United Nations
Educational, Scientific and
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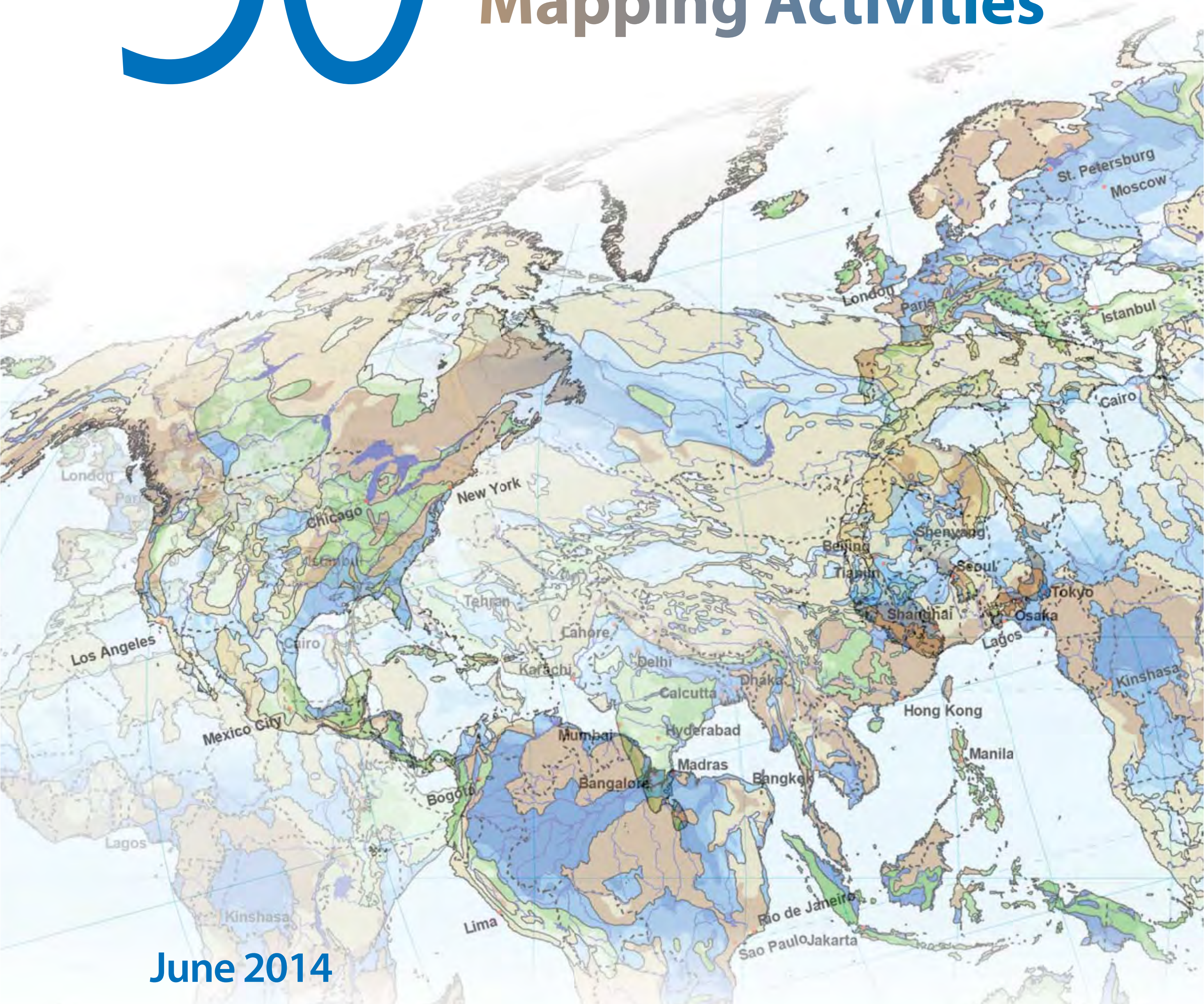
International
Hydrological
Programme

50 Years of Hydro(geo)logical Mapping Activities



June 2014

A Report by W.H. Gilbrich and W.F. Struckmeier

in cooperation with A. Richts, K. Duscher, A. Günther, U. Philipp and P. Winter

50 Years of Hydro(geo)logical Mapping Activities

Under the auspices of UNESCO, CGWM, IAH and BGR

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Acronyms

AAC	African Association for Cartography
ACSAD	Arab Center for the Studies of Arid Zones and Dry Lands
AOCRS	African Organisation for Cartography and Remote Sensing
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BRGM	Bureau de Recherches Géologiques et Minières
CGMW	Commission for the Geological Map of the World
COHYM	IAH Commission on Hydrogeological Maps
CPRM	Serviço Geológico do Brasil
DNPM	Departamento Nacional da Produção Mineral
ESRI	Environment Systems Research Institute
FAO	Food and Agriculture Organisation
GIS	Geographic Information System
GRDC	Global Runoff Data Center
IAEA	International Atomic Energy Agency
IAH	International Association of Hydrogeologists
IAHS	International Association for Hydrological Sciences
IASH	International Association of Scientific Hydrology (former name of the IAHS)
ICID	International Commission on Irrigation and Drainage
ICSI	International Commission on Snow and Ice
ICSU	International Council of Scientific Unions
IGCP	International Geological Correlation Programme / International Geoscience Programme
IGME	International Geological Map of Europe
IGN	Institut Géographique National (France)
IGRAC	International Groundwater Resources Assessment Center
IGY	International Geophysical Year
IHD	International Hydrological Decade
IHME	International Hydrogeological Map of Europe
IHP	International Hydrological Programme
ILH	Internationales Landkartenhaus
ISARM	Internationally Shared Aquifer Resources Management Programme
IUGS	International Union for Geological Sciences
IYPE	International Year of Planet Earth
NGO	Non Governmental Organisation
OACT	Organisation Africaine de Cartographie et de Télédétection
OHP	Operational Hydrological Programme (of the WMO)
TDH	Technical Document in Hydrology (UNESCO)
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WMO	World Meteorological Organisation
WHO	World Health Organisation
WHYMAP	World-Wide Hydrogeological Mapping and Assessment Programme

People world-wide are using hydrological maps, often much simplified, for the transfer of knowledge from scientists to politicians and to the general public, because maps deliver an idea of hydrological processes and of trends much better than only numerical presentations.

Foreword

St. Petersburg
Moscow
London
Paris
Istanbul
Cairo
New York
Chicago
Los Angeles
Mexico City
Tehran
Lahore
Karachi
Delhi
Calcutta
Dhaka
Mumbai
Hyderabad
Madras
Bangalore
Bangkok
Beijing
Tianjin
Shenyang
Seoul
Shanghai
Tokyo
Osaka
Lagos
Kinshasa
Hong Kong
Manila
Bogota
Lima
Rio de Janeiro
Sao Paulo
Jakarta
Buenos Aires
Santiago
Sydney

Despite the Cold War which splitted the World into hostile blocks with political and military tensions, open and secret negotiations permitted to launch a truly international venture, the International Geophysical Year (IGY) from mid 1957 until the end of 1958. The IGY extended until the end of 1959 with 67 countries cooperating in fields like meteorology, oceanography, polar glaciology etc. and turned out to be such a success that it served as a model for other international research programmes. Making use of the momentum of the IGY and using again the UN system as a carrier a vast international programme on water sciences was suggested, then negotiated and finally conceived by world top scientists and with the active support of leading politicians. During the early nineteen sixties an agreement could be found to create an international programme on the hydrology of inland waters. UNESCO was entrusted with the execution and was encouraged to ensure the cooperation of other UN Agencies, particularly the WMO, but also of recognised non-governmental organisations such as the IASH (later IAHS) and the IAH. The experience from the IGY had shown that a longer time span was needed for successful execution and a ten years period, a decade, was agreed upon. Another important change had to be taken into account, the emergence of a large number of new independent countries, often former colonies, and the new programme had also to serve the requirements of these new nations. UNESCO provided the logistic basis for the new programme so that the International Hydrological Decade (IHD) could start in 1965.

The International Hydrological Decade (1965 – 1974) constituted a world-wide effort to advance the hydrological sciences and to incorporate hydrological activities into the national water resources administrations and into the university educational programmes.The aim was to introduce hydrology as a new independent science on almost all aspects concerning water such as linked with meteorology, surface water bodies, soil sciences, geology, groundwater, physics, chemistry and the influence of man, practically all forms and movements of water over, on and in the upper layers of the earth. A clear definition of hydrology often has been tried but never suceeded. To understand the processes turned out even more difficult, and a well-known Dutch hydrologist felt that to become a hydrologist either required life-long studies or divine inspiration.

It was evident that a Decade could not cope with all aspects and all variations from polar to moderate, to arid, tropical, inland and coastal aspects. This explains why, during the first years of the IHD, the IHD Council was in a permanent search for the most important hydrological processes, rejected some of them, included other ones. This could be understood as an instability but in reality those topics needed to be found which an international programme efficiently could treat. Some processes at that time could not be treated due to lack of data or instrumentation, other ones had to be eliminated because of the time needed for execution. A good example is the project "Representative and Experimental Basins" for which at least thirty years would have been required, far too long for a Decade. Other themes like the world water balance with the technical means of that time had to be reduced to the discharge of the major rivers and there are many examples that the inital programme had to be changed, that the wishful had to be replaced by the feasable.

Coming back to the IHD, the Council defined eight major scientific fields and added an educational component making nine fields. Some fields later were modified, enlarged or reduced or even abandoned, other ones (water quality, hydrobiology) were added. The IHD Council met annually and at each session modified programme and priorities. It also created sub-programmes or individual small projects (hydrology of saline inland water, aquatic vegetation etc.) for execution by small expert panels. Hence, it is difficult to provide a clear picture within a few lines.

As a kind of coverage the IHD established a tenth programme on mapping in order to visualise the hydrological processes. The aim was to arrive at a better understanding of the hydrological cycle, its components and its interferences. Working Groups and Expert Panels worked on the various aspects and subjects and issued publications.

These few lines are not meant as a description of the IHD but to raise an understanding why the covering project on hydrological mapping necessarily had to follow the Council's priorities. There were stable elements such as hydro-meteorological maps (entirely under the umbrella of the WMO) or groundwater mapping, at least what the term meant at that time. Other aspects such as surface water bodies: river discharge turned out so difficult for mapping that in the end only one publication resulted. Looking back, WMO took over the hydrometeorological part, UNESCO-IHD closed the field of surface water maps, and finally the groundwater maps occupied UNESCO-IHP and the IAH as a dominating enterprise. This programme encompassed the natural hydrogeology as well as the human influences.

At the end of the IHD hydrologists became aware that although a good start had been made a follow-up and continuation was needed. UNESCO therefore decided to extend the Decade (or IHD) beyond 1974 and created the International Hydrological Programme (IHP), subdivided into thematical sections, called phases, of six years duration each. Both programmes, the IHD and the IHP, enjoyed the cooperation of a number of international organisations, both governmental and non-governmental. In view of their great impact, the World Meteorological Organisation (WMO), the International Association of Hydrological Sciences (IAHS), the International Association of Hydrogeologists (IAH), and the ICID (International Commission on Irrigation and Drainage) deserve particular mentioning, but the input from the FAO and the IAEA should not be underestimated. Later the WHO played an important role.

The IHD Council was aware that a picture speaks more than a thousand words and a map more than a thousand pictures. Maps therefore have become an indispensable tool for water scientists and professionals to document data and describe hydrological situations. The art of hydrological mapping has developed historically from geographical, meteorological and geological mapping.

This decision was facilitated by the existence of mapping programmes of WMO and some scientific associations, particularly the IAHS and the IAH and the Commission for the Geological Map of the World (CGMW). The decision was supported by relevant national institutions (particularly geological services) who already had embarked on the production of national maps. They had developed test maps and legends so that the IHD could base its work on a rich treasure of national experience. The work of the CGMW opened the gate towards regional cooperation with Geological Surveys and global mapping and delivered the basic tools and the know-how for the map compilations, particularly appropriate base maps and legends.

During the 1960s and 1970s a great deal of progress was made in the field of hydrogeological mapping. Efforts were made to develop a methodology, to compile model legends, and to print small-scale maps. UNESCO, IAH, and IAHS joined forces and a number of continental, regional, and national maps resulted from their cooperation. Particular milestones were the 1970 *International Legend for Hydrogeological Maps* and in 1977 the UNESCO/WMO publication *Hydrological Maps*. The present report will show how these basic and early publications fertilized the actual mapping programmes and how, later, these mapping projects enabled the compilation of newer, modern guidance material in form of books and legends. Both, actual mapping and conceiving international publications cannot be separated, they cross-fertilized.

These national experiences but also the broadening of scientific work from a national activity to regional and finally even global assessment of water resources favoured the work of the various bodies created under IHD and IHP. The symbiosis of several scientific fields fostered an increasing political interest and occupied UNESCO over more than fifty years. These five decades saw periods of high productivity, action valleys and new efforts. They also reflect the changes of scientific fields and interests and new developments during this long time span, new political issues and new technologies. Water and the whole environment, originally largely scientific issues, became politically driving forces. People world-wide are using hydrological maps, often much simplified, for the transfer of knowledge from scientists to politicians and to the general public, because maps deliver an idea of hydrological processes and of trends much better than only numerical presentations.

The various activities of numerous panels and working groups on the development, harmonization and standardization of hydrological and hydrogeological maps in which UNESCO was involved for more than fifty years are worth being documented and archived. Therefore, the present report has been compiled.

UNESCO owes thanks and acknowledgements to the hundreds of scientists, to all organisations involved and last not least to the generosity of donors, because mapping is a costly affair. Fortunately, each of the periods of high productivity found outstanding personalities who devoted their time and energy to

develop mapping technologies, mostly far beyond the usual cooperation work.

The programmes doubtlessly benefitted from the fact that two persons almost throughout the reporting period devoted their continuous services to the various mapping projects, Mr. W.F.Struckmeier from the German Federal Institute for Geosciences and Natural Resources (BGR) at Hannover, and Mr.W.H.Gilbrich from the UNESCO Secretariat and he even continued for a long time after his retirement. Both main authors are looking back on almost half a century of scientific hydrological and hydrogeological mapping projects and on the development of the respective tools in form of guides, teaching materials and legends. They both feel obliged to give honour and to express friendly feelings to all the scientists who contributed to the world-wide achievements in hydro(geo)logical mapping, tools, guides, legends and regional maps. They particularly remember the difficult times of political tensions and how the scientists from East and West, North and South formed a brotherly community in the spirit of friendship. They feel it a duty to commemorate fifty years of fruitful work and to share the pride of the cooperating scientists.

The Report consists of three major parts, on (1) Hydrological Maps, General Issues and Surface Water Maps, on (2) Groundwater Maps, Tools and Results and (3) the World-wide Hydrogeological Mapping Assessment Programme WHYMAP. An Annex contains the list of relevant literature and of meetings and their participants, to the extent names could be still found in reports and files. Unfortunately, many of the official files and archives have not survived and the two authors often had to rely on the personal collections and diaries. Ideally, nobody should have been forgotten, but the authors would enjoy receiving additional information if corrections are required.

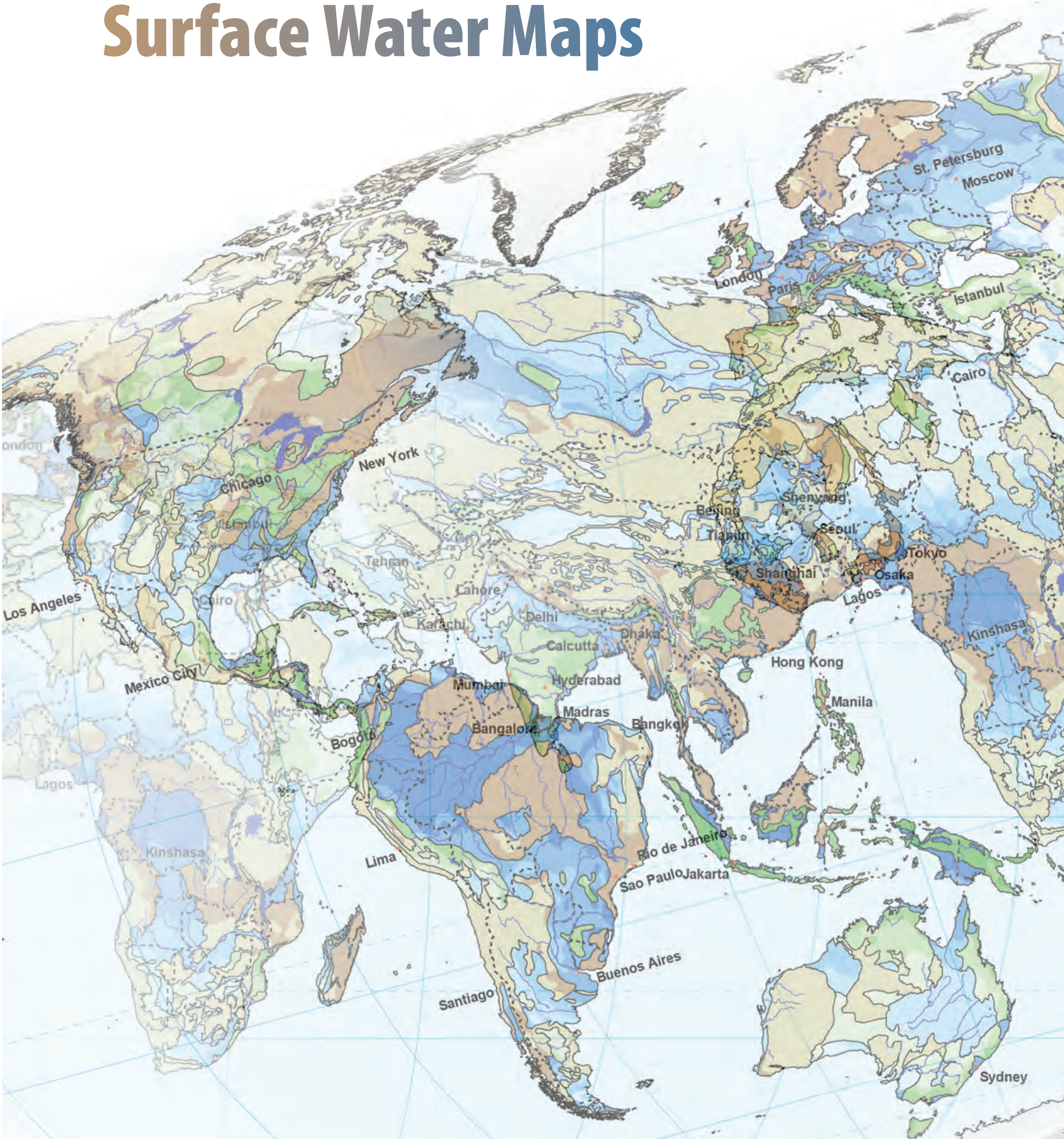
The authors are aware of gaps and omissions and they apologise for missing entries.

The Annex to this Report constitutes an effort, an attempt, to record as many meetings as possible as well as the names of the participants. The list provides an impressive picture of a world-wide participation, thus ensuring that the requirements of the developing countries were fully taken into account.

This Report has been conceived with the consent and active cooperation of UNESCO and its staff.

Hannover and Paris, May 2014

1. Hydrological Maps, General Issues and Surface Water Maps



1.1 Initial Remarks

The international scientific community had quite different ideas about the contents of a programme on hydrology and the Co-ordinating Council of the IHD selected eight major fields of general international interest and appropriate for execution by an internatinal work system involving UN-Agencies, Non-Governmental Organisations (NGOs), national research and educational institutions and outstanding individual experts. These eight fields also provided the basic platform for the first mapping programme.

When the IHD Council established a Working Group on Hydrological Maps it needed advice from as many scientists as possible from various disciplines, practically from representatives from all the other IHD working groups, particulaly from those concerned with hydrometeorology, the flow of surface water bodies, floods and droughts, and groundwater. This diversity but also the multitude of scientists involved can best be visualised by an excerpt from the basic UNESCO/WMO publication "Hydrological Maps, 1977" in form of the "Acknowledgements" and this summary provides a feeling of the broad basis of the work and the vast facette of contributing persons (see Box at the end of chapter 1).

The initial IHD Working Group became soon aware that two major fields existed which could not easily be unified, surface water maps and groundwater maps. The zone in between, the unsaturated zone, although most important in soil sciences and for the vegetation, from the very beginning was almost omitted but later was taken care of by the FAO. The historical development showed that surface water maps attained high attention in the seventies of the last Century but for several reasons the programme phased out and the whole efforts were directed towards groundwater maps. The publication of the 1977 Guide can be seen as the end of the scientific surface water mapping programme within IHD/IHP.

Given the character of UNESCO as an intergovernmental organisation all work had to satisfy internationally and UNESCO could not embark on national mapping projects. On the other hand, most of the work based on national maps as they not only delivered the data but also the mapping know-how and the legends. The aim always was directed towards internationally applicable guides and legends as well as to the compilation of regional, continental and finally global maps. UNESCO and the scientists involved were aware that these small-scale maps hardly could satisfy practical needs for an individual project but they well lent for an assessment of water resources, their vulnerability and use potential. The climate debate finally appreciated the small-scale maps for a trend review.

A user of a geographical map normally assumes a certain stability of the map contents and a visible similarity between the presented subject and the symbol chosen. Conventions have been accepted, for example oceans always are depicted in blue, high mountains in dark brown, towns by a point symbol the size of it indicating the number of inhabitants. Hydrological maps largely follow this philosophy but in many cases an abstraction cannot be avoided up to the necessity to present invisible hydrological processes such as the so-called surface runoff, an arithmetic expression of two parameters, river discharge and size of the catchment.

Geographical, political, or road maps change only slowly in time, while the hydrological cycle parameters and variables are characterised by movement and instability. The instability of weather charts is well known, therefore, they are being published daily. Rivers are posing greater difficulties since the water level and discharge are also changing almost daily but people are more interested in the location of the streams, in averages and in particular extremes. There a major problem becomes visible, for example a map of innundations normally shows an individual event like a television picture, and nobody knows whether and when an even more extreme event may arrive, so what to map? However, innundation maps play an important role in practice since the administratively fixed innundation areas and frequencies are determining town and country planning and decide on the land utilisation. River flow in arid zones is posing even higher problems because of the greater span between a dry river bed and a devastating flood, and the extreme may be reached in wadis where mapping apart from their location may become meaningless or technically impossible.

1.2 IHD Publication "Hydrological Maps"

The IHD Working Group on Maps, founded in 1965, has been activated only in 1969 under the chairmanship of Mr G. Santing (Netherlands). Both, shortage of appropriate staff in the UNESCO Secretariat but also the difficulty within the IHD-Council to select priority fields for the Working Group explain the delay. The Archives do not contain any longer material concerning the meetings and their participants (see Annex B). One meeting took place at UNESCO House in 1969, others in Freiburg in the South of the Federal Republic of Germany in 1970 and in 1973, always with a changed composition (no longer as IHP Working Group but as a Panel of Authors). The excerpt (such as recorded in the Guidebook of 1977 and reproduced at the end of this Part) shows the large numer of scientists involved, and, of course, only a limited number could be invited by UNESCO to attend the meeting. Freiburg had been chosen for a good reason, because Prof R. Keller could be considered the most competent expert in surface water mapping at his time and also the driving force in the Group, respectively in the Panel. The Working Group established a number of principles for its future work but had to modify its method and aim of work, when the IHD Council in the middle of the Decade changed its priorities and ways of execution and when it decided to replace the Working Group and Panel of Authors by a Panel of Experts as a Subgroup of the IHD Groups on Water Balances and on Groundwater Studies. This Subgroup lost much of its momentum, became inactive for some time but then again recovered and later evolved towards a Panel on Hydrological Maps and then to a Team of Authors for the 1977 Guidebook. These instabilities explain the long time span of almost eight years of work until the final product could be printed by UNESCO and the WMO.

Over years a confusing situation had to be observed, parallel work and stand still because of the absence of a clear policy of the IHD Council. The present report reflects the absence of clear planning goals. The situation also suffered from problems between UNESCO and the WMO and from the question to which extent UNESCO and the NGOs (basically the IAHS and IAH) should take the leading role. As will be shown in Part 2 of this report, the situation improved with the IAH and the BGR and regional cooperations taking over the responsibility with UNESCO assuming often only the guidance and financially supporting the activities to the extent that UNESCO's financial problems permitted a financial input at all. One of the consequences was that hydrometerological mapping disappeared completey from the programme and that the hydrogeological mapping programmes became almost independent.

The newly created Panel held its meeting again in Freiburg from 30 September to 12 October 1973, with the following participants : R.Keller (GER), L.Heindl (USA), N. Rogovskaya (USSR), G.McKay (Canada), P.Newson (UK/WMO) and W.H.Gilbrich (UNESCO). The Panel reiterated the concept for the intended Guidebook and developed an outline. It also assigned authorships for the various chapters, partially from the Panel, partially from outside. Each chapter has been compiled by a team. Today it is impossible to list all contributors, since they have not been mentioned in the Guidebook. As the manuscript evolved small editorial teams met, each time with a slightly different composition. The most important meeting was convened at Wallingford (UK) in 1974. Given the many transformations of the groups, the changing composition and the different chairmanships the compilation of the guidebook met enormous organisational difficulties which only could be overcome thanks to the high dedication of the authors and their contributors.

L.Heindl (USA) developed a conceptual basis for the classification of hydrological maps. The illustration taken from the Guidebook provides an idea of the complexity and of the interferences of zones which could be mapped. It is evident that the Group limited its work to the most important fields, also since a clear delineation is not always possible. The Group also developed a matrix for a map classification according to purpose, data geometry, scale and data reliability, applicable for each of the fields shown in the Conceptual Basis, and it tried to settle the problem of data instability by using statistical methods for the reliability and hydrological relevance and to distinguish observed (single-event), derived and interpreted data. The Group tried to arrive at a clear presentation of the hydrological situation in time and space but with a view to the variability of the data in order to produce maps with the greatest use potential possible.

