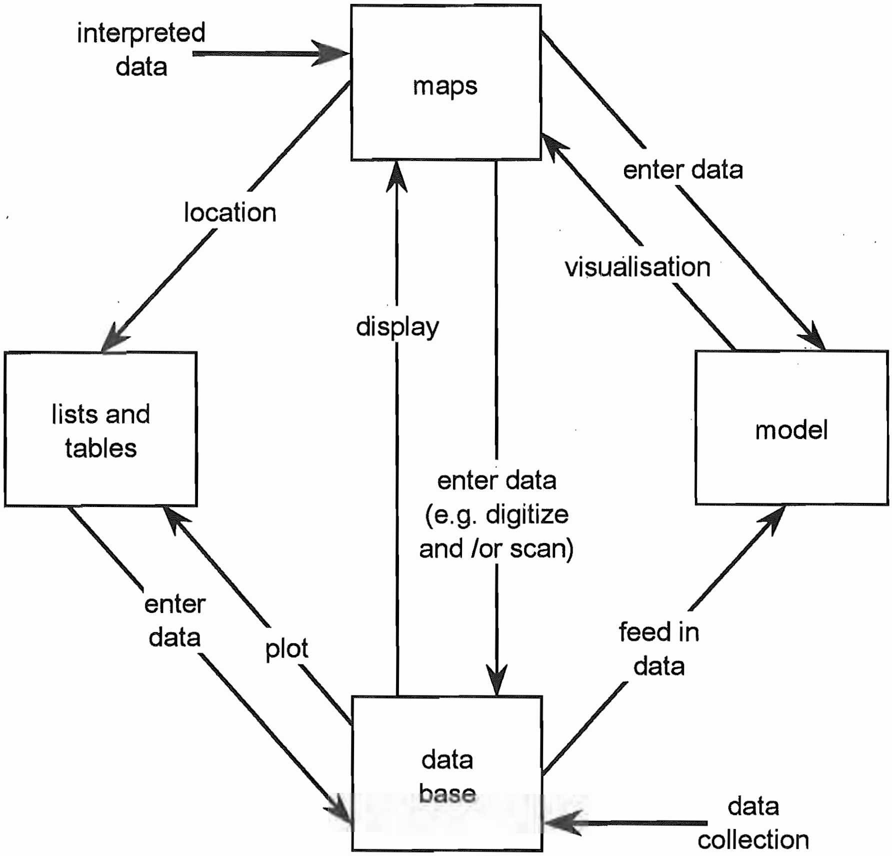


Figure 6. Relations between elements and ways of treatment and expression of hydrogeological information.

This continuous source of profound misunderstanding between natural scientists like geologists or hydrologists on the one hand and technical and administrative staff on the other must be overcome by education as well as better map design.

Therefore, a standard legend providing a common graphic language to both map makers and map users, facilitating mutual understanding is included in this volume (Part II). This legend has been inspired by other legends broadly related to water and earth sciences, and it stresses the symbolic value of colours and ornaments. Thus users should not have to guess or develop by analogy what is indicated by the colours and/or symbols used.

Hydrogeological maps using this sound representational concept can be very powerful tools for conveying information, particularly for planning and management as well as for education and public information.

The advantages as well as disadvantages and limitations of hydrogeological maps are summarized on Table 1.

Table 1. Pros and Cons of (hydrogeological) maps.

Advantages	Disadvantages, limitations
• synoptic representation (clear, quick overview, exact locations, to scale, can be measured) • quick grasp of situation • easy to use, particularly if legend is already known • reveals gaps and disconformities in quantity/quality of information (areas to be studied, information to be generalised) • can serve a multitude of users (many copies, good distribution of information, different users) • large amounts of information and data are safely stored/plotted, can be further processed • easy to handle • nice, decorative picture • graphical picture language for visual users (specialists and laymen) • avoids misunderstandings • high aesthetic value	• high cost of production • long production process • static • representation limited by two-dimensional paper display (either two-dimensional to scale or perspective with scale distortion) • clearness of representation requires generalisation and selection of themes/features shown, but also pretends equal state of knowledge throughout the map area • map unusable, because overcrowded with information • legend too complicated • information desired not found • not available at required scale • map unusable, because topographic information outdated or unreadable • in many cases additional expertise of specialized hydrogeologists required
= excellent tool, if required information is shown correctly at a suitable scale	= most limitations can be overcome by careful preparation, adequate execution and new techniques

Their usefulness has been proved in many countries where precious drinking water resources have been discovered and protected within the framework of mapping programmes. Failures of drilled wells have decreased considerably, and public awareness for groundwater created, to name but a few outstanding positive results. Hydrogeological maps have become an indispensible tool for environmental planning and protection policies. They can also help to reduce the costs of management of water resources and thus constitute an important element in the overall economy of a country. Maps also form the base for legal and administrative issues, as they define the spatial, temporal and gradual utilisation of water resources.

In conclusion, time and money are never wasted by a properly designed hydrogeological mapping project; the costs of map preparation and printing are low, related to those of geophysical soundings, drilling or even to the commonplace leakage of water in our distribution systems (Collin in Struckmeier et al., 1989).

THE OVERALL EVOLUTION OF HYDROGEOLOGICAL MAPS

Hydrogeological maps serve various purposes and are used by professionals and others interested in hydrogeology. Clearly, the purpose of the map and the target group of map users decisively determine the content and format of a map. Therefore representation and format of hydrogeological maps may vary widely, e.g. from simplified to complex, rough to detailed, or hand drawn black and white to cartographically drafted and colour printed. Hence, the aim of a map must not necessarily to be cartographically perfect, but to be perfectly adapted to its purpose.

However, considering the wealth of existing hydrogeological maps, one may trace an evolution of maps, as shown in Figure 7 (Struckmeier et al., 1989).

This scheme, comprising a main stem of systematic, general maps and various derived maps designed at different stages for various purposes, can serve as an indication for hydrogeological map makers to structure their work in a logical and efficient way.

The cornerstones of any hydrogeological mapping programme are information on topography, geology, climate, hydrology and, of course, basic and more advanced data on groundwater and rocks, particularly aquifers.

Two distinct groups of hydrogeological maps can be distinguished, which correspond with the two main roles of the maps and their uses:

- general hydrogeological maps and groundwater systems maps associated with reconnaissance or scientific levels are suitable tools to introduce the importance of water (including groundwater) resources in the political and social development process;

- parameter maps and special purpose maps corresponding to economic thinking are part of the basis of economic development for planning, engineering and management; they differ greatly in content and representation according to whether they are designed for specialists or non-specialists in hydrogeology. Special purpose maps are also those which e.g. for waste disposal reasons show areas with no or highly protected groundwater resources.

Both groups are closely interrelated and complementary, as e.g. a general hydrogeological map cannot be compiled without information on the hydraulic parameters of rock bodies, or specific hydrogeological knowledge will not be considered in development projects if politicians, planners and scientists are not aware of the crucial importance of groundwater, both in qualitative and quantitative terms, for development.

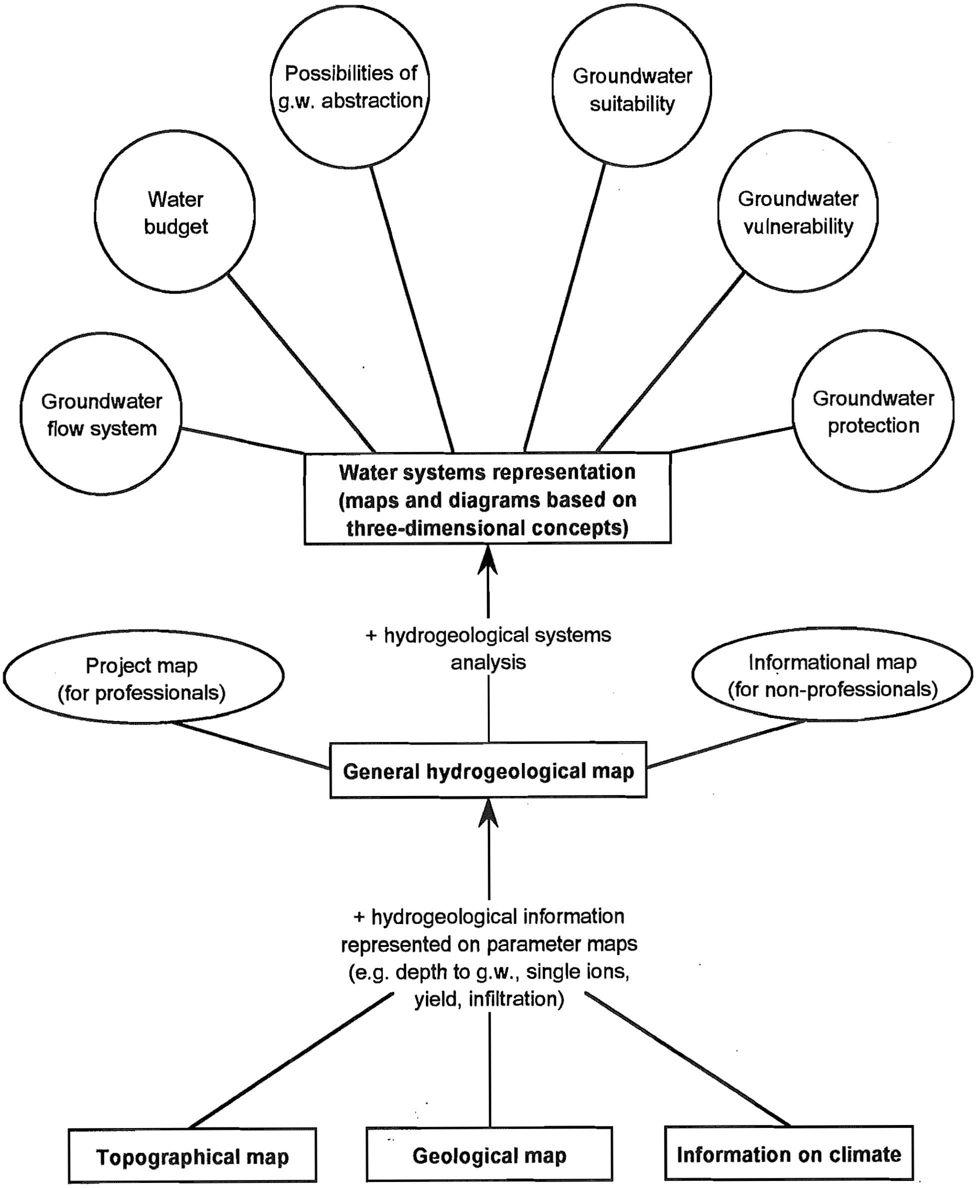


Figure 7. Evolution of hydrogeological maps.

Chapter 2.

BASIC INFORMATION FOR HYDROGEOLOGICAL MAPS

BASIC REQUIREMENTS FOR HYDROGEOLOGICAL MAPS

Hydrogeological maps portray information on groundwater and the relevant rock bodies in relation to the earth's surface, i.e. topography. Therefore, some basic requirements must be fulfilled, otherwise the map would be incomplete and useless.

First and foremost, the map must answer, as precisely as possible, the following basic questions:

- What are the conditions in a certain place or area?
- Where can I find what I am interested in?

And, at a more detailed level,

- what quantitative and qualitative information is there, and where do I find it?

From these basic questions, it is clear that there are three fundamental requirements for the preparation of a hydrogeological map,

- an adequate topographic base map
- reliable hydrogeological and associated data
- a suitable representational scheme and map legend.

It must be remembered, that owing to the three-dimensional nature of hydrogeological and groundwater systems and the intended use of the map, the full range of graphical representations (maps, cross-sections and diagrams) should be considered and used to complement each other. In any case, a plain hydrogeological map should also contain at least one representative cross-section, to reveal the structure in the vertical plane. If this cross-section cannot be accommodated on the map itself, or data is too abundant to be plotted on a single sheet, a second sheet or an explanatory booklet, to accompany the principal map, should be envisaged. To a certain degree and within limits, sets of isolines can show the three-dimensionality of a groundwater system. However, isolines will fail if the system is complex.

In the following paragraphs, the interdependence between topography and relief, drainage network, climate, soils, geology and structure of the underlying strata will be stressed. For the hydrogeological map author it is crucial to collect and exploit this information attentively, particularly when available in map form. A good hydrogeological map therefore includes a careful analysis and interpretation of existing data and a careful "reading" of respective areal information, e.g.

- topographical maps
- oro-hydrographical maps
- meteorological and hydrological maps
- geological maps
- satellite images
- air photographs.

TOPOGRAPHIC BASE MAP

The topographic map is a basic element for any hydrogeological mapping programme. Its importance is twofold, first as a guide for orientation on the surface and secondly as a source of useful hydrological information, e.g. river network, watersheds and surface properties.

Nowadays, most countries have a national public cartographic or geographic institution responsible for the establishment of topographic maps at various scales. Hydrogeological map makers, therefore, should contact this body to obtain a suitable base map for their work.

The topographic base map must be up-to-date and contain all information essential to foster the understanding of the hydrogeological situation of the area mapped. An obsolete base map devalues a new hydrogeological map considerably, as it may lead the map user to the conclusion that merely careless and superficial work has been produced by the map maker. If a good topographic base does not exist or the map is outdated, input from the hydrogeologist himself or other helpful persons from cartographic and remote sensing units can help to update the topographic base map.

Usually it is well worthwhile to use air photographs and satellite images to update the topographic base map, or to produce one if not available. In special cases, e.g. when topographic maps at a given scale are not readily available, new maps have to be produced at the beginning of the map project, using photographic processes. Sometimes it may be politically desirable to represent units such as countries, counties or communities, as a whole, so that new base maps must be prepared.

In heavily populated areas where hydrogeological maps are particularly useful for groundwater protection purposes, it may be necessary to simplify the existing topographic map considerably, to be able to show essential hydrogeological information. This is a cartographic art, as the generalized and simplified topography must reflect the setting of the area and all essential topographic information such as springs, rivers, roads, landmarks, etc. must be kept on the map.

Thus the existence of a suitable and modern base map can be considered an essential cornerstone for any hydrogeological mapping exercise.

TOPOGRAPHIC BASE MAPS AS A SOURCE OF INFORMATION FOR THE HYDROGEOLOGIST

Topographic base maps, chiefly at larger scales (> 1 : 100 000) present a valuable source of information for the hydrogeologist. Therefore they must be studied in detail, and useful information has to be grasped directly or derived from interpretation. Features that may be grasped directly are springs, bogs, sinkholes, rivers and creeks, which are often classified as perennial or intermittent. However, since these maps are generally designed only by cartographers this classification has to be critically checked by the hydrogeologist on the basis of runoff records. Other information can be inferred, e.g. from surface contours, river density or vegetation. In some countries oro-hydrographic maps exist that show only the natural conditions without the situation and land use information. These special maps are particularly useful for hydrogeological interpretation.

A study of the river network on a topographical or oro-hydrographical map, particularly when coupled with the interpretation of aerial and satellite imagery, provides useful hints on the geological substratum, morphology and the climatic setting of the area. It is, therefore, desirable to define the main descriptive characteristics possibly with quantitative estimates.

A study of a hydrographic system consists of:

(a) Delimitation of the watershed and description of different runoff regimes

The "watershed" or drainage basin of a stream is the surface within which water flows towards a stream or tributary (Figure 8). In most areas, the watershed boundaries roughly coincide with groundwater divides. In arid zones, however, the drainage network and watershed boundaries may be independent from the groundwater flow setting.

Two different runoff regimes may be distinguished in general:

- The "exoreic" regime, where water falling on the basin is drained by a main stream towards the external part of the basin (Figure 8, upper part). This is a normal case in humid and semi-arid areas, where streams carry water continuously or at least over long periods.

- The "endoreic" regime, where the water falling on the basin is drained towards the inner part of the basin and forms a lake, chott or sabkha (Figure 8, lower part). These closed basins occur chiefly under arid conditions, where flow in rivers is occasional and surface water evaporates quickly.

(b) Study of the aspect of a stream network, its density as well as its relationship with the slope, lithology and structure of the geological substratum

The density and shape of a stream network inherently contains a lot of useful information for hydrogeological mapping. In areas having a very dense and finely ornamented network (Figure 9, upper part), one may conclude a priori that they are underlain by impervious strata and that the groundwater table is generally close to surface. Moreover, the area receives relatively high rainfall forming a dense stream pattern.

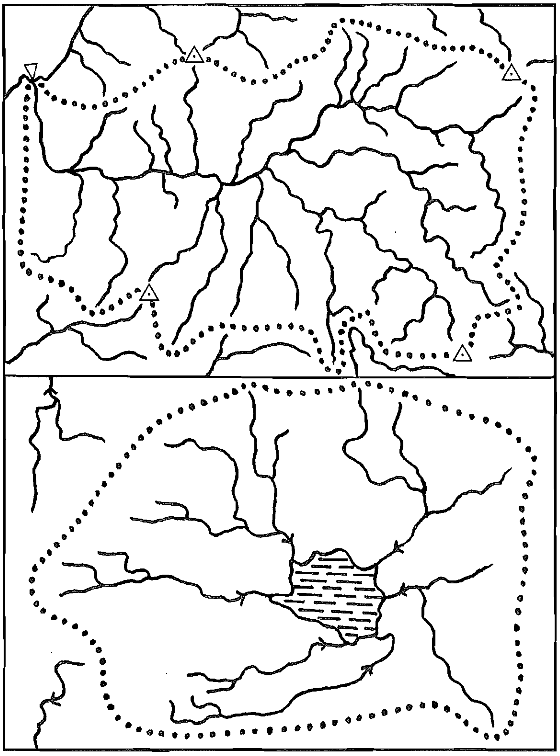
By contrast, in areas having a sparse stream network (Figure 9, lower part), water flows chiefly underground. Such networks point to very pervious strata like karstified limestone, dolomite or gypsum. In such areas evidence of karst features like sinkholes may also be found on topographic maps. Of course, the stream network is very sparse or even absent in arid areas, too. However, the hydrogeologist will at least know roughly the climatic conditions of his working area and draw the right conclusions.

A sudden change of the stream network can be due to the presence of faults or changes in lithology (Figure 9). These structural features may largely influence the runoff and consequently the shape of the network and its density.

For comparison, it is sometimes necessary to measure the density of a river network quantitatively, i.e. the ratio between the cumulative length of the rivers in a defined surface area [km/km^2]. However, comparison of densities is only valid for values derived from maps at equal or similar scales having the same degree of generalization.

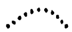
(c) Study of the orientation and control of the hydrographic system

The shape of the river courses, whether straight or undulating and meandering, is interrelated with the slope, the lithology and the geological and tectonic development. In most cases meandering rivers indicate a low slope gradient, high groundwater table and possibilities of bank storage.



Legend

Outlet: meeting point of the main stream (drain) and limit of the basin



limits of the watershed linking the highest points (crest lines) and cutting the main stream at the outlet

△ principal high points

Figure 8. Types of runoff regimes on hydrographic and hydrologic maps.

Valleys with braided streams suggest irregular flash floods when large quantities of water run down a broad river bed, reducing to small undulating, interconnected channels.

In some areas, the stream network is markedly controlled by the regional structural pattern, in particular by faults and fractures (Figure 9). The rivers have a clear orientation expressed by parallel to subparallel, rather linear sections which extend along certain directions. These directions, however, do not necessarily form planes of preferential groundwater flow, as many examples from basement regions all over the world show (Proceedings of the IAH Congress on Hydrogeology of hard rocks, Oslo, 1993).
More detailed geomorphological investigations examining the close interrelationship between geology (chiefly lithology), structure and tectonics as well as climate, slope, soil and vegetation can be obtained from textbooks on geomorphology, soil science and remote sensing.

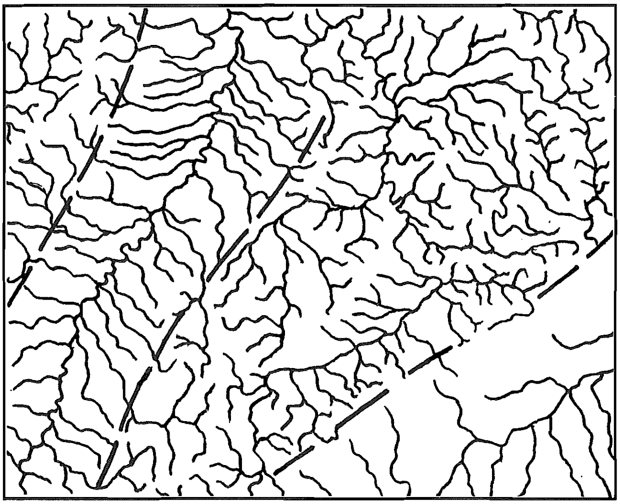


Figure 9. Stream network controlled by geology (lithology and structure).

Finally, it should be mentioned that the place names on topographic maps may provide very helpful information to the hydrogeologist who studies the topographic map attentively. Particularly in the industrialized countries the landscape may have been transformed considerably, e.g. by building canals, dewatering bogs, exploiting raw materials by deep and open pit mining or just by building houses, roads and railroads. Here, historical topographical names may present hints, e.g. on former discharge areas or occurrence of salt water close to surface.

In conclusion, both historical and present-day topographical maps should be analysed carefully since they may yield valuable indications and information for the hydrogeologist embarking on hydrogeological mapping.

AUXILIARY INFORMATION

In the initial phase of compiling a hydrogeological map, the author should collect information from all sources available, the most important being

- remote sensing
- geological maps and reports
- meteorological and hydrological information.

In addition, geomorphological, geophysical and soil science investigations may contain information that may be of interest.

REMOTE SENSING

Remote sensing techniques may contribute effectively to the preparation of a hydrogeological map, though they must not be overestimated. Besides updating and refining the topographic base map, they may yield information on the structural setting, lithology, soils and land use.

The first two features are very important in hard rock areas, particularly when no suitable geological base maps are available.

Indications about groundwater are generally secondary on air photos and satellite images, since they have to be deduced from vegetation, soil moisture and temperature. Therefore, remote sensing can optimize but never replace hydrogeological field work. In some countries, where satellite images are not available and air photos kept secret, one has to renounce the remote sensing techniques and prepare hydrogeological maps without using remote sensing. There are numerous examples where this has been done, with quite satisfying results.

GEOLOGICAL MAPS AND REPORTS

As geology is a cornerstone for any hydrogeological work, a careful examination of geological maps and reports, whether published or not is an indispensable step for the preparation of a hydrogeological map.

The information provided by interpreting a geological map for hydrogeological mapping purposes generally comprises the following two aspects, i.e.

- the conversion of litho-stratigraphical units into hydro-lithological units and

- the identification and selection of structural information necessary to describe and understand the aquifer and groundwater flow systems, as well as the types and conditions of their boundaries as controlled by geology and structure.

INTERPRETATION OF LITHOLOGICAL DATA

The classification of underlying rocks after their hydrogeological character, i.e. their capacity to transmit and/or store water, is usually the essential step in the conversion of a geological into a hydrogeological map. It is a function of the description of lithological facies on a geological map, which sometimes is not available in detail especially if the map units are only classified after their stratigraphical age. Geological maps showing rock/time units are more appropriate for hydro-lithological interpretation.

A plain lithological/petrographical map may be most valuable for the hydrogeologist, however it only presents partial information.

The hydro-lithological conversion of a geological map may be done at different levels:

(1) The distinction between unconsolidated and consolidated, permeable and impermeable rock bodies is made on a rather crude and qualitative basis. The rock bodies considered permeable are then classified

    - continuous or discontinuous after the nature of the groundwater bodies contained

    - porous/intergranular or fissured according to the dominant flow characteristics.

    This leads to a classification into three different categories (porous, fissured, karstified), possibly complemented by intermediate classes. Prominent examples of such aquifers are:

    - gravel, sand and volcanic scoria beds (porous)
    - sandstone, marlstone, basalt (frequently fissured)
    - limestone, dolomite, gypsum (frequently karstified).

Mixed flow characteristics (porous and fissured) often occur in sedimentary (sandstone) and volcanic (alternation of thin scoria and lava beds), but may also be characteristic of basement areas with a relatively thick cover of alteration products (regolith).

Most of the rock bodies can be differentiated easily after this classification, even by less experienced hydrogeologists. As this classification is based on very limited hydrogeological field data, it is often used to prepare basic hydrogeological maps of hitherto "unknown" areas. Most of the maps based on the international UNESCO legend simply apply this classification system.

(2) The classification of rock units can be refined on the basis of permeability considerations often derived from pure analogy between geology (lithological rock type) and hydrogeology (K-values). However, it has to be remembered that K-values may vary widely, even in lithologically relatively uniform areas. Frequent mean values and their variation are summarized on Table 2.

This semi-quantitative classification system usually groups the hydrogeological units into

- permeable formations ($K > 1 \cdot 10^{-6}$ m/s) forming important aquifers of relatively high permeability and productivity,

- semi-permeable formations (K between $1 \cdot 10^{-6}$ and $1 \cdot 10^{-9}$ m/s) forming less productive aquifers, subdivided into

  -- relatively thick aquitards
  -- resistant layers in multi-aquifer systems

- impermeable formations (aquicludes) ($K < 1 \cdot 10^{-9}$ m/s).

(3) In areas of unconsolidated porous sediments, even more quantitative information about transmissivity (T) can be drawn from a geological map, by considering the K-value assessed together with the saturated thickness. However, this requires good knowledge of the depth dimension, and transmissivity values derived from this guess may be unreliable.

INTERPRETATION OF STRUCTURAL INFORMATION

Structural information drawn from geological maps may be twofold, concerning

- the geometry of the aquifers ("anatomy")
- the boundary conditions of aquifer systems which are often determined by the geological structures.

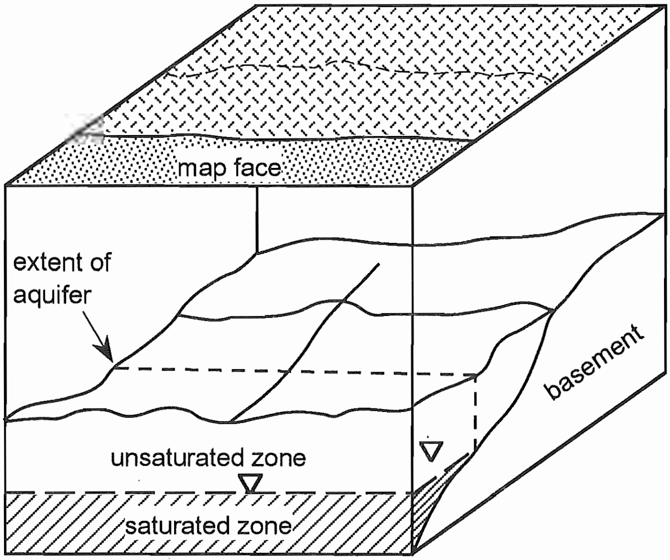
A geological map shows the location of outcropping boundaries of rock units. Aquifer outcrops generally form recharge areas characterised by water table conditions. However, the limit of extension of the rock unit may not necessarily coincide with the extent of the aquifer, particularly in platform areas or in areas of deep lying water tables, where the unsaturated part of the aquifer attains a considerable thickness (Figure 10). On small scale overview maps, these boundaries generally do not differ substantially from each other.

Geologists and hydrogeologists are accustomed to reading geological maps with a three-dimensional perception. This is based on the stratigraphic concept of superimposed strata as well as on structural information providing a characteristic pattern at the earth surface and thus on a plane map. Non-geologists often lack this three-dimensional view, and will rarely be able to recognize features such as synclines, anticlines, monoclinal folds, tilted blocks, cuestas, troughs, horsts and grabens from a geological map (Butler & Bell, 1988). However, volcanic flows and cones may be much easier to recognize, as well as faults, fractures and other lineaments.

Table 2. Ranges of permeability values of different lithological rock types (after various hydrogeological textbooks and documentation).

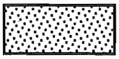
Hydraulic conductivity [m · s^{-1}]	Rocktype		
	unconsolidated rocks	hard sedimentary rocks	igneous and metamorphic rocks
1		*karstified*	
10^{-1}	gravel		lava
10^{-2}	*coarse*		
10^{-3}	sand	limestone	
10^{-4}			
10^{-5}	*fine* / loess		*fissured*
10^{-6}	silt	*fissured*	
10^{-7}		sand-stone	
10^{-8}	moraine,	*compact*	
10^{-9}	clayey drift		basalt / granite, gneiss
10^{-10}	deposits		meta-morphic
10^{-11}	clay	slate	rocks
10^{-12}		shale	
10^{-13}			*compact*

The macro-fracturing represented by faults on geological maps is also often highly relevant to hydrogeological maps. Faults may act as barriers or drains for the flow of groundwater, or even may not affect it, while fracture zones in hard rock areas usually are highly transmissive. These linear features are often reflected in the drainage network (see above) and can easily be traced on satellite images in areas lacking geological maps.



Legend (units on the hydrogeological map)

Basement rocks (non-aquifers) in part overlain by unsaturated sand deposits



Sand aquifer

Figure 10. Hydrogeological map and block diagram of a typical geological setting in flat platform areas.

The structural analysis of a geological map, together with borehole data and cross-sections always permits an initial interpretation of the type of aquifer system and its hydrodynamic conditions, i.e.

- mono- or multilayered aquifer systems, and
- phreatic (water table) or confined aquifers.

However, this first interpretation has to be verified on the basis of hydrogeological field checks and measurements.

From the previous paragraphs it may be deduced that geological maps may be a great help to a hydrogeologist producing a hydrogeological map. However, the geological maps have to be interpreted wisely, and only information relevant to hydrogeology should be retained on the hydrogeological map. This implies that geological boundaries delineating stratigraphical units must be omitted if they do not coincide with hydro-lithological boundaries, and new boundaries within stratigraphic units must be added if hydrogeologically relevant.

The interpretation of geological maps, together with the information on watersheds, springs and the stream network obtained from the topographic map may already enable the hydrogeologist to develop a first conceptual understanding of the groundwater flow systems in the area to be mapped. This conceptual model, of course, has to be proved or rejected, refined and quantitatively defined with the aid of true hydrogeological data.

METEOROLOGICAL AND HYDROLOGICAL INFORMATION

Meteorological services exist in all countries of the world. In addition to the weather forecast, they issue reports on the climatic setting which may provide very valuable information to the hydrogeologist. Within the continuing international programmes IHP (International Hydrological Programme) and OHP (Operational Hydrological Programme) sponsored by UNESCO and the World Meteorological Organisation (WMO), numerous meteorological and hydrological data have been published in yearbooks, reports and maps.

The hydrogeologist needs information about the rainfall pattern, the long run of temperatures, particularly freezing periods, as well as evaporation and aridity. In addition he should use hydrological data, know the gauging stations with long term records, and consider particularly the runoff in dry periods. Again, this information forms the background for the understanding of groundwater conditions in the map area and the interpretation of groundwater flow systems, chiefly their recharge and discharge.

Abundant literature on hydrological data is available almost everywhere, and the hydrogeologist should make use of it.

However, appropriate maps of the water balance are less abundant, as the components of the water balance are measured in different ways and are not always well suited to portrayal areally on maps. Moreover, special care has to be paid to their consistency and time reference. Qualified data for evapotranspiration are usually not available.

In the Eastern European countries, an interesting project to map the regional groundwater runoff on the basis of hydrological data was carried out. The groundwater part of the water balance, often neglected in hydrological calculations, has been quantified on the basis of hydrograph separation and river runoff analysis. This information is very useful for hydrogeological mapping, as it provides an approximate quantitative assessment of the groundwater component of the water cycle.

In this context it is essential to bear in mind the principal differences between humid and arid conditions. The climatic conditions largely influence the components of the water balance as well as the flow of groundwater systems. In humid areas, rainfall chiefly determines the recharge, and the storage conditions of phreatic aquifers are of secondary importance. Surface and underground runoff are determined by rainfall intensity, slope, soils, vegetation and land use.

In arid areas, where rainfall is random, surface runoff is only local, flashy and negligible on a regional scale. However, significant groundwater runoff from depleting flow systems may occur, e.g. in springs or deep lying flats (sabkhas). Here, the storage of the aquifer, the volume and the depletion of the regional groundwater systems are decisive factors that must also be considered on hydrogeological maps.

Finally, the filling of the groundwater systems differs profoundly from humid to arid areas: whilst under humid conditions the flow systems are filled, as may be deduced from water levels close to surface, even in recharge areas and extended discharge areas in river beds, wetlands and close to the sea; arid areas are generally characterized by great depth to the groundwater levels, i.e. very thick unsaturated zones, and few and small discharge areas.

However, since most of the world's population and therefore most of the demand for groundwater is found in humid and semi-arid rather than in purely arid regions, hydrogeological maps of these regions usually have to cope with most of the components of the water balance.

A study of the other auxiliary sources of information, e.g. soil maps which contain indications on soil physical parameters controlling percolation, the depth of water or certain groundwater controlled soil types, may be most useful. Moreover, geophysical, geomorphological and other relevant data should be collected and interpreted whenever possible.

HYDROGEOLOGICAL DATA

Although in many countries a wealth of hydrogeological data is obtainable from various, commonly scattered, sources, it is rarely considered sufficient to prepare a reliable hydrogeological map. Reasons for this insufficiency are incomplete data sets, lack of data in particular areas, contradictory data in places, data measured by different, incompatible methods, etc. It is, therefore, necessary to foresee additional data collection as an essential step in hydrogeological map preparation. However, any field work for producing new hydrogeological data should be carefully planned and priorities set for data collection before going to the field. A thorough pre-treatment and reinterpretation of the data available in archives, data banks and on maps is generally the best way to render the additional data collection most efficient.

The purpose and proposed content of the hydrogeological map exert, of course, influence on the decision as to which data should be considered important. Anyway, one should aim at complete and homogeneous data sets rather than focussing on just single parameters and variables. Since the hydrogeological and hydrochemical parameters are interrelated, a study of a set of parameters often reveals errors or lack of data.

In the following, emphasis is placed on the relevance of data as well as on the need for proper documentation and pre-treatment of the data provided from field or laboratory measurements or from existing literature and reports.

As regards the frequency of a single parameter or variable registered from the same observation point one also may distinguish "individual data" (such as altitude of land surface) and "periodical data" dependent upon time (such as groundwater abstraction or hydrochemical analyses).

Figure 11 provides an overview of the types of data to be considered and their treatment.

HYDROGEOLOGICAL FIELD INVENTORY

Independent of the scope of the maps, a minimum amount of data, comprising a basic set is indispensable for the preparation of all types of maps. There are hydrogeological key points such as springs and wells which have to be surveyed in any case. Their exact location is of prime importance, to allow their correct siting on the hydrogeological map.

Certain hydrogeological data can be considered essential since without them even basic hydrogeological maps (e.g. showing groundwater contours, salinity and depth-to-groundwater) could not be prepared properly.

- Observation point number or well number necessary for an orderly identification, storage, retrieval and plotting of the data. This identification number must be systematic and unambiguous.

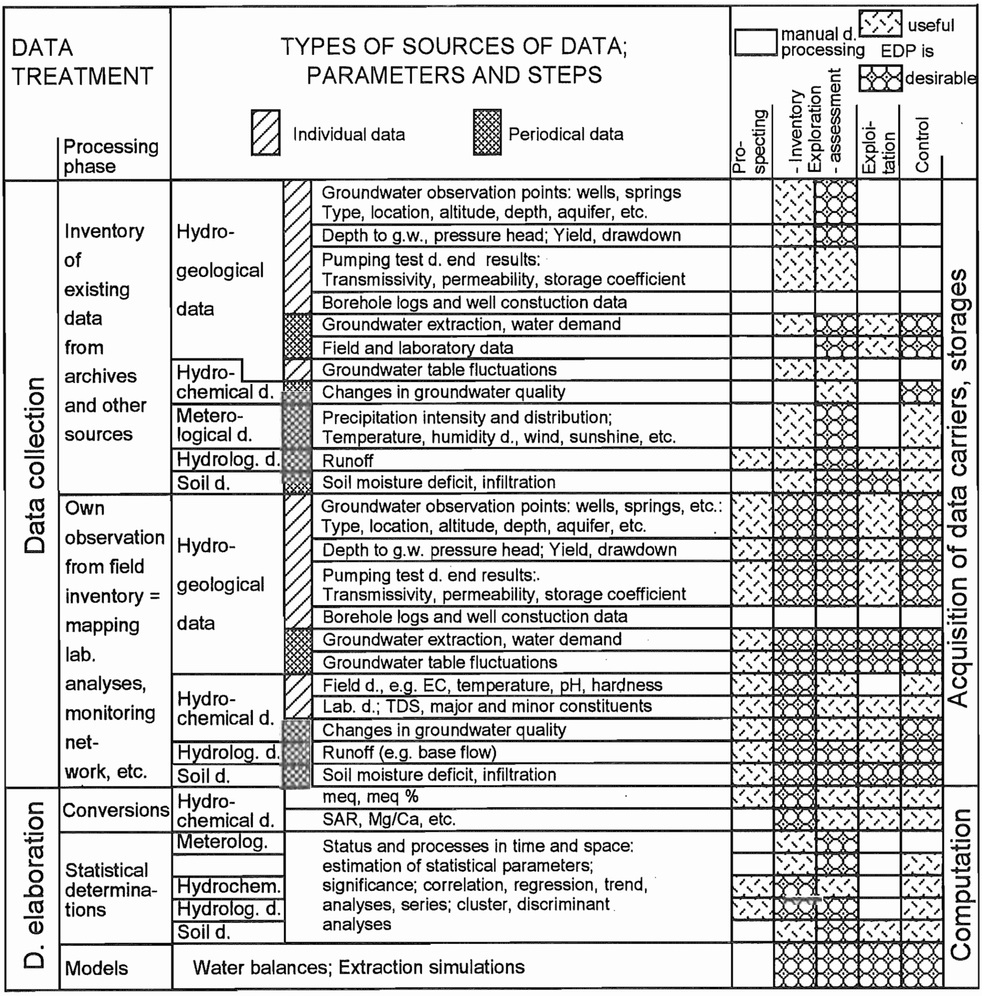


Figure 11. Scheme for the treatment of hydrogeological data.

- Location (by coordinates, preferably UTM grid) necessary for exact plotting and orientation of points for repeated observation.

- Map sheet referenced to the regular coverage of topographic base maps at rather large scale (1 : 10 000 to 1 : 50 000), necessary to facilitate the numbering of observation points.

- Altitude of land surface necessary e.g. for computing the elevation of the groundwater table. The reliability must be qualified, e.g. by mentioning the method of determination.

