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Federal Institute for Geosciences and Natural Resources

UNITED NATIONS
ECONOMIC AND SOCIAL COMMISSION
FOR ASIA AND THE PACIFIC
(ESCAP)

REGIONAL MINERAL RESOURCES
DEVELOPMENT CENTRE
(RMRDC)

W. F. Grimmelmann
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PREFACE

The Government of the Federal Republic of Germany has supported the Regional Mineral Resources Development Centre (RMRDC) of the United Nations Economic and Social Commission for Asia and the Pacific since 1970 by providing advisers in the fields of geology and mining.

The development of the region depends essentially on an adequate supply of water for all sectors of the economy and daily life, principally drinking water for both rural and urban areas, as well as suitable water for agriculture and industry. In many of the countries there are still major problems to be solved concerning the assessment, development and protection of groundwater resources.

Hydrogeological maps represent the most important basis for the planning and implementation of water-supply and groundwater-protection projects. They contain information about availability, extractable quantities, suitability, and vulnerability of groundwater to pollution.

It is for this reason that the Federal Minister for Economic Cooperation has decided to concentrate his support for the RMRDC onto the field of hydrogeology, particularly on institution-building and assistance in the preparation of planning documents.

The Federal Republic of Germany has for many years been promoting a number of national and international mapping projects in the field of geology through the competent authority, the Federal Institute for Geosciences and Natural Resources (BGR). In line with these activities, the Federal Ministry for Economic Cooperation supported the ESCAP-RMRDC Workshop on Hydrogeological Mapping by providing specialists from the BGR and by meeting the bulk of the printing costs of the proceedings of the workshop. The Federal Ministry for Economic Cooperation is confident that this assistance will contribute to the development of the ESCAP region.

Dr. U. Lorenzen
Ministry for Economic
Cooperation

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F O R E W O R D

Hydrogeological mapping has increased considerably in the last two decades, due mainly to the support which this subject has received from international organisations. The publication of the International Legend for Hydrogeological Maps (UNESCO, 1963; amended version by UNESCO, IAH, IAHS, and IGS London, 1970) was an important step in this. The first sheet of the International Hydrogeological Map of Europe, scale 1 : 1 500 000 was issued in 1970 and generated additional interest and attention.

In recent years many projects in hydrogeological mapping have been started on a national basis and there is a clear tendency to use legends derived from the UNESCO recommendations. Criticism and suggestions concerning the International Legend have led to a new draft which was discussed during the workshop.

Although the trend towards the standardization of general hydrogeological maps will continue, there are still a great number of cases which require special legends. This is particularly true for arid regions where hydrochemical problems predominate.

Fortunately, the practice of undertaking hydrogeological mapping only after a rather high data level has been attained, has been abandoned in recent years. The urgent necessity to provide information on groundwater for development planning coupled with the scarcity of hydrogeological data in underdeveloped areas has induced many governments to prepare draft maps at an early stage of groundwater exploration, i.e. as soon as the geological composition of the area is known and descriptions of the main lithological units are available.

RMRDC organized this workshop in awareness of the probability that the meeting would be attended by participants of different professional background and origin and that there might be some difficulty in finding a common level for discussion. The following papers which reflect this variety made it possible for the meeting to look at problems from different positions.

The workshop was intended to be a review of achievements as well as a source of information on different subjects. We hope that it will have also provided incentive either to start mapping or to improve ongoing projects.

We acknowledge the support which RMRDC has received for the workshop from the Government of Indonesia. We appreciate also the contribution of the Governments of Australia, the Netherlands, the Federal Republic of Germany and of UNESCO, which provided funds for some participants.

RMRDC has promoted hydrogeological mapping since the early seventies when it was still a geological advisory group based with ESCAP in Bangkok. In those days, this kind of activity was regarded as rather academic in some ESCAP countries. Since then, the situation has greatly improved. The common interest in hydrogeological maps today is a recognition of the growing importance of groundwater and the need to monitor the development and use of this resource in view of the fact that it is being threatened by a variety of human activities.

James F. McDivitt
Coordinator,
RMRDC

Wolfgang F. Grimmelmann
Senior Hydrogeologist,
RMRDC

OPENING ADDRESS

Dr. John A. Katili, Director General of Mines, Republic of Indonesia

Distinguished audience, ladies and gentlemen,

On behalf of the Government of Indonesia, I would like to express my sincere welcome to all participants of this workshop. This is the first workshop on hydrogeological mapping organized for countries of the ESCAP region.

Hydrogeology, or groundwater geology, has become an important branch of geology in the past 3 decades. Essentially, there are two reasons for this development: first, water resources have become extremely precious in some parts of the world, due to the increase in population and consequently water consumption. Second, pollution of various kinds has spread over large areas and there is a growing awareness of the necessity to protect water resources from certain activities of man.

Hydrogeological maps have turned out to be useful tools for coping with both problems: water supply and water protection. Hydrogeology deals with water-bearing rocks and most aquifers can be defined as geological units or parts of them. It is fair to state that no hydrogeological map can be produced without prior or simultaneous geological mapping.

Fortunately, the importance of geological mapping has been recognized and in many countries geological mapping has been carried out on different scales, long before groundwater investigations were commenced on a large scale. The availability of geological maps in many parts of the world has enhanced the activities of hydrogeological mapping.

The scarcity of data on the occurrence of groundwater, aquifer productivity, groundwater quality, etc., is commonly regarded to be the greatest constraint in resources assessment for the purpose of regional development planning. As a developing nation we have become aware of this fact and in Indonesia the first modern hydrogeological mapping in this country on a scale of 1 : 250 000 was started earlier in 1969 and it will take some time before the 150 sheets of this scale will be completed.

A map on a scale of 1 : 2 500 000 covering the whole Archipelago has recently been printed. Detailed information on the state of the art of hydrogeology of Indonesia will be presented during this workshop.

Allow me now to expose some serious problems that are currently being encountered in this country in relation to hydrogeology.

1. HYDROGEOLOGICAL PROBLEMS IN URBAN AREAS

In the beginning of this century, groundwater was found to be artesian in the area of the capital-city Jakarta. That means that the hydraulic head of the groundwater was several meters above the earth's surface and wells which tapped deep aquifers were self flowing.
Rapidly increasing groundwater extraction has changed the original situation profoundly.
Groundwater levels have dropped on a regional scale. The zero-line, once having been beyond the coastline, has been drawn far inland. Huge depression cones have developed in some parts of the city in which the groundwater level has dropped down to 20 - 30 m below sea level. As a consequence, sea water is drawn far inland to many wells and salinization of the originally fresh groundwater has set in. This disturbance of the fresh-saltwater interface is endangering the water supply of greater Jakarta which still depends widely on groundwater resources. This serious situation has been amplified by the fact that most rivers and canals in the urban areas are highly polluted and offer no significant substitute for a safe water supply.
Land subsidence is also threatening the city and it is well known to us that this phenomenon has already struck many large cities in Southeast and East Asia. In most cases the lowering of the groundwater table has been identified as the main cause of land subsidence. Much more damage can be caused by subsequent disturbance of the drainage pattern. When the base levels do not function any more, extended flooding will occur. Since Jakarta is situated in a flat coastal plain, it is rather vulnerable to this threat.

2. HYDROGEOLOGICAL PROBLEMS IN RURAL AREAS

The islands east of Bali, known as the Lesser Sunda Islands, have an annual rainfall of only 1420 mm as compared to the average annual rainfall in Indonesia of 2620 mm.
Topographic, geologic and vegetational conditions are responsible for relatively high annual evapotranspiration. Consequently, almost every year these islands are struck by drought severely damaging crops and killing cattle. Shortage of drinking water for the rural population is a common feature.

The problems stated above, one caused by the intervention of man and the other due to natural conditions, have been recognized by the Indonesian authorities and steps are being undertaken to remedy the situation.

With the rapid increase in the demand of water resources, groundwater will certainly play an increasing role to overcome the shortage of this valuable resource. Much will depend on our wisdom to prevent a renewable resource such as groundwater from being degraded to a non-renewable one. There is much new scientific theory, and new technological apparatuses and equipment which can be brought to bear on these investigations to remedy the situation when crises arise.

The meeting which is opening today, I hope will chart the paths of these investigations, to identify major areas which must be dealt with and institutions which can collaborate in dealing with them. I therefore hope that this workshop will come up with practical recommendations to the governments of the ESCAP member countries on how to deal with problems pertinent to hydrogeology.

With inadequate funds, limited knowledge and weakness in scientific and technological infrastructure, the development of groundwater resources in our region is a demanding challenge.

The problems to be encountered are so numerous and so complex that a satisfying solution will not be so easily achieved without regional and international cooperation.

I wish you every success in your deliberation.

Hydrogeological Mapping in Asia and the Pacific Region
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THE ASSESSMENT AND MAPPING OF AUSTRALIA'S GROUNDWATER RESOURCES

G. Jacobson

ABSTRACT

Groundwater is a vital resource for Australia's future development but its use is constrained by various factors including salinity. Australia's groundwater resources have not been fully investigated and a national hydrogeological mapping programme has been initiated and is expected to become a basis for groundwater assessment, development and management. In the hydrogeological maps so far published, groundwater salinity has been the main parameter mapped, and in this respect Australian maps are different from those of other countries. Problems which need to be addressed in the Australian hydrogeological mapping programme include the determination of appropriate map scales and the cartographic representation of groundwater salinity, superimposed aquifers, and variations in recharge. Automated cartography may aid the immense task of the hydrogeological mapping of Australia.

GROUNDWATER USE AND DEVELOPMENT IN AUSTRALIA

The quality and quantity of groundwater vary greatly in different parts of Australia. This variability is due to the complex geology; and to the variable topographic, climatic and surface hydrological conditions, both present-day and in past geological time. The hydrogeological mapping of the continent is therefore a difficult task!

Three broad aquifer types have been distinguished in reviews of Australia's groundwater resources: surficial aquifers including unconsolidated sediments and calcrete, deeper aquifers in large sedimentary basins, and shallow aquifers in fractured rock provinces (Fig. 1). The surficial aquifers cover about 25 percent of the continent and partly overlie the sedimentary basins and fractured rock aquifer provinces. Sedimentary basins cover about 65 % of the continent and fractured rock provinces about 35 %. Groundwater abstraction in Australia totals about 2500 million m³ annually, of which the surficial aquifers supply about

60 %, the deeper aquifers in sedimentary basins about 30 %, and the fractured rock aquifers about 10 %.

Overall, less groundwater is used than surface water in Australia. Nevertheless, about 60 % of the country is totally dependent on groundwater, and in another 20 % of the country, more groundwater is used than surface water. The groundwater-dependent area includes most of the arid zone (Fig. 2) which has sparse and unreliable surface water, high evaporation (Fig. 3), and frequent and lenghty droughts. Groundwater is therefore specially significant for arid-zone agricultural and domestic water supplies, and for the important pastoral and mining industries.

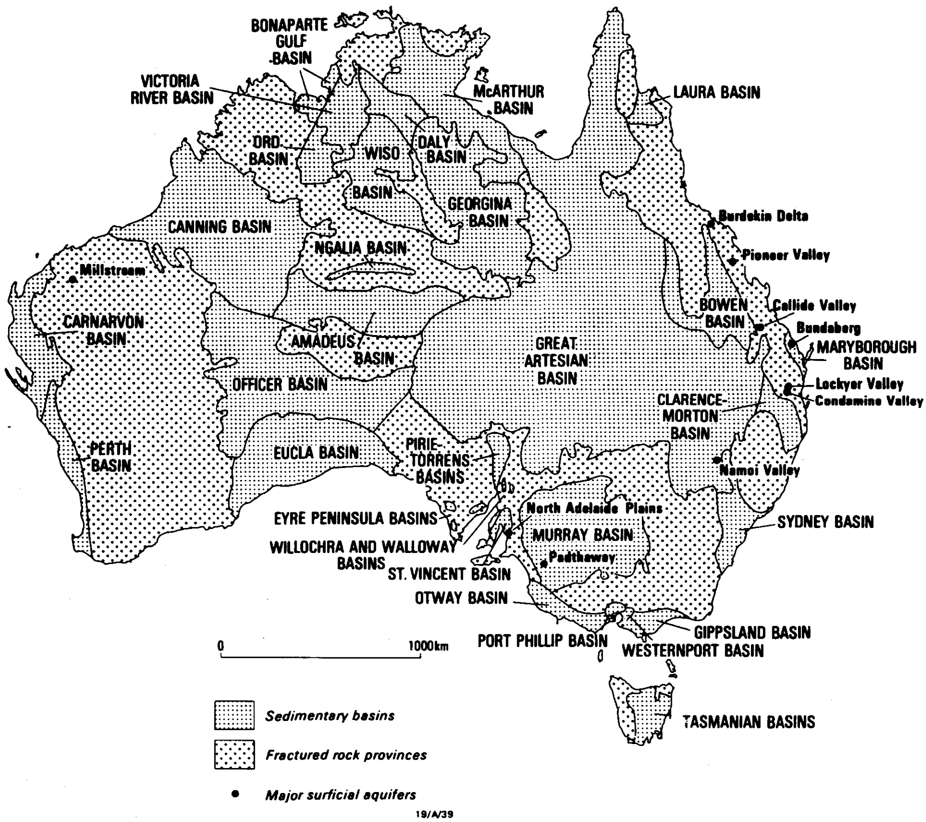

Figure 1. Australia: Major hydrogeological divisions.

Present-day groundwater recharge is shown in Figure 4. In the arid zone, low recharge means that future groundwater development will depend on abstraction from groundwater storage. The total amount of groundwater in storage is very large, many times the available storage of surface waters. In the large sedimentary basins, the total storage is of the order of 10^{14} m³, although not all of this is available for abstraction. Much of the groundwater in storage is fossil water derived from recharge during wetter periods of the Quaternary.

Figure 2. Australia: Mean annual rainfall, and extent of the arid zone.

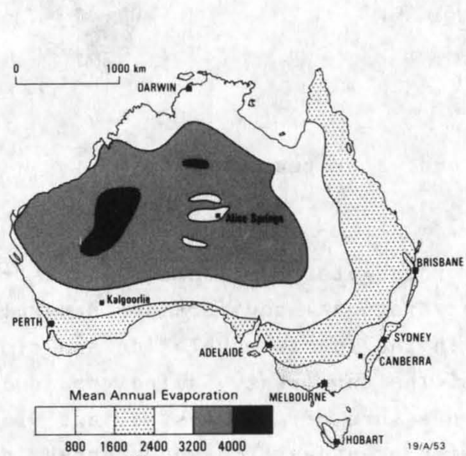

Figure 3. Australia: Mean annual evaporation.

The intensive use of groundwater in some areas, especially for irrigation, has led to the overdevelopment of some regional aquifers. This has occurred in at least 13 areas (Jacobson, Habermehl & Lau, 1983) and is manifest as low water-tables or increased salinity. These problem areas are now being managed by controlling the abstraction of groundwater, or by artificial recharge or by the conjunctive use of surface water.

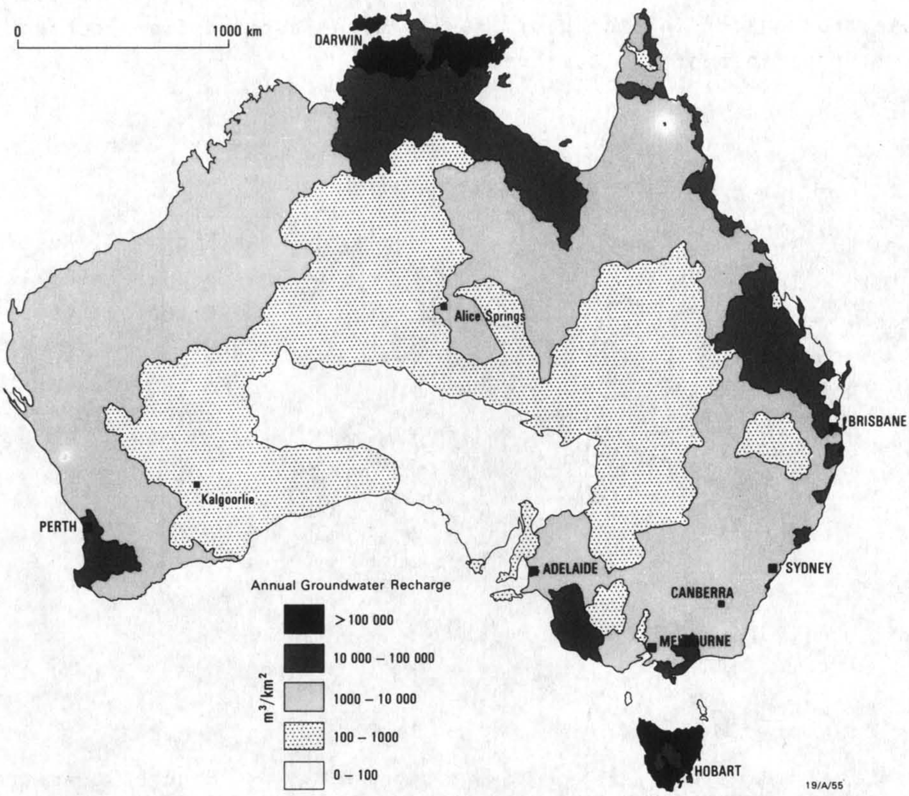

Figure 4. Australia: Annual groundwater recharge.

The main constraint to future groundwater development in Australia is likely to be water quality. Many regional aquifers are naturally saline (Fig. 5) and this is a factor in the sparse population and slow development of much of the interior of the continent. Saline groundwater may also be a factor in the high blood pressure of many Australians! In addition, salinity problems associated with groundwater have occurred in parts of Australia as a result of changes in land use since European settlement of the country began in the late 18th century. Rising salt has affected several thousand kilometres of agricultural land, and is attributed to reduced evapotranspiration after land clearing, and to poor irrigation drainage.

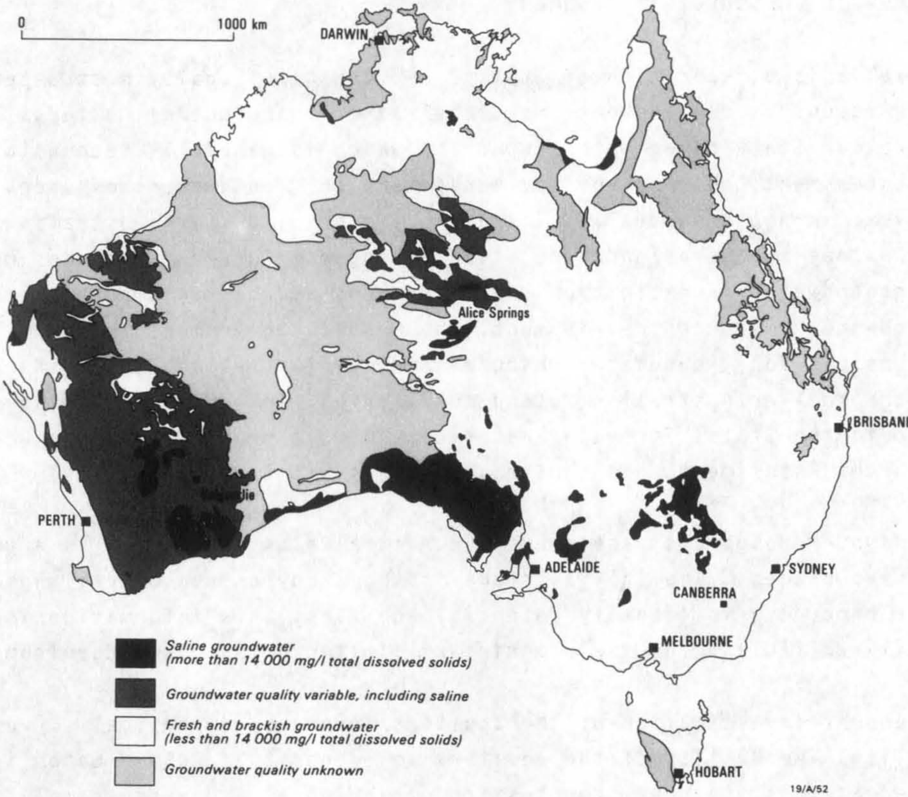

Figure 5. Australia: Salinity of main aquifers.

Many aquifers in the arid zone contain freshwater which has relatively high concentrations of nitrate, fluoride or other deleterious chemicals which limit the usefulness of the water. In addition, at least two important regional aquifers are polluted by urban and industrial wastes, and a number of important local aquifers are also polluted.

GROUNDWATER RESOURCES ASSESSMENT

Australia is a federation of States, and constitutionally most aspects of water resources development are State rather than federal matters. Each Australian State has a water authority which is generally responsible for the assessment, development and management of groundwater resources. However, in South Australia, Tasmania, Victoria, Western Australia and to some extent in Queensland, the State Geological Survey undertakes much of the groundwater investigation and assessment and has an important role in groundwater resources development. The Federal government is directly responsible for groundwater resources in the Australian Capital Territory and the smaller Australian island territories. In addition it disburses funds to the States for major water development projects and for water resources assessment, and thus has an oversight of water policy.