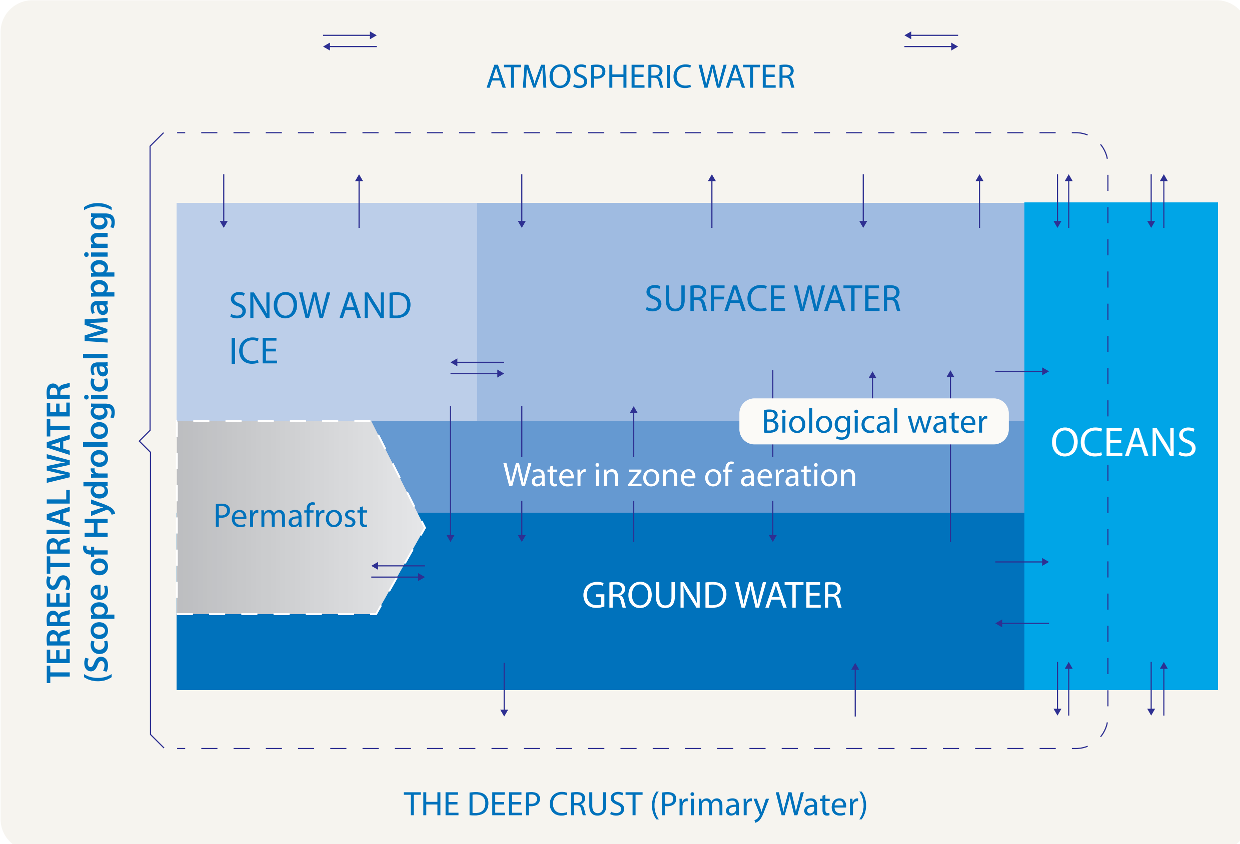


Fig. 1 – Conceptual basis for classification of hydrological maps (after Heindl, 1970)

The maps of our common use are based on relatively simple parameters. Everybody knows where Paris is located, for example; there is no doubt about the border between Norway and Sweden and the position of the Mississippi River is known. In the same way road maps do not pose difficulties, the location of the roads is known and does not vary and the class (motorway down to field track) is defined. Hydrological data suffer from some incertainties, even the best discharge measurement underlies errors. The methods to stabilise data for mapping purposes shall not be discussed here but the Working Group recommended several methods for testing the data quality and consistency with their variability in space and time.

The Guidebook as a cooperation between UNESCO and the WMO logically spent much effort to describe the maps of atmospheric waters with the uncertainties from the monitoring network. One striking example shall illustrate the problem. In deserts the density of measurement stations is extremely low and it may occur that none of the stations has measured a great storm while the wadi shows an excessive discharge, again not measured due to lack of appropriate stations. Evaporation even poses greater difficulties, yet the book contains a number of recommendations for arriving at meaningful maps. The book devotes much space on precipitation maps taking into account the annual, seasonal and short-time variations.

None of the hydrological maps is posing that much of problems as surface water maps and this may explain why such maps have only rarely been published in scientifc reports. The problem briefly can be indicated by the fact that discharge generally ist considered cartographically as a line effect in the river network. Here again the wide span between low water, mean, high and highest discharge needs to be considered and graphically presented. Generally this span is shown on maps by bands of different width and this often prevents easy reading because of the number of lines and bands and interaction with the bands from tributaries. The more a map tries to visualise the different amounts of discharge (in order to provide a real picture of the flow regime) the more bands must be drawn. This presentation becomes highly confusing and unreadable, and since the same method must be applied for the tributaries, in the end the many lines cross and mix and mingle and the understandig goes to zero. The book contains many proposals but they all suffer from the impossibility to invent understandable graphical means. It should be taken into account that today's computer facilities did not exist at that time. A large part of the problem lies in the fact that a river consists of a dense network of tributaries with often very different run-off characteristics. The river constitutes the visible part of the surface water drainage. In reality the whole catchment contributes and respective runoff maps have been developed and proposed. The problem increases because of the interaction between river and groundwater, both cases occur, recharge and discharge (gaining and losing), with variations and even reverse movements over the year. The surface runoff illustrates the problem for the map maker. In reality it is practically invisible (there is no flow on all of the surface), but the runoff coefficient constitutes an invisible phenomenon, the discharge of a catchment section divided by the size of the segment. Yet it must be considered one of the most important parameters in surface water hydrology. One must imagine, something invisible is being mapped and is considered the best description of the hydrological behaviour and regime of a catchment or part of it. The need for abstraction often limits the use of these maps to specialists.

The many examples shown in the Guidebook provide an idea of the complexity of the discharge/runoff situation in a basin. These difficulties, only summarized here, may be considered the reason, that such maps are relatively rare and generally linked to special hydrological case studies. Because of the high variability of the discharge/runoff system over the year and over the years, these maps have not become too popular and remained limited to special studies. This also may be the reason why a regional or continental map never has been proposed for publication by UNESCO and why the Council had decided not to pursue the theme beyond the Decade. At that time nobody could foresee that the actual climate debate is demanding maps of river runoff and of floods in order to visualise trends.

Easier to map is the snow cover with the typical dates for the start of the snow season and its end and the thickness and density of the snow layer. These maps have reached a certain popularity in the countries concerned. Therefore, the International Commission on Snow and Ice (ICSI) during the first years of the Decade has issued a number of scientific reports in the UNESCO series "Technical Papers in Hydrology". The subject has not been pursued under the IHP given the fact that the number of countries concerned was too limited and that these countries developed their programme independently. During the IHD also the mapping of glaciers was treated but was abandoned about in 1970. The priorities moved to tropical countries and even much more to the arid zones.

The Guidebook also includes a chapter on maps of water in the zone of aeration, particularly on infiltration, and this field later has been treated in more detail by the FAO for local project studies. A small-scale map never has been issued given the enormous local differences and variations over time and space.

The publication of the Guidebook in 1977 terminated the IHD/IHP work on surface waters. A major part of the Guidebook has been devoted to groundwater maps, and the respective activities will be described in chapter 2 of this Report. The following years saw the production of groundwater-related guides, model legends and particularly the compilation of regional, continental and even global maps, because the groundwater situation was poorly known in most countries of the world but there was a growing focus on safe water supplies from groundwater, particularly in economically fast growing regions and in areas of increasing water shortage of surface water resources. For administrative reasons many of these projects have been conducted outside the IHP as cooperative ventures between UNESCO, the German Federal Institute for Geosciences and Natural Resources (BGR), IAH and regional institutions such as the Arab League with its Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), the Russian Academy of Sciences, the Organisation of African Unity and its African Association for Cartography (AAC), the Commission for the Geological Map of the World (CGMW) and many others more. It should be noted that in these maps practically all countries covered by a continental mapping project cooperated, sent representatives and opened their data collections. Consultative regional meetings have been convened in order to discuss discrepancies along the political borders on the national maps and it should not only be mentioned but underlined that all problems have been peacefully solved. Scientific findings overcame national ambitions, colleagues and friends were discussing. UNESCO experienced true international cooperation and a common spirit of good will.

One additional activity must be mentioned although UNESCO played only a minor role in a joint WHO/UNESCO project, largely financed by UNEP on the Quality of Water. Fortunately the same UNESCO professional who served in the IHD/IHP ventures participated in the WHO-guided project thus assuring the same approach. A book «Water Quality Surveys (1978)" and its successor "Water Quality Assessments (1992)" contained a section on water quality maps for surface waters (rivers and lakes) and it followed the world-wide used Saprobia system. The books belong to the great IHD/IHP family of scientific literature on maps.

"Foundation of the Guidebook on Hydrological Maps"

The foundations of the Guidebook on Hydrological Maps were laid by an IHD working group consisting of Messrs S. Buchan (representing IAHS), H. Combe (Morocco), L.A. Heindl (United States), R. Keller (Federal Republic of Germany), G.A. McKay (representing WMO), J. Margat (France), V. Myslil (Czechoslovakia), T.W. Plumb (Australia), W. Richter (representing IAH), Mrs N.V. Rogovskaya (U.S.S.R.) and Mr G. Santing (Netherlands), Chairmann. A great deal of background information for the group was contributed by a panel of rapporteurs : Messrs W.H. Gilbrich (representing UNESCO), Mr R.Keller, Mr G.A. McKay, Mrs N.V. Rogovskaya and Mr G. Santing.

The work begun by this Working Group was continued by its successor, a Subgroup of the IHD Working Group on Water Balances composed of Messrs I.C. Brown (representing IAHS), Chairman, G.H. Davis (representing the Working Group on Groundwater Studies), W.H. Gilbrich (representing UNESCO), D. Lazarescu (representing the Working Group on Water Balances), G.A. McKay (representing WMO) and A.A. Sokolov (representing the Working Group on Water Balances). The Subgroup was assisted by Messrs T.G. Chapman (Australia), L.A. Heindl, R. Keller and T.W. Plumb.

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Before the middle of the past century the increasing demand for water, particularly in the industrialized countries, called for a rational planning of water resources. 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.

2. Hydrogeological and Groundwater Maps, Tools and Results

2.1 Introduction

An Interim Report on Hydrogeological Maps in the large sense was exhibited during the 17th Session of the IHP Council in 2006 and a desire was expressed for a more elaborated and complete version. The present Report is based on this advance draft provided by UNESCO and has been jointly elaborated by BGR staff and a UNESCO Consultant, namely Mr W. Struckmeier (BGR, chair), Mr P. Winter (BGR, Berlin), Mrs A. Richts (BGR) and Mr W.H. Gilbrich (UNESCO Consultant).

The international development of hydrological mapping saw rather different streams. Surface water maps within the IHD/IHP have been conceived to a large extent on the basis of cartographical considerations by hydrologists more oriented towards geography and they derived their know-how from geographical practices which had evolved over centuries. Only the hydrometeorological mapping techniques could be based an a long tradition developed by national weather services and standardised by the WMO. The IHD/IHP project on hydrogeological maps went the other way and it built on the national expertise of geological maps.

Groundwater is encountered in geological formations, either composed of unconsolidated deposits or of fissured or karstified hard rock formations owing to tectonic stresses in the upper earth crust and/or weathering processes near the surface of the earth, groundwater is found in most geological formations in sizeable quantities. Therefore, there is usually a close relation between geological maps and maps displaying the existence of groundwater beneath the surface. For this reason, early hydrogeological maps often used stratigraphic colouring and are very similiar to geological maps.

The way from a groundwater prospection to a map is long because much abstraction and cartographical know-how is necessary to understand why, for example, a karst aquifer should be mapped in green and what the ornaments mean since there is no absolute evidence between the observed parameter and the ornament used on the map. This explains why almost each map maker in the past went his own way and almost no national map resembled another one. To analyse this situation and to arrive at internationally adopted cartographical practices was the aim of several large IHD/IHP projects, their working groups and expert panels.

The population growth and an increasing demand for water are heavily stressing the water resources of the globe, however with large differences due to the climatic conditions, hydrogeological conditions, population density and the requirements for potable water, for agricultural use or industrial processing. At the same time, pollution of the water bodies both surface water and groundwater limits the water use so that the exploitable resources underlie a double stress, more consumption against a steadily limited potential for use.

In the past, surface water constituted the main resource. Increasing pollution of surface water and the growing demand requires more and more groundwater to be pumped. While an assessment of the surface water resources is relatively easy, the invisible groundwater requires an intensive exploration. The depiction of groundwater – for example on maps – is posing difficulties and necessitates special techniques. A three-dimensional phenomenon needs to be shown on two-dimensional paper.

In many parts of the world demand-driven water consumption is gradually being replaced by management-driven practices, considering both, surface and groundwater systems that are closely interlinked. For example, groundwater feeds river base flows in dry periods, and alluvial aquifers can store excess river flows after heavy rains. In order to properly manage the groundwater resources hydrogeologists need to know the extent and productivity of the aquifers since an over-exploitation may lead to a conflict of the users. Aquifers ignore political borders so that conflicts between countries with shared aquifers are pre-programmed unless management strategies will be developed. Common tools are maps and regional modelling projects leading to legal agreements.

Before the middle of the past century the increasing demand for water, particularly in the industrialized countries, called for a rational planning of water resources to serve for public supply, agriculture and industry. 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.

The first hydrogeological maps were sporadically produced in several countries already more than hundred years ago but the boom started during the 1950ies. The scales employed varied widely, for the most part between 1:25 000 and 1:200 000, but with a few maps up to 1:500 000 and even smaller. These maps were intended to serve as a basis for the national or sub-regional water resources planning. Since these hydrogeological maps were produced in connection with local developments, the features shown tended to be those considered important to each individual scheme, and even when these features were common to a number of maps they were generally depicted in different colours, with various dissimilar ornaments, and by a wide range of symbols. Comparison of the hydrogeology between areas shown on different even neighbouring maps was often difficult, and the maps themselves were not always easy to understand. Moreover, there were few, if any, hydrogeological maps which displayed a coverage on an international, a national, or even a truly regional base.

The present Report, while describing the mapping projects supported by UNESCO, also informs of pertinent literature. Usually mapping projects are resulting in a major report or accompanying booklet which describe the map sheet(s) and provide the references. UNESCO and the cooperating NGOs, particularly the IAH, also have embarked on compiling appropriate instruction material for legends but also for the know-how in hydrogeological cartography and map compilation.

These activities comprised maps and written publications. As will be shown in the present Report, the International Hydrogeological Map of Europe turned out to be the driving force for or the thematic background of almost all mapping projects, the publications included.

The European project has reached its end and also this event has been taken for reason to compile a comprehensive view on the achievements of the last five decades.

The present Report does not follow the historical sequence of events since many activities were implemented in parallel and cross-fertilized. The paper is divided into thematic sections and firstly describes the mapping principles and the way of execution with the help of legends. It then refers to the world-wide echo on the first venture of the European map when, as a result, in all continents maps were developed, partially with the strong support of UNESCO or of German technical assistance, partially at the own initiative of geological services and/or regional organisations of a continent or sub-continent. The Report then turns to selected major projects with a high UNESCO involvement.

Experience over the past decades has shown that large-scale project maps and national ones must remain the domain of national services. They are helped by the tools developed for international, continental and global maps. Experience also has shown that the legends must be extremely flexible and adaptable to situations all over the world. UNESCO cannot impose the application of the legend – as a UN organisation it is not authorised to do so. Yet, it is surprising to see that so many different authors, services and organisations have made intensive use of it, voluntarily.

The present Report has been conceived for a broad readership. The paper primarily provides an overview of the various activities related to hydrogeological and hydrological maps mostly conducted under UNESCO's leadership since practically half a century, it provides information about maps existing in the world, it opens the eyes for the complexity of groundwater systems and for their transboundary character. The report also invites for assessing the groundwater resources of continents, their exploitability but also their vulnerability. Risk and trend maps can help politicians and planners to develop better management practices, as risk reduction and for settling conflicts. Thus, the paper invites to understand small-scale hydrogeological maps as the visualisation of groundwater configurations and to derive from here more detailed and larger-scale visual information material for solutions in concrete projects.

2.2 The Role of UNESCO and Non-Governmental Organisations

While the above publications deal with hydrological mapping in general, a need has also arisen to prepare guidelines for special applications and to test them in existing aquifer systems. Aquifers are no longer protected natural water bodies. The ever growing demand for water today means that not even the smallest aquifer is forgotten – intensive exploitation has become the rule. Protection has become essential, particularly with regard to aquifer contamination brought about by human interference. Some aquifers are well protected by nature by covering layers, others are extremely vulnerable.

The origin of today's level of the art of groundwater mapping can be found in maps for individual groundwater exploration projects. They later were combined and harmonised in national groundwater maps which differed much from country to country, by legend, scale and by interpretation of the essential features. There was no common opinion of what was essential to be portrayed on maps and even less uniformity about how to depict hydrogeological items on maps. However, the desire was felt to depict groundwater provinces exceeding national boundaries and to speak in a common cartographic language.

A particular problem emerged on the maps along the political borders. When putting two national maps together rarely the hydrogeological features harmonised. UNESCO convened a number of (sub-) regional meetings where the differences were discussed and eliminated. No national pride but (hydro-) geological data determined the solution adopted.

It became evident that no satisfying solution could be found at national level but international cooperation was indispensable. Scientists from international non-governmental organisations (NGO's) such as the International Association of Hydrogeologists (IAH) and the International Association of Hydrological Sciences (IAHS) were the forerunners and already in the fifties in the last Century took the initiative for elaborating mapping procedures applicable universally. UNESCO, in the early sixties of the last Century, established an international programme in the water sciences, the International Hydrological Decade (IHD). The IHD proved the appropriate platform for joining forces and for establishing a scientifically based general legend which combined the occurrence of groundwater, the geology and possible uses.

The fact that UNESCO and its international water programmes took over the leading role in a number of mapping projects or related publications had some implications. UNESCO, by its very nature as a UN specialised agency for education, science and culture, primarily is acting at international level, this being understood as global, continental or regional. National projects by definition remain the domain of the Member States but UNESCO are partners if cooperation with other countries is needed. Hence, all publications are addressed to an international readership and all mapping projects either concern the globe, a continent or a major region.

The international organisations concerned and a number of national geological services met in Helsinki in 1961 and exhibited national hydrological and hydrogeological maps which revealed the full range of possible cartographic solutions, and many largely differing map representations were recognised although the items presented on the maps were quite similar. As a matter of consequence a decision was made to compile regional and continental maps based on a standardised and harmonised, scientifically justified approach. In order to compare groundwater features with the geology and other earth sciences disciplines, use has been made of existing topographical or geological maps. The organisation of these map series in scale, projection and sheet delineation usually is identical within one region or continent. Thus, full comparability at low cost resulted.

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, were criticized. Already in 1960 and 1961, the International Association of Hydrogelogists (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 on an 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. A joint meeting of the IAHS Committee and the IAH Working Group was held in Paris in 1962 under the auspices of UNESCO. Agreement was reached on a draft legend for hydrogeological maps which was published by UNESCO in 1963 on the basis of the hydrogeological maps of Morocco (Ambroggi & Margat, 1969).

UNESCO and the NGO's involved alone could not solve the practical problems of legend compilation and map drawing and printing. Data but also financial resources were needed and without the very dynamic assistance of a large number of national geological services the enormous task could not be nor could have been accomplished. In order to create a long-term stable basis UNESCO in 1970 concluded a general contract with the German Federal Institute for Geosciences and Natural Resources (BGR) in Hannover, primarily at that time for a hydrogeological map of Europe, later thanks to a generous interpretation of the contract by the two partners extended to other international hydrogeological mapping activities.

2.3 Publications

The history of publication roughly can be divided into two major periods. The first one from about 1960 to about 1980 concerned basic issues of maps concerning surface water and groundwater. These publications can be considered the fundament and reference is made to chapter 1 of this Report.

The late seventies of the last century suffered from an apparent stand still, as many diverse concepts about hydrogeological mapping had to be tested and verified. At the end of this period a new generation of scientists and a revival of mapping activities within UNESCO's IHP gave rise to new activities, not only for the production of regional maps but also for the compilation of new publications. A visible change was the concentration on groundwater issues. Within some ten years a large number of hydrogeological features and mapping practices developed.

At the Budapest meeting of the IAH Ground Water Protection Commission in 1987, an idea was introduced to include among the future Commission activities the topic of groundwater vulnerability assessment and mapping. The initial position paper was prepared in 1988 by H.G. van Waegeningh. The paper and the topic of vulnerability mapping was discussed at the Commission meeting in Czechoslovakia in 1989, where a Project Working Group was established and a tentative content of a guidebook was developed. At the next Commission meeting in The Netherlands in 1990 an outline of a report on groundwater vulnerability maps was prepared and authors of chapters were tentatively selected.

At the same time, UNESCO prepared the Fourth Phase (1990-1995) of the International Hydrological Programme (IHP). Within Sub Programme M "Management of Water Resources for Sustainable Development", Theme 1 was related to methodologies for water resource assessment and hydrological design. One of the projects under this theme, namely Project M-1-2 (a), foresaw the preparation of a methodological guide for mapping groundwater resources and their vulnerability. In order to avoid duplication of efforts and parallel work, UNESCO suggested merging the IAH and IHP working groups and to jointly prepare the guidebook. A fee contract between UNESCO and IAH was signed in 1991.

Because of the inclusion of the Commission project on vulnerability maps into IHP-IV Project M-1-2a, it was necessary to modify its original schedule and objectives to make it fit to UNESCO IHP goals. The first meeting of the IAH/IHP Joint Working Group was held in Tampa, Florida, USA in April 1991. The outline and schedule of the study were revised, the individual chapters reassigned to authors, and Dr. Vrba and Dr. Zaporozec were appointed as editors of the report. First drafts of the chapters were reviewed at the 1992 meeting of the joint group in Torino, Italy. A subgroup met at Leiden, The Netherlands in early 1993 and approved at the editorial group meeting in Norway in June 1993 and at the joint group meeting in Wallingford, UK in May 1994.

Besides the listed authors, many other members of the Ground Water Protection Commission of IAH provided valuable suggestions during the preparation of this study and participated in the review of the final report. Stimulating ideas and recommendations concerning its contents were presented at discussions held during the Commission sessions in 1989 (Skály, Czechoslovakia), 1990 (Bilthoven, the Netherlands); and 1991 (Tampa, Florida, USA). A special group met at Oegstgeest (The Netherlands in 1993). Thanks are expressed to UNESCO for funding the project; to the Wisconsin Geological and Natural History Survey for the administrative and technical support; and particularly, to Mr. W.H. Gilbrich, Project Officer, UNESCO Division of Water Sciences, who cooperated actively in the realization of the IAH/UNESCO Project "Preparation and Use of Ground Water Vulnerability Maps". The book has been published by the IAH under the title "VRBA, J. & ZAPOROZEC, A. (1994): Guidebook on Mapping Groundwater Vulnerability, IAH, Vol. 16; Hannover".

Already prior to the Hannover symposium referred to below, work had started on a revised version of the 1977 publication "Hydrological Maps" restricted however to groundwater mapping. Preparations were initiated during meetings in Cambridge 1985, Karlovy Vary 1986 and Duisburg 1988.

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 entitled "International Symposium on Hydrogeological Maps as Tools for Economic and Social Development". With the financial assistance of UNESCO, a meeting took place in Hannover in January 1988 with Messrs Day, Engelen, Gilbrich, Margat, Romijn, Šarin and Struckmeier participating. The meeting reached a preliminary concept and assigned authors for chapters. A subgroup (Engelen, Khouri, Krásny, Romijn, Šarin, Struckmeier) subsequently met in Duisburg, Federal Republic of 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 reason 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 the 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 serves as 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.

Fig. 2 – Various Standard Legends published with the help of UNESCO between 1970 and 1995

The book has been published by the IAH under the title "MARGAT, J. & STRUCKMEIER, W. (1995): Hydrogeological Maps – A Guide and a Standard Legend, IAH, Vol. 17; Hannover".

Since both IAH publications are out of stock, revised versions are under discussion but most likely will only be published in electronic form.

This Report again and again refers to the International Hydrogeological Map of Europe and there are good reasons for doing so. This mapping project extends over the whole time period covered by the present Report. It has been designed as a prototype for regional hydrogeological maps. The project also helped to generate legends, guidance material but also, as originally intended, to launch mapping projects in other regions. The World-Wide Hydrogeological Mapping and Assessment Programme (WHYMAP) certainly could not have been developed without the European ancestor and the guidebooks on Hydrogeological Maps.

It is the fate of a report that the historical description ends with the time of writing. Hydrogeological mapping however proceeds. The present Report therefore shall be understood to constitute an incentive for basically three issues:

- Firstly, the collection of more data in many parts of the world needs to be intensified and data storage and data accessibility must be improved.
- Secondly, modern techniques must continue to be developed towards easier map compilation, data analysis and modelling.
- Thirdly, the traditional maps on only aquifers and groundwater availability must be thematically enlarged.

Hydrogeological maps in conjunction with ecosystem maps, maps of the vulnerability of groundwater systems, on the replenishment of aquifers, on climatic issues and on water quality parameters need to complete the map sets, and finally maps of trend analyses and for forecasting purposes need refinement.

UNESCO's water programme has much changed throughout the different IHP Phases suggesting a variety of thematic priorities. Hydrogeological mapping however has persisted over the decades. It also has continuously attracted the cooperation of other UN agencies, of a number of NGO's but – most essential – of national (hydro-) geological services. Many great names of scientists are in our memory. The present Report therefore shall not only describe the mapping activities in which UNESCO was and is involved. The report also is meant to give due credit to all organisations, services and individuals who over the years have spent efforts and important funds for developing hydrogeological mapping, the related techniques and for generating an understanding of the complex processes of the groundwater hydrological cycle. This understanding is a world-wide movement and it encompasses many scientific and professional levels, from the water user up to decision-makers and politicians, and for teaching purposes.

UNESCO's water programmes contain an important component, education and training. Hydrogeological maps have been considered an appropriate tool for the transfer of knowledge and therefore a sheet of the European map has been included in the book "Teaching aids in hydrology" (TDH No. 27, 1985) so as to support a chapter on maps as a vehicle for knowledge transfer. In order to enable UNESCO to distribute the publication free of charge the German National Committee for IHP kindly took over the extra costs for the printing of the map sheet.

Another paper should be mentioned although it never has been really published. Co-Author Mr. W.H. Gilbrich over some twenty-five years lectured on hydrological mapping in the international UNESCO-sponsored postgraduate hydrology courses and there he distributed his detailed lecture notes of some fifty pages (in English and French versions) to the students, and in this way some two thousand copies worldwide are in the hands of practicing hydrologists.