- Discharge of springs or baseflow of streams, necessary to estimate the natural discharge conditions of groundwater flow regimes.

- Depth to groundwater (sometimes called "static water level") necessary for computing the water table elevation in order to obtain indications of processes acting from land surface and vegetation on the groundwater (e.g. evapotranspiration).

- Elevation of groundwater table, essential for the construction of groundwater table maps, which enable the hydrogeologist to recognize the direction of groundwater flow, its gradient, and, together with topographical data, (surface water) recharge and discharge areas. A groundwater table map is one basic requirement, together with values for transmissivity, to assess the quantity of groundwater flow. Note that in areas of perennial river runoff the river bed is the intersection of the groundwater table and the land surface.

- Type of well giving a first indication of the number of aquifers.

- Total depth of well indicating the relative position of an aquifer, and, in connection with depth to groundwater, the level head characteristic (e.g. whether confined).

- Salinity (deduced from field measurements of electrical conductivity) is a basic datum which indicates groundwater suitability.

- Date informing about the time of observations of either own field investigations or previous observers (this date does not necessarily correspond with the date of filling in the survey form).

- Source of data roughly describing the reliability of the data.

Essential also are those data which enable the hydrogeologist both to prepare further basic maps and to include more details on the hydrogeological maps based on essential data. Further basic maps which may be prepared are those which show aquifer thickness, aquifer lithology, depth to aquifer, areas of highly confined (e.g. outflowing) groundwater, subdivisions into aquifer (hydraulic) systems, transmissivity, groundwater vulnerability (hazard), and others.

- Top of aquifer or aquifers, obtained by subtraction of depth to aquifer from altitude of land surface.

- Base of aquifer or aquifers, obtained by a similar subtraction as in top of aquifer. In cases of superposition of a fresh water lens on top of saline water, the depth of the fresh/salt water interface should be known.

- Number of aquifers, referring to amount of aquifers either encountered (described) or tapped.

- Relative position of aquifer(s), numbered from the top (e.g. labelled A) to bottom.

- Lithology of aquifer(s) and also type of overlying strata with hydraulic characteristics of correlating strata (permeability).

- Yield of well together with location and frequency of wells (well number), gives a rough picture of present productivity.

- Drawdown necessary to describe more exactly the aquifer productivity; yield and drawdown (dynamic water level) are basic data for computing specific capacity.

- Specific capacity, computed value from yield and drawdown, both obtained from pumping tests, which suggests groundwater productivity.

- Transmissivity, obtained from (preferably) long-term pumping or aquifer tests. In addition to aquifer thickness, width of groundwater flow section and hydraulic gradient, it is essential for estimating the regional quantity of groundwater flow, which is one factor, together with figures on groundwater suitability, useful in assessing the groundwater potential.

- Level head characteristic, indicating the existence of free, confined or highly confined (artesian outflow) groundwater.

Additional data that may be collected and documented during the field inventory provide useful additional information. They facilitate map preparation and indicate the reliability of the data collected. Their importance may be judged variously due to differing conditions of environment and of groundwater development status. A list of such data may comprise:

- Period of observation or period for which the information is valid; it is very important to register information which is related to the dimension of time (e.g. to be used for depth to groundwater, electrical conductivity, discharge figures of springs or streams). The data may be derived from archives, oral information or own investigations. This set might be designed in two different ways: (i) more comprehensively, indicating the dates (altogether 8 to 10 observations are needed), or (ii) more simply, indicating units of time (either hours or days or weeks) and their number.

- Recording sequence for the same observation point is required, if more than one recording sequence occurs, or if several field visits were undertaken, if data from different periods were available or if the content of a series taken at the same time varied. This latter may be valid in the case of varying depths (e.g. several aquifers, lithological descriptions) or ranges of quantity (e.g. step drawdown tests), or quality (e.g. electrical conductivity or temperature by depth), or diameter (e.g. due to reductions of casing and screen).

- Fluctuation of water level, yield/discharge, salinity.

- Various data obtained through hydrochemical or physical field observations, such as pH value, groundwater temperature, odour, colour and others.

- Data on the ionic content; the content of specific ion(s) describes the suitability of groundwater resources for specific uses; a hazard value for a certain use must not necessarily exclude other uses.

- Name of well (owner and/or location); it supports the above-mentioned data which describe the well location by coordinates; further additional remarks on local well numbering are very important sometimes for both easy orientation in the field and comparison with archive data.

- Province and/or other administrative unit or subdivision, for grouping and also to recognize or to prove the density or existence of data in various areas.

- Date of termination of well, for assisting orientation in the field and proper location of wells. The date of termination is very often the only means of distinguishing one well from another (by oral information).

- Well use to classify the use of the groundwater abstracted, e.g. for drinking, industrial or irrigation purposes.

- Drilling method assists in problems related to reliability of lithological descriptions, condition of filter screen, water samples extracted during drilling and/or well construction, etc.

- Data on further technical details of well, such as type, size and diameter of screen, gravel pack, position and size of pump are an aid to appraising information about pumping test equilibrium achieved or to plan water level or flow-meter measurements.

- Diameter of well, desirable for planning and interpreting pumping tests, as well as planning geophysical well measurements.

- Highest perforations of filter screen; it is desirable to obtain rough information about the approximate position of the (top) of the aquifer, especially if no data on lithology are available.

- Duration of pumping; to be associated with yield and drawdown; gives an idea of the reliability of data on specific capacity and transmissivity.

- Pumping test equilibrium achieved?; this is an additional value related to the latter-mentioned subjects. An indication can be obtained whether the "dynamic water level" during pumping was still decreasing or apparently constant or the well exhausted; "unknown" conditions should also be stated.

- Yield of well or discharge of spring (or stream) measured by means of ... (bucket?, tank?, weir?, etc.).

- Mode of abstraction or groundwater withdrawal; a regional overview contributes to an assessment of the state of groundwater development.

- Sample by means of ... / at ..., this indicates the manner in which a groundwater sample was extracted or obtained and is a desirable datum from which to assess the value of hydrochemical information; an indication of duration of pumping before sampling is also desirable.

- Topographic setting, whether on slope, terrace, river bed, hill top, etc. It helps, together with data on depth to groundwater, to interpret problems related to checking estimates of altitude, salinity, recharge.

- Record by (code for surveying staff); this contributes to the responsibility of the personnel and their participation in the work.

The field data collected and documented on suitable forms are a valuable basis for any further hydrogeological mapping. They have to be checked and verified, complemented, interpreted and selected for depiction on hydrogeological maps, as outlined in Chapters 4, 6 and 7.

Chapter 3.

CARTOGRAPHIC REPRESENTATION AND SCALE

CARTOGRAPHIC PRINCIPLES

The author of a hydrogeological map must be familiar with at least some important cartographic principles. This will avoid painful misunderstandings between the hydrogeologist and the cartographic draughtsman and ensure that the map be readable and follow cartographic standards.

The general sequence of cartographic preparation of a hydrogeological map is outlined in Figure 12. The author should contact the cartographic drawing unit in the initial phase of preparation, to seek advice and assistance both for the topographic base map as well as for the drafting of the thematic sheets. For more comprehensive, systematic mapping programmes involving many map authors, managers should provide, in addition to a general legend and a model map, instructions for the preparation of map manuscripts by authors. This will guarantee that map drafts meet an agreed standard and that the cartographic processing may be optimized, shortened and possibly automated.

Cartography is part science, part art, part technology, and its aesthetic value should not be neglected. It comprises the projection of a curved surface on a plane and a reduction to a given scale using standardized symbols (legend) to make the map understandable to its future users. The principal aim of thematic cartography is to convey even complex thematic, e.g. hydrogeological information, to the map user in an exact, clear and easily readable manner. This chiefly implies that the map must not be overloaded with information and that the colours and symbols used on the map follow a logical system, explained in the legend.

All thematic maps have in common that three-dimensional models are transferred onto a two-dimensional, plane surface, usually paper. This transfer is made by projecting the idealized spherical earth's surface and the hydrogeological features beneath onto a plane, whereby inevitable projection distortions should be minimal and the projection should follow a mathematic algorithm. All points on the map must be recognizable through their coordinates (latitude related to the equator and meridian related to the Greenwich meridian) and their altitude (related to datum sea level). Various projections and grids have been developed, each having particular advantages and disadvantages, but all aiming at fulfilling and optimising the theoretical requirements that distances and surfaces should be exact in relative size and azimuths, and angles correct. As none of them really can fulfill these theoretical requirements, maps based on selected, suitable projection systems are used preferentially by geodesists and cartographers differing from one country or area to another. Therefore, hydrogeologists planning hydrogeological maps should contact, in time, the relevant geodetic, cartographic and ordnance services in their country.

Decisions on the system of representation, mainly the legend to be applied and on the scale, projection and suitable topographic base map must be made in the preparatory phase of a hydrogeological map project.

RULES FOR REPRESENTATION

Whilst the projection covers chiefly the mathematical framework, the cartographic work consists of portraying topographic and thematic information on the map by using a semantic system of cartographic elements. These are grouped points, lines and areas. Variations of these graphic elements are made by varying density/tone, ornament, colour, orientation, size and form (Figure 13).

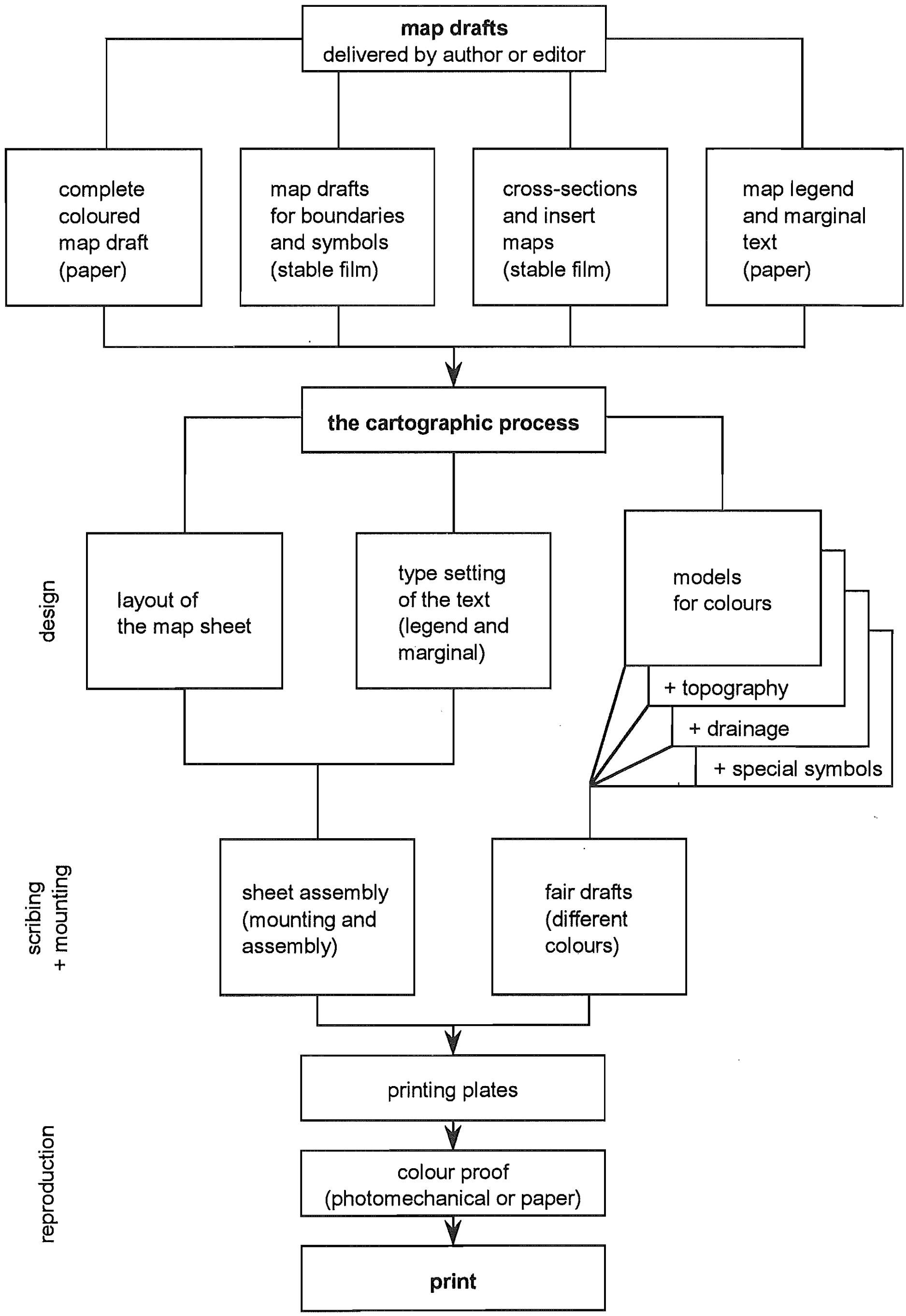


Figure 12. The cartographic preparation of a hydrogeological map.

The graphic variables form, size, orientation and colour are principally used for point and line information, e.g. springs, wells, contours, flow directions.

In the hierarchy of optical perception on a map, areal colour provides by far the most outstanding information, while line and point symbols are subdued and must rather be 'read' by the map user. All three elements, but particularly lines and points must not be overcrowded on the map, to ensure its readability and to avoid an areal perception when line or point symbols are applied too densely.

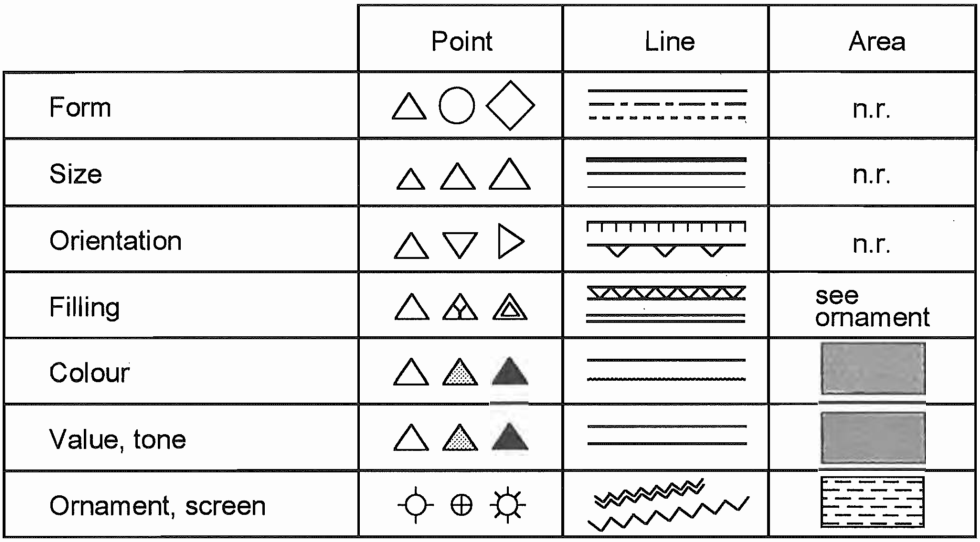


Figure 13. Variations of graphic elements.

Mathematically speaking, points have no dimensions. In cartography however, a point will cover a small area. Thus, the point symbol fulfills a double function; it locates the feature and it expresses, e.g. by size or filling, its magnitude or importance. More sophisticated point symbols are able to show additional properties of the hydrogeological feature. For example, the point symbol illustrates the location of a well, its size, the yield and the infill, the water quality, whilst additional ornaments may refer to temperature, etc. Point symbols always should relate to a figure with a centre, histograms therefore are not suited to the indication of localities. Tabulated information, e.g. histograms and tables, do not belong on the map but to the margin.

Line symbols are used for linear features such as water courses, delineations and boundaries. The thickness of the line refers to magnitude or importance; a double line, often called band, permits an infill indicating an additional property. For example, the line allows the location of the water course, the thickness of the band indicates the discharge, and the infill may explain the water quality. Although not always adhered to, broken lines should be reserved for expressing uncertainties or lack of knowledge. Isolines constitute a special case. They connect points of equal value but the space in between two isolines already indicates an areal character.

Atlasses, for example, used to fill the space between isolines of altitude by colour conceptualising the relief of the surface by colour. Isolines always occur in multiples. Visual aids should be exmployed to facilitate reading, e.g. by reinforcing each fifth line. If more than one system of isolines occurs, different colours or patterns must be employed since crossing isolines of the same colour cannot be identified. Each isoline must be accompanied by a figure indicating its value; the bases of these figures should always face the lower values.

Colours will be used to depict areal properties. Full colour will be used for the predominant feature, whilst hatching will be reserved for the secondary feature. For example, on a hydrogeological map full colour will be used for the yield/availability of groundwater and hatching or ornaments will indicate the properties of the rocks. By contrast, on a lithological map full colour will be used for the rock and hatching for the groundwater. This method permits depiction of two areal properties without creating confusion; added isolines would increase areal information. The map maker should follow the hierarchical use of full colour, areal ornament and isolines as functions of the importance of the parameters to be mapped; such parameters are largely defined by the theme and purpose of the map. It may happen that readability decreases with the number of colours used, however costs will increase.

The graphical elements are usually attributed logically and by analogy to different features, so as to achieve optimal clarity on the map. The variables density, colour and ornament are chiefly used for quantitative and qualitative areal features, following the general principle "the darker, the greater". In general, up to six different tones on a map can be subdivided optically by man (Bertin 1973). Therefore, cartographers recommend the use of not more than four tones of each different colour, if clarity and legibility are to be preserved. An excellent means to present different areas in an unambiguous way are ornaments (patterns having a particular structure e.g. as used for lithology in the general legend, see Part II). They are sometimes applied subsequently, to improve clarity. However, the superposition of ornament may sometimes create undesired "Moiré" effects. These can be excluded with the help of cartographers or draughtsmen.

Colours, ornaments and symbols should be based on recommended international standards, as far as possible. For hydrogeological maps, the international legend included in Part II of this guidebook is recommended for use. It has been applied successfully throughout the world. With the proposed list of symbols, ornaments and colours this multilingual hydrogeological map legend provides a common graphic language to both map makers and map users, thereby facilitating mutual understanding, adding to the existing multilingual glossaries in hydrology and hydrogeology. Provided a map user is acquainted with the legend, he will be able to read a map issued in any country.

The use of colour is always recommended for more complex maps which aim at a wider readership. Colour makes maps much easier to read (which might be crucial for the non-hydrogeologist). Full colour must be subdued to preserve legibility. Full use should be made of the symbolic power of a colour in order to permit the reader to develop a sense of analogy. For example, water surfaces and streams are commonly shown in blue, glaciers in white, and most of the maps designed for the public follow the 'traffic lights' principle (green-orange-red). Yellow has turned out to be the least resistant colour, white implies "unknown" or "not applicable". Black as an areal colour should be employed only on sketch maps. The possible alteration of colours owing to the exposure of the map to sunlight (which usually makes the yellow component disappear in the first instance) has to be considered technically, but is generally of low relevance to hydrogeological maps based on the standard legend. However, superposition of certain colours used for points, lines or hachures may considerably alter the tone or even fade the symbols. Cartographers are well trained in colour composition and should always be asked for advice, to avoid negative results.

As simple handdrawn maps may under certain circumstances be more appropriate than printed coloured maps, the advantages of black and white, as opposed to multicoloured graphical representations, are summarized on Table 3:

Table 3. Advantages of black and white versus coloured thematic maps.

Black and white maps	Coloured maps
• quick and economic production • low cost print and reproduction • pre-fabricated aids available (ornament foils, adhesive symbols) • the black to white scale/range allows more distinctions in tone than any other colour range • corrections and updating easy to achieve • no troubles with colour-blind users • no alteration of colours owing to exposure to sunlight	• clear separation between back ground information (topography) and thematic information • clear distinction of different superimposed thematic layers • quick grasp of even complex situations, facilitated by associative colouring (e.g. traffic lights principle), even without studying the legend • complementary colours may be used to indicate increase or decrease • map manuscripts easy to draw • maps have a more pleasing appearance and are instructive at the same time

Ultimately, the sophistication and complexity of a map will depend on the intended audience and thus the format of a map is the full responsibility of the map maker. The proposed legend (Part II), however, has been designed to assist even less skilled readers, since all colours, symbols and ornaments have been chosen by virtue of their symbolic nature.

DECISION ON SCALE

In thematic cartography, the following definitions of scales are commonly used:

large scale	-	1	:	10 000	to	1	:	100 000
medium scale	-	1	:	200 000	to	1	:	500 000
small scale	-	1	:	1 million	to	1	:	10 million.

However, this scale range may differ, depending on the size of the country considered. For example, "small scale" overview maps in Luxemburg, Hongkong and Singapore are at scales 1 : 50 000 or 1 : 100 000, while in Algeria, Australia or Russia overview maps range from 1 : 2 million to 1 : 10 million.

The expression small, medium, large scale, is thus arbitrary. However, the sequence of what is small, medium and large is clearly defined in cartography. Attention is drawn to the fact (and much confusion has been derived from it) that modellers apply these expressions in the opposite sense. What may be depicted on a small scale map, could constitute a large scale model.

The question of scale is crucial to any hydrogeological mapping project. Here again, technical boundary conditions may considerably influence a decision, in addition to the purpose, use and potential users of the map. For example, in some countries the size of paper available or the maximum size offset colour print machines are able to accomodate must be regarded as real limits for published maps. Hence, sets of maps are needed when maps must be at a given scale, for a given area and a given purpose, e.g. at 1 : 25 000 or 1 : 50 000 for the planning of a county or province.

If required as a wall map, large paper formats are even desirable. If intended for a book or for inclusion into a hard cover box, it is generally more appropriate to cut the map into several sheets or reduce it in scale which usually requires additional generalisation.

To facilitate a technical decision on the scale and to estimate the map size needed, a table relating different scales with area covered and nomograms at bilogarithmic scale of the same relations are provided below (Table 4, Figure 14).

Table 4. Ratio between area covered by the map and scale, for different sizes of paper.

Scale	Area [km^2] covered by the map at paper size		
	20 x 28 cm (A4)	50 x 50 cm	100 x 100 cm
1 : 5000	1.4	6.25	25
1 : 10000	5.6	25	100
1 : 50000	140	625	2500
1 : 100000	560	2500	10000
1 : 500000	14000	62500	250000
1 : 1000000	56000	250000	1000000
1 : 5000000	1400000	6250000	25000000

Although the aforementioned technical boundary conditions are decisive factors for the consideration of scale, the chief criterion for a decision on scale should be the purpose a map is intended to serve. This decision is to be taken by the hydrogeological map author together with the institution supporting and financing the map project. However, several other criteria are practically important, too, which often reduce the range of possible decisions considerably, e.g.

- whether a suitable topographic base map exists,
- whether the map is a separate edition or whether it belongs to an atlas or a systematic thematic map series,
- whether sufficient data is available,
- which technical boundary conditions for cartographic work and print are to be considered.

As hydrogeological maps are designed for both practical planning as well as overview purposes, maps at various scales should be prepared even for the same areas. Hydrogeological maps for practical purposes must be handy, accurate and permit unambiguous siting in relation to topography. Therefore maps for local planning purposes should be larger than 1 : 100 000. However, a large scale should not imply a false impression of position, and therefore the accuracy of data should correspond with the scale chosen.

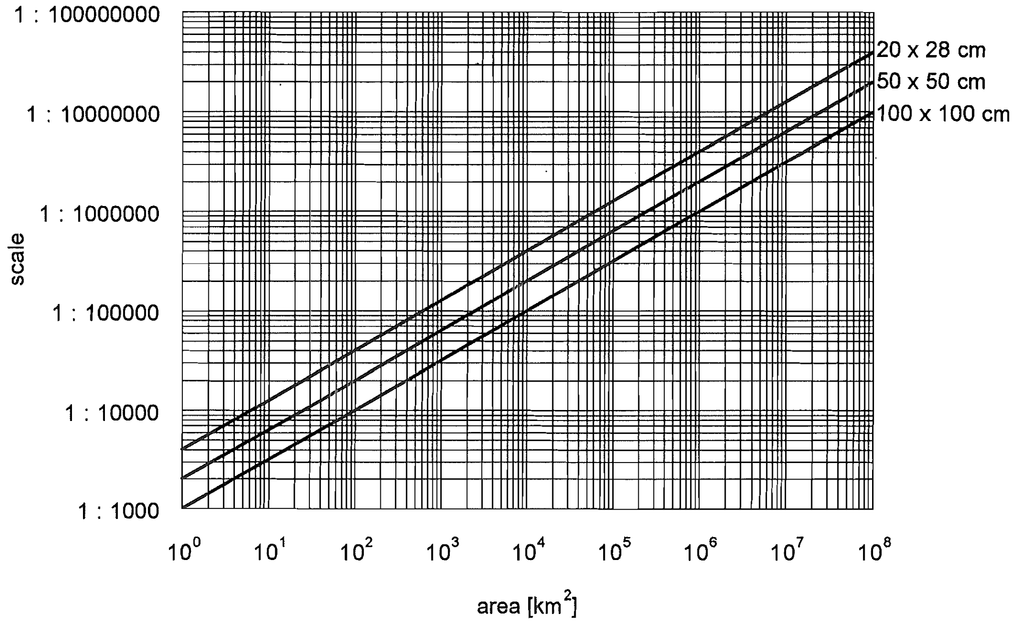


Figure 14. Relation between map scale and area covered, for different map formats.

A wealth of information can be accommodated on maps at smaller scales, without affecting their legibility or losing accuracy, provided that modern cartographic techniques are applied. Generally, the map scales for different purposes, as well as different generalization and accuracy levels, should at least differ by a factor of 4 or 5, e.g. 1 : 1 million as a national overview, 1 : 200 000 for regional planning and 1 : 50 000 for local planning purposes.

Hydrogeological mapping of larger areas is often considered an important information service for the development of the country. The choice of the scale may result from the need to compare the respective map with other thematic maps of the same region; e.g. in an atlas, one will find a set of maps of the same scale relating to precipitation, soils, land use, etc., as it is understood that the projection and topography should also be the same.

For good practical reasons, the existence of an up-to-date topographic base map may also be a decisive factor in the selection of the map scale (see Chapter 2).

Less frequently, a decision on scale is made on the basis of the availability of data for the map. It should be borne in mind, that doubling the scale means quadrupling the space and thus quadrupling the need for data. On the other hand, reducing the scale generally requires generalisation for the new map.

Within the mapping procedure one should always start with a draft at a larger scale and then reduce for publication at smaller scale. Thus, field and draft maps should always be larger in scale than the map to be published. The draft map should show all details (number or name of a well, etc.), all auxiliary construction and all information necessary for understanding the hydrogeology. The final product will largely abandon this information in favour of a clear description of the hydrogeological situation, thereby making full use of all cartographic tools described in Part II of this publication. In other words, the field observations will be transformed and translated into cartographic language and thus become understandable for the reader, even if he is completely unaware of the local situation.

Three additonal principles are mentioned here, though they are not purely cartographical:

- Legend and map should be regarded as a single unit, printed on the same paper sheet.
- Each map must have a clear name, date, publisher, scale, copyright to allow correct citation (see Annex B).
- Where legends have been prepared in a national language which is not widespread it is advisable to include the terms in one or several international languages.

Obeying the fundamental recommendations provided in this chapter will ensure high quality and economic map publications.

Chapter 4.

COMPONENTS AND CHARACTERISTICS OF HYDROGEOLOGICAL MAPS

FEATURES AND CONTENT

Hydrogeological maps generally contain three basic kinds of information, in relation to the topographic background:

- depth, altitude, quality, distribution of groundwater and aquifers,
- the geological framework (type, structure and extent of aquifers and hydrogeological units),
- the hydrographic network related to groundwater discharge or recharge.

Before recommending a general legend for hydrogeological maps - i.e. a cartographic language or the cartographic symbols and their meaning and significance (Part II) - it is worthwhile to summarize, as completely as possible, the features and concepts to be displayed on the map. At the same time we can present a complete list of features which may be shown on a map, together with their semantic explanation, their spatial extent and the constraints of representation. A programme for hydrogeological map preparation thus requires a selection of features to be represented, depending on the intended use of the map and the cartographic restraints imposed by scale.

The features on a map may be classified according to their

- physical or phenomenological nature;
- natural or artificial nature;
- relative importance;
- duration or time dependence (permanent, unstable, variable);
- degree of conceptualisation (observed, calculated or interpreted features);
- usefulness and readiness for direct or indirect usage, i.e. according to the purpose of the map;
- form and dimensions (determining the possibility of their representation);
- scale or degree at which these features assume significance.

These features have in common that they can be shown in space, whether they are stable, or variable, in which case an average or actual state (referred to a specified date) may be described.

Any of the above classifications should be considered in order to optimize cartographic representation and to avoid overloading the map with symbols. An overcrowded map simply becomes unusable, and therefore a proper selection of features to be shown and their graphical compatibility is of paramount importance.

The field of hydrology covers both the hydrosphere and the lithosphere. Therefore two subdivisions of hydrogeological features may be distinguished:

- water, particularly groundwater features (the content),
- rock bodies or hydrogeological structures classified according to their relationship to water (the container).

Clearly the full range of features must not be portrayed on one single map, but a useful selection should be made in respect of the purpose and type of the map.

In the following, some salient features of these subdivisions are listed, which partly correspond with the list of measurable field data (Chapter 2), and are derived partly (deduced or calculated) from these data and additional information:

Groundwater features (hydrological, hydrochemical)

- Presence, extension and continuity (groundwater reservoir).
- Depth to water table, relative to surface level.
- Height of potentiometric surface (water table or confined), relative to datum level; piezometric or water table contours; delineation of areas with (at a certain date) water table (phreatic), confined, or artesian conditions.
- Flow directions and hydraulic gradients derived from potentiometric surfaces (of a continuous single aquifer); flow lines and slopes of potentiometric surface; relatively stable hydrodynamic boundaries (groundwater divides, no-flux boundaries) defined after the potentiometric pattern.
- Inferred or known macroscopic flow connections in discontinuous aquifers (e.g. connections between sink holes and karst springs).
- Difference of potentiometric levels (e.g. between high and low levels at different dates, water level fluctuation, or drawdown resulting from pumping compared to the initial natural condition) and delineation of drawdown areas.
- Volume of groundwater in a groundwater reservoir or per unit area.
- Volume of groundwater at different saturation levels.
- Flux at interfaces of aquifer, ground surface and surface water, with direction of flux:
  -- entering flux = recharge to groundwater
  -- exit flux = discharge from groundwater.
- Distinction between recharge and discharge areas.
- Recharge flux due to infiltration of meteoric water (regionally variable):
  mean values per unit area.

- Discharge flux: spring or draining river discharge.

- Type of spring discharge regime: permanent, intermittent or temporary; variability; mean discharge values or coefficients, eventually spring hydrographs.

- Quantity of water withdrawn at locations (pumping stations, artesian wells) or in an area, within a certain time (mean flux).

- Characteristics, either physical (thermal, isotopic, etc.) or chemical, of groundwater at certain points (e.g. springs) or zones, at a certain date; spatial distribution of these characteristics, especially chemical composition of water; diagrams may be used to show the chemical composition of the groundwater at certain sampling points.

- Water quality defined on hydrochemical classification or water usage criteria; in many arid and semi-arid regions, salinity of groundwater is a major issue portrayed on thematic maps.

Note: These features are related to a single groundwater reservoir or aquifer. In the case of several superimposed aquifers each individual aquifer has its own set of characteristics.

Hydrogeological (physiographical) features

- Lithological type of geological formations (outcropping or deeper beneath covering deposits) classified according to their capacity to transmit, store and yield water: type and order of magnitude of both permeability and porosity, in continuous or discontinuous media (porous intergranular, fissured or fractured, karstified).

- Extension, structure and geometry of rock bodies, particularly aquifers:
  - -- position (projected on a two-dimensional sheet) and type of boundaries limiting areas of different permeability
  - -- height of base and top of an aquifer
  - -- thickness of the saturated rock mass
  - -- location of internal heterogeneities relevant to groundwater flow (fracture zones, barriers, faults).

- Values of parameters quantifying the hydraulic properties of rocks, e.g. permeability, transmissivity, storage, and their spatial distribution.

- Estimated values for the unsaturated zone, e.g. the water bearing capacity of soils which are required for water balance modelling (indicated in mm).

- Position of hydrographic network elements (permanent or temporary) which may suggest the delineation of aquifer boundary conditions (potential or flux).

- Relationship between rivers and adjacent aquifers: close relationship, continuous and permanent or discontinuous and temporary, decreased by river bed sealing, no relation between river and aquifer ("perched" river).

- Position of individual points and sites with a discharge or recharge function, e.g. springs, seepage areas or lines, evaporation pans; sinkholes and water losses in rivers.

- Genetic and or morphologic type of spring or sinkholes.

- Classification of zones according to their hydrogeological complexity and structure (degree of homogeneity, one aquifer, phreatic or confined, or multilayered aquifers, continuous or discontinuous aquifers, etc.).

- Finally all anthropogenic features, e.g. position of wells, pumping stations, injection wells, artificial recharge, irrigated areas, mined areas, soil drainage, tunnels, dams and canals, etc.).

The features mentioned under both sections are often interdependent, e.g. the thickness of an aquifer depends both on its geometry and on the potentiometric head, or the transmissivity depends both on this head and on the permeability.

The correlation between hydraulic data and structural information allows a precise description of aquifer systems which can be distinguished by different hydrogeological conditions, e.g.

- delineation and definition of boundaries and their condition, chiefly by combining structural geological and hydrographical features,

- description of transmissivities, storage and the flow field (equipotential lines, heads),

- order of magnitude of entering and leaving fluxes (recharge and discharge) and their variability,

- changes in the natural groundwater regime induced by man.

This correlation also provides useful practical information, e.g. on the accessibility of aquifers, the expected yield of wells, pumping levels, quality or suitability of groundwater for a particular use, sustainability of groundwater resources, etc. From this, a system of varied derived hydrogeological maps can be produced, as outlined in Figure 15, which are extremely valuable for planning and development purposes.

PARTICULAR CHARACTERISTICS

Hydrogeological maps differ from most of the other thematic geoscientific maps because of the time dependency of the various features they deal with. These maps refer to a particular time and portray information of a quasi-stationary, but transient situation, whereby the groundwater features are much more subjected to change in time than the more static hydrogeological features. In addition, man is increasingly developing groundwater in all parts of the world, thereby changing the original conditions considerably.

Both natural and anthropogenic features have to be portrayed together on a hydrogeological map to indicate the state of exploitation of groundwater resources and possible changes of the natural regime. This may produce lowering or rising water tables, migration of groundwater divides, changes in head distribution and the flow field, disappearance of artesian conditions and considerable changes of groundwater quality parameters; not to mention resulting changes at surface, e.g. land subsidence, drainage regime, or drying up of springs, lakes and rivers.

Hydrogeological maps of the same area showing a set of highly time dependent parameters (such as spring discharge, groundwater table or chemical ion contents) at different dates may look very different. Therefore hydrogeological maps should always make reference to a date or time period, and they have to be updated and re-issued from time to time.

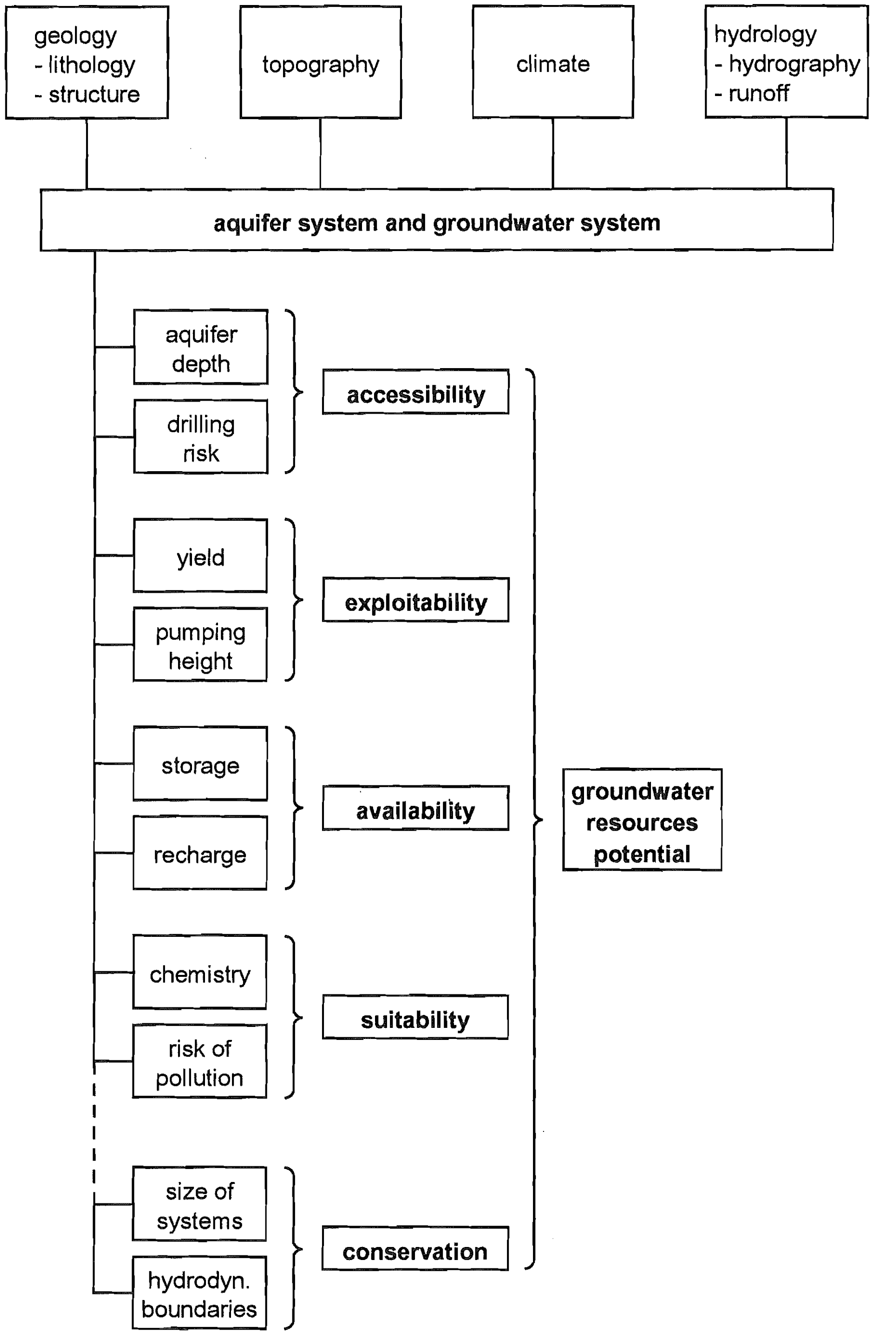


Figure 15. A system of specialized hydrogeological maps for planning and development.