Groundwater resources assessment, in Australia as elsewhere, is a progressive process. The initial stage is the study of geological maps and water bore data to identify potential aquifers. This information is usually sufficient for the planning of limited groundwater development.

Subsequent investigation of the aquifers involves geophysical surveys and drilling. The ability of the aquifers to transmit and store water is evaluated at this stage by pump testing of the bores and water samples are taken for chemical analysis to determine water quality. At this stage detailed information becomes available for planning extensive groundwater development and for determining its broad-scale effects. An estimate of the safe yield of an aquifer or basin can be made, based on the amount and timing of recharge and the amount of water in storage.

At a later stage, responses of the aquifers to various patterns of abstraction and recharge are assessed, generally by modelling the hydraulics of the groundwater system.

The adequacy of the groundwater resources data that is available for planning and management purposes varies throughouth Australia, and is related to the intensity of groundwater development in a particular region. In a recent review of Australia's groundwater resources estimates of possible yield were made for the nation's 238 drainage basins. The reliability of the resources estimates was categorised (Fig. 6). Some 39

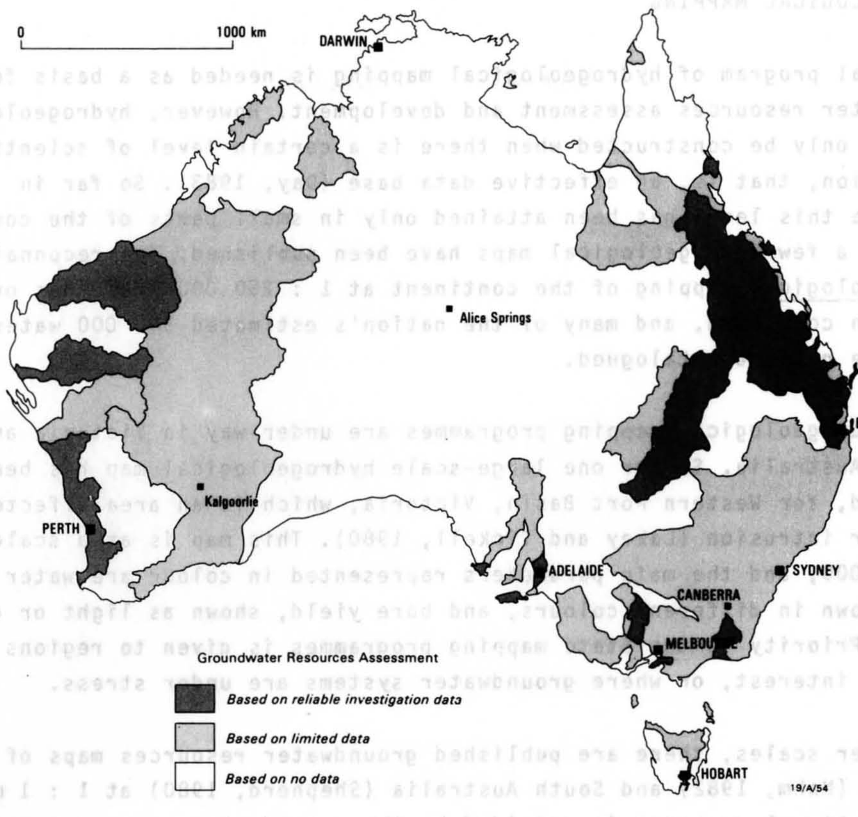

Figure 6. Australia: Reliability of groundwater resources assessment.

drainage basins (16 %) were described as having reasonable groundwater investigation data; the other 199 (84 %) were described as having limited or no investigation data. Thus there are substantial gaps in knowledge of Australia's groundwater resources, and a pressing need for the upgrading of that knowledge.

HYDROGEOLOGICAL MAPPING

A national program of hydrogeological mapping is needed as a basis for groundwater resources assessment and development. However, hydrogeological maps can only be constructed when there is a certain level of scientific information, that is, an effective data base (Day, 1983). So far in Australia this level has been attained only in small parts of the country, and only a few hydrogeological maps have been published. The reconnaissance geological mapping of the continent at 1 : 250 000 scale has only just been completed, and many of the nation's estimated 500 000 water bores are not yet catalogued.

State hydrogeological mapping programmes are under way in Victoria and Western Australia. So far one large-scale hydrogeological map has been published, for Western Port Basin, Victoria, which is an area affected by saltwater intrusion (Lakey and Tickell, 1980). This map is at a scale of 1 : 100 000, and the main parameters represented in colour are water salinity, shown in different colours, and bore yield, shown as light or dark shades. Priority in the State mapping programmes is given to regions of economic interest, or where groundwater systems are under stress.

At smaller scales, there are published groundwater resources maps of Victoria (Nahm, 1982) and South Australia (Shepherd, 1980) at 1 : 1 million scale. National coverage is provided by the groundwater resources map of Australia, scale 1 : 5 million (Australian Water Resources Council, 1975). This map is in 4 sheets, representing the three main aquifer types: shallow, unconsolidated sediments, sedimentary basins, and fractured rocks; and a composite sheet showing principal groundwater resources. It is essentially a hydrochemical map and water quality in each sheet is shown in five salinity ranges representing particular uses of the water. Thus, water of less than 1000 mg/l total dissolved solids is considered suitable for domestic use or irrigation. Water with 1000-3000 mg/l is considered good-quality water for livestock. Water with 3000-7000 mg/l is considered fair-quality for livestock. Water with 7000-14000 mg/l is poor quality but still suitable for sheep, whereas water with more than 14 000 mg/l is unsuitable for any livestock.

The distinguishing feature of all the Australian hydrogeological maps published so far is that groundwater salinity is the parameter represented in colour. Hydrogelogical maps with a primary geological base, as in the International Hydrogeological Map of Europe, have not yet been published. Future hydrogeological mapping programmes in Australia will have to address fundamental cartographic problems because the hydrogeological environment is different from that of Europe. These problems include the determination of appropriate map scales; the great variations in salinity; superimposed aquifers in large sedimentary basins; and great variations in groundwater recharge.

THE PROBLEM OF MAP SCALE

The area of the Australian continent is about 7.7 million km^2, which is in the same order as that of the United States, or of Europe. The development of groundwater resources is concentrated in certain areas, and there are vast areas with little or no data. The need for hydrogeological maps is two-fold. Firstly there is a need for maps at scales of 1 : 250 000 and 1 : 100 000 in areas of intensive groundwater development, or where salinity problems have arisen. Secondly, there is a need for continent-wide coverage including the areas of presently sparse settlement and future development promise. There are existing topographic base maps at a scale of 1 : 250 000 and 1 : 1 000 000, and there are geological maps at 1 : 250 000, 1 : 2 500 000 and 1 : 5 000 000. These provide the basis for a national hydrogeological mapping program.

SALINITY VARIATIONS

Variations in groundwater salinity, both areally and in depth, are so marked that salinity has been regarded as the most important parameter in Australian hydrogeological maps published so far. For instance the Western Port Basin map and the hydrogeological map of the Australian Capital Territory (Evans, in press) both show three classes of groundwater salinity (Table 1), which are related to the usefulness of the water for domestic, irrigation and stock watering purposes. Secondary subdivisions have been made on the basis of bore yield or aquifer type. In this respect, Australian hydrogeological maps are different from those of Europe or Southeast Asia where the aquifer type, i.e. fissured or porous, is the main mapping parameter, and most groundwater is fresh.

Table 1

Colour matrix for the Hydrogeological Map of the Australian Capital Territory (Evans, in press)

		PROBABLE YIELD (l/s)		
		Low	Moderate	High
SALINITY (mg/l total dissolved solids)	Low	light blue	medium blue	dark blue
	Moderate	light green	medium green	dark green
	High	light red	medium red	dark red

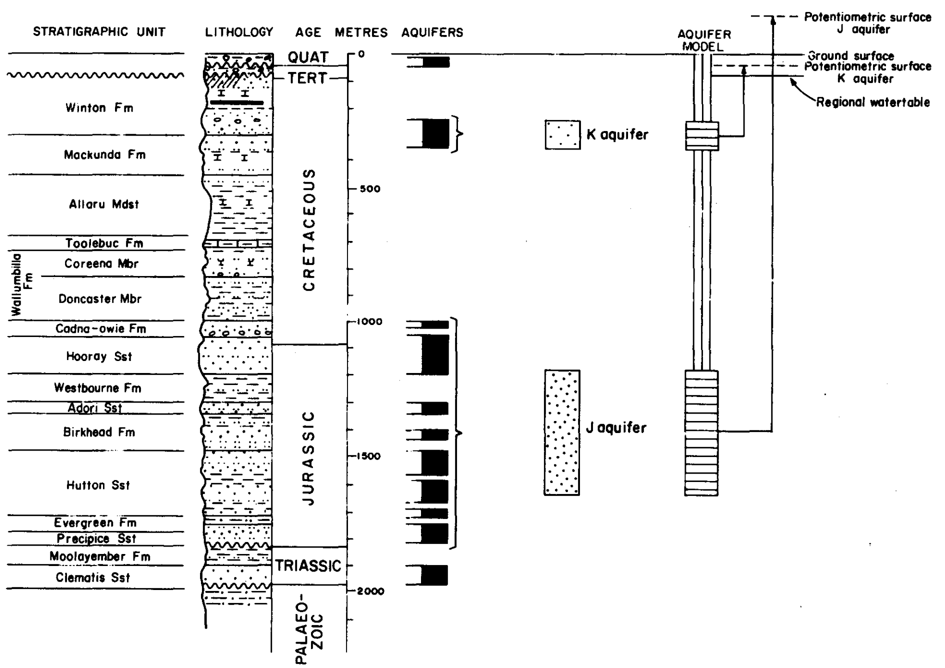

Figure 7. Layered aquifers in the Great Artesian Basin (after Habermehl, 1979).

SUPERIMPOSED AQUIFERS

At least half of Australia has superimposed aquifers. Thus, surficial aquifers in alluvium or calcrete commonly overlie deeper aquifers in sedimentary basins or fractured rock provinces. In addition, there are multiple aquifer systems in the large sedimentary basins such as the Murray Basin (Fig. 1) which covers about 280 000 km^2 and has layered aquifers of different salinity, in poorly consolidated sediments up to 500 m thick. The Great Artesian Basin (Fig. 7) covers about 1.6 million km^2, and has layered sandstone aquifers which are productive from depths of up to 2000 m. Methods of portraying these groundwater systems cartographically have yet to be devised.

VARIATIONS IN RECHARGE

The Australian arid-zone has low recharge (Fig. 4) and large-scale groundwater development depends on abstraction from groundwater storage, including the mining of fossil waters. Palaeohydrology is thus an important consideration in groundwater resources assessment, and techniques for its cartographic representation need to be devised.

CONCLUSIONS

Much of Australia is dependent on groundwater. Groundwater development has been intense in some areas, but overall the resources are not fully developed, and are inadequately known. A national program of hydrogeological mapping is required as a basis for groundwater resources assessment, development, and management. The hydrogeological maps produced so far have been hydrochemical in character and the special problems of the Australian hydrogeological environment require different cartographic representation from that of other countries.

Groundwater systems are dynamic in nature and there are changes in hydraulics and chemistry within the normal lifetime of a published map. The problems of scale and the cartographic complexity necessary to show variations in many parameters suggest that digitised hydrogeological maps should be developed at an early stage in Australia. These would be based on the manipulation of groundwater data bases to produce thematic maps of various aquifers.

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HYDROGEOLOGICAL MAPPING IN FIJI

Alfred T. Simpson

ABSTRACT

Hydrogeological mapping in Fiji is essentially in its infancy. An attempt to produce a tentative hydrogeological map of the largest island, Viti Levu, was started in September 1983 with the help of the RMRDC Hydrogeological Consultant.

The exercise has provided a good case study on the production, in a short time, of a hydrogeological map using limited data. Though the map produced is far short of the printing stage, it has provided the first step in an exercise which would be of enormous benefit to the country.

1. INTRODUCTION

Fiji lies wholly within the tropics in the southwest Pacific Ocean and comprises over 800 islands and islets, including numerous atolls and reefs. It covers an area of ocean of 650 000 km², but of that only 18 280 km² are land. Of this figure 10 390 km² make up the main island of Viti Levu, and 5540 km² the second largest island of Vanua Levu.

The two main islands have pronounced wet and dry zones, with marked vegetational contrast; the northwest areas are dry grass country, whereas the southeast is mostly forest covered. The annual rainfall in the dry zones averages 170 cm, whereas in the wet zones the range is from 300 cm to more than 650 cm in the high country. The average temperature range is about 20 to 30 °C.

The last census in Fiji was carried out in 1976 when the population of the country was found to be 588 068.

In Fiji water supply and most matters pertaining to surface water are the responsibility of the Public Works Department. The Drainage and Irrigation Division is part of the Department of Agriculture and the Hydrogeology Unit is a section of the Department of Mineral Resources.

2. HYDROGEOLOGICAL HISTORY

Systematic geological mapping at the scale of 1 : 50 000 was begun by the Fiji Geological Survey in 1957. It was not until the late 1960s that hydrogeological studies on several smaller islands began. Prior to this, and in the absence of hydrogeologists, ad hoc requests for groundwater information were handled by staff of the Geological Survey. Later the Geological Survey merged with the Mines Department to form the Department of Mineral Resources.

Apart from short-term consultants, the first established hydrogeologist was S.A. Gill whose work resulted in a number of unpublished internal reports. Gill worked mainly on small islands and village groundwater projects. "Survey of Groundwater Resources in Fiji" (Carr, 1974) was the first major hydrogeological study. All hydrogeological data up to this stage were kept as internal departmental reports.

During and following Carr's work, the need to collect hydrogeological data was established though the practical application of the idea has been full of frustrations and problems. Lack of finance, staff and the absence of groundwater legislation have been the main reasons for an inefficient data collection and storage system. Since 1974 several projects have been carried out and though the volume of data collected has increased, the distribution is still very much confined to the project areas and large information gaps still exist.

Hydrogeological expertise in Fiji is at present with the Department of Mineral Resources in the form of Hydrogeological and Drilling Sections. The Hydrogeology Section consists of two hydrogeologists, one an ex-patriate officer and four technical officers/assistants. The work of the Section is primarily funded by the Public Works Department for site specific work. The small staff are under extreme pressure in trying to accommodate the various ad hoc requests, this naturally leaves insufficient time to carry out research work or to effectively deal with the new data.

3. HYDROGEOLOGICAL MAPPING

The collation and presentation of data, though essential, has been somewhat of a luxury in the light of our staffing problems. Carr's 1974 report included geological maps onto which spot data from boreholes were drafted.

Earlier this year, 1983, the Regional Mineral Resources Development Centre (RMRDC) was approached on the possibility of providing a short-term consultant to prepare a preliminary hydrogeological map.

On the 11 September 1983, Dr. W.F. Grimmelmann arrived in Fiji and as his visit was limited to three weeks it was mutually agreed that his task was to prepare a tentative hydrogeological map of Viti Levu. His working schedule was roughly the following:

First week: Study of reports, maps etc. mainly concerning the general geological, climatic and hydrogeological situation.
Second week: Collection and evaluation of data and the choice of a legend.
Third week: Draft of hydrogeological map.

The author drafted three sheets which would normally be printed as one multicolour map.

a) Surface water features (Fig. 1): Main water divides (catchment areas of the main rivers), gauges, dams.
b) Lithological map with cross sections (Fig. 2).
c) The hydrogeological map proper (Fig. 3), conceived as a "yield-map".

As a first approach the consultant used the legend of the International Hydrogeological Map of Europe, scale 1 : 1 500 000. The main characteristics of this legend are summarised in Table 1. As most of the projects in Viti Levu have been based in the drier northwestern areas, this has resulted in the uneven distribution of hydrogeological data. The consultant's initial step, based on this scarce data, was to apply "light blue" to areas covered with unconsolidated Quaternary rocks and "light brown" for the remainder of the island.

The second step was to delineate the areas of "no groundwater resources worth mentioning". These areas were shaded "dark brown" and were attributed to the Colo Plutonics which appeared to have the lowest yields. The resultant map was far from satisfactory as large parts of the island were without subdivisions. In the European legend the dark blue and green shades are defined as "extensive and highly productive aquifers". As these are almost non-existent on the island, it was decided to use a legend which would be more suitable for the Viti Levu situation (see Table 2). This was the third step and on this basis the map was completed.