2.4 Mapping Principles and Legends

2.4.1 General

To conceive a road map is relatively easy, the position of the roads is known and visible and the state administration delivers the classification. Also geographical maps do not pose major problems, the earth surface is practically two-dimensional like the paper of the map and the main features like river networks, coast lines, elevation above sea level can be easily plotted, necessarily in a vertical projection.

Hydrogeological maps differ: the groundwater is located somewhere below the surface, the aquifer has a thickness and the rock sequence is only partially filled by water depending on the pores or fissures of the rock. It is not surprising that as long as no standardised legends existed almost each map author had developed his own concept. A survey undertaken by UNESCO in about 1970 revealed this variety. UNESCO had asked its Member States to send national maps and the material received exceeded all expectations. It turned out that each map was different in approach, scale, presentation, interpretation and hydrogeological features, always dictated by the purpose of the map. Some resembled more geological maps, other ones tried to depict the three-dimensional character of groundwater and its aquifer, often available in more than one horizon. This survey conducted by the Russian scientist N.V. Rogovskaya served for a classification of existing map types and for collecting elements of the compilation of legends. She prepared a historically most valuable book with photos of the maps inside, in three copies only and all written and glued by hand. This collection established an order and a system by purpose and contents of the map and later enabled the respective IHP bodies and NGO's to select those fields suitable for international use and those permitting to develop material and legend elements for later use. Since one and the same feature has been described by different ornaments the survey delivered an overview of mapping practices and helped to select the most appropriate graphical representation, for use in an international legend.

Groundwater constitutes a particular mapping problem. The carrying rock or granular formation contains water masses that are controlled by gravity with a lower bottom and an upper free surface (unless confined between two impermeable layers). Hence, it is a three-dimensional phenomenon and thus escapes from conventional two-dimensional mapping practices. On top of the problems the groundwater moves. The underground filled with water is called aquifer. In order to add to the difficulties one has to know that only part of the aquifer is filled, namely only the pores or fissures. It is therefore not surprising that map makers had to be extremely creative in order to develop appropriate mapping techniques and also a legend which transfers the information on groundwater into a comprehensive, legible and understandable form. Many attempts failed and the way was long in order to arrive at a solution which the international hydrogeological community could readily accept. UNESCO, IAHS and IAH as well as CGMW succeeded.

The development of the International Legend occurred in parallel with the compilation of the International Hydrogeological Map of Europe (IHME) and thus benefited from the experience gained over the years. In this way, climatic and geological peculiarities could be taken into account. The legend and the map cross-fertilized.

The purpose of hydrogeological maps is to enable various areas to be distinguished according to their hydrological character in relation to the geology. They should indicate, on a topographic base, such items as the extent of the principal groundwater bodies, the scarcity of groundwater elsewhere, the known or possible occurrence of artesian basins, areas of saline groundwater and the potability of groundwater. They should also show, according to the scale, information of a local character, such as the location of boreholes, wells and other works, contours of the potentiometric surface, the direction of groundwater flow, and variations in water quality.

In general, any information leading to a better understanding of occurrence, movement, quantity and quality of groundwater, should be shown on hydrogeological maps, depending upon the scale adopted. The data normally presented relate to such matters as precipitation, evaporation, surface hydrology, geometric data on water-bearing formations, hydrochemistry and availability of water. In addition, sufficient geology should be shown to lead to a proper understanding of the hydrogeological conditions. However, the geology should remain subdued and the hydrogeological features should be prominent. The concept of the legend thus takes note of the two main factors generally controlling the groundwater setting, i.e. the type and nature of the rocks and their hydraulic properties. The use of hydrogeological maps goes beyond the transfer of hydrogeological information such as abstracted on a map. Maps can be considered a pictural message and well lend for visualising natural phenomena and therefore maps can serve for a large range of information strategies.

2.4.2 Role of the International Hydrogeological Map of Europe

Since part of the draft legend elaborated around 1960 was based more on theoretical considerations rather than on practical experience, the IAH Commission used the preparation of the series of hydrogeological maps for the European Continent, named the International Hydrogeological Map of Europe (IHME), as a practical test. Part of the Sheet C5 (Bern) was selected for the prototype since it covered a region with very a varied geology and for which a large amount of data was available. The scale was 1:1 500 000. The Geological Map of Europe had been issued at the same scale and with the same cutting and order of sheets so that the same geographical base map could be used, resulting in cost reduction, time saving and comparability. Hydrogeologists from Austria, Czechoslovakia, the Federal Republic of Germany, France, Italy, Switzerland and Yugoslavia were involved in the compilation of the representation methods on this map sheet from 1962 to 1966. In order to evaluate the different ideas put forward to the Working Group, many of which differed from the draft legend, it was necessary to produce printed examples of the map. In all, four variations were printed, referred to as Models 1 to 4, using the relatively inexpensive but less accurately registerable silk-screen process. Excerpts of these models are included in this Report as Figure 3.

Models 1 and 2 were presented at the International Congress of the IAH in New Delhi (1964). Both models were basically geological maps, with Model 1 having notes in the map legend on the permeability and other hydrogeological data for each formation depicted, while Model 2 attempted to show potential yields in the different formations. As the colouring of the map units followed essentially the geological time dimension and stratigraphic position of rock bodies neither model proved generally acceptable for hydrogeological maps.

A third version, Model 3, was produced in 1965. Geological formations were classified into good aquifers, moderate aquifers, and poor aquifers (including non-aquifers). The lithology was illustrated by a background ornament in grey. Good aquifers were distinguished by a blue colour, moderate by green, and the poor by brown. Unfortunately, the members of the Working Group experienced considerable difficulty in finding general agreement of what constituted "good", "moderate" and "poor". Arid countries and humid regions such as Skandinavia, for example, have a quite different understanding of these terms. In consequence, a fourth model was elaborated that was placed in 1966 before a joint meeting of the IAH Working Group and the IAHS Committee.

This version took the fundamental step of illustrating the aquifer type by colouring green the outcrop of those aquifers through which the dominant groundwater flow was by fissures, and blue for those with intergranular flow. Brown was reserved for those strata generally considered to be poor aquifers without considering the type of porosity. Additionally, dark green and dark blue indicated the outcrop of extensive aquifers with large resources, while light green and light blue indicated local or discontinuous aquifers with lesser resources. Similarly, light brown represented strata which might have small but very localised resources (aquitards), and dark brown related to rocks with little or no usable groundwater (aquicludes and aquifuges). Lithology was still shown by grey base ornament, and was used also to assist in stratigraphic differentiation. While the previous models had departed from being simple geological maps with hydrogeological additions, Model 4 had moved away from the concept of well yield into that of aquifers and groundwater resources. Model 4 was accepted as the prototype of the planned series of the International Hydrogeological Map of Europe, scale 1:1 500 000, and the final version on Sheet C5 (Bern) was published in 1970.

Much of the information assembled during the preparation of Sheet C5 could not be shown on the map itself without obscuring more essential features. After the sheet had been published, it was considered advisable to prepare a volume of Explanatory Notes, limited to not more than 100 pages on a B5 format. This volume could, it was felt, usefully supplement the map with tabulated information (particularly on groundwater chemistry), detailed vertical cross-sections of special interest, additional small maps to illustrate features of local importance, and a general explanatory text. Compiling this first volume involved the participation of more than fourteen geological surveys. The Explanatory Notes for Sheet C5 (Bern) were published as a 96 page volume in Hannover in 1974. The same principle has been followed with almost all of the subsequent sheets of the series, similar volumes being published as standard accompaniments.

The progress through the four versions of the draft for sheet C5 led naturally to additions and modifications to the draft Legend. Moreover, new symbols and ornaments for karst areas, for arid zone features and for other hydrogeological aspects had been considered by the IAH Working Group and by the IAHS Committee at joint meetings during 1967. The revised draft was finally published in 1970 in colour, and the text was printed in English, French, Spanish and Russian.

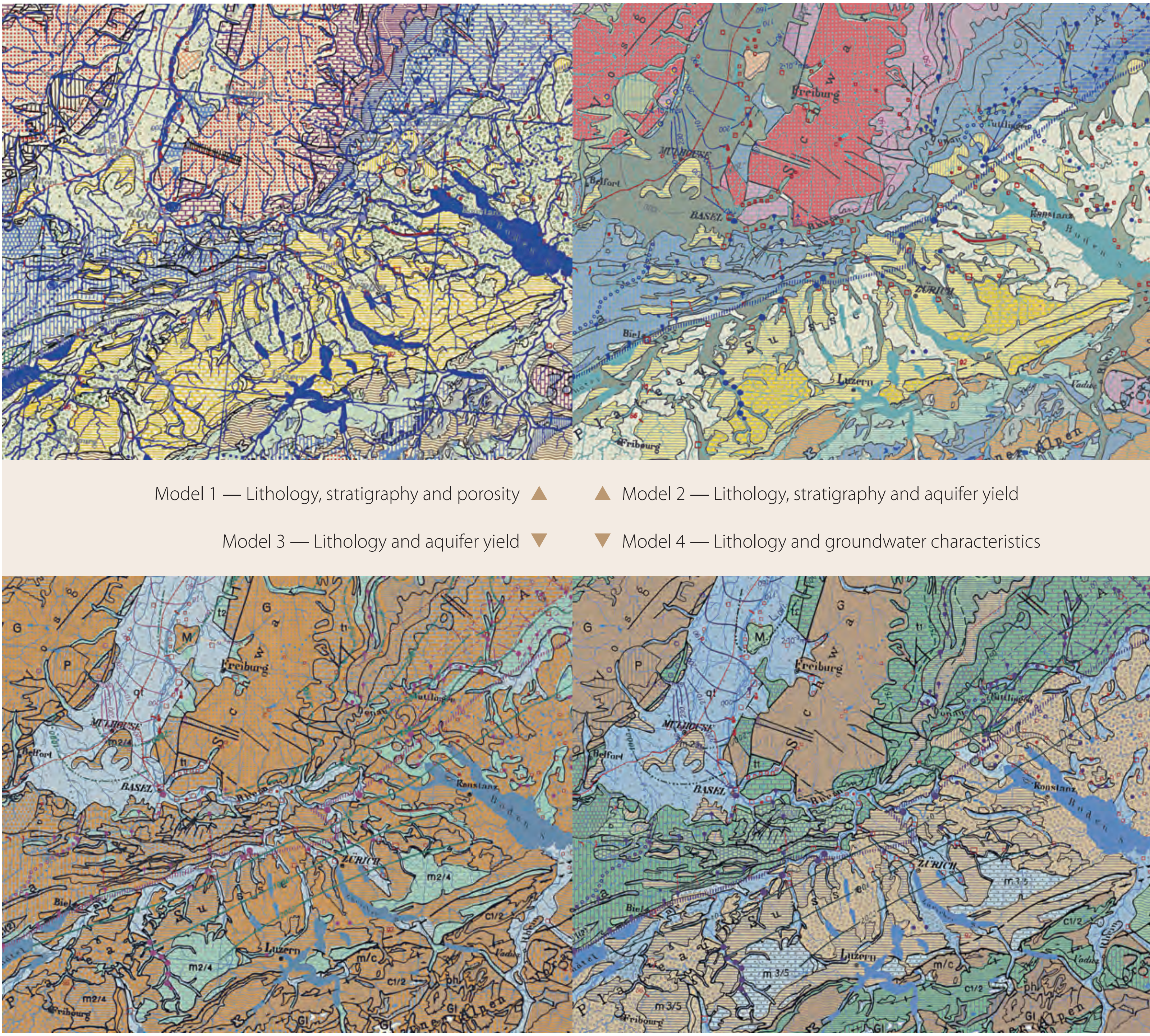


Fig. 3 – The Four Models for the representation of the International Hydyrogeological Map of Europe (Models 1 – 4)

2.4.3 Guidebooks Emanating from the European Experience

Work upon the European hydrogeological map series has shown up a number of inadequacies in the 1970 Legend. The lithologies of the strata depicted upon the maps proved to be more varied than had been anticipated, and additional symbols were needed to quantify groundwater resources or to illustrate groundwater flow. A special additional list of these symbols and ornaments was prepared in 1974 for use by the editors of the European map series as a forerunner for a new version to be printed later.

The 1970 publication soon was out of stock. However, a reprint could not be considered in view of the numerous innovations and supplements derived from international mapping projects. Since on the one hand the market called for a publication but since the development of legend items still was progressing UNESCO in 1983 issued a cheap black-and-white version in its series "Technical Documents in Hydrology". This version is based on the 1970 publication and largely included the innovations experienced since.

For the purpose of preparing this interim version of the Legend a Panel of Experts had been established consisting of Mr. W. Struckmeier (Chairman), Mr. R.A. Monkhouse (IAH), Mrs. S. Jelgersma (IAHS) and Mr. W.H. Gilbrich (UNESCO). The Panel met in Hannover. It is worthwhile to note that the original of the manuscript became a victim of the famous UNESCO fire in October 1982 but fortunately the Chairman had kept an equally good copy which then served for the 1983 publication.

The 1970s and 1980s can be considered as the great time of regional and continental mapping. The experience gained from these ventures, but also the fact that all respective IAHS and UNESCO publications were sold out, stimulated UNESCO-IHP and the IAH to modernise former versions of the legends and to issue a revised one without, however, contradicting the former ones. IAH publication no. 17 of 1995, "Hydrogeological Maps: A Guide and A Standard Legend" by W. Struckmeier and J. Margat, contains the last edition (see Figure 2).

A question which never has been solved is whether a standard legend should only contain truly hydrogeolopial features or whether it also should cater for special cases. In order to satisfy special demands UNESCO in 1975, in cooperation with IAH and IAHS published the Legend for geohydrochemical maps which already has been referred to. Within the UNESCO mapping framework another specialised legend for groundwater vulnerability maps was published by the IAH in 1994 with Mr Vrba and Mr Zaporozec as chief editors, as already mentioned above.

While the general legend covered the bulk of hydrogeological features a number of issues deserved a treatment more in depth. While in contrast to surface water biological parameters – at that time – played only a minor role the chemistry often decided on the usability of groundwater, particularly in arid and semi-arid regions. A Panel of Experts had been established by the Council consisting of Mr. G. Castany (IAH, Chairman), L. Monition (IAHS), W. Richter (BGR, UNESCO Consultant) and W.H. Gilbrich (UNESCO). The Panel met three times, always at UNESCO House (17-18 April 1972, 4-6 December 1972 and 15-16 May 1973).

The origin of the considerations was the general term "salinity" but the Panel agreed that it was hardly possible to define saline water with regard to mapping activities, and that the term "salinity" was too indistinct and ambiguous for international purposes. It agreed, therefore, to discuss the subject under the heading of "Legends for Geohydrochemical Maps" and to concentrate on subsurface water maps, bearing in mind that the requirements for surface water mapping differ considerably. The publication lists the major dissolved solids, defines types of water and proposes means of mapping. It should be noted that the Panel hesitated to propose areal coverage but preferred point data valid only for the point of measurement.

2.5 Cartographic Tools and Definitions

2.5.1 Overview

A first decision refers to the cartographic projection and to the scale of the map. A broad variety of map projections are in use for hydrogeological maps, preference should be given to projections which are true in area (in contrast to projections true in length or in angle), to provide a close-to-nature idea of the extension of the aquifers. In any case the detailed projection parameters must be documented on the map, to allow digital transformations into different projections. Geographical coordinates are to be preferred.

In general, small scale maps (1:1 000 000, or smaller) will show only the general location and disposition of aquifers and non-aquifers, together with a broad picture of the surface drainage. It may be possible in some cases to show a small number of other features, such as generalised contours of the potentiometric surface in the more extensive and important aquifers. However, the introduction of fine detail is not usually warranted, particularly for features potentially changing over short periods such as potentiometric data, and on such small scales may well be meaningless. At the other extreme, a considerable array of data may be expressed on large scale maps (1:250 000, or greater) and this may often be increased by insert maps, on a small scale, illustrating factors of general importance such as rainfall, relief and certain aspects of groundwater chemistry.

The selection of a particular scale for a hydrogeological map may depend not only upon the purpose to which the map may be put, but also to the amount of information that is either available for inclusion or desired to be shown. There is little advantage in producing large scale maps of areas for which there is only scanty information, and equally little in entering data so profusely upon a small scale map that a clear distinction of the individual factors can no longer be made. Recommendations for the choice of an appropriate scale are contained in the publication of Struckmeier & Margat (1995).

A Standard Legend can only satisfy normal demands and necessarily arrives at certain simplifications. Earlier attempts to map complicated cases generally failed with the tools of classical cartography. The authors remember mapping projects particularly in Australia and in the USA to present multi-layer aquifers. An Australian example presented each aquifer on a transparent sheet, however the entirety of superimposed sheets led to more confusion rather than clarification, likewise attempts in the USA with mixtures of cross-sections and horizontal plotting did not really satisfy.

The situation now has changed with the application of modern high-power computers but running these cartographic master pieces requires team work of hydrogeologists, cartographers and specialised software designers but even these sophisticated models cannot escape from a certain simplification. One old problem be it for classical paper maps or for three-dimensional computer maps however remains, the availability of sufficient and good data.

2.5.2 Definitions

Three basic cartographic elements are used on thematic maps, i.e. points, lines and polygons, to symbolise spot information (generally related with coordinates), linear vector data, and areal information (full colour).

Certain terms are used rather loosely in both hydrogeology and cartography, and it is easy for misunderstandings to arise. The following short list of definitions refers to the usage for the legends, issued under the auspices of UNESCO and the IAH, in which care has been taken to adopt the signs symbolically to nature.

Symbol	a single graphical representation to denote the presence of a particular factor at a point location on the map; e.g. a small circle to show the location of a spring.
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.
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.
Ornament	a pattern of marks, lines or other symbol denoting the occurrence of a particular factor over an area of ground as represented upon the map; e.g. a stipple to represent sandy strata.
Sign	a sign may consist of a line, a symbol, or an ornament, or a combination or any or all of these.

2.5.3 Features of the International Standard Legend (1995)

a) Background information

This comprises largely geographical details such as major roads, railways, the larger conurbations, and so forth. Relief or hill shading are generally not shown on the map since this tends to obscure hydrogeological detail, but insert maps can be used for this purpose.

Background information is generally printed in grey with the grid or latitude lines in black. Regional and town names may also be printed in black, but the type faces should be clearly different from those used e.g. for the stratigraphic symbols.

b) Aquifers and non-aquifers (colours and tones)

On a thematic map the most important themes are usually portrayed by colours which are optically the most visible subjects. Therefore, the groundwater-bearing properties are the most important item to be shown on hydrogeological maps. This scheme is explained in Figure 4.

All strata that appear in outcrop upon the map, whether aquifers or non-aquifers are shown in plain colour.

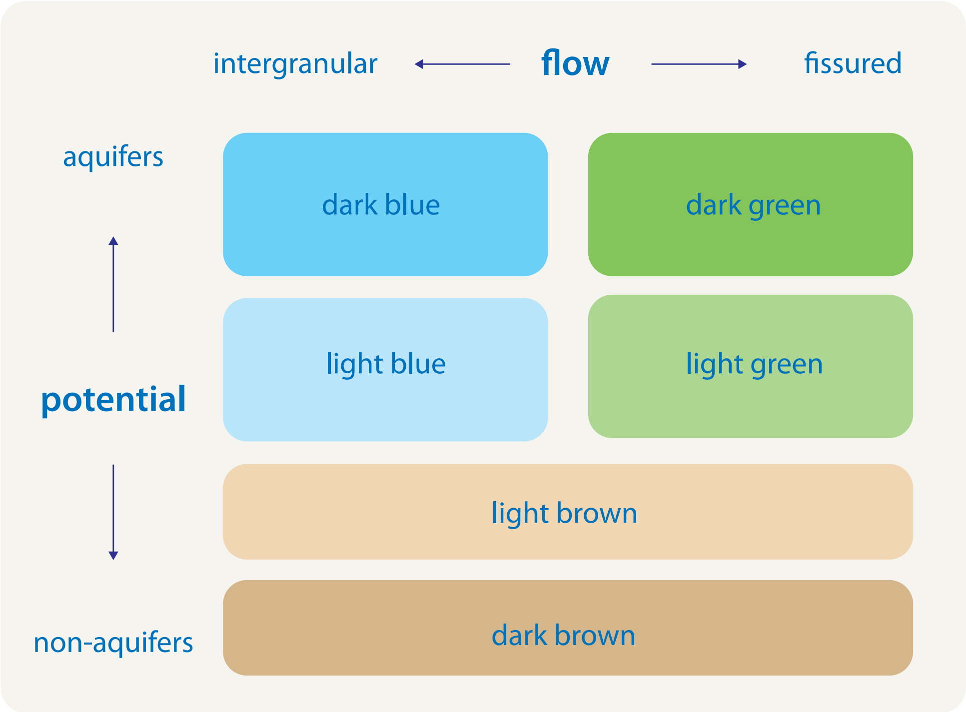


Fig. 4 – The colour scheme of the Standard Legend for Hydrogeological Maps

Intergranular aquifers are coloured blue and fissure aquifers are coloured green, in each case a dark colour indicating an extensive and highly productive aquifer while a lighter tone indicates other aquifers. Less aquiferous strata whether porous or fissured are lumped into a brown colour category. Formations giving only limited or local yields are coloured a light tone of brown, while strata with essentially no groundwater resources are coloured dark brown.

The models 1 to 4 previously described clearly demonstrate the evolution from a geological to a truely hydrogeological map by gradually breaking away from a colour scheme essentially showing geological and stratigraphical information to a colour scheme expressing the hydrogeological nature of aquifers and rock bodies.

Where it is considered to be particularly important to show the continuation of an aquifer beneath a thin but persistent impervious cover of drift, the appropriate aquifer colour (blue or green) may be continued over the relevant area, but should be crossed by vertical bands of the appropriate colour of brown. The legend normally printed in the margin of the map sheet should state the order of thickness of the drift cover.

c) Lithology

The lithology of the strata in outcrop is represented by ornament printed in grey beneath the colour. The ornament is arranged horizontally (in an east-west orientation upon the map), where it indicates horizontal or gently inclined strata, and arranged in a vertical position (a north-south orientation upon the map) indicating steeply inclined or folded strata.

A list of suggested ornaments is given, and these may be varied in size, or combined with each other, either to show mixed lithologies or to differentiate between different formations.

d) Representation of detailed data

Detailed hydrological and other relevant information is shown by the use of symbols, and lines, but occasionally of ornaments, printed in various colours. Numerical figures, in the same colours, may be added for clarification, e.g. to put values on contours. The different sections into which the data are grouped are as follows:

Group	Colour
1. Groundwater, including springs	Violet
2. Groundwater quality and temperature	Orange
3. Surface water and karst hydrography	Blue
4. Man-made features and alterations to the natural groundwater regime	Red
5. Horizon contours, isopachytes and limits of permafrost	Dark green
6. Geological and stratigraphical information	Black

e) Stratigraphy

While stratigraphic information is not of primary importance upon hydrogeological maps, it is generally convenient to indicate at least the approximate age of the strata depicted. On large scale hydrogeological maps, it may prove advisable to use symbols of more local than international significance.

f) 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 be presented either in insert maps upon the margins of the hydrogeological map, or as figures in any accompanying text.

g) Vertical Sections

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.

The colours, lines, symbols and ornaments used on the vertical cross-sections should be the same as those used upon the map. While in general the horizontal scale should be the same as that of the map, the vertical scale may need to be exaggerated to permit details to be shown. However, the minimum exaggeration possible should be employed since, particularly upon large scale maps, an over-exaggeration may present a misleading picture. The solution consists in "try it out".

The above description refers to conventional hydrogeological maps. For special cases, such as vulnerability maps, supplementary legends have been prepared, and they are in agreement with the 1995 legend. For other specialised fields, such as maps of risks, ecological implications etc., additional legend elements need to be developed, and an attempt should be made to create symbols which fully comply with the natural situation.

2.6 International Hydrogeological Map of Europe 1:1 500 000 (IHME)

2.6.1 Antecedents and Concept

Today it is difficult to imagine the situation in Europe during the immediate post-war period after 1945. In large parts ruins, hunger, refugees formed the picture. This epoch of desperation - in contrast to many devastated areas in our days - awoke a new spirit namely to reconstruct a new Europe in joint efforts among countries and by encouraging international cooperation by promoting industrial, agricultural production, commerce and scientific cooperation. This new spirit recalled earlier ventures, partially taken up by the UN system and thus building bridges over political blocks. One of the new challenges was the revival of scientific NGO's and their symbiosis with UN agencies. In this new spirit memories were awakening about earlier successes such as the International Geological Map of Europe (IGME) and hydrogeologists were calling for a European Map. As will be explained below only few hydrogeologists had an idea how to map hydrogeological features. The idea was born in the fifties – still in the first reconstruction phase in Europe – to venture a hydrogeological map of the whole of Europe irrespective of the political situation. It was also hoped that such a systematic map would lead to the improvement of national mapping projects. As outlined in this report, the map required a legend and the legend required a natural area for testing. As a matter of consequence, model legends were developed (cf. chapter 2.4.2) and tested and the test results referred back to the legend specialists. It has been mentioned that only the fourth model could convince – temporarily – since the improvements never came to a stand-still as the European and other continental maps developed and advanced. To describe the history of map and legend resembles the attempt to convincingly explain the problem of hen and egg. Thus, cross-references can be found in this report everywhere and the authors will congratulate the gifted writer who separates the two themes and thus avoids repetitions in a report like this one.

Like in politics many time periods have their great personalities who look over the fence and who have visions. Hydrogeology was fortunate to know a great number of eminent promoters of new ideas and projects. The development of both, map and legend (or legend and map) cannot be separated from Prof. Herbert Karrenberg from Krefeld, Federal Republic of Germany and – again compared with politics – he was fortunate to find co-fighters from many countries, in particular from France and Great Britain.

In 1960, the International Association of Hydrogeologists (IAH) initiated a project for the preparation of an International Hydrogeological Map of Europe, having realized that although a large number of hydrogeological maps at various scales existed in almost all European countries, none of them were the same in their scientific approach, content, presentation, or use of cartographic symbols, making comparison practically impossible and even leading to erroneous conclusions. The fact that no obvious effort was made to prepare maps in a uniform way lead to the suggestion that a small-scale map covering the whole of Europe should be prepared. However, even for a relatively small continent like Europe, such a map exceeds normal paper size. To remedy this situation, therefore, it was decided to divide the surface area into a composite of several map sheets.