To cope with the time factor on a hydrogeological map, three options may be considered by the map maker:

- Repesenting a momentary situation referred to a particular reference date, when the variables have been determined (which is, however, hard to fulfill in practice).

- Representing an average situation referred to a common period of observation, generally a long, multiannual period of records.

- Representing the frequence of occurrence of particular situations, e.g. minimum and maximum stages of water levels, maximum depth of water table, minimum discharge of spring, chiefly to provide information on the "safety" of water resources.

Modern, computer assisted graphic representation tools particularly suit the requirements of fre-quent updating and re-issuing of maps displaying rapidly changing parameters (see Chapter 7).

In conclusion, particular types of hydrogeological maps are less subject to changes and, therefore, less vulnerable to outdating. As, for example, the "hydro-lithological" conditions tend to be relatively stable in time, so that their knowledge is crucial for the understanding of the complex setting of groundwater flow systems including their quantitiative and qualitative assessment. Such a map may be considered fundamental and long-lasting; thus it should be prepared early in a programme.

DEGREE OF INTERPRETATION

The data and information presented on hydrogeological maps may correspond with different degrees of treatment and interpretation. In general, the following five levels are distinguished:

(a) Basic data, i.e. results of direct observations or measurements that should be as objective as possible and depend only on the site and date, if varying in space or time (see also Chapter 2).

(b) Primary derived data based on simple treatment and interpretation, e.g. isolines derived from point data on water level or chemical parameters.

(c) Secondary data derived from (b) or more complex treatment and investigation methods, e.g. statistics, computing, well tests, geophysics, including results of modelling, estimates of spatial variables deduced from numerical simulation methods, e.g. recharge, transmissivity and fluxes.

(d) Results of tertiary interpretation and classification, e.g. transformation of lithology into hydrogeological units, classification of productivities of aquifers, accessibility, exploitation cost, suitability of groundwater for special uses, etc. (cf. Figure 15).

Table 5 summarizes these features whether relatively constant (hydrogeological) or more transient (groundwater and man made).

The general conceptual development of hydrogeological maps (see Chapter 5) corresponds with this development in the interpretation of data, i.e. from raw simple descriptive and analytic data towards derived synthetic, complex and interpreted information.

Table 5. Features represented on hydrogeological maps and degree of their interpretation.

Features / Degree of interpretation	Hydrogeological	Groundwater	Antropogenic
Basic data (results of measurements and observation)	Location of observation point (x, y, z); characteristics of outcropping strata; depth of top or base of aquifer; thickness of aquifer; characteristics of aquifer.	Location of observation point (x, y, z); depth to groundwater; spring discharge; pH; conductivity; temperature; ion content.	Location of well, borehole, shaft (x, y, z); depth of well; discharge of well; drawdown.
Primary interpreted data (derived from simple treatment and interpolation)	Hydrogeological boundary; height of top or base of aquifer; isohypses (depth lines) and isopachytes (lines of equal thickness) of aquifer.	Equipotential line; groundwater fluctuation; mean spring discharge; boundary of particular aquifers; isobath of groundwater system; isolines of pH, temperature, specific ion contents, isotopes.	Position of screen relative to datum level (mean sea level); mean well yield; mean abstraction or injection; mean drawdown.
Secondary interpreted data (derived from complex treatment and modelling)	Hydrogeological formation or aquifer parameters, e.g. porosity, permeability, transmissivity; grain size analysis; hydrogeological classification	Boundaries of phreatic, confined, artesian groundwater; flow directions and velocities, groundwater divides; relation between groundwater system and river; fluxes of groundwater systems (recharge and discharge).	Specific yield; induced recharge; artificial drainage.
Tertiary interpretation for decision making (information)	Accessibility; risk of failure of drillings; possibilities of leakage; protectedness of aquifer	Groundwater quality, suitability; vulnerability; protection areas.	Expected productivity; mean abstraction per unit area; injection possibilities; pollution.

This leads directly to the dualism of data versus information, which is also relevant for hydrogeological mapping:

- data (facts) analytical as well as synthetic, usually describe the situation as precisely, completely and objectively as possible, generally against a scientific ("cognitive") background;

- information includes selection, transposition, interpretation and/or combination of data in view of the real or expected user, particularly for decision or regulation purposes.

Information always requires first the availability of reliable data and, second, a particular demand as well as skilful personnel to tailor the information both in content and in graphical expression for the user.

Planners and executives are generally not interested in scientific hydrogeological details, nor do they know the hydrogeologist's terminology. Therefore scientific data must be translated into a language, both graphical and verbal to enable the non-hydrogeologist to grasp the information he needs.

Here again, computer based interactive interpretation, transformation and visualization methods are very powerful tools to meet the demand of special users or user groups.

RELIABILITY OF DATA AND INFORMATION

Data and information, whether plotted in reports, tables or maps, inherently are related to a certain degree of reliability. This is, however, not always stated, so that on maps in particular the customer may draw the conclusion that proved, reliable information is provided throughout the map.

Usually a distinction is made e.g. between observed and inferred contours on geological and hydrogeological maps. However, this does not generally apply to areal information which may imply a relatively homogeneous reliability. Therefore additional information on reliability should be provided on insets or in the explanatory notes to the map, where appropriate. This can be demonstrated by statistical methods, provided that the number of measurement points or boreholes is sufficient.

Of course, such indications on the reliability of map information cannot prevent misuse, such as naive drillers assessing their prospects for boreholes from generalized overview maps without more detailed local studies. To tackle this problem, a relevant disclaimer on the map margin should explain the possible uses and limitations of the map.

The hydrogeologist should never withdraw from producing hydrogeological maps simply because of insufficient, incomplete and unreliable data (in fact, this is the normal case). Note that even a rough guess of a hydrogeological professional is much more valuable than the dowser's advice! And realize that even simple hydrogeological reconnaissance maps are as valuable in the initial phase of development as more advanced and specific maps in the later management and protection phases.

Chapter 5.
TYPES AND CLASSIFICATION OF HYDROGEOLOGICAL MAPS

INTRODUCTION

Hydrogeological maps and other graphic representations reflect the state of the art in hydrogeological knowledge and reflect the specific requirements of their users. A wealth of such material exists worldwide, which corresponds to the evolution in water science at various stages throughout the world (see selected list, Annex A). This wealth of existing maps, the level of data and information available and the possible use of the maps enables a number of types of hydrogeological maps to be distinguished. These are outlined in Figure 16, in relation to the other parameters shown (Struckmeier et al., 1989).

The aforementioned classification is considered most useful and practical, though other classifications according to various criteria are possible, as outlined in Annex C.

level of information / *possible use*	low (scarce and heterogeneous data from various sources)	advanced (+ systematic investigation programmes, more reliable data)	high (+ hydrogeological systems analysis and groundwater models)
reconnaissance and exploration	general hydrogeological map (aquifer map)	hydrogeological parameter maps (map sets, atlasses)	regional groundwater systems maps (conceptual model representations)
planning and development	map of groundwater resource potential	specialized hydrogeological maps (planning maps)	graphic representation derived from geographic information systems (maps, sections, perspective diagrams, scenarios)
management and protection	map of groundwater vulnerability		
possible use / parameters of representation	static ——— time-dependence ———► dynamic low ——— reliability ———► high low ——— cost per unit area ———► high large ◄——— area represented ——— small small ——— scale ———► large		

Figure 16. A classification system for hydrogeological maps.

The commonest types of hydrogeological maps in the broad sense are

(a) general comprehensive hydrogeological and groundwater resource potential maps

(b) parameter maps (this type includes both parameters and variables, as well as other basic data portrayed on single value maps)

(c) groundwater systems maps

(d) special aspect or purpose groundwater maps, including derived maps, such as vulnerability, suitability and protection maps.

The growing widely-varying range of computer-derived graphical representations is an additional type which is developing rapidly in certain countries with access to good data bases and advanced geo-information system (GIS) technology. This group is dealt with in Chapter 7.

GENERAL, COMPREHENSIVE HYDROGEOLOGICAL AND GROUNDWATER RESOURCES POTENTIAL MAPS

General, comprehensive hydrogeological maps and maps of groundwater resource potential are grouped together, for two reasons. Firstly, they correspond to earlier stages of hydrogeological investigation and knowledge and secondly they present comprehensive data and information as a synthesis, varying from mere superposition to integration of different layers of data and information. They differ, as comprehensive hydrogeological maps chiefly lay emphasis on hydrogeological features such as the type of aquifers, while maps of groundwater resources potential primarily present information on the availability and suitability of the groundwater. However, there is a gradual transition from one type to the other.

The prototype of the general, comprehensive hydrogeological map is the International Hydrogeological Map of Europe, a series of map sheets at scale 1 : 1 500 000. It is also the model for the International Legend for Hydrogeological Maps (see Part II) and many other maps and legends. A colour plate showing part of this map is included in this volume (Plate I). It is a true synoptic data base providing, together with the corresponding explanatory notes, a full range of useful interrelated data and information at a supra-regional scale. The degree of interpretation is, however, less advanced, compared to resource potential maps. Therefore additional interpretation and translation is required, if non-hydrogeologists are to make full use of it. For hydrogeologists, it is in any case an easily usable and powerful tool. Hence this type of map is considered basic at professional level, and therefore is used for systematic map coverage in many countries of the world (see Annex A).

Maps of groundwater resource potential can be prepared in two ways and at different stages: (a) by integrating various kinds of specific information layers at a fairly advanced stage of hydrogeological investigation, as outlined in Figure 15 or (b) by using the relevant experience and skill of the regional hydrogeologist at a relatively early stage of groundwater investigation. Such a 'reconnaissance' investigation map implies a rather subjective but fairly reliable and extremely quick estimation, whereas large amounts of data have to be collected and stored before (a) can be implemented. An example of this map type from a semi-arid area in Africa (Botswana) is shown on Plate II. This map at scale 1 : 1 million shows an integrated interpretation of the hydrogeologically relevant data of the country and is largely based on the existing hydrogeological reconnaissance map series at scale 1 : 500 000.

Both general and groundwater resource potential maps utilise small and medium scales, but also can be produced at large scales.

HYDROGEOLOGICAL PARAMETER MAPS

The parameter map shows with maximum accuracy a specific set of data (parameter or variable) relevant to groundwater and aquifers, its occurrence, extent, magnitude and hydro-geochemical characteristics. Parameters and variables displayed on such maps are

- physical, showing groundwater contours, depth-to-groundwater, groundwater temperature, depth of structural surfaces (isobaths) and thickness of aquifers, and

- chemical, e.g. groundwater salinity, specific ion contents (e.g. chloride, fluoride, iron, nitrate).

The representation of a single groundwater-related parameter or variable should take into account at least one other parameter; e.g. a groundwater contour map has to be logically linked with the river network and regime (whether losing, gaining or independent), the topographic setting and locations.

A base map showing observation points and (simplified) topography is generally indispensable for all single-parameter maps. This also is true for the representation of further values, such as transmissivity, coefficient of permeability, storage coefficient, field capacity, infiltration rates, fluctuation of groundwater table, hydraulic head characteristics and so forth.

Single-parameter maps often serve for the precise presentation of many individual details and therefore require the use of larger scales. If appropriate, values or data may be stated on the map, in numbers, to be extended or revised, but also because of the need to update these maps frequently. These maps, therefore, are very suitable for preparation by CAD (computer aided design) techniques.

Such maps require interpretation by hydrogeologists.

Usually, parameter maps are prepared as simple black and white maps, mainly for practical and cost reasons.

GROUNDWATER SYSTEMS MAPS

Groundwater systems maps are prepared to highlight the hydrodynamic setting and the boundary conditions in a given area. They may encompass a whole country or region or focus on individual hydrological or groundwater flow systems thereby laying the base for further hydrodynamic modelling. They greatly facilitate understanding of groundwater flow systems and define the boundary conditions of models.

These maps are particularly useful in the conceptual phase of modelling and are, of course, based on many parameter maps, together with an integration of auxiliary information such as morphological, geological, structural, pedological, hydrological and other relevant information. They require a relatively advanced stage of data acquisition and are usually coupled with conceptual model thinking. As they originate from a very comprehensive, integrated view of the relevant features, they may advance the understanding of the hydrogeological setting considerably and even lead to new conclusions. A by-product of the combination of data, information and models is the clear identification of gaps and a hierarchical classification of data. Therefore such maps are most efficient to outline monitoring networks, preferably at key positions in the groundwater systems.

At present there are few maps of this type, although their great value is recognized by hydrogeologists and modellers. Their cartographic elements have been included in the standard legend (Part II) to facilitate preparation of such maps, which are particularly useful for groundwater protection and environmental management purposes. Plate III shows a section of the holotype of the map of aquifer systems of France at scale 1 : 1 500 000. Another example of a groundwater systems map at scale 1 : 500 000 is shown on Plate IV.

SPECIAL PURPOSE OR ASPECT HYDROGEOLOGICAL MAPS

As this family of maps is destined to specifically serve a particular purpose and the range of users and user groups may vary widely, a broad spectrum of such maps exists. In general, they can be grouped according to their use into planning, exploitation and management:

- maps providing direct information on groundwater and its availability, accessibility and cost of abstraction,

- planning and management maps providing information on groundwater quality,

- groundwater vulnerability maps indicating the vulnerability of groundwater to pollution,

- groundwater protection maps indicating the state of exploitation of groundwater resources, protected areas and future reserves which may require protection.

Moreover, more generalized maps for educational purposes could be added to this group. The value of these maps, often underestimated, lies in the instruction of the public, particularly at school level. Such maps inform about the occurrence, vulnerability and necessity for proper management and protection of water resources, so vital to the health of mankind's environment.

Most of these special purpose or aspect maps are designed to aid the efficient planning and management of groundwater resources, and thus make significant contributions to a nation's economy. The cost of producing such maps will generally be more than offset by their potential to generate economic gain. All hydrogeological organisations should therefore make every effort to make their accumulations of data and professional expertise publicly available, through the medium of hydrogeological maps, to all those - politicians, administrators, engineers, managers etc. - responsible for the social and economic development of a country or region.

EXPLANATORY NOTES FOR HYDROGEOLOGICAL MAPS

Explanatory notes complementing and completing hydrogeological maps have proved to be most useful to both map author and map user, since they

- contain detailed information that could not be accommodated on the map itself for reasons of readability,

- offer possibilities to give further explanations on interesting items on the map, thereby expanding the map legend,

- explain how to read the map and fully grasp the information presented.

Explanatory notes are particularly valuable for systematic, general purpose maps designed as optical data bases with different kinds of data and information, and generally presenting a low level of interpretation.

Such maps together with the corresponding explanatory notes thus constitute real regional hydrogeological monographs suggesting many ways for further application.

Maps and explanatory notes must be closely interrelated, and they should be prepared simultaneously. Whilst systematic geological base maps exist in many countries, similar hydrogeological maps series are less abundant. Where they do exist, they are usually issued as books with a map (or maps) in a pocket.

General purpose specific aspect maps, by contrast, are rarely complemented by explanatory notes. Their aim is to quickly inform the map user on a particular question. They may comprise concise and short explanations, e.g. a general hydrogeological summary, an appraisal of the reliability of map information and hints for using the map. Such maps are largely selfexplanatory. However, the authors of these maps should always prepare a corresponding publication in a regionally relevant scientific or practical journal, to introduce the map to the public and to provide additional information on the preparation, representational concept, legend and use of the map. The maps should also be registered in map catalogues (see Annex B).

Chapter 6.

TECHNIQUES FOR PREPARATION AND PUBLICATION OF HYDROGEOLOGICAL MAPS

GENERAL REMARKS

This chapter refers to the technical procedures for hydrogeological map preparation, a knowledge of which may greatly contribute to the smooth and efficient planning and implementation of hydrogeological mapping programmes. This implies that careful discussions have taken place between the map makers and potential users leading to a suitable concept. The possible users, promoting or financing bodies for systematic mapping programmes or single maps may be international organisations, government agencies, universities or private companies, such as geological surveys, river authorities, water supply companies, planning and environmental protection agencies, etc.

The hydrogeologist elaborates the appropriate map concept on the basis of the requirements of data and resources on the one hand, and the user's needs and destination of the map on the other. He may be greatly helped by the previous chapters of this guidebook. However, both the development of a final concept of a map as well as the procedure for map preparation should not be schematized. Sufficient flexibility must be kept, to adapt the map as much as possible to the particular situation. Therefore the technical recommendations in this chapter as well as the standard legend presented in Part II of this guidebook are neither obligatory nor binding; but they have proved to be useful for numerous map projects at various scales and in various environments worldwide.

This chapter focusses on published coloured maps which require somewhat costly, time and manpower-consuming preparation that should be carefully conducted, in order to optimize the cost/benefit ratio. Therefore, the bulk of parameter maps, being part of most specialized investigation reports, are not described in this chapter, since they are chiefly prepared in black and white and in many formats. At the end of this chapter, recommendations are given for the preparation of explanatory notes, to complement the map sheets.

The general concept of hydrogeological mapping programmes is often disputed, even by hydrogeologists themselves. A crucial point is whether preference is given to top > down or bottom > up methods, i.e. starting with large or small scales. Although nothing is wrong with a concept based on a large number of detailed maps which are generalized and plotted onto maps of larger areas at smaller scales, it is usually preferable and more practical to apply a telescoping system. It starts from rather crude and general, small overview scales to more detailed, larger scales, particularly in areas where more precise and quantitative information is needed, e.g. in population centres or areas of conflicting land use. This latter strategy is advantageous for three reasons: firstly, general information on groundwater is provided at an early stage of the nation's development, when it is badly needed; secondly, hydrogeological capacity building and public awareness about groundwater matters are fostered by good overview maps; and thirdly, the more detailed mapping programmes can be planned more efficiently. The first, rough reconnaissance maps can be updated, corrected and refined later.

The wise statement of an old, experienced teacher in cartography also applies to hydrogeological maps; it should be remembered by all concerned: "the most important thing about a map is, that it is prepared, if possible, in time and that it is completed".

The preparative synopsis for a hydrogeological map is given in Figure 17.

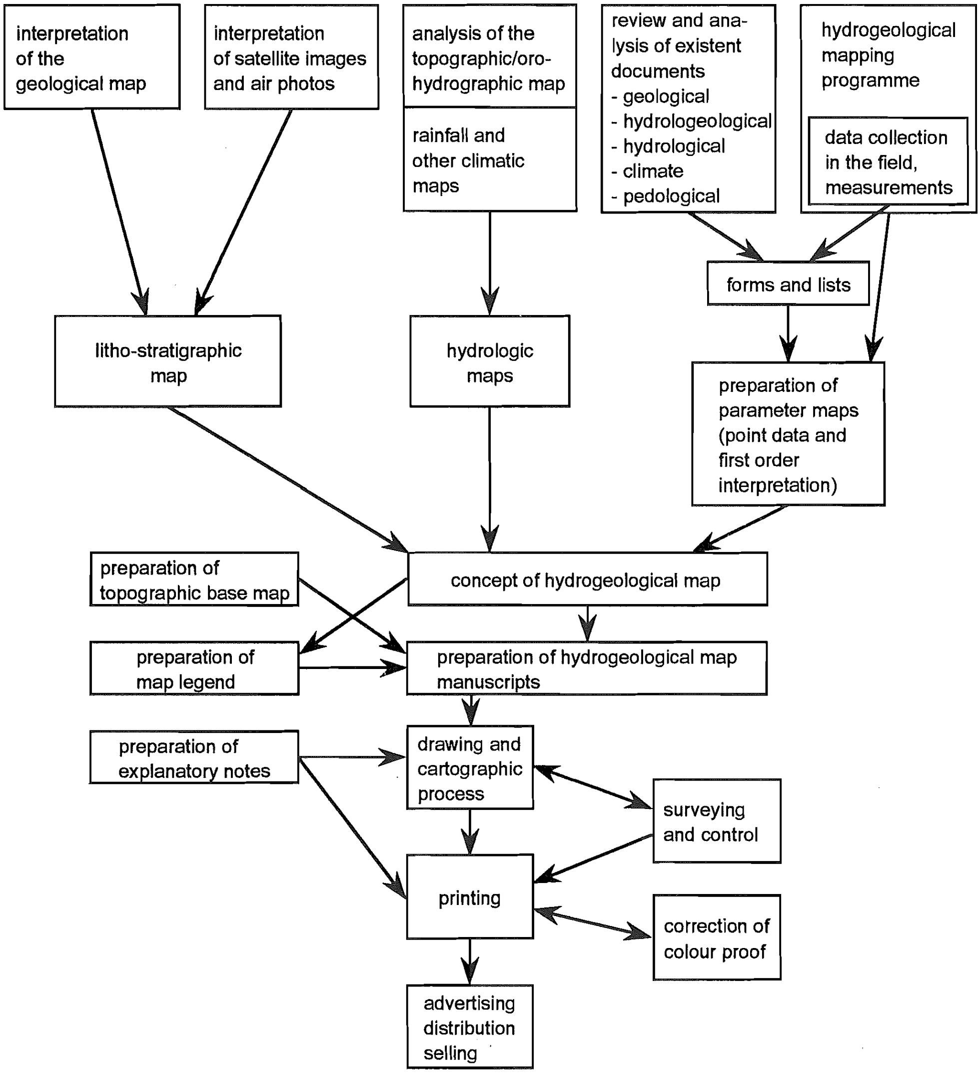


Figure 17. Flow diagram for the preparation of hydrogeological maps.

In general, there are three or four specialists (or groups of specialists) that have to co-operate to ensure the preparation and publication of a map in the most economic way, i.e. the author, the draughtsman and the printer, and - optionally - a map editor (see Figure 18).

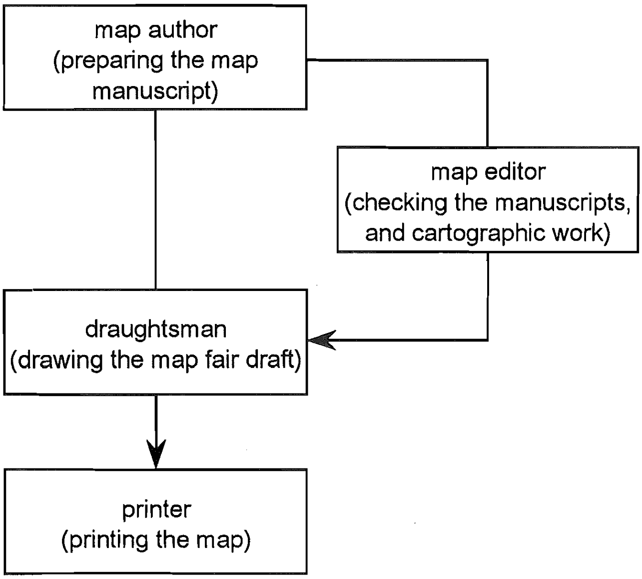


Figure 18. Specialists co-operating in map preparation and publication.

Topographical and simple thematic maps for which standards and rules of representation are available usually require only map authors, cartographers and printers.

However, the assignment of a map editor is frequently warranted, since generally agreed technical standards of representation are still not available for all individual types of maps (too much standardisation would seem undesirable when one realizes the huge variety of themes that can be presented on hydrogeological maps). The editor should serve as a link between the scientific (the author of a hydrogeological map) and technical (cartographer) levels; on the one hand he has to advise and discuss scientifically with the map author, and to supply the author with material facilitating the map drafting (e.g. legends, examples, technical instructions); on the other hand he has to supervise the cartographic work and he should hold discussions with the cartographer who transfers the author's manuscripts into final cartographic drafts.

In many countries, short of manpower and skilled professionals, it may not be possible to employ an expert for map editing only. However, it is recommended that every agency concerned with hydrogeological mapping should assign an expert who will be trained and upgraded in hydrogeological map production techniques, so as to ensure the good standard of any published maps. Official maps should be published only after authorization by this expert and by the head of the hydrogeological survey.

If systematic hydrogeological mapping is carried out (e.g. a series of maps), a map editor or an editorial board is absolutely necessary, since the interpretation and representation of the data must be uniform throughout the map series.

MAJOR STAGES OF HYDROGEOLOGICAL MAP PREPARATION AND PUBLICATION

The input of authors, editors, draughtsmen and printers for the compilation and scientific and technical preparation of a hydrogeological map varies widely, generally depending on the purpose of the map and on the given constraints, such as availability of manpower, time, or funds.

There are, however, several typical and distinct stages in the preparation and publication of a hydrogeological map; they usually follow a chronological order (from the map compilation and drafting to the printing), as outlined on Figure 19. It shows an example from Indonesia which, however, is universally applicable.

The author's stage

It should be said at the outset that in view of the complex nature of hydrogeology any author of a hydrogeological map should have comprehensive knowledge about all components influencing the groundwater regime (e.g. climate, surface hydrology, orography, land use, geology). This knowledge will allow him to find an explanation for the features observed in nature. In other words, he should be a qualified hydrogeologist.

Next, the map author has to define the objective of the map and the possible map users, since they largely control the extent of work and cost for the map production. Every author of a map, however, should bear in mind that 'his' map will be used by different map users, all of them expecting complete and reliable information. Thus the author should document all data from which the map interpretation is derived; and he should provide an explanatory note which contains information about reliability, period of data collection and additional data not shown on the map.

In general, the preparation of a hydrogeological map by the author consists of the following phases:

(i) initial (office)
(fact finding, orienting, preparing, checking, planning)

(ii) field work
(data collecting, questioning, clearing)

(iii) interpretation (office)
(interpreting, explaining, completing, representing).

The initial phase of map prepation largely comprises preparatory work in the office both with respect to scientific content and to the careful scheduling of the subsequent phase of field work. At this stage the feasibility of the map project (personal, financial and technical resources) has been mostly ascertained so that the basis for a successful project is laid. It is essential in this phase to:

- define the map concept (purpose, content, scale and representation)
  - -- talk with potential users
  - -- work out the legend
  - -- select a suitable topographic base map
  - -- contact cartographers and (eventually) printers

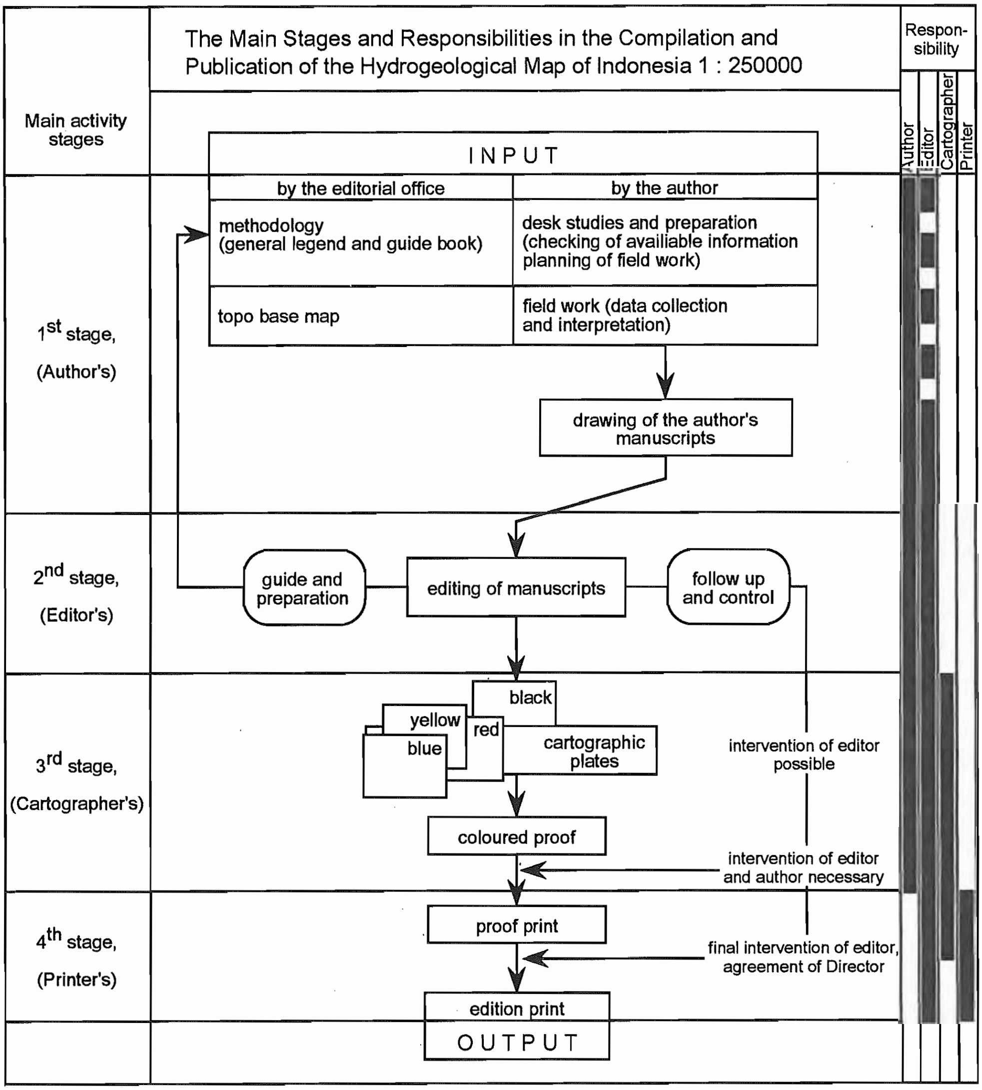


Figure 19. Stages of preparation and responsibilities during the publication of the Hydrogeological Map of Indonesia (example, expanding on the lower part of Figure 17).

- prepare the topographic base map
  -- update the topographic base map
  -- interpret (morphology, drainage pattern)
  -- select the elements to be retained on the thematic hydrogeological map as well as their representation

- exploit existing reports
  -- abstract hydrogeological information
  -- check information on climate, hydrology, geology, land use, water management

- check geological maps
  -- study geological (lithological) units
  -- understand structure and tectonics
  -- discuss with geological map authors

- interpret air photos and satellite images
  -- regarding topography, hydrogeological features, including karst vegetation, land use, geology, tectonics

- discuss with colleagues
  -- concept for field work
  -- field infrastructure

and

- check equipment for the field survey.

At the end of this phase a reliable schedule for field work (time, manpower and equipment) must be available and priorities for data collection (essential - very important - useful - optional) should be set.

Since Chapters 2 and 4 largely focussed on field data and data requirements for hydrogeological maps, only a rough summary is given here.

Necessary field work should be carefully planned and carried out, since it is usually costly and limited in time, e.g. a field campaign during the dry season. Therefore, priority must be given to the quality of data, i.e. the collected data has to be correct, complete and reliable, rather than to the quantity of data (many measurements) (see also Chapter 2).

During field work, the map authors should

- visit, assess, measure and plot 'water points'
  -- 1. springs, 2. boreholes, 3. water works, 4. wells, 5. stream flow, particularly base flow, 6. additional
  -- fill in well schedules
  -- plot location on field map, make notes

- correct base maps (topographical and geological)
  -- new canals, reservoirs, irrigation schemes
  -- geological units

- collect information from all water-related and other relevant authorities
  - -- project consultants and drillers

- subdivide the map area according to hydrogeology
  - -- delineate areas of similar hydrogeological character (hydro-lithological units)
  - -- define recharge and discharge areas
  - -- interpret all field observations
  - -- return to areas where data are contradictory or incomplete

- outline additional investigations, e.g.
  - -- drilling
  - -- aquifer testing
  - -- geochemistry
  - -- geophysics

At the end of the field work, the author should check that essential hydrogeological data for map preparation are complete and that no contradictions or important gaps in knowledge are likely to occur on the map.

At this stage, it is important to critically review, compare and correlate the data collected and retrieved elsewhere. This applies to all data and information derived from different sources, particularly data from boreholes and analyses, which are very valuable to the hydrogeologist since they allow a look at the vertical component and development of a semi three-dimensional understanding of the regional hydrogeological setting.

Lithological data at depth are usually derived from sampling during or after drilling or digging wells. Indirect, deduced lithological information can be derived from geophysical measurements. Lithological descriptions of cuttings or cores are made out not only by geologists but also by drillers or auxiliary technical staff. These descriptions are subject to a number of factors such as:

- method of sampling and sample storage;
- experience and knowledge of the staff who describe the samples, e.g. misunderstanding technical terms such as fine sand for silt or silt for clay, etc.
- daylight conditions to distinguish colours;
- whether the sample has been washed;
- moisture content of sample.

There are many possibilities for wrong descriptions and lithological records may vary greatly. Thus, this information has to be handled with care. However, as lithology and structure largely govern the groundwater flow setting, this information is particularly valuable for hydrogeological mapping purposes.

For registering lithological data, abbreviations for grain sizes of major and minor constituents are used including remarks on colours, specific minerals and other relevant features. All information should be reported on special borehole documentation forms. These can either be adapted for the use of electronic data processing or transcribed on diagrams (lithological or well logs). As lithology often varies greatly with increasing depth, the wealth of lithological information should be pre-treated by correlation and compared with existing geological maps.

The visual correlation of well logs by the hydrogeologist has proved to be most useful, using the following methods:

(a) Plotting of primary data from each log at the respective location on the map. These data are not adjusted to or correlated with neighbouring logs before being plotted.

It is important to look for consistent data, that is to say, values over the same depth or the same thickness, etc. The data may be grouped and the classes marked by colours or symbols. The observation points can then be reviewed visually and possibly combined in areas.

(b) Plotting of data derived from a correlation of logs, after making any necessary visual comparisons.

Both methods, which are largely complementary, should be used.

The preparation of well logs at a standard scale is also necessary for the construction of vertical cross-sections.

The main lithological constituent must always be emphasized; for example, "sandy clay" means that primarily clay is involved; "clayey sand" should clearly show that it is primarily a sand. The symbols can be mixed, approximating to the percentage value of the constituents.

The distinction between "good", "fair" and "poor" aquifers or the use of similar statements should generally not be made at this stage of the investigation. A generalization will be more meaningful if many complete logs can be correlated.

The correlation of lithological logs results in a regional overview of the geological structure. By this means, the hydrogeologist will be able to deduce information about the possible depth, thickness and extent of aquifers and to apply it to the hydrogeological map.

A correlation should not be made by combining primarily all layers with the same description, but to develop it step by step. As the lithological description is only one criterion, it is more reasonable to look for similar sediment associations, similar values of thickness or depth, similar tendencies of grain-size changes (but independent of absolute grain-size values), etc..

The initial step comprises a discussion of certainty subdivided as follows:

(a) Correlation is sure. All logs indicate the same or very similar material. The position (depth) and thickness of the layer are the same or very similar in all logs.

(b) Correlation is probable. The boundaries indicated by this letter correspond to divisions between thick series which are characterized by different predominant grain sizes in the various logs. Less attention is paid to the direct correlation of descriptive terms (such as "coarse sand" with "coarse sand" or "fine sand" with "fine sand").

Firstly, characteristic changes or sequences are studied within each log separately. Secondly, similar sequences (e.g. fine to coarse) are recognized in neighbouring logs.

The certainty is supported by the fact that no material described had to be ommitted from the correlation.

(c) Correlation is possible. By jumping one log and generalizing, good (regional) correlation has been obtained, e.g. between "coarse and with medium sand" below and "fine with coarse sand and medium sand".

(d) Correlation is problematic, when only fragmentary data or very crude descriptions are available.

(e) Correlation is impossible due to lack of imformation.

Figure 20 shows a generalized transverse section in which two main types of hydrogeologically relevant formations are distinguished by using diagonal hatching (for main aquitards) and dots (for main aquifers A, B and C).

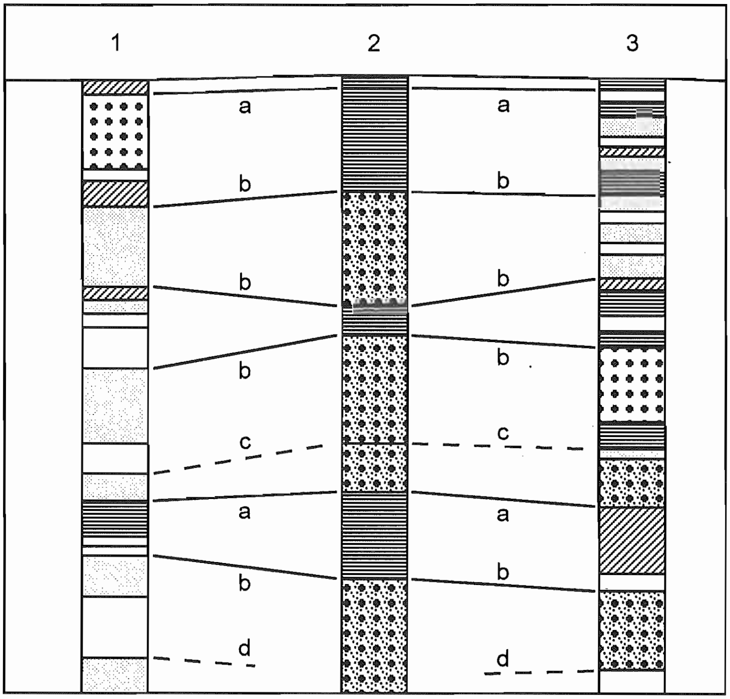


Figure 20. Correlation of borehole logs on a cross-section.

In addition, the respective symbols for coarse and fine material are added to each main aquifer and/or aquitard in accordance with the logs where such material was recorded. Such finalization is important in order to indicate possible hydraulic connections between the main aquifer series.

The correlation of lithological borehole information together with geological and structural information of a given area enable the hydrogeologist to develop a first coherent concept of the hydrogeological setting of the map area. This has to be verified, however, step by step by integrating other data on groundwater quantity and quality.

Hydrochemical field or laboratory data are registered either on special forms by analyses individually or on comprehensive data sheets, both types being useful for the hydrogeologist.

Comparable with the handling of lithological data, the hydrochemical data should also be pre-treated in a systematic and consistent way before being plotted on a map. Particular attention should be paid to the vertical zoning, which may be disturbed by pumping wells. This may lead to an undesired mixture of water entering at different screen levels having different chemical composition. This problem can be overcome by multilevel wells permitting depth related chemical water analyses.

After this phase of field work, correlation and pre-interpretation of the field data and additional data and information drawn from archives and data bases, the map author proceeds to the interpretation phase for drafting the map. It should follow the field work immediately, even if additional investigations are to be carried out.