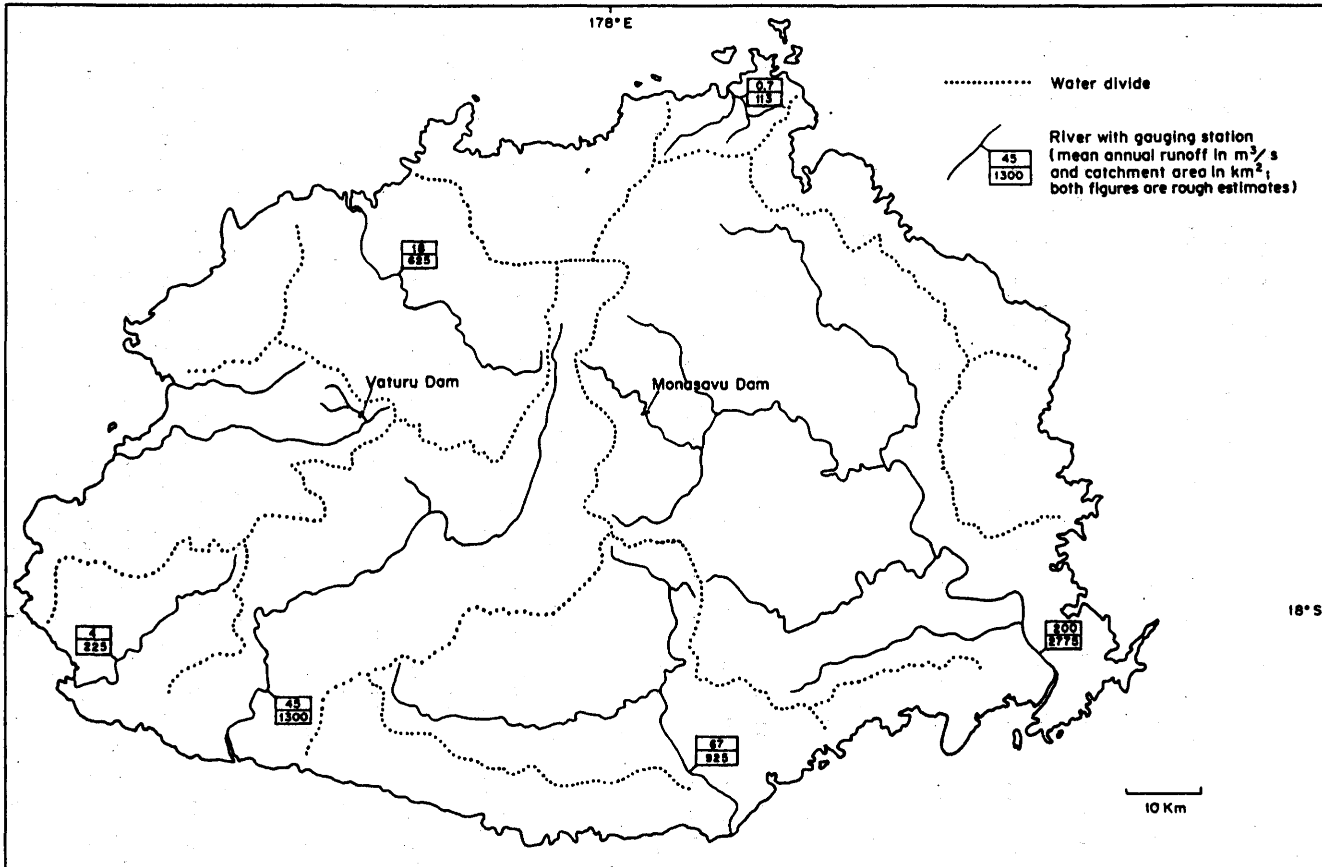

Fig. 1. Surface water features of Viti Levu

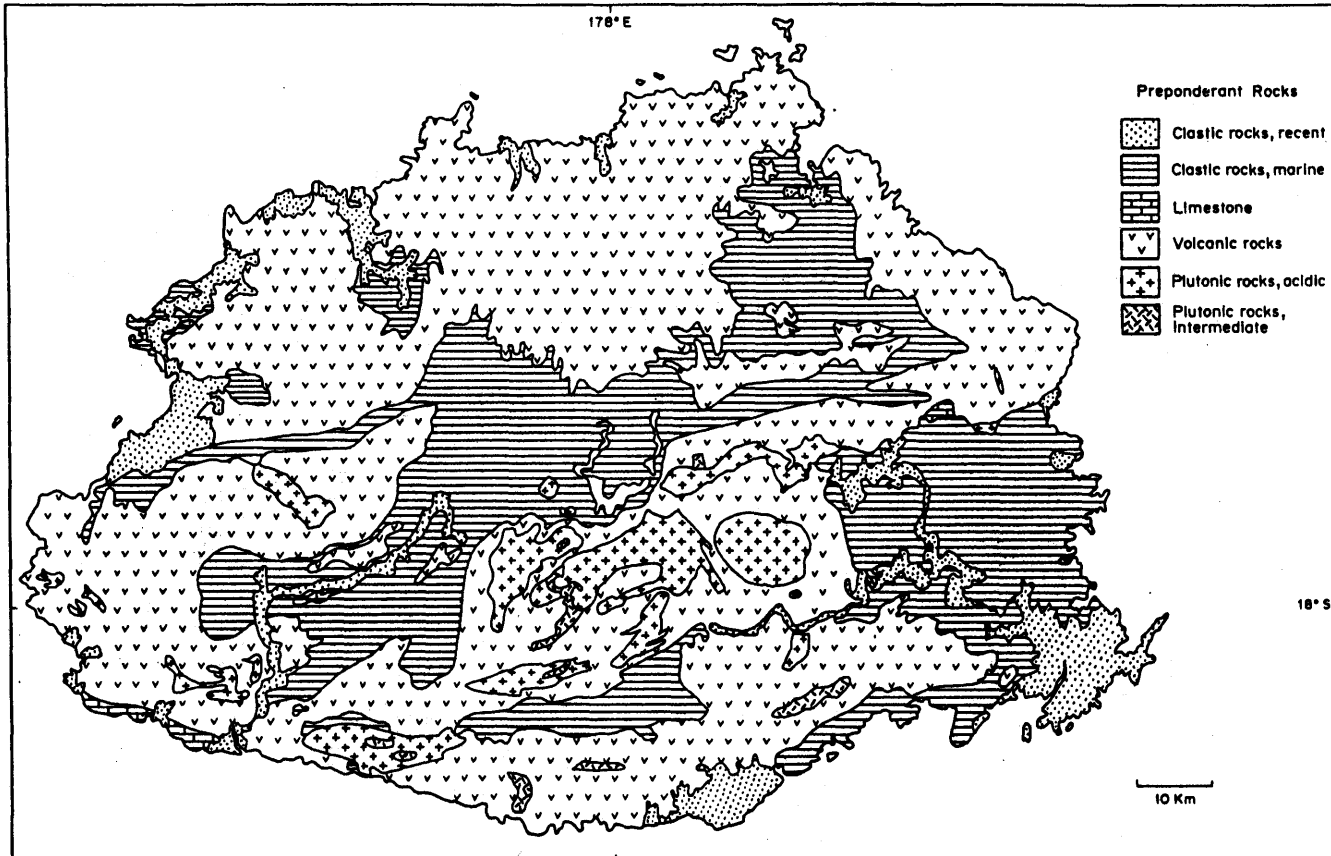

Fig. 2. Lithological map of Viti Levu

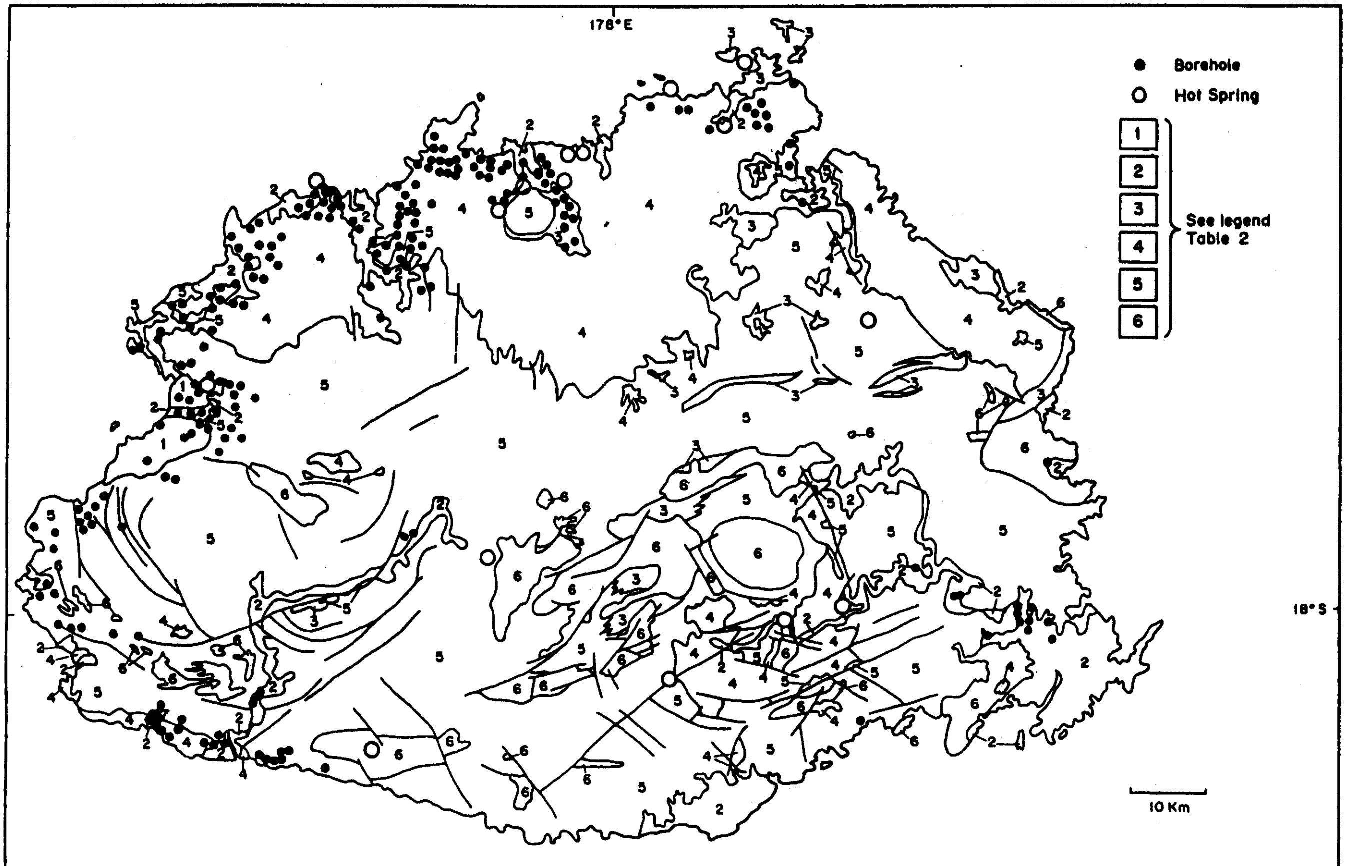

Fig. 3. Groundwater resources of Viti Levu

Table 1: Simplified European Legend

I. Porous (usually unconsolidated) rocks

1. Dark Blue: Extensive and highly productive aquifers.
2. Light Blue: Local or discontinuous productive aquifers, resp. extensive, but only moderately productive aquifers.

II. Jointed rocks, including karstified rocks.

3. Dark Green: Extensive and highly productive aquifers, often only at great depth.
4. Light Green: Local or discontinuous productive aquifers, resp. extensive but only moderately productive aquifers.

III. Only local occurrence of groundwater (in porous or fissured rocks) or areas without groundwater resources worth mentioning.

5. Light Brown: Local occurrence of groundwater, especially in zones of fractured and weathered solid rocks.
6. Dark Brown: No groundwater resources worth mentioning.

Table 2: Legend used for Viti Levu

I. Porous (commonly unconsolidated) rocks.

Colour No. 1: Extensive and highly productive aquifers (yields of wells generally > 5 l/s).
Colour No. 2: Less extensive or less productive aquifers (yields of wells generally < 5 l/s).

II. Jointed rocks, including karstified rocks.

Colour No. 3: Aquifers of medium to high productivity (yields of wells generally > 2.5 l/s).
Colour No. 4: Local or discontinuous productive aquifers (yields of wells generally < 2.5 l/s).

III. Porous and fissured rocks.

Colour No. 5: Local occurrence of groundwater, mainly in fractured and weathered zones, generally low yields.
Colour No. 6: No groundwater resources worth mentioning.

The consultant stated that the hydrogeological classification of the geological units are only partly based on borehole data. In the central mountainous part of Viti Levu, the rocks have been classified mainly according to descriptions such as degree of jointing, porosity, weathering, petrography, etc.

Base flow data, where available, also aided in the classification of some units. The assumption was used that low base flow generally occurs where poor aquifers occupy the greater part of an area.

4. VITI LEVU HYDROGEOLOGY

As previously stated, there are large information gaps in the understanding of the hydrogeology of Viti Levu. Further problems can be directly attributed to the complex tectonics and geology of the area.

The main identifiable aquifers are the unconsolidated deposits occurring in sedimentary basins or as alluvial deposits along the major rivers. The older submarine flows, pillow lavas and volcaniclastics are generally found to be relatively impermeable.

Groundwater is found in small quantities in localised areas of subaerial volcanics. The present state of knowledge indicates that groundwater is not a large resource.

5. CONCLUSION

The way Fiji has embarked on hydrogeological mapping has a number of advantages and disadvantages. Two immediately obvious disadvantages are:

-- The consultant is usually not familiar with local conditions (hydrogeology etc.) which would result in loss of time through the need for additional studies.

-- During his stay, the consultant has to collect information from local staff which further impedes their work.

The advantages on the other hand are:

-- The consultant's visit is for a limited time and in case of difficulties he will rather make mistakes than not complete the map.

Local staff faced with the same problems would probably postpone the project.

-- The consultant's reputation is in most cases not affected by minor mistakes as he is regarded as an 'outsider'. On the other hand there is little incentive for the local staff to tackle such a project as the "first" map is usually both incomplete and partly incorrect.
-- The urge to correct a thing is much more developed in human nature than the impetus to create something new oneself. The existence of an incomplete and incorrect tentative map should stimulate hydrogeological research, provoke corrections and lead finally to an improved edition which will hopefully be worth printing.

The completed map will contain and present information which will be useful in planning exercises. Nearly all developmental schemes or projects need water resources. Often in Fiji, project design and construction are based purely on the availability of surface water supply. Groundwater is rarely considered as an option by the planners, often due to the absence of information. The presence of hydrogeological maps would hopefully present groundwater as a viable option to be considered in certain areas.

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POSITION PAPER, SOLOMON ISLANDS

Steve Booth

ABSTRACT

Water resource assessment in the Solomon Islands has been confined to meeting the immediate needs of small scale demand. Progress in water resources assessment and development has been limited by a shortage of professional expertise, in 1983 this shortcoming was alleviated by the secondment from New Zealand of a Water Resources Officer.

Approximately 66 % of the Solomon Islands have now been geologically surveyed at the 1 : 50 000 scale and 1 : 50 000 scale topographic maps are available for the whole country.

The Solomon Islands Geological Survey is interested in the methods other ESCAP countries employ to acquire and present their hydrogeological information and is particularly interested in assessing the usefulness of hydrogeological maps in an island(s) context.

INTRODUCTION

The population of the Solomon Islands numbers about 214 000 and is mainly rural. The 1976 cencus recorded that less than 10 % of the population lived in the capital Honiara or one of the Provincial Centres. Until recently the relatively low population density (7.5 people/km² in 1980) and the dispersed nature of the village settlements together with a generally high but variable rainfall (with average of 3000 - 5000 mm) has meant that serious water shortages have been infrequent.

Relatively small projects such as village-scale water supply schemes have been implemented with only a modicum of water resource information.

However, projects which depend on the availability of large flows or which place costly investments at risk of flood or drought require more water resource information than is generally available.

The rate of increase of population (forecast as doubled by the year 2000) combined with a general move from isolated settlements to larger villages and the increasing demand from the Honiara urban development and by large scale commercial agriculture has indicated a National need for water resource information for future planning.

There is a serious shortage of professional skills in the area of hydrogeology and water resource assessment; in 1983 this shortcoming was alleviated by the secondment from New Zealand of a Water Resources Officer. It is hoped that this meeting will provide some guidance on the acquisition, presentation and usefulness of hydrogeological map information which will aid the formulation of the Solomon Islands Geological Survey's future policy on water resource assessment.

GEOGRAPHICAL SETTING

The Solomon Islands lie some 2000 km north-east of Australia. They form a double en echelon island chain whose axis trends at about 45° south of east; extending across some 1200 km from Buka-Bougainville in the north-west to beyond San Cristobal to the Santa Cruz Islands in the south-east, between the latitudes of 6°35'S and 11°50'S, longitudes 155°30'E and 162°20'E.

Politically the Solomon Islands also include Ontong Java and Stewart Islands to the north, and the uplifted atolls of Rennell and Bellona to the south. The archipelago (with a total landmass of 27 750 km^2) comprises six major islands or island groups (namely Choisel, Santa Isabel, Malaita, New Georgia, Guadalcanal, and San Cristobal) and a multitude of small islands, atolls, sandcays, and fringing reefs.

Solomon Islands gained independence in 1978 and is now a member of the Commonwealth.

GEOLOGICAL SETTING

The Solomon Islands form part of a complex of Melanesian island arcs and marginal basins. The absence of allochthonous continental material indicates that the islands have evolved in an entirely oceanic environment and for much of its' history has developed through a complex interaction between the Australian and Pacific plates. The Solomon Islands arc is characterised by intense seismicity along the north-western and south-eastern

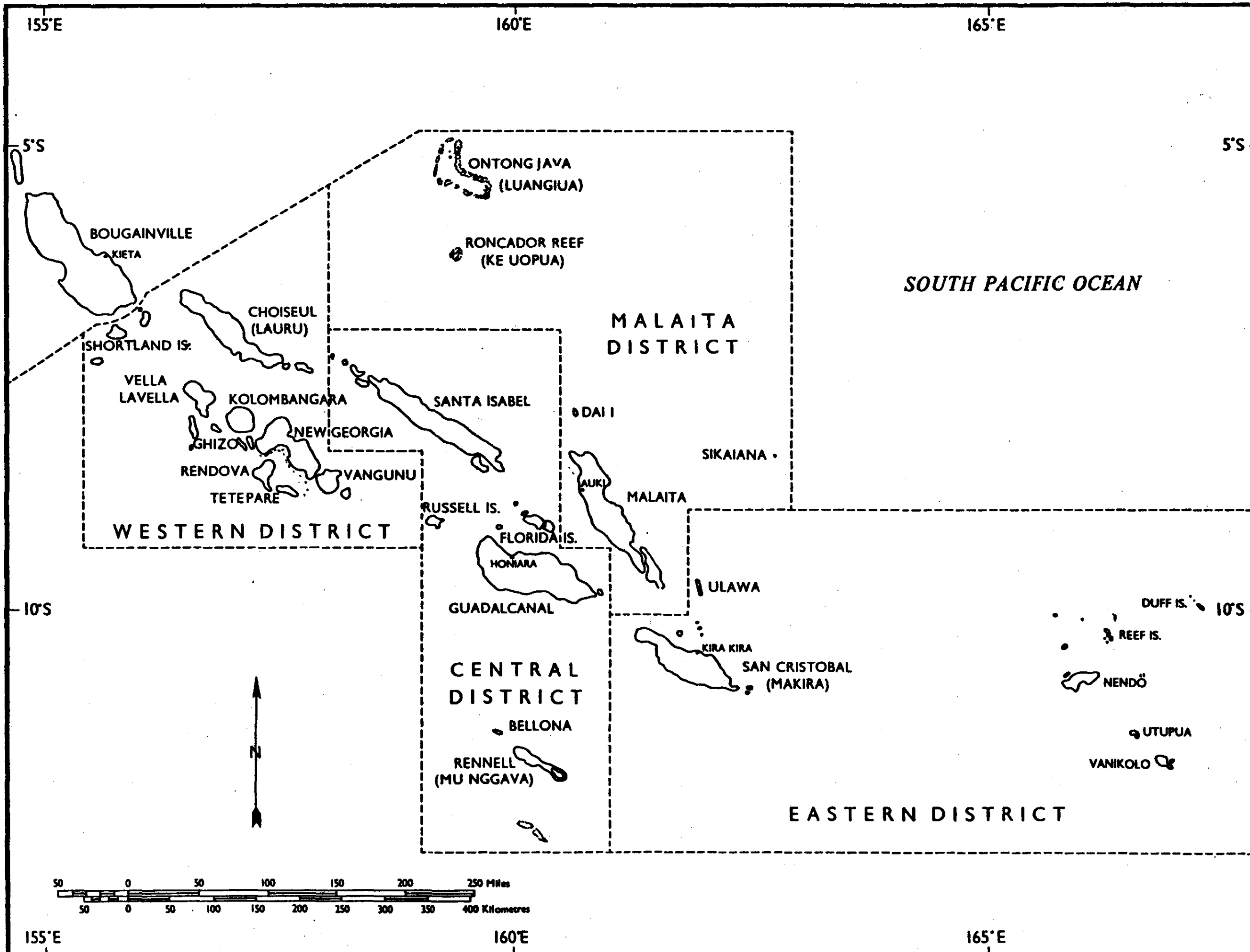

Figure 1. Map of Solomon Islands

parts of the arc which is an important consideration for any major water management construction.

Coleman (1965) subdivided the Solomon Islands arc into three Geological Provinces (Figure 2).

Within the Central Province (Choisel, south-western side of Santa Isabel, Florida Islands, Guadalcanal, and San Cristobal), the islands are characterised by intensely faulted cores of pre-Miocene basic lavas and associated gabbros and dolerites in part metamorphosed to a low grade (greenschist or amphibolite facies). Bodies of serpentinised ultra basic rocks are widespread within the 'basement'. These are overlain by a varied sedimentary succession ranging in thickness from 5 km in east-central Guadalcanal to less than 700 m on San Cristobal. The sediments include biogenic limestones, calcarenites, and arenaceous and volcaniclastic material ranging in age from lower Miocene to Holocene. In general, the sedimentary rocks display shallow dips, extensive block faulting and gentle 'drape' folds, the latter usually reflecting underlying basement structures.

The Pacific Province includes the whole of Malaita, Ulawa and the north-eastern flanks of Santa Isabel. This province also has a basement of oceanic basalt, but it is not metamorphosed. The overlying sediments include about 1200 m of chalky pelagic carbonates which, in contrast to the Central Province, range in age from Cretaceous to Holocene.

The Volcanic Province which forms the south-western flank of the arc, includes the islands of the New Georgia Group and extends northwards to include certain volcanics on Choisel and eastwards to include the Russell islands, north-west Guadalcanal and Savo. The Province, which is typified by the New Georgia Group, forms a series of emergent volcanic islands and lava piles of sub-alkaline basalts and lesser andesites surrounded by fringing and off-shore reef which provides the framework for the accumulation of sediments ranging form volcaniclastic to biogenic origin. In total, there are nearly thirty well-preserved volcanic centres and two active or quiescent volcanoes, notably the submarine volcano of Kavachi south-west of New Georgia.

In addition to the three main Provinces, there is the Atoll Province (Coulson, 1983) which includes Lord Howe and Sikaina Islands on the Ontong Java Plateau to the north of the main island chain, whilst to the south the uplifted atolls of Rennell and Bellona lie on a sinuous ridge that links New Caledonia with Papua New Guinea.

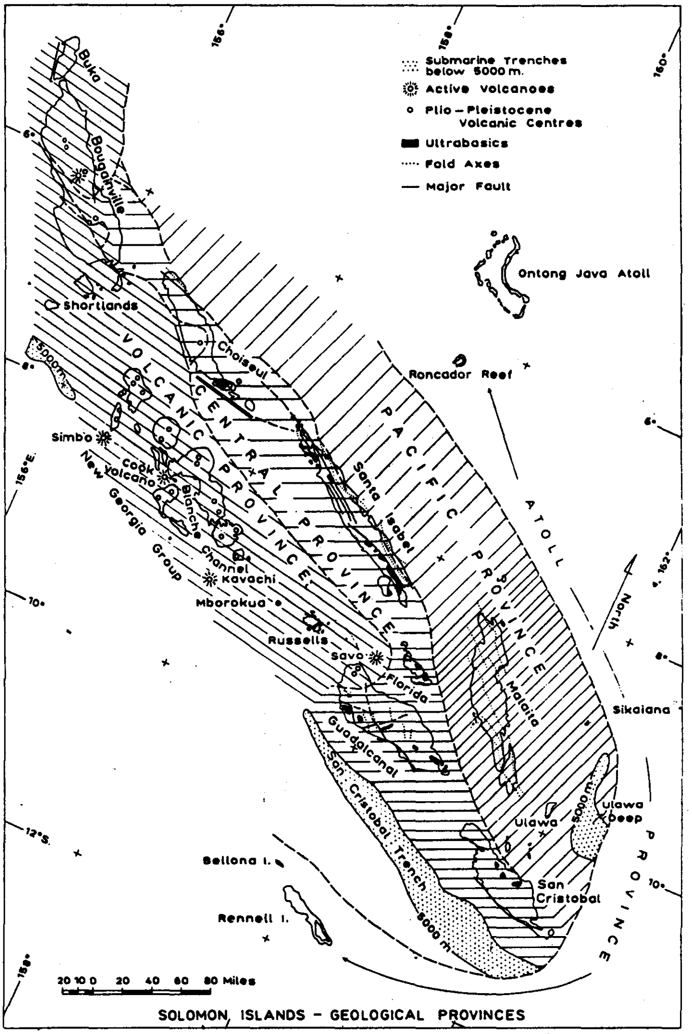

Fig. 2 Geological Provinces in the Solomons area. The Atoll Province (see text) is a geographical expression.