The general purpose of the map was to provide a simplified representation of the groundwater setting in Europe as related to the geological situation. These small-scale maps only give a general picture and are therefore used primarily for information, teaching purposes, planning and scientific work. Their main objective is to show the location, geographic extent and constitution of the major groundwater bodies, classified according to the main types of aquifers.

In order to prepare an international map series, agreement must be reached by the participating countries and international organisations regarding scale, an easily applicable legend and a meaningful scientific approach. Since the suggested European map was the first international venture in the field of hydrogeological mapping, it was essential, from the very beginning, to secure the collaboration of a large number of scientists and to make full use of the experience of countries with a long tradition in mapping activities and hydrogeology. It is, therefore, not surprising that it took almost ten years to gather and evaluate such information and to establish suitable models for discussion by the scientists involved. Although the model that was finally adopted had been discussed in great detail, serious problems emerged during the preparation of the actual map, and these had to be solved at international level.

The compilation of the sheets comprising the map is far from being a routine job and shows that hydrogeological mapping needs to be developed further. At the start of the actual work, it was understood that both the legend applied and the scientific approach had to be flexible so that, on the one hand, individual or unique events could be shown and, on the other, the necessary uniformity and clearness of the map could be maintained. The history of this map, therefore, reflects both an attempt at perfection and an aim for uniformity, as well as the peculiarities of an international undertaking. These peculiarities stem from the different ways of identifying problems in different countries, from varying hydrogeological interpretations to different national regulations concerning the compilation and publication of data and information. These rather limiting factors and the varying amount of information available in each country would have led to an unjustified simplification of the map if the permitted or actual minimum of information available in certain countries had been taken as a standard. This difficulty was overcome by the flexible nature of the map, which contains all information necessary for the understanding of the hydrogeological situation.

2.6.2 Choice of Scale

When choosing a scale there must always be a compromise between the size of the paper, the number of sheets forming the composite, and the amount of information to be included. The European geologists had agreed to a scale of 1:1 500 000 which allows sufficient detail but which is still viable economically and is also easy to use. The individual map sheets are organised in a pattern with horizontal (numbers) and vertical (letters) rows. Each sheet has a key (say B5) and is named after an important city (e.g. Paris). The geological base maps were provided by the Commission for the Geological Map of the World (CGMW), affiliated to the International Council of Scientific Unions (ICSU) and the International Union of Geological Sciences (IUGS). In view of the success of the International Geological Map of Europe (IGME 1500) the same scale and division of sheets has also been applied for the European hydrogeological map series.

Based on the experience with the geological map series in Europe and considering the great value of sound geological information for groundwater, it was logical to issue a hydrogeological map at the same scale, with the same projection and topographic base. The advantages are obvious: low cost, easy comparability, similar scientific approach, similar systematic. In 1962, the choice of scale and the sub-division of the map sheets were daring. However, acceptance by the scientific community confirmed the appropriateness of the decision and no questions were posed with regard to the Hydrogeological Map of Europe. Nevertheless, there was a certain amount of resistance as national maps at this scale were very few, and each country was required to re-draw its contribution at the jointly agreed-upon scale of 1:1 500 000. The fact that all European countries agreed to this scale is proof in itself of the good will of all partners involved. The fact that national maps could not be used without transformation helped to overcome eventual national rivalries or ambitions. There is no doubt that there was a temptation for countries with highly developed hydrogeological maps to impose their approach, scale and legends, but this was overcome and finally all the European countries contributed and co-operated.

2.6.3 Legend for the Map

It was evident that first, a legend for the map had to be developed by experts from different countries with the support of various organisations and institutions. The hydrogeological situation in all parts of Europe and its map representation was to be considered. A General Legend for the International Hydrogeological Map of Europe was printed in three languages (English, French, German) by the Commission for Hydrogeological Maps of the International Association of Hydrogeologists (IAH) in the year 1974, as a special support tool for the European map makers.

The General Legend consists of four parts. The first two parts (A and B) have a geologic-petrographic basis and characterise the lithology of aquifers in porous and fissured rocks, including karstified rocks or non-aquifers, with suggestions of the grey ornament to be applied. Part C of the general legend shows in six classes the productivity of the aquifers and part D contains special information about groundwater and springs, surface water, artificial works and geological symbols.

2.6.4 Historical Milestones

The preparatory work largely had been undertaken by NGO's and particularly interested geological services. UNESCO observed this development and offered to bring the European venture on an international level by making it an item of the newly created International Hydrological Decade (IHD). At its first session in 1965, the Co-ordinating Council of the International Hydrological Decade (IHD), when discussing hydrogeological mapping activities in general, endorsed that a small-scale hydrogeological map of Europe be prepared, under UNESCO auspices. This task was entrusted to the International Association of Hydrogeologists (IAH) who were requested to enlist the co-operation of other international non-governmental scientific organisations including, in particular, the International Association of Scientific Hydrology (IAHS). The Council emphasised that such a map would be part of an international hydrological mapping operation linked to the preparation of a world groundwater atlas.

At its third session in 1967, the Co-ordinating Council accepted IAH Model 4 as a suitable form of representation and scientific approach, and recommended that it be adopted for all sheets. It thus confirmed the recommendations of the former IHD Working Group on Hydrological Maps, which had discussed the scientific approach to the map in detail.

It should be pointed out that in 1968, in view of the enormous financial implications of this project the Intergovernmental Council for the IHD decided that it should be given the status of an individual project activity funded by the Regular Programme of UNESCO and that it should no longer be executed within IHD which, until then, had provided the necessary organisational framework. IHD, and afterwards IHP, therefore, no longer played a role in the compilation of the map although a very active interest in the project was retained and reports on progress continued to be made.

However, UNESCO convened a number of regional meetings in order to settle problems concerning the interpretation of national data or disagreements along the political borders. Such meetings particularly covered Scandinavia, the Iberian Peninsula, the Danube Basin, South-East Europe, and as a special case Sheet F6, Haleb with Eastern Turkey, parts of Syria and the Lebanon that was thought to be the link to the Hydrogeological Map of the Arab Region planned by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), (however this Sheet never has been printed owing to political reasons). The Annex to this Report contains a list of coordinating meetings, and the participants have been included to the extent their names could still be retrieved.

Following the Council's acceptance of the mapping project, the General Conference of UNESCO, at its fifteenth session in 1968, decided that UNESCO should collaborate over the preparation and publication of the International Hydrogeological Map of Europe, together with the IAHS, the IAH and the Sub-Commission for the Hydrogeological Maps of the Commission for the Geological Map of the World (CGMW). This decision was renewed and re-confirmed by the General Conference of UNESCO at its sixteenth session in 1970 and at its seventeenth session in 1972. Besides allocating funds for the actual printing, UNESCO hosted the annual meetings of the Sub-Commission and of its Editorial Board. Later sessions of the General Conference considered the project a routine affair and, in fact, no problems of either a scientific, organisational or political nature, ever have arisen.

In view of the long term commitment of the General Conference of UNESCO, a general contract could be concluded in 1970 with the BGR, in order to ensure a smooth implementation of the project. While this general contract concerned the project as a whole, addenda have been made for each sheet and explanatory note once it became ripe for printing. However, problems of a financial nature occurred during the second half of the eighties and during the early nineties shortage of funds lead to a complete standstill. Efforts have been made in the late nineties to re-vitalise the project and they have been successful.

However, it took another decade to finalise the map series with its 25 map sheets, and the last two map sheets (Sheets D5 Budapest and E5 Bucuresti) have only been printed in 2013. A final "International Workshop on Groundwater Systems in Europe" was held in August 2013 in Berlin, on the occasion of the completion of the "International Hydrogeological Map of Europe". It concluded the cooperation project of the IHME that lasted for almost 50 years.

2.6.5 Structure and General Descriptions

The functioning of the original project was assured at two levels: one level consists in the general agreement between UNESCO and the BGR. For the second, the executing level, a Chief Editor is responsible for the overall work and an Editorial Committee checks the uniformity of the map. Individual scientific editors (sheet coordinators) ensure for each sheet, that national contributions are harmonised to form a coherent draft of the map sheets and explanatory notes.

Since one sheet usually covers more than one country, the Sheet Editors has to contact the scientists responsible in the countries concerned, which so far has resulted in excellent bilateral, multilateral and regional co-operation. The assistance of the National Committees for IHP and the IAH as well as that of the Geological Surveys and other competent authorities has always been willingly given.

The Sheet Editor largely coordinated by correspondence. Practise however showed that not all problems could be solved in this way, and UNESCO therefore convened and financed coordination meetings assembling possibly all country representatives. Practically in all cases, agreement on open questions could be reached.

In the past, these meetings have been paid from UNESCO's regular budget. However, as of 1995, UNESCO changed its financing policy and the meetings had to be accommodated under the UNESCO Participation Programme. This implied that the German National Commission for UNESCO had to formulate the respective requests. The Commission successfully negotiated and obtained full support from UNESCO.

This model of regional meetings also has been applied for regional hydrogeological maps in other continents, and ultimately also for the Steering Committee of WHYMAP, as will be described later (cf. chapter 3).

As the sheets become available, they are cartographically prepared and printed by the "Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)" in Hannover, Germany and published jointly by the BGR and UNESCO. The map is available from UNESCO and through a German Agent, ILH, GeoCenter in Stuttgart. It should be noted that most of the sheets are accompanied by explanatory notes, which contain additional information, e.g. on climate, chemical composition of groundwater and any geological features of significance to groundwater flow. Additional drawings, hydrogeological borehole and cross sections are supplied, too. A map sheet and the corresponding explanatory notes, thus, are considered as one unit.

The map has been drawn up along the same lines as the International Geological Map of Europe. While the latter consists of 49 sheets, the International Hydrogeological Map of Europe is composed of only 25 sheets, as certain regions outside Europe and in the extreme North have not been included. Each sheet measures approximately 90 cm x 70 cm and contains not only a section of the map but also the legend in English, German and another language, either French, Russian, Spanish, or occasionally another one, depending on the countries depicted. The bulk of the explanatory notes have been published in English and some of them in French.

2.6.6 Present Status

A large number of map sheets have already been prepared in the Seventies and Eighties but, largely due to financial constraints and because of the political changes in East Europe the project stagnated for several years in the early nineties.

In 1998 the difficulties had been overcome and a new work programme was concluded concentrating on the furthermost parts of the Iberian Peninsula, parts of Italy, the Danube Basin and Southeast Europe. The new programme got off to a good start with the holding of a regional meeting on the Danube Basin in Bratislava, September 1999. Further editorial meetings have been held in Madrid (2000, for Portugal and Spain), in Bucharest (2000 and 2004, for Bulgaria, Moldavia, Romania, Turkey and Ukraine), in Budapest (2000 and 2003, on the Danube Basin), in Athens (2002, for Southeast Europe) and in Berlin (2005, for Southeast Europe).

The printed map series of IHME was concluded in August 2013 at an international workshop on Groundwater Systems in Europe, jointly organised by BGR, EuroGeoSurveys and UNESCO-IHP in Berlin. More than 60 participants of 19 countries of Europe and many European organisations and scientific institutions discussed the accomplished status (cf. Table 1) and future applications of the IHME series.

Another project published in 2008, as a contribution to the International Year of Planet Earth, is a mosaic of the Hydrogeological Map of Europe at the scale of 1:5 000 000. It consists of a coherent assemblage of all printed and two draft map sheets of IHME that have been geo-referenced and harmonised (Figure 5). The raster data of the IHME are also accessible via the BGR

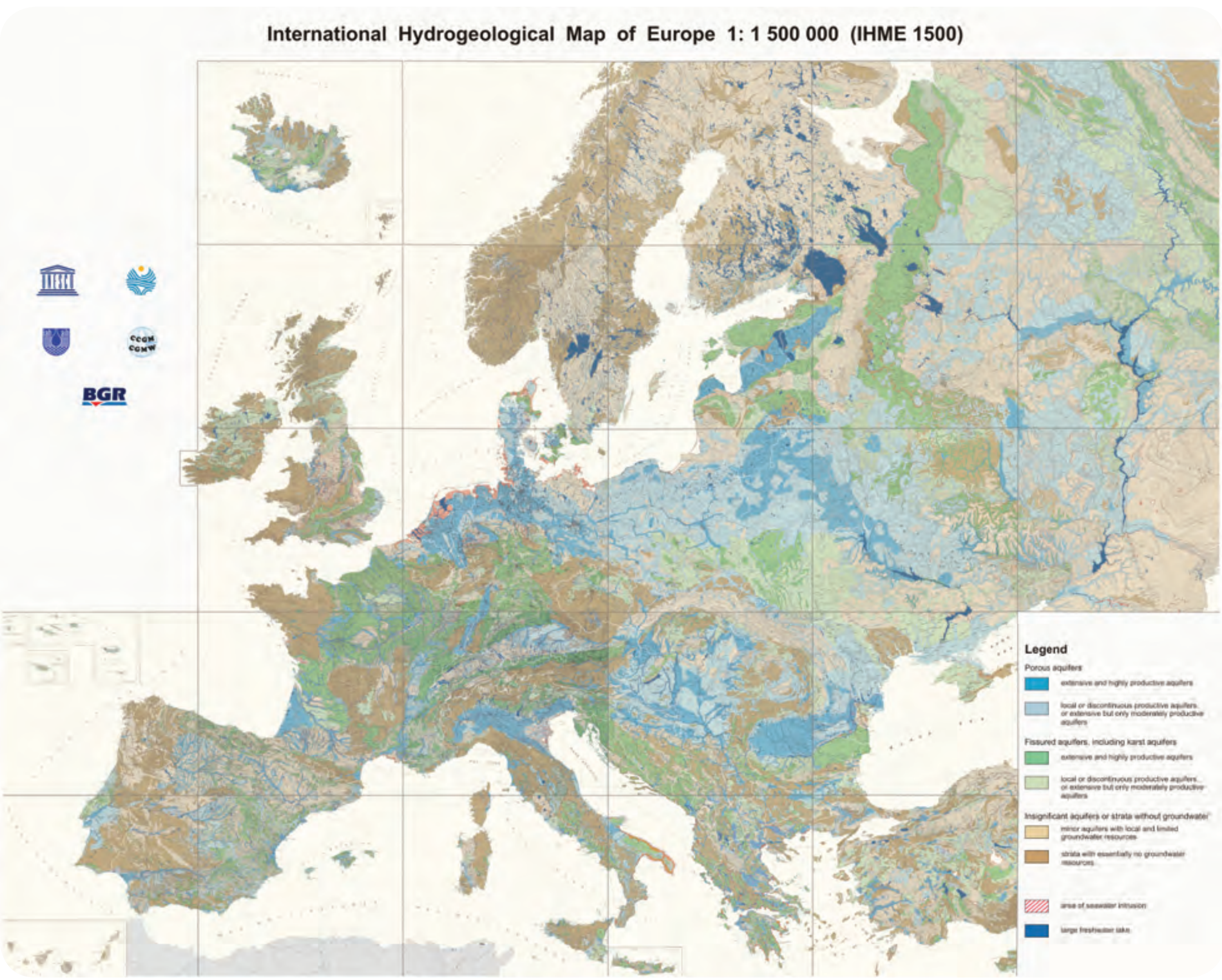


Fig. 5 – Mosaic of the map sheets of the series of the International Hydrogeological – Map of Europe at the scale of 1:1 500 000 (IHME 1500)

web site (www.bgr.de/IHME) where the scans of the individual map sheets can be downloaded.

Over the long period of almost 50 years of executing the IHME not only the hydrogeological knowledge has progressed tremendously, but there was also a paradigm change in the cartographic techniques. Geographic information systems (GIS) have almost totally replaced conventional cartography and printed maps. Therefore, the IHME series of 25 map sheets printed as paper editions at the scale of 1:1,5 million has been converted into a digital, harmonised, seamless, properly georeferenced pan-European data set by BGR, assisted by The Geological Surveys of Europe (EuroGeoSurveys). The data will primarily serve for the work of EuroGeoSurvey's Expert Groups and will be available after quality assurance in early 2014.

The International Hydrogeological Map of Europe at the scale of 1:1 500 000 (IHME 1500) was the forerunner of similar hydrogeological maps, and it demonstrated the applicability of the thematic treatment, and concluded the general legend in a variety of climatic settings. The success of this map inspired hydrogeologists in other regions and continents to adopt this model and to draw maps according to their requirements, to the availability of data and to the size of the continents. Today, practically the whole globe has been mapped, for the benefit of scientists, educators, planners and politicians. The maps deliver the tools for water management, water sharing and for ecohydrological management of the groundwater resources in order to ensure safe groundwater for mankind on a sustainable basis for the regeneration of disturbed ecosystems.

UNESCO invested much effort and also largely funded the IHME 1500. When the whole mapping project of the IHME 1500 as one issue of the UNESCO-BGR contract ended in 2013, more than 330 scientists from all European countries independent of their philosophy of life, affiliation to a political system and their religions denomination have successfully cooperated – even during the time of the cold war. This experience could serve as a model for other regions in the world, too.

Table 1: Map Sheets of the International Hydrogeological Map of Europe and year of publication of printed Map Sheets and Explanatory Notes

Sheet	Year of printing	
	Map Sheet	Explanatory Note
A5 – La Coruña	1983	-
A6 – Lisboa	2001	-
B2 – Island	1980	1980
B3 – Edinburgh	1980	1980
B4 – London	1976	1978
B5 – Paris-Sud	1975	1978
B6 – Madrid	1978	-
C2 – Trondheim	1984	1985
C3 – Oslo	1979	1979
C4 – Berlin	1977	1977
C5 – Bern	1970	1974
C6 – Roma	1990	-
D2 – Haparanda	1984	1985
D3 – Stockholm	1981	1982
D4 – Warszawa	1981	1987
D5 – Budapest	2013	-
D6 – Athina	2009	-
E2 – Archangel'sk	1987	1987
E3 – Moskva	1979	1979
E4 – Kiev	1981	1985
E5 – Bucuresti	2013	-
E6 – Ankara	1978	-
F2 – Kirov	1992	1994
F3 – Kazan	1990	1984
F4 – Astrakhan	1995	1998

2.7 Existing Small-Scale Regional, Continental and Global Hydrogeological Maps

Numerous thematic maps portraying hydrogeological information have been compiled on almost all continents of the world, except for Antarctica (see Figure 6), and published in the last two decades of the past century. In addition to the large number of national and local hydrogeological maps, regional, continental and global maps have been produced in concerted, international cooperation projects, to cover large areas or continents by small-scale overview maps without considering national boundaries. They are listed below in chronological order. Those projects assisted by UNESCO, mainly by helping to develop the map concepts and organising regional meetings, are highlighted in bold in the following list and are briefly described in this report (sections 2.7.1 to 2.7.4.)

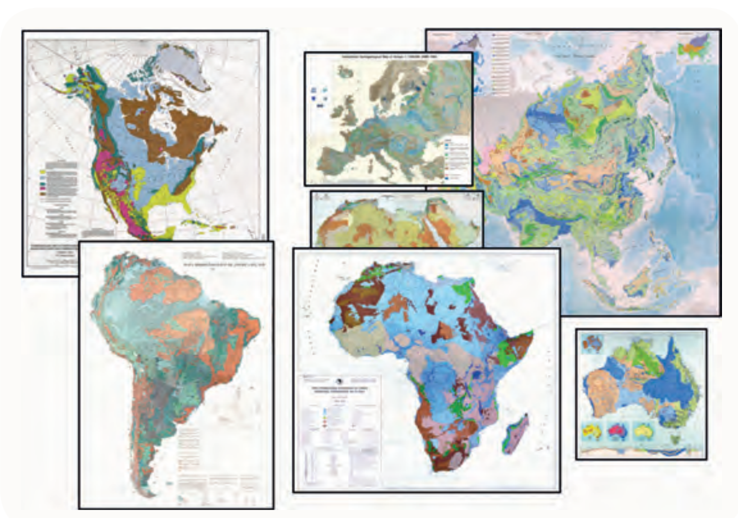


Fig. 6 – A Medley of Existing Continental Hydrogeological Maps

Regional and continental maps (maps with UNESCO assistance in **bold**)

- **International Hydrogeological Map of Europe 1:1 500 000 (BGR & UNESCO), 25 sheets, 1970 – 2013 (IHME)**
- Hydrogeological Map of Australia 1:5 000 000 (J.E. Lau, D.P. Commander & G. Jacobson), 1987
- **Hydrogeological Map of the Arab Region and Adjacent Areas 1:5 000 000 (ACSAD and UNESCO), 2 sheets, 1988**
- Hydrogeology of North America (R.C. Heath), 2 maps 1:13 333 333, 1988/89
- Ground Water in North and West Africa, 2 maps 1:20 000 000 (UN/TDC), 1988
- Middle East Hydrogeology 1:8 000 000 (Tübinger Atlas des Vorderen Orients), 1990
- **International Hydrogeological Map of Africa 1:5 000 000 (Organisation of African Unity/ African Organisation for Cartography and Remote Sensing, Ed. M. Safar-Zitoun), 6 sheets, 1992**
- **International Hydrogeological Map of South America (Mapa hidrogeologico de America del Sur) 1:5 000 000 (UNESCO, IHP and Government of Brazil), 2 sheets, 1996**
- Hydrogeology of the Great Artesian Basin 1:2 500 000 (Australian Geol. Survey Org., M.E. Habermehl & J.E. Lau), 1997
- Hydrogeological Map of Asia 1:8 000 000 (Eds. Jiao Shuqin et al.), 6 sheets, 1997
- The National Atlas of the United States of America, Principal Aquifers 1:5 000 000 (J.A. Miller), 1998

Global maps and mapping programmes

- **World Map of Hydrogeological Conditions and Groundwater Flow 1:10 000 000 (Eds. R.G. Dzhamalov & I.S. Zektser), 6 sheets, 1999**

- **Worldwide Hydrogeological Mapping and Assessment Programme (WHYMAP), Programme under compilation with the following map editions:**
  - **Groundwater Resources of the World, 1:50 000 000 (Special Edition with explanation on the back for the International Geological Congress, Florence, 2004)**
  - **Transboundary Aquifer Systems, 1:50 000 000 (Special Edition with explanations for the World Water Forum, Mexico City, 2006)**
  - **Groundwater Resources of the World, 1:25 000 000 and 1:40 000 000 (Contributions to the International Year of Planet Earth, 2008)**
  - **River and Groundwater Basins of the World, 1:50 000 000 (Special Edition with explanations for the 6th World Water Forum, Marseille, 2012)**

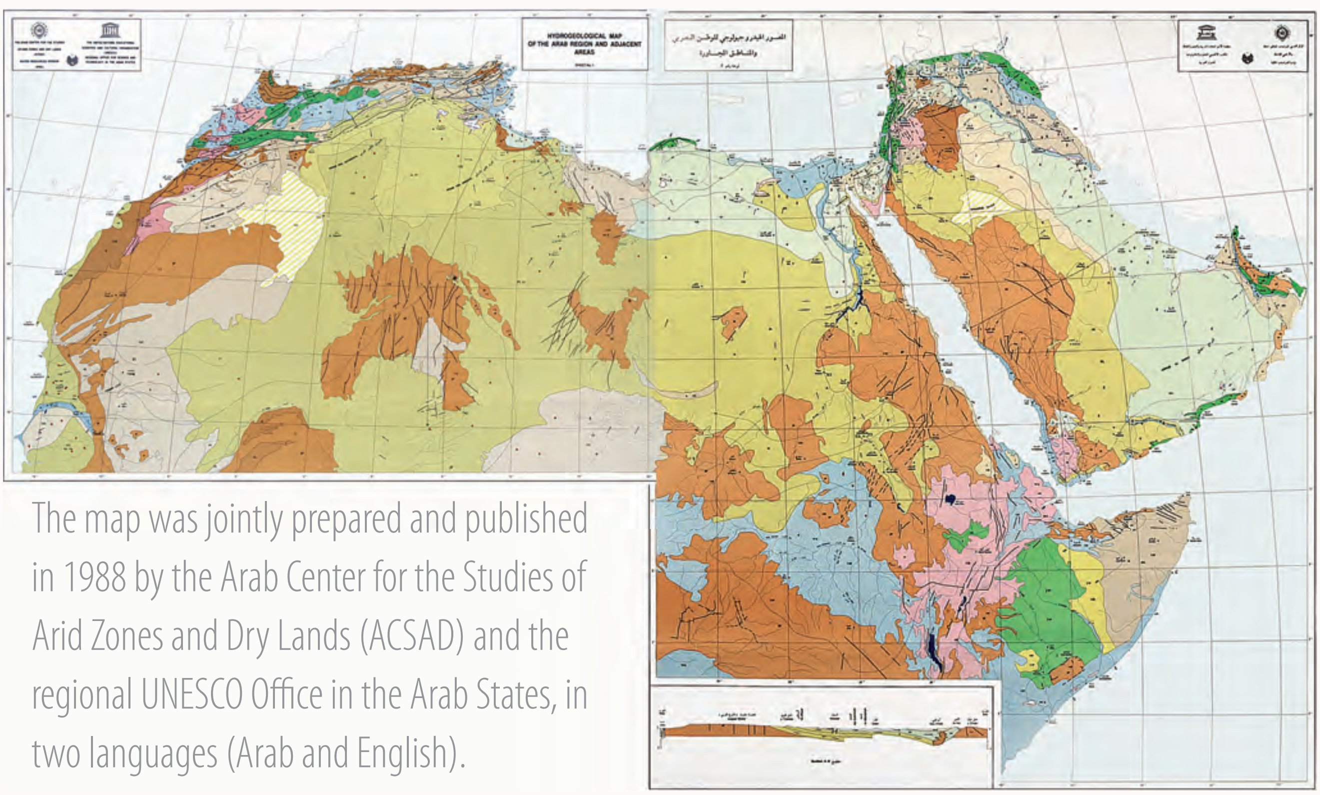
With all these thematic, continental or global hydrogeological maps the hydrogeological conditions close to the surface of the earth are generally described and portrayed at overview scale. However, much more detailed knowledge about deeper aquifers and groundwater reservoir structures is necessary, together with better data on the water budgets, groundwater quality and flow systems, to lay a reliable basis for groundwater management and contribute to integrate water resource planning and management.

Further details about WHYMAP and its related map visualisation system WHYMIS will be provided in chapter 3 of this Report.

2.7.1 Hydrogeological Map of the Arab Region and Adjacent Areas, Scale 1:5 000 000

The map was jointly prepared and published in 1988 by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and the regional UNESCO Office in the Arab States, in two languages (Arab and English).

The map consists of two sheets and was compiled by the chief editors J. Khouri and A. Droubi with the support of a co-editor from UNESCO and of scientific advisors from six involved countries. The information depicted on this map is based on ACSAD and UNESCO files.