During the phase of interpretation and map drafting the map author should

- correct and update the topographic base map
  - -- drainage pattern, reservoirs, canals, irrigation areas
  - -- cities, important roads

- transform the geological base map into a lithological base map
  - -- subdivide significant lithological units
  - -- group adjacent, similar rocks into one unit

- plot point data exactly on the base map
  - -- amount and kind of data depending on type of map

- make an areal evaluation of data
  - -- define map legend
  - -- generalize and regionalize the data

- draw representative cross-sections
  - -- to cross important hydrogeological units
  - -- include drillings and profiles in section line

- write an explanatory text
  - -- define map compilation procedure
  - -- present a synthesis of hydrogeology of mapped area
  - -- describe additional features not represented on map.

An example of an author's work plan, as used in hydrogeological mapping programmes in Indonesia, is presented in Figure 21.

The phase of interpretation and map drafting is crucial and requires the full attention and skill of the hydrogeologist. It comprises mainly the interpretation of point and line data into areal information, whereby all data, information and observations are correlated and arranged with the aid of hydrogeological methods and models. The phase of map drawing is concluded by delivering the complete map manuscript to the cartographer.

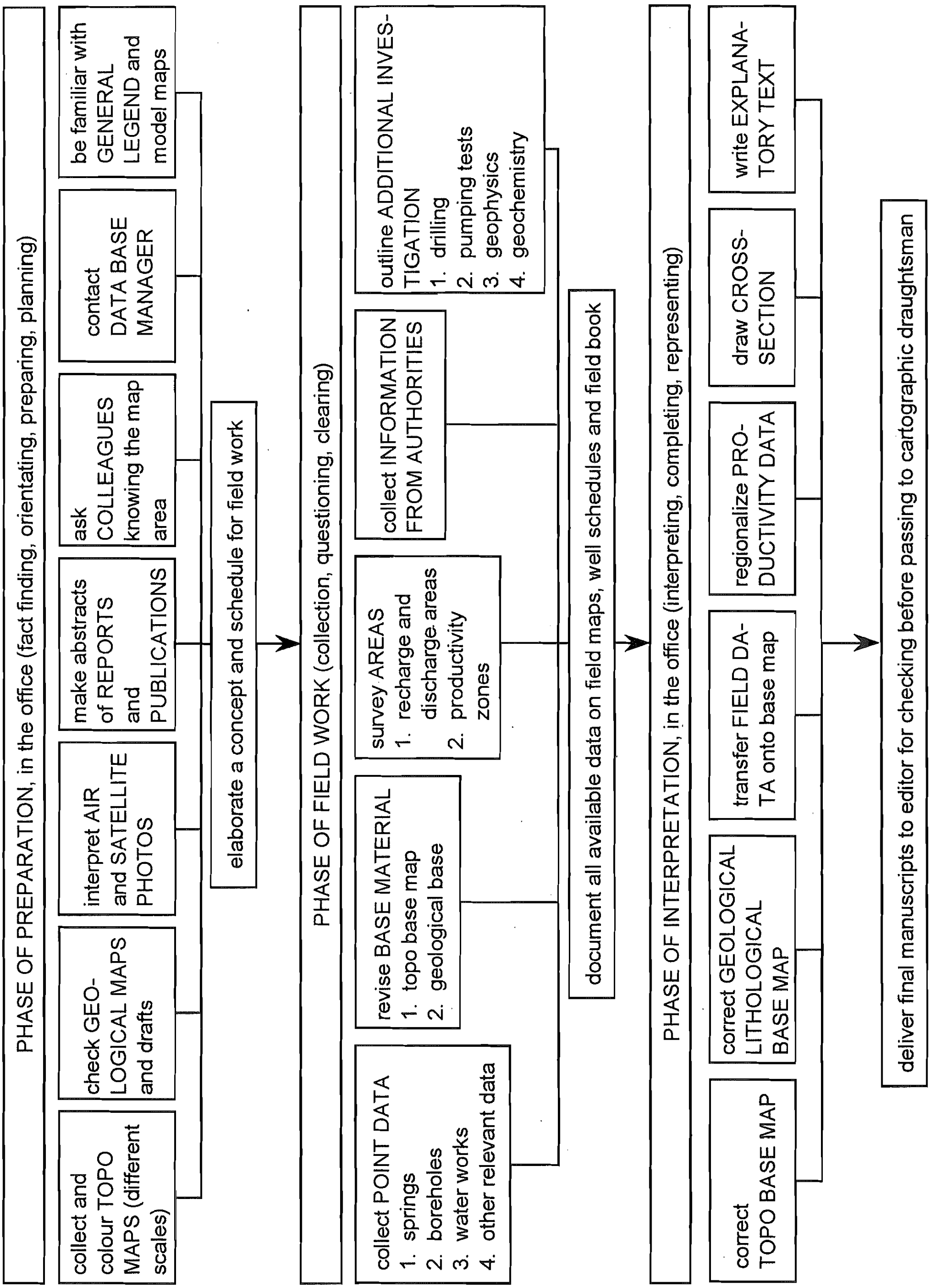


Figure 21. Example of an author's organizational plan for hydrogeological mapping.

This material, which should meet minimum technical standards, e.g. points, lines and other geographically referenced symbols, must be drawn on dimensionally stable sheets (plastic drawing foil), while areal colours, types of areas, type of symbols and the sheet layout should be unambiguously defined on additional paper sheets (preferably photo prints (heliocopies) of the transparent plastic sheets which are coloured by hand).

In the case of a simple hydrogeological map the author will try to explain his wishes for the format of the map to the draughtsman and will check from time to time that his desires are being met.

For complex hydrogeological maps, particularly a series of systematic maps, an editor or editorial board should oversee the work of both map author and draughtsman.

The drawing of instructive cross-sections is essential, to provide information on the vertical extension of structures or features on the map. It must always be composed together with the map draft, since map and cross-sections must form a homogeneous unit. Moreover, the map author has to transfer his three-dimensional grasp of the hydrogeological systems on two planes (horizontal and vertical) which must be coherent. Any changes in the map thus have to be considered on the cross-sections, too. The corresponding explanatory notes should be written simultaneously or immediately after the preparation of the map.

Outline of explanatory notes

Explanatory notes contain both information which could not be placed on the main map face in order to cope with cartographic requirements and preserve legibility, and information usually not mappable such as cross-sections, hydrographs, tables and other graphics.

A typical outline of an explanatory note to a general hydrogeological map may comprise the following table of contents:

1. Introduction
2. Geographical overview
3. Climate and hydrology
4. Summary of geology
5. Detailed hydrogeological descriptions
6. Explanation of the main map and map inserts
7. Bibliography

The introduction comprises definition and limitations of the map as well as a review of steps towards the completion of the map including cooperation and references.

In the geographical overview, a succinct outline of the relief, landuse, population, etc. is provided. In addition, regulations for land management, such as nature protection areas, should be mentioned.

The climate and hydrology chapter highlights the climatic factors, particularly precipitation, and presents useful hydrological information, e.g. on the water cycle, components of the water balance, hydrological regimes of rivers, drainage network, drainage basins, karst features, etc.

The summary of geology contains information on the full sequence of rocks occurring on the map sheet, their lithology, facies, thickness and stratigraphy. The structural setting must also be described, together with tectonic explanations. Information on borehole logs, soils and superficial formations should also be included in this chapter.

The detailed hydrogeology chapter is of course the central part of the explanatory notes. It should contain a coherent regional appraisal of hydrogeological units, the aquifer and groundwater systems as well as detailed information related to the hydraulic properties of individual aquifers and other rock bodies. Any interesting information on drilling and well construction, recharge or discharge, vulnerability and protection of groundwater, tables and statistics about groundwater abstraction, use, pumping tests, chemical analyses, temperatures, isotopic datings, as well as water levels and flow directions, underground karst features and water balance calculations should be presented here, or as annexes. The text should largely be complemented by cross-sections, sketch maps and other figures. Finally, particular problems, uncertainties and need for further investigations and research should be mentioned.

In the chapter explaining the main map and the map insets a brief summary of the elements shown on the map face and the special inset maps should be given. It should summarise the legends of the maps and explain, by the aid of examples or models, what can be seen on the map and how it can be interpreted. Reference should be made to cross-sections, to lead the map user to a pseudo three-dimensional grasp of the hydrogeological setting. The inset maps should be explained briefly, and their relation to the main map established.

A bibliography should conclude the text part of the explanatory notes. It must comprise the most appropriate geographical, geological and climatic publications and should include all relevant hydrological and hydrogeological reports, even if unpublished.

Summary tables, e.g. on stratigraphy, lithology, climate, hydrology, springs, groundwater abstraction, chemical characteristics, etc. could be listed as annexes, allowing the reader a quick and systematic comparison and overview.

The role of an editor/editorial board for a hydrogeological map

The main tasks of an editor or an editorial board for a hydrogeological map are

- to supply the map author with all base material suitable to facilitate the author's job (e.g. base maps, general legends, guidelines for the drawing of map manuscripts, drawing devices);

- to check and discuss the map drafts with the map author (e.g. representation, generalization, layout);

- to ensure the proper and timely technical execution of the map;

- to advise, discuss and oversee the cartographic work and printing of the map.

The responsibilities of an editor for a hydrogeological map thus extend in part from the very beginning of map preparation to the printing of the map (cf. Figure 19).

The editor of a hydrogeological map should always be a professional hydrogeologist, but he should know about cartographic working methods and equipment.

By ensuring proper co-operation between author and draughtsmen losses of efficiency, time and money will be minimized.

The technical preparation of a hydrogeological map

Technical preparation comprises all cartographic work and the printing of the map.

The manuscript map provided by the map author (and editor) is transformed into fair drafts (plates) suitable for printing, by cartographic draughtsmen.

The cartographic work falls into three stages, i.e. design, scribing and mounting, and reproduction (see Chapter 3).

It goes without saying that the draughtsman depends on the drafts of the author/editor and has to be sure that their information is correct and complete. Therefore, he will request correct and accurate map drafts on stable material, where e.g. all point and line information is plotted in the correct location on the topographical base map. The same holds for the text and any additional information to be presented on the map.

As the cartographic techniques for modern, sophisticated map preparation are rather costly and time consuming, alterations to the map manuscript should be avoided. As evidenced by experience, however, desire for corrections and modifications of the map author/editor will always arise, even in the advanced stage of map preparation. This should be minimized by speedy cartographic processing immediately after the completion of the author's manuscript as well as by continuous contacts with the cartographer.

Provided that all parties involved in preparation and publication fulfill their tasks properly, a hydrogeological map will usually be published up to six months after the completion of the map drafts by the author/editor. In view of the complexity of the map preparation procedure, (an example is outlined in Figure 22), good co-operation and mutual understanding between all parties concerned is indispensable.

ESSENTIALS FOR SYSTEMATIC, GENERAL HYDROGEOLOGICAL MAPPING

Authors, editors, draughtsmen and printers must collaborate closely to achieve a hydrogeological map at least possible cost.

The assignment of an editor/editorial board usually boosts the efficiency of map preparation; for a series of maps uniformity throughout the series must be sought.

For systematic, general hydrogeological maps, which should be prepared by the responsible groundwater authorities so as to contribute to the development and proper planning of a country's natural resources, the following essentials must be considered:

Boundary conditions:
- no general hydrogeological map available
- availability of manpower and funds

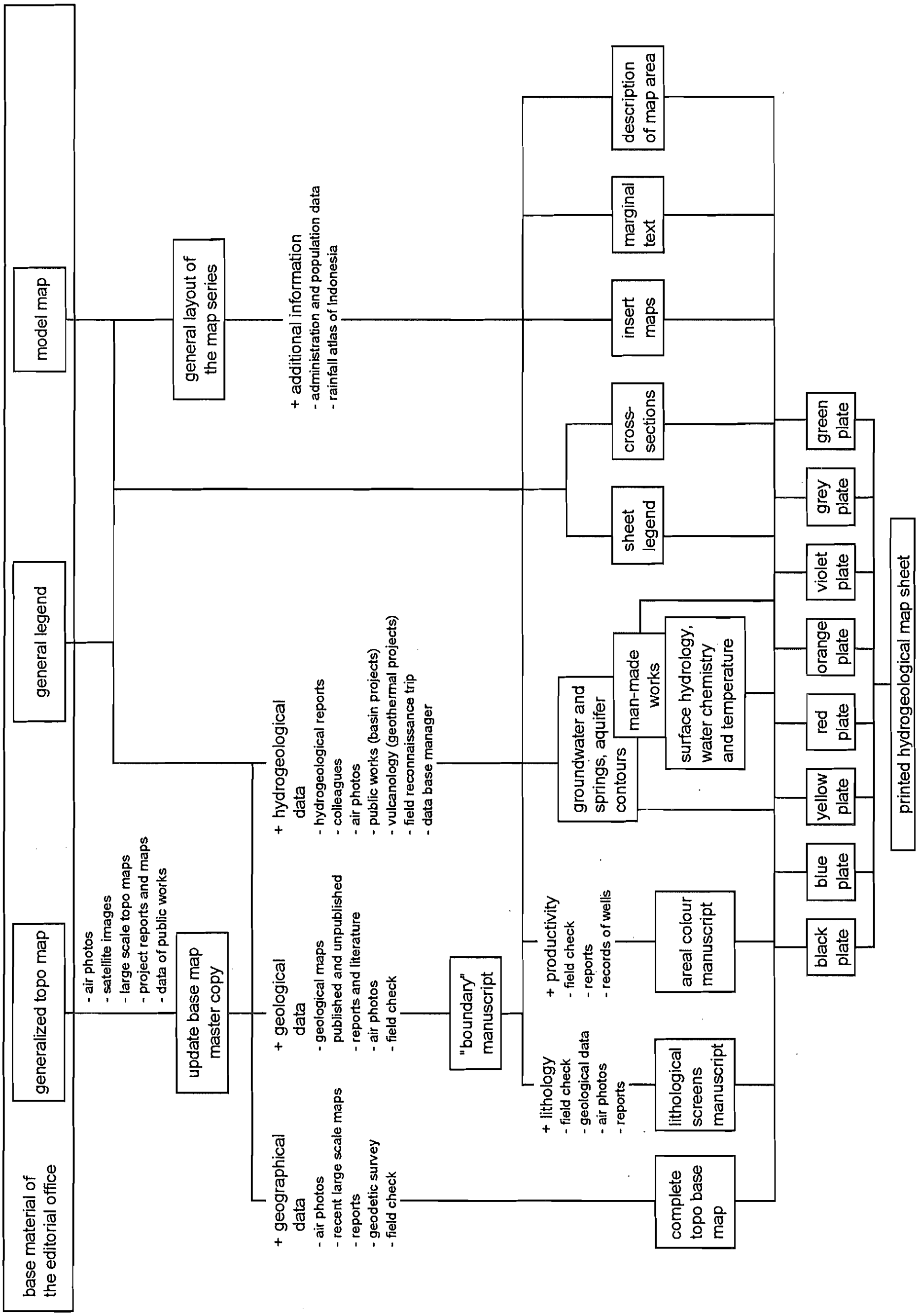


Figure 22. Example of the compilation and technical preparation of a hydrogeological map series (Hydrogeological Map of Indonesia).

Relevant steps in map preparation:

1. Appoint editor or editorial board responsible for a systematic mapping project
2. Elaborate general legend
3. Use updated topographic base map
4. Schedule mapping work, of the
   -- authors (office and field)
   -- draughtsmen
   -- printers
5. Ensure proper facilities for cartography and printing
6. Produce model sheet and discuss with authors and map users
7. Adjust general legend from time to time
8. Keep contact with map producers and map users.

If authors, editors, draughtsmen and printers co-operate effectively according to their tasks and responsibilities, hydrogeological maps are very economical tools for planning and development in every country or region. For example, drilling failures reduced considerably after hydrogeological reconnaissance mapping and improved borehole siting techniques in Botswana; in many European countries, natural resources planning has been optimized considerably, since conflicting strategies for exploitation, e.g. between gravel excavation, agricultural land use and groundwater development are recognized in advance.

This guidebook gives merely a brief indication of the principal points to consider for practical hydrogeological mapping. The list is neither complete nor definitive, and modifications and additions will eventually be needed, depending on the type, use and format of future hydrogeological maps, as well as on their actual location in the particular region or country. However, a systematic strategy should always be followed and worked out properly in flow charts, time tables and a network plan, to run the programme efficiently. The hydrogeological mapping programme thus serves not only for producing a map but, sometimes even more importantly, to set up a systematic data base. This should then be completed and refined, step by step.

Thus, systematic hydrogeological mapping must also be regarded as an essential step in hydrogeological capacity building, particularly important for hydrogeological surveys.

Chapter 7.

DEVELOPMENTS IN HYDROGEOLOGICAL REPRESENTATION

To complete the information on traditional map preparation provided in the previous chapters, a quick glance is given in this chapter to computer-based or computer-assisted methods of representation which are in common use today. This is not intended to replace textbooks already available or in compilation, but merely to make the hydrogeological map maker acquainted with the most relevant concepts and elements of these techniques.

Hydrogeological mapping, i.e. the whole process from data collection, treatment and interpretation to their visualisation and representation, is being optimized by the application of developed computer techniques (Vinken, 1988). The development of powerful hardware with large memory capacity and fast processors, even on personal computers has entailed a proliferation of sophisticated software both for CAD (computer aided design) and GIS (geographic information systems and database management systems). Many software products are currently in use and are continuously refined and adapted to geological and hydrogeological applications.

Applications of computer-based techniques in hydrogeology are manifold, however, the most important advances include the fields of

- data storage, retrieval and management
- data processing and treatment
- visualization and representation.

Among the applications for hydrogeological purposes, numerical calculations, statistical treatment as well as construction of isolines are the most common, in addition to relatively simple drawing programmes.

Powerful storage, retrieval, management, processing and treatment facilities are chiefly needed to handle the continuously growing wealth of hydrogeological data, both site specific (point) as well as areal, and information. These require adequate data bases together with suitable software to organize and manage them, in addition to appropriate tools for interpretation and visualization. They depend on the type of data, whether point or related to a surface area (usually a polygon or a pixel). They may be characterized by a particular set of data and may also have a depth component.

The following chapters will not dwell on the wealth of software existing for the handling of well data (lithological logs, well construction, pump tests, hydraulic parameters). Hence, mainly the concepts and models applying to areal, graphical data, highly important for hydrogeological mapping purposes will be dealt with.

CAD VERSUS GIS

Two main branches of computer related techniques connected with graphical representation can be distinguished, i.e.

- CAD = Computer-aided-design and
- GIS = geo(graphic)-information-system techniques.

They differ fundamentally from each other, since CAD techniques simply are advanced drawing techniques while GIS encompasses the storage, treatment and visualisation of alphanumeric and graphical information usually referred to the earth's surface, hence the coupling of data banks and tools for data treatment and graphic presentation.

CAD IN HYDROGEOLOGY

Numerous software packages of the CAD family (AutoCAD, ISM etc.) are available today. Most of them are running on personal computers equipped with a digitizing tablet and a plotter or printer.

Initially they were developed to show numerical records and calculations graphically, e.g. water level or pumping test records and calculations of transmissivity, storage or leakage from measured data. These relatively mathematical graphic representations are widely used in hydrogeological reports.

Another important and most useful application of CAD facilities is the drawing of borehole sections, e.g. as geological columns or cross-sections of wells. The graphic representation is usually derived from data captured or calculated and generated by a specialised drawing programme using defined standard symbols.

These techniques are also used for the drawing of plans and simple single value maps such as isolines of ion contents, salinity, electrical conductivity and so forth. However, the graphical result of the mathematical calculation usually kriging, has to be critically checked, since the computer considers all point data equal, consistent and homogenous, and no geological background information causing inconsistencies is usually included. The first automatic interpretation may thus lead to a false picture which has to be interactively edited by the hydrogeologist on the basis of his regional expert knowledge.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems are currently, sometimes concurrently, built up by a wealth of organisations and institutions, on local, regional, national and international levels. Although dedicated to serve a wide variety of uses, such as geodetic-cartographical, land use, administrative, geological, pedological, hydrological, etc., and although based on various hardware platforms and using various software packages, they are all based on the same concept: to store real world spatial data in layer-oriented data banks which can be manipulated by software tools to interpret and to model the real world as well as possible. This setup allows interrogating the system, selecting the data available, comparing various interpretation methods and tailoring the output to the user's needs. Therefore, they are excellent tools to support planning and decisions, e.g. on land use. However, they require adequate data bases, i.e. a wealth of consistent data of good quality usually available in industrial countries; and an efficient data management as well as advanced hardware and software installations.

In countries already using such GIS for various applications it is generally planned to connect the branch systems, so as to allow full grasp of all relevant data. The general structure of this overall geo-information system comprising numerous thematic branch information systems is outlined on Figure 24 (Vinken, 1988). It is characterized on the one hand by a steering system comprising registers and catalogues on databases, both data and methods, thesauri and vocabularies and may regulate the access to the data bases. On the other hand are the special branch information systems, e.g. geology, hydrogeology, ecology, vegetation, cartography, composed of data and method areas.

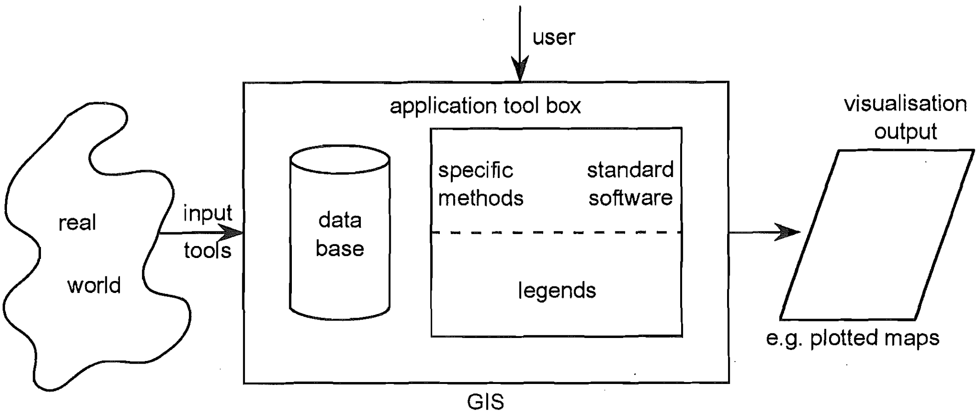


Figure 23. Transformation of real world data by GIS in view of user's needs.

Each information system possesses a data base in which the relevant data (graphical data and attributes) are stored. The data are geographically referenced to allow their overlay and interaction. Geographically referenced data include point data defined by coordinates, straight lines running from one defined point to another, curved lines stored in vector format, as well as areal information based on a regular rectangular raster cutting the whole area into picture elements (= pixel), each pixel having defined characteristics or, finally, sets of polygons or curved lines delimiting defined areas, each of these areas being characterized by an inpoint to couple the attributes of the area.

The toolbox containing the software to manipulate the data is generally built up of

- a branch specific method area (collection of methods, i.e. algorithms permitting adequate mathematical treatment of the thematic data, closely coupled with the specific data base) and

- a general area containing the tools required for data capture, storage management, editing, and graphical or alphanumeric display of data and results.

Part of these software tools is independent of the specific data base and belongs to the commercial standard packages. However, another part may be highly specialized and data base specific, such as standards for graphical representation and specific map legends.

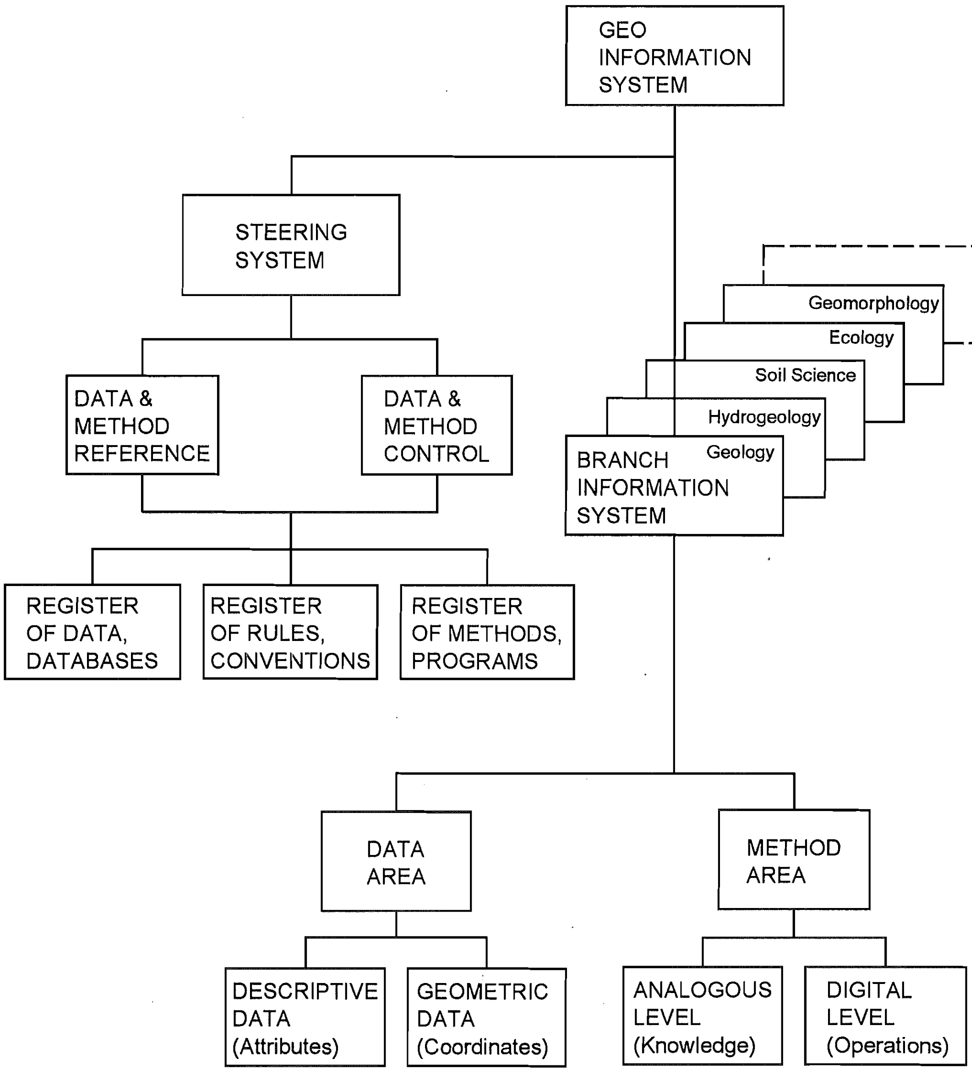


Figure 24. The structure of the geo-information system.

GIS IN HYDROGEOLOGY

Hydro-geo-information systems (HYGIS) are computer based systems to capture, store, edit, manipulate and display geographically referenced hydrological data and information. Hydrogeological data comprise spatial data, measurement (often time dependent) data and descriptive data (attributes) (Figure 25).

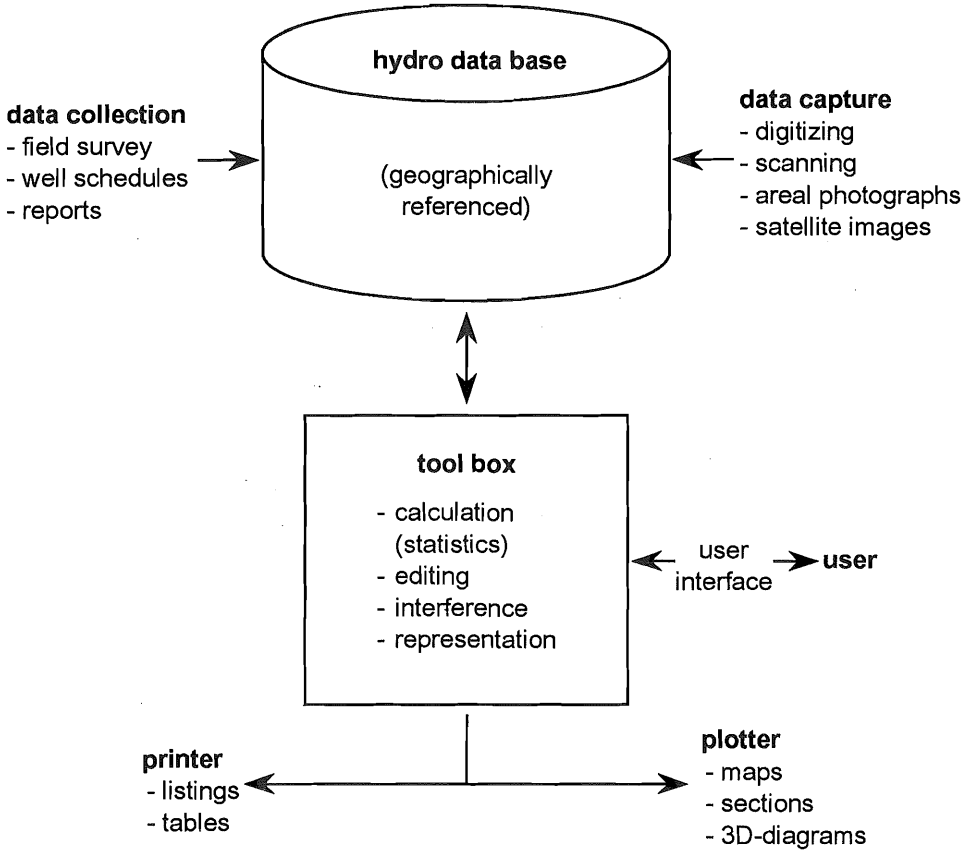


Figure 25. Format of a hydro-geo-information system (HYGIS).

Owing to the complex response of groundwater systems to the prevailing earth systems (geological system, soil system, geomorphological system, landuse system) as well as the climatic and hydrological systems (rainfall, surface water, soil water) and the degree and mode of groundwater withdrawal (man-made systems), hydro-geo-information systems have to deal with the large number of thematic layers which comprise the geosphere, hydrosphere, atmosphere and biosphere.

The HYGIS itself comprises a hydro-data base in which all sorts of hydrogeologically relevant data are stored, as well as a toolbox to manipulate the data and to represent the results; it includes a legend of conventional symbols and colours for aerial map representation. The toolbox usually contains a collection of methods, models and procedures which allow the data to be analysed and processed according to user-specified needs. In current software packages, the most useful components are usually included, such as statistical calculations, overlay and interference, and the most up-to-date two- or semi-three-dimensional representations.

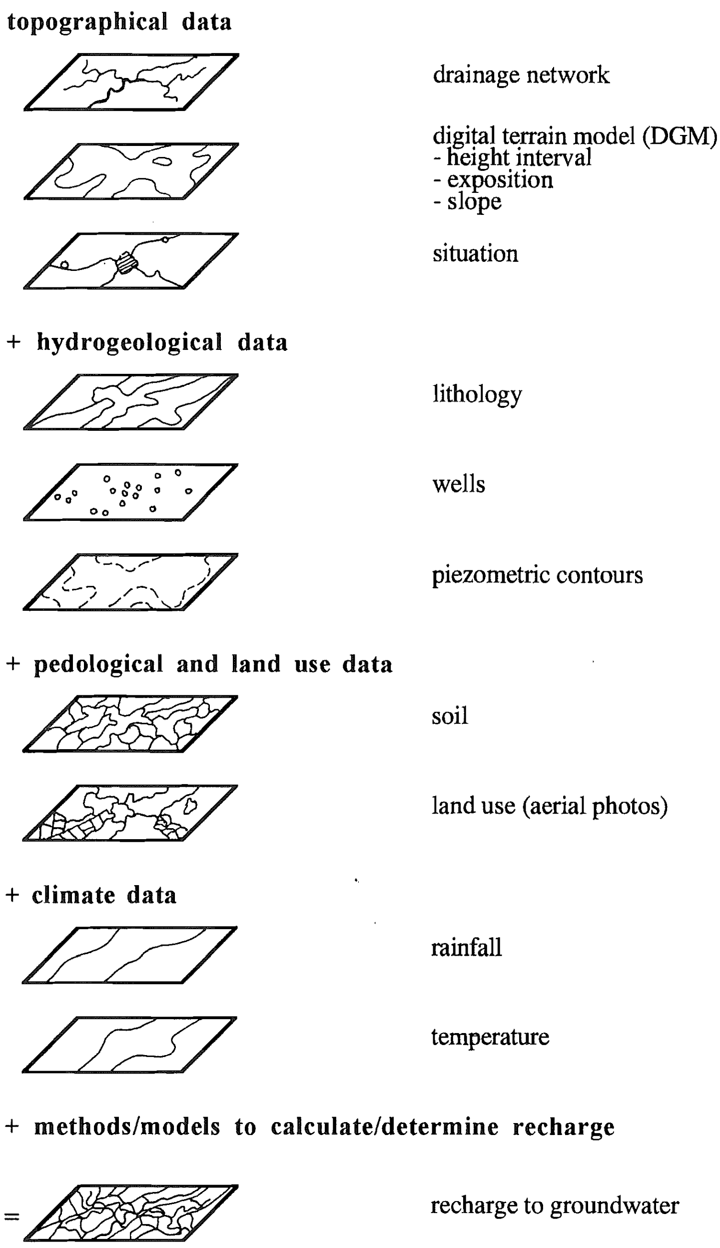


Figure 26. Example using the HYGIS for the determination of recharge.

The data base contains both alpha-numerical and graphical data. The alpha-numerical data usually comprised

- borehole or well data
- chemical analyses
- time series (for water levels, precipitation, chemical analyses, etc.).

Spatial, geographically referenced data in hydro-data bases comprise primarily lithological and soil data as well as the whole range of quantitative (permeability, transmissivity) data and data about the physical and chemical properties of groundwater (temperature, age, pH-value, chemical composition). In addition, topographic data as well as other specific data, e.g. on vegetation, landuse, climate, and administration can be drawn from other branch information systems or must be stored in the hydro-data base, if not available elsewhere.

The layer-oriented structure of a HYGIS is outlined on Figure 26. It shows an example of the procedure to calculate and determine recharge which requires, in addition to the topographic data, areal data on hydrogeology, soils, land use and climate. These thematic data, stored in layers, are linked with the aid of models describing the interdependence of the thematic areal values and leading to the desired result. The resulting recharge layer, after verification, is stored in the HYGIS data base. Hence, it can be used for other calculation and modelling purposes, e.g. water level response to groundwater withdrawal or underground migration of con-taminants.

Up to the present, existing HYGIS constitute advanced professional tools paving the way for more up-to-date consultancy to the customer requiring hydrogeological advice. It is generally not yet possible for hydrogeological laymen to make proper interactive use of the systems. However, the hydrogeologist in close association with the user is able to make full use of the power of the system, as outlined on Figure 27. In this process, the professional hydrogeologist, knowing about the data stored in the hydro-data base, the tools to use and in particular the appropriate graphical output holds a key position comparable to that formerly held by a cartographer. His advice, however, will be more sophisticated and generally more appreciated, since he can use the powerful modelling and visualization possibilities of the HYGIS, to tailor the graphical outputs exactly to the user's needs.

The proliferation of visualization techniques is certainly to be considered among the most useful outcomes of the GIS-techniques. It offers a wide range of complex graphical representations, particularly perspective diagrams, which hitherto required enormous mathematical and technical skills. Within the advanced GIS toolbox it is now readily available to the specialist working with the system. In some systems, the 3D-diagrams can be rotated, to allow perspective views from different angles. In sequence, this produces a movie-like picture.

Properly applied, these new techniques could greatly foster badly needed better comprehension of the various aspects of groundwater issues. The importance of such issues is often underestimated since man does not care about what he cannot see ('out of sight, out of mind'). Thus clear and easily understood graphics are particulárly valuable tools, not just for planners, administrators and engineers, but for the creation of better public awareness of the vital need for the protection of such a precious natural resource.

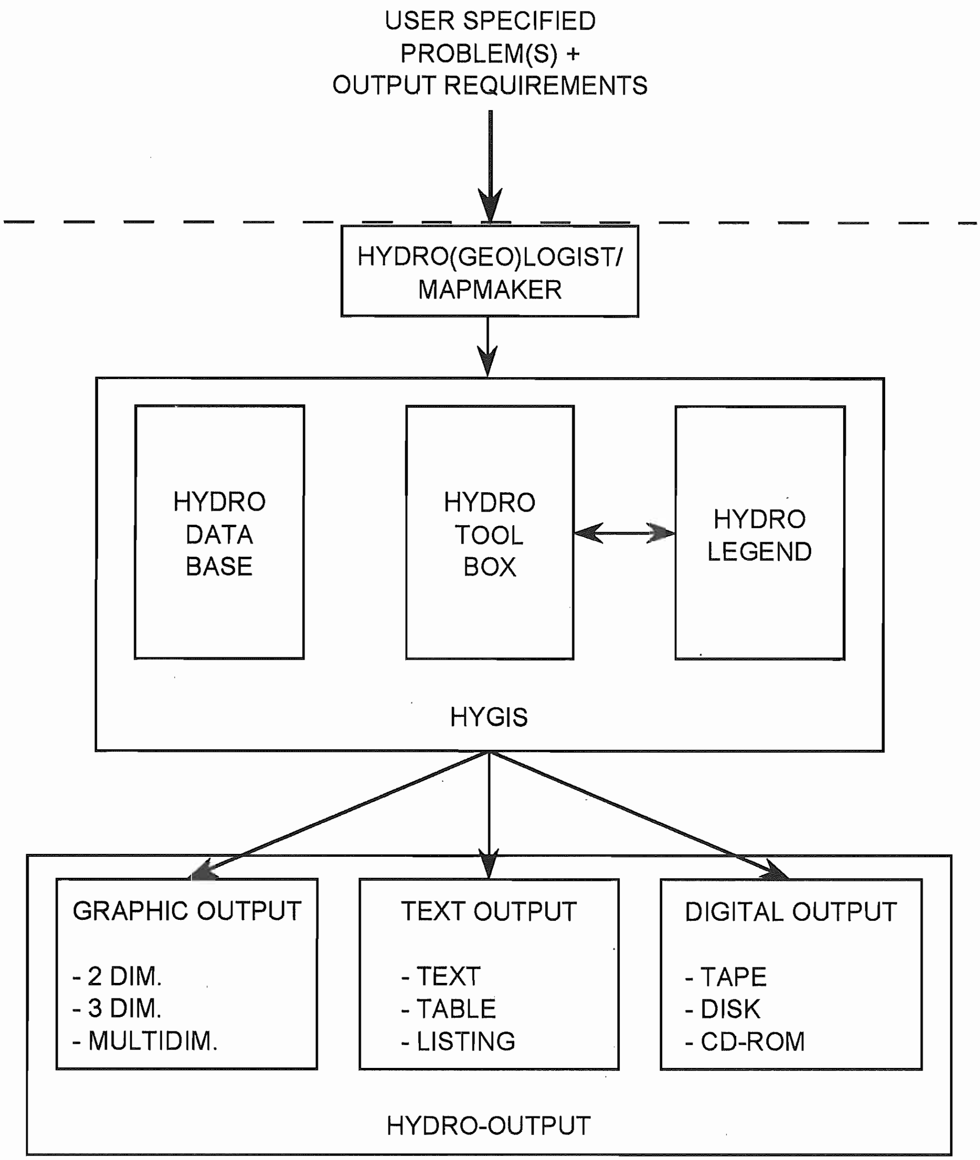


Figure 27. Use of a HYGIS system to tailor outputs to a user's request.