THE GEOLOGICAL SURVEY: PRESENT STATE OF MAPPING

Topographic maps at the 1 : 50 000 scale are available for the whole country whilst approximately 66 % of the Protectorate has now been geologically surveyed at the 1 : 50 000 scale with maps generally published at 1 : 100 000, 1 : 150 000, 1 : 200 000, and 1 : 250 000 scales (Figure 3).

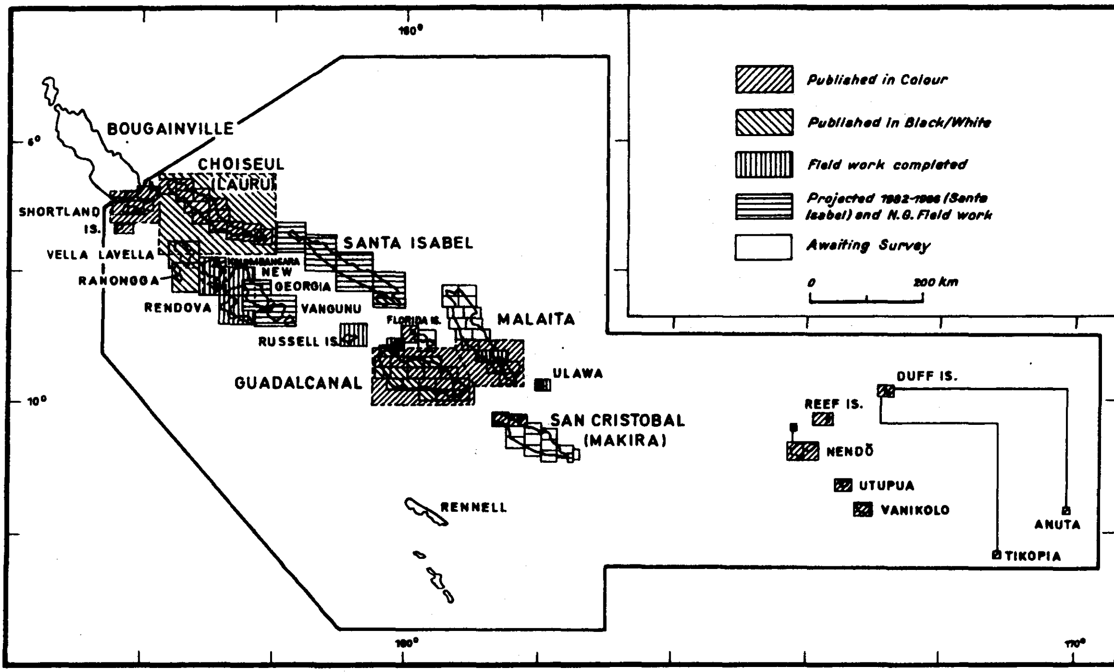

Fig. 3. Index of Geological Maps in Solomon Islands to 1982.

Prior to the establisment of the Geological Survey in 1950 by J.C. Grover, the Solomon Islands were geologically speaking relatively unexplored. The earliest scientific report was made by Guppy (1887) entitled "The Solomon Islands: their geology, general features and suitability for colonisation".

The survey initiated a programme of reconnaissance geological mapping at a scale of 1 : 200 000 carried out as a collaborative effort between the University of Sydney and the Geological Survey. In 1962, this early work was compiled into the first geological map of the Solomon Islands.

In 1963, following the provision of accurate 1 : 50 000 scale topographic maps, a regional 1 : 50 000 scale geological mapping programme was started. Regional mapping continued during the period 1963 - 1975 although progress was fairly slow.

From 1976, the regional mapping programme was considerably accelerated by the introduction of a British Technical Cooperation Project with Senior staff supplied by the Institute of Geological Sciences, U.K.

HYDROGEOLOGY

Water resource assessment in the Solomon Islands has been confined to meeting the immediate needs of small scale demand.

For some years, a Hydrology Section of the Geological Survey has monitored river levels and flows principally at sites where hydroelectric development has been proposed -- this data will be augmented by information from a proposed National network of river gauging stations.

Collection of hydrogeological data has been complicated by the fact that well drilling equipment and staff have operated as part of another Ministry. Attempts by the Survey to maintain adequate borehole records and to provide some expert supervision during drilling operations have been hampered by poor coordination between the two Ministries.

From 1984 it is planned to transfer control of the drilling operations to the Geological Survey which should result in substantial improvements in the recording of hydrogeological data. In addition, the survey has recently acquired some resistivity equipment which will provide information quickly and cheaply where the geological structures are simple and the resistivity contrasts well marked.

CONCLUSION

Many of the water resource development problems in the Solomon Islands are common to all developing small countries.

Water supplies are presently mostly tapped from spring sources or impounded surface water. In 1978, only 24 % of the rural population was served by safe water supplies (Minister of Health and Medical Services, 1982). By 1981 this had been increased to approximately 45 % -- the Solomon Island Rural Water Supply and Sanitation Project aims to provide all the population with safe water by 1990.

Many sites have been considered for hydroelectric development. In particular, the Lungga River, Guadalcanal, has been the subject of a detailed study -- a three stage development with an initial output of 5 MW growing to 20 MW by the year 2000 has been planned (Preece, Cardew and Rider, 1977).

Proposals to develop a major port and industry (including a fish cannery) at Noro, New Georgia, has caused concern about the adequacy of water supplies. A series of studies has indicated that locally derived groundwater could only supply 40 % of the short term requirements (Buckley, 1981).

An adequate knowledge of the available water resources of a region is recognised as a prerequisite to wise planning and successful management of these resources as is the adequate coverage of the area by suitable topographic and geological maps.

The Solomon Islands Geological Survey hopes that the experience gained by other ESCAP countries in producing hydrogeological maps and the use to which the information has been put will aid at the planning stage the Survey's approach to the assessment of National Water Resources.

REMARK: The views expressed in this paper are those of the author and do not necessarily represent the official Solomon Island Government policy.

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Hydrogeological Mapping in Asia and the Pacific Region
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REPORT FOR THE KINGDOM OF TONGA

David R. Tappin

The Kingdom of Tonga is located about 1000 kilometers north of New Zealand in the Southwest Pacific Ocean, with most of the islands lying between the latitudes of 19° and 21° south. There are three inhabited groups of islands; in the south, Tongatapu-Eua; centrally, the Ha'api-Nomuka group; in the west, Vava'u. The population is 100 000 of which 60 000 are concentrated on the largest island in the Kingdom, Tongatapu. At the present time, Tonga is experiencing rural depopulation, resulting in an increasing concentration of the population in the capital Nuku'alofa on Tongatapu. This, together with an increasing demand for water, from planned agricultural schemes, is placing an increasing demand upon the water resources of the Kingdom.

Geologically the islands have been fairly well studied, mostly over the last two decades. Numerous researchers from all disciplines of the science have passed through, with most results being published in scientific journals, although oil company interest has given the Kingdom its first rudimentary geological maps.

The inhabited islands are for the most part uplifted Pleistocene coral limestone blocks on the edge of the Tonga Trench. They are, with the exception of Eua, flat-lying, elevations are low (on Tongatapu up to 65 m, Ha'api-Nomuka up to 20 m and Vava'u up to 100 m). On Eua the geology is more complex, the island being composed of a series of Pleistocene to Oligocene reef limestones on an Eocene volcanic basement. It is unique amongst the group in that elevations on the east side of the island reach 300 m.

For the most part the vegetation consists of coconut plantations and scrub, the only natural forest remaining on Eua and Vava'u.

On the flat lying limestone islands, there is no surface water. Water is mostly from wells and carried by pipeline, this is supplemented by rainwater roof catchment operated on an individual basis. Piped water is metered and costed accordingly. The only hydrogeological study has been carried out on Tongatapu (Hunt, 1978). This study, using data from 40 wells, identified a fresh water lens up to 20 m thick. A high chloride content of the water was ascribed to upward diffusion from the underlying salt water layer. Out of an average rainfall of 1700 mm p.a., it is estimated that 25 % percolates through to the fresh water aquifer.

On the other limestone islands, it is assumed that there exists a simple fresh water lens, probably on Vava'u thicker than that on Tongatapu. The lenses or the low lying islands of the Ha'api-Nomuka group are very thin as has been proved where overpumping has resulted in salt water intrusion and contamination of the wells.

Only on Eua is there surface water and this provides the source for consumption. Supplies here are intermittent, at one time the recently constructed saw mill had to shut down during a water shortage.

Due to the present and planned situation within the Kingdom, the pressure on the water resource will only increase. At the present time it is planned to drill additional wells on Tongatapu. It is within this paradigm that Tonga's requirement for further hydrogeological investigation is of the utmost importance. At present a geological mapping programme is about to be implemented, associated with this it is proposed to gather hydrogeological information. At a future time it may well be necessary to receive advice from a hydrogeological expert on aspects of exploitation, planning and management of groundwater resources.

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HYDROGEOLOGICAL DEVELOPMENT IN VANUATU

Richard J. Marks

ABSTRACT

Vanuatu gained its independence in 1980. At present, the country relies heavily on aid. One of the greatest priorities in development is the construction of rural water supplies. These village water-supply schemes rely heavily on surface water sources. However, groundwater is becoming increasingly important as new government establishments are built and agriculture, industry and tourism expand. Most of the more advantageous areas for development are situated on the coastal platform, which is often formed of reef limestone. Such areas typically lack surface water, while groundwater is often plentiful and easily accessible.

The islands have been mapped geologically, and this, together with other related data, would form the basis for a hydrogeological mapping programme. The work is necessary to aid the development and protection of groundwater resources in this current phase of development. Unfortunately, due to restricted funds this work is unlikely to commence unless it is supported by financial aid.

1. GENERAL BACKGROUND

The Republic of Vanuatu is situated in the Southwest Pacific, 1700 km northeast of Australia. Vanuatu forms a N-S chain of some eighty islands extending over 800 km between latitudes 13° and 22° south of the equator (Fig. 1). The islands were formerly known as the New Hebrides, a Condominium jointly administered by France and the United Kingdom, and gained their independence in July 1980. The country has a total land area of 14 763 km², more than half of which is accounted for by the larger islands of Espiritu Santo, Malekula, Erromango and Efate. The islands are generally mountainous with a tropical-oceanic climate and marked seasons. A wet summer lasts from November to April, and a drier winter under the influence of the southeast trade winds from May to October. The mean annual rainfall varies from 4100 mm on Vanua Lava in the north to 1600 mm on Tanna in the south. The average temperature in Vila ranges from 26 °C in the summer to 23 °C in the winter.

The population of approximately 130 000 is predominantly Melanesian, about 17 000 of whom live in Port Vila on the island of Efate, the administrative and industrial capital. The only other town is Luganville with a population of 6000 on the island of Santo. However, of the total population, 80 % live in rural communities scattered throughout the islands. These people are basically self-sufficient, subsisting on a largely vegetarian diet with very low income. The total figures show a low population density, but the overall growth-rate of 3.2 % is above the world average. The economy is largely dependent on the export of copra, although fish, meat and cocoa are of increasing importance. Tourism has been promoted in the last few years and is responsible for the rapid development of Vila. Nevertheless, the country is largely dependent on aid, although it looks to development particularly in agriculture to achieve a more self-sufficient economy.

Piped water supplies to houses have been constructed in Vila and Luganville and in the government stations of Lakatoro and Norsup on Malekula and Isangel on Tanna. All of these supplies are based on groundwater abstraction. Water supplies to the villages are less sophisticated and are largely based on roof catchment and gravity supplies. A large amount of aid is being supplied to give all communities a water supply by 1990 in line with the United Nations' Decade of Water Supply and Sanitation.

2. GEOLOGY

The Vanuatu archipelago is part of a narrow chain of island-arc volcanicity associated with the Pacific and Australian plate margins, which extend through the Solomon Islands to the north and Fiji to the east. The Vanuatu sector is a partly emerged ridge, underlain by the easterly dipping Benioff Zone and bordered by the New Hebrides Trench to the west. These volcanic islands range in age from Upper Oligocene to Holocene and have been divided into four provinces based on age and composition (Carney and Macfarlane, 1982). From oldest to youngest these are: the western province (Upper Oligocene to Middle Miocene), eastern province (Upper Miocene to Lower Pliocene), marginal province (Pliocene to Lower Pleistocene) and the central chain (Upper Pliocene to the present).

The western province is made up of Santo, Malekula and the Torres Islands. They are formed of submarine lavas and derived volcaniclastics and capped by reef limestone. The islands of Maewo and Pentecost form the eastern province, which is composed of terrigenous sediments and volcaniclastics overlain by submarine basic lavas. This sequence is also capped by exten-

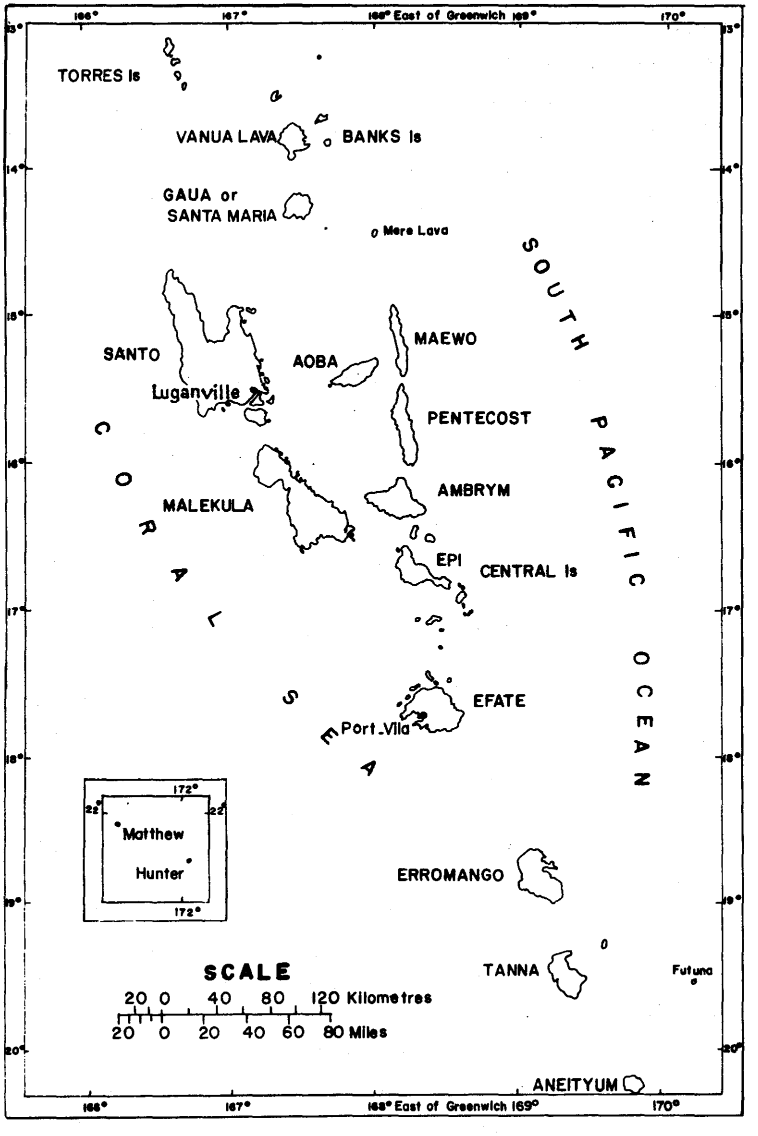

Fig. 1. Vanuatu. Situation Map.

sive areas of reef limestone. The marginal province is represented by the island of Futuna, which is made up of basic lavas overlain by reef limestone. The present volcanic line, the central chain, is essentially a continuation of marginal province volcanism into Recent times. The central chain includes all the remaining islands from Matthew and Hunter in the south to the Banks Islands in the north. These are largely formed of subaerial volcanics, pyroclastics and lavas and include the currently active volcanoes. In these islands the raised reef limestone is generally absent apart from a narrow coastal formation found on some islands. Efate, however, is exceptional and has a 60 % cover of limestone.

3. HYDROGEOLOGY

The main aquifer in the archipelago comprises the raised reef limestone and the alluvial sands and gravels. The volcanic rocks vary greatly depending on composition, but at best form poor aquifers.

In general, most of the population lives in coastal areas, which are often underlain by raised reef limestone. Such areas are relatively easy to develop due to the characteristic raised reef terrace features. Due to the highly porous, open structure of this formation, it generally lacks surface water resources. However, while being a good aquifer the limestones are easily polluted by effluent and salt water intrusion due to overpumping. Many villages have constructed dug wells at the back of the beach because of the ease of construction, but these are typically rather brackish due to mixing caused by tidal action. The limestone aquifer is found in a number of hydrogeological environments. The most common is typically found adjacent to the shore where the limestone extends below sea level. Due to the open nature of this formation the groundwater hydraulic gradient is very low, and as a result the fresh water lense is relatively thin. However, it is possible to produce large quantities of water from this hydrogeological environment. Luganville has a well-designed water supply drawing water from this aquifer. The east coast of Santo is formed of well-developed limestone terraces,which rise to elevations of 60 m - 100 m a.s.l. within a kilometre of the shore. Although the wells in this area are deep, since the water table is usually only a few metres above sea level even at a distance of several kilometres inland, many plantations have been developed here. In the vicinity of Vila the limestone seldom reaches 40 m in thickness. In many of the surrounding areas the limestone-tuff interface occurs above sea level, giving rise to relatively rapid drainage of the aquifer. As a result, many test boreholes are dry, due to the undulating nature of the limestone-tuff contact. It has also caused difficulties during the current drought, with many wells running dry.

Alluvial sands and gravels generally form more reliable aquifers, particularly where they receive recharge from areas of limestone. The alluvial deposits tend to act as a reservoir and thus represent a more constant resource, at the same time as offering greater filtration properties. The Vila water supply is drawn from this hydrogeological environment on the Mele Plain adjacent to the reef limestone contact and is now producing about 6000 m^3/d. The alluvial plains have mostly been extensively developed for plantations due to their flat-lying topography, fertile soils and availability of both surface and groundwater supplies.

We have limited experience with groundwater in the volcanic rocks. The tuffs and pumice formations, while acting as an aquiclude for overlying limestones in the Vila areas, also act as a poor aquifer. Although the supply is restricted, it can be maximised by use of a dug well with galleries. The lavas are completely impermeable, although small supplies can be collected from joints where no other supply is available.

4. PREPARATIONS FOR HYDROGEOLOGICAL MAPPING

A programme of Hydrogeological Mapping has yet to be established in Vanuatu, though a wealth of data has been amassed that will greatly aid this work. The islands have been covered by aerial photography in both 1962 and 1972, and a third coverage is due in 1984. With the aid of this material the islands have been mapped at 1 : 50 000 with the latest revision in the late 1970s. A programme of geological mapping at 1 : 50 000 is now complete, with all of the eleven 1 : 100 000 sheets published along with accompanying regional reports. This detailed work would form a sound base for hydrogeological mapping.

Soil maps of the islands are now also published at 1 : 100 000 with accompanying reports.

Drilling for groundwater on the main islands with percussion rigs has been carried out in a simplistic manner since the mid 1970s. The earliest drilling dates back to 1962, when the Vila groundwater supply was extended under contract. This, and later work on the Vila supply has included assessment of the resource by accurate pump tests with test bores and chemical analysis (Wilton & Bell, 1968). A data bank of borehole logs is available for most of the drillings, but, unfortunately, some wells have gone unrecorded.

A series of meteorological stations has been established throughout the islands, particularly associated with airfields. These collect data on rainfall, temperature and winds. Some stations have data back to 1948, but most have more limited information, which is often incomplete. Since 1982, the hydrology of five rivers, the Teouma and Colle on Efate, the Sarakata and Jordan on Santo and the Brenwe on Malekula, have been studied with the view to generating power. Data on river flow and rainfall has been collected for these drainage basins. Geothermal springs and geothermal areas have been studied in detail on Efate, again with a view to power generation (Carney, 1982). During a recent visit, the Senior Hydrogeologist of ESCAP studied the Vila water supply with a view to protecting the groundwater resource and assessing its potential development (Grimmelmann, 1983). His report makes recommendations on the monitoring of the resource at the same time as suggesting increased staffing and training in electrical resistivity surveying.