The map was jointly prepared and published in 1988 by the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and the regional UNESCO Office in the Arab States, in two languages (Arab and English).

Fig. 7 – View of the Hydrogeological Map of the Arab Region

The main issues on the map are the different hydrogeological units including groundwater basins with fossil waters in deep aquifer systems, information on the groundwater quality (total salinity) and the interconnection between groundwater with surface water and springs. The lithology and stratigraphy of the rocks forming the different aquifers are presented, too. The map is accompanied by two characteristic hydrogeological cross-sections. Explanatory notes have been published in the Arab language in order to ensure wide dissemination and use in the area.

2.7.2 International Hydrogeological Map of Africa, Scale 1:5 000 000

The International Hydrogeological Map of Africa project was launched by the Organisation of African Unity at the beginning of the 1980's, after the Lomé summit of African Heads of States. The African Association for Cartography (AAC), later transformed into the African Organisation for Cartography and Remote Sensing (OACT/AOCRS) based in Algiers, was endowed with the map execution in 1982.

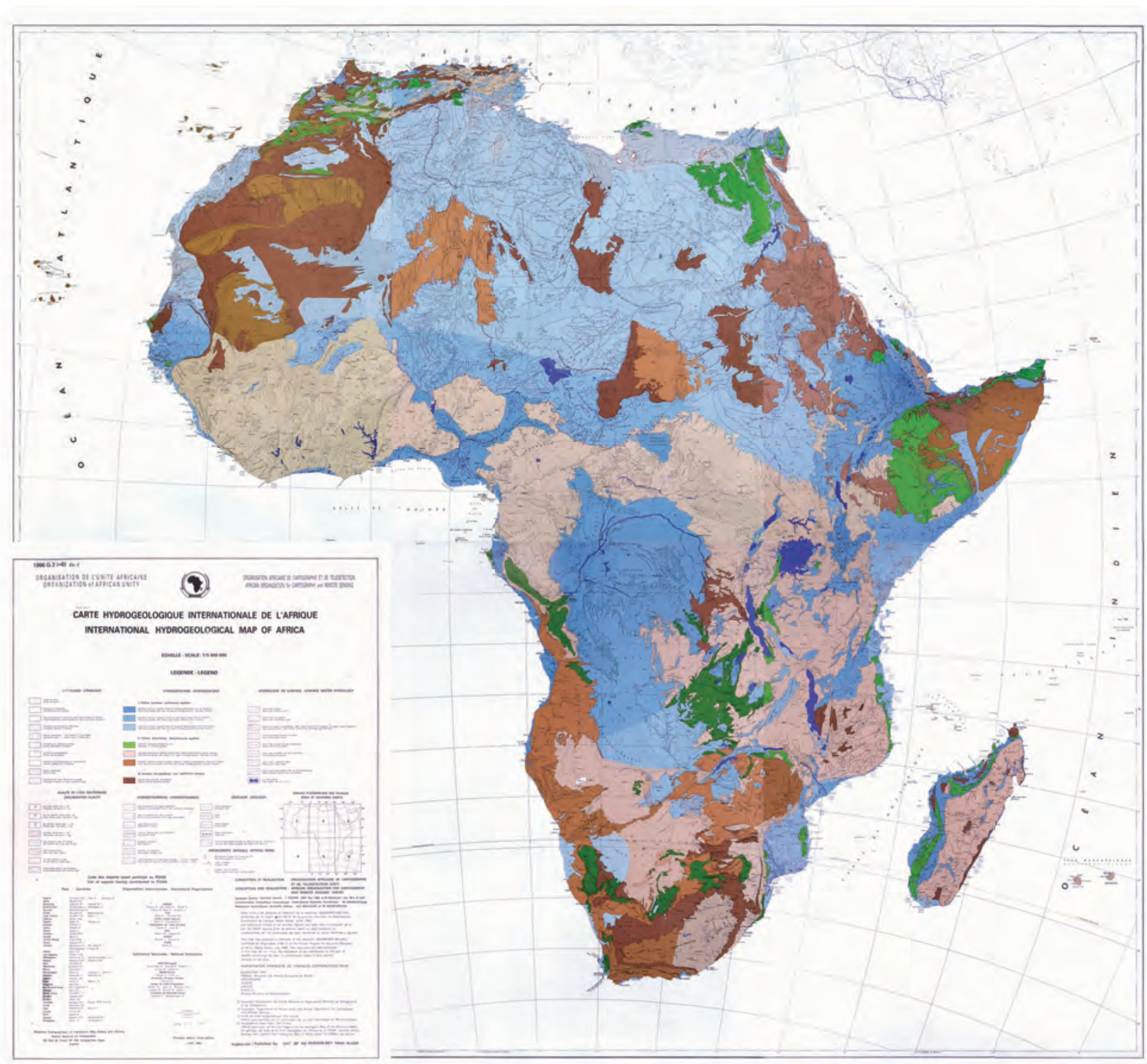


Fig. 8 – View of the International Hydrogeological Map of Africa

After the preparation of a feasibility study by the OACT and agreement of a common legend, drafts of the map sheets were produced, region by region, and finalised during a series of workshops. The map project involved almost 100 scientists from 41 African countries and some twenty international experts. The scientific coordination of the project was conducted by M. Safar-Zitoun, C. Fezzani and A.C. Nouiouat. UNESCO, Germany, France, Switzerland and Yugoslavia provided financial input and expertise.

The topographic base for the hydrogeological map was provided by the French National Geographic Institute (IGN) and the Commission for the Geological Map of the World (CGMW) via the project of the Geological Map of Africa at the same scale.

The five map sheets and the legend sheet have been published between 1988 and 1992. Most of the sheets are accompanied by explanatory brochures describing the hydrogeological conditions of the sheet areas in French and/or English. The cartographic production and printing were executed in Algeria.

The map shows, on the background of topographic data,

- the lithological type of rock units grouped into ten categories by grey ornament,
- a hydrogeological classification into continuous and discontinuous aquifers and non-aquifers, expressed by blue, green and brown colour wash, whereby the aquifers are further subdivided into three shades of blue or green, respectively, according to the supposed recharge from rainfall.

Point and line symbols provide additional information on surface water hydrology, groundwater quality, hydrodynamics, artificial works and geology.

2.7.3 Mapa Hidrogeologico de America del Sur (Hydrogeological Map of South America), Scale 1:5 000 000

In 1976, the First Meeting of South America National Committees to UNESCO started an extensive mapping programme for the accomplishment of the "Hydrogeological Map of South America". This project was carried out within two phases organised and coordinated by Nelson da Franca Ribeiro dos Anjos and Albert Mente, both from Brazil, with the contribution of numerous national coordinators and authors. During the first phase, 1976-1986, each South American country prepared its own hydrogeological map and corresponding explanatory notes at scales ranging from 1:2 500 000 to 1:500 000, using a common legend approved by UNESCO. The second phase, 1987-1989, comprised the compilation of the actual continental map at a scale of 1:5 000 000 based on the hydrogeological maps of the different countries and a cartographic base which was provided by the Commission for the Geological Map of the World (CGMW).

The Hydrogeological Map of South America 1:5 000 000 was finally published in 1996 by UNESCO-IHP, Republica Federativa do Brasil, Departamento Nacional da Produção Mineral (DNPM), Serviço Geológico do Brasil (CPRM) and CGMW.

It consists of two map sheets and an accompanying explanatory booklet. The map shows important characteristics of the main hydrogeological units, represented by:

- types of aquifers,
- hydrogeological characteristics of rock formations,
- classes of productivity of the aquifers,
- chemical quality of the groundwater,
- subterranean flows,
- the relationship between surface water and groundwater.

As a special feature the map includes a regionalisation of groundwater related information by delineating hydrogeological provinces defined as "regions with general characteristics as far as groundwater occurrence is concerned", mainly described by geological formations and physiographic / climatic characteristics.

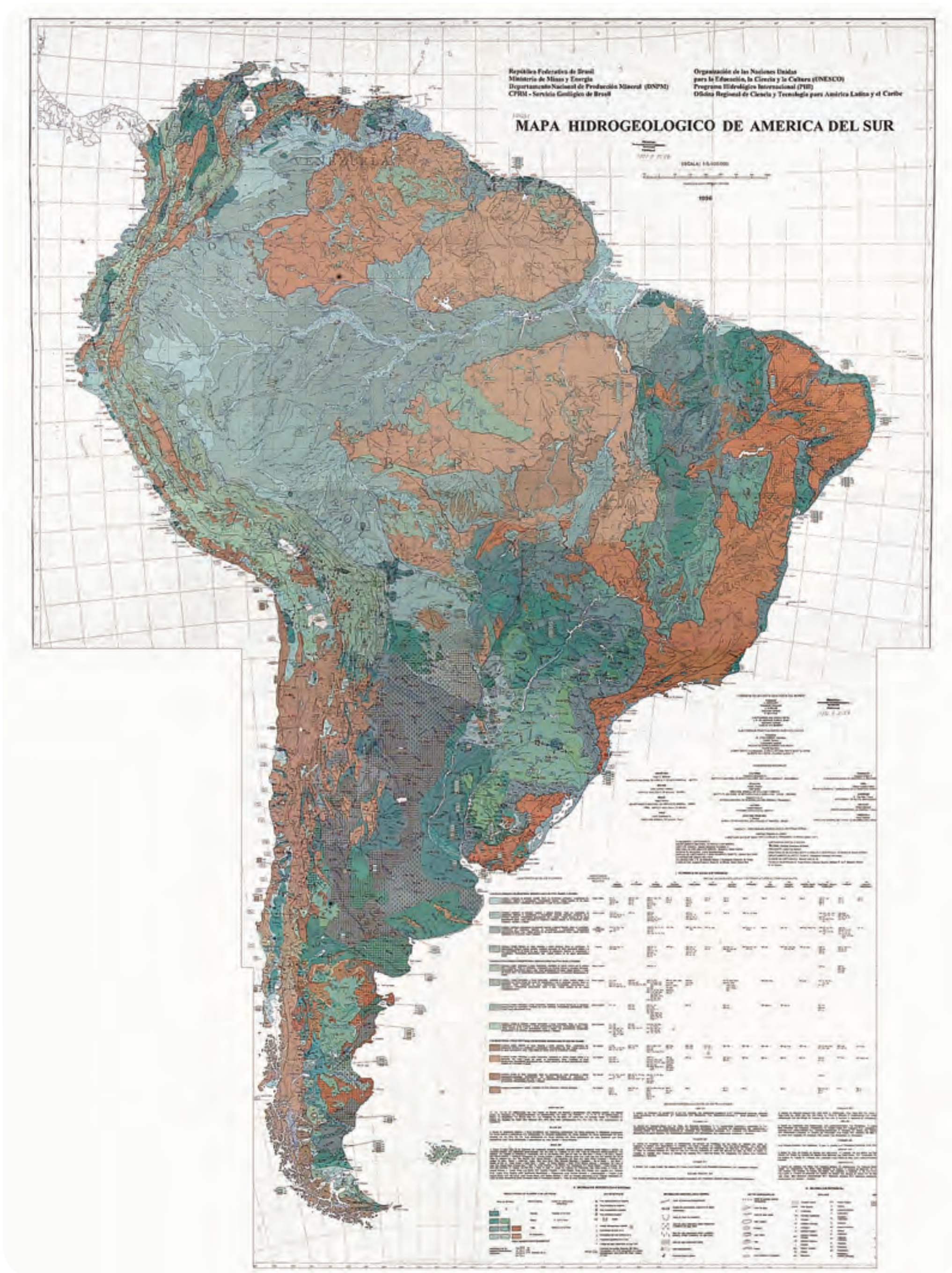


Fig. 9 – View of the Hydrogeological Map of South America

2.7.4 World Map of Hydrogeological Conditions and Groundwater Flow, Scale 1:10 000 000

The Sixth Session of the UNESCO Intergovernmental Council of the IHP (Third IHP Phase) adopted the Project 2.3 "Role of Groundwater in the Hydrological Cycle and in Continental Water Balance" in its programme. The main result of this project is the above mentioned map, which has been published in 1999. It is available as either a coloured paper map consisting of six sheets or as a digital map on CD-ROM. The map was compiled by the Russian Academy of Sciences (responsible editors: I.S. Zektser and R.G. Dzhamalov).

On the map the average long-term values of groundwater discharge (in litres per second per km^2) are shown in seven ranges for each of the distinguished four main groundwater flow media: sedimentogenic-pore, sedimentogenic-fracture, karst and magmatogenic-metamorphogenic.

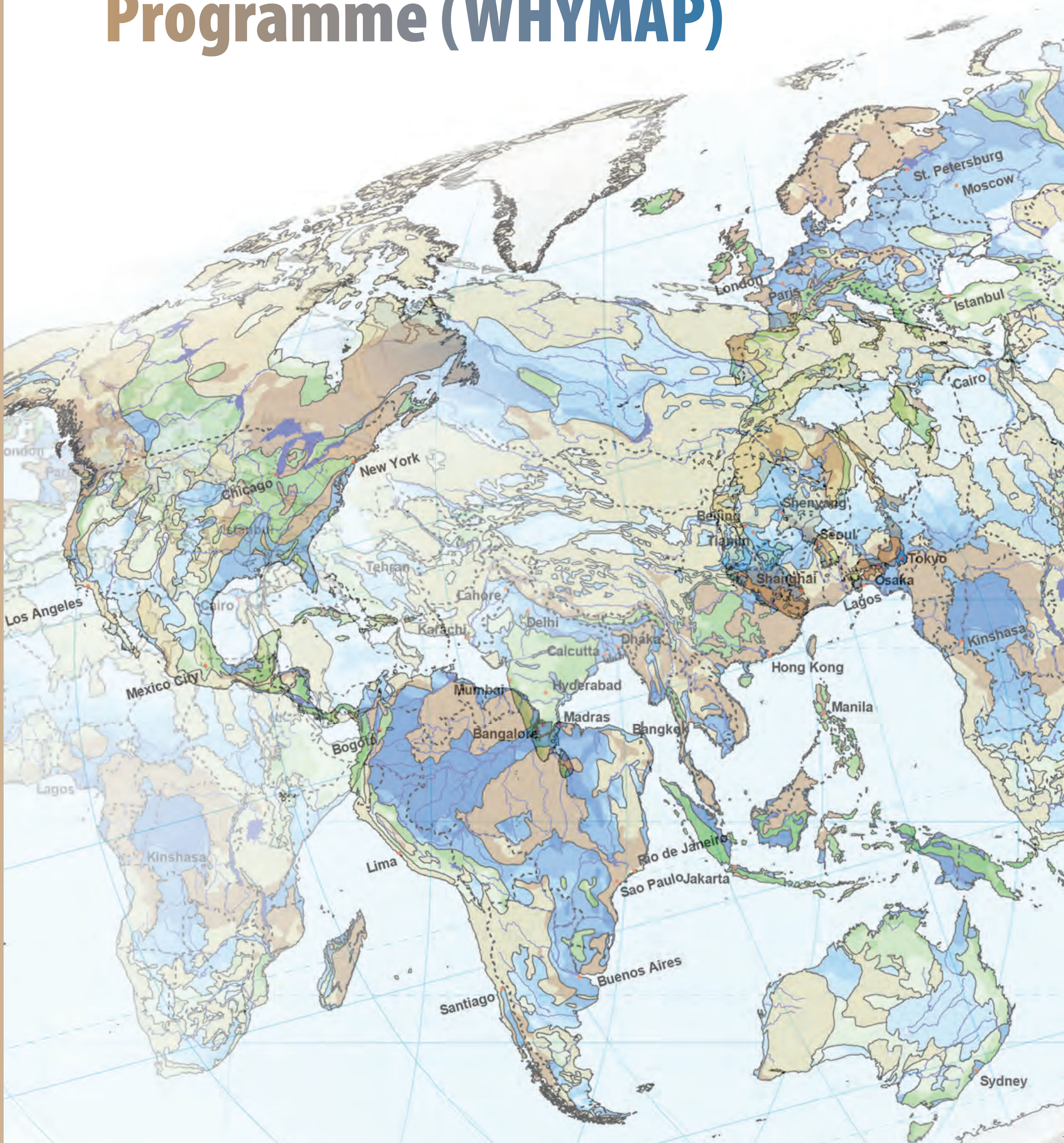
The map is a special thematic hydrogeological map, which is different from the above described ones, as it shows the distribution of quantitative groundwater flow characteristics – specific groundwater discharge values and coefficients.

The combined cartographic representation of these two quantitative characteristics proved to be possible using two different modes: a colour cartogram (for the annual specific groundwater discharge values) and isolines (for groundwater run-off / precipitation ratios). Furthermore, the conditions of direct groundwater discharge to seas and oceans and the identification of groundwater flow media on the sea bottom are represented on the map.

Fig. 10 – View on the World Map of Hydrogeological Conditions and Groundwater Flow

The purpose of the books and maps 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.

3. World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP)



3.1 General Issues as seen at the End of the Second Millennium

The European map, the above mentioned guidebooks 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 Report to describe all variations known to the authors. Hence, a list of maps brought to the attention of the IAH Commission on Hydrogeological Maps (COHYM) and SCHYM was included as an Annex to the Guidebook published 1995 to show the broad variety of hydrogeological maps existing and many more maps have been issued since. A striking feature, however, is the universal applicability of the UNESCO legend which with some extensions could be used even for very difficult and specialised 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 (Federal Republic of Germany) in May/June 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 1986. Work however, only showed substantial progress much later during the Fourth Phase of the International Hydrological Programme (IHP, 1990 – 1995).

The purpose of the books and maps 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. These international efforts are intended to contribute towards better understanding of hydrogeological phenomena through visual presentation in the most appropriate way as required by different circumstances: in other words, investigation and understanding, throughout the world, of hydrogeological systems when shown in thematic form.

3.2 Background and Inherent Philosophy of WHYMAP

Largely but not solely, UNESCO, CGWM, IAH and, last but not least, BGR played a major role in the establishment of small-scale hydrogeological maps all over the world. Mapping projects particularly those of FAO, UNDP and a number of regional organisations add to these ventures. A not exhaustive number of examples have been listed in chapter 2.7.

While the preceding decades saw the compilation of firstly national as well as regional or continental maps, at the end of the twentieth century the ideas to synthesise the continental maps by compiling a world map emerged in many international conferences. The idea was much supported when the UN system pursued the World Water Assessment Programme (WWAP) in 2000.

The availability of, and access to, fresh water is an important issue on the agenda of planners, politicians and executives all over the world. Although there seems to be an abundance of water in global calculations, surface and groundwater resources are increasingly under stress at regional and local scale, although about 96 % of all liquid freshwater is found in aquifers, many of them transboundary in extent. Rising demands from population growth, and irrigated food production, particularly in the semi-arid and arid regions of the world, call for larger and reliable quantities of water on the one hand, but declining resources due to pollution, over-pumping and climatic changes on the other hand reduce the per capita usable water resources. In addition, the needs of ecosystems are essential and must be sustained. Although groundwater is found practically everywhere, not always in large quantity and quality, aquifer resources constitute the only reliable water resource for drinking water supply and irrigated food production, particularly in the semi-arid and arid regions of the world.

In spite of the outstanding importance and the sharply increasing use of groundwater in the past decades, the knowledge about the groundwater in aquifers and its management is still weak in many places. Investments in groundwater schemes are frequently founded on inadequate aquifer information in terms of quantitative data, reliable models and poor monitoring.

In the mid 1970s UNESCO established its International Hydrological Programme (IHP). Since 1974 the UNESCO-IHP developed significantly the understanding of aquifer system characteristics. The Sixth Phase of the IHP (2002-2007) concentrated on the contribution of knowledge of the water resources at risk and the development of strategic plans about the effects of human activities on groundwater resources, and the Seventh Phase of the IHP.

In order to contribute to the world-wide efforts to better study and manage aquifer resources, UNESCO-IHP, the thematic hydrogeological map commissions and sub-commissions of the International Association of Hydrogeologists (IAH) and the Commission for the Geological Map of the World (CGMW) launched the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP). WHYMAP aims at collecting, collating and visualizing hydrogeological information at the global scale, to convey groundwater related information in an appropriate way for global discussion on water issues for the sustainable management of groundwater within Integrated Water Resources Management (IWRM) concepts at national and regional level, and to give recognition to the invisible underground water resources within the UNESCO Programme on World Heritage. WHYMAP also brings together the huge efforts in hydrogeological mapping at regional, national and continental levels, which permits overview and comparison of the major aquifer systems of the world with an idea of their stress situation.

3.3 Historical Development and Project Design

Several agencies joined UNESCO, IAH and CGMW and provided their specific contribution to WHYMAP. A consortium was then established in 2002, consisting of the UNESCO International Hydrological Programme as lead agency, the Commission for the Geological Map of the World (CGMW), the UNESCO/IUGS International Geoscience Programme (IGCP), the International Association of Hydrogeologists (IAH), the International Atomic Energy Agency (IAEA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The consortium was responsible for the general thematic outline and the management of the programme. UNESCO provided financial support for the venture, and BGR provided important resources in terms of manpower, mapping capabilities and data. All partners were committed to supply relevant scientific input.

The participation of regional experts, focussing on the relevant regional groundwater knowledge and information is considered crucial for WHYMAP. A Steering Committee of eminent international experts was established under the supervision of the consortium. Its first meeting was organized by the UNESCO IHP National Committee of Germany in Koblenz in June 2003, followed by a second session at UNESCO House in Paris in March 2004 and a third meeting, again in Paris, in April 2005. The UNESCO regional offices and the National Committees of the UNESCO IHP, the continental vice presidents of the IAH and CGMW have provided a valuable contribution to the project.

Close cooperation with the International Groundwater Resources Assessment Centre (IGRAC) is assured through UNESCO, and the WHYMAP data are shared with IGRAC. Furthermore the Global Runoff Data Centre (GRDC) has become part of the network providing valuable global and regional data sets of surface water systems. Other regional centres, scientific organisations, universities and freelance experts in hydrogeology also participate in WHYMAP. The structure of the WHYMAP network is shown in Figure 11.

The WHYMAP Consortium agreed on an iterative approach. This consists in the first instance of

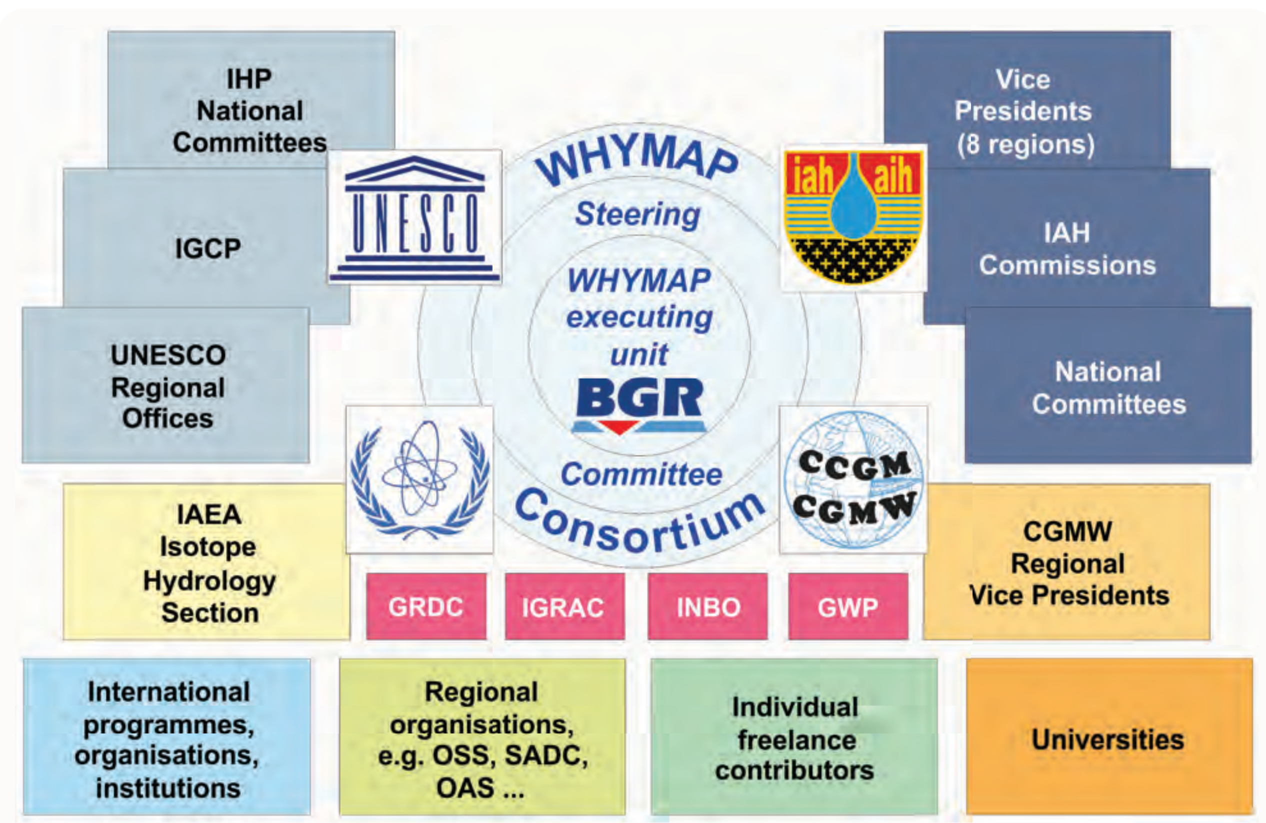


Fig. 11– The WHYMAP network

providing global data sets of topographic and general hydrogeological information; then, collecting and capturing consolidated, up-to-date information and also, establishing and maintaining a comprehensive Geo-Information System (WHYMAP-GIS) for groundwater relevant data on a global scale as a global network on groundwater. A printed wall map at the scale of 1:25 000 000 was finally derived from this GIS, together with a digital map server application on the Internet, and an explanatory booklet with a CD-ROM was planned.

3.4 The WHYMAP Geo-Information System (WHYMAP-GIS)

The main focus of the WHYMAP Programme (www.whymap.org) is the establishment of a modern digital Geo-Information System (GIS) in which all data relevant to groundwater is stored together with its geographic reference.

The design and creation of the GIS had to consider two aspects at the same time: the data structure had to prove useful for both the handling and processing of the digital data as well as for the representation of cartographic aspects for the output of high quality thematic maps.