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Annex A

Selected list of hydrogeological maps

Preliminary remark

This list of selected hydrogeological maps contains both continentwide and international as well as national maps at various scales.

The list is not complete but gives an indication of the variety of hydrogeological maps world-wide.

These maps have been brought to the attention of the authors (further information on additional maps to COHYM is appreciated).

A. International and Continental or Regional Hydrogeological Maps

AFRICA

Carte des Ressources en eau souterraine, 1:20000000, UN/TCD, 1987.

Groundwater in Africa, 1:17000000, New York, 1973.

Carte Hydrogéologique Internationale de l' Afrique, 1:5000000, 5 sheets, Alger, 1988-1992.

1:5000000 - scale mapping of the groundwater resource potential of West and Central Africa, Orleans, 1986.

Hydrogeological Map of the Arab region and adjacent areas, 1:5000000, Damascus, 1988.

Water resources map of the Arab Countries, 1:1000000, Damascus, map series, 1982 -.

Carte hydrogéologique des terrains éruptifs et métamorphiques d'Afrique occidentale, 1:2000000, Ouagadougou, Orléans, 1969.

Carte de planification pour l' exploitation des eaux souterraines de l'Afrique sahélienne, 1:1500000, Orleáns, 1975.

Carte de planification des ressources en eau: Côte d' Ivoire, Ghana, Togo, Benin, 1:1000000, Ouagadougou, 1979.

Carte de planification des ressources en eau souterraine, Afrique Soudano-Sahélienne, 1:1500000, Ouagadougou, 1976.

AMERICA

Hydrogeological map of South America, 1:5000000, Rio de Janeiro, 1988.

Hydrogeological Atlas of the Caribbean Islands, UNESCO, 1990.

Hydrogeological map of North America, 1:13333333, 2 sheets, Boulder, 1988/89.

ASIA

International hydrogeological map of South and East Asia, 1:5000000, 1987.

AUSTRALIA and OCEANIA

Hydrogeological Map of Western Australia, 1:2500000, Perth, 1989.

Groundwater resource map, South Australia, 1:2000000, Adelaide, 1982.

Groundwater resources of South Australia, 1:1000000, Adelaide, 1980.

Groundwater resources of Australia, 1:5000000, 4 maps, Canberra, 1975.

Australia. Underground water, 1:5000000, Canberra, 1963.

Hydrogeological Map of 1:5000000, Canberra, 1987.

EUROPE

International hydrogeological map of Europe, 1:1500000, Hannover/ Paris, map series, 1970 -.

Groundwater resources of the European Community, 1:500000, 4 different maps:
(1) Aquifers; (2) Groundwater hydrology; (3) Groundwater abstraction;
(4) Balance of resources, Bruxelles-Luxembourg, 1982-1986.

Groundwater flow map of Central and Eastern Europe, 1:1500000, Moscow, 1983.

B. National Hydrogeological Maps

AFRICA

Algeria

Cartes hydrogéologiques, 1:100000, 1:200000 and 1:1000000, several sheets, Alger, 1973 -.

Carte hydrogéologique du Hoggar et des Tassilis, 1:1000000, Alger, 1990.

Carte hydrogéologique, région de Béchar, 1:500000, Alger 1994.

Benin

Carte des ressources en eau, 1:500000/1:1000000, Ouagadougou, 1978/79.

Carte hydrogéologique du Bénin, 1:500000, Paris, 1985.

Carte hydrogéologique du bassin sédimentaire côtier du Bénin, 1:200000, Paris, 1985.

Botswana

Groundwater Resources of the Republic of Botswana, 1:1000000, Lobatse, 1987.

Hydrogeological reconnaissance map, 1:500000, 11 sheets, Lobatse, 1979-1988.

Groundwater resources map, 1:1000000, Gaborone, 1987.

(United Republic of) Cameroon

Cartes hydrogéologiques, 1:500000 et 1:1000000, 1975.

Carte de planification des ressources en eau, 1:1000000, 1980.

(République) Centrafricaine

Carte de planification des ressources en eau, 1:1500000, 1987.

Chad

Carte hydrogéologique de la République du Tchad, 1:1500000, 1969.

Carte hydrogéologique de reconnaissance de la République du Tchad, 1:500000, 7 sheets, 1963-68.

Djibouti

Carte de reconnaissance des eaux souterraines de la République de Djibouti, 1:300000, Hannover, 1983.

Egypt

Hydrogeological Map of Egypt, 1:2000000, Giza, 1988.

Ethiopia

Hydrogeological map, 1:2000000, Addis Ababa, 1988.

Ghana

Hydrogeological map, 1:1000000, 1972.

Kenya

Groundwater quality map of Kenya, Nairobi, 1973.

Lesotho

Hydrogeological Map of Lesotho, 1:300000, Maseru, 1994.

Madagascar

Hydrogeological Map, 1:500000, 1972.

Mauritania

Carte hydrogéologique du bassin sédimentaire Sud-Ouest Mauritanien, 1:500000, Nouakchott, 1962.

Carte hydrogéologique de la région d'Oumm Dferat-Fort-Gouraud, 1:200000, 1965.

Cartes hydrogéologiques de Faraoun, de Chingetti et d' Atar, 1:200000, 3 sheets, 1966.

Morocco

Cartes hydrogéologiques, 1:200000, 1:500000 and 1:1000000, Rabat, 1960 -.

Carte des Systémes Aquifères du Maroc, 1:1000000, 2 sheets, Rabat, 1976.

Carte hydrogéologique du bassin de Meknès-Fès, 1:100000, Rabat, 1960.

Carte hydrogéologique de la plaine des Triffa, 1:50000, 1966.

Mozambique

Hydrogeological map, 1:1000000, 1987.

Carte hydrogéologique, 1:250000, 1971.

Namibia

Hydrogeochemical maps, 1:1000000, 4 sets, Windhoek, 1978 -.

Niger

Carte de reconnaissance hydrogéologique du Niger sud-oriental, 1:1000000, 1964.

Atlas des eaux souterraines du Niger, 1:500000 à 1:5000000, Niamey, 1979.

Hydrogeologische Karte des Adar Doutchi (Département Tahoua, Republik Niger), 1: 200000, Hannover, 1991.

Atlas hydrogéologique de l' Adar Doutchi, 1:200000, 6 sheets, Paris, 1967.

Senegal

Carte hydrogéologique de la République du Senegal, 1:500000, 4 sheets, Paris, 1980.

Carte hydrogéologique de la presqu'île du Cap Vert, 1:50000, 3 sheets, 1968.

Somalia

Carte hydrogéologique, 1:1000000.

Sudan

Hydrogeological map of Sudan, 1:2000000, Delft, 1989.

Tanzania

Hydrogeological map of Zanzibar, 1:125000, UNDP/New-York, 1987.

Tunisia

Carte des ressources en eau de la Tunisie, 1:500000, 3 sheets, Tunis, 1991.

Carte hydrogéologique de la Tunisie, Sud 1:500000, Tunis 1964.

Cartes des ressources en eau souterraines, 1:200000, several sheets, Tunis, 1965-1972.

Carte hydrogéologique de la Tunisie, 1:50000, different sheets, Tunis, 1951-1960.

Zimbabwe

Zimbabwe regional hydrogeological map, 1:500000, 4 sheets, 1990.

Map showing ground-water provinces of Southern Rhodesia, 1:2000000, Washington, 1964.

AMERICA

Argentina

Mapa hidrogeológico de la Républica Argentina, 1:5000000, Buenos Aires, 1963.

Mapa hidrogeológico de la Républica Argentina, 1:2500000, 2 sheets, Buenos Aires, 1989.

Mapa hidrogeológico de la Républica Argentina, 1:500000, 12 sheets, Buenos Aires.

Brazil

Mapa hidrogeológico do Brazil NA, 1:5000000, Rio de Janeiro, 1983.

Canada

Major hydrogeological maps of provinces and regions, often at the scale of 1:7603000, Ottawa, 1967 -.

Hydrogeological maps, 1:500000, for different regions of Alberta, Edmonton, 1978 -.

Groundwater map of the Calgary district, 1:50000, Alberta, 1961.

The hydrogeological reconnaissance maps of Alberta, Edmonton, 1977.

Chile

Hydrogeological map of Chile, 1:250000, Santiago de Chile, 1990.

Colombia

Mapa hidrogeológico de Colombia, 1:2500000, Bogota, 1989.

Costa Rica

Mapa hidrogeológico del valle central de Costa Rica, 1:50000, Wallingford (BGS), 1985.

Ecuador

Hydrogeological map of Ecuador, 1:1000000, Quito, 1983.

Haiti

Carte hydrogéologique, République d'Haïti, 1:250000, UNDP/New York, 1990.

Nicaragua

Mapa hydrogeológico de la Républica de Nicaragua, 1:250000.

United States of America

National atlas of the USA. Productive aquifers and withdrawals from wells, 1:7500000, Washington, 1970.

Many hydrogeological maps at different scales (1:62500 to 1:3168000), of states or regions, Washington, 1960 -.

Hydrologic investigation atlas HA, 1:750 000 and 1:1000000, several sheets, Reston, 1990.

Venezuela

Mapa de posibilidades de abastecimiento de aguas subterráneas en Venezuela, 1.200000, Caracas, 1969.

Mapa hidrogeológico de Venezuela, 1:500000, atlas of 13 sheets, Caracas, 1972.

ASIA

Afghanistan

Hydrogeological map of Afghanistan, 1:2000000, Kabul, 1977.

Cambodia

Carte d' orientation des recherches d'eau souterraine du Cambodge, 1:500000, 1967.

China

Hydrogeologic Atlas of the Peoples Republic of China, Peking.

Hydrogeologic Map of China, 1:4000000, Beijing, 1987.

Hydrogeological Map of Jiangsu Province, 1:500000, 1980.

Hydrogeologische Karte der Provinz Anhui, 1:500000, Beijing, 1977.

India

Hydrogeological map of India, 1:5000000, Calcutta, 1976.

Hydrogeological map of India, 1:2000000, Madras, 1969.

Indonesia

Hydrogeological map of Indonesia, 1:2500000, two sheets, Bandung, 1983.

Peta hidrogeologi Indonesia, 1:250000, several sheets, Bandung, 1981 -.

Tentative hydrogeologic map of the Island of Lombok, 1:400000, Hannover, 1972.

Reconnaissance hydrogeological map of Bali, 1:250000, Jakarta, 1972.

Iran

Water resources atlas of Iran, 1:1000000, Teheran, 1988.

Israel

Groundwater Atlas of Israel, 1:500000, Jerusalem, 1979.

Japan

Hydrogeological map of Japan, 1:2000000, Kawasaki-Shi, 1964.

Hydrogeological map of the southern Yonezawa Basin, Yamagata prefecture, 1:25000, 1993.

Jordan

Map of ground water provinces, surface extent of aquifer systems and aquitards, and distribution of available ground water, 1:1000000, Amman, 1988.

(Republic of) Korea

Hydrogeological map of the Anseong River Basin, 1:40000, 1969.

Lebanon

Carte hydrogéologique du Liban, 1:200000, UNDP/New-York, 1967.

Malaysia

Peta hidrogeologi semenanjung Malaysia, 1:500000, Ipoh, 1975.

Mongolia

Hydrogeological map of Mongolia, 1:1500000, Moscow, 1971.

Hydrogeological map of Mongolia, 1:1000000 Khlan-Bator (in compilation).

Pakistan

Hydrogeological map of Pakistan, 1:2000000, Lahore & Islamabad, 1989.

Hydrogeological map of Pakistan, 1:500000, Islamabad, 1991.

Philippines

Hydrogeologic map of Central Luzon, Philippines, 1:600000, Manila, 1970.

Sri Lanka

Groundwater data and geological characteristics, 1:2000000, Colombo, 1970.

Syria

Schematic map of the first below the surface water bearing formation of Syria, 1:1000000, Moscow-Damascus, 1964.

Taiwan

Hydrogeological map of Taiwan, 1:250000, Tai-peh, 1968.

Thailand

Hydrogeological map of Thailand, 1:1000000, 2 sheets, Bangkok, 1983.

Hydrogeological map of Southern Thailand, 1:500000, 2 sheets, Bangkok, 1983.

Hydrogeological map of Northern Thailand, 1:500000, 2 sheets, Bangkok, 1982.

Hydrogeological map of western lower Central and eastern Thailand, 2 sheets, Bangkok, 1978.

Hydrogeological map of northeastern Thailand, 1:500000, 2 sheets, Bangkok, 1975.

(Republic of) Yemen

Hydrogeological map, 1:100000, Sana, 1992.

AUSTRALIA and OCEANIA

Australia

Groundwater resources of Queensland, 1:2500000, Brisbane, 1971.

Preliminary shallow groundwater salinity map of the Murray Basin, 1:1000000, Canberra, 1988.

Groundwater resources of Victoria, 1:1000000, Melbourne, 1982.

Hydrogeology of the Lake Amadeus-Ayers Rock region, Northern Territory, 1:500000, Canberra, 1988.

Hydrogeological map of Bendigo and part of Deniliquin, 1:250000, Melbourne, 1985.

Hydrogeological map of Ballarat, 1:250000, Canberra, 1986.

Northern Territory 1:250000 hydrogeological series, Darwin, 1979.

Perenjori Hydrogeology, 1:250000, Perth, 1988.

Hydrogeology of the Australian Capital territory and environs, 1:100000, Canberra, 1984.

Hydrogeological map of Western Port Basin, 1:100000, Melbourne, 1980.

Fiji

Hydrogeological map of Viti Levu, 1:250000, New York, 1974.

Tonga

Grundwasser-Karte der Insel Tongapu, 1:300000, Hannover, 1972.

EUROPE

Albania

Hydrogeological map of PSR of Albania, 1:200000, 3 sheets, 1985.

Austria

Hydrogeologische Karte der Republik Österreich, 1:1000000, Wien, 1969.

Übersichtskarte der Mineral- und Heilquellen in Östereich, 1:500000, Wien, 1966.

Hydrogeologische Karte von Oberösterreich, 1:250000, Linz, 1973.

Grundwasserkarte von Kärnten, 1:200000, Klagenfurt, 1987.

Grundwasserkarte von Tirol, 1:200000, Innsbruck, 1977.

Belgium

Hydrogeologie I und II, 1:500000, in: Atlas de Belgique, Bruxelles, 1964.

Carte hydrogéologique du Tournaisis (calcaire carbonifère), 1:50000, Bruxelles, 1970.

Bulgaria

Atlas Narodna Republika Bulgaria. Chidrogeolozka Harta, 1:1500000, Sofija, 1973.

Map of mineral waters of Bulgaria, 1:800000, Sofia, 1967.

Cyprus

Hydrogeological map of Cyprus, 1:250000, Nicosia, 1970.

Groundwater quality map of the Nicosia-Lanarca-Limassol region (Cyprus), 1:100000, 3 maps, Nicosia, 1985.

former Czechoslovakia

Mapa odtoku podzemni vodu CSSR, 1:1000000, Praha, 1981.

Hydrogeological map of Czechoslovakia, 1:1000000, Praha, 1964.

Preskúmanost' hydrogeologickych rajónov CSSR, 1:500000, Bratislava, 1986.

Map of mineral waters in Czechoslovakia, 1:500000, Praha, 1985.

Karte des natürlichen Grundwasserschutzes in Böhmen und Mähren, 1:500000, 1968.

Mapa vyuzitelnych zásob podzemnych vod Slovenska SR, Bratislava, 1988.

Hydrogeologischer Atlas für Böhmen und Mähren, 1:200000, 2 Karten, 1975.

Hydrogeological map of the Czech Republic, 1:50000, several sheets, Praha, 1990 -.

France

National maps and map series

Carte hydrogéologique de la France. Systémes aquifères, 1:1500000, Orléans, 1980.

Utilisation de pompes à chaleur sur eaux de surface ou aquifères superficiels, 1:1000000, Orléans, 1979.

Carte de la qualité chimique des eaux souterraines de la France, 1:1000000, Paris-Orléans, 1977.

Carte des eaux minérales et thermales de la France, 1:1000000, Orléans, 1973.

Carte du coût moyen du captage et de l'exploitation de l'eau souterraine en France, 1:1000000, Paris, 1971.

Atlas des eaux souterraines de la France, 1:1000000, Paris-Orléans, 1970.

Carte de vulnérabilité à la pollution des nappes d'eau souterraine de la France, 1:1000000, Orléans, 1970.

Carte et catalogue des principaux systémes aquifères du territoire français, 1:1000000, Orléans, 1970.

Carte de débit moyen des nappes d'eau souterraine de la France, 1:1000000, Orléans, 1970.

Carte des nappes d'eau souterraine de la France, 1:1000000, Orléans-Paris, 1965.

Atlas des bassins de la Seine et les cours d'eau Normands, 1:500000, 6 maps, Paris, 1972.

Zonage des productivités probables des ouvrages d'exploitation des eaux souterraines, aquifères superficiels, aquifères captifs, 1:500000, 2 maps, Orléans, 1977.

Atlas hydrogéologique de la Beauce, 1:250000, Orléans, 1975.

Carte hydrogéologique du Languedoc-Roussillon, 1:200000, several sheets, Montpellier/Orléans, 1972-1979.

Carte hydrogéologiques départementales, 1:100000 à 1:200000, several sheets, 1976-1987.

Carte de la nature chimique des eaux souterraines, 1:100000, 18 sheets, Lyon, 1967.

Carte hydrogéologique de la France, 1:50000, Orléans, 27 sheets, 1964-1980.

Atlas hydrogéologique du Languedoc-Roussillon, 1:50000, 6 sheets, Montpellier, 1969-1973.

Maps of specific areas

Atlas des ressources du sous-sol par département (planches "eaux souterraines"), 1:500000, Orléans, 1974. Coût d'exploitation de l'eau souterraine dans la région Languedoc-Roussillon, 1:500000, Montpellier-Orléans, 1978.

Carte hydrogéologique du bassin Rhin-Meuse, 1:500000, Moulin-lès-Metz, 1975.

Carte hydrogéologique du bassin de Paris, 1:500000, 2 sheets, Orléans, 1967.

Carte des systèmes aquifères de la région Languedoc-Roussillon, 1:250000, Montpellier, 1985.

Carte de vulnérabilité des eaux souterraines à la pollution de la région Franche-Comté, 1:250000, Orleáns, 1987.

Atlas des nappes aquifères de la région parisienne, 1:200000, Paris, 1970.

Carte d'aptitude à l'implantation de pompes à chaleur, carte de synthèse Ile-de-France, 1:150000, Paris, 1986.

Carte hydrogéologique de la France. Région karstique nordmontpelliéraine, 1:80000, Paris, 1964.

Carte de vulnérabilité des eaux souterraines à la pollution, 1:50000, feuille Chambéry (Savoie), Orléans, 1984.

Utilisation des nappes d'eau souterraine comme source froide des pompes à chaleur dans les régions bastiaise et ajacienne, 1:50000, Bastia, 1986.

Exploitation thermique des aquifères superficiels sur le territoire de la Communauté urbaine de Bordeaux, 1:25000, Bordeaux, 1986.

Utilisation thermique de la nappe phréatique d'Alsace au niveau de Strasbourg, 1:10000, Strasbourg, 1982.

Germany, Federal Republic of (inclusive former GDR)

National maps and map series

Grundwasservorkommen von Deutschland, 1 : 1000000, 3 maps (Ergiebigkeit, Qualität, Verschmutzungsempfindlichkeit), Berlin, 1993.

Grundwasservorkommen in der Bundesrepublik Deutschland, 1:1000000, 3 maps (Ergiebigkeit, Qualität, Verschmutzungsempfindlichkeit), Bonn, 1980.

Hydrogeologischer Atlas der Bundesrepublik Deutschland, 1:1000000, Bonn-Bad Godesberg, 1978.

Hydrogeologische Übersichtskarte, 1:500000, 14 sheets, Remagen, 1952-1957.

Hydrogeologische Übersichtskarte von Sachsen, 1:400000, Freiberg, 1992.

Hydrogeologisches Kartenwerk Hessen, 1:300000, 5 Karten, Wiesbaden, 1991.

Geowissenschaftliche Karte des Naturraumpotentials von Niedersachsen und Bremen, 1:200000, 12 sheets, Hannover, 1981.

Hydrogeologische Übersichtskarte der DDR, 1:200000, 4 maps, Berlin, 1963-1971.

Hydrogeologische Karte von Nordrhein-Westfalen, 1:100000, several sheets, Krefeld.

Hydrogeologisches Kartenwerk Hessisches Ried und Untermain, 1:100000, Wiesbaden, 1981-1983.

Umweltatlas Berlin, 1:50000, Berlin, 1987.

Hydrogeologisches Kartenwerk der DDR, 1:50000, 190 sheets, 4 maps each, Berlin, 1979 - 1984.

Hydrogeologische Karte von Bayern, 1:50000, several sheets.

Hydrogeologische Karte von Nordrhein-Westfalen, 1:50000, several sheets, Krefeld, 1984 -.

Hydrogeologische Karte von Nordrhein-Westfalen, 1:25000, 3 maps.

Grundwasserkarte von Bayern, 1:25000/1:50000, 7 maps, 1965.

Maps of specific areas

Karte der Verschmutzungsgefährdung der Grundwasservorkommen in Nordrhein-Westfalen, 1:500000, Krefeld, 1973.

Karte der Grundwasserlandschaften in Nordrhein-Westfalen, 1:500000, Krefeld, 1973.

Hydrogeologische Übersichtskarte des Münsterländer Beckens, 1:500000, Düsseldorf, 1990.

Hydrogeologie Schleswig-Holstein, 1:500000, Hannover, 1973.

Übersichtskarte der Grundwasserergiebigkeit, der Grundwasserbeschaffenheit und der Verschmutzungsempfindlichkeit des Grundwassers in Hessen, 1:300000, Wiesbaden, 1985.

Übersichtskarte der hydrogeologischen Einheiten grundwasserleitender Gesteine in Hessen, 1:300000, Wiesbaden, 1991.

Karte der Grundwasserbeschaffenheit in Hessen, 1:300000, Wiesbaden, 1966.

Stadtkarte Hannover, 1:200000, Baugrundkarte, Ausgabe C: Grundwasser, Hannover, 1980.

Hydrogeologische Karte von Baden-Württemberg, 1:50000, Stuttgart, Wiesbaden, Mainz, 1980.

Hydrogeologische Übersichtskarte des Raumes Hamburg (Tertiär), 1:50000, 1976.

Hydrogeologische Übersichtskarte des Elbtales von Hamburg, 1:50000.

Hydrogeologische Karte von Schleswig-Holstein, 1:50000.

Hydrogeologische Karte des Kreises Paderborn und angrenzender Gebiete, 1:50000, 1972.

Hydrogeologische Karte des Warsteiner Massenkalk-Gebietes, 1:50000, 1974.

Karten der Gefährdung der Grundwässer in Bayern durch Nitrat, München, 1987.

Hydrogeologische Karte des Rheinisch-Westfälischen Steinkohlenbezirkes, 1:10000, Bochum.

Greece

Hydrogeological map of Greece, 1:1000000, Athens, 1970.

Geotectonic-hydrogeological map Megalopolis-Dimitsana area, 1:50000, Athens, 1988.

Hydrogeological map of Greece, 1:50000, several sheets, 1971-1987.

Hungary

Groundwater map of the Great Hungarian Plain, 1:200000, Budapest, 1961.

Magydrorszàg Vizfoldtani Atlasza, 71 sheets, 1:1000000 to 1:100000, (Atlas hydrogéologique de Hongrie), Budapest, 1939.

Borsod es Környekenek vizföldtani atlasza, 1:150000 and 1:300000, Budapest, 1978.

Italy

Schema idrogeologico dell'Italia centrale, 1:500000, 2 sheets, Roma, 1987.

Schema idrogeologico dell'Appennino Carbonatico Centro-Meridionale, 1:400000, Napoli, 1979.

Schema idrogeologico della Campania, 1:500000, Napoli, 1974.

Carte idrogeologica della Sicilia occidentale, 1:200000, Roma, 1972.

Carta idrogeologica del vallo di Diano, 1:100000, Napoli, 1969.

Carta idrogeologica del' alto bacino del Liri, 1:80000, Roma, 1969.

Carta idrogeologica della Campania nord-occidentale, 1:100000, 2 maps, Palerme, 1973.

Hydrogeologische Karte Italiens, 1:50000, sheet Mistretta, Catania.

Carta idrogeologica del massicio del Terminio-Tuoro (Campania), 1:50000, Napoli, 1969.

Carta idrogeologica dell' alta pianura dell' Adige, 1:30000, Padova, 1989.

Luxembourg

Carte hydrogéologique Beaufort, 1:200000, Luxembourg, 1980-1981.

The Netherlands

Provisional map of the (ground) water flow systems in the Netherlands, 1:600000, 1988.

Hydrological map of the Netherlands, 1:1500000, Delft, 1972.

Grondwaterkaart van Nederland, 1:50000, Delft, 1970.

Poland

Mapa hydrogeologiczna Polski, 1:1000000, Warszawa, 1970.

Atlas of the geothermal water of Polish lowland: Early Jurassic and Early Cretaceous reservoirs, 1:500000/1:1000000, Krakow, 1990.

Karte über den Schutz der wichtigsten Grundwasservorkommen von Polen, 1:500000, Krakow, 1988.

Map of mineral waters of Poland, 1:500000, Warszawa, 1974.

Hydrogeological Map of Poland, 1:200000, 1967 -.

Hydrogeological Map of Wojewodschaft Olsztyn, 1:100000, 1967.

Portugal

Carta hidrogeólogica de Portugal, 1:1000000, Lisboa, 1970.

Carta hidrogeológica do Sul de Portugal, 1:200000, Lisboa, 1989.

Carta hidrogeológica de Portugal, 1:200000, Lisboa, 1986.

Romania

Apele Subterane (Atlasul Republicii Socialiste Romanis), 1:1500000, Bucuresti, 1975.

Carte Hydrogéologique, 1:1000000, in: Atlas Géologique de la République Socialiste de Roumanie, Bucarest, 1969.

The hydrogeological map of Romania, 1:1000000, 1975.

Karte der hydrogeologischen Rayonierung, 1:100000, Blatt Birlad, 1965.

Harta hidrogeologica, 1:100000, several sheets, 1968 -.

Spain

Mapa de Sintesis de Sistemas Acuiferos de España Peninsular, Baleares y Canarias, 1:1660000, Madrid, 1971.

Unidades hidrogeológicas de la España peninsular e islas Baleares, 1:1000000, Madrid, 1990.

Mapa hidrogeológico de España, 1:1000000, Madrid, 1985.

Mapa hidrogeológico nacional, 1:1000000, Madrid, 1972.

Mapa de vulnerabilidad a la contaminacion de la España Peninsular, Baleares y Canarias, 1:1000000, Madrid, 1972.

Carte hydrogéologique de reconnaissance de l'Espagne, des Baléares et des Canaries, 1:1000000, Madrid, 1971.

Mapa hidrogeológico de España, 1:500000, Madrid.

Mapa hidrogeológico de España, 1:200000, Madrid.

Sweden

Hydrogeological maps, 1:250000, Uppsala, 1981 -.

Hydrogeological map of Sweden, 1:50000, several sheets, Stockholm, 1974 -.

Switzerland

Hydrogeologie, 1:500000, in: Atlas der Schweiz, Wabern-Bern, 1965-1978.

Carte hydrogéologique de la Suisse, 1:200000, 1965.

Hydrogeologische Karte der Schweiz, 1:100000, several sheets, 1972 -.

Carte hydrogéologique du Canton de Neuchâtel,1:50 000, Neuchâtel, 1973.

Carta idrogeologica del Cantone Ticino, 1:25000, 1974 -.

Hydrogeologische Karte Emmental, 1:25000, 3 Blätter, Bern, 1980.

Turkey

Hydrogeological map of Turkey, 1:1500000, 2 sheets, Ankara, 1971.

Hydrogeological map of Turkey, 1:500000, 18 sheets, Ankara, 1967 -.

Map of mineral and thermal waters of Turkey. Aegean region, Ankara, 1983.

Hydrogeological map of Turkey, 1:200000, several sheets, 1967-1974.

Hydrogeological map of Acigöl basin, 1:100000, 1967.

former Union of Soviet Socialist Republics

Atlas of Hydrogeological Maps, 1970.

Karta gidrogeologiceskich struktur USSR, 1:10000000, Leningrad, 1974.

Hydrochemical map of the USSR, 1:10000000, Moscow, 1982.

Map of mineral groundwaters of the USSR, 1:7500000, 1960.

Hydrogeological map of the USSR, 1:5000000, 18 sheets, Leningrad, 1963.

Map of the USSR groundwater discharge in percentage of total river flow and ground discharge coefficient in percentage of precipitation, 1:5000000, Moscow, 1964.

Hydrochemical map of the USSR, 1:5000000, Moscow, 1966.

Map of groundwater flow of the USSR (zone of active exchange between different waters), 1:5000000, Moscow, 1965.

Map of predicted resources and safe-yield of basic types of mineral waters of the USSR, 1:5000000, Moscow, 1984.

Map of mineral medicinal waters of the USSR, 1:4000000, Moscow, 1968.

Map of mineral groundwaters of the USSR, 1:4000000, Moscow, 1969.

Hydrogeological map of the USSR, 1:2500000, Moscow, 1969.

Hydrochemical map of the USSR, 1:2500000, Leningrad, 1976.

Map of the mineral groundwater of the USSR, 1:2000000, Moscow, 1967.

Map of the groundwater in the European part of the USSR, 1:1500000, Moscow-Leningrad, 1958.

Gidrogeologiceskaja karta Kemerovskoj oblasti u Altajskogo kraja, 1:1000000, Moskva, 1972.

National hydrogeological map of the USSR, 1:200000, several sheets, Moscow, 1985.

United Kingdom

Hydrogeological map of England and Wales, 1:625000, London, 1977.

Hydrogeological map of Scotland, 1:625000, London, 1988.

Hydrogeological map of North and East Lincolnshire, 1:126720, London, 1967.

Hydrogeological map of the Chalk and Lower Greensand of Kent, 1:126720, 2 sheets, London, 1970.

Hydrogeological map of of Northern East Anglia, 1:125000, 2 sheets, London, 1976.

Hydrogeological map of Southern East Anglia, 1:125000, London, 1981.

Hydrogeological map of the area between Cambridge and Maidenhead, 1:100000, London, 1984.

Hydrogeological map of the Dartford (Kent) district, 1:63360, London, 1968.

Hydrogeological map of the Carnmenellis Granite, 1:50000, London, 1989.

Hydrogeological map of Jersey, 1:25000, London, 1992.

former Yugoslavia

The Basis of the Hydrogeological Map of the Dinaric Karst, 1:500000, Zagreb, 1974.

Hidrogeoloska karta slivnog podrucja gornje Tare uzvodno od Mojkovca, 1:500000, Titograd, 1974.

Hidrogeoloska karta Jugoslavije, 1:500000, Beograd, 1976.

Hydrogeological map of Yugoslavia, 1:500000, Belgrade, 1980.

Carte hydrogéologique de la Serbie, 1:500000, Belgrade, 1957.

Osnovna hidrogeoloska karta lista Vrsac, 1.100000, Beograd, 1965.

Hidrogeoloska karta sliva rijeke Save, 1:200000, atlas of several sheets, Zagreb, 1969.

Hidrogeoloska karta Hrvatske, 1:200000, 12 sheets, Zagreb, 1976-1994.

Hidrogeoloska karta (of a general type and mostly accompanied a hydrochemical map) 1:100000 or 1:200000, at least one sheet for each of 53 regional hydrogeological studies, 1959-1984.

Hidrogeoloska karta vodnog podrucja slivova Drave i Dunava u Hrvatskoj, 1:200000, Zagreb, 1986.

Hidrogeoloska karta, 1:100000 (Dalmatian drainage areas within Croatia), 7 sheets, Zagreb, 1976-1994.

Osnovna hidrogeoloska karta Jugoslavije, 1:100000, several sheets, 1985-1991.

Osnovna hidrogeoloska karta Hrvatske, 1:100000, 5 sheets, Zagreb, 1994.

Osnovna hidrogeoloska karta, List Tuzla 1, 1:50000, Zagreb, 1961.

Annex B

Documentation form for hydrogeological maps

A. Regular map coverage (Systematic hydrogeological maps)

1. Continent / country
2. Title of the map series
3. Scale of map
4. Part of national earth science map system or atlas
5. Format of map sheet
6. Average area covered by one map sheet (km^2)
7. Date of publication of first sheet
8. Date of publication of last sheet
9. Number of published sheets
10. Total number of sheets of the series
11. Description of inset maps (theme, scale) or other representations on the sheet margin
12. Explanatory Notes to map sheets: number of published notes
13. General legend for the map series (if available), with citation
14. General explanatory note for the whole map series, with citation
15. Author(s), Institution(s) and Editor(s) of map sheet, with addresses
16. Sales agency, with address
17. Sheet index showing the recent state of preparation of map sheets (published, edited, in preparation)
18. Price (at stated date)
19. Coordinates of the map cornerpoints

B. Single hydrogeological maps

1. Continent / country
2. Title (heading and sub-headings)
3. Author(s)
4. Date reference (contents of map)
5. Date of publication
6. Scale
7. Format, size
8. Representation: one or several sheets
9. Area covered by map sheet (km^2)
10. Co-ordinates of map sheet cornerpoints
11. Type of map (General, specialized ...)
12. if the map forms part of an atlas: citation of the atlas
13. Description of inset maps (theme, scale) and other representations on the sheet margin (cross-sections, graphics, etc.)
14. Explanatory Notes: - Authors - Publication year - Number of pages - Complete citation
15. Author and institution, with address
16. Editor, with address
17. Sales agency, with address
18. Outline map showing the map area
19. Citation of publication
20. Price

Annex C

Criteria for classification of hydrogeological maps

I. after content:

- water data (water parameters, physical properties, chemistry)
- hydrogeological data (hydro-lithology, rock parameters, recharge)
- quantitative data
- qualitative data
- field data
- treated field data (interpolated, grouped)
- derived data
- modelled data
- interpretations, assessments
- facts, data, numerical values
- information (interpretations, selections)
- synthetic
- analytic

II. after purpose:

- general or multi-purpose:
    - part of earth science mapping concept
- special purpose:
    - scientific
    - education
    - planning
    - administration
    - construction
    - management
    - conservation
    - protection

III. after target group:

- professional in hydrogeology:
    - experienced hydrogeologists
    - young hydrogeologists
    - consultant (project)
    - land survey (government)
- non-professional in hydrogeology:
    - earth scientists (geologists, hydrologists, geographers)
    - technicians
    - engineers
    - planners
    - administrators
    - teachers
    - public (farmers, customers)

IV. after reliability:

- certain, reliable
- assessed, inferred, relatively reliable
- estimated, inferred, relatively unreliable
- unreliable

V. after amount of data or information:

- abundant
- numerous
- sufficient
- small, scarce
- no

VI. after area covered:

- town, community
- district, subregion
- country
- region
- part of continent
- continent

VII. after scale:

- large (1: 5 000 to 1: 100 000)
- medium (1: 100 000 to 1: 500 000)
- small (1: 500 000 to 1: 5 000 000)
- very small (1: 5 000 000 and smaller)

VIII. after representation:

- graphics:
    - point symbols
    - linear symbols
    - area symbols (patterns, ornaments)

- complexity:
    - one element
    - two elements
    - three elements
    - more than three elements

- degree of abstraction:
    - detailed, realistic
    - schematic
    - overview

IX. after technical format:

- black and white
- coloured
- hand-drawn (manuscript, heliographed)
- drawn by draughtsman
- computer-plotted
- printed

X. after cost:

- cheap
- expensive

XI. after accessibility:

- published
- available in reports
- unpublished, but open file
- restricted for internal use
- secret

XII. after form:

- part of a map series
- part of an atlas
- single sheet
- annex of a report
- rectangular cutting
- "island" map

Part II

A STANDARD LEGEND FOR HYDROGEOLOGICAL MAPS

Introduction

From the first part of this volume it is clear that a single standard legend cannot serve all types of hydrogeological maps and map users. However, a legend proposing certain recommended standards for representation is considered useful, since it contains both a catalogue of signs, symbols, ornaments and colours as well as an explanation of their meanings, significance and definitions. This Standard Legend, therefore, should be regarded as a toolbox, rather than an exhaustive and complete list of colours and symbols binding hydrogeological map authors. It is by no means recommended to use all elements of this Legend on a single map. However, a skillful selection has to be made, to find the right balance between the content and the format of the map. Thus the Legend constitutes a common graphic 'alphabet', but not a unique cartographic programme.

The Legend adds to a number of specialized legends for various purposes which are recommended internationally, e.g.

- Legend for geohydrochemical maps (UNESCO, 1975)
- Speleological conventional signs (ISU, 1978)
- Legend for groundwater vulnerability maps (IAH, 1994).

The above does not take into account the wealth of existing instructions and legends for regional or national use only.

The present Standard Legend is based upon its forerunners (1970, 1983) which have been applied successfully in all parts of the world, chiefly at small and medium scales (from 1:5000000 to 1:200000) but also at large scales. For some maps it has been amended and modified.

The overall setting of this Standard Legend includes three modular sections which are as much as possible interchangeable and complementary to each other, depending upon the type of map chosen:

- Section I: General and special purpose hydrogeological maps
- Section II: Maps of groundwater flow systems
- Section III: Groundwater vulnerability maps.