A considerable amount of hydrogeological and related data exists in Vanuatu. Nevertheless, at present there is neither the trained staff, equipment nor funds to be able to commence a programme of hydrogeological mapping. There is now a considerable backlog of groundwater projects at government and agricultural establishments, schools and village communities to be carried out using government drilling equipment. The increased development since Independence illustrates the need to commence a regional study on which to base development plans. However, this is unlikely to go ahead unless financial aid is made available.

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Hydrogeological Mapping in Asia and the Pacific Region
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STATUS REPORT, DEMOCRATIC REPUBLIC OF AFGHANISTAN

Nassir A. Formoli

The Democratic Republic of Afghanistan is situated in Central Asia sharing boundaries to the north with the U.S.S.R., to the northeast with China and India, to the east and south with Pakistan, and to the west with Iran. The country has a population of 15.5 million and a surface area of 647 000 km².

Four-fifths of the country is occupied by mountainous regions, and only one-fifth by flat plains.

GENERAL HYDROGEOLOGICAL FEATURES

The Democratic Republic of Afghanistan is a mountainous country with altitudes of up to 6500 m a.s.l., the lowest plains lying at around 500 m a.s.l.

The very heterogenous hydrogeological conditions prevailing throughout Afghanistan are governed by the exceptionally complex geomorphological, geological and tectonic structure of the country. Geologically, all formations are represented from the Archaean to the Quaternary; also represented are all kinds of sedimentary, igneous and metamorphic rocks, all tectonic structures from platforms to the most complex folding and dislocation.

Add to this the diverse morphological and climatic conditions, then it is certainly no simple task to find a common denominator for a uniform hydrogeological classification of the territory of Afghanistan.

Groundwater can be found in various formations -- unconsolidated-porous and consolidated-fissured. For practical purposes, however, such as supplying water for the population, irrigation and for industry, only fresh water which can be found at exploitable depths (for Afghanistan at around 200 m) is of interest. There are also mineral waters to be found with varying degrees of mineralisation, ranging from a low total dissolved solids content of 100 ppm to an extremely high total dissolved solids content of 10 000 ppm.

HYDROGEOLOGICAL MAPPING

The Democratic Republic of Afghanistan is as yet at a preliminary stage in hydrogeological mapping. But since Afghanistan is a partly arid and partly semi-arid country and has only 2-4 months precipitation annually, following the revolution in 1979 the Government has devoted much attention to the problems of groundwater-resources development, hydrogeology and, especially, hydrogeological mapping.

A hydrogeological map of the whole country at a scale of 1 : 1 000 000 has been completed; in addition, some maps of special regions have been produced at the scale of 1 : 500 000 but these maps are not in great detail and serve as preliminary maps for the areas. In some of the provincial centres, the hydrogeological maps have been completed at the scale of 1 : 25 000 with rather more detail.

For the compilation of these maps we make use of hydrological data and maps, logs from dug pits, boreholes and deep exploration wells for investigating hydrogeological parameters, analyses of water samples, geophysical investigations and data from inventories of the area.

The hydrogeological map of the Kabul area shows:

a. Hydrological networks (rivers, canals, swamps, dams, springs, etc.);
b. depth of water table in different places;
c. site, number, depth and diameter of all deep wells and exploration boreholes;
d. all hydrogeological parameters of water-bearing formations;
e. chemical composition of water;
f. direction of groundwater flow;
g. geological section to the depth of 200 m.

I hope that this review of the situation in the Democratic Republic of Afghanistan will explain why our country still has far to progress in the field of hydrogeological mapping and why we would welcome the support of both ESCAP and UNESCO in tackling this problem and other problems arising from the development of groundwater resources.

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WATER-BEARING ZONES IN THE MINING AREA OF THE NORTHERN REGION OF BANGLADESH WITH REGARD TO UTILISATION OF MINE WATER FOR IRRIGATION AND OTHER USES

Muhammad Siddique Ali

ABSTRACT

Two basic economic resources of a developing nation such as Bangladesh are mining and agriculture. Rapid economic development can be achieved if mineral resources are explored and utilised properly and if arable lands are put under widespread and intensive cultivation by providing irrigation facilities in the dry seasons. In the mining sector, the per capita consumption of minerals and mineral products in Bangladesh is one of the lowest in the world. There are few opportunities of finding minerals on the surface. Quite a few minerals of economic value have so far been found in the country, some of which are covered by highly permeable sandstones, sands and gravels. Thus, the high water content in the overburden makes the sinking of mine shafts extremely difficult and expensive. As far as agriculture is concerned, the economy of Bangladesh is mainly agro-based. Agriculture contributes more than 55 % to her total GDP. The contribution of the northern region in this sector to the total GDP is nearly 20 % in terms of current prices. But due to the serious lack of surface water in lean seasons, a process of desertification has set in here. Fortunately, the favourable geological and hydrogeological conditions promise unlimited availability of fresh groundwater in this region. This groundwater, together with mine water as a by-product, can be used in a profitable and planned way in agriculture and for domestic and industrial supply.

1. INTRODUCTION

The northern region of Bangladesh is an alluvial plain with slightly elevated terraces. The region lies roughly between latitudes 24°45' and 26°40' north and longitudes 88°5' and 89°45' east. It slopes gently from north (85 m a.s.l.) to south (20 m a.s.l.) and is bordered by the Jamuna, the Teesta and the Ganges, one of the greatest river systems of the world.

The region has a total area of 8.96 million acres of which 6.44 million acres serve as arable land. This alluvial soil is very fertile. The north-eastern and eastern parts, amounting to 20 % of the total area, are occasionally flooded during the monsoon season (June - October). But during the dry season (November - May), the reduction of rainfall in this region is a matter of grave concern. According to expert opinion, a process of desertification has set in owing to changes in the weather and ecological conditions. This poses a threat to the forest resources and vegetation on the surface of the land. The serious lack of surface water has affected agriculture in the region, and this has, in turn, affected the country's economy, which is overwhelmingly agricultural. We have to import 2 - 2.5 million tons of food grain from abroad every year. This has an unfavourable effect upon our balance of payments, which has increased by 17 % from 1974 - 1975 to 1979 - 1980, and hinders the import of essential equipment and machinery. The development of our agricultural potential depends on the formulation of comprehensive plans for the management, development and for the exploitation of groundwater resources.

Government departments and agencies and consulting companies have been conducting water tests in this region for the past two decades. Considerable work has been carried out by them in the field of groundwater flow and development.

The north of the country has mineral deposits overlain by a thick overburden. The discovery and assessment of rocks and minerals of economic interest in this area are now in progress. Indication of metallic minerals has caused optimism and opened up new horizons in the development of mineral resources in the country. In terms of energy, the Gondwana coal deposit of this region exceeds that of the country's known gas reserve. The mining of the coal is technically feasible. Moreover, a foraminiferal limestone occurs at a relatively shallow depth; it is bedded horizontally, largely unfaulted and is of mineable thickness. The mining, together with a cement plant, can be expected to be a profitable enterprise. But water stored in the youngest and the most recent sediments of fluvial origin and Tertiary formations is the principal factor in the loss of stability of the soft rocks and shales.

The objective of this paper is:

i) to discuss the preparation of a hydrogeological map of the northern part of the country based on available field data and laboratory-test results;

ii) to suggest how to utilise the water from deep mines for irrigation and domestic purposes.

2. MINES AND MINERALS

The minerals so far found in the northern region of Bangladesh are deep seated and covered by a thick overburden. The sedimentary layers overlying the Archaean crystalline basement are 130 - 1200 m thick in the study area. Limestone, bituminous coal, mineralised granodioritic rocks and kaolinite have been located at economically exploitable depths.

The basement complex, consisting of calc-alkaline, igneous and slightly metamorphosed rocks, constitutes the floor of the Bengal basin. The structural units of the basin in the region under study are controlled by the Precambrian platform.

The platform consists of three parts, namely: (i) the Rangpur saddle, (ii) the Ruhea flank and (iii) the Bogra slope. The Rangpur saddle is possibly a connection between the Indian platform and the Shillong massif. It is bounded by N-S trending faults. The depth of the basement measures only 130 m at the Maddhapara Hardrock Mining Project at Dinajpur.

In the shelf area, continental Gondwana sediments were deposited on an uneven surface and in a deep depression in a fluvio-lacustrine environment. Due to a major faulting zone extending south of the Jairpurhat Limestone Mine in an E-W direction, the coal measures (Gondwana sediments) terminate beyond the Jamalganj area.

During the extensive Cretaceous and Paleocene marine transgression the foraminiferal limestones, known as the Sylhet limestones, and associated materials were deposited in shallow, clear water and in a marine environment.

Later, during the orogenic activity of the Miocene-Pliocene, the study area was exposed to erosion and subsidence. The youngest sediments are fluviatile in origin and were deposited after the orogeny.

2.1 Mineral Industries in Operation

2.1.1 Jaipurhat Limestone Mining and Cement Works Projects

Limestone was found over an area of 390 km^2 at depths of 400 - 550 m with an average thickness of 20 m. The reserve amounts to more than 12 billion tons. An area of 13.25 km^2 with a reserve of 100 million tons of limestone has been projected for development to produce 1.7 million tons of limestone per year. A cement plant will produce 1 million tons of portland cement per year.

2.1.2 Jamalganj Coal Mines Project

The coal deposit is 6 km from the Jaipurhat Limestone Mining site and occupies a large area. The deposit consists of seven coal seams of thicknesses varying from 0.69 m to 32.2 m and lies at a depth of 823 - 1037 m below the ground surface. The total reserve of bituminous coal in the mining area of 11.5 km^2 is over 1000 million tons. Further technical study and the provision of funds are prerequisites for the start of work.

2.1.3 Maddhapara Hard Rock Mining Project

Metals and construction stone are in short supply in the country. Calc-alkaline igneous and slightly metamorphosed rocks lie at a depth of 130 m from the surface at Maddhapara. The rocks (diorite-granodiorite-monzonite) are hydrothermally altered and porphyritic in nature, suggesting that there may be a concentration of porphyry copper. Rock in various shapes and sizes will also be supplied at a cheaper rate for the requirements of flood control, town protection, construction of dams, bridges, embankments, roads and motor ways, river channelling, railway ballast, etc. Once started, the project will produce 1.7 million tons per year.

2.2 Mining Problems

Exploitation of the minerals mentioned in the foregoing paragraphs, necessitate underground mining because of their depth. Access to the deposits is to be made by means of twin shafts. The high water content of the unconsolidated sediments renders them less stable and necessitates expensive methods of shaft sinking by freezing the unconsolidated sediments. Water from the working faces requires to be removed by special methods.

3. HYDROLOGY

A hydrological study of the northern region has been established. A considerable amount of work has been done by the Bangladesh Mineral Exploration and Development Corporation (BMEDC), the Bangladesh Water Development Board (BWDB), the Bangladesh Agricultural Development Corporation (BADC), the Geological Survey of Bangladesh (GSB), the Oil and Gas Corporation (Petro-Bangla), Public Health Engineering (PHE), consulting companies, the World Bank, USGS, etc. Hundreds of logs of wells and exploratory boreholes of the region have been analysed, all of which claim an abundance of fresh groundwater in the region.

3.1 Surface Water

Withdrawal of the Ganges water from outside the territory of Bangladesh has caused havoc in the study area. It has adversely affected the agriculture due to lack of surface water for irrigation and also disrupted the ecological balance. However, rainfall has considerably hindered the process of desertification, which is setting in. The precipitation of the last three years is shown in the following table:

Table 1: Rainfall (in mm) in north Bangladesh, 1980 - 1982.

Recording station	1980	1981	1982
Iswardi	1372	1138	893
Rajshahi	1270	1016	584

Whereas in the month of July an average of 500 mm of rainfall was recorded in the study area, this year (1983) measures only 30 mm in the same month. The water level in the Ganges has fallen below the water table. This has affected storage in river-banks as the groundwater drains into the rivers. Consequently, shallow tube-wells in the south and southwest of the study area have become dry, thus affecting agriculture.

3.2 Groundwater Potential

3.2.1 Aquifer Characteristics

In the mining area the strata overlying limestone, coal and hardrock are loose or semi-compact sediments of Tertiary and Quaternary formations, composed of loose sand, gravels, pebbles and sandstone with little or no cementing medium. Most of them are porous, being permeable both vertically and horizontally.

The major lithological units of the study area are the Recent piedmont sands and gravels, often flanked by Pleistocene sediments, the transition being lateral. The piedmont unit consists of medium to coarse sand (90 %) more rarely with fine sand and 10 % clay with occasional gravels. Gravel increases in frequency and in grain-size from south to north. Silts seem to be absent. Different grain sizes occur as follows:

(D50) 0.38 mm -- 10 %
" 0.53 mm -- 40 %
" 0.67 mm -- 50 %

The Pliocene sediment, known as Dupitila, is composed of coarse-grained, friable sandstones, coarse sands and gravels. The thickness of the sediments varies from 45 m to 75 m at a depth of 130 m in the study area. They are highly permeable.

The aquifer may be divided into three types, based on depth, grain size, transmissivity and storage coefficient:

i) Finer, shallow aquifers: these consist predominantly of fine to very fine sand with lenses of clay and silt. Most of the dug wells as well as shallow wells tap water from such water-bearing zones.

ii) Coarser aquifers: such aquifers exist in the piedmont deposit and Pliocene deposit (Dupitila) and consist of gravels, pebbles, cobbles, loose sands and weakly cemented sandstones. Transmissivity as estimated from the irrigation wells in the study area is shown in Table II.

Table II: Transmissivities in coarser aquifers in Bangladesh.

Area	Transmissivity (m^2/s)
1. Piedmont area	2.4×10^{-2}
2. Bogra-Rajshahi (mining area)	3.4×10^{-2}
3. Gangetic flood plane	3.4×10^{-2}
4. Northern Rangpur areas	1.6×10^{-2}
5. Rangpur area	1.9×10^{-2}
6. Bogra-East Sherpur areas	1.3×10^{-2}

Most of the irrigation wells in the area tap water from these water-bearing zones.

iii) Deep aquifers: some major and confined aquifers exist below 400 m to a great depth in the Tertiary sediments. In the Jaipurhat limestone mine three such aquifers exist between 501 and 532 m, 547 and 556 m, and 559 and 563 m in close vicinity of the mining horizons. The permeability is 4.04×10^{-4}.
Table III shows the hydrogeological conditions in the formations.

Table III: Generalised stratigraphic sequence and aquifer characteristics.

Formation	Lithological unit	Depth of aquifer base(m)	Aquifer characteristics Water content	Porosity	Permeability (m/s)
Alluvium (Holocene)	Sandy clay, sand, silt and clay	50	15-35 %	40-50 %	10^{-8}-10^{-2}
Maddhapara Clay (Pleistocene)	Sticky clay		10-15 %	10-15%	
Dupitila (Pliocene)	Sandstone weakly cemented and coarse-grained, pebbly sandstone and pebble beds	100	20-30 %	40-50 %	Horizontal 10^{-2}-10^{-1} Vertical 10^{-2}-10^{-1}
Surma (Lower Miocene to Upper Oligocene)	Sandy shale, claystone, siltstone and mudstone	500	20 %	30-40 %	Hor. 10^{-1}-10^{-2} Ver. 10^{-9}-10^{-4}
Kopili (Eocene)	Calcareous sandstone, loose sand	520	10-25 %	40-45 %	4.02×10^{-4}
Sylhet (Eocene)	Limestone and sandstone	560	10 %	15 %	3×10^{-10}
Tura (Eocene)	Laminated mudstone and sandstone	800-1000	20-25 %	30-55 %	4.04×10^{-5}
Raniganj coal measure (Permian)	Coal seams, sandstones	1000-1200	10 %	15-40 %	6.65×10^{-5}

Precambrian Granitic Gneiss (Depth at Maddhapara -130 m; Jamalganj -800 to -1200 m ; Jaipurhat -630 m

3.2.2 Hydrochemical Conditions

The hydrochemical conditions typical for different depths of groundwater are presented in Table IV.

Table IV: Hydrochemical characteristics.

Probable aquifer depth (m)	:	up to 100	501-531	546-556	558-563
Odour	:	normal	normal	normal	slight sewage smell
pH value	:	7.4	7.3	7.4	9.2
Sp. gr. at 15.5 °C			1.0017	1.0017	1.0020
Freezing point (°C)	:		0.135	0.139	0.165
Dissolved solids (mg/l)	:	72-242	2220	2250	2550
Suspended solids (mg/l)	:		330	390	620
Hardness (temporary) (in terms of $CaCO_3$)	:	37	135	136	73
Excess alkalinity (in terms of $CaCO_3$)	:		95	90	465
Calcium (mg/l)	:	0.5-1.5	46	48	12
Magnesium (mg/l)	:	0.5-1.5	8	8	6
Sodium (mg/l)	:	1-2.5	500	550	800
Potassium (mg/l)	:	-	5	6	4
Iron (mg/l)	:	2.5	4	4	3
Manganese (mg/l)	:		0.4	0.4	0.1
NO_3 (mg/l)	:		0.5	10	5
SO_4 (mg/l)	:	10	10	10	10
Cl (mg/l)	:		600	600	1000
F (mg/l)	:		5	6	5
Degree of salinity	:	fresh water	slightly saline	slightly saline	slightly saline

3.3 Hydrogeological Mapping

On the basis of available data, the study area (Fig. 1) has been divided into 9 groups.

The boundaries of the identified areas (Fig. 2) are liable to modification following more detailed survey, but the general boundaries will remain more or less the same. The criteria for identification of different groups are:

i) Grain-size
ii) Transmissivity (details in Table II).
iii) Specific yield
iv) Depth of water table
v) Fluctuation of water table
vi) Thickness of aquifer
vii) Depth of aquifer
viii) Total dissolved solids content
ix) Recharge conditions

Recharge = Precipitation-(evapotranspiration + soil moisture deficit + runoff).

3.4 Irrigation Using Groundwater

Hydrogeological data suggest that 4.62 million acres of land can be irrigated in a planned way by groundwater without any side-effects, as shown in the following table:

Table V: Irrigation areas (in million acres)

District	Irrigable land	Irrigation coverage by groundwater
Rajshahi	1.70	0.80
Pabna	1.07	0.80
Bogra	0.87	0.86
Rangpur	1.60	1.20
Dinajpur	1.20	0.96
Total:	6.44	4.62