In its final form the WHYMAP-GIS is supposed to contain a number of thematic layers, e.g.:

- structural hydrogeological units
  - sedimentary basins
  - coastal aquifers
  - complex hydrogeological regions with important aquifers
  - karst aquifers
  - local and shallow aquifers
- transboundary aquifer systems
- aquifer properties
- groundwater potential
- storage volumes
- accessibility and exploitability of groundwater resources
- groundwater recharge (renewable / non-renewable)
- groundwater runoff, discharge, climatic dependence
- groundwater exploitation (sustainable / mining)
- depth / thickness of aquifers
- hydrodynamic conditions (groundwater divides / flow directions / confined - artesian conditions)
- groundwater vulnerability
- interaction with surface water bodies
- land subsidence
- permafrost
- geothermalism
- hydrochemistry
- stress situations of large groundwater bodies
- "at risk" areas

From the WHYMAP-GIS database a variety of high quality thematic map products at different scales and complexity can be and has already been derived to satisfy the individual requirements of different users.

Step by step, different thematic layers are prepared for the global groundwater map, partly under the supervision of one of the partners. For instance, the information on groundwater recharge is developed under the auspices of IAEA; the layer on transboundary aquifer systems is mainly realised by IGRAC and the Internationally Shared Aquifer Resources Management (ISARM) group of UNESCO. Different IAH commissions are working on global maps of karst aquifers, groundwater vulnerability, coastal aquifers and the hydrogeology of hard rocks.

In addition an internet based map server application has been developed which integrates WHYMAP data and information on national hydrogeological maps (the embedded WHYMIS). UNESCO will ensure that all data compiled by the WHYMAP could be accessible in the UNESCO Water Portal. UNESCO with the support of BGR will pay attention that the WHYMAP could constitute the entry gate for subsequent development of more detailed, regional hydrogeological map information in particular in less developing countries.

3.5 The Process of Developing a GIS-based Global Groundwater Map

The compilation and printing of appealing global groundwater maps are closely interrelated with the gradual installation of the WHYMAP Geo-Information System (GIS) for the storage, processing and visualisation of groundwater relevant information and other data on a global scale.

The process of (digital) map compilation can be summarised as follows:

- select topographic base map and projection
- develop legend and representation
- design and create GIS structure
- review information from existing data sources
- compile continental drafts at scale 1:10 000 000
- digitize continental drafts and add attributes in GIS
- prepare first drafts of the global groundwater map and other thematic layers
- discuss and improve drafts with members of the WHYMAP steering committee, IAH vice-presidents, CGMW vice-presidents and IHP regional offices
- complete and optimise WHYMAP-GIS information including cartographic layout
- compile and print the final global groundwater resources map at scale 1:25 000 000.

The main output consists of a representation of the general hydrogeological situation on the globe aiming at comparable quality representation of all continents, so as to permit a global view and comparison.

The selection of the appropriate data sources became a very sensitive aspect in the beginning. BGR started to evaluate existing national, regional and continental maps at small to very small scales from 1:1 000 000 to approximately 1:15 000 000, existing data bases and statistical material concerning groundwater, surface water, precipitation and population density (as an expression of the stress on the fresh water resources) chiefly collected by the members of the Steering Committee. The statistical material available poses some problems since data relates to countries as an entity rather than to the actual geographic distribution within the country. Caution therefore is recommended in cases of vast territories or extremely variable hydrogeological conditions.

However a world map must be much more inter- or supranational, although all input data originate from national files and data banks, even if stored in regional or international data centres. Therefore, the information depicted on the map is necessarily as good as the data delivered and there is no doubt that the quality of data differs, despite efforts to impose an international standard for the collection and treatment of data.

In addition to making use of the data archives of national institutions and international organisations primarily the following existing maps at global, continental and regional scale have finally been thoroughly studied:

- Geological Map of the World 1:25 000 000 (CGMW 1990, digital version 2000)

- Maps of the World Environment during the Last Two Climatic Extremes 1:25 000 000 (CGMW & ANDRA 1999)

- World Map of Hydrogeological Conditions and Groundwater Flow 1:10 000 000 (compiled by the Water Problems Institute, Russian Academy of Sciences under UNESCO supervision 1999)

- Maps of the WaterGAP model of the Universities of Kassel and Frankfurt (P. Döll et al, 2003)

- all regional or continental small-scale maps enumerated in chapter 2.7.

Very striking, again visible on a test map, is that very often geological and hydrological zonations do not correspond to hydrogeological units. Particularly in arid regions, surface water catchment basins differ completely from the underground system. A test map showed the lack of congruence for large parts of the world. As a matter of consequence, an integrated water management by catchment / river basin is unsuitable in arid areas where surface water catchments and deep aquifers are totally different. No-recharge areas are posing a particular problem for water managers since only the aquifers and groundwater systems can be considered to constitute the relevant water management regions.

Summing up, a hydrogeological map is related to other thematic maps (geology, lithology, climatology etc.), but it forms a fully independent species of its own, built on data describing the occurrence of water, the properties of the aquifer and the dynamics in time as an expression of recharge, inflow and discharge.

Another crucial point was the selection of a suitable cartographic projection. The WHYMAP Consortium wished to achieve utmost compatibility with existing map products of Consortium members. Therefore, the WHYMAP Steering Committee studied the Geological Map of the World, published 1990 by CGMW, UNESCO and BRGM, to test its suitability for the global groundwater map, and made the following observation: Despite its wide application, the Mercator projection was considered unsuitable since it exaggerates the regions in the north and south of the globe, usually remote from the populated areas and usually of minor concern for groundwater. Therefore, a more appropriate projection has been found in the form of the Robinson projection, widely in use in the UN system. The information held in the WHYMAP-GIS in geographical coordinates has been plotted on a global map in the Robinson projection, whereas it can be transformed into various other kinds of projections.

The existing continental and regional maps had to be transferred and captured in the GIS to be able to make use of this information for the global map. A special challenge became the identification and implementation of the different projections of those existing maps as these parameters are often not or only partly available on the maps and corresponding documents.

Continental and regional work sheets at the scale of 1:10 000 000 constituted key elements in the preparation of the global maps. Eight work sheets were provided to selected experts from all continents and relevant scientific agencies and suggestions for changes and amendments incorporated (see Figure 12).

Each producer of a map must focus on the potential users. It is evident that details are lost with scale reduction and that a global map cannot serve for specific projects at project planning level. Other maps at larger scale are meant to fulfil such requirements. A world map serves for general orientation and world-wide comparison, and less for scientists but more for the advanced general public, such as politicians, decision makers and, last but not least, the media. In view of these users, absolute clarity of information is required: the symbolic value

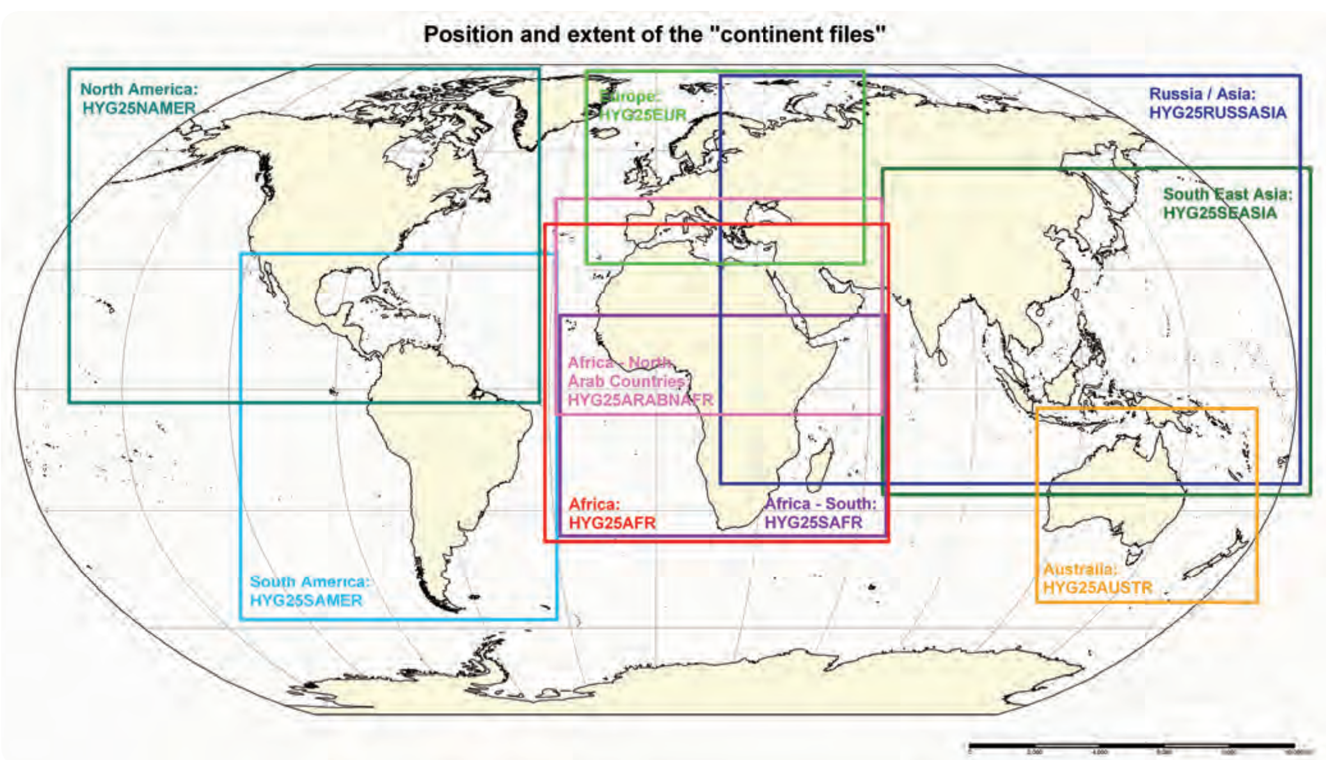


Fig. 12 – Subdivision of the global map into continental work sheets at the scale of 1:10 000 000

of colours and ornaments must be easily understood, without major guessing. The map contains a message and this message must be brought to the intended readership without ambiguity. Lastly, the map must harmonise with maps on other themes, and the general public in first hand will think of climatological and geological maps but also maps of population density and their water demand. Here again, the political focus of the map becomes visible. The synthesis of population pressure, groundwater availability and recharge results in the risk assessment and is an indispensable basis for sustainable groundwater management.

3.6 First Results and Products

3.6.1 General

The present report is called an interim report, because the WHYMAP programme is ongoing and the report can only describe the picture of the present moment. Therefore, the main milestones of the achievement of the programme are highlighted and an outlook into the near future is given.

Important activities regarding water on the global scene, in particular the 3rd World Water Forum in Japan, March 2003, the 4th World Water Forum in Mexico, March 2006 and the 6th World Water Forum in Marseille, March 2012 as well as the establishment of the first and second World Water Development Report, called for global groundwater maps in various formats. In addition the International Year of Planet Earth 2008 was a unique chance to summarize the existing groundwater related information on a large size wall map for educational purposes on the map of Groundwater Resources of the World. This publication policy required a very flexible approach from the editorial team.

Different kinds of map products have been produced so far which present a very general visualisation of the global distribution of groundwater and aquifers in an attractive and convenient format and are intended to raise awareness of groundwater and generate additional input to WHYMAP:

- various small scale global maps showing the global groundwater situation for use as figures in reports and publications with a global water perspective, e.g. the World Water Development Report
- an educational wall map of Groundwater Resources of the World at the scale of 1:25 000 000 as a contribution to the International Year of Planet Earth in 2008, launched at the International Geological Congress in Oslo 2008, to fit into the series of earth science maps of UNESCO
- a first special edition of the global map of groundwater resources at the scale of 1:50 000 000 issued for the International Geological Congress and the CGMW meeting at Florence, Italy, in August 2004
- a second special edition of the global map at the scale of 1:50 000 000 focussing on the Transboundary Aquifer Systems of the World, issued for the 4th World Water Forum in Mexico City in March 2006
- a third special edition of the global map focussing on River and Groundwater Basins of the World at the scale of 1:50 000 000, issued for the 6th World Water Forum in Marseille, March 2012.

The most comprehensive map resulting from WHYMAP is certainly the map of groundwater resources of the world. It presents the background information for all WHYMAP products, chiefly for the large-size wall map at the scale of 1:25 M, but also for the special editions at smaller scale (1:50 M), as well as for text figures at even smaller scales.

3.6.2 Description of the World Map of Groundwater Resources and its Legend

At the occasion of the International Year of Planet Earth, a first edition of a large size wall map on Groundwater Resources of the World at the scale of 1:25 M was printed and exposed at the International Geological Congress in Oslo, August 2008. This wall map is a major result of WHYMAP and lumps the related data known or published so far (Figure 13).

The World Map of Groundwater Resources at the scale of 1:25 M is designed chiefly for educational purposes. It displays by colour the global setting of aquifer systems, their characteristics and groundwater resources encountered by showing various generic groundwater environments in their areal extent: blue colour is used for large and rather uniform groundwater basins (aquifers and aquifer systems usually in large sedimentary basins that may offer good conditions for groundwater exploitation), green colour areas have complex hydrogeological structure (with highly productive aquifers in heterogeneous folded or faulted regions, often in close vicinity to non-aquifers), and brown colour symbolises regions with limited groundwater resources in local and shallow aquifers.

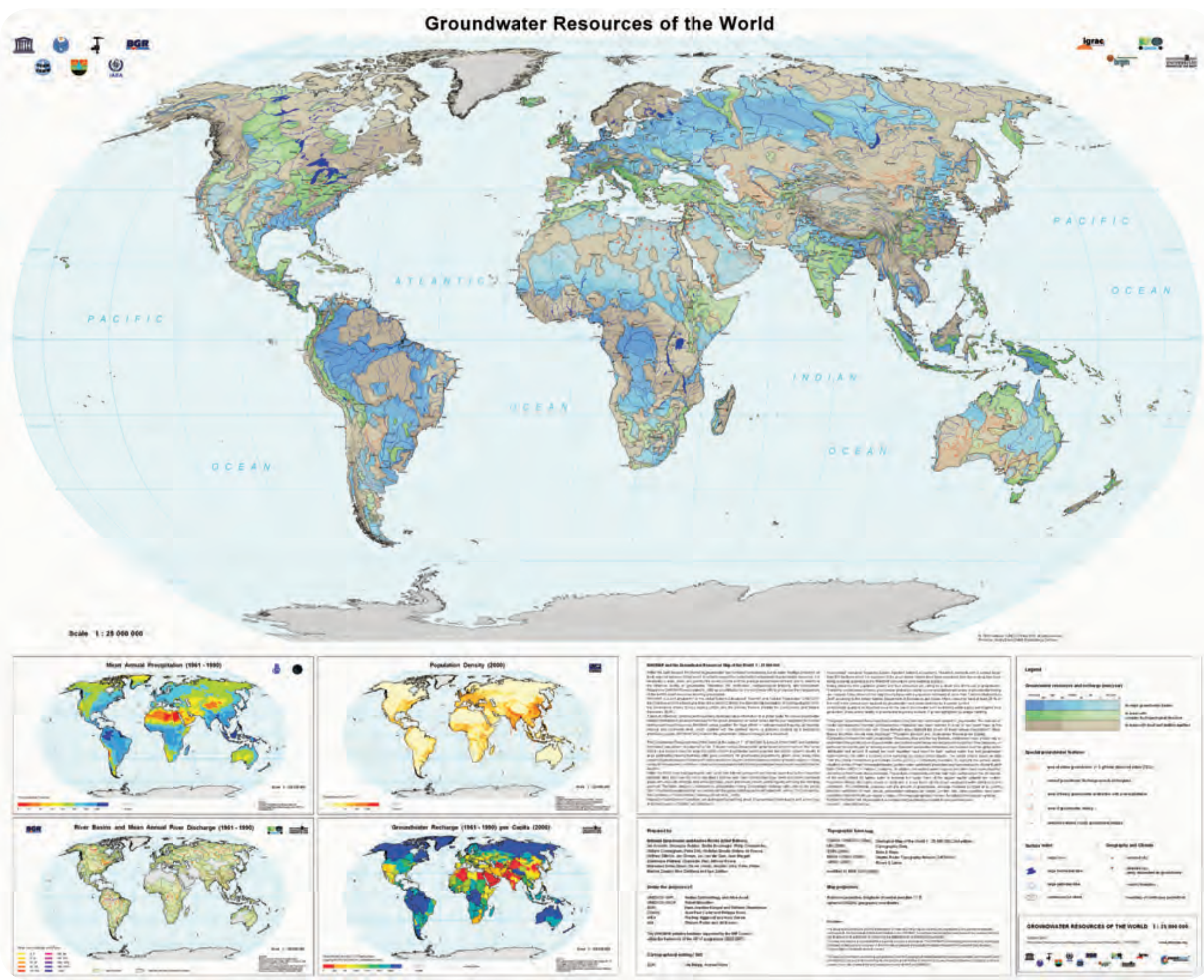


Fig. 13 – View of the Wall map of Groundwater Resources of the World as contribution to the International Year of Planet Earth, published for the International Geological Congress, Oslo, August 2008

Within the three main hydrogeological units up to five different categories are defined according to their potential recharge rates from over 300 mm per year to less than 2 mm/y ranking from dark blue, green and brown colours representing areas with very high recharge rates to light blue, green and brown colours outlining regions with very low recharge potential. The latter category is vulnerable to groundwater mining. Groundwater recharge rates refer to the standard hydrologic period 1961 – 1990 and are derived from simulations with the global hydrological model Water GAP, version 2.1f by the University of Frankfurt in 2006.

A number of important groundwater features usually localised to small areas or points are shown by point symbols on the main map. Such places have formed famous water points in historic times and may be sustaining valuable aquatic ecosystems. This refers mainly to dryer regions where groundwater discharges on ground level (e.g. wetlands, endorheic basins or chotts and sebkhas). Such discharge points are usually related to deeper aquifers in which groundwater is under pressure and rises up to the surface. Many wetlands that are likely to be sustained by groundwater are also shown on the map. Most of them have been selected from the International Union for Conservation of Nature (IUCN) data base on sites covered by the RAMSAR convention. However, it is evident that the density of sites in many countries reflects the status of environmental awareness of governments and administrations rather than the true existence of wetland sites that are relevant for biodiversity or may be an indicator for the status of the natural environment.

Important sites of groundwater abstraction have been also shown on the map, where known. This feature highlights places of heavy groundwater pumping usually related with a drawdown of groundwater levels, or even groundwater mining in places where there is almost no present-day recharge.

Orange hatching has been applied in areas where the salinity of the groundwater regionally exceeds 3 or 5 g/l. In these places the groundwater is generally not suitable for human consumption, but some livestock may find it drinkable.

Parts of the northern latitudes close to the Arctic are affected by permafrost. Here even the groundwater is generally frozen and unusable for water supply. The boundary of permafrost therefore has been indicated by a dark green line on the map.

The surface water features should provide a general idea about the relationship between groundwater, lakes and large rivers. They have been provided by the Global Runoff Data Centre (GRDC) in close cooperation with BGR on the basis of long term average runoff data. Accumulations of inland ice and large glaciers have been shown by grey colour wash. About two thirds of the global freshwater resources are associated with these ice sheets, however, they are generally confined to remote and unpopulated areas and are thus of less importance for water supply.

The topographic features shown on the map answer the need for orientation and geographic reference. Major population centres usually represent points of peak water demand. In the first instance, the cities with a population exceeding three million inhabitants are shown, but a number of smaller population centres have been added for the sake of geographic reference. The political boundaries, which are taken from the global data sets of United Nations Cartographic Section, highlight that most of the groundwater areas worldwide cross political borders, forming shared transboundary aquifers.

The legend (see Figure 14) follows those applied elsewhere in regional and continental hydrogeological maps and it largely adopts the International Standard Legend for Hydrogeological Maps published by IAH in 1995.

Because of the educational nature of the large-size wall map on groundwater resources four thematic inset maps at the scale of 1:120 M have been also printed on the map sheet in order to be able to understand the global picture of groundwater and surface water resources and provide insight into their pressures. Thus WHYMAP strives to compare and combine its own results with other thematic maps, e.g. on precipitation, surface water, recharge or population density. The maps also show the various ways of representation of geographic data, from true geographical distribution (polygons related to the earth's surface) via raster cells (pixels) to information for political units, mainly countries or states.

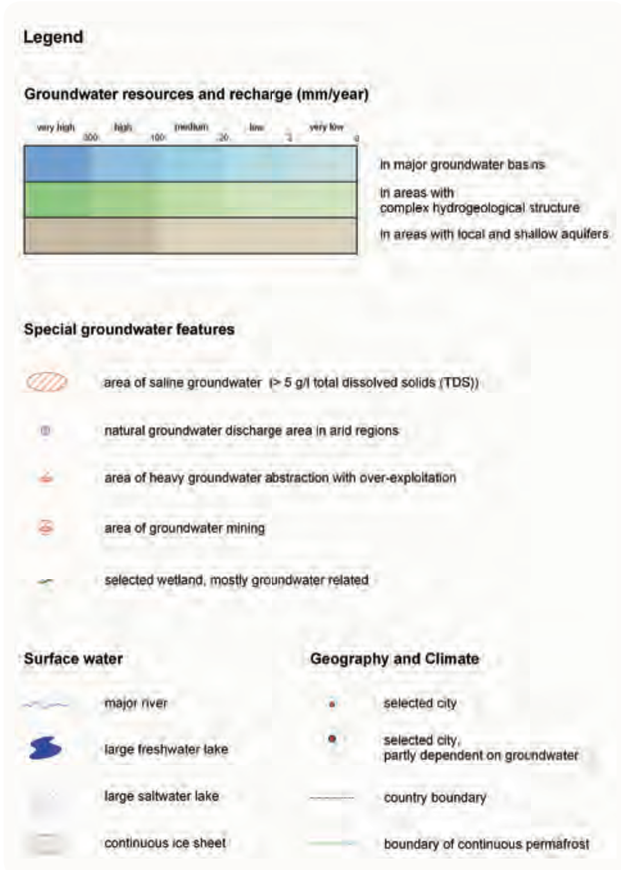


Fig. 14 – Legend of the Groundwater Resources Map of the World, 2008

Two inset maps covering the themes population density and precipitation will not be further explained, because their data are derived from sources outside the WHYMAP programme, namely the gridded UN-CIESIN data set on population density and the data from the Global Precipitation and Climate Centre (GPCC). Both data sets present very useful complementary data for WHYMAP, because the population density is a good proxy for the regional variation of the demand for water including groundwater for drinking, although the per capita water demand may vary considerably between less than 20 litres per person and day in developing countries to more than 500 in certain wealthy arid countries, however, the map may allow a rough grasp on the pressures on the water resources including groundwater owing to the number of people living on earth.

The rainfall data was provided by the Global Precipitation and Climate Center (GPCC in Offenbach/Germany) of the World Meteorological Organisation WMO. It has been computed by using data from the international standard hydrological period 1961 – 1990. Rainfall is the main input for the recharge of groundwater resources on the one hand, and the importance of groundwater increases significantly in areas of low precipitation namely the arid zones of the earth.

The other two inset maps on River Basins and Mean Annual River Discharge and the Groundwater Recharge per Capita are true WHYMAP products that have been elaborated in cooperation with the Global Runoff Data Centre (GRDC) in Koblenz/Germany and with the University of Frankfurt/Germany, using the global Water GAP model of the universities of Frankfurt and Kassel as an essential tool for calibration and calculation.

The map of "River Basins and Mean Annual River Discharge" shows the major surface water catchment basins together with the corresponding river courses and lakes, which have been classified according to their mean annual discharge (see Figure 15).

A global map computed on the basis of recharge values of the Water GAP model and the population density has been prepared in cooperation with the Chair of Geography of the University of Frankfurt a.M./Germany, Prof. Petra Döll (see Figure 16).