In its structure and semantics this Legend is generally consistent, and its principles are known to many hydrogeologists and map users worldwide. In its many applications it has shown great flexibility and usefulness in various climatic and hydrogeological environments. Moreover, it can be used for simple special maps as well as for comprehensive general purpose maps.

As the Legend is both a reasonably complete catalogue of graphical elements and a cartographic language, it forms a basis for communication with the cartographer as well as with the map user. Therefore some technical cartographic details as well as three languages for explanation (English, French, German) have been used. The colour definition refers to the ITC Colour standard (ITC, 1983).

A suitable topographic base forms the background of any hydrogeological map. However, it is not explained in detail in this Legend, except for the drainage pattern which is expanded under Section I D 1.

Definitions

Certain terms are used rather loosely in both hydrogeology and cartography, and it is easy for misunderstandings to arise. A short list of definitions is here included which refers to the usage for this Legend.

Sign: a sign may consist of a symbol, a line, or an ornament, or a combination of any or all of these.

Symbol: a single graphical representation to denote the presence of a particular feature at a point location on the map, e.g. a small circle to show the location of a well. This includes also letters or figures to indicate hydrogeological or geological information.

Line: a solid or broken line may be used either to delimit an area (such as an aquifer outcrop), or to join points of equal altitude (contour), equal thickness (isopachyte), or similar parameters or variables.

Ornament: a pattern of marks, lines or other symbols denoting the occurrence of a particular feature within an area of ground as represented upon the map; e.g. a stipple to represent sandy strata.

Colour: a colour refers to an even "wash" of constant tone; it may be used for lines, symbols or ornaments as well as for emphasising areas of importance.

Tone: screens may be used in order to reduce the density of a colour. The value of the tone is usually expressed as a percentage of the original or full (100 %) colour.

The format of the three sections always includes modules for background, mostly topographical information (A), the main areal theme represented by colour (B), and/or ornament (C), and finally the symbols representing detailed information and data (D).

Within these groups, colours, ornaments and symbols are used logically and consistently, to optimise clarity and facilitate expansion, amendment and modification of the Legend. Such representational methodology produces excellent results, by displaying a wealth of hydrogeological information. From a few meters, one can quickly and easily grasp the areal information on the type and characteristics of hydrogeological units, while much interesting detail becomes apparent only when studying the map closely.

A couple of general remarks and explanations are made here, to explain the coherent philosophy of these thematic maps and to properly introduce the following sections.

Background topographical information (A)

The background information should lead to easy interpretation of the map. It goes without saying that all background information should be represented in the most up-to-date form. A hydrogeological map printed on an antiquated topographical base map will be obsolete immediately as no map user will find it acceptable.

In cartography, particular emphasis is placed on the geographic names (typonomy), such as rivers, mountains, cities, which are carefully drawn in different letter fonts and printed in different colours.

On thematic hydrogeological maps, a precise drainage network must be shown. It should be supplemented by important surface hydrology features further specified below. This information should be printed in blue. The same holds for the names of rivers, lakes and reservoirs.

Topographical information on roads, railroads, towns and settlements, and all geographical names are shown in dark grey or black. On very small scale maps it may be justifiable to omit altitude contours, but generally they are of great value to the map user. They should be printed in a grey tone.

The grid, preferably referring to international rather than national coordinates, should always be in black.

The rules outlined above principally apply to all of the three following sections.

Thematic areal information (B)

The main theme of the map is always represented by colour wash outlining the areal characteristics. This implies that different colours are recommended for use on the different types of maps. However, the colours are selected on the basis of hydrogeologically and cartographically defined concepts.

- General and special purpose hydrogeological maps (representation of occurrence of groundwater) Since general hydrogeological maps should be produced at a relatively early phase of hydrogeological reconnaissance, sufficient emphasis should be placed on geological information. However, the colours blue, green and brown, as used on the map, do not refer to the age of rock units (as was proposed and applied by many map authors in the 1960s), but rather to the hydrogeological character of the formations.

The general principle followed is to represent aquifers, their hydrogeological characteristics and the contained groundwater in much more detail than strata containing little or no groundwater. Therefore the scheme outlined on Figure 1 offers many more colours in the upper part. On the International Hydrogeological Map of Europe and in this Legend, only the extremes of flow regimes within the aquifers are shown with blue or green colour, based on an arbitrary "either/or" decision. The spectrum from blue to green may be expanded, where appropriate, e.g. to unambiguously outline karst aquifers, aquifers having a typically mixed regime such as several sandstones or volcanic sequences or productive alteration zones in basement areas. The introduction of mixed colours between blue and green must, however, not be overdone, since mixtures of blue and yellow (producing green wash colour) should be clearly distinguishable on the map, even when altered by sunlight.

All strata at outcrop appear in colour on the map, whether aquifers or non-aquifers. Aquifers in which flow is mainly intergranular (mostly unconsolidated material) are coloured blue; fissured aquifers, including karst aquifers, are coloured green. In each case a dark tone of the colour indicates large and extensive groundwater resources and a high productivity of the aquifer, while a lighter tone indicates local and smaller resources and a lower productivity. Formations containing only limited or local groundwater resources are coloured light brown, while strata with essentially no groundwater are coloured dark brown. The colours, therefore, combine information on the occurrence of groundwater with information on groundwater flow regimes. This information is essential for the recognition of the hydrogeological units occurring in the mapped area.

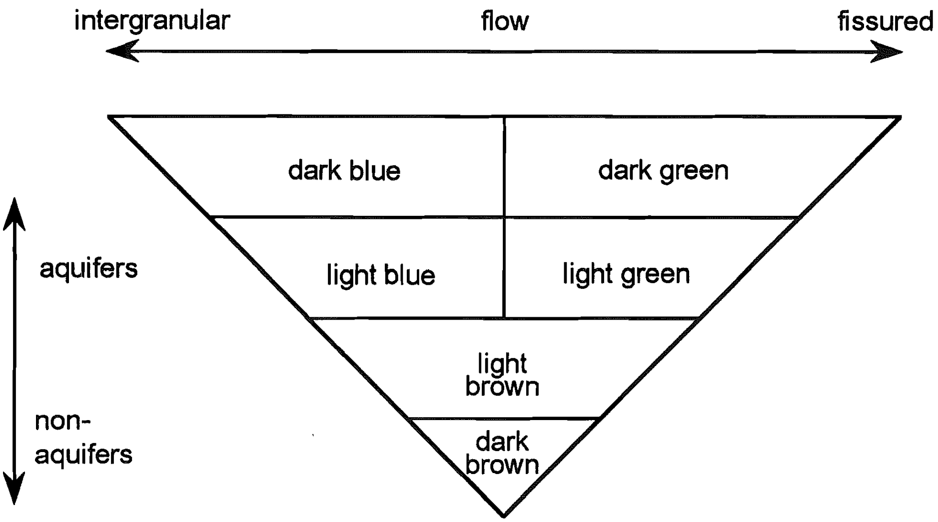


Figure II-1. Scheme of areal colours to represent hydrogeological characteristics and occurrence of groundwater.

Depending on the purpose and scale of the map it may be useful to omit relatively thin covering layers (e.g. 10 - 20 m), to be allow clear map information on the underlying aquifers.

Hatching with fine, vertical, brown stripes is used where thin covering layers of low permeability overlie major aquifers or groundwater systems. Reference to this type of representation should be made in the Legend.

Aquifer or groundwater systems maps (representation of groundwater flow systems)

This map type, particularly useful for hydrogeological modelling, puts emphasis on the hydrodynamic characteristics and is based on a hydrological systems analysis. It defines input (recharge), through-flow (transit) and output (discharge) areas of groundwater flow systems and characterises the value of flow systems on the basis of their extension and fluxes.

Two main principles have been followed, to define the colours (see Figure 2):

- the transition from red or pink (in recharge areas) via purple or violet (in transit areas) to blue or green (in discharge areas)
- the transition from bright colours (red, purple, blue) indicating important regional systems to subdued colours (brown, olive, grey) indicating local or insignificant systems.

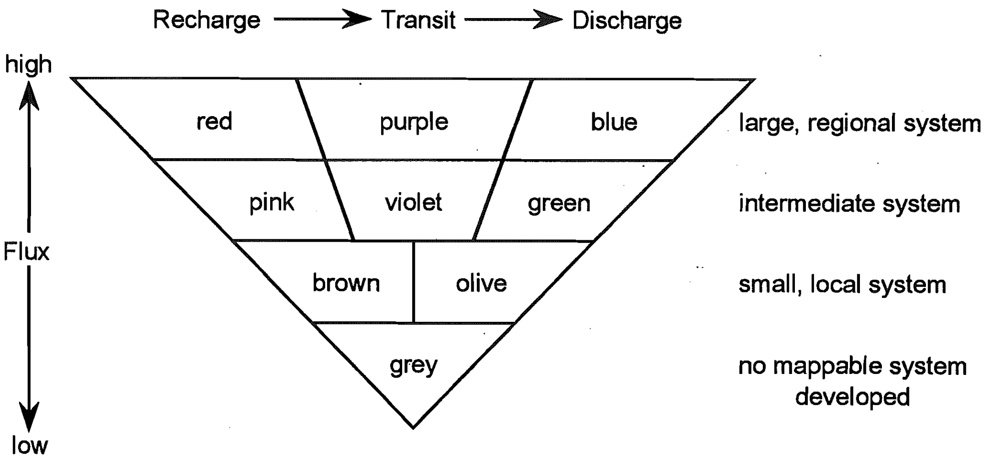


Figure II-2. Scheme of areal colours for maps of aquifer and groundwater systems.

In some cases, where shallow local systems overlie the transit areas of regional or subregional intermediate systems, vertical bands of colour may be used to identify the particular situation.

Groundwater vulnerability maps (vulnerability of groundwater to contamination)

Groundwater vulnerability maps are useful tools for land utilization planning and for the protection of valuable groundwater resources. They provide areal information on the protection from or the vulnerability of groundwater to contamination and pollution, whereby the geological and hydrogeological situation is principally taken into account. They also depict the major sources of contamination whether areal, linear or point.

The background, concept and justification for groundwater vulnerability maps have been described in detail (Vrba and Zaporozec 1994). Therefore, only the legend elements are included here.

The system of areal colours generally follows the 'traffic light' concept: green and olive for very low and low vulnerability risk, yellow for medium, rose and red orange for areas having highly or extremely highly vulnerable groundwaters (see Table II-1).

Table II-1. Vulnerability of the aquifers system according to the overlying strata (after Vrba and Zaporozec 1994)

VULNERABILITY	COLOR	NATURE OF UNSATURATED ZONE STRATA	EXAMPLE
EXTREMELY HIGH	Red Orange	Ineffective and/or insignificantly thick or discontinuous	Fissured or highly karstic
HIGH	Rose	Highly permeable with unsaturated zone <2 m thick	
MEDIUM	Yellow	Moderate permeability (k_v=-10^3-10^{-5}); depth to saturated zone 2-20 m (or 2-50 m in karst with low karstic index)	Commonly unconsolidated formation
LOW	Light olive green	Low permeability; depth to saturated zone > 20 m	
VERY LOW	Dark olive green	Practically impermeable and of significant thickness	Clay or shale

Additional areal information, e.g. lithology (C)

The lithology of strata at outcrop is generally decisive for the type of groundwater characteristics, flow systems and vulnerability assessment. It may be represented, in addition to the theme shown by colour wash, by grey screen patterns (ornament). These symbolize in a general way the main components of the strata. Screens representing sedimentary strata are recognizably laminar and are arranged horizontally where strata are gently inclined or horizontal, while steeply inclined or folded areas are represented by vertical screen patterns.

Aquifer systems composed of a number of superimposed layers of different lithology which are too small to be split up into different units are usually represented by a mixed screen pattern.

Other areal information, e.g. on groundwater chemistry or salinity, may also be provided by ornament, in addition to the areal colour wash.

Representation of detailed hydrogeological data and information (D)

Information on specific hydrogeological data is illustrated by the use of symbols or lines printed in various colours on general and special purpose maps, each colour symbolizing a particular group of hydrogeological features (Section I):

1. violet for information on groundwater and springs,

2. orange for information on physical and chemical characteristics of groundwater,

3. blue for information on surface water and karst hydrology,

4. red for all man-made (anthropogenic) features and alterations to the natural groundwater regime,

5. dark green for horizon contours and permafrost,

6. black for geological information.

The map author may decide how much detailed information is to be shown on the main map or on insert maps. However, even a general small scale hydrogeological map should contain the most important features which reduce groundwater development prospects, such as poor quality of the water or insignificant recharge.

Numerical figures, in the same colour, may be added for clarification in appropriate places e.g. values on contours.

On maps of groundwater systems (Section II) and groundwater vulnerability (Section III) colours used for the representation of specific point and line information are modified or changed according to the concepts of these map types.

In Section II this applies chiefly to the hydrodynamic relationship between aquifers and the surface hydrological network, as well as to the hydraulic significance of boundaries (see Sections II D 2 and 3).

In the legend of Section III, colours for point and line features are used to indicate the potential for contamination of the features shown on the map. As vulnerability maps are particularly useful at larger scales, the variety of point and linear contamination sources is great, e.g. ranging from silage to cemeteries. However, the sections grouping groundwater and surface water features (III D 1 and 2) are nearly identical to Section I (I D 1 and 3).

Stratigraphy (chrono- and biostratigraphy)

While stratigraphic information is not of primary importance on hydrogeological maps, it is generally convenient to indicate at least the approximate age of the strata depicted on general hydrogeological maps.

For informational hydrogeological maps, however, stratigraphic information should be omitted, to assist the non-geological user.

The stratigraphic symbols are printed in black; they help to identify the unit which is represented on the map, whenever it is not characterized unequivocally by a combination of areal colour and screen. With a knowledge of the stratigraphy, the geological map reader can more easily recognize the geological structures.

For areas underlain by sedimentary strata, the use of stratigraphic symbols is recommended according to the general legend used in the country or continent; alternatively, refer to the "International Geological Map of Europe and the Mediterranean Region 1 : 1 500 000, Hannover 1962". In magmatic and metamorphic areas the age determination is often problematical. It is, therefore, up to the author to decide whether or not to show stratigraphic symbols in those areas, since the combination of areal colour and screen is often sufficient.

Note: Stratigraphic symbols are to be used sparingly on hydrogeological maps. The representation of hydrogeological features should in any case be predominant.

Climatology

It is rarely possible to include meteorological information on a hydrogeological map without obscuring more pertinent data. Therefore, it is recommended that climatological information, e.g. precipitation, evaporation, temperature or other climatological features, be shown either on insert maps on the margins of the hydrogeological map, or as figures in any accompanying explanatory text.

Vertical sections and perspective diagrams

Vertical cross-sections are commonly used to illustrate the relationships between aquifers and non-aquifers in relation to depth. Other hydrogeological features are also amenable to such treatment. The use of vertical cross-sections to accompany hydrogeological maps is strongly recommended.

These sections may be printed on the margin of the map, or alternatively within an accompanying explanatory text. The colours, lines, symbols and ornament used on the vertical cross-section should be the same as those used on the map.

The lines along which the sections are drawn should be clearly indicated by lines printed in black on the map. The significance of these lines should be clearly explained in the sheet legend and labelled, also in black, with the number identifying the particular section.

The horizontal scale of the cross-section should generally be the same as that of the map. The vertical scale is often exaggerated to permit detail to be shown; however, the vertical exaggeration should be limited to that necessary to illustrate the required detail since over-exaggeration, especially at large scales, may present a grossly misleading picture.

The end-points of each section, together with any point of importance along the section, should have their locations specified, preferably by the use of grid references. A bar-scale of altitude (vertical scale) at each end of the section is essential.

Particularly on special purpose hydrogeological maps dedicated towards more public use, perspective diagrams should be shown on the map, to give the map reader a three-dimensional perception of the hydrogeological setting. The same applies to groundwater flow systems which can conveniently be shown as perspective diagrams.

Inset maps and explanatory notes

Features which have not been represented on the map face for the sake of clarity, should be portrayed as insets if space permits, or explained in notes accompanying the map. The themes of inset maps should be relevant to the main map, e.g. rainfall, land use, actual groundwater abstraction or reliability of map information. The information should be relatively simple to match the smaller scale of the inset. If more than one inset map is shown, consistency of scale and format should be preserved.

Explanatory text on the map face in addition to the legend should generally be avoided; it can be included with the accompanying (separate) notes. However, under certain circumstances it might be advisable to provide hints how to use the map or to print a disclaimer to avoid misuse on the main map sheet.

Explanatory notes prepared together with maps must be entirely consistent, i.e. using the same terminology and similar graphical elements on both map and figures.

INTERNATIONAL STANDARD LEGEND (English)

Section I General and special hydrogeological maps

I A Background information

1 All background information is printed in screened black with the exception of the simplified topographic base map which is printed in dark grey (60 % black). It shows mainly the location and names of important localities and geographic names, international and administrative boundaries.

2 The drainage (stream or river) network is printed in blue.

3 Grids or lines of longitude and latitude are printed in black.

4 Additional background information to topography and orography where required is given on insert maps or in the explanatory notes.

I B Groundwater and rocks

1 Aquifers in which flow is mainly intergranular

1.1 extensive and highly productive aquifers

1.2 local or discontinuous productive aquifers or extensive but only moderately productive aquifers

2 Fissured aquifers, including karst aquifers

2.1 extensive and highly productive aquifers

LEGENDE INTERNATIONALE MODELE (Français)

Section I Cartes hydrogéologiques générales et spéciales

I A Fond

1 Tout le fond planimétrique est représenté en noir atténué à l'exception de l'hypsométrie simplifiée qui est représentée en gris foncé (60 % de noir). Il comporte principalement la position et le nom des localités importantes, les toponymes et les frontières internationales ou administratives.

2 Le réseau hydrographique (fleuves ou rivières) est représenté en bleu.

3 Les quadrillages géographiques, ou méridiens et parallèles sont représentés en noir.

4 Si nécessaire, des informations topographique et orographique de base complémentaires sont à donner dans les cartons annexes ou dans la notice explicative.

I B Eau souterraine et roches

1 Aquifères poreux

1.1 aquifères étendus et à productivité élevée

1.2 aquifères locaux ou à productivité irrégulière, ou étendus mais à productivité médiocre

2 Aquifères fissurés, comprenant les aquifères karstiques

2.1 aquifères étendus et à productivité élevée

INTERNATIONALE MUSTER-GENERALLEGENDE (Deutsch)

Teil I Hydrogeologische Übersichts- und Spezialkarten

I A Hintergrundinformation

1 Die Hintergrundinformation wird in gebrochen schwarz dargestellt; die vereinfachte topographische Karte wird in dunkelgrau (60 % schwarz) hinterlegt. Sie enthält vor allem die Situation, Ortsnamen und andere geographische Namen sowie internationale und Verwaltungsgrenzen.

2 Das Gewässernetz (Flüsse) wird in blau gedruckt.

3 Netz bzw. Längen- und Breitenkreise werden in schwarz gedruckt.

4 Weitere topographische und orographische Hintergrundinformation wird nötigenfalls in den Erläuterungen bzw. in Beikarten gegeben.

I B Grundwasser und Gesteinseinheiten

1 Porengrundwasserleiter

1.1 ausgedehnte und sehr ergiebige Grundwasservorkommen

1.2 lokale oder unzusammenhängende Grundwasservorkommen höherer Produktivität bzw. ausgedehnte, aber nur durchschnittlich ergiebige Grundwasservorkommen

2 Kluftgrundwasserleiter, einschließlich Karstgrundwasserleiter

2.1 ausgedehnte und sehr ergiebige Grundwasservorkommen

2.2 local or discontinuous productive aquifers, or
extensive but only moderately productive aquifers

3 Strata (granular or fissured rocks) forming insignificant aquifers with local and limited groundwater resources or strata with essentially no groundwater resources

3.1 minor aquifers with local and limited groundwater resources

3.2 strata with essentially no groundwater resources

3.3 where there is an extensive aquifer immediately underlying a thin cover the appropriate aquifer colour should be used crossed by brown stripes (one mm wide and three mm separation)

Note: Certain aquifers combine intergranular and fissure characteristics. In such cases the relevant colours described in sections 1 and 2 should be used depending on which characteristic is dominant, or another tone of colour (e.g. a bluish green) may be added.

I C Lithology

Ornament indicating lithology is printed in grey.

The orientation of the ornament indicates the type of bedding:
horizontal = unfolded, horizontal or gently inclined strata
vertical = folded strata

The following list contains ornaments which indicate general lithological types as well as some combinations to symbolize strata of varying lithology.

2.2	aquifères locaux ou à productivité irrégulière, ou étendus mais à productivité médiocre	2.2	lokale oder unzusammenhängende Grundwasservorkommen höherer Produktivität bzw. ausgedehnte, aber nur durchschnittlich ergiebige Grundwasservorkommen
3	Formations poreuses ou fissurées offrant des ressources en eau souterraines locales ou limitées, ou formations stériles n'offrant aucune ressource	3	Formationen (porös oder klüftig) mit lokalen oder begrenzten Grundwasservorkommen bzw. Gebiete ohne nennenswerte Grundwasservorkommen
3.1	formation n'offrant que des ressources en eau souterraine locales et limitées	3.1	untergeordnete Grundwasserleiter mit lokalen und begrenzten Grundwassern
3.2	formation essentiellement stérile	3.2	Gesteine ohne nennenswerte Grundwasservorkommen
3.3	sous une couverture semi-perméable un aquifère brunes étendu peut être représenté par des bandes de couleur appropriée alternant avec des bandesbrunes (bandes larges d'1 mm et intervalles de 3 mm)	3.3	Überdeckung von ausgedehnten Grundwasserleitern durch gering-durchlässige Deckschichten kann mit einer Signatur brauner Streifen angegeben werden (1 mm breit, 3 mm Abstand)

N.B.: Certains aquifères présentent en même temps des caractéristiques poreuses et fissurées. Dans ce cas, il est recommandé de choisir la couleur représentant les caractéristiques prédominantes (1 ou 2) ou d'ajouter une couleur mixte, par exemple vert bleu ou turquois.

Beachte: Bestimmte Grundwasserleiter vereinigen Poren- und Kluftdurchlässigkeit. In diesen Fällen sollte die Farbe (1 oder 2) entsprechend der dominanten Form der Durchlässigkeit gewählt werden oder eine Mischfarbe, z.B. Blaugrün, Türkis, hinzugefügt werden.

I C Lithologie

Les figurés exprimant la nature lithologique sont imprimés en gris.

L'orientation du figuré exprime l'ordre du pendage:
horizontale = couches horizontales ou peu inclinées
verticale = couches redressées

La liste suivante comprend les figurés qui représentent les types lithologiques généraux aussi bien que quelques combinaisons correspondant à des formations de nature lithologique variée.

I C Lithologie

Sichtraster für Lithologie werden in grau gedruckt.

Die Ausrichtung der Sichtraster verdeutlicht die Lagerung:
horizontal = ungefaltete oder flach geneigte Schichten
vertical = gefaltete Schichten.

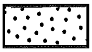
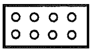
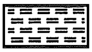
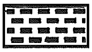
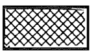
Die folgende Aufstellung enthält lithologische Haupttypen sowie einige Kombinationen für Schichten unterschiedlicher lithologischer Zusammensetzung.

Note: The ornament represents the lithology of the strata which is shown on the map. The exact lithological composition may be explained in detail in the map legend. Where combinations of ornaments are required, examples are shown in section C 3.

Combination of more than two ornaments is not recommended. The identification numbers given below are purely for convenience and do not refer to any commercial listings. Additional ornaments other than those listed here can be used for special purposes.

Recommended ornaments

Lithology of sedimentary rocks

	1	clay, clayey loam, mud, silt, marl
	2	clayey-loamy alteration products
	3	loess
	4	sands (units can be distinguished by variation of thickness of points)
	5	gravels (distinction by varying the arrangement of circles)
	6	moraines
	7	peat
	8	lignite
	9	pyroclastics
	10	made ground
	11-19	additional ornaments

N.B.: Les figurés représentent la lithologie des formations cartographiées. La composition lithologique exacte peut être précisée dans la légende de la carte. Des exemples de combinaison de figurés, lorsqu'elles sont nécessaires, sont donnés ci-dessous.

La combinaison de plus de deux figurés est déconseillée. Les indices donnés ci-après par pure commodité ne se réfèrent à aucun répertoire commercial. Des figurés additionnels, en sus de ceux indiqués ici, peuvent être utilisés à des fins spécifiques.

Figurés préconisés

Lithologie des roches sédimentaires

1	argile, limon argileux, boue, silt, marne
2	altérite argileuse
3	loess
4	sables (différenciation possible par variation de grosseur des points)
5	graviers (différenciation possible par variation de disposition des cercles)
6	moraines
7	tourbe
8	lignite
9	formations pyroclastiques, projections volcaniques
10	terrain artificiel
11-19	autres figurés possibles

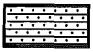
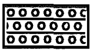
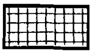
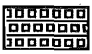
Beachte: Die Sichtraster geben die Lithologie der dargestellten Gesteinseinheiten wieder. Die genaue lithologische Zusammensetzung kann in der Legende angegeben werden. Beispiele für Kombinationen von Sichtrastern sind im Abschnitt C 3 angegeben.

Ratsam ist, nicht mehr als zwei Sichtraster zu kombinieren. Zur einfacheren Handhabung sind die Sichtraster numeriert. Die Numerierung gibt keine Firmenbezeichnungen wieder. Bei Bedarf können zusätzliche Sichtraster benutzt und mit den freigelassenen Nummern gekennzeichnet werden.

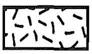
Sichtraster

Lithologie der Sedimentgesteine

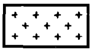
1	Ton, toniger Lehm, Schlick, Schluff, Mergel
2	tonig-lehmige Verwitterungsbildungen
3	Löß
4	Sand (Einheiten können durch unterschiedlich dicke Punkte unterschieden werden)
5	Kies (Unterscheidung durch unterschiedliche Anordnung der Kreise)
6	Moräne
7	Torf
8	Lignit
9	Pyroklastika
10	Aufschüttung
11-19	Zusätzliche Signaturen

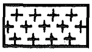
	20	mudstone, siltstone, shale
	21	sandstone (distinction by varying the size of dots)
	22	conglomerate
	23	limestones (distinction by varying the rectangle size)
	24	dolomites (distinction by varying the parallelogram size)
	25	travertine
	26	marlstone
	27	flysch
	28	complex alternation of different lithologies
	29	radiolarite, lydite, siliceous shale
	30	rock salt
	31	gypsum
	32-39	additional ornaments

Lithologies of igneous and metamorphic rocks

	40	acid to intermediate extrusives (distinction by varying the triangle size)
	41	basic extrusives (distinction by varying the triangle size)
	42	ultrabasite, serpentinite

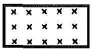
20	argilite, pélite, schiste	20	Tonstein, Schluffstein, Tonschiefer
21	grès (différenciation par variation de grosseur des points)	21	Sandstein (Unterscheidung nach unterschiedlicher Punktstärke)
22	conglomérat	22	Konglomerat
23	calcaires (différenciation par variation de taille des rectangles)	23	Kalkstein (Unterscheidung nach Größe der Rechtecke)
24	dolomie (différenciation par variation de taille des parallelogrammes)	24	Dolomitstein (Unterscheidung nach Größe der Parallelogramme)
25	travertin	25	Travertin
26	calcaire argileux	26	Mergelstein
27	flysch	27	Flysch
28	alternance complexe de roches variées	28	komplexe Wechsellagerung
29	radiolarite, lydienne, schiste siliceux	29	Radiolarit, Lydit, Quarzschiefer
30	sel gemme	30	Steinsalz
31	gypse	31	Gips
32-39	autres figurés possibles	32-39	Zusätzliche Signaturen
Lithologie des roches cristallines et métamorphiques		Lithologie der kristallinen und metamorphen Gesteine	
40	roches extrusives acides à intermédiaires (différenciation par variation de taille des triangles)	40	saure bis intermediäre Extrusiva (Unterscheidung durch Größe der Dreiecke)
41	roches extrusives basiques (différenciation par variation de taille des triangles)	41	basische Extrusiva (Unterscheidung durch Größe der Dreiecke)
42	roches ultrabasiques, serpentine	42	Ultrabasit, Serpentinit

 43 acid to intermediate intrusives (distinction by varying the arrangement of crosses)

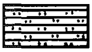
 44 basic intrusives

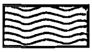
 45 slate, phyllite, mica schist, etc.

 46 gneiss

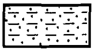
 47 gneiss and granite, undifferentiated

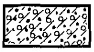
 48 marble

 49 quartzite

 50 metamorphic rocks, undifferentiated

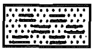
Examples of combined types

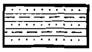
 1+4

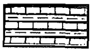
 2+4+5

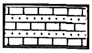
 1+30

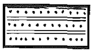
 4+9

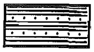
 4+7

 20+21

 20+23

 21+23

 21+26

 21+45

Distinction between different geological formations may be made by varying the size of the ornament.

43	roches intrusives acides à intermédiaires (différenciation par variation de disposition des croix)	43	saure bis intermediäre Intrusiva (Unterscheidung durch Anordnung der Kreuze)
44	roches intrusives basiques	44	basische Intrusiva
45	ardoise, phyllade, micaschiste	45	Schiefer, Phyllit, Glimmerschiefer
46	gneiss	46	Gneis
47	gneiss et granite indifférenciés	47	Gneis und undifferenzierte Granite
48	marbre	48	Marmor
49	quartzite	49	Quarzit
50	roches métamorphiques indifférenciées	50	undifferenzierte Metamorphite

Exemples de combinaisons de figurés (facies mixtes)

1+4	20+21
2+4+5	20+23
1+30	21+23
4+9	21+26
4+7	21+45

Beispiele von Kombinationen der Sichtraster (Mischtypen)

1+4	20+21
2+4+5	20+23
1+30	21+23
4+9	21+26
4+7	21+45

La variation de la taille des figurés permet de distinguer différentes formations géologiques.

Unterscheidungen zwischen geologisch unterschiedlichen Schichten können durch unterschiedliche Größe der Sichtraster (Ornamente) getroffen werden.

I D Representation of detailed data

Signs are printed in several colours grouped as shown below:

1. violet: groundwater and springs

2. orange: physical and chemical characteristics of groundwater quality and temperature

3. blue: surface water and karst hydrography

4. red: man-made features and alterations to the natural groundwater regime

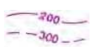
5. dark green: horizon contours (isopachytes) and limits of certain features, such as permafrost

6. black: geological information

Detailed examples of internationally used colour charts (ITC Colour Chart [1982], ITC Journal 1982-2, Enschede) are given in brackets to standardize the colours.

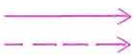
1 Groundwater and springs

colour: violet (ITC No. 062)



1.1 contours of the potentiometric surface (solid or broken lines with height relative to reference level)

1.2 direction of groundwater flow



1.3 connection between karstic loss and resurgence,
a) proven,
b) inferred

1.4 groundwater divide
a) stationary,
b) periodically changing

I D Representation de données spécialisées

Les symboles se groupent par couleur (voir ci-dessous):

1. violet: eau souterraine et sources
2. orange: qualités et température de l'eau souterraine
3. bleu: eau de surface et hydrographie karstique
4. rouge: artefacts et modifications du régime naturel des eaux souterraines
5. vert foncé: lignes structurales (isohypses, isopaches) et limites d'extension de certains caractères, tels que le permafrost
6. noir: données géologiques

Des exemples détaillés des couleurs selon la planche de couleur de l'ITC (ITC Colour Chart [1982], ITC Journal 1982-2, Enschede) ont été ajoutés entre parenthèses.

1 Eau souterraine et sources

couleur: violet (ITC No. 062)

1.1 ligne équipotentielle (lignes continues ou discontinues avec mention de hauteur relative à un niveau de référence)

1.2 ligne de courant et sens d'écoulement d'eau souterraine

1.3 liaison entre une perte karstique et une résurgence
a) prouvée
b) supposée

1.4 ligne de partage des eaux souterraines
a) instable
b) à migrations périodiques

I D Spezielle Darstellungen

Die Symbole sind in Farbgruppen geordnet (s.u.):

1. Violett: Grundwasser und Quellen
2. Orange: Chemische Beschaffenheit und Temperatur des Grundwassers
3. Blau: Oberflächenwasser und Karsthydrographie
4. Rot: Bauwerke und Änderungen der natürlichen Grundwasserverhältnisse
5. Dunkelgrün: Strukturlinien (Isohypsen, Isopachen) und Grenzen von Ausdehnungsgebieten, z.B. Permafrost
6. Schwarz: Geologie

In Klammern die Referenzfarben nach der international verbreiteten ITC-Farbtafel (ITC Colour Chart [1982], ITC Journal 1982-2, Enschede).