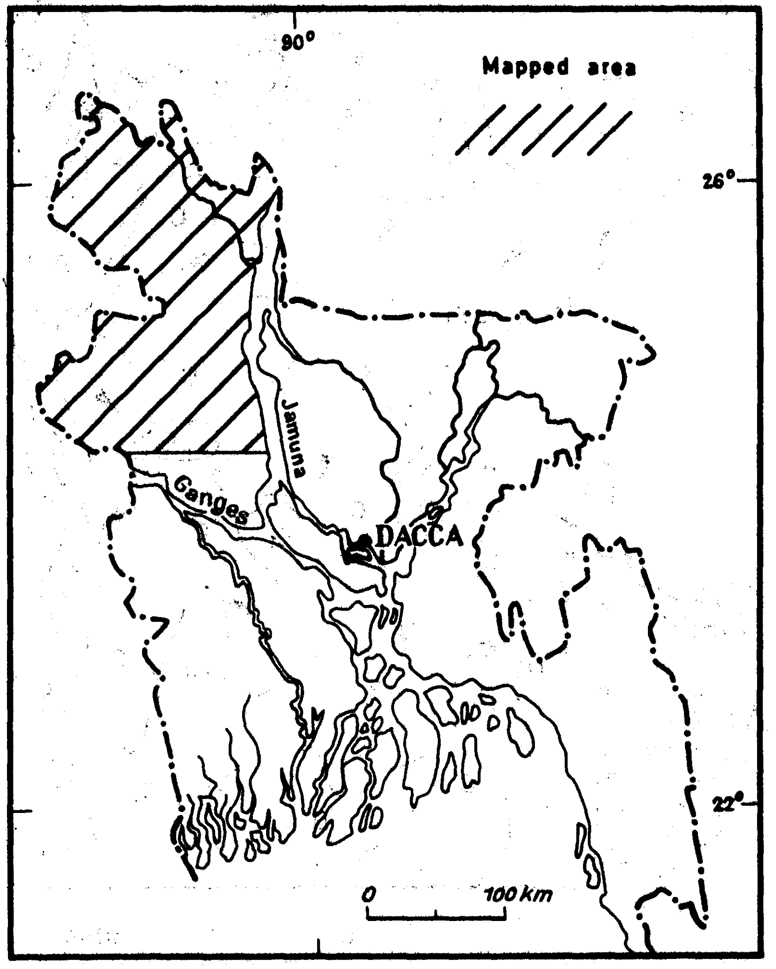
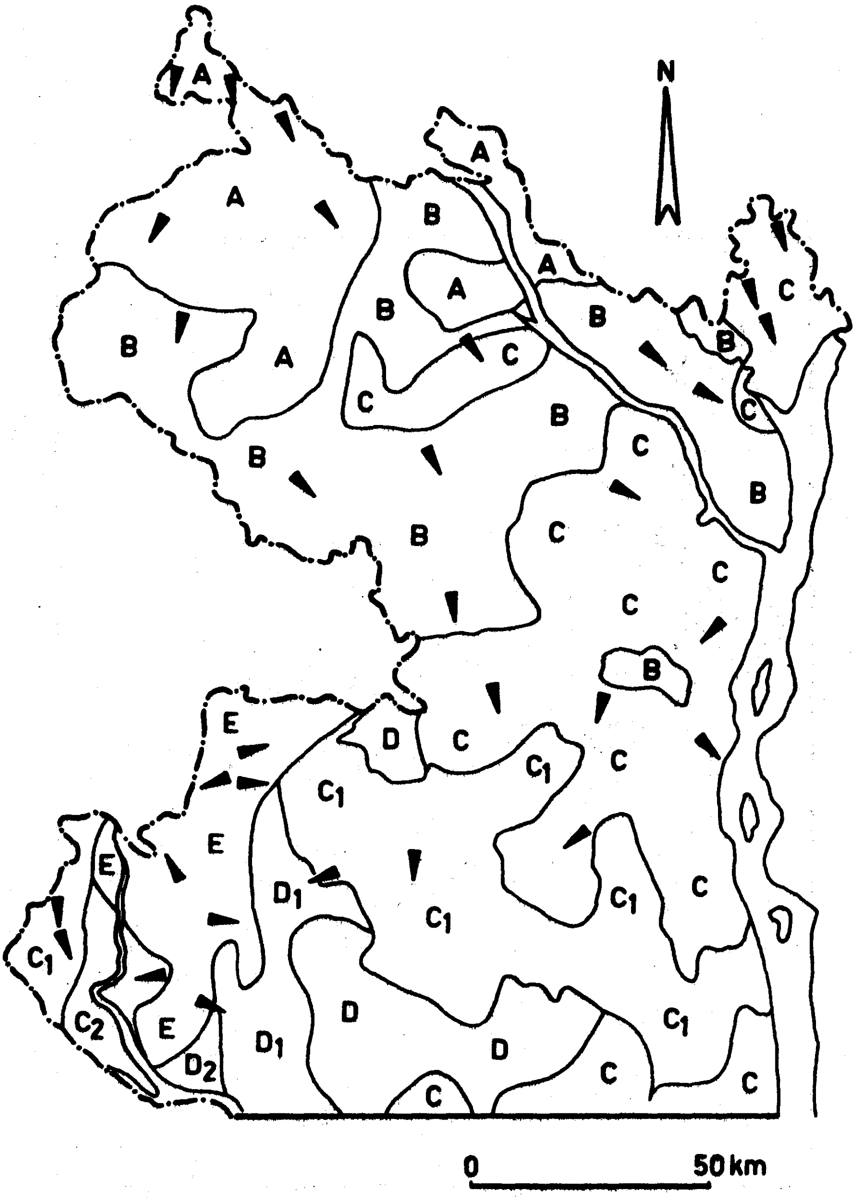


Fig. 1. Map showing the location of the study area



A	Highly good prospective areas
B	Good prospective areas
C - C_2	Moderately good prospective areas
D - D_2	Poor prospective areas
E	Areas unsuitable for groundwater development
▬	Direction of groundwater flow

Fig. 2. Groundwater prospects in the study area

3.5 Groundwater Potential of the Mining Region

The mine openings are subject to water flow. Water has to be removed from the working faces by means of special facilities. The estimated inflow to shafts and working faces in each mine is as follows:

3.5.1 Jaipurhat Limestone Mine

There are few major aquifers in the close vicinity of the mining horizon. The inflow of water into the mine has been ascertained by hydrogeological tests. Under normal conditions, inflow to the shafts and into the workings amounts to 710 l/s and 400 l/s, respectively. In the case of roof and floor collapses this will increase to 1710 l/s. Four pumping units, each with a capacity of 2750 kW, will be installed.

3.5.2 Jamalganj Coal Mine

Inflow into the faces under normal conditions measures 3.5 m^3/min during the first phase of development. The whole total amount of mine water will be pumped from the pump rooms (sump capacity is 6000 m^3) with four pumping units, each with a 2750 kW capacity.

3.5.3 Maddhapara Hard Rock Project

The water-logged sedimentary formations overlying the crystalline basement all over the mining region are unconsolidated beds of coarse sand and gravel. Because of their considerable porosity, permeability is very high.

It is estimated that the dewatering units in the mines can replace 130 - 180 irrigation wells each of two cusec (ft^3/s) capacity.

4. CONCLUSION

The main conclusions are as follows:

i) There are no salinity hazards involved in irrigating with deep groundwater in the study area.

ii) There is no alkalinity hazard even in the heavy clays.

iii) There may be minor corrosion difficulties.

iv) Low pH values in the water from the hot aquifers inside limestones indicate close contact with igneous and metamorphic rocks.

v) The TDS content of the overburden is favourable in using the water for domestic and irrigation needs.

vi) The Mg levels of mine water make its use as drinking water problematic, but the water would pose no problems for irrigation.

vii) In the mining region, 0.6 - 0.8 million acres of land in the Dinajpur-Rangpur-Bogra area can be put under economically viable irrigation.

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HYDROGEOLOGICAL MAPPING IN BRUNEI

Abdul Ghani

1) The Government Survey Department of Negara Brunei Darussalam is the only mapping institution in the country which undertakes cartographic processes in map production. The Mapping Section of this department, which is responsible for topographic map production, consists of:

   i) Photogrammetric Unit with 3 stereo plotters and 6 operators;
   ii) Cartographic Unit with 8 cartographic technicians and
   iii) Reprographic unit with 1 process camera, 2 photographic contact frames, 1 aerial photo rectifier, 1 aerial photo printer and 4 technicians.

   The Photogrammetric Unit supplies manuscripts at scales of 1 : 1000 and 1 : 10 000. These maps are used for the production of topographic maps at scales of 1 : 100 000, 1 : 50 000, 1 : 10 000 and 1 : 1000. The first two series of these are in colour while the other two are in black and white. The colour map process is carried out up to the colour proof stage by the Cartographic Unit with the assistance of the Reprographic Unit. The printing is undertaken by the Printing Department.

2) As yet, the Department has not produced any hydrogeological maps, nor did it have sufficient source material to do so. However, two geological maps, produced by the National Directorate of Mapping, Malaysia, have been in use. They are:

   i) Geological Map of Brunei and adjacent parts of Sarawak, Sheets 1 and 2.
   ii) Geological Map of Brunei.

   These are general geological maps and do not contain specific hydrogeological information. Thus, it would seem that this Department does not possess any experience in the compilation or production of hydrogeological maps. It does not, however, mean that the subject of geology has not reached the attention of the government of Brunei. Extensive geological investigations were carried out in 1957 - 1960 by the

Geological Survey Department, British Territories in Borneo, assisted by the Brunei Shell Petroleum Company Limited. But these investigations were largely aimed at Civil Engineering aspects and mineral resources. At the same time, some work was done on groundwater supplies, details of which appear in a report titled "The Geology and Mineral Resources of Brunei and Adjacent Parts of Sarawak".

3) The most populated areas in Brunei lie along the coast within a strip of about 30 miles from the coast. Despite the high annual rainfall, which varies from 100 to 150 in., water supply schemes are very expensive, because the low-lying coastal areas permit brackish water to extend as much as 20-30 miles up the main rivers, making treatment essential. In order to locate and operate such schemes efficiently and economically, hydrogeological mapping is an urgent requirement which the country will be facing soon. This Department has recognised this fact, and it is expected that the necessary arrangements for this will be made in the near future.

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DEVELOPMENT AND ACHIEVEMENTS OF HYDROGEOLOGICAL MAPPING IN CHINA

Chen Mengxiong and Jiao Shuqin

ABSTRACT

This paper presents a brief outline of regional hydrogeology in China. It reviews the process of development in compiling hydrogeological maps with various aims and scales (including map series or atlases) on the basis of the hydrogeological mapping which has been carried out all over the country in a planned manner following the founding of our People's Republic and explains the important role of these maps in the course of constructing the national economy. The principles and methods of compilation of hydrogeological maps and the major experiences as well as present problems are discussed in this treatise.

1. INTRODUCTION

Since the establishment of new China, great attention has been paid by the government to the investigation and development of groundwater resources. In the 1950s, the Bureau of Hydrogeology and Engineering Geology was set up in the Ministry of Geology. This Bureau is chiefly responsible for the regional hydrogeological mapping throughout the country. An institute was founded at the same time. Hydrogeological teams were set up in the geological bureaus of both provinces and autonomous regions. Since the 1950s, regional hydrogeological mapping, mainly on the scale of 1 : 200 000, has been carried out according to plan under the direction of the Ministry of Geology. So far, a great part of China has been covered by regional surveys, with the exception of the Qing-Zang Plateau, some desert regions and high mountainous regions.

In the last ten years, a great number of hydrogeological maps on separate sheets at the scale of 1 : 200 000 and their accompanying explanatory notes have been published. Hydrogeological maps or atlases have been compiled at various scales for provinces and basins, according to the needs of the national economic construction. At the same time, the Atlas of Hydrogeological Maps of the People's Republic of China was also published.

All of these played an important role in promoting the development of the national economic construction.

2. AN OUTLINE OF REGIONAL HYDROGEOLOGY

China is a country with a vast territory of 9.6 million km². The various regions differ greatly in climate, geology and geomorphology. The whole country not only embraces various climatic zones at different latitudes but also features varied geomorpholgy, ranging from coastal plains to uplands and the Qing-Zang Plateau, the roof of the world. Our country is, therefore, characterized by great complexity of regional hydrogeological settings and by differing hydrogeological characteristics within the various regions.

The Qinling Mountains are located in the centre of the country and ranges in a latitudinal direction. It forms a natural boundary between North and South China and produces the very different geographical conditions which distinguish the two areas. At the same time, the longitudinally oriented, zonal distributions which natural conditions display in eastern China and western China are clearly due to the influence of the Pacific Ocean monsoon.

Geographically, the country is divided into six hydrogeological regions. In the north, from east to west they are: i) the Great East Plain, containing mainly the Songliao Plain and Huang-Huai-Hai Plain; ii) the Inner Mongolia Plateau and Loess Plateau; iii) the western inland basin -- a typical, extremely dry Gobi desert region, mainly consisting of the Hexi Corridor, Zhungeer Basin, Talimu Basin and Chaidamu Basin. In the south, from east to west the hydrogeological regions are: i) the southeastern and southern central uplands; ii) the southwestern karst uplands; iii) the Qing-Zang Plateau.

The chief hydrogeological characteristics of the area to the north of the Qinling Mountains are as follows: i) the wide expanse of the great plain, including the vast piedmont plain with very thick deposits of Quaternary sand and gravel, forms a good and thick aquiferous bed; ii) precipitation in the region of the Great East Plain amounts to almost 800 mm; thus, the groundwater there receives its main recharge by precipitation through vertical percolation. To the west the climate changes to that of a typical inland dry climatic zone, but the piedmont plain is recharged by mountain stream infiltration, therefore it has plenty of groundwater; iii) the Inner Mongolia Plateau and Loess Plateau form the intermediate zone between the semi-humid zone in the east and the dry desert zone in the west and suffer seriously from lack of groundwater due to restrictions imposed by geological conditions; only in some places in the faulted basins, for example in the Guanzhong Plain and the Hetao Plain, is there abundant groundwater; iv) the chemical property of the groundwater is more complicated than that of the south.

The main characteristics of the area to the south of the Qinling Mountains are as follows: i) bedrock is widely exposed and forms hilly uplands, while the area covered by plains is smaller, so that fissure water dominates in this region; ii) the southwest is characterized by widely distributed carbonate rocks, and karst water is the main form of groundwater with well developed subterranean streams; iii) precipitation generally measures between 1000 and 2000 mm, but some places, such as the Mesozoic red bed basins and coastal plains, suffer serious lack of water; iv) the hydrogeological character of the Qinzang Plateau is entirely governed by its altitude, and its groundwater is mainly of the permafrost or glacial genetic type.

The regional hydrogeological surveys, which have been carried out during the last thirty years throughout the country, have clarified the hydrogeological conditions of the above areas, and many different hydrogeological maps have been completed and published. The data and maps provide a scientific basis for the rational development of groundwater resources in our country.

3. DEVELOPMENT DURING THE PAST THIRTY YEARS

In the early fifties, the Bureau of Hydrogeology began to collect data and compiled and published the first hydrogeological map of China at the scale of 1 : 3 000 000 using the geological map of China as a base. In the late fifties, we began hydrogeological mapping at the scale of 1 : 200 000 according to international standards. In order to coordinate working methods, the first standard of regional hydrogeological mapping was published in China. The standard defined various technical norms, mainly relating to observation points in the field, water points, control boreholes, pumping tests, as well as water quality analyses, etc. According to the standard, two surveying groups are expected to complete the compilation of, on average, one international map sheet each year. For ordinary areas every sheet was supposed to have on average 1000 to 3000 m of boreholes. Each surveying team was provided with various drilling rigs, pumping equipment, geophysical apparatus and a laboratory for water quality analyses. In addition to hydrogeological maps, a Quaternary geological map, a geomorphological map, a map of water-table depth and a geohydrochemical map as well as reports were presented as a result of the work.

In North China, the surveying work was conducted first of all in the agricultural areas, for example in the Hubei Plain, the Songliao Plain, the Hetao Plain and the Hexi Plain. In the early sixties, North China suffered a bad drought which lasted several years. In order to overcome the drought, people in many provinces began to dig wells. To assist these efforts, the provincial geological bureaus carried out a lot of hydrogeological prospecting work and made maps at scales of 1 : 50 000 to 1 : 100 000 for agricultural water supply, which provided a scientific basis for the rational arrangement of wells and development of groundwater.

In order to meet the needs of developing agriculture, small-scale maps of large areas were compiled in the early 60s on the basis of reconnaissance surveys, for example the atlas of hydrogeological maps, 1 : 1 000 000 of the Songliao Plain and Huang-Huai-Hai Plain, which includes ordinary hydrogeological maps, maps of water table depth, hydrochemical maps of groundwater, hydrogeological maps for agricultural water supply, maps of Quaternary geology and hydrogeological maps for the amelioration of soil salinity. This is the first atlas of small-scale hydrogeological maps published in our country.

With the cooperation of other units, the Institute of Hydrogeology and Engineering Geology compiled the hydrogeological maps of the arid areas in Northwest China and Inner Mongolia and of the karst area in Southwest China. In addition, the map of phreatic water and the map of artesian water in China were compiled.

In the seventies, our national economy entered a new period of development. In order to meet the needs of the new situtation, hydrogeolocial mapping was stepped up in the whole country. Reconnaissance surveys were carried out everywhere, especially in South China. At the same time, a new standard was made on the basis of the experiences of the past 20 years. The methods of compiling hydrogeological maps were improved considerably. New stipulations were made and a new standardized legend was decided upon. Taking into consideration the complexity of geological conditions in our country, regulations for hydrogeological mapping in specific areas were added to the new standard, including mainly the plains, the coastal, karst and mountainous areas, the loess plateau, and the permafrost areas. This greatly enhanced the quality of the maps.

Regional surveys were completed in most provinces and districts in the seventies. Therefore, many provinces, for example Hebei, Inner Mongolia, Liaoning, Jilin, Jiangsu, Zhenjiang, Yunnan etc., began to compile provincial hydrogeological maps on smaller scales and local maps with descriptive reports for key districts, such as the hydrogeological maps of the Hexi Corridor, southern periphery of Zhungar Basin, Guanzhong Plain, and Sichuan Basin. These maps were much appreciated by the map users (production units).

At the same time, the Institute of Hydrogeology and Engineering Geology, with the help of the provinces, began systematic research work in some dry regions, such as the Heilunggang area in Hebei Province. As a result of this work an evaluation of the groundwater resources was made and various maps, including a map of groundwater resources, were completed. As an aid to the prevention and control of drought, waterlogging and salinization in the Huang-Huai-Hai Plain, a map showing rechargeable resources in shallow aquifers and a hydrogeological map showing areas suitable for artificial groundwater recharge were compiled. The same work was done in the Fengqiou district of Henan Province and in the basin of the Shiyanghe River in Gansu Province.

In the late seventies, the Institute of Hydrogeology and Engineering Geology, in cooperation with the provinces, systematically processed all the data collected since the founding of the People's Republic of China and published in 1979 "The Atlas of Hydrogeological Maps of the People's Republic of China". The atlas has 68 maps in total, including national, regional and provincial maps. This atlas is a reflection of the main results that we have gained in the research of regional hydrogeology over the last 30 years, since the founding of the PRC. The atlas contains a descriptive text, which introduces the regional hydrogeological conditions and groundwater resources of various areas, the recent situtation regarding groundwater development, the existing problems and future prospects. In a word, the published atlas not only has a practical value, but is also an important contribution to the theoretical study of laws governing the formation and distribution of groundwater.

4. A DISCUSSION OF THE PRINCIPLES AND METHODS OF COMPILATION

Hydrogeological maps can, on the whole, be classified under two headings; one being the general hydrogeological map, the other the special map. The present article focuses discussion chiefly on the principles and methods of compilation of the general hydrogeological map, i.e. the regional hydrogeological map. The regional hydrogeological map reflects mainly the regional features and the basic, characteristic distribution of groundwater over large areas. Various hydrogeological elements, such as the water-bearing units, water quantity, water quality and its buried condition, must all be shown on the map. Thus, this kind of map is also called the comprehensive hydrogeological map or national hydrogeological map and can be used widely as a basic map for the national economic programme. For the regional hydrogeological map of our country, the basic scale of 1 : 200 000 has been adopted; only in remote districts or regions where difficult conditions prevail are scales of 1 : 500 000 to 1 : 1 000 000 used. In the 1950s, the hydrogeological map chiefly showed the distribution of water-bearing formations, which were distinguished according to the stratigraphic position, so the map contained more geological factors and fewer hydrogeological elements, and people who are not specialists in this subject will have had some difficulties in understanding it.

Conformity to the principle of simplicity, clarity and practicality, the methods of compilation were improved in the 1960s. Emphasis was placed upon the water storage capacity of water-bearing formations. In the 1970s, on the basis of past experience, with reference to the standardized international legends published by Unesco and at the same time taking into consideration the actual situtation in China, the methods of compilation were further improved, and a new "Legend and Method of Compilation of the Comprehensive Hydrogeological Map" was published.

According to the new methods, groundwater may be divided into five basic types according to the aquifer type, storage conditions and hydrodynamic characteristics; these are: i) pore water in unconsolidated deposits; ii) fissure-pore water in clastic rocks; iii) fissure-cavity water in carbonate formations; iv) fissure water in bedrock; and v) groundwater in permafrost. Having adopted the above-mentioned methods, the geological content was simplified, whereby the hydrogeological elements, such as the aquiferous deposit, storage conditions of groundwater as well as the different exploitation conditions, could be shown better on the map.

The pore water in unconsolidated sediments mainly occurs in the Quaternary aquifers, only very little in the Tertiary rocks. The pre-Cenozoic strata are mostly hard rocks; which contain mainly fissure water. In the Mesozoic red basins, especially the Cretaceous sandstones distributed widely over the country, contain fissure-pore water of good quality under favourable conditions. Thus, it is neccessary to distinguish such types of pore-fissure water from ordinary fissure water. Carbonate rocks, mostly of Palaeozoic age, are widely distributed in China; here, karstification is well developed, often forming subterranean drainage systems in South China with high discharge rates. As a consequence, karst waters must be grouped separately. Permafrost regions are mainly distributed in the Qing-Zang Plateau and the northern part of Heilongjiang Province or in high mountainous areas, where the aquifers usually occur within the frozen layer. It is treated as a special type of groundwater.

Depending on the actual conditions, each type can also be subdivided. For example, groundwater in loess deposits has its own characteristics, and should be treated as a subtype of the unconsolidated type; according to texture and lithological character, karst groundwater is divided into karst water in pure carbonate rocks and karst water in alternations of carbonate and clastic rocks. The fissure water may be controlled by structural patterns, weathering, or basalt cavities. The permafrost water is divided into two subtypes: permafrost water in unconsolidated rocks and in bedrocks.

From the practical point of view, the map should be useful either in agriculture or in water conservancy and should be simple, clear and easy to understand. For this reason, the water storage capacity of the water-bearing rock is emphatically indicated in the maps. In designing the legend, each groundwater type was assigned one or two basic colours, and the different shades of the colours are used to distinguish the degree of water storage capacity. Since the water storage capacity of the pore or pore-fissure water is comparatively stable, the discharges of individual wells are considered representative, enabling the water storage capacity to be divided into 3 to 5 classes. For fissure and cavity waters, the water storage capacity is expressed by the modulus of groundwater flow and the discharge of springs. As regards determining the boundary line between different water storage capacities, apart from considering the specific yield of boreholes and the discharge of springs, the key solution is to study the Quaternary geological structures in detail by means of exploration and field investigation, with special regard to the distribution of present and ancient buried alluvial-proluvial fans, buried channels and ancient coastlines. For this reason we must pay attention to the sedimentary environment. To decide upon zone boundaries reflecting type and degree of water storage capacity in bedrock in mountainous regions, and to determine whether fissure water or karst water is present, all the elements concerned should be studied, such as geomorphology, lithology, geological structure, vegetation, precipitation, etc.