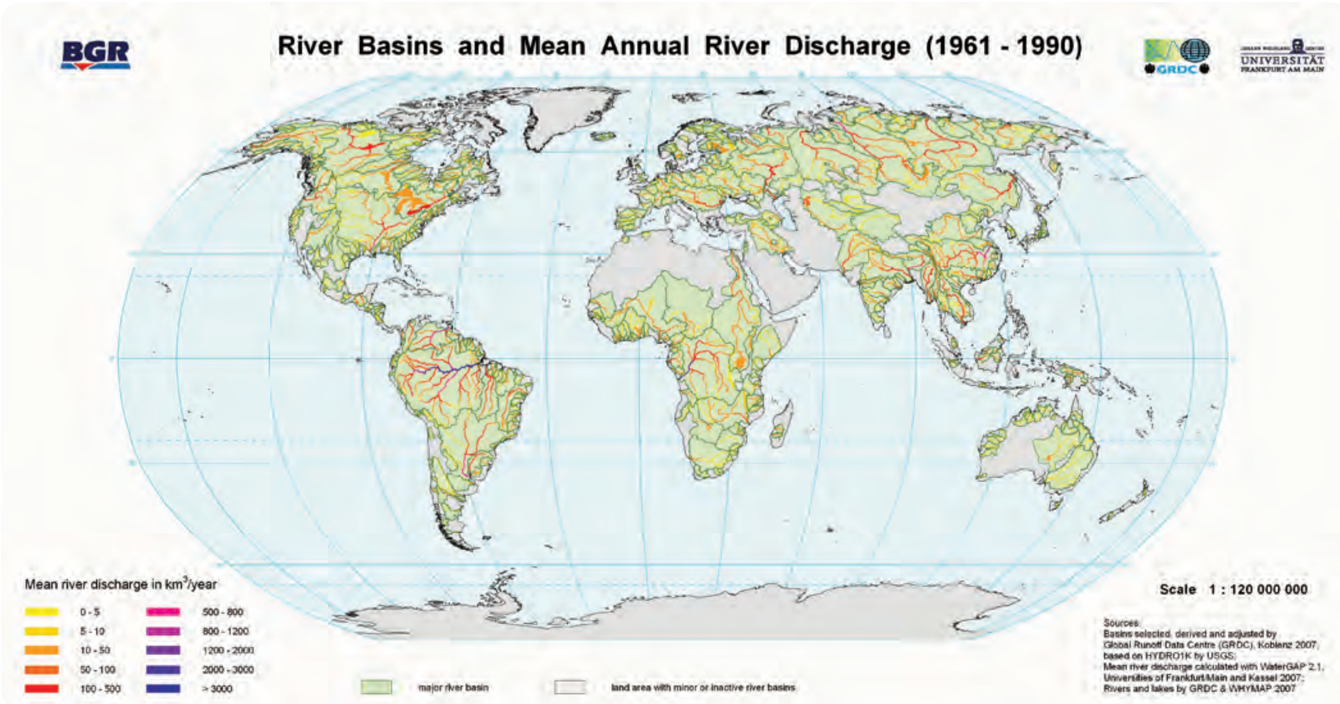


Fig. 15 – River Basins and Mean Annual River Discharge

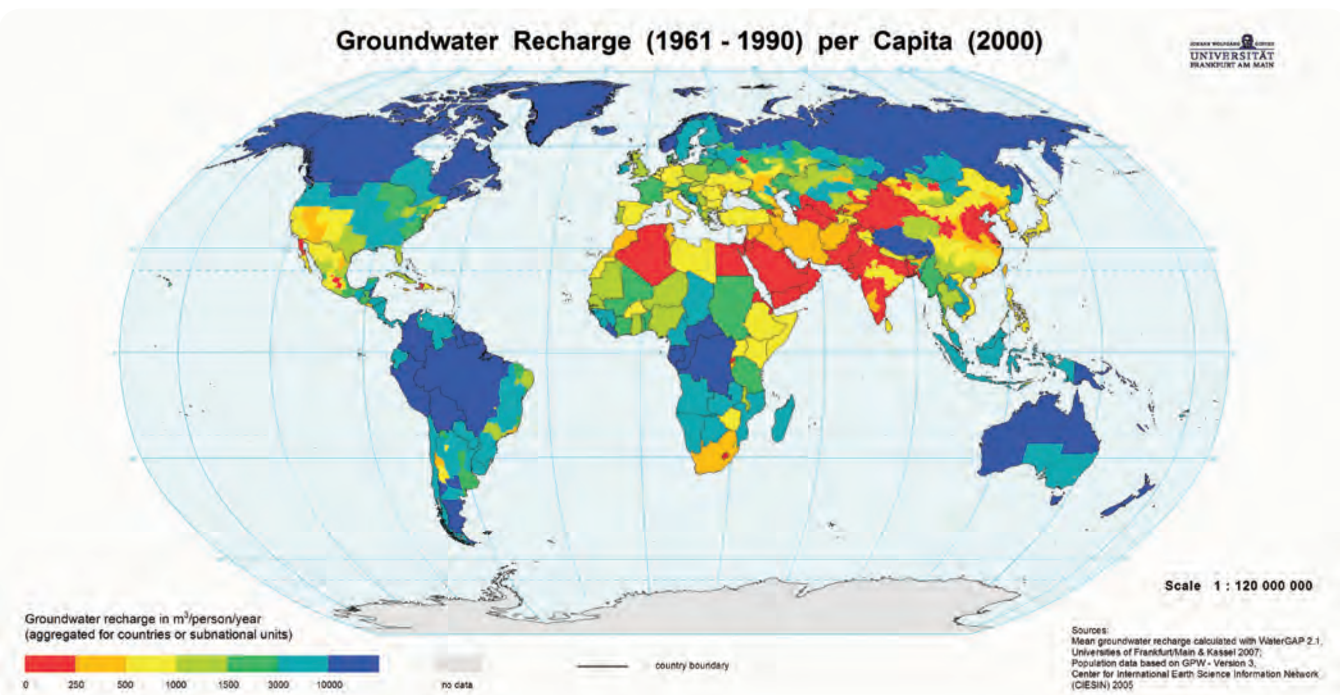


Fig.16 – Map of Groundwater Recharge per Capita

The map shows rather large variations from country to country. In several large countries with federal structures, e.g. Australia, Brazil, China, India, Mexico, Russia and the United States, the data have been related to the individual states to highlight the regional variation.

Last but not least, a brief explanation describing the major features of the maps completes the printed wall map on paper. All map information is also accessible via the WHYMAP web site (www.whymap.org) as downloads.

3.6.3 Description of Maps Published at the Scale of 1:50 Million (Special Editions)

Three so-called special edition map publications about WHYMAP and relevant thematic issues have already been printed in order to inform important international meetings, i.e. the International Geological Congress in 2004, the 4th World Water Forum in Mexico City 2006 and the 6th World Water Forum in Marseille 2012 about groundwater in the global context and relevant thematic issues. All three maps have used the same format, with a global map at the scale of 1:50 000 000 and an explanation on the reverse side of the map (see Figures 17 to 19 below). The map users thus enjoy a very handy and concise source of information.

On a global map at a scale of 1:50 000 000 only a selection of features can be represented in order to keep it readable. These features chiefly cover the nature of the groundwater regime and whether or not they are regularly recharged. This is shown by colour wash using the three basic colours blue, green and brown as explained in chapter 2.6.1, as well as the recharge categories explained by colour tone (Figure 17).

Also the other features presented on the special edition maps follow the representation of the global wall map, e.g. the Orange hatching for groundwater salinity or the green line for permafrost areas.

The surface water features should provide a general idea about the relationship between groundwater, lakes and large rivers. They originate from the Geological Map of CGMW. The course of the rivers and size of lakes have been updated in places. They have also been checked by the Global Runoff Data Centre (GRDC) on the basis of long term average runoff data. Accumulations of inland ice and large glaciers have been shown by grey colour wash.

The topographic features shown on the map should allow orientation on the continents. Major population centres usually represent points of peak water demand. In the first instance, the cities with a population exceeding three million inhabitants were shown, but a number of smaller population centres have been added for the sake of geographic reference. The political boundaries are taken from the global data sets of the Environmental Systems Research Institute (ESRI). The WHYMAP Consortium cannot be made liable for any errors in this data set whatsoever.

The reason for showing political boundaries on the map is twofold; firstly for geographic orientation, but also, and even more importantly, to highlight that most of the groundwater areas worldwide cross political borders, forming shared transboundary aquifers. To deal with this situation, UNESCO and IAH have launched the Internationally Shared Aquifer Resources Management Programme (ISARM) within the frame of the IHP.

To start with a global view on transboundary aquifer systems, the second special edition of WHYMAP published in 2006 devoted itself to this issue. It shows the location and approximate size of regionally important transboundary aquifers, symbolised by circles or ellipses (see Figure 18). The minimum size is generally in the order of several thousand square kilometers, however the largest ones are about two million km^2. In some cases the circles encompass a number of associated sub-basins, which could not be shown individually. The transboundary aquifer system shown on the map are numbered and have been listed in a table together with suggested names, the countries sharing the systems, the type of aquifer system and their approximate size.

Solid lines of the circles or ellipses are shown for all transboundary aquifer systems where recent and reliable data on their extent and thickness exists, and where reliable regional hydrogeological models are available or are in an advanced state of preparation, which allow simulations for a sustainable use of the groundwater in each of the sharing countries. In all other cases where such useful and indispensable tools do not exist, the lines are broken. These systems require up-to-date investigations and modelling, before further groundwater abstraction should be considered.

A third special edition was published for the 6th World Water Forum in Marseille in March 2012 (see Figure 19). Its main aim was to shed light on the river basins of the world together with the groundwater basins from WHYMAP, because both entities have to be considered jointly in sound integrated water resources management (IWRM), but their delineation often deviates considerably. This is particularly true in semi-arid and arid regions of the world where the groundwater resources are often more important and reliable than occasional fresh water resources on the surface, however, the groundwater management lacks attention.

Three fundamental constellations with respect to the spatial relationship between surface water and groundwater are highlighted by various hatchings on the map, e.g. i) river or lake basins encompassing underlying groundwater basins, ii) areas where the groundwater basin extends beyond the river or lake basin and iii) areas without active river or lake basins (mainly in arid zones) underlain by important groundwater basins. All three basic settings require appropriate strategies for IWRM.

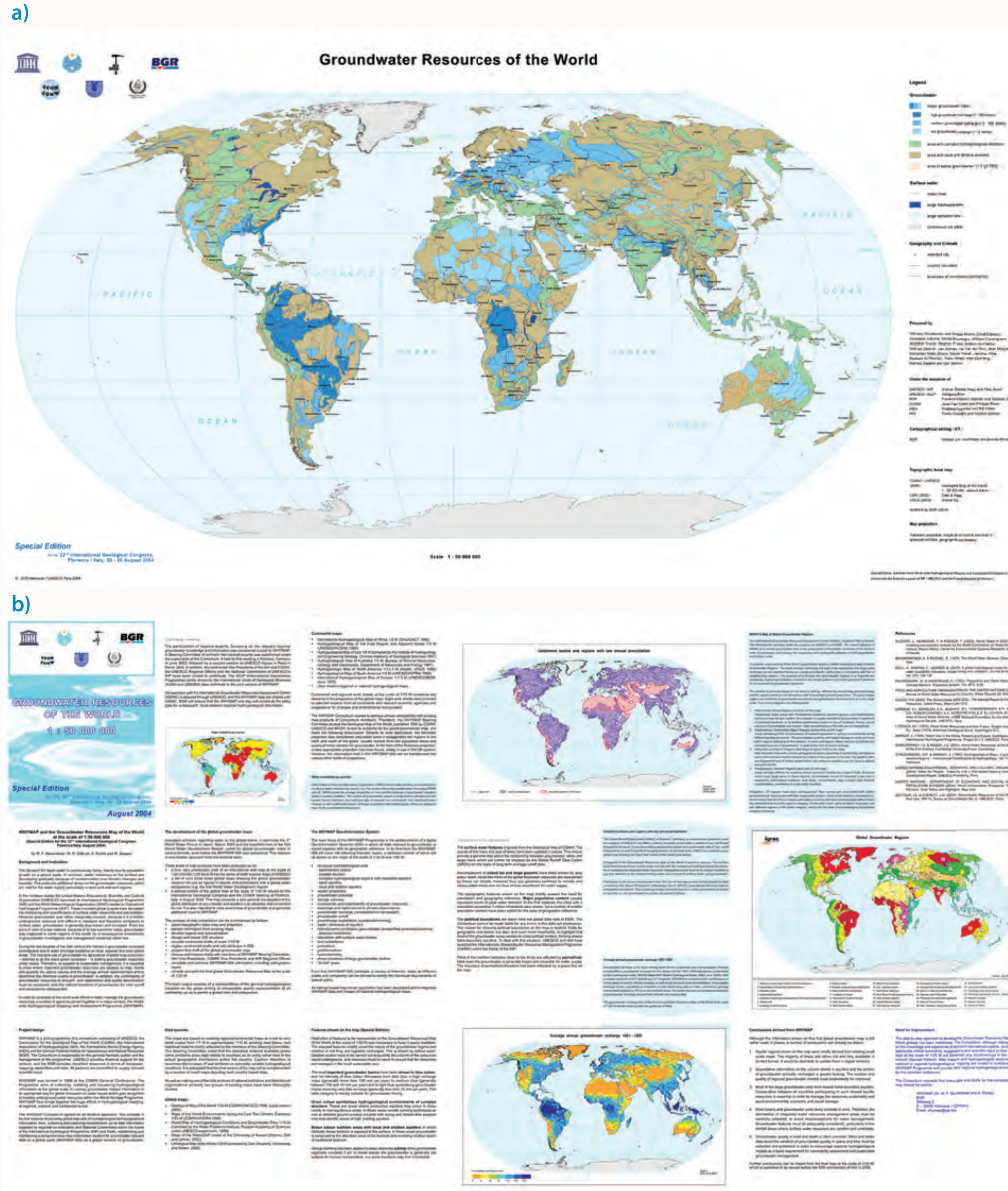


Fig. 17 – View on the 1st WHYMAP Special Edition for the International Geological Congress, Florence, Italy, August 2004

a) Global Groundwater Resources Map

b) Explanation on the reverse side of the map a)

b)

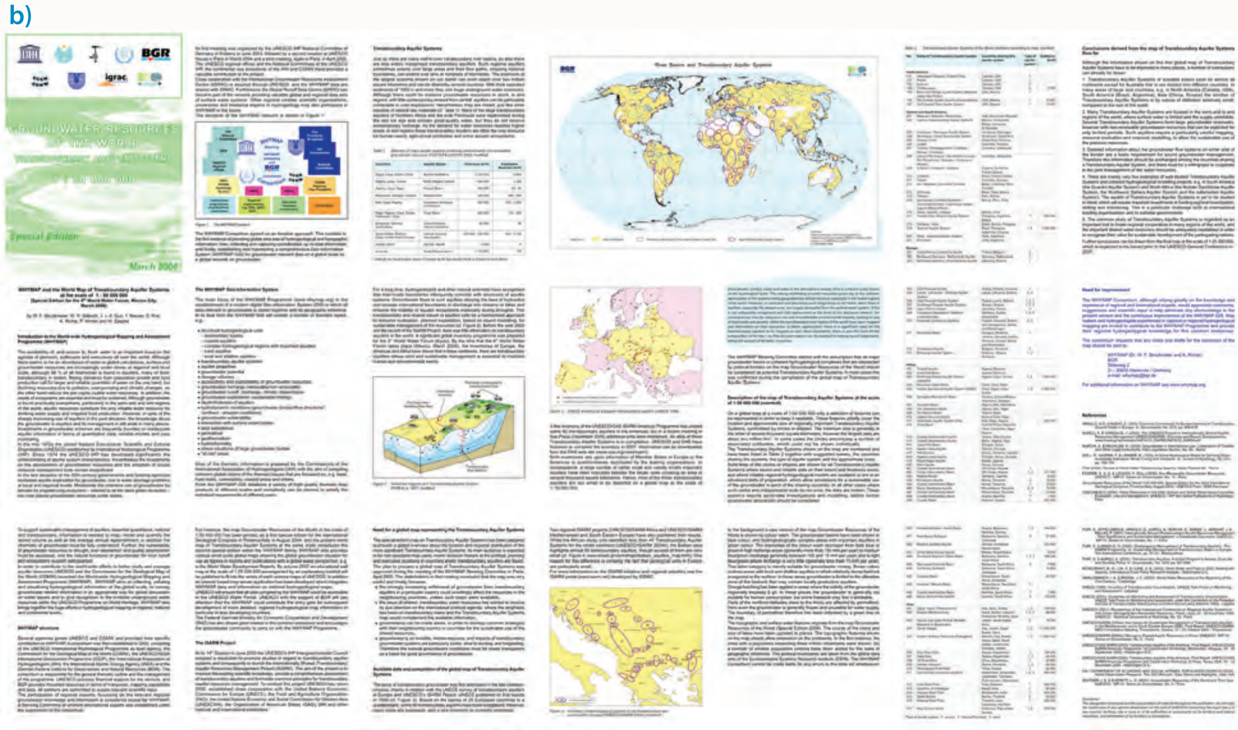


Fig. 18 – View on the 2nd WHYMAP Special Edition for the 4th World Water Forum, Mexico City, March 2006

a) Global Map of Transboundary Aquifer Systems

b) Explanations on the reverse side of the map

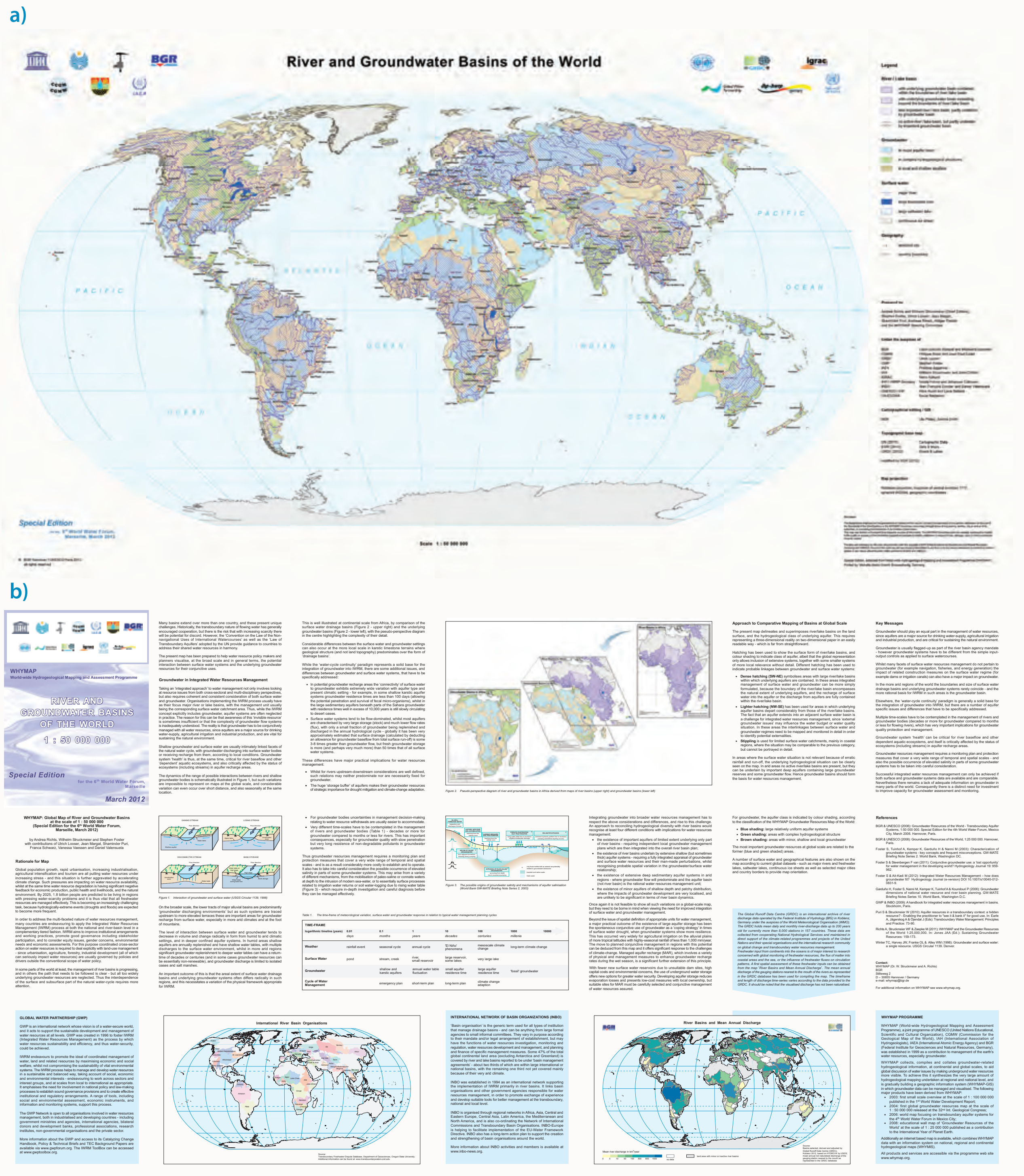


Fig. 19 –View on the 3rd WHYMAP Special Edition for the 6th World Water Forum, Marseille, France, March 2012

a) Global Map of River and Groundwater Basins

b) Explanations on the reverse side of the map

3.6.4 The WHYMAP Portal and Map Application

An independent web domain named www.whymap.org has been set up in order to serve as an entry portal for all users seeking digital information originated from the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP). This portal essentially encompasses some basic information about WHYMAP and groundwater, a web mapping application for WHYMAP data using Java mode or not (Figure 20), and corresponding Web Map Services (WMS). It also provides downloads of certain global or continental maps.

The WHYMAP viewer offers merely simple functionalities, however, the map application system includes an archive function called WHYMIS (World-wide Hydrogeological Map Information System) that presents scans of some 200 regional or national hydrogeological maps at scales larger than 1:10 million, in order to provide more detailed information of existing hydrogeological maps and their legends. The meta data of these maps are also provided, and links to related national web sites are being established gradually.

After opening the WHYMAP web mapping application, the global groundwater resources map and various clickable legend elements may help design the most appropriate view for system users at various zoom-in states. Users interested in making use of GIS data may inquire at whymap@bgr.de.

3.7 Future WHYMAP Activities

The World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) is an evolving project of a multitude of partners under the auspices of UNESCO, CGMW, IAH, IAEA and BGR. It strives essentially at providing groundwater related information in a global context towards the political bodies leading the international water agenda. Therefore, WHYMAP uses

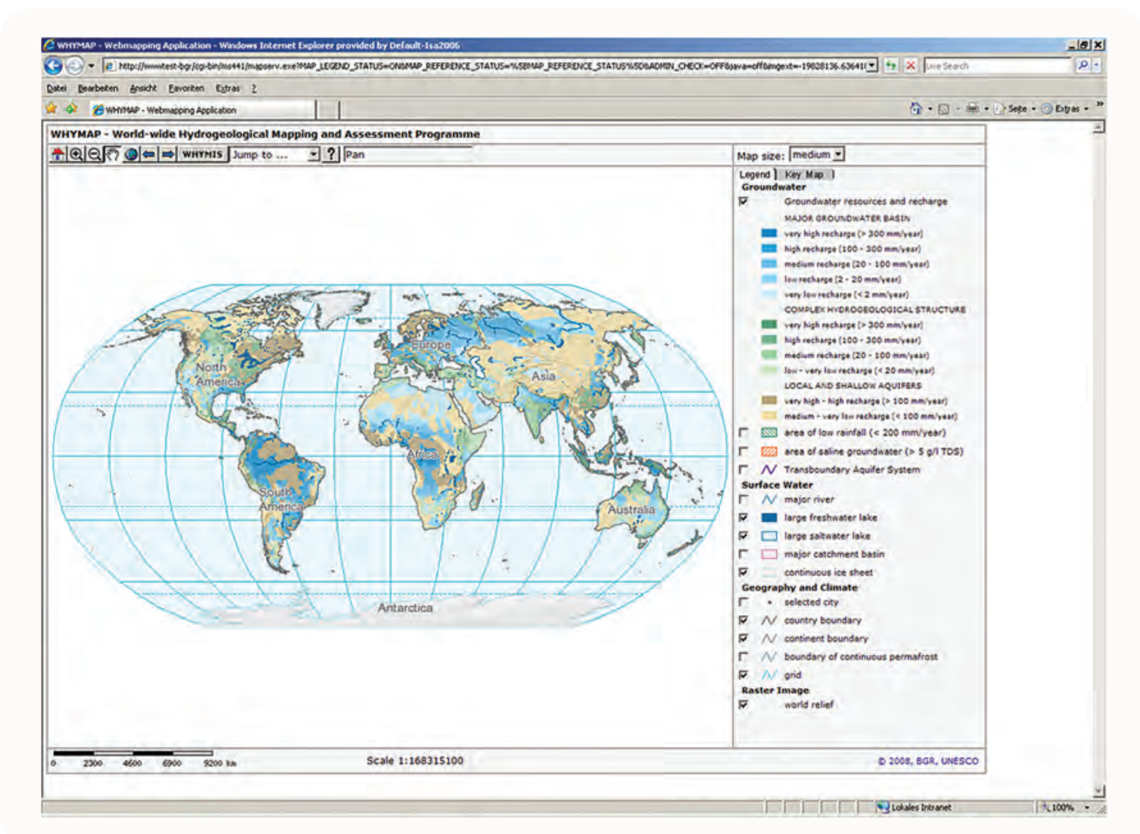


Fig. 20 – Portal of the WHYMAP Web Application System

a flexible approach in addressing the issues that are pertinent for global representation.

Within the next years the following steps are planned:

- Compilation of additional thematic layers to complete the list in chapter 4 of this report; some of the thematic information is under preparation by the Commissions of the International Association of Hydrogeologists (IAH) with the aim of compiling coherent global visions of the thematic issues that are focussed on, e.g. karst, hard rocks or coastal areas; IAH and its Karst Commission have started the compilation of a thematic layer on karst for the WHYMAP GIS.

- A new special edition within the WHYMAP series is elaborated by a UNESCO working group on Groundwater in Emergency Situations (GWES) with the support of the WHYMAP executing team at BGR: This global map focusses on hydro-climatic extremes and vulnerabilities, and the role groundwater can play for creating more resilience.

- Completion and enhancement of the WHYMAP Geo-Information System and the web-based components WHYMAP portal (www.whymap.org).

- Update and publication of the wall map of Groundwater Resources of the World and an explanatory booklet and DVD summarising the essential information about groundwater and the hydrogeological settings on all continents except Antarctica, including an appraisal of groundwater resources and reserves globally.

With the WHYMAP achievements, the essential groundwater resources will receive an improved profile on the global water agenda. This is particularly necessary, because groundwater is a hidden, invisible asset for mankind and nature, and more awareness needs to be created in order to manage it properly as an important component of integrated water resources management (IWRM), and protect the groundwater reserves from degradation.

The small-scale does not allow to recognise individual issues and one of the conclusions might be to embark on maps at much larger scales, particularly for zones at risk and for disputed internationally shared resources. However, such more applied maps are not a focus of WHYMAP yet, but may benefit from the experience which can be drawn from the WHYMAP enterprise.

Only true information is politically correct and in this spirit UNESCO and the cooperating organisations and associations have tried to deliver the tools needed. UNESCO and its partners are looking back on a fifty years work and they know that this work never can and will end.

4.
Appraisal and Outlook

A report normally indicates the completion of an activity, and in fact, a considerable number of hydrogeological mapping projects have been closed. However, the present publication purposely has been conceived as an interim report since the projects mentioned are serving for new ventures. This chapter, therefore, will highlight outcomes but also throw light on activities now under work, envisaged or suggested for the future.

The report describes small-scale hydrogeological mapping activities which started in Europe fifty years ago and successively covered the whole globe. The International Hydrogeological Map of Europe has been treated in much detail since it served as a model and scientific approach for other continents and regions, and since it generated standard legends, textbooks and teaching aids.

The European map started under difficult political circumstances, but could be conducted successfully. UNESCO, NGO's and Member States formed a symbiosis and a remarkable motivation of the organisations and geological services could be observed which led to a high degree of enthusiasm among the participating scientists. More than three hundred hydrogeologists and other scientists were involved and many of them contributed more than could be expected. Numerous meetings have been held but no conflicts can be reported: a network, a family of hydrogeologists developed. This network was able to collect, interpret, harmonise and digest data, fill data gaps and arrive at a common understanding of the presentation of hydrogeological phenomena on small-scale maps. No model existed, no national map could be used without adaption, and a completely new set of maps was generated.

The enterprise needed an umbrella and UNESCO together with cooperating scientific associations delivered it. UNESCO not only paved the political ground and propagated the idea. UNESCO generously supported the mapping project by financing the compilation and printing of the map sheets together with German resources and the BGR is credited an outstanding contribution in money, kind and personnel. UNESCO also convened a large number of regional meetings where coordination required the personal contact between country representatives. The European map served as a model for other continents and again UNESCO helped to promote the cooperation and also was able to assure the involvement of other potent partners such as ACSAD, etc.

At the end of this Report an Annex contains a list of meetings under the umbrella of UNESCO, to the extent they could still be retrieved in the files and in the archives. The authors regret omission and incomplete lists. However, they feel it a duty to give honour and a respectful memory to all persons who contributed.