1 Grundwasser und Quellen

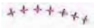
Farbe: Violett (ITC No. 062)

1.1 Grundwassergleichen (durchgezogene oder unterbrochene Linien mit Höhenangabe, bezogen auf eine Normalhöhe)

1.2 Grundwasserfließrichtung

1.3 Verbindung zwischen Versickerungs- und Austrittsstelle
a) nachgewiesen
b) vermutet

1.4 Grundwasserscheide
a) stationär
b) periodisch wechselnd

	1.5	limit of area with confined groundwater
	1.6	limit of area of artesian flow
	1.7	lens of fresh water surrounded by salt water
	1.8	limit of area with insignificant natural replenishment from rainfall to groundwater (50 % screen colour)
	1.9	spring, classified after average discharge, e.g. a) less than 100 l/s, b) 100 - 1000 l/s, c) more than 1000 l/s
	1.10	perennial karst spring
	1.11	submarine spring
	1.12	group of springs (relevant symbols are enclosed by circles)
	1.13	temporary karst spring
	1.14	line of springs
	1.15	groundwater seepage area
	2	Groundwater quality and temperature
		colour: orange (ITC No. 650)
	2.1	boundary of saline groundwater in an aquifer (the definition of fresh, brackish and saline water may differ from one area to another, but should be defined on the basis of TDS or chloride content)
	2.2	isolines of equal groundwater salinity (isochlors)

1.5	limite de zone à nappe captive	1.5	Grenze gespannter Verhältnisse
1.6	limite de zone de jaillissement possible	1.6	Grenze artesischer Verhältnisse
1.7	lentille d'eau douce entourée par des eaux salées	1.7	Süßwasserlinse umgeben von Salzwasser
1.8	limite de zone sans alimentation significative des aquifères par les précipitations (couleur tramée de 50 %)	1.8	Grenze des Gebietes mit unbedeutender Grundwasser-neubildung (50 % gerastert)
1.9	source, classée d'après le débit moyen, par exemple: a) moins de 100 l/s b) 100 à 1000 l/s c) plus de 1000 l/s	1.9	Quelle, nach Schüttung in Gruppen zusammengefaßt, z.B.: a) weniger als 100 l/s, b) 100 bis 1000 l/s, c) mehr als 1000 l/s
1.10	source karstique permanente	1.10	perennierende Karstquelle
1.11	émergence subaquatique ou sous-marine	1.11	submarine Quelle
1.12	groupe de sources (symboles correspondants entourés d'un cercle)	1.12	Quellengruppe (entsprechende Symbole mit Außenkreis)
1.13	source karstique temporaire	1.13	temporäre Karstquelle
1.14	ligne de source	1.14	Quellenlinie
1.15	zone d'émergence diffuse d'eau souterraine	1.15	Quellgebiet mit diffusen Quellaustritten
2	Qualités et température de l'eau souterraine	2	Chemische Beschaffenheit und Temperatur des Grundwassers
	couleur: orangé (ITC No. 650)		Farbe: Orange (ITC No. 650)
2.1	limite d'extension d'eau salée dans un aquifère (les définitions des eaux douce, saumâtre et salée peuvent différer d'une région à l'autre, mais elles doivent être basées sur la teneur en chlorure)	2.1	Grenze der Salzwasserausdehnung im Grundwasserleiter (Definition der Begriffe Salz-, Brack- und Süßwasser unterschiedlich nach Region, aber festgelegt aufgrund des Lösungsinhaltes bzw. des Chloridgehaltes)
2.2	lignes d'égale salinité de l'eau souterraine (isochlores)	2.2	Isochloren (Linien gleicher Grundwassersalinität)

2.3 contours of the interface between fresh and saline groundwater, in m below reference level

2.4 area of sea water intrusion

2.5 area of mineralized groundwater inland

2.6 area with mineralized water overlying fresh groundwater

2.7 limit of mineralization of shallow groundwater inland

2.8 stream with mineralized water (blue stream with orange band)

2.9 lagoon or lake with saline or brackish water (blue shoreline with orange band inside)

2.10 periodical salt-water lake (broken blue shore line with orange band inside)

2.11 shott (playa) with episodical water (dotted blue shore line with orange band inside)

2.12 salt marsh

2.13 limit of formations containing minerals with potential for affecting groundwater quality (grey line with orange band)

2.14 spring of cold mineral or brackish water

2.15 thermal spring

2.16 thermomineral spring

2.17 area of increased geothermal heat

2.3	isohypses d'interface entre eaux souterraines douces et salées, en m sous le niveau de référence	2.3	Isohypsen der Salz-/Süßwasser-grenzfläche, in m unter Bezugshöhe
2.4	zone d'invasion d'eau marine dans un aquifère	2.4	Gebiet der Meerwasserintrusion
2.5	zone à eau souterraine continentale minéralisée	2.5	Gebiet inländischer Versalzung
2.6	zone à eau minéralisée surmontant une nappe souterraine d'eau douce	2.6	Gebiet mit versalztem Grundwasser über Süßwasser
2.7	limite d'extension d'eau minéralisée continentale dans un aquifère de faible profondeur	2.7	Grenze der Ausdehnung der oberflächennahen Inlandversalzung
2.8	cours d'eau à eau salée (ligne bleue avec une frange orangée)	2.8	Salzwasserfluß (blaue Linie mit orangem Saum)
2.9	lagune ou lac à eau salée ou saumâtre (rive bleue avec une frange orangée)	2.9	Lagune oder See mit Salz- oder Brackwasser (blaue Küstenlinie mit orangem Saum im Innern)
2.10	lac d'eau salée temporaire (ligne de rivage bleue discontinue avec une frange orangée)	2.10	periodischer Salzwassersee (unterbrochene blaue Küstenlinie mit orangem Saum)
2.11	chott (sebkhas) à eau épisodique (ligne pointillée de rivage bleue avec une frange orangée)	2.11	Schott (Sebkha) mit episodischer Wasserführung (gepunktete blaue Linie mit orangem Saum)
2.12	marais-salant	2.12	Salzmarsch
2.13	limite d'extension de formation comportant des minéraux pouvant influencer les qualités de l'eau souterraine (ligne grise avec une frange orangée)	2.13	Grenze salzhaltiger Formationen, die das Grundwasser versalzen können (graue Linie mit orangem Saum)
2.14	source minérale ou d'eau saumâtre froide	2.14	Mineralquelle oder kalte Brackwasserquelle
2.15	source thermale	2.15	Thermalquelle
2.16	source thermominérale	2.16	Thermomineralquelle
2.17	zone à flux géothermique élevé	2.17	Gebiet erhöhter Erdwärme

2.18 meltwater chamber beneath glacier

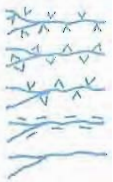
2.19 glacier burst from meltwater chamber beneath glacier

3 Surface water and karst hydrography

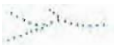
(For mapping karst areas on large scale maps, more symbols are available in special literature, and the map maker is referred to special legends, e.g. Burger & Dubertret (1975); ISU (1978).)

colour: blue (ITC No. 006)

3.1 stream with
a) perennial,
b) intermittent runoff



3.2 hydraulic character of streams
a) gaining (fed by groundwater)
b) losing (feeding the aquifer), including bank infiltration
c) alternating (gaining or losing)
d) independent (no communication with the aquifer)
e) no information

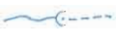


3.3 dry valley, possibly with episodical runoff (ephemeral stream)

3.4 braided stream (sandur)

3.5 stream ending in inland depression

cf.2.8 stream with mineralized water (blue stream with orange band)



3.6 karstic loss in river valley
a) perennial flow downstream
b) seasonal flow downstream
c) no flow downstream

2.18	poche d'eau sous-glaciaire	2.18	Schmelzwasserkammer unter dem Gletscher
2.19	"lahar" de fonte glaciaire du à une poche d'eau sous-glaciaire	2.19	Gletscherlauf aus einer Schmelzwasserkammer
3	Eaux de surface et hydrographie karstique	3	Oberflächenwasser und Karsthydrographie
	(Pour les cartes à plus grande échelle en domaine karstique il existe, d'autres symboles plus spéciaux, par exemple Burger & Dubertret (1975), ISU (1978).)		(In der Speziallitteratur, z.B. Burger & Dubertret (1975), ISU (1978), existiert eine Vielzahl von speziellen Symbolen für Spezialkarten in Karstgebieten.)
	couleur: bleu (ITC No. 006)		Farbe: Blau (ITC No. 006)
3.1	cours d'eau a) pérenne b) temporaire	3.1	Fluß a) ständig fließend b) zeitweilig fließend
3.2	type de liaison entre cours d'eau et aquiféres: a) drainant (alimenté par l'eau souterraine) b) perdant (alimentant l'aquifère, incluant les infiltrations dans les berges) c) alternativement drainant ou perdant d) indépendant (sans liaison hydraulique avec l'aquifère) e) inconnu	3.2	hydrodynamischer Charakter des Flusses a) Vorfluter (vom Grundwasser gespeist) b) Grundwasser anreichernd (einschließlich Uferversickerung) c) alternierend (a oder b) d) unabhängig (keine Verbindung mit Grundwasserleiter) e) unbekannt
3.3	vallée sèche, avec écoulement épisodique possible (cours d'eau éphémère)	3.3	Trockental mit gelegentlichem Oberflächenabfluß
3.4	ensablement	3.4	Sander
3.5	aboutissement d'un cours d'eau dans une dépression fermée	3.5	Fluß, in Inlandsenke versiegend
cf.2.8	cours d'eau à eau minéralisée (ligne bleue avec une frange orange)	cf.2.8	Salzwasserfluß (blaue Linie mit orangem Saum)
3.6	perte karstique de cours d'eau a) permanent en aval b) saisonnier en aval c) sans écoulement en aval	3.6	Karstversickerung/-versinkung a) mit dauerhaftem Abfluß unterstrom b) mit jahreszeitlichem Abfluß unterstrom c) ohne Oberflächenabfluß unterstrom

cf.1.3	connection between karstic loss and resurgence, a) proven b) inferred
3.7	aven, karstic shaft or cave
3.8	limit of karst area
3.9	main surface water divide
3.10	secondary surface water divide
3.11	flow gauging station, mean annual runoff [m³/s] catchment area [1000 km²]
3.12	glacier
3.13	glacier burst from ice dammed lake
3.14	waterfall
3.15	fresh water lake
cf.2.9	lagoon or lake with saline or brackish water (blue shore line with orange band inside)
cf.2.10	periodical salt-water lake (broken blue shore line with orange band inside)
cf.2.11	shott (playa) with episodical water (dotted blue shore line with orange band inside)
3.16	periodical fresh water lake
3.17	dry lake with only episodical water
3.18	river marsh
3.19	bog

cf.1.3	liaison entre une perte karstique et une résurgence a) prouvée b) supposée	cf.1.3	Verbindung zwischen Versickerungs- und Austrittsstelle a) nachgewiesen b) vermutet
3.7	aven, gouffre ou cavité karstique	3.7	Schlot, Kamin oder Karsthöhle
3.8	limite d'extension de zone karstique	3.8	Grenze des Karstgebietes
3.9	ligne de partage des eaux de surface principale	3.9	Hauptwasserscheide
3.10	ligne de partage des eaux de surface secondaire	3.10	Nebenwasserscheide
3.11	station hydrométrique, $\frac{\text{débit moyen annuel } [m^3/s]}{\text{aire du bassin versant } [1000\ km^2]}$	3.11	Abflußmeßstation, $\frac{\text{mittlerer jährlicher Abfluß } [m^3/s]}{\text{Fläche des Einzugsgebietes } [1000\ km^2]}$
3.12	glacier	3.12	Gletscher
3.13	"lahar" de fonte glaciaire à partir d'un lac glaciaire	3.13	Gletscherlauf von einem Gletschersee
3.14	chute d'eau, cascade	3.14	Wasserfall
3.15	lac d'eau douce	3.15	Süßwassersee
cf.2.9	lagune ou lac d'eau minéralisée (rive bleue avec une frange orangée)	cf.2.9	Lagune oder See mit Salz- oder Brackwasser (blaue Küstenlinie mit orangem Saum im Innern)
cf.2.10	lac salé temporaire (ligne de rivage bleue discontinue avec une frange orangée)	cf.2.10	periodischer Salzwassersee (unterbrochene blaue Küstenlinie mit orangem Saum)
cf.2.11	chotts (sebkhas) à eau épisodique (ligne pointillée de rivage bleue avec une frange orangée)	cf.2.11	Schott (Sebkha) mit episodischer Wasserführung (gepunktete blaue Linie mit orangem Saum)
3.16	lac d'eau douce temporaire	3.16	periodischer Süßwassersee
3.17	lac desséché à eau seulement épisodique	3.17	ausgetrockneter See mit gelegentlicher Wasserführung
3.18	cours d'eau marécageux	3.18	Flußmarsch
3.19	marais	3.19	Sumpf

4 Man-made features and alterations to the natural groundwater regime

(More detailed graphical elements frequently used on vulnerability maps, depictions of human influence on groundwater systems and pollution are provided in the IAH guidebook on vulnerability mapping, see Section III of this Legend.)

colour: red (ITC No. 660)

 4.1 well, shaft or borehole, for monitoring or with little output, with phreatic or confined groundwater

 4.2 group of wells or boreholes, with phreatic or confined groundwater

 4.3 well or borehole, artesian flowing

 4.4 group of wells or boreholes, artesian flowing

 4.5 mineral water well

 4.6 thermomineral water well

 4.7 thermal water well

 4.8 injection well

4.9 pumping station, pumped well field, average quantity of discharge or pumping (categories at the discretion of the author), e.g.

 a) 3 - 30 million m^3/year

 b) 30 - 300 million m^3/year

 c) more than 300 million m^3/year

 4.10 pumping station from spring (red square with violet dot inside)

 4.11 underground drainage gallery (e.g. Kanat)

 4.12 river intake

4	Artefacts et modifications anthropiques du régime naturel des eaux souterraines	4	Bauwerke und Änderungen der natürlichen Grundwasserverhältnisse
	(D'autres éléments graphiques, fréquemment utilisés sur les cartes de vulnérabilité, des symboles indiquantes l'influence humaine sur les systèmes d'eau souterraine et la pollution sont inclus dans le guide AIH sur la cartographie de la vulnérabilité, voir Section III de cette légende.)		(Weitere, häufig auf Karten der Verschmutzungsempfindlichkeit verwendete, graphische Elemente, Zeichen für menschliche Einflüsse auf Grundwasser-Systeme und Verunreinigungen sind im IAH Guidebook on vulnerability mapping enthalten; s. Abschnitt III dieser Legende.)
	couleur: rouge (ITC No. 660)		Farbe: Rot (ITC No. 660)
4.1	puits ou forage d'observation ou faiblement exploité, en aquifère libre ou captif	4.1	Brunnen, Schacht oder Bohrloch, als Maßstelle oder mit geringer Fördermenge, mit freiem oder gespanntem Grundwasser
4.2	groupe de puits ou forages, en aquifère libre ou captif	4.2	Gruppe von Brunnen oder Bohrlöchern, mit freiem oder gespanntem Grundwasser
4.3	puits ou forage artésien jaillissant	4.3	Brunnen oder Bohrloch mit artesischem Ausfluß
4.4	groupe de puits ou forages artésiens jaillissants	4.4	Gruppe von Brunnen oder Bohrloch mit artesischem Ausfluß
4.5	forage de captage d'eau minérale	4.5	Mineralwasserbrunnen
4.6	forage thermominéral	4.6	Thermomineralwasserbrunnen
4.7	forage thermal	4.7	Thermalwasserbrunnen
4.8	puits d'injection	4.8	Versenkbrunnen
4.9	station de pompage, champ captant (par pompage), débit moyen écoulé ou pompé (classes au choix de l'auteur) par exemple: a) 3 à 30 hm^3/an b) 30 à 300 hm^3/an c) plus de 300 hm^3/an	4.9	Pumpstation, Brunnenfeld mit Förderung, mittlere Schüttungs- oder Fördermenge, z.B. a) 3 à 30 Mio m^3/Jahr b) 30 à 300 Mio m^3/Jahr c) mehr als 300 Mio m^3/Jahr
4.10	station de pompage sur une source (carrée rouge autour d'un point violet)	4.10	gepumpte Quellfassung (rotes Quadrat mit violettem Innenpunkt)
4.11	galerie captante (par exemple: kanat, foggara)	4.11	Wasserfassungsgalerie (z.B. Khanat, Fogghara)
4.12	prise en rivière	4.12	Flußwasserpumpstation

4.13 pipeline

4.14 aqueduct

4.15 storage reservoir or pond,
a) perennial,
b) temporary

4.16 dam or weir, with capacity of the reservoir in million m³

4.17 levee or coastal dyke

4.18 flood-tide barrage or tidal power plant

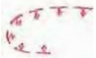
4.19 groundwater recharge site

4.20 installation for desalination

4.21 oasis

4.22 limit of area of intensive groundwater exploitation

4.23 area of underground mining affecting the natural groundwater regime

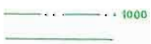


4.24 area of open cast mining affecting the natural groundwater regime

4.25 irrigation area

5 Horizon contours (isopachytes) and limits of certain features, such as permafrost

colour: dark green (ITC No. 606)



5.1 horizon contours or isopachytes (solid or broken lines with depth in m relative to reference level)

4.13	conduite d'eau	4.13	Fernwasserleitung
4.14	aqueduc	4.14	Aquädukt
4.15	réservoir a) permanent b) temporaire	4.15	Rückhaltebecken a) dauernd wasserführend b) zeitweise wasserführend
4.16	barrage ou digue, et capacité du réservoir en million de m^3	4.16	Staudamm oder Wehr, mit Inhalt des Stausees in Mio m^3
4.17	levée ou digue cotière	4.17	Fluß- oder Küstendeich
4.18	barrage de crue de marée ou usine marémotrice	4.18	Hochwasserabwehrbauwerk oder Gezeitenkraftwerk
4.19	site d'alimentation artificielle d'eau souterraine	4.19	Anlage zur künstlichen Grundwasser-Anreicherung
4.20	usine de dessalement	4.20	Entsalzungsanlage
4.21	oasis	4.21	Oase
4.22	limite de zone d'exploitation intensive d'eau souterraine	4.22	Grenze des Gebiets starker Grundwasser-Förderung
4.23	aire d'influence de travaux miniers sur le régime naturel des eaux souterraines	4.23	Bergbaugebiet mit Beeinflussung des natürlichen Grundwasser-Regimes
4.24	aire d'influence de mine à ciel ouvert sur le régime naturel des eaux souterraines	4.24	Tagebaugebiet mit Beeinflussung des natürlichen Grundwasser-Regimes
4.25	périmètre d'irrigation	4.25	Bewässerungsgebiet
5	Lignes structurales (isohypses, isopaches) et limites d'extension de certains caractères, tels que le permafrost	5	Strukturlinien (Isohypsen, Isopachen) und Grenzen von Ausdehnungsgebieten, z.B. Permafrost
	couleur: vert foncé (ITC No. 606)		Farbe: Dunkelgrün (ITC No. 606)
5.1	isohypses de toit ou isopaches de formation (lignes continues ou discontinues avec mention de profondeur relative à un niveau de référence)	5.1	Isohypse oder Isopache bestimmter Formationen (durchgezogene oder unterbrochene Linien mit Tiefenangaben in m, bezogen auf NN)

40

5.2 thickness of aquifer in m

5.3 limit of permafrost area (variation of broken lines for continuous, discontinous and isolated distribution)

5.4 talik (unfrozen zone) under a river, lake or reservoir (river or lake in blue, green dots surrounding)

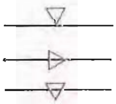
6 Geological information

colour: black

6.1 geological or hydrogeological boundary (a more detailed classification of boundaries based on their hydrodynamic character is given in Section II of this Legend)

6.2 fault, certain (solid line) or inferred (broken line)

6.3 overthrust, certain or inferred

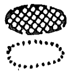
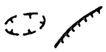
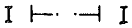


6.4 hydraulic character of boundaries (combined with no. 6.1 to 6.3)
a) acting as barrier
b) acting as conduit
c) without significance to groundwater flow
d) no information

6.5 fractured belt of hydrogeological importance

cf.2.13 limit of formations containing minerals with potential for affecting groundwater quality (grey line with orange band)

5.2	profondeur d'un aquifère (toit) en m	5.2	Mächtigkeit des Grundwasserleiters in m
5.3	limite d'extension du permafrost (lignes discontinues différentes indiquant une extension étendue, réduite ou locale)	5.3	Grenze der Permafrostverbreitung (verschiedene gestrichelte Linien für ausgedehnte, kleinflächige und stellenweise Verbreiterung)
5.4	"talik" (zone non gelée) sous un cours d'eau, lac ou réservoir (cours d'eau ou lac en bleu, points verts en surcharge)	5.4	Talik (ungefrorene Zone) unter Flüssen, Seen oder Stauseen) (Fluß oder See in Blau, Umrandung mit grünen Punkten)
6	Géologie	6	Geologie
	couleur: noir		Farbe: Schwarz
6.1	contour géologique ou hydrogéologique (une classification plus détaillée des contours, selon leur caractère hydrodynamique se trouve en Section II de cette légende)	6.1	Geologische oder hydrogeologische Grenze (im Abschnitt II dieser Legende findet sich eine genauere Untergliederung der Grenzen gemäß hydrodynamischem Charakter)
6.2	faille reconnue (ligne continue) ou supposée (ligne discontinue)	6.2	Störung, nachgewiesen (durchgezogene Linie) oder vermutet (unterbrochene Linie)
6.3	contact anormal (chevauchement), reconnu ou supposé	6.3	Überschiebung, nachgewiesen oder vermutet
6.4	caractère hydrodynamique des contours et lignes (en combinaison avec les symboles 6.1 à 6.3) a) perméable b) semi-perméable c) étanche (barrière) d) non spécifié	6.4	Hydrodynamische Charakterisierung der Grenzen (für Signaturen 6.1 bis 6.3) a) durchlässig b) halb-durchlässig c) undurchlässig (Barrierewirkung) d) keine Information
6.5	champ de fracture d'importance hydrogéologique	6.5	Kluftzone mit hydrogeologischer Bedeutung
cf.2.13	limite d'extension de formation comportant des minéraux pouvant influencer les qualités de l'eau souterraine (ligne grise avec une frange orangée)	cf.2.13	Grenze mineralführender Formationen, die das Grundwasser beeinträchtigen könnten (graue Linie mit orangem Band)

	6.6	salt plug (Diapir) a) near surface b) at depth (dotted line)
	6.7	area and edge of solution chambers formed in saline formations (subrosion)
	6.8	boundary of infilled erosional channel
	6.9	volcanic cone
	6.10	volcanic crater
	6.11	line of cross-section

Section II Special legend for aquifer and groundwater systems maps

II A Background information

The principles outlined in section I A generally apply also to this section. However, the drainage network is classified after its hydrodynamic character and its relation with groundwater, and may be represented by colour on the map. In addition, the runoff is classified in quantitative categories which are symbolized on the map by different widths of lines. The special representation generally requires full redrawing of the drainage network.

Topographic information (situation, typonomy) should be dark grey.

The grid should be printed in black.

6.6 dôme de sel (diapir)
a) subsuperficiel
b) en profondeur (ligne en pointillé)

6.7 extension et limites d'une cavité de dissolution dans une formation salifère (subrosion)

6.8 limite de chenal d'érosion comblé

6.9 volcan

6.10 cratère volcanique

6.11 trace de coupe

6.6 Salzdom (Diapir)
a) oberflächennah
b) tiefliegend (Punktlinie)

6.7 Ausdehnung und Grenze von Lösungshohlräumen in Salinarformationen (Subrosion)

6.8 Grenze eines gefüllten Schmelzwasserkanals

6.9 Vulkan

6.10 Vulkankrater

6.11 Schnittlinie

Section II Légende spéciale pour cartes des systèmes aquifères

II A Fond

Les principes présentés dans la section I A s'appliquent également pour cette section. Cependant, le réseau hydrographique doit être représenté par des couleurs selon le caractère hydrodynamique des cours d'eau. En plus, l'écoulement superficiel moyen est regroupé en catégories symbolisées par des largeurs différentes des traits des cours d'eau. Cette représentation particulière nécessite donc de redessiner la carte du réseau hydrographique.

Les informations topographiques (situation, typonymie) sont représentées en gris foncé.

Les quadrillages géographiques sont représentés en noir.

Teil II Speziallegende für Karten der Grundwasser-Fließsysteme

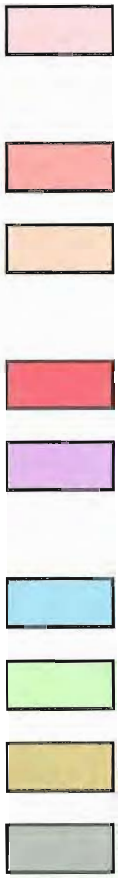
II A Topographie und Hintergrund

Die Grundsätze des Abschnitts I A gelten auch für diesen Teil. Allerdings wird das Gewässernetz gemäß der hydrodynamischen Verhältnisse untergliedert und gegebenenfalls mit unterschiedlichen Farben dargestellt. Darüber hinaus wird der Oberflächenabfluß in Mengenklassen eingruppiert und mit unterschiedlichen Strichstärken dargestellt. Die besondere Darstellung erfordert daher seine kartographische Neubearbeitung der Gewässernetzplatte.

Topographische Angaben (Situation, Namen) werden dunkelgrau wiedergegeben.

Das Netz wird in schwarz gedruckt.

II B Areal colours for aquifer or groundwater systems maps



1 Recharge area

1.1 of a large, regional groundwater system (the entering flux classified after volume by tone)

1.2 of an intermediate groundwater system

1.3 of a small, local groundwater system

2 Transit area

2.1 of a large, regional groundwater system

2.2 of an intermediate groundwater system

3 Discharge area

3.1 of a large, regional groundwater system

3.2 of an intermediate groundwater system

3.3 of a small, local groundwater system

4 No groundwater system developed

Note: Recharge areas are generally characterized by a significant unsaturated zone above the aquifer, mainly downward flow gradients, whilst discharge areas have water tables close to surface and upward flow. Transit areas are characterized by chiefly lateral groundwater flow and may be overlain by local or intermediate systems.

II B Couleurs pour les systèmes aquifères

1 Zone d'alimentation (à flux entrant)

1.1 Aire d'alimentation d'un grand système régional (diverses classes de flux entrant, diverses valeurs de la couleur rouge)

1.2 Aire d'alimentation d'un système moyen sous-régional

1.3 Aire d'alimentation d'un petit système local

2 Zone de transit

2.1 d'un grand système régional

2.2 d'un système moyen sous-régional

3 zone d'émergence (à flux sortant)

3.1 Aire d'émergence d'un grand système régional

3.2 Aire d'émergence d'un système moyen sous-régional

3.3 Aire d'émergence d'un petit système local

4 Région sans système aquifère

N.B.: Les zones à flux entrant (aires d'alimentation des systèmes aquifères) sont caractérisées par des couches non-saturées épaisses et un gradient de flux descendant. Par contre, dans les zones à flux sortant (aires d'émergence), les niveaux piézométriques se trouvent proches de la surface et le gradient est dirigé vers le haut. Les zones de transit se caractérisent par un flux latéral prédominant; elles peuvent être recouvertes par de systèmes aquifères moins profonds (moyens et locaux).

II B Flächenfarben für Karten der Grundwasser-Fließsysteme

1 Eintragsgebiet

1.1 Große, regionale Grundwassersysteme (Eintrag gruppiert gemäß jährlicher Menge, m verschiedenen Farbwerten dargestellt

1.2 Mittlere, subregionale Grundwassersysteme

1.3 Kleine, lokale Grundwassersysteme

2 Durchflußgebiet

2.1 Große, regionale Grundwassersysteme

2.2 Mittlere, subregionale Grundwassersysteme

3 Austragsgebiet

3.1 Austragsgebiet eines großen, regionalen Grundwassersystems

3.2 Austragsgebiet eines mittleren, subregionalen Grundwassersystems

3.3 Austragsgebiet eines kleinen, lokaler Grundwassersystems

4 Gebiet ohne nennenswerte Grundwassersysteme

Beachte: Eintragsgebiete (Grundwasserneubildungsgebiete) sind in der Regel durch eine mächtige ungesättigte Zone über dem Grundwasserleiter und abwärts gerichtete Gradiente gekennzeichnet; in Austragsgebieten liegt die Grundwasseroberfläche meist nahe der Geländeoberfläche und die Gradienten sind aufwärts gerichtet. Durchflußgebiete sind durch einen im wesentlichen lateralen Grundwasserfluß gekennzeichnet; oberflächennah können sie durch mittlere oder lokale Grundwassersysteme überlagert werden.

As the recharge areas are usually much larger in extent than the discharge areas, the recharge can be quantified in categories represented by different tones of the areal colour. However, clear distinction on the map must be maintained, hence, 4 - 5 subdivisions are recommended at maximum.

II C Type of system and conditions of groundwater flow

Particularly large and intermediate aquifers and groundwater systems may be further subdivided according to lithology or type of groundwater flow, using visible, widely spaced regular ornaments. As these ornaments are added to the areal colours, they should be optically subdued and should not alter the colour wash adversely.

The ornament should be printed in grey or red, e.g.

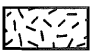
1 Relatively homogeneous, continuous, intergranular flow in (mostly sedimentary or volcanic) single aquifer systems

2 Complex, continuous flow in multi-aquifer systems

3 Chiefly heterogeneous, fissured flow in massive hard rock (sedimentary, volcanic or igneous) aquifer systems

4 Heterogeneous, wide fissure and channel flow in karstified or volcanic aquifer complexes

5 Complex, heterogeneous flow in folded and faulted hard rock complexes



6 Combinded intergranular and fissure flow in the alteration zones of hard rock areas

Les zones d'alimentation étant généralement très étendues, il est conseillé de quantifier le flux entrant moyen et de le représenter, groupé en classes, par différentes valeurs de la couleur rouge. Le nombre de classes représenté sur la carte doit être inférieur à 6, pour des raisons cartographiques.

Da Eintragsgebiete im allgemeinen erheblich größer als Austragsgebiete sind, wird innerhalb der Eintragsgebiete die Grundwasserneubildung, in Mengenklassen gruppiert, mit verschiedenen Farbintensitäten wiedergegeben. Allerdings sind maximal 4 bis 5 Farbabstufungen zu verwenden, damit die Abstufungen auf der Karte klar unterschieden werden können.

II C Type de système aquifère et caractéristiques du flux

Les systèmes grands et moyens peuvent être distingués, selon leur lithologie et les conditions de flux, par des figurés (trames). Ces figurés doivent être simples et légers, car ils sont appliqués en combinaison avec les couleurs sur la carte et ne doivent pas altérer celles-ci.

Les figurés sont représentés en gris ou rouge.

1 Flux étendu et continu, principalement en domaine poreux sédimentaire ou volcanique

2 Flux complexe mais continu dans des systèmes aquifères multicouches

3 Flux discontinu en domaine fissuré (roches dures sédimentaires, volcaniques ou plutoniques)

4 Flux discontinu et hétérogène dans des réseaux karstiques ou volcaniques

5 Flux complexe discontinu en région à couches redressées et tectonisées

6 Flux mixte des zones altérées et fracturées du socle

II C Typ des Systems und Charakteristika des Grundwasserflusses

Große und mittlere Grundwasserleiter und Grundwasserfließsysteme sollten gemäß ihrer Lithologie oder der Charakteristika des Grundwasserflusses mit groben Sichtrastern weiter gegliedert werden. Da diese Sichtraster mit den Flächenfarben kombiniert werden, sollten sie optisch nicht zu stark hervortreten oder den Farbeindruck verfälschen.

Die Sichtraster sollten in grau oder rot gedruckt werden, z.B.

1 Räumlich und zeitlich recht gleichmäßiger Fluß in (meist sedimentären oder vulkanischen) Porengrundwasserleitern

2 Komplexer, gleichmäßiger Grundwasserfluß in Mehrschicht-Grundwasserleiter-Systemen

3 Meist unregelmäßiger Grundwasserfluß in mächtigen Kluftgrundwasserleitern (Sedimentgesteine, vulkanische und Tiefengesteine)

4 Unregelmäßiger Grundwasserfluß in Spalten und Rinnen in Karst- oder vulkanischen Grundwasserleitern

5 Komplexer, unregelmäßiger Grundwasserfluß in gefalteten oder gestörten Festgesteinsbereichen

6 Vermischter Grundwasserfluß in Poren- und Kluftgrundwasserleitern in der Verwitterungszone von Festgesteinsbereichen

Note: As this information is considered secondary on the map, it must not overload the visual impression of the map picture. Hence it should be used only for large and intermediate rather than for small systems but it should be clearly recognizable on the map. This implies reduction of ornament to about 6 typical patterns, as indicated above.

II D Special signs and symbols

Most of the signs and symbols of section I D of the Legend can also be used in section II D. However, several items relevant to hydrodynamics are detailed in this latter section, to fully meet the requirements of the particular map type. This chiefly applies to groundwater flow, surface water features and to the hydraulic significance of boundaries.

1 Groundwater flow

colour: purple (ITC No. 082)

1.1 Upward seepage (inflow from the bottom)

1.2 Downward seepage (system losing groundwater to system below)

1.3 Alternating seepage (depending on changing hydraulic gradient)

1.4 Deep lateral groundwater flow (the flux may be classified by additional arrows)

2 Relation between surface and groundwater

2.1 Stream draining the groundwater system (blue)

2.2 Stream feeding the groundwater system (red)

N.B.: Les informations sur les caractéristiques du flux ne doivent pas surcharger la représentation cartographique. Il est donc conseillé de les appliquer pour les systèmes grands et moyens seulement, pour conserver la lisibilité de la carte. L'application de plus de six figurés est déconseillée.

Beachte: Die o.g. Angaben dürfen das Kartenbild nicht überladen, zumal sie weniger wichtig einzustufen sind. Sie sollten daher nur in großen und mittleren, nicht aber kleinen, lokalen Systemen verwendet werden, um eindeutig erkennbar zu bleiben. Die Zahl der o.a. 6 Sichtraster sollte daher nicht überschritten werden.

II D Signes et symboles spéciaux

La plupart des symboles présentés en Section I D de cette légende peuvent être utilisés également dans cette Section II D. Ou y ajoute quelques symboles particuliers représentant les conditions hydrodynamiques. Il s'agit principalement de données relatives au flux d'eau souterraine, aux eaux de surface et aux caractères hydrodynamiques des contours et limites.

II D Spezielle Symbole

Die Mehrheit der Symbole im Abschnitt I D dieser Legende können auch in diesem Abschnitt II D verwendet werden. Einige Angaben zur Hydrodynamik wurden jedoch in diesem Abschnitt weiter verfeinert, um das für den Kartentyp notwendige Inventar an Signaturen bereitzustellen. Dies betrifft im wesentlichen die Angaben zum Grundwasserfluß, zum Oberflächenwasser und zur hydrodynamischen Charakterisierung von Grenzen.

1	Flux d'eau souterraine	1	Grundwasserfluß
	Couleur: pourpre (ITC No. 082)		Farbe: Purpur (ITC No. 082)
1.1	flux entrant ascendant (de la base)	1.1	Aufwärts gerichteter Grundwasserfluß (Zufluß an der Basis)
1.2	flux sortant descendant (vers le système sousjacent)	1.2	Abwärts gerichteter Grundwasserfluß (Abstrom zum unterlagernden System)
1.3	flux alternatif (dépendant du gradient hydraulique)	1.3	Wechselnder Grundwasserfluß (abhängig von wechselnden hydraulischen Gradienten)
1.4	flux latéral profond (unités de flux différentes selon largeur des flêches)	1.4	Tiefer, horizontaler Grundwasserfluß (die Fließstärke kann mit unterschiedlichen Pfeilen unterschieden werden)
2	Relation entre eau de surface et eau souterraine	2	Beziehung zwischen Oberflächenwasser und Grundwasser
2.1	cours d'eau drainant (alimenté par l'eau souterraine) (bleu)	2.1	Vorfluter (vom Grundwasser gespeist) (Blau)
2.2	cours d'eau perdant (alimentant un aquifère) (rouge)	2.2	Infiltrierender (Grundwasser anreichernder) Fluß (Rot)

2.3 Stream without connection to the groundwater system (violet)

2.4 Stream closely related to the adjacent shallow groundwater system (alternating feeding or draining, depending on the height of the river and the phreatic water table) (dark green)

2.5 Reservoir feeding the groundwater system (red)

2.6 Reservoir without connection to the groundwater system (violet)

2.7 Canal draining the groundwater system (blue)

2.8 Canal feeding the groundwater system (red)

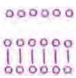
3 Hydraulic significance of boundaries (outcrop or subcrop boundaries of aquifers (geological boundaries, faults) or hydrodynamic boundaries of groundwater flow systems)

3.1 Boundary receiving inflow to the groundwater system (red)
a) outcropping
b) buried

3.2 Boundary of outflow from the groundwater system (blue)
a) outcropping
b) buried overflow from one system to an adjacent system

3.3 Impermeable boundary (brown),
a) outcropping
b) buried

3.4 Significance of the boundary unknown (grey)



cf.ID 1.4 Groundwater divide
a) stationary
b) periodical

2.3	cours d'eau indépendant (sans liaison hydraulique avec l'aquifère) (violet)	2.3	Hydraulisch unabhängiger Fluß (ohne Beziehung zum Grundwasser) (Violett)
2.4	cours d'eau dépendant de la nappe alluviale (alternativement drainant ou perdant selon les niveaux piézométriques du fleuve et de la nappe) (vert foncé)	2.4	Fluß mit enger Beziehung zum oberflächennahen Grundwassersystem (alternierend, je nach Höhe des Wasserstandes im Fluß und benachbarten Grundwasser) (Dunkelgrün)
2.5	réservoir infiltrant (rouge)	2.5	Infiltrierender Stausee (Rot)
2.6	réservoir sans liaison hydraulique avec l'aquifère (voilet)	2.6	Stausee ohne Beziehung zum Grundwasser (Violett)
2.7	canal drainant (bleu)	2.7	Kanal mit Drainagewirkung (Blau)
2.8	canal perdant (rouge)	2.8	Infiltrierender Kanal (Rot)
3	Caractéristiques hydrauliques des contours et limites (Contours superficiels ou couverts, mais près de la surface, des aquifères (contours litho-stratigraphiques, failles) ou limites hydrodynamiques des systèmes d'écoulement)	3	Hydraulische Charakterisierung der Grenzen (Grenzen an der Oberfläche und oberflächennahe, verdeckte Grenzen von Grundwasserleitern (geologische Grenzen, Störungen) sowie hydrodynamische Grenzen von Grundwassersystemen)
3.1	limite à flux entrant (rouge) a) affleurante b) couverte	3.1	Grenze mit Zufluß zum Grundwassersystem (Rot) a) ausstreichend b) verdeckt
3.2	limite à flux sortant (bleu) a) affleurante b) flux-couvert d'un système à l'autre	3.2	Grenze mit Abfluß aus dem Grundwassersystem (Blau) a) ausstreichend b) verdeckter Übertritt von einem System zum benachbarten System
3.3	limite étanche (brun) a) affleurante b) couverte	3.3	Undurchlässige Grenze (Braun) a) ausstreichend b) verdeckt
3.4	inconnu (gris)	3.4	Charakterisierung unbekannt (Grau)
cf.ID 1.4	ligne de partage des eaux souterraines a) permanente b) périodique	cf.ID 1.4	Grundwasserscheide a) stationär b) periodisch wechselnd

cf.ID 1.5 Limit of area with confined groundwater

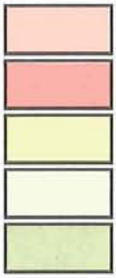
cf.ID 1.6 Limit of area of artesian flow

Section III Special legend for groundwater vulnerability maps

III A Background information (see Section I A)

The principles outlined in Section I A generally apply also to this section. However, it may be necessary to redraw part of the topographical background information, since particular features are represented in red, to show their groundwater contamination potential. As groundwater vulnerability maps frequently apply to medium and large scale maps, full representation of man-made objects potentially polluting or threatening groundwater quality is desirable.

III B Areal colours for groundwater vulnerability (see Table II-1)



1 Extremely high vulnerability (Red orange)

2 High vulnerability (Rose)

3 Medium vulnerability (Yellow)

4 Low vulnerability (Light olive green)

5 Very low vulnerability (Dark olive green)

Note: The vulnerability expressed by colour is generally assessed by considering the nature/type and thickness of the unsaturated zone overlying the aquifer (see Vrba & Zaporozec 1994). The colour wash may be combined with screens indicating lithology or areal information on groundwater quality, if appropriate.

cf.ID 1.5 limite de zone captive

cf.ID 1.6 limite de zone de jaillissement possible

Section III Légende spéciale pour les cartes de vulnérabilité

III A Fond

Les principes présentés dans la section I A s'appliquent également pour cette section. Cependant, il faut en partie retracer cartographiquement le fond topographique, pour bien représenter le potentiel de pollution de certains éléments du fond topographique. Pour le cartes à échelles moyenne ou grande, une représentation exacte et complète des artefacts est souhaitable.

III B Couleurs pour la vulnérabilité (voir tableau II-1)

1 très grande (rouge-orangée)
2 grande (rose)
3 moyenne (jaune)
4 faible (olive-vert pâle)
5 très faible (olive-vert)

N.N.: La vulnérabilité représentée par une couleur est définie généralement selon le type et l'épaisseur de la zone non-saturée au-dessus du système aquifère (Vrba & Zaporozec 1994). On peut combiner ces couleurs avec des figurés (trames), p.ex. pour indiquer la lithologie ou la qualité de l'eau souterraine.

cf.ID 1.5 Grenze gespannter Verhältnisse

cf.ID 1.6 Grenze artesischer Verhältnisse

Teil III Speziallegende für Karten der Grundwasserverschmutzungs-empfindlichkeit

III A Hintergrundinformation (s. Abschnitt I A)

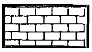
Die Grundsätze des Abschnitts I A gelten auch für diesen Abschnitt. Teilweise wird eine Neubearbeitung der topographischen Angaben notwendig, wenn das Verschmutzungspotential bestimmter, in der Topographie enthaltener Signaturen in rot dargestellt werden soll. In Karten mittlerer und größerer Maßstäbe ist eine möglichst vollständige Darstellung grundwassergefährdender Bauwerke anzustreben.

III B Flächenfarben für die Grundwasserverschmutzungsempfindlichkeit (s. Tabelle II-1)

1 Besonders hoch (Rot-orange)
2 Hoch (Rosa)
3 Mittel (Gelb)
4 Gering (Hell-olivgrün)
5 Sehr gering (Olivgrün)

Beachte: Die durch Farbe dargestellte Verschmutzungsempfindlichkeit wird im allgemeinen aufgrund der Ausbildung und Mächtigkeit der ungesättigten Grundwasserüberdeckung bestimmt (s. Vrba & Zaporozec 1994). Die Flächenfarben können mit Sichtrastern, z.B. zur Lithologie oder zu Angaben über die Grundwasserqualität, kombiniert werden.

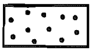
III C Nature of aquifer and ornament (see Vrba and Zaporozec 1994, Table A2)


1 Karstified


2 Coarse gravel sediments


3 High fracture index


4 Low karst index


5 Medium gravel sediments


6 Medium fracture index


7 Fine grained sediments


8 Low fracture index


9 Non-aquifer

Note: Further subdivision based on soil classification for use in determining aquifer vulnerability is possible (see Vrba and Zaporozec 1994, Table A1a)

III D Man-made activity

This special legend is based largely on the symbols recommended in Section I of this Standard Legend. In addition to a particular colour scheme of areal colours (wash), the legend expands the variety of symbols representing man-made activities (Section I D 4) for the particular purposes of vulnerability maps. Further symbols and colours should follow as much as possible the recommendations provided in Section I.