With regard to the hydrogeological map in plains where Quaternary aquifers are distributed, the main difficulty is to distinguish between the water storage capacity of phreatic and that of confined aquifers or multi-aquifer formations. In this case, we attempt to apply the so-called "dualistic method", which is to simplify the situtation by assigning the aquifer system to one of two groups, such as shallow groundwater and deep groundwater, or phreatic water and confined water, and then making use of broad and close hatching to distinguish them. Shallow or phreatic water is shown by widely spaced hatching and deep or confined water by narrow close hatching. The direction of the stripes (horizontal, slanted or vertical) indicates the depth to the top of confined aquifers.

In addition, this method can be used in similar cases, for instance when fresh water overlies saline water, or vice versa, when buried karst water or pore-fissure water appears under a Quaternary aquifer, or in the case of supra-permafrost water and intra-permafrost water, etc.

Based on the total dissolved solids content in groundwater, water quality is divided into fresh water (less than 1 g/l), slightly brackish water (1 to 3 g/l), brackish water (3 to 10 g/l), and saline water (more than 10 g/l). Saline water aquifers are not suitable for exploitation and are shown by grey colour. Brackish and slightly brackish waters, however, are distinguished by different symbols. In most parts of our country, there are too many Fe and F-ions in the groundwater, so water with a high Fe and F content has to be distinguished as such. Other harmful ions or compounds in artificially polluted water must be indicated, too.

All these stipulations are mainly applicable to maps at the scales of 1 : 200 000 to 1 : 500 000. They need to be simplified further for maps at smaller scales. Considering the complexity of regional hydrogeological conditions in China, many special problems are certainly to be encountered and should be solved rationally.

Since the methods described above were established in the 1970s, good results have been achieved, but many problems still remain, calling for further improvement and research, e. g. which method is the most suitable for quantitative evaluation of aquifers: specific discharge of wells, transmissivity or modulus of recharge? What is the best way to indicate a multiaquifer formation, long-term fluctuations of a water table, spatial changes in hydrogeochemical composition and temperature? In order to perfect the method of compilation, it is necessary not only to carry out more practical work but also to gain useful experience both at home and abroad.

5. SIGNIFICANCE OF HYDROGEOLOGICAL MAPPING IN NATIONAL CONSTRUCTION

Because extensive hydrogeological mapping has already been carried out and the groundwater distribution has basically been ascertained since the founding of the state, groundwater resources of our country can now be exploited in a planned way; consequently, hydrogeological maps have played an important role in developing industry, agriculture, and urban construction. In particular, they were of great benefit in developing irrigation agriculture, combatting drought, ensuring stable agricultural yields and raising its output value.

The northern part of our country frequently used to suffer from drought because of the scarcity of rainfall, and the agricultural yield was very low. However, after hydrogeological mapping was carried out in the fifties, it was demonstrated that the main agricultural regions, such as the North China Plain, Song-Liao Plain, Hetao Plain, Hexi Corridor, etc., are rich in groundwater. Since the sixties, irrigation by means of wells has been developed in a planned way as the main method of water conservancy in those regions. According to statistics, the area irrigated by wells in 17 provinces in the north reached 170 million mu (11.3 million ha), and the annual exploitation of groundwater amounted to about 40 000 million m^3; more precisely, the area irrigated by wells in the North China Plain measured 110 million mu (7.3 million ha), which accounts for 61 % of the total effective irrigated area. As a further example, more than 400 000 irrigation wells have been sunk in the Hebei Plain during the last 20 years, its annual exploitation of groundwater lies at around 10 000 million m^3, and its total area irrigated by wells is more than 30 million mu (2 million ha), which constitutes more than one-third of its cultivated area. Because of this, rich harvests were still gathered in the plain despite the many bad droughts.

The Loess Plateau is one of the regions in China which badly lacks water. It has been shown by hydrogeological mapping that loess layers in the Yuan area are, in fact, good aquifers, and at present, groundwater in Yuan areas is being extensively exploited. At the same time, an artesian basin of more than 14 000 km^2 located under the loess cover and consisting mainly of Cretaceous rocks has been discovered through hydrogeological mapping and shows fairly good prospects. All these discoveries have considerable significance in solving the problems of water supply for the local population and livestock as well as in solving a part of the problem of water supply for irrigation.

In the fifties, as a result of thorough investigation in the Peninsula Leizhou, which is one of the areas in the south short of water, the area was found to have a well-structured artesian basin composed mainly of Tertiary and Quaternary formations and abundant in groundwater resources. Since the sixties, irrigation by groundwater has been developed with much energy, so that now the total irrigated area reaches 400 000 mu (6667 ha). The "Red Basin" in Province Sichuan is also one of the areas suffering water shortage in the south. After many years of investigation and hydrogeological mapping, groundwater from the "Red Bed" is being exploited in more than 40 counties, and 680 000 mu (45 333 ha) of farmland are being irrigated. Consequently, the water supply problem of more than 3 million people who lived in the areas of water shortage has been solved; this amounts to 42 % of the total population from areas of water shortage in the province.

Karst waters, including many underground streams with large discharges, are distributed widely in the southwest of the country; for example, 602 underground streams were found within an area of 80 000 km^2 in the northern part of the Province Guizhou with a total discharge of 192 m^3/s in dry season, and 353 underground streams are distributed over an area of 150 000 km^2 in the middle of the Province Guangxi with a total discharge of 158 m^3/s in dry seasons. At present, some of the underground streams are being exploited, but most of them have still been utilized, so there are good prospects for developing groundwater in those regions.

Due to the development of industry and the growth of the urban population, groundwater is year to year becoming increasingly important as an industrial and municipal water supply. According to statistics of 181 large and medium-sized cities throughout the state, 61 cities mainly rely on groundwater for water supply, while 40 cities use groundwater and surface water jointly. In North China, the total daily water consumption of 27 major cities is 7.82 million m^3, of which groundwater accounts for 6.86 million m^3, i.e. 87 % of the total. Annual exploitation of groundwater in Beijing reaches 2500 million m^3 (including water for irrigation), i.e. 60 % of the total water supply of the city. The lower part of the Liao-he Plain in Province Lioaning is a major industrial area in our country. Many important industrial cities, such as Shenyang, Liaoyang, Anshan, etc., are located in this area, and the exploitation of groundwater for industrial purposes reaches 830 million m^3/year. As for other cities, such as Xian, Taiyuan, and Shijiazhuang, the groundwater extraction reaches 1 million m^3/day everywhere. In the south, many large and medium-sized cities have turned to using groundwater because the surface water has already been polluted; for example, the total annual groundwater exploitation in 10 cities of the Province Jiansu, including Nanjing, Changzhou and Xuzhou, now amounts to 450 million m^3.

Only a few examples are mentioned above to show the success in promoting the development of industry and agriculture which has been gained through hydrogeological mapping.

Since the beginning of the eighties, indoor data processing and analysis have been intensified in order to meet better the needs of national construction. In addition to the hydrogeological maps or atlases of hydrogeological maps for provinces and autonomous regions in accordance with their administrative divisions, some special maps for large, interprovincial, natural units are being compiled for specific purposes. For example, hydrogeological maps for agricultural development are being compiled to meet the needs of the programme of agricultural regionalization which is being carried out at present in China; a set of special maps, including a map of groundwater resources evaluation, a map of groundwater salinity, a map of soil amelioration, a map of artificial recharge, etc., are being compiled for the North China Plain as an aid in the desalinization of soils and in the control of drought and waterlogging. In the Shanxi Plateau, in connection with the construction of an energy base, a set of special hydrogeological maps showing water-supply conditions of the planned power stations are being compiled. In the delta plain of the Yangtze River, various special maps are being compiled in connection with problems of municipal water supply, land subsidence, sea water intrusion, groundwater pollution etc. On the Loess Plateau, a systematic study of the Cretaceous artesian basin and the compilation of a set of hydrogeological maps of the basin are in progress. In the vast, remote northern area around Heilongjiang, Inner Mongolia, Gansu, etc., special maps are being compiled to aid in the construction of windbreak forests. In regions along the long coastline, specific hydrogeological maps for developing marine resources are going to be prepared. In northern provinces, various special maps concerning endemic diseases are in preparation on the basis of hydrogeochemical data. In many important cities, sets of hydrogeological maps devoted to environmental problems are being compiled in order to solve various problems of environmental geology. It is obvious from all of the above-mentioned examples that hydrogeological mapping in our country has entered a new historical era.

6. CONCLUSIONS

1. The regional hydrogeological map, known as the national hydrogeological map, is one of the basic data sources for planning the national economy, for industrial and agricultural construction, and for scientific research. It serves a multitude of purposes. Thus, conducting hydrogeological mapping throughout the country in a planned way has considerable significance for the development of the national economy.

2. After hydrogeological mapping at basic scales is completed, various maps at medium and small scales, such as hydrogeological maps of provinces, autonomous regions, cities or basins, can be compiled on the basis of the regional hydrogeological maps in accordance with given requirements. A

more comprehensive atlas of maps or map system can be prepared on the basis of analysis and study. At the same time, special maps for certain purposes can be compiled on the basis of additional investigations directly serving the national construction programme.

3. According to practical experience in our country, the scale of 1 : 200 000 is the most suitable fundamental scale for national hydrogeological maps. But there are still many problems concerning the principles and methods of map compilation which need to be studied further, for example problems relating to the basic content of the map, the precision of mapping, the method of quantitative evaluation of aquifers, as well as the problem of how to express three-dimensional characteristics of aquifers, and how to express groundwater resource values and parameters, etc. To sum up, the question is how to use a hydrogeological map to reflect a groundwater system in a particular region in the most comprehensive way.
All of these problems need to be solved step by step in the future.

4. The natural conditions prevailing in countries in the region of Asia and the Pacific, especially in Asia, have many common features, and the existing hydrogeological problems are similar or the same. But, exchange of scientific knowledge in the filed of hydrogeological mapping has been very limited in the past; therefore, it is necessary to strengthen contacts so that we can learn from each other and exchange experience and information. We think it would be fruitful to take the necessary measures to study some common problems together, to compile international hydrogeological maps of a large area, and further, to compile the hydrogeological map of Asia or the Asian-Pacific Region. We believe that this conference provides a good start for international cooperation in hydrogeological mapping between countries in Asia and the Pacific region.

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GROUNDWATER IN CHINA

Jiao Shuqin

1. PHYSIOGRAPHICAL FEATURES AND GEOLOGICAL SETTINGS AFFECTING THE DISTRIBUTION AND FORMATION OF GROUNDWATER

China lies in the eastern part of Asia, having a vast territory of about 9.6 million km^2.

The general topography of China runs high in the west and low in the east. From the Qinghai-Xizang (Tibet) Plateau in the west to the coastal areas in the east the average altitude decreases from 4000 m (locally over 5000 m) to less than 50 m above sea level. Mountains, hills and plateaus cover about two-thirds of the total territory, while basins and plains make up only one-third. The mountain ranges trend mostly west-east or northeast-southwest. Amongst these, the W-E ranges may be grouped from north to south into three belts, i.e. the Yinshan-Tianshan, the Qinling-Kunlun and the Nanling belts, which form the boundaries between physiographic regions. The NE-SW ranges may be roughly divided into two, i.e. the belt joining the Changbai Mountains, the Liaodong hilly regions and the Wuyi Mountains, and the belt of the Greater Khingan-Taihang-Wushan-Wuling-Xuefeng Mountains, with broad plains lying in between. The latter belt is also the eastern edges of the Nei Monggol (Inner Mongolia), Loess and Yunnan-Guizhou plateaus. Besides, the N-S Helan-Longmen-Daxue Mountains constitute an important dividing line between the eastern and western parts of China. On account of the topography and sharp reliefs, permafrost occurs on plateaus in west China, and vertical zoning of climates appears in places. The annual precipitation in some of the high mountainous areas in the northwest increases abruptly with the rise of altitude, which may reach a maximum of more than 1000 mm. It is an important source of groundwater recharge not only in the mountainous areas but also in the piedmont belts adjoining the interior basins.

Judging from the regional climate, the vast areas to the west and north of the line of the Greater Khingan-Yinshan-Helan-Bayan Kara-Gangdisi Mountains (except the Altai, Tianshan, and Qilian Mountain areas) belong to the arid climatic zone, with mean annual precipitation less than 200 mm. The areas eastwards and southwards from this line to the line of the southeastern Xizang Plateau -- eastern Qinghai -- the southernmost part of Gansu -- southern slope of the Qinling Range -- north of the Huai River -- Shandong Peninsula (except the areas of the Changbai and Greater and Lesser Khingan Mountains in northeast China) belong to the semi-arid and semi-humid climatic zone, the mean annual precipitation ranging from 200 to 800 mm. The vast areas extending further southwards belong to the humid climatic zone, the mean annual precipitation being generally greater than 800 mm, the maximum up to 2000 mm.

With regard to the surface water bodies, the external drainage systems running over a total area about two-thirds of the whole territory of China are mainly distributed in the eastern and southern parts of China, with most rivers flowing eastwards into the Pacific Ocean. Whereas the internal river systems drain the northern and western parts, forming lakes in their lower reaches or depressions or disappearing in the deserts. Rivers and lakes are densely distributed in the areas south of the line of the Qinling Range and the Huai River. They carry a heavy quantity of water and serve as important groundwater recharge sources or discharge outlets in the areas. To the north of the Qinling Rang-Huai River divide, rivers and lakes are sparsely scattered. As the small amount of precipitation is concentrated in summer, the seasonal variations of water volume and water level in these rivers and lakes are considerably great. The mean annual precipitation over the whole country is about 600 mm, or about 600 million m^3.

On the basis of the regional geological and tectonic features and with the Yingshan-Tianshan and Qinling-Kunlun latitudinal structural zones as the boundaries, the whole country can be divided into three major regions, the northern, central and southern regions. These three major regions have respectively gone through different geologic histories; hence they have different geologic features.

As a result of great subsidence and strong Variscan movement in the region north of the Yinshan-Tianshan Mountains, a thick sequence of Paleozoic marine formations was tightly folded and intensely metamorphosed; it is covered by part of Mesozoic alternating marine and continental strata. the Variscan granites and the late Paleozoic volcanic rocks are relatively common, especially in the Greater and Lesser Khingans and Altai Mountains, where granites cover one-fifth or a quarter of the region's total area. In the eastern part of northeast China they occupy two-thirds or so.

In most parts of the region between the Yinshan-Tianshan Mountains and the Qinling-Kunlun Mountains, the crustal movement was relatively moderate in the Paleozoic period. This is mainly marked by: (1) the uplifts and subsidence en masse, (2) the relatively weak magmatic activity, (3) the limited regional metamorphism, (4) the gently folded strata, and (5) the fractures large in size but less in number. About two-thirds of this region is occupied by a series of large- and medium-size Mesozoic and Cenozoic structural basins, in which are distributed Mesozoic, Tertiary and Quaternary sediments in substantial thickness mainly of continental origin. In other parts of the region there are mainly tightly folded and metamorphosed Archean rocks and less tightly folded, essentially unmetamorphosed or slightly metamorphosed rocks of Sinian period and partly of Paleozoic or Mesozoic era.

To the south of the Qinling-Kunlun Mountains is a region which has the longest duration of transgressions since the Sinian period, and marine formations have been developed the best. It is also a region where the orogenic movement has been strong and the compressive folding, faulting and magmatic activity have been relatively intense since the Mesozoic. The structural basins of the Mesozoic and Cenozoic eras are small in extent and also few in number. Quaternary sediments are not developed in large extent.

It is evident that the latitudinal Qinling-Kunlun structural zone plays a dominant role in the regional occurrence and distribution of groundwater.

2. MAIN CHARACTERISTICS OF THE DISTRIBUTION OF GROUNDWATER IN CHINA

The E-W-trending Qinling-Kunlun structural zone separates the whole territory of China into the northern and southern parts either geologically or physiographically bringing about remarkable differences in the distribution of groundwater between the two parts. Therefore, in the sense of regional hydrogeology, the Qinling Mountains may be regarded as decisive regional divide of groundwater distribution. And further, owing to the differences in geological structure, topography, climate and surface water in an east-west direction, the distribution of groundwater, which is different between the southern and northern parts, also varies in an east-west direction. The main differences of the groundwater between the major southern and northern regions are as follows:

2.1 Distribution of Pore Water in Unconsolidated Sediments

Since the Mesozoic and Cenozoic, especially since the Yanshanian Orogeny, a series of structural basins of various sizes have come into being in China and the large- and medium-sized ones are distributed in the vast areas north of the Qinling-Kunlun Mountains. In the eastern part of China are the Song-Liao Plain and the Huang-Huai-Hai Plain which is connected southwards with the Changjiang (Yangtze) Delta. In the northwest are the major interior basins, at the edges of which extend the sloping piedmont plains, while the centres of which are are occupied by deserts. In the middle reaches of the Huanghe (Yellow) River, the distinctive Loess plateau lies between the eastern plains and the interior basins. All the major interior basins are extensively covered by thick sediments, which are very favourable to the concentration and migration of pore water. In the eastern plains, the alluvio-diluvial deposits yield copious and relatively stable quantities of pore water, which up to now has been relatively highly exploited and utilized in China. South of the Qinling-Kunlun Mountains, only thin layers of loose deposits can be found over very small areas in the intramontane basins. In a word, pore water in unconsolidated sediments occurs over large areas to the north rather than to the south of the Qinling-Kunlun Mountains.

2.2 Distribution of Karst Fissure-Cavity Water in Carbonate Rocks

There are appreciable differences in the distribution of karst fissure-cavity water between the areas north and south of the Qinling-Kunlun Mountains. In the northern areas, the karst fissure-cavity water occurs mainly in old carbonate rocks of Cambrian and Ordovician times of the Early Paleozoic. Most of the rocks are solidified or dolomitized, but karstified to a lower degree. Generally, karst features are not conspicuous on the surface, and big springs or spring groups gush out only in the places where buried karst is relatively developed. In the southern areas, karst fissure-cavity water occurs abundantly in the Upper Paleozoic and Lower Mesozoic carbonate rocks. These rocks are younger in age, pure in carbonate composition and rather intensely karstified, resulting in a series of underground rivers and huge solution caves, and also typical karst landscapes as such in southwest China. So it is quite natural that karst fissure-cavity water is dominant over larger areas to the south of the mountains.

2.3 Variations in the Quality of Shallow Groundwater

The quality of shallow groundwater (unconfined or slightly confined groundwater at shallow depths) to the north of the Qinling-Kunlun divide is entirely different from that to the south. Groundwater at shallower depths tends to have a higher mineralization towards the north. The amount of total dissolved solids is often greater than 1g/l, and it may attain in the northwestern region as high as some tens of grams per liter under the condition of high evaporation. On the contrary, the total dissolved solids in groundwater on the southern side of the dividing line are mostly less than 1g/l owing to the strong leaching. In the eastern part adjoining the coastal belt, which is influenced by the moisture-laden monsoons and amply supplied by precipitation, groundwater is commonly fresh and contains about 1g/l of total dissolved solids or less, except the coastal areas where groundwater is relatively highly mineralized. While in west China, the quality of groundwaer varies exceedingly with regard to the chemical composition of groundwater, areal and vertical zonings can be clearly recognized in the major interior basins and plains in the north, whereas in the southern intramontane basins the zoning is very indistinct.

2.4 Fluctuations of Groundwater Level

From the south to the north of the Qinling Mountain-Huai River line, the pattern of curve of groundwater level fluctuations changes gradually from multiple peaks to double peaks or to a single peak. The peak time is also postponed gradually fom south to north. Generally speaking, in the southern areas, as the rainy season is longer, the curve of groundwater level fluctuation mainly assumes the form of multiple peaks; and owing to the influence of "plum rains" (intermittent drizzles in the rainy season), the peak occurs relatively earlier. In the northern areas, as the rainy season is shorter and the rains mostly concentrate in autumn, the curve of groundwater level fluctuation generally assumes the form of double peaks or a single peak, which occurs relatively late. In the high moutain areas in northwest China, the vertical changes of climate give rise to varying patterns of groundwater fluctuations from high mountains to plains.

2.5 Groundwater in Permafrost

In China, besides the southern-edge permafrost of the Eurasian continent in the northernmost part of China, there appears on the Qinling-Xizang Plateau low-latitude and high-altitude permafrost groundwater due to the increasing height of the western areas. This is rarely seen in the middle- and low-latitude zones in the world.