The European map generated by-products. One was that people -beyond the professionals- realised the existence of the invisible resource groundwater, its extension, movement, exploitation limits and the problems centering around recharge and pollution. This insight has a high societal importance since not only the scientists learned about the advantages of groundwater but also about the vulnerability of the resource and about the functioning of groundwater systems and their relationship to ecosystems.

An important outcome of the mapping projects was the development of new tools for public instruction as an awareness raising. The media started to make use of maps for highlighting ecological or economical problems. Maps also were discovered as educational tools. Hydrogeological maps were more and more used as planning tools for city and country planners beyond their original purpose for supply of potable water. Other by-products were legends. The history of published legends reveals a steady learning process since legends did not only become more perfect and correct but since they also gradually incorporated parameters beyond pure hydrogeology. The pollution problems opened a gate towards new applications and an upper end of legend development cannot be envisaged. UNESCO and the IAH also convened expert groups to compile textbooks for map-makers and the commercial success was so great that at present all books are out of stock. New electronic versions are under consideration.

The time period of compiling the European map also saw the technical revolution from hand-drawn analogue maps to electronically composed ones and the last few sheets have been produced in digital format. Other, more recent hydrogeological map projects are increasingly using digital techniques, too. This revolution did not only change the production procedure, it also opened new ways of communication through GIS-based information systems, the Internet, and finally, also UNESCO is opening its portal for hydrogeological mapping information. These innovations enable many new customers world-wide to participate in the results of the UNESCO assisted mapping programmes to which they otherwise hardly would have had access. It should be underlined that the transition from the classical map drawing procedure to computer-based ones did not hamper the mapping programme since the BGR was able to prepare appropriate instruction, in good time, for the country representatives.

Up to this point, the appraisal was rather retro-perspective and gave a short, condensed account of the achievements of the past decades and of the implications for the present time. The trend for globalisation also reached the hydrogeological maps and WHYMAP was the response. In the course of project preparation UNESCO and the competent NGO's recognised the great potential and developed a production mechanism similar to the European map with UNESCO as the financial carrier, the BGR as executor and a Steering Committee as advisor.

The initial phase of WHYMAP immediately revealed the need for a map of this type. It also became evident that small-scale specialised maps were needed and the WHYMAP consortium decided on a map of internationally shared aquifers. Further specialised maps will follow and focus on the protection of groundwater resources, on risk assessment and on other problems considered a societal requirement. WHYMAP is a world mapping programme and there are justified expectations that continental and regional – of course also national – maps on special applications will follow. WHYMAP has opened a new horizon and the present Report therefore with full justification can only be an interim report which points to the solution of groundwater problems in the new age. WHYMAP thus is not only a wall map but a future oriented programme, that is an integral part of the International Hydrological Programme (IHP).

WHYMAP also can be considered a valuable contribution to the present climate debate delivering data in an unbiased and scientificly correct manner. Only true information is politically correct and in this spirit UNESCO and the cooperating organisations and associations have tried to deliver the tools needed. UNESCO and its partners are looking back on a fifty years work and they know that this work never can and will end.

The Annexes present the list of relevant literature and of meetings and their participants, providing an impressive picture of a world-wide participation.

5.
Annexes


St. Petersburg
Moscow
London
Paris
Istanbul
Cairo
New York
Chicago
Los Angeles
Mexico City
Tehran
Lahore
Karachi
Delhi
Dhaka
Calcutta
Mumbai
Hyderabad
Madras
Bangalore
Bangkok
Beijing
Tianjin
Shenyang
Seoul
Tokyo
Osaka
Shanghai
Lagos
Hong Kong
Manila
Kinshasa
Bogota
Lima
Rio de Janeiro
Sao Paulo
Jakarta
Buenos Aires
Santiago
Sydney

Annex A

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Annex B

List of Meetings with UNESCO Sponsorship (in bold)

This list has been derived from Reports, files and archives, yet particularly from personal notes taken by the authors. The list may only be incomplete with regard to the meetings themselves, particularly however concerning the participants. The authors deeply regret these gaps since also those experts not mentioned have greatly contributed to the numerous publications and maps. The Authors only can apologise.

Panel of Experts on Hydrological Maps

UNESCO House, Paris, 13 – 14 March 1969
G. Santing (NL), R. Keller (GER), N. V. Rogovskaya (USSR), L. A. Heindl (USA), W. H. Gilbrich (UNESCO)

Freiburg (GER), 16 – 20 February 1970
G. Santing (NL), R. Keller (GER), N. V. Rogovskaya (USSR), G. McKay (WMO/Canada), W. H. Gilbrich (UNESCO)

Freiburg (GER), 30 September – 12 October 1973
R. Keller (Chairman, GER), L. A. Heindl (USA), N. V. Rogovskaya (USSR), G. McKay (Canada), P. Newson (UK/WMO), W. H. Gilbrich (UNESCO)

IHD Working Group on Hydrological Maps

UNESCO House, Paris, 14 – 18 April 1969
G. Santing (Chairman, NL), N. V. Rogovskaya (USSR), L. A. Heindl (USA), W. Richter (BGR/GER and IAH), S. Buchan (IASH), H. Combe (Morocco), G. A. McKay (Canada and WMO), J. Margat (FRA), V. Myslil (CSSR), W. Plumb (Australia), R. Keller (GER), W. H. Gilbrich (UNESCO)

IAH-Commission for Hydrogeological Maps (COHYM)

First Meeting at BGR Hannover (GER), 4 – 5 February 1969
H. Karrenberg (GER), G. Castany (FRA), W. Richter (GER) and many other participants no longer retrievable, W. H. Gilbrich (UNESCO)

Second Meeting at UNESCO House, 23 – 24 March 1972
Similar composition as above

Third Meeting at UNESCO House, 15 – 16 May 1973
Similar composition as above

Fourth Meeting at BGR, Hannover (GER), 23 – 24 April 1975
Similar composition as above

IAH General Assembly, Birmingham (UK), 25 – 26 July 1977

Following the dissolution of the Sub-Commission on Hydrogeological Maps of the Commission for the Geological Map of the World (CGMW) an ad-hoc meeting was held during the IAH General Assembly with leading mapping experts and representatives of the IAH Commission on Hydrogeological Maps: H. Karrenberg (IAH), L. Dubertret (FRA), S. Buchan (UK), W. H. Gilbrich (UNESCO) and others

Many more COHYM meetings (not sponsored by UNESCO) were held during the following IAH Congresses between 1978 and 2012, attended by numerous mapping experts.

Inter-Secretariat Meeting on Hydrological Maps

In conjunction with the Panel on Hydrological Maps of the IHD Working Group on Water Balances

UNESCO House, Paris, 13 May 1971
I. C. Brown (IAHS), G. H. Davis (Working Group on Groundwater Studies), D. Lazerescu (Working Group on Water Balances), G. A. McKay (Canada and WMO), A. A. Sokolov (Working Group on Water Balances), T. G. Chapman (Australia), L. A. Heindl (USA), R. Keller (GER), T. W. Plumb (Australia).

Second session of the joint meeting of the Sub-Group on Hydrological Maps and of the Panel of Authors of the Guidebook on the Preparation of Hydrological Maps,

UNESCO House, Paris,
27 November – 1 December 1972
Composition similar to the above meeting

Panel of Authors/Editors of the Guidebook on Hydrological Maps

The November 1972 Meeting was followed by a meeting entirely devoted to the compilation of the Guidebook

Freiburg (GER), 1 – 12 October 1973
R. Keller (GER, Chairman), L. A. Heindl (USA), P. Newson (UK/WMO), N. V. Rogovskaya (USSR), G. McKay (Canada/WMO), W. H. Gilbrich (UNESCO), for one day only H. Lüken (GER)

Wallingford (UK), 25 February – 1 March 1974
L. A. Heindl (USA), N. V. Rogovskaya (USSR), P. Newson (UK/WMO), W. H. Gilbrich (UNESCO)

Legend for Geohydrochemical Maps

3 Meetings, all of them at UNESCO House, 17 – 18 April 1972, 4 – 6 December 1972, 15 – 16 May 1973
G. Castany (Chairman, IAH), L. Monition (IAHS), W. Richter (BGR, UNESCO Consultant), W. H. Gilbrich (UNESCO)

Legend for Hydrogeological Maps

Hannover (BGR), 15 February 1983
W. Struckmeier (Chairman, BGR), R. A. Monkhouse (IAH/UK), S. Jelgersma (IAHS/NL), W. H. Gilbrich (UNESCO)

Guidebook on the Vulnerability of Aquifers (IAH/IHP)

First Meeting, Tampa (USA), 22 – 25 April 1991
J. Miller (USA), J. Hahn (BGR/GER), J. Vrba (CZ), A. Zaporozec (USA), E. Gosk (DEN), W. H. Gilbrich (UNESCO) and others

Second Meeting, Torino (ITA),
14 – 16 September 1992
M. Civita (ITA), E. Gosk (DEN), J. Vrba (CZ), A. Zaporozec (USA), B. Adams (UK), H. van Waegeningh (NL), W. H. Gilbrich (UNESCO) and others

Third Meeting, Oegstgeest (NL),
13 – 15 January 1993
Same composition as above

Further Meetings (without the participation of UNESCO) have been held in Norway in June 1993 and at Wallingford, UK, in May 1994; Guidebook published 1994 (International Contributions to Hydrogeology, Vol. 16)

Guidebook Hydrogeological Maps – A Guide and a Standard Legend

Hannover (BGR) January 1986, Karlovy Vary (CSSR) and Duisburg (GER)
Preparatory Meetings

First Meeting Hannover (BGR),
18 – 19 January 1988
W. F. Struckmeier (BGR), G. B. Engelen (NL), J. Margat (FRA), E. Romijn (NL), A. Sárin (YOU), W. H. Gilbrich (UNESCO)

Second Meeting, Rinteln (GER), 15 – 17 June 1994
W. F. Struckmeier (BGR/GER), J. Margat (FRA), E. Romijn (NL), W. H. Gilbrich (UNESCO)

Guidebook published 1995 (International Contributions to Hydrogeology, Vol. 17)

International Symposium on Hydrogeological Maps as Tools for Economic and Social Development

BGR, Hannover, 30 May – 02 June 1989
More than 200 participants from 40 countries attending.

Editorial Meetings for the International Hydrogeological Map of Europe (IHME)

Stockholm (SWE), 9 – 12 February 1976
(for Skandinavian and Russian Sheets): H. Karrenberg (IAH/GER), A. Voges (BGR), G. Persson (SWE), J. Hyypää (FIN), C. Kolago (POL), S. V. Egorov (USSR), W. H. Gilbrich (UNESCO)

Athens (GRE), 12 – 15 June 1978
(for Sheet E6): W. F. Struckmeier (IAH/BGR), Mrs N. Atuk (TUR), S. Kallergis (GRE), V. Spassov (BUL), B. Mijatovic (YOU)

Damascus (SYR), 24 – 25 May 1983
(for Sheet F6 Haleb): J. Khouri (ACSAD), Mrs N. Atuk (TUR), W. F. Struckmeier (IAH/BGR),

Roma (ITA), 10 – 11 April 1984
(for Sheet D6): W. F. Struckmeier (IAH/BGR), M. Manfredini (ITA), Mrs Gioni (GRE), W. H. Gilbrich (UNESCO)

Madrid (ESP), 24 – 26 June 1985
(for Sheets A5 (La Coruna), A6 (Lisbon) and B6 (Madrid)): Porras Martin (ESP), A. Costa (POR), W. F. Struckmeier (IAH/BGR), W. H. Gilbrich (UNESCO)

Duisburg (GER), 26 April 1988
C. Ghenea (ROM), J. Khouri (ACSAD), J. Krásny (CSSR), J. Margat (FRA), E. Romijn (NL), A. Sarin (YOU), W. F. Struckmeier (BGR), W. H. Gilbrich (UNESCO)

Bratislava (SLK), 7 September 1999
(for Sheet D4 (Budapest)): P. Winter (BGR/Berlin), G. Tóth (HUN), N. Gál (HUN), I. Dudan (HUN), G. Schubert (AUT), J. Cwecle (CZ), J. Jetel (Slovakia), A. Sadurski (POL), Y. Shestopalov (UKR), P. Enciu (ROM), V. Spassov (BUL), P. Cubzilovic (YOU), A. Sarin (Croatia), S. Kranjc (Slovenia), W. H. Gilbrich (UNESCO-Consultant), and many other participants from the Danube Basin

Madrid (ESP), 5 – 7 April 2000
(for Sheets on the Iberian Peninsula): E. Custodio (ESP), V. Fabregat Ventura (ESP), M. A. de Morais (POR), A. Costa (POR), L. A. Lopez Geta (ESP), S. N. Pla (ESP), M. del Pozo Gomez (ESP), K. Krampe (BGR), C. Neumann-Redlin (BGR), W. H. Gilbrich (UNESCO-Consultant)

Bucharest (ROM), 12 – 15 September 2000
(for Sheet E5): P. Enciu (ROM), V. Spassov (BUL), A. Kaya (TUR), C. Moraru (Moldavia), Y. Rudenko (Ukraine), K. Krampe (BGR/Berlin), P. Winter (BGR/Berlin), W. H. Gilbrich (UNESCO-Consultant)

Athens (GRE), 24 – 26 November 2002
(for Sheet D6): K. Karagounis (GRE), L. Martarelli (ITA), V. Spassov (BUL), B. Mijatovic (YOU), W. F. Struckmeier (BGR), P.Winter (BGR/Berlin), W.H.Gilbrich (UNESCO-Consultant)

After 2004, several bilateral editorial meetings for South-Eastern Europe were held in Budapest and Bucharest (all with P. Winter); the last meeting with L. Robu (ROM) was held in Berlin, 4 – 7 September 2012)

Consultation Meetings on the International Hydrogeological Map of Europe (IHME)

All (so.called annual) meetings have been held at the premises of the **BGR in Hannover**, always with A. Voges (in the beginning, later P. Winter (BGR/Berlin), always W. F. Struckmeier (BGR/Hannover) and W. H. Gilbrich (UNESCO, from 1995 UNESCO-Consultant)
4/5 December 1986
18/19 January 1988
5 April 1991
16 December 1998
16 June 1999
15 December 1999
9 October 2000
4 November 2002
3 March 2003
23 February 2004

Final IHME Workshop

Berlin (BGR), 22 – 23 August 2013
International Workshop on Groundwater Systems in Europe at the occasion of the completion of the International Hydrogeological Map of Europe (IHME) at the scale of 1 :1 500 000
Attended by fifty national experts and H. Treidel (UNESCO)

Hydrogeological Map of the Arab States

Tunis, 19 – 20 October 1982
Preparatory Meeting: NN (ALECSO), J. Khouri (ACSAD), A. Droubi (ACSAD), W. F. Struckmeier (BGR), W. H. Gilbrich (UNESCO), K. Saad (UNESCO/Cairo)

Damascus, 7 – 9 February 1983 and 25 May 1983
same participation

Tunis, (ALECSO), 24 – 27 September 1984
J. Khouri (ACSAD), J. Margat (FRA), W. F. Struckmeier (IAH/BGR), K. Saad (UNESCO-Cairo), W. H. Gilbrich (UNESCO)

Damascus (ACSAD), 16 – 18 December 1984
J. Khouri (ACSAD), A. Droubi (ACSAD), K. Saad (UNESCO-Cairo), W. H. Gilbrich (UNESCO)

Damascus (ACSAD), 30 Nov – 01 December 1987
Final consultation: J. Khouri (ACSAD), A. Droubi (ACSAD), K. Saad (UNESCO-Cairo), W. H. Gilbrich (UNESCO)

Hydrogeological Map of Asia

Bandung (Indonesia), 1 December 1983
In connexion with ESCAP/RMRDC UNESCO-supported Workshop (RMRDC = Regional Mineral Resources Development Centre) with some sixty participants

International Hydrogeological Map of Africa (PCHIA)

Dakar (SEN), 3 – 10 December 1983
OAU/AAC Meeting for the preparation of the International Hydrogeological Map of Africa
C. Fezzani (Coordinator), M. Himida (EGY), W. F. Struckmeier (IAH/BGR) and some hundred mapping experts and country representatives

Dakar (SEN), 29 April – 3 May 1985
C. Fezzani (Coordinator), M. Himida (EGY), W. F. Struckmeier (IAH/BGR) and some twenty experts and country representatives

Lomé (TOG), 11 – 26 April 1986
First PCHIA (International Hydrogeological Map of Africa) Workshop
C. Fezzani (Coordinator), M. Safar-Zitoun (AAC), M. Himida (EGY), W. F. Struckmeier (IAH/BGR) and some twenty experts and country representatives

Addis Abeba (ETH), 12 – 15 November 1986
Session of Experts on the International Hydrogeological Map of Africa
C. Fezzani (OACT), M. Safar-Zitoun (OACT), W. F. Struckmeier (IAH/BGR), J. Margat (FRA), B. Mijatovic (YOU), A. Sárin (YOU)

Addis Abeba (ETH), 29 November – 11 December 1987
Second PCHIA (International Hydrogeological Map of Africa) Workshop
C. Fezzani (Coordinator), M. Safar-Zitoun (OACT), W. F. Struckmeier (IAH/BGR) and some twenty experts and country representatives

Ouagadougou (BKF), 20 – 21 February 1989
Seminar on Hydrogeological Maps of Africa
C. Fezzani (OACT), M. Safar-Zitoun (OACT), B. Diagana (CIEH), W. H. Gilbrich (UNESCO)

Zagreb (CRO), 29 May – 7 June 1988
Third PCHIA (International Hydrogeological Map of Africa) Workshop
C. Fezzani (Coordinator), M. Safar-Zitoun (OACT), W. F. Struckmeier (IAH/BGR) and some thirty experts and country representatives

Orléans (FRA), 11 – 26 April 1986
Fourth PCHIA (International Hydrogeological Map of Africa) Workshop
C. Fezzani (Coordinator), M. Safar-Zitoun (AAC), W. F. Struckmeier (IAH/BGR) and some twenty experts and country representatives

Nairobi (KEN), 8 – 18 March 1991
Fifth PCHIA Workshop and Final Workshop for the International Hydrogeological Map of Africa
M. Safar-Zitoun (OACT), C. Nouiouat (OACT), W. F. Struckmeier (IAH/BGR) and some twenty African and European experts

World Map of the Groundwater Flow to the Oceans

UNESCO House, Paris, 13 – 17 November 1989
I. S. Zektser (USSR), R. G. Dzhamalov (USSR), J. Margat (FRA), W. H. Gilbrich (UNESCO)

Worldwide Hydrogeological Mapping and Assessment Programme (WHYMAP)

UNESCO House, Paris, 27 August 2001
First Consultative Meeting with IAH, BGR, CGMW, UNESCO: W. F. Struckmeier (IAH/BGR), A. Szölösi-Nagy, A. Aureli, W. Eder, F. Repetto (all UNESCO), J. P. Cadet and P. Bouysse (both CGMW), W. H. Gilbrich (UNESCO-Consultant)

IAH Congress, Munich, 10 September 2001
Discussion on WHYMAP proposal at IAH Commission on Hydrogeological Maps (COHYM):
W. F. Struckmeier (Chairman, IAH/BGR), G. Barroccu (ITA), E. Bocanegra (ARG), J. P. Cadet and P. Rossi (CGMW), O. Fouche (FRA), J. P. Heederik (NL), J. Krásny (CZ), K. Sami (RSA), A. Salih and W. v. Igel (UNESCO), I. S. Zektser (RUS)

UNESCO House, Paris, 31 January 2002
First Consortium Meeting:
A. Salih, A. Aureli, W. Eder, F. Repetto (all UNESCO), J. P. Cadet and P. Rossi (CGMW), W. F. Struckmeier (IAH/BGR)

UNESCO House, Paris, 6 – 7 March 2002
Second Consortium Meeting and First Expert Meeting for WHYMAP: W. F. Struckmeier (BGR/GER), A. Salih, A. Aureli, W. Eder, F. Repetto (all UNESCO), J. P. Cadet and P. Rossi (CGMW), I. S. Zektser (RUS), J. Margat (FRA), M. Safar-Zitoun (OACT, Algeria), W. H. Gilbrich (UNESCO-Consultant)

First WHYMAP related IAEA Workshop,
Vienna, 10 – 12 April 2002
P. Aggarwal (IAEA), A. Aureli (UNESCO), P. Hearn and V. Schneider (USA), E. Custodio (IAH/ESP), M. Edmunds (UK), A. Khater (EGY); J. Khouri (ACSAD/SYR), J. Margat (FRA), W. F. Struckmeier (IAH/BGR)

Second WHYMAP related IAEA Workshop,
Vienna, 15 – 17 January 2003
P. Aggarwal, B. Wallin, P. Hearn (all IAEA), A. Khater (EGY), K. Abu Zeid (EGY), M. Geyh and P. Fröhlich (IAEA consultants), M. Edmunds (UK), W. F. Struckmeier (IAH/BGR)

Koblenz (GER), Bundesanstalt für Gewässerkunde, 25 – 27 June 2003
First Steering Committee Meeting
18 participants, Chairman W. F. Struckmeier

Paris, UNESCO House, 7 November 2003
Third Consortium Meeting:
A. Aureli, W. Eder, R. Missotten, M. Tanaka (all UNESCO), W. H. Gilbrich (UNESCO-consultant), J. P. Cadet and P. Rossi (CGMW), W. F. Struckmeier (IAH/BGR)

Paris, UNESCO House, 8 – 10 March 2004
Second Steering Committee Meeting
Large number of participants: E. Bocanegra (ARG), B. Cunnigham (USA), N. da Franca (BRE), J. Girman (RSA), J. Margat, H. Dürr and D. Poitrinal (FRA), J. P. Cadet and P. Rossi (CGMW), J. v. d. Gun and S. Vasak (IGRAC), J. Vrba (CZ), Han Zaisheng (CHN), A. Aureli, A. Teji Guibert (UNESCO), A. Richts, P. Winter, W. F. Struckmeier (all BGR), W. F. Gilbrich (UNESCO-consultant)

Paris, UNESCO House, 13 – 17 April 2005
Third Steering Committee Meeting
More than twenty participants

Third WHYMAP related IAEA Workshop,
Vienna, 20 – 21 November 2004
P. Aggarwal and four colleagues (IAEA), P. Döll (GER), W. Kinzelbach (SUI), J. Vrba (CZ), W. F. Struckmeier (IAH/BGR)

Paris, UNESCO House, 31 January 2007
Fourth Consortium Meeting
A. Aureli, R. Missotten (UNESCO), W. H. Gilbrich (UNESCO-consultant), J. P. Cadet and P. Rossi (CGMW), J. Margat (FRA), A. Richts, P. Winter (BGR), W. F. Struckmeier (IAH/BGR)

Annex C

The "Hydro(geo)logical Mapping" Story

1957/58	International Geophysical Year (IGY)	
1960	IAHS Committee + IAH commission start work on hydro(geo)logical maps = based on map legend of Ambroggi & Margat, Morocco (1960)	
1960	UNESCO Book "Hydrological Maps"	
1961	IAHS General Assembly, Helsinki (exhibition of more than 200 maps = all different)	
1960 – 61	IAH survey of mapping techniques = Questionnaire	
1962	Joint meeting (IAHS + IAH + FAO + CGMW) at UNESCO/Paris	
1962 – 66	4 models for IHME (parts of Sheet Bern)	
1968	Adoption of model 4	
1970	BGS publication "General Legend" in colour (based on Ambroggi & Margat 1960)	
1970	UNESCO survey of Hydrogeological Maps (lead: Mrs. Rogovskaya)	
1970	General Legend for the series of International. Hydrogeol. Map of Europe (IHME)	
1970	IHME Sheet C5 Bern published	
1972 – 73	Panel of experts for "Legend Hydrogeochemical Maps"	
1977	UNESCO/WMO publication "Hydrological Maps"	
02/1983	Editorial meeting for simple General Legend in Hannover	
1983	Publication of "cheap black/white Genenaral Legend for Hydrogeological Maps" (Techn. Doc. in Hydrology, UNESCO; to replace 1970 BGS Legend)	
1985	Cambridge	Three meetings for the revised book "Hydrological Maps"
1986	Karlovy Vary	
1987	Duisburg	
01/1988	Hannover	Meetings for preparing a new General Legend (update of the B/W 1983 legend)
03/1988	Duisburg	
1989	Hannover: International Symposium on Hydrogeological Maps (ca. 200 participants)	
1994	Publication of Guidebook on Vulnerability Maps (ICH 16)	
1995	Publication of Guidebook on Hydrogeological Maps (ICH 17)	
2000	WHYMAP proposal agreed by UNESCO/IAH/CGMW	
2004	Draft GW Resources Map of the World (published for IGC Florence)	
2006	Transboundary Aquifers Map (for WWF Mexico City)	
2008	Groundwater Resources Map of the World (1:50 M + 1:40 M, for IYPE and IGC Oslo)	
2012	River and Groundwater Basins of the World (for WWF Marseille)	
2013	Completion of IHME-series (25 sheets) and International Workshop of GW systems in Europe, Berlin	

The UNESCO International Hydrological Programme (IHP) is the intergovernmental programme of the United Nations system devoted to water research, water resources management and water education and capacity building.

IHP facilitates an interdisciplinary and integrated approach to watershed and aquifer management, which incorporates the social dimension of water resources, and promotes and develops international research in hydrological and freshwater sciences.

In the framework of its Eighth Phase (IHP-VIII, 2014-2021), the UNESCO IHP programme will bring innovative methods, tools and approaches into play by capitalizing on advances in water sciences, as well as building competences to meet the challenges of today's global water challenges.

The World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) contributes to worldwide efforts towards better management of the Earth's water resources, particularly groundwater.

The goals of the programme are to collect, collate and visualize hydrogeological information at the global scale to convey groundwater-related information on maps in an appropriate manner for global discussion on water issues and to emphasize the presence of underground water resources. The programme thereby centralizes and showcases the results of the significant efforts in hydrogeological mapping that have been undertaken at regional, national and continental levels. The maps resulting from these activities provide an immediate, visual representation of key characteristics of water resources and can be used by politicians and planners to develop sound management practices.

This report has been conceived for a broad readership. It provides an overview of the various hydrogeological and hydrological mapping activities conducted mostly under UNESCO's leadership for nearly half a century , and describes the maps that are currently available. The report also calls for greater attention to a number of water-related issues, including the need for sustainable groundwater resources management.

However, after more than 50 years' work, the mapping of the world's groundwater and aquifers is still far from complete. In a next step, the existing data will be digitalised and integrated in a geographic information system. UNESCO stands ready to continue with its partners this outstanding scientific work that provides visual tools that inform and facilitate solutions in concrete projects.