III C Nature de l'aquifère et ornement (voir Vrba and Zaporozec 1994, Table A2)

1	Karstifié
2	Sédiments graveleux grossiers
3	Indice élevé de fracturation
4	Indice élevé du karst
5	Sédiments graveleux moyens
6	Indice de fracturation moyen
7	Sédiments a grains fins
8	Indice de fracturation faible
9	Non-aquifère

N.B.: Une subdivision plus detaillée est possible selon la classification des sols pour déterminer la vulnerabilité (voir Vrba and Zaporozec 1994, Tableau A1a)

III C Grundwasserleiter und Sichtraster (s. Vrba und Zaporozec 1994, Tab. A2)

1	Verkarstet
2	Grobkörnige, kiesige Sedimente
3	Hoher Klüftungsgrad
4	Erhöhter Verkarstungsgrad
5	Kiesig-sandige Sedimente
6	Mittlerer Klüftungsgrad
7	Feinkörnige Sedimente
8	Geringer Klüftungsgrad
9	Grundwassernichtleiter

Beachte: Aufgrund der Bodenklassifikation ist eine weitere Unterscheidung der Verschmutzungsempfindlichkeit möglich (s.Vrba und Zaporozec 1994, Tab. A1a)

III D Artefacts et objets anthropiques

Cette légende spéciale se base principalement sur les données présentées dans la section I de cette légende modèle. Le schéma des couleurs dur les cartes de vulnérabilité ainsi que la finalité de ces cartes demandent des symboles supplémentaires surtout pour les objets anthropiques. Les symboles supplémentaires et leurs couleurs suivent les recommandations données en section I.

III D Maßnahmen des Menschen

Diese spezielle Legende gründet sich weitgehend auf die Symbolik des Teils I der Standardlegende. Aufgrund des für Grundwasserverschmutzungsempfindlichkeits karten verwendeten Farbschemas der Flächenfarben und der speziellen Zielstellung dieser Karten werden über den Abschnitt I D 4 hinausgehende, zusätzliche Symbole für Maßnahmen des Menschen eingeführt. Weitere Symbole sollten mit ihrer Symbolik und Farbgebung den Empfehlungen im Teil I folgen.

1 Objects of protection

1.1 Important undeveloped spring


1.2 Important spring developed for potable water supply

1.3 Thermal (T) and/or mineral (M) spring (or group of springs)


1.4 Source protection zone (the delineation of source protection zones will depend upon local practice and/or legislation)


1.5 Site of ecological importance, e.g. wetland

1.6 Well (L = multi-layered aquifer system)


a) industrial and/or agricultural water supply


b) potable water supply

1.7 Well field (L = multi-layered aquifer system)


a) industrial and/or agricultural water supply


b) potable water supply


1.8 Groundwater recharge site


1.9 Fenced perimeter of groundwater development works

1.10 Drainage tunnel/trench for water development

1.11 Aqueduct


1.12 Underground storage for potable water


1.13 Water tower for potable water

2 Potentially polluting activities

colour: red (ITC No. 660)

1	Objets à protéger	1	Zu schützende Objekte
1.1	source importante, non-captée	1.1	Bedeutende, nicht genutzte Quelle
1.2	source importante, captée pour l'approvisionnement en eau	1.2	Bedeutende, für die Trinkwasser-versorgung gefaßte Quelle
1.3	source thermale (T) et/ou minérale (M), groupe de sources	1.3	Thermalquelle (T) und/oder Mineral-quelle (M) bzw. -Quellengruppe
1.4	zone de protection de source (selon les règlements locaux et/ou la législation)	1.4	Quellenschutzgebiet (Ausweisung des Quellenschutzgebietes aufgrund örtlicher Vorgaben und/oder Gesetzgebung)
1.5	aire d'importance écologique, p.ex. zone humide	1.5	Gebiet mit ökologischer Bedeutung, z.B. Feuchtgebiet
1.6	puits (L = aquifère multicouche) a) pour l'approvisionnement industriel et/ou agricole b) pour l'approvisionnement en eau potable	1.6	Brunnen (L = Mehrschicht-Grundwasserleiter) a) industrielle und/oder landwirtschaftliche Wasserversorgung b) Trinkwasserversorgung
1.7	champs de puits (L = aquifère multicouche) a) pour l'approvisionnement industriel et/ou agricole b) pour l'approvisionnement en eau potable	1.7	Brunnenfeld (L = Mehrschicht-Grundwasserleiter) a) industrielle und/oder landwirtschaftliche Wasserversorgung b) Trinkwasserversorgung
1.8	site d'alimentation artificielle d'eau souterraine	1.8	Anlage zur Grundwasseranreicherung
1.9	périmètre cloturé de captage de l'eau	1.9	Eingezäunter Bereich von Wasserfassungsanlagen
1.10	fossé ou tunnel de captage de l'eau souterraine	1.10	Dränagegraben bzw. -tunnel zur Wasserfassung
1.11	conduite d'eau, aqueduc	1.11	Wasserleitung, Aquädukt
1.12	réservoir souterrain d'eau potable	1.12	Untergrundspeicher für Trinkwasser
1.13	château d'eau, réservoir d'eau potable	1.13	Wasserturm, Hochspeicher für Trinkwasser
2	Artefacts et activités anthropiques potentiellement polluants	2	Potentiell verschmutzende Anlagen und Maßnahmen
	couleur: rouge (ITC No. 660)		Farbe: Rot (ITC No. 660)

2.1 Highway, motorway, railway

2.2 Urban area or similar, no sewerage network

2.3 Urban area or similar, with sewerage network

2.4 Main sewer trunk line

2.5 Collection point for non-treated urban and/or industrial sewage

2.6 Treatment plant for urban wastewater (figure indicates primary, secondary, tertiary treatment)

2.7 Poisonous and/or noxious liquid waste spill point, accidental or illegal

2.8 Treatment plant for poisonous and noxious wastes (PNW) and similar

2.9 Treatment plant for urban solid wastes (USW) and similar

2.10 Waste disposal (figure or letter indicates class of site - they will be classified according to national legislation)

2.11 Animal husbandry with indication of number of units of manure

2.12 Manure and/or livestock waste storage

2.13 Chemical storage or stockpile

2.14 Chemical factory/refinery

2.15 Oil or fuel storage, garage, service station and/or mechanical workshop

2.16 Pipeline (letter indicates nature of fluid, e.g. G = gas, P = petroleum, C = chemicals, etc.)

2.1	autoroute, route, voie ferrée	2.1	Autobahn, Straße, Gleisanlage
2.2	zone habitée ou urbaine sans réseau d'assainissement	2.2	Stadt- oder Siedlungsgebiet ohne Abwassernetz
2.3	zone habitée ou urbaine avec réseau d'assainissement	2.3	Stadt- oder Siedlungsgebiet mit Abwassernetz
2.4	égout principal	2.4	Hauptabwasserleitung
2.5	point de collecte d'eaux usées urbaine et/ou industrielle	2.5	Sammelpunkt für ungeklärte städtische und/oder industrielle Abwässer
2.6	site de traitement d'eaux usées urbaines et/ou industrielles (nombres indiquant le degré de traitement primaire, secondaire ou tertiaire)	2.6	Kläranlage für städtische und/oder industrielle Abwässer (Ziffern symbolisieren primäre, sekundäre, tertiäre Klärung)
2.7	point de décharge de fluides toxiques et/ou dangereux, accidentel ou illégal	2.7	Austrittspunkt giftiger und/oder gefährlicher, flüssiger Abfälle, infolge Unfalls oder illegal
2.8	installation de traitement de polluants toxiques et/ou dangereux (PNW)	2.8	Aufbereitungsanlage für giftige und/oder gefährliche Abfallstoffe (PNW)
2.9	installation de traitement de déchets solides urbains (USW)	2.9	Aufbereitungsanlage für feste, städtische Abfallstoffe (USW)
2.10	décharge (nombre ou lettre indiquant le type selon la législation nationale)	2.10	Deponie (Ziffer bzw. Buchstabe symbolisiert Art der Deponie, aufgrund nationaler gesetzlicher Vorschriften)
2.11	élevage de bétail	2.11	Tierzucht mit Angabe der Dung- oder Bestandseinheiten
2.12	fosse à purin	2.12	Dung- bzw. Jauchebehälter
2.13	stockage de produits chimiques	2.13	Lagerung von Chemikalien
2.14	usine chimique, raffinerie	2.14	Chemiefabrik, Raffinerie
2.15	réservoir de pétrole ou carburant, station et/ou atelier mécanique	2.15	Öl- oder Treibstoffbehälter, Werkstatt, Tankstelle und/oder mechanischer Betrieb
2.16	conduite (lettre indiquant le liquide contenu, p.ex. G = gaz, P = pétrole, C = produits chimiques)	2.16	Fernleitung, Pipeline (Buchstabe symbolisiert Leitungsinhalt, z.B. G = Gas, P = Treibstoff, C = Chemicalien)

2.17 Disposal well, cesspool, septic tank

2.18 Thermoelectric power plant

2.19 Nuclear power plant

2.20 Military installations

2.21 Airfield

2.22 Slaughter-house

2.23 Hospital

2.24 Cemetery

2.25 Industry with organic biological effluents and/or wastes (S = linked to urban sewerage)

2.26 Industry with marginally biodegradable biological effluents and/or wastes (S = linked to urban sewerage)

2.27 Industry with inorganic effluent and/or wastes (S = linked to urban sewerage)

2.28 Active quarry (P = excavation to piezometric surface)

2.29 Abandoned quarry (P = excavation to piezometric surface)

2.30 Filled quarry (P = excavation to piezometric surface)

2.31 Uncontrolled and/or unauthorised landfill (M = solid waste, I = mining and industrial waste)

2.32 Abandoned landfill (uncontrolled), with nature of fill material (e.g. M = mixed solid, I = industrial, P = poisonous or noxious wastes)

2.17	puits perdu, fosse septique	2.17	Schluckbrunnen, Klärgrube, Kloake
2.18	centrale électrique thermique	2.18	Wärmekraftwerk
2.19	centrale nucléaire	2.19	Kernkraftwerk
2.20	zone militaire	2.20	Militärisches Gelände
2.21	aéroport	2.21	Flugplatz
2.22	abattoir	2.22	Schlachthof
2.23	hôpital	2.23	Krankenhaus
2.24	cimetière	2.24	Friedhof
2.25	industrie avec déchets liquides et/ou solides, bio-organiques (S = reliée au réseau d'égouts urbain)	2.25	Industrie mit flüssigen und/oder festen, biologisch-organischen Abfällen (S = mit Anschluß an städitsches Abwassernetz)
2.26	industrie avec déchets liquides et/ou solides, biodégradables (S = reliée au réseau d'égouts urbain)	2.26	Industrie mit flüssigen und/oder festen, z.T. abbaubaren biologischen Abfällen (S = mit Anschluß an städtisches Abwassernetz)
2.27	industrie avec déchets liquides et/ou solides, organiques (S = reliée au réseau d'égouts urbain)	2.27	Industrie mit flüssigen und/oder festen, anorganischen Abfällen (S = mit Anschluß an städtisches Abwassernetz)
2.28	carrière en activité (P = excavation atteignant le niveau piézométrique)	2.28	Steinbruch, in Betrieb (P = Abbau bis zur Grundwasseroberfläche)
2.29	carrière abandonnée (P = excavation atteignant le niveau piézométrique)	2.29	Aufgelassener Steinbruch (P = Abbau bis zur Grundwasseroberfläche)
2.30	carrière comblée (P = excavation atteignant le niveau piézométrique)	2.30	Verfüllter Steinbruch (P = Abbau bis zur Grundwasseroberfläche)
2.31	comblement non-controlé et/ou sauvage (M = produits solides, I = terre ou déchets industriels)	2.31	Unkontrollierte und/oder nicht bewilligte Verfüllung (M = fester Abfall, I = Abraum oder Industrieabfall)
2.32	comblement abandonné (non-controlé), lettre indiquant le produit de comblement (p.ex. M = mixte, I = industriel, P = toxiques ou dangereux)	2.32	Altablagerung (nicht kontrolliert), mit Kennzeichnung des Füllmaterials (z.B. M = gemischte, I = industrielle, P = giftige oder gefährliche Abfallstoffe)

2.33 Mine, pit (arrow indicates presence of pumping plant)

2.34 Abandoned and/or improperly constructed well, potential conduit of surface pollution to aquifer(s)

III E Current quality state of groundwater bodies and areal pollution hazards

1 Area with salty groundwater (e.g. seawater intrusion, inland salinization)

2 Area with naturally poor groundwater quality (requiring treatment for potable use)

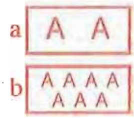
3 Area with groundwater pollution beyond national/international potable limits

4 Area with groundwater pollution due to non-biodegradable organic compounds

5 Area with groundwater pollution due to organic/biological matter

6 Area with groundwater pollution due to inorganic compounds

7 Area of intensive horticultural activity



8 Area of agricultural use
a) limited use of pesticides, fertilizers etc.
b) frequent and abundant use of pesticides, fertilizers etc.

9 Flood irrigation area (e.g. rice field, water meadow)

2.33	mine, excavation à ciel ouvert (la flêche indique une station de pompage)	2.33	Bergwerk, Tagebau (Pfeil symbolisiert Pumpwerk)
2.34	puits abandonné et/ou mal construit (pollution potentielle d'aquifère par la surface)	2.34	Verwilderter und/oder unsauber ausgebauter Brunnen (potentieller Weg für Oberflächenverschmutzung im Grundwasserleiter)

III E Composition chimique de l'eau souterraine et pollutions potentielles étendues	*III E Chemische Beschaffenheit der Grundwasservorkommen und flächenhafte Verschmutzungsgefährdungen*

1	zone d'eau souterraine salée (p.ex. invasion d'eau marine, eau minéralisée continentale)	1	Gebiet mit salzigem Grundwasser (z.B. Meerwasserintrusion, Inlandversalzung)
2	zone d'eau souterraine de qualité naturellement médiocre (nécessitant traitement)	2	Gebiet mit von Natur aus qualitativ schlechtem Grundwasser (Aufbereitung für Trinkwasserzwecke notwendig)
3	zone de pollution de l'eau souterraine (au-dessus des valeurs permises nationales ou internationales)	3	Gebiet mit Grundwasserverschmutzung oberhalb nationaler bzw. internationaler Trinkwassergrenzwerte
4	zone de pollution par des produits organiques non-biodégradables	4	Gebiet der Grundwasserverschmutzung durch organische, biologisch nicht abbaubare Stoffe
5	zone de pollution par des produits organiques et biologiques	5	Gebiet der Grundwasserverschmutzung durch organisch-biologische Stoffe
6	zone de pollution par des produits minéraux	6	Gebiet der Grundwasserverschmutzung durch anorganische Stoffe
7	zone d'horticulture intensive	7	Gebiet mit intensivem Obstbau
8	zone agricole a) application restreinte de pesticides, d'engrais, etc. b) application fréquente et intensive de pesticides, d'engrais, etc.	8	Gebiet landwirtschaftlicher Nutzung a) eingeschränkte Anwendung von Pestiziden, Düngemitteln usw. b) häufige und starke Anwendung von Pestiziden, Düngemitteln usw.
9	zone d'irrigation par submersion (p.ex. rizière, prairie innondée)	9	Überstau-Bewässerungsgebiet (z.B. Reisfeld, Flutungsgrünland)

—4—	10	Isoline defining contamination, with related value (units must be specified in the Legend, e.g. µg/l or mg/l)

10	ligne d'isovaleurs de la pollution (unités à expliquer dans la légende, p.ex. µg/l, mg/l)	10	Isolinie der Verschmutzung, mit entsprechenden Werten (Einheiten müssen in der Legende angegeben werden, z.B. µg/l or mg/l)

Plate I

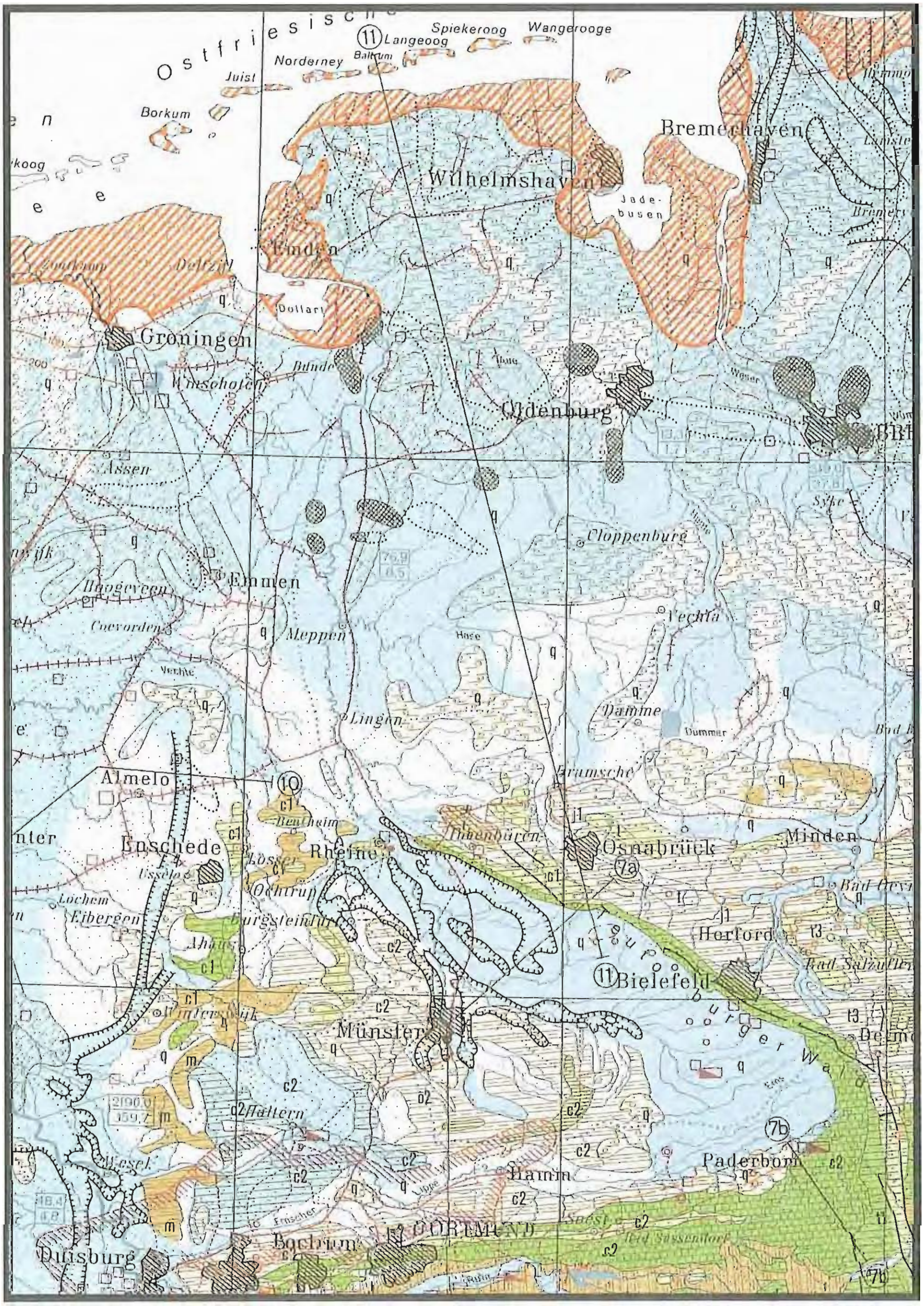

Spiekeroog
Wangerooge
Langeoog
Norderney
Juist
Borkum
Bremerhaven
Wilhelmshaven
Jadebusen
Emden
Dollart
Groningen
Winschoten
Oldenburg
Assen
Cloppenburg
Emmen
Hoogeveen
Coevorden
Meppen
Vechta
Lingen
Damme
Dümmer
Almelo
Bramsche
Bentheim
Enschede
Rheine
Ibbenbüren
Osnabrück
Minden
Ochtrup
Eibergen
Herford
Burgsteinfurt
Bielefeld
Bad Salzuflen
Münster
Haltern
Paderborn
Wesel
Hamm
Soest
Duisburg
Bochum
DORTMUND
Teutoburger Wald

Plate I. Part of the International Hydrogeological Map of Europe at scale 1:1500000, Sheet C4 Berlin (Legend)

Groundwater and rocks

Aquifers in which flow is mainly intergranular

extensive and highly productive aquifers

local or discontinuous productive aquifers or extensive but only moderately productive aquifers

Fissured aquifers, including karst aquifers

extensive and highly productive aquifers

local or discontinuous productive aquifers, or extensive but only moderately productive aquifers

Strata (granular or fissured rocks) forming insignificant aquifers with local and limited groundwater resources or strata with essentially no groundwater resources

minor aquifers with local and limited groundwater resources

strata with essentially no groundwater resources

Lithology (selected ornaments)

Alluvial sand and gravel deposits

Sand and gravel with boulder clay and silt

Chalk and limestone

Sandstone

Sandstone and claystone

Marl and claystone

Signs and symbols (selected)

Area of sea water intrusion

Artificial recharge plant

Area of deep mining

Salt diapir

Quarternary subglacial channel

c2 Stratigraphic symbol (Upper Cretaceous)

Plate II

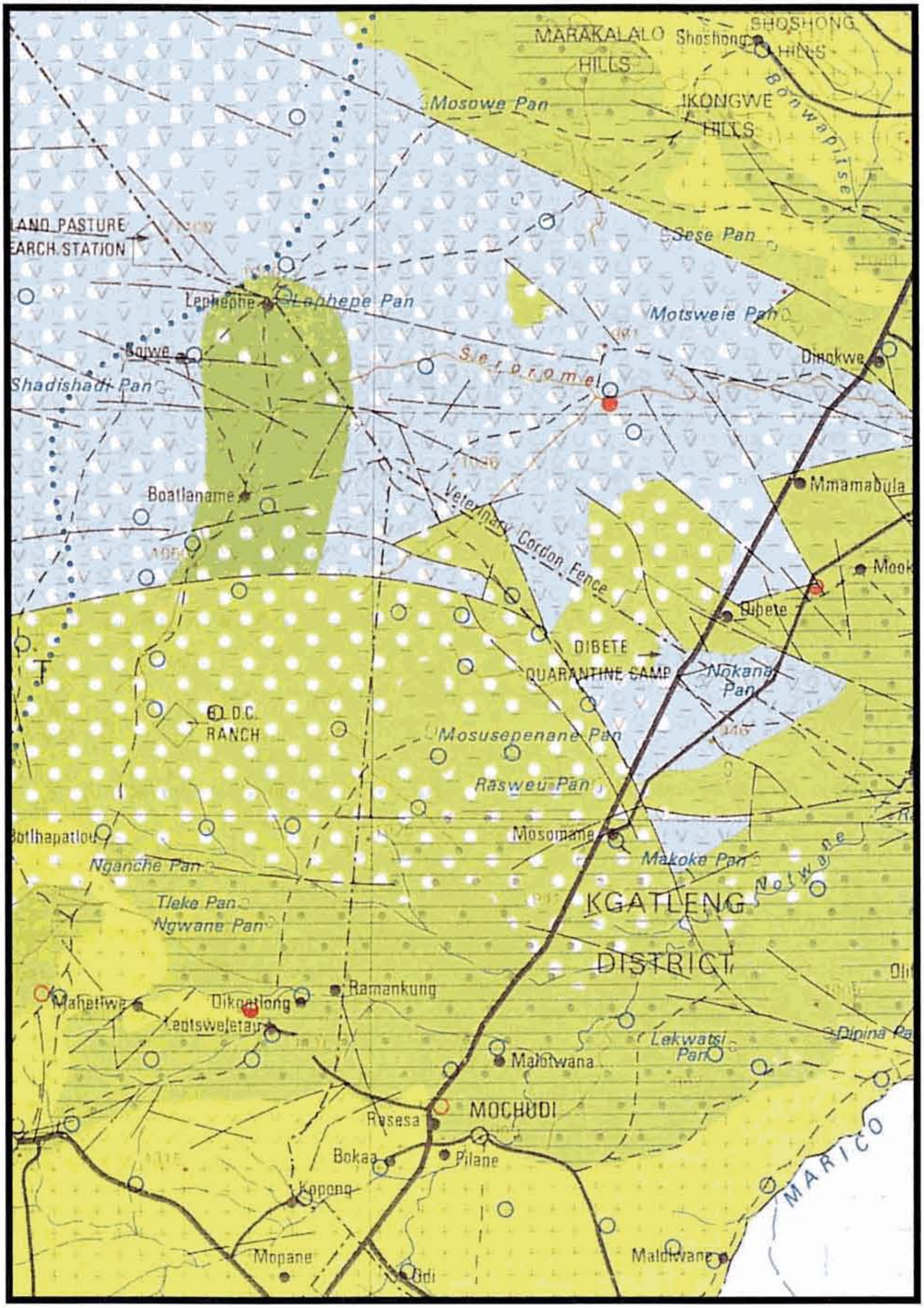

MARAKALALO HILLS
Shoshong
SHOSHONG HILLS
Mosowe Pan
IKONGWE HILLS
Bonwapitse
LAND PASTURE
EARCH STATION
Sese Pan
Lephephe
Lephepe Pan
Motsweie Pan
Dinokwe
Sojwe
Shadishadi Pan
Seroromel
Boatlaname
Mmamabula
Veterinary Cordon Fence
Mook
Dibete
DIBETE QUARANTINE CAMP
Nokana Pan
B.D.C. RANCH
Mosusepenane Pan
Rasweu Pan
Botlhapatlou
Mosomane
Nganche Pan
Makoke Pan
Notwane
Tleke Pan
Ngwane Pan
KGATLENG DISTRICT
Mahetlwe
Dikgatlong
Ramankung
Lentsweletau
Lekwatsi Pan
Dipina Pa
Malotwana
MOCHUDI
Rasesa
Bokaa
Pilane
Kopong
MARICO
Mopane
Odi
Malolwane

Plate II. Part of the Map of Groundwater Resources of the Republic of Botswana at scale 1:1000000 (Legend)

1. Groundwater resources potential

regular recharge | occasional or no recharge

high and uniform

fair and uniform

high, but variable

fair, but variable

generally poor, but locally fair

2. Lithology

(combinations of ornaments possible)

basalt

sandstone

arkose, mudstone, coal

quartzite, shale, conglomerate

igneous and metamorphic rocks

3. Special symbols

a. Groundwater

Quality and potability of water (based on TDS only)

fresh, generally potable (TDS < 1500 mg/l)

slightly saline, marginally potable (TDS 1500 - 5000 mg/l)

moderately saline, suitable for livestock (TDS 5000 - 10000 mg/l)

highly saline, generally unsuitable (TDS > 10000 mg/l)

b. Surface water features (selected)

ephemeral river

pan

surface water divide

c. Geology and topography (selected)

geological boundary

fault

fossil river bed

prominent hill

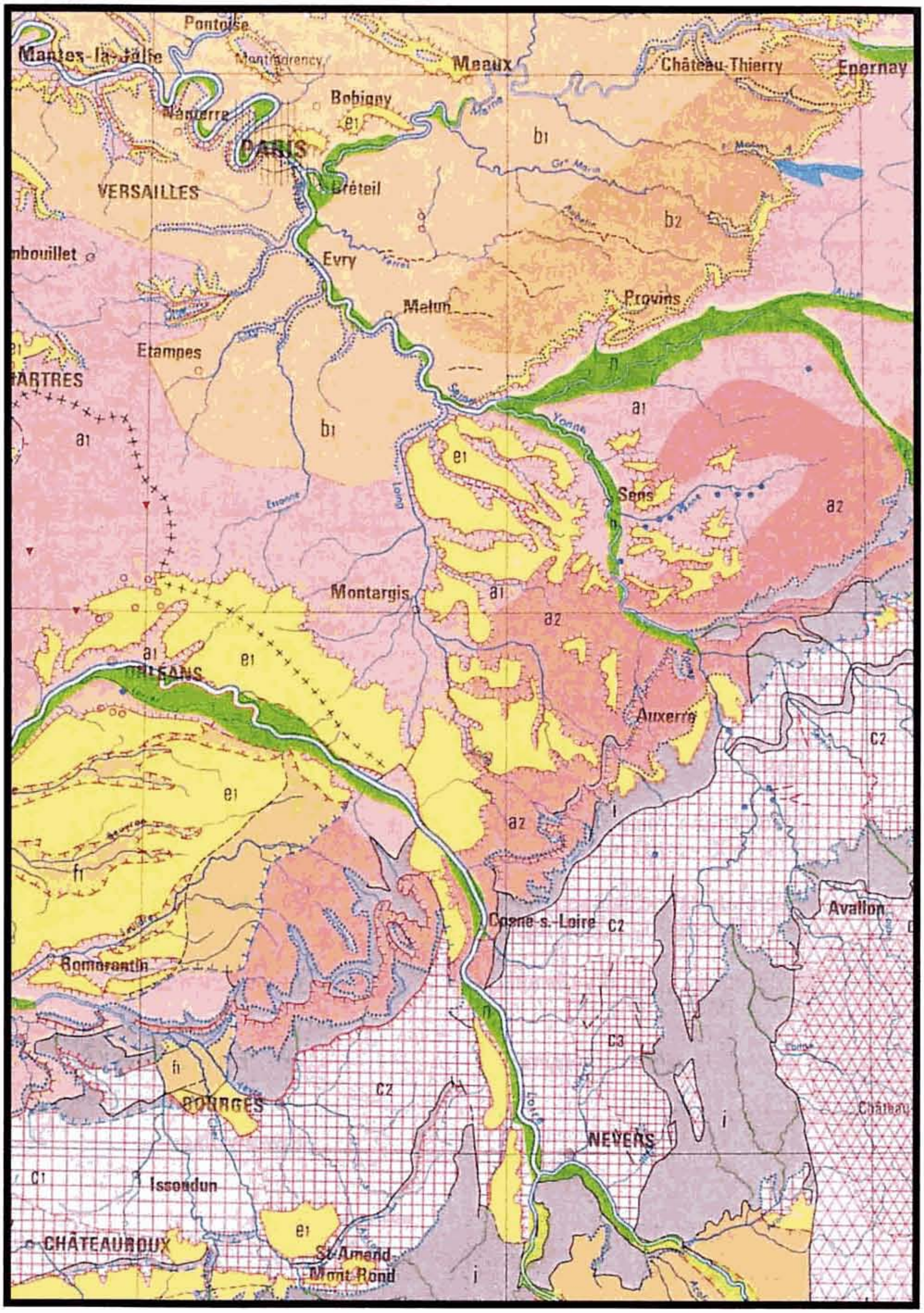
international boundary

town, village

road

track

Plate III



Pontoise
Mantes-la-Jolie
Montmorency
Meaux
Château-Thierry
Epernay
Bobigny
Nanterre
PARIS
VERSAILLES
Créteil
Evry
Melun
Provins
Etampes
Sens
Montargis
ORLÉANS
Auxerre
Romorantin
Cosne-s.-Loire
Avallon
BOURGES
NEVERS
Issoudun
CHÂTEAUROUX
St-Amand
Mont-Rond

Plate III. Part of the Hydrogeological Map of France at scale 1:1500000 (carte des systèmes aquifères) (Legend)

a. Recharge areas of aquifer systems

mm/year <100 100-200 200-500 500-1000 >1000

Continuous aquifer

Multilayered aquifer

Discontinuous aquifer, flat lying

Discontinuous, folded aquifer

Discontinuous basement aquifer

Semi-permeable covering layer, single aquifer

Semi-permeable formations recharging multilayered aquifers

b. Discharge areas

Discharge area, unconfined water table

Discharge area, confined groundwater

Fresh water body in hydraulic continuity with an aquifer

c. Low permeability formations

Cover above confined deep aquifer

Area without aquifers

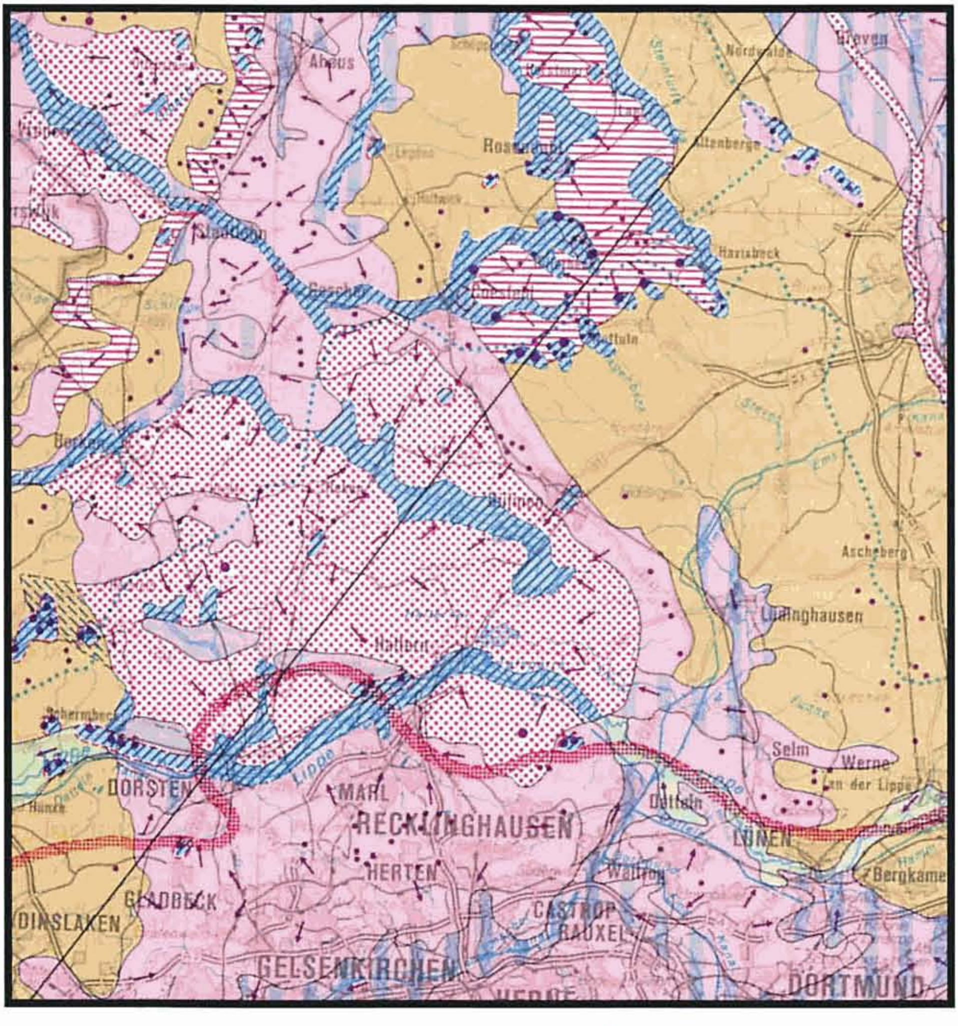
Complex area (chiefly mountainous)

d. Alluvial aquifers

Alluvial aquifer independent of surface water bodies

Alluvial aquifer closely related to surface water body

Plate IV


Ahaus
Greven
Havixbeck
Ascheberg
Haltern
Selm
Werne
an der Lippe
DORSTEN
MARL
RECKLINGHAUSEN
HERTEN
CASTROP
RAUXEL
GELSENKIRCHEN
DORTMUND
Lippe

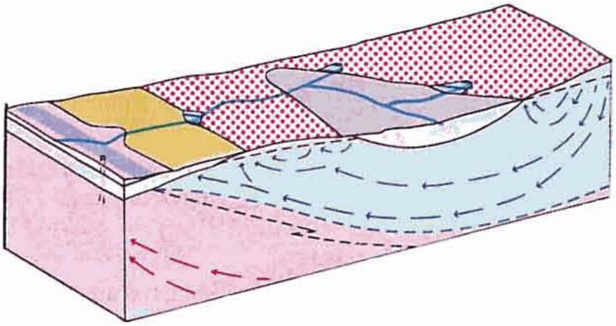


Plate IV. Part of the Map of groundwater flow systems of the Münsterland Basin at scale 1:500000 (Legend)

Regional and sub-regional systems

1. Recharge areas

1.1 Area with high recharge

a. high, regular and continuous flux in porous aquifers

b. high, irregular and discontinuous flux in fissured and karst aquifers

c. fair and irregular but continuous flux in multilayered aquifer systems

1.2 Area with low recharge

2. Transit areas of flow systems

2.1 Transit area (only lateral flow)

2.2 Transit area with overlying shallow local flow systems

3. Discharge areas

3.1 Discharge at surface
a) fresh groundwater
b) mineralized water

3.2 Deep, buried discharge to an overlying aquifer

Local, shallow groundwater systems

4. Areas with numerous shallow and minor groundwater systems

4.1 Area with shallow groundwater flow in hydraulic continuity with surface water bodies

4.2 Area with very low groundwater flow

Boundaries of groundwater flow systems

Fixed boundary
a) outcropping
b) buried

Hydrodynamic boundary
a) natural
b) artificial

Springs and withdrawal

Large spring
a) fresh water
b) mineralized water

Artesian well
a) fresh water
b) mineralized water

Direction of groundwater flow

a) uppermost system
b) deep flow system

Surface water bodies

Perennial stream

Periodical stream

Surface water divide

Types of flow systems in the perspective diagram

Fresh groundwater system

Saltwater and brine systems

Area with very low permeability (natural boundaries of flow systems)

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Hydrogeological maps are synoptic representations of the features related to geology, groundwater and surface water. They are useful tools for planning, as they show the situation of groundwater features and characteristics in relation to topography.

This book is composed of two parts: Part I contains a methodological guide on the preparation of hydrogeological maps; Part II is an international standard legend with a catalogue of colours, signs and symbols explained in English, French and German. The volume is, therefore, both a textbook and a toolbox.

The guide and the standard legend assist map makers in preparing hydrogeological maps and to harmonize the format and representation of hydrogeological maps. They also help map users to understand and fully grasp the information provided on hydrogeological maps.

The book is a joint publication of IAH, IAHS, CGMW und Unesco. It is based on experience in hydrogeological mapping all over the world, and presents a comprehensive follow-up of the international legends published in 1970 and 1983, now out of print. Numerous mapping experts of the IAH and CGMW commissions on hydrogeological mapping have contributed to the book in the frame of projects M-1.2(a) and M-1.3 of Unesco's International Hydrogeological Programme, Phase IV.

The guide and standard legend complement the 'Guidebook on Mapping Groundwater Vulnerability', recently published as Volume 16 of this series 'International Contributions to Hydrogeology'.

It is hoped that this guidance material will be helpful to map makers and users at regional, national and international levels.

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