3. REGIONAL DESCRIPTION OF THE MAIN TYPES OF GROUNDWATER IN CHINA

On the basis of the above-mentioned physiographic and geologic conditions and the main characteristics of groundwater occurrence, a summary account of the regional distribution of groundwater in China may be given as follows:

3.1 Groundwater in the Great Plains in the Eastern Part of China

The Song-Liao Plain (Songhua River-Liaohe River Plain) in northeast China, and in the Huang-Huai-Hai Plain (the Yellow River-Huai River-Haihe River Plain or the North China Plain), the Changjiang Delta (Yangtze Delta) and the Jiang-Han Plain (Yangtze-Hanshui Plain) in east China are the major plains, where unconsolidated Quaternary alluvio-diluvial, alluvio-lacustrine and marine deposits are accumulated in varying thicknesses. Pore water occurs in these deposits, providing abundant water resources. The aquifers are mainly sands and gravels, which are loose in structure and uniform in water abundance, and often appear in multi-layered form.

THE HUANG-HUAI-HAI PLAIN is the largest plain in China, with a total area of about 320 000 km², occupying one-third of the total area of the plains of the whole country. It is one of the principal agricultural regions in China. The plain is bounded on the north by the Yanshan Mountains, on the west by the Taihang and the Tongbai Mountains, on the south by the Daibie Mountains and the Jiang-Huai Hills, and on the east by the Bohai and Huanghai (Yellow) Seas. The plain is generally sloping eastwards: the piedmont belts are nearly 200 m above sea level while the central part of the plain is less than 100 m. It belongs to the temperate, semi-humid, monsoon climatic zone. The mean annual precipitation of the whole area is 500 - 800 mm, increasing gradually from north to south. Since the Cenozoic, the whole plain has intermittently been a large subsiding zone, where Quaternary sediments are quite well-developed. The thickness of the sediments is controlled by the relief of the basement, varying from place to place between 200 - 600 m and reaching the maximum of more than 1000 m in the depressions. Since the deposition environment south of the Huanghe River is absolutely different from that north of the river, the hydrogeological conditions are also quite different.

AREAS NORTH OF THE HUANGHE RIVER. There is a very marked variation in the distribution of water-bearing formations from the piedmont belts through the middle part to the coastal areas. Especially at the southern foot of the Yanshan Mountains and the eastern foot of the Tai Hang Mountains, the alluvio-diluvial fans composed of Quaternary gravels are very well developed, and constitute significant water-bearers in the piedmont belts. The aquifers in the alluvio-diluvial fans are loose in structure and relatively thick in single layers, the total thickness being generally 40 m and reaching over 60 m at most. The sediments become gradually fine-grained and thin from the axial part to the fringe of the fan. In the inter-fan terrains, there often occur intercalations of clayey soil. Generally, groundwater in these areas is unconfined. The major alluvio-diluvial fans include those of the Yongding, Hutuo and Zhanghe Rivers. These fans slope gently away from the the foot of the mountains, with superimposed multiple layers of deposits. Consequently, the lower parts of the fans often extend so far that their front edges often go under the bottom of the alluvial deposits of Recent rivers. The front edges of the later two fans described above are deep-buried at about 120 - 200 m below the surface. Therefore, in the piedmont belts the aquifers are lithologically coarse-grained and highly pervious. The underground runoff circulates freely due to great hydraulic gradients. In addition, the rivers originating in the mountain areas often find their way through the fans, replenishing the aquifers sufficiently. The specific yields of wells are commonly greater than 30 m^3/h.m, with a maximum up to 200 m^3/h.m. The water is commonly of good quality, and very simple in chemical type either vertically or laterally belonging to calcium (magnesium) bicarbonate type, with total dissolved solids less than 0.5 g/l. It is an excellent source for water supply.

Starting from the front edges of the piedmont plains is the middle part of the alluvial plain of the Huang-Huai-Hai. This alluvial plain is stretching wide and open, and the unconsolidated sediments therein are very thick and fine-grained. The gently sloping aquifers are mostly composed of alternating thin layers of medium-fine sands, silts and sandy clay. The groundwater is mainly unconfined or slightly confined at the depths of 60 - 80 m below the surface, and entirely confined downwards at the producing depths, locally artesian. The unconfined groundwater is generally about 1 - 3 m deep, mostly occurring in the form of discontinuous bands. The aquifers have a low permeability and a gentle hydraulic gradient. Infiltrated meteoric water and surface water, as well as irrigation water, are the main recharge sources of groundwater. The water is of poor quality, commonly brackish or saline, containing more than 2 g/l of total dissolved solids. The base of the saline aquifer is marked by an uneven curved surface, buried at depths of about 60 - 100 m. Small amounts of fresh water occurring sporadically in banded forms can only serve as drinking water for man and livestock. However, deep confined aquifers widespread in the middle part are the main sources for local water supply. Near the piedmont belts in the west, the aquifers are shallower, and become deeper eastwards. The tops of the aquifers are generally about 60 - 80 m deep, and the piezometric heads are mostly below the depths of 3 - 5 m. The water is of good quality, commonly containing less than 1 g/l of total dissolved solids. The chemical type of water changes from the mixed type of bicarbonate, sulfate and chloride in the west to the chloride of sulfate-chloride type in the east.

AREAS SOUTH OF THE HUANGHE RIVER. The piedmont belts are featured by ridges and mounds, and the fans are not quite well-developed. Only on the western side of the piedmont extends the alluvio-diluvial fan of the ancient Huanghe River in an easterly direction. In the flat plain area are mainly alluvial and alluvio-lacustrine deposits. The total thicknes of the Quaternary sediments is thinner than that in the north. The aquifers are composed mainly of layers of medium and fine sands. The water is good in quality, with total dissolved solids less than 1g/l in most parts of the area; 1 - 2 g/l in some parts; and locally greater than 2 g/l. In the alluvial fan of the ancient Huanghe River and the deposition area of the ancient Huaihe River, the aquifers are lithologically coarse-grained, locally composed of medium-coarse sands and gravels. The total thickness of the aquifers is more than 40 m. They have larger storage capacity and the wells yield generally greater than 10 m^3/h.m. In most of the other areas, the aquifers are composed of fine silts 5 - 10 m thick, with very small storage capacity. Southwards, the aquifers become more and more fine in grain size, gradually thinner in thickness, and lower in storage capacity. The water is commonly good in quality, with less than 1 g/l of total dissolved solids. Saline water occurs occasionally in local places, with greater than 2 g/l of total dissolved solids.

In coastal areas along the Bohai and the Huanghai Seas are mainly distributed alternating alluvial, alluvio-lacustrine and marine deposits. The aquifers are composed of fine silts and sandy clays. The unconfined aquifers mostly occur as silt lenses involved in marine silty clays. The depth of water level is shallow, generally about 0.5 - 1.0 m below the surface. The aquifers have very small storage capacity; the specific yields of the wells are commonly less than 1 m^3/h.m. The water is mainly of chloride type, with total dissolved solids commonly greater than 3 g/l, sometimes exceeding 30 g/l. That is to say, water at shallow depths is entirely saline except some fresh water lenses. However, at greater depths in coastal areas, confined fresh water with a content of total dissolved solids less than 1 g/l is commonly encountered, generally below the depth in the range of 80 - 200 m. The aquifers are composed of medium and fine sands of alluvial and alluvio-lacustrine origins, yielding large amounts of water. The only exception is the coastal area of the Huanghe river delta, where saline water is tapped within the depth of 450 m. The total dissolved solids contained in the water amount to two grams per litre. In the coastal area of northern Zhejiang Province, saline water often occurs in the piedmont at the mouth of a river. This is due to the fossil sea water remaining extensively in marine-facies strata and the salinization caused by sea water intrusions. The water is of sodium chloride type and contains as much as over 12 g/l of total dissolved solids.

Considering the Huang-Huai-Hai Plain as a whole, the hydrogeological conditions from the piedmont plain through the middle plain to the coastal area are characterized by the genetic types of the aquifers from alluvio-diluvial through alluvial to alternating marine and continental or to marine facies; the grain size from coarse to fine; the geologic structure from simple to complex; the number of aquifers from single to multiple; the gradually thinning thickness; the weakening permeability and water abundance; the chemical type of water from simple to complex; the increasing mineralization of groundwater, etc.

THE SONG-LIAO PLAIN is one of the largest plains in China, about 1000 km long and 400 km wide, with a total area of about 250 000 km^2. The plain is bounded on the east by the Changbai and Qianshan Mountains, on the west by the Greater Khingan Mountains and the West Liaoning upland, on the north by the Lesser Khingan Mountains and on the south by the East Liaoning Gulf. It is surrounded on three sides by mountains, with one side facing the sea. The Kangping and Fadong Hills separate it into two parts, the northern plain and the southern plain. The former is high on its outer fringe, dipping low towards the centre and its altitude ranging between 120 - 500 m above sea level. The latter slopes down from the north like a dustpan open southwards to the sea, with the whole plain being entirely below 50 m in altitude. The landform is low and flat; the river beds are wide and open. The mean annual precipitation is 300 - 700 mm. The thickness of the Quaternary deposits is about 80 - 150 m in the northern part and 40 - 300 m in the southern part.

The piedmont belts on the periphery of the Song-Liao Plain are mostly alluvio-diluvial fans, which spread out in a northwesterly direction at the eastern foot of the Greater Khingan Mountains. The unconfined aquifers are generally of 20 - 60 m thick with their upper limits at the depth of 15 m below the surface. The specific yields of wells are 10 - 15 m^3/h.m. The water is of bicarbonate type, containing less than 0.3 g/l of total dissolved solids. Other piedmont belts are mostly mound-like plains studded by monadnocks or covered by eolian sands, with a very poor storage of groundwater. In the central part of the plain, owing to the thick confining bed of muddy and sandy clays, the aquifer can be divided into two parts; the upper part of unconfined water and the lower part of confined water. The source of unconfined water recharge is mainly the percolating meteoric water and surface water, and also subsurface runoff in mountainous areas. Part of the unconfined water discharges into the rivers, and part becomes consumptive waste through vertical evaporation. As the topography is rather flat, the subsurface runoff becomes sluggish and the evaporation tends to be strong, the salts in unconfined water gradually concentrate, thus causing the total dissolved solids in groundwater in the middle part of the plain to increase markedly, which sometimes may attain up to 30 - 50 g/l. In most parts of the plain, the specific storage capacity of unconfined aquifers is less than 1 m^3/h.m. The flow direction of the groundwater is essentially identical to that of the surface water. Generally, the unconfined water is small in quantity and poor in quality. The confined aquifers are composed mainly of sands and gravels, generally about 10 - 30 m thick, at the depths of 20 - 80 m. The top parts of the aquifers are sandy clays ranging between 15 - 60 m thick. The piezometric heads are buried 2 - 5 m deep, in places up to 10 - 20 m. The water quality is good. The wells generally yield 10 - 30 m^3/h.m. Groundwater in Tertiary and Cretaceous clastic rocks underlying the unconsolidated sediments in the middle part of the plain is of good quality, containing less than 1 g/l of total dissolved solids. The specific yields of some wells may attain 7 m^3/h.m. However, in the coastal area in the extreme south of the plain, as the topography is flat and low-lying and the subsurface runoff is sluggish, the unconfined water deteriorates, with the content of total dissolved solids as high as more than 30 g/l. The shallow groundwater is completely saline except some fresh water lenses. Nevertheless, good-quality confined water occurs abundantly at depth.

THE JIANG-HAN PLAIN lies in the middle reaches of the Changjiang River, covering a total area of more than 60 000 km^2. The plain is surrounded by mountains, and its low central part lies broad and flat, its altitude being less than 50 m above sea level. As rainfall is profuse over the whole area, the drainage system there is well-developed and the rivers are densely netted. The Quaternary loose sediments spread all over the plain, generally about 170 m thick, and up to 200 m or more in the Tongting Lake area where the depression is relatively deep. Sands and gravels alternate with clays and sandy clays in the Quaternary system, and the multi-layered sands and gravels are the main aquifers in the area. The storage capacity of the aquifers depends upon the number and thickness of the individual water-bearing layers, which are thick in the middle part of the plain and become gradually thinner towards the edges. For example, the thickness of the sand layer is over 100 m in the central part, but decreases to about 20 m on the edges, and even less in the outermost terraced area. The storage capacity of the aquifer is larger in the central part, with yields of individual wells about 10 - 30 m^3/h.m, but only about 2 m^3/h.m on the edges. Groundwater in this area is mainly in a confined state. The water heads are mostly near the surface, generally 0.4 - 3 m deep, locally gushing high up above the surface. The groundwater commonly has a simple chemical composition and low mineralization. It is of bicarbonate type, containing less htan 1 g/l of total dissolved solids, usually 0.1 - 0.6 g/l. Within the plain, the content of iron ions in groundwater is commonly higher, and gradually increases from north to south, the highest average content attaining 10.8 mg/l.

THE CHANGJIANG DELTA PLAIN is bordered in the north by the northern Jiangsu Plain and reaches the Hangzhou Gulf in the south. The plain is generally not more than 10 m above sea level, crisscrossed by rivers and densely studded with lakes and ponds. The climate is mild, and rainfall is plentiful. The unconsolidated Quaternary sediments are up to 200 - 300 m thick and in a few places more than 300 m. This is the place where the confined aquifers occur. Commonly 4 confined aquifers can be recognized, which may be grouped into shallow and deep water-bearers. Between the two groups is an extensive and relatively persistent confining bed of clay. The shallow water-bearers are characterized by alternating marine and continental deposits and marine deposits; whereas the deeper ones by continental deposits. From the upper end of the delta to the southeastern edge, the aquifer gradually changes from single layer to multiple layers, from greater to smaller thickness, and from coarser to finer grain size. Both the deep and shallow aquifer groups yield relatively large amounts of water, but differ markedly in water quality. The water of the shallow aquifer group changes southeasterly from fresh water with less than 1 g/l of total dissoled solids to brackish water with greater than 3 g/l, and in places saline water is found to have more than 10 g/l. Whereas the water of the deep aquifer group is mostly fresh water containing less than 1 g/l of total dissolved solids, which is an important source for local municipal and industrial water supplies.

3.2 Groundwater in the Sloping Piedmont Plains of the Interior Basins in the Northwestern Part of China

The Dzungar, Tarimu and Caidamu basins and the Hexi Corridor to the west of the Helan Mountains and north of the Kunlun Mountains are large interior basins in northwest China. These basins are separated by E-W trending high mountains, and are elongated in an E-W or NW-SE direction. The terrains on the periphery of the basins are broad and wide, where lie stretches of sloping piedmont plains with a considerable thickness of loose sediments. The top parts of the plains are often represented by Govi gravels, while the middle and front zones are filled with loose Quaternary gravels and sandy clays. All these basins are fringed with high mountains. The climate at the edges of the basins is arid, with mean annual precipitation generally less than 200 mm and mean annual evaporation more than 1500 mm. The mountainous areas adjoining the peripheries of the basins receive ample precipitation, and snows cover the place all year round. Apart from replenishing the mountainous areas, the precipitation and melting ice and snow often afford abundant groundwater recharge to the basins through underflows and percolations. The effectiveness and amount of groundwater recharge depend upon whether there are structural belts in the piedmont plains. For example, the Tertiary folded uplifts in the piedmont belts often constitute cut-off barriers for the Quaternary water-bearing formations. Meanwhile, the piedmont plains of various basins have a common character, that is, the loose sediments at the southern edges of the basins are better developed than those at the northern edges, which leads to the complexity of the hydrogeological conditions: the occurrence of groundwater varies greatly in the piedmont belts of different basins and even in different places of the same piedmont belt.

In the piedmont belt of the Altai Mountains, at the northern edges of the Dzungar Basin, the diluvium is distributed thinly in the upper part of the high platform due to denudation. It bears hardly any water under such an unfavourable condition for groundwater recharge. Occasionally small quantities of water can be found in the alluvium of river valleys. The circumstances are the same in the piedmont belt of the Dzungarjie (Dzungar Border) Mountains.

In the northern piedmont belt of the Tianshan Mountains, at the southern edge of the Dzungar Basin are the nearly E-W trending anticlinal uplifts and synclinal depressions. The depressions are filled by pebbles within a width of about 20 - 40 km. The grain size of the pebbles becomes gradually finer towards the basin. The unconfined groundwater directly receives the vertical-percolation replenishment from the mountain rivers, and flows subterraniously towards the basin in a relatively great gradient, and in this way a 50-to-200-m-thick unconfined groundwater zone composed of Quaternary pebbles is formed in the piedmont belt. The storage capacity is relatively large, with a well specific yield of about 30 $m^3/h.m$. The water is of good quality and contains less than 1 g/l of total dissolved solids.

In the case of the piedmont belt of the Tarimu Basin, the alluvial sands and gravels in river valleys attribute their abundance of unconfined groundwater at the depth of about 5 - 15 m to the existence of block mountains and uplift structures of Tertiary clastic rocks in the pediment. The water is of good quality, and the specific yields of wells are about 5 - 10 $m^3/h.m$. From the piedmont belt towards the basin, the aquifers gradually become fine-grained, and the water becomes more mineralized. Although confined groundwater occurs locally, the mineralization gradually increases with the distance away from the piedmont belt. Up to the north of the Tarimu River, the water becomes highly mineralized brine, and the storage capacity decreases abruptly.

At the southern edge of the Tarimu Basin (the piedmont belt at the northern foot of the Kunlun Mountains), there are very thick and loose diluvial deposits. In the western piedmont plain, Tertiary uplifts appear. According to the occurrence, runoff and discharge of the unconfined groundwater, two independent units may be distinguished on both sides of the uplift belt. On the southern side, the unconfined groundwter is buried about 30 m deep. Blocked by the uplift belt, it overflows to form a spring group, with a discharge up to 15 m^3/h. On the northern side, gravel beds of fairly large width are often formed, and the burial of unconfined groundwater grows deeper. However, the water of bicarbonate type is good in quality and contains less than 1 g/l of total dissolved solids. The sloping piedmont plain in the eastern area is directly connected with the mountainous area, mainly diluvial sediments about several hundreds of metres thick. The water-bearing formations are composed of sands and gravels. The unconfined groundwater is buried over 30 m deep, generally containing 1 - 2 g/l of total dissolved solids. The storage capacity is relatively small. The Caidamu Basin lies between the Qilian Mountains and the eastern section of the Kunlun Mountains. The deposits at the southern edges are developed better than those at the northern edges. A belt of gravels deposited at the southern edge near the mountains approximately 15 - 30 km wide (up to the maximum of 60 km in the western part) and 1200 m thick. Fresh groundwater occurs in a narrow long belt along the foot of the mountains. In other places, however, only saline water and high-mineralized water can be found. The piedmont belt at the southern foot of the Qilian Mountains is separated by Tertiary hills, forming many small basins. Groundwater either confined or unconfined is high-mineralized in the whole basin except in the piedmont belt at the southern foot.

The Hexi Corridor is an elongated intramontane plain having very thick Quaternary sediments, generally up to nearly one thousand metres a the thickest segment. Due to the strong structural movement the Corridor plain was divided into two lines of small basins in a south-north direction. The gravel plains in the small basins in the southern part are wider than those in the northern part; and the sediments are also more coarse-grained. The quality of groundwater is generally good, and the quantity is large.

With respect to the northwestern region as a whole, the exploitable groundwater resources are mostly concentrated in the sloping piedmont in the interior basins. Though the piedmont plains account for about 45 % of the region's total area according to statistics, more than 65 % of the fresh water in the northwest is distributed there.

3.3 Groundwater of the Loess Plateau

China is a country with most developed loess in the world. Loess in China is characterized by extensive distribution, large thickness and successive deposition. The main region where loess is distributed lies in the middle reaches of the Huanghe River, from the eastern section of the Qilian Mountains in the west to the Taihang Mountains in the east from the Great Wall in the north to the Qinling in the south, covering an area of abut 350 000 km². The general topography is higher in the northwest and lower in the southeast, with an altitude of 700 - 2400 m above sea level. The regional climate is arid and rainfall is scarce. The time of precipitation is concentrated mainly in July, August and September. In the northern area, the mean annual precipitation is 300 - 500 mm, and increases progressively southwards to 700 mm.

The prominent features of the loess plateau in the middle reaches of the Huanghe River are characterized by yuans[1)], liangs[2)], maos[3)], gullies and valleys, which are arranged alternately and constitute special landforms. In the eastern and southern parts, loess occurs morphologically as taiyuans[4)]. As the loess plateau is exposed to intense erosion of log duration by running water, the valleys are deeply incised and the terrains are broken, thus leading to the complexity of groundwater occurrence. In loess deposits unconfined groundwater can be found continuously over small areas and discontinuously in local places.

The continuous unconfined groundwater mainly occurs in the yuan areas such as the loess yuans at Xifeng, Luochuan and Jixian as well as the loess taiyuans in the Fen-Wei, Taiyuan and Luoyang Basins. The yuan surface in loess yuan areas is broad and flat, and there often exist depressions and dish-shaped lands, which are favourable for the collection of meteoric water and recharge of groundwater by infiltration, resulting in extensive storage of unconfined groundwater. The aquifers in loess yuan areas are mainly composed of porous loess and fossil soil, generally 60 - 90 m thick, up to 110 m in maximum. Each yuan is an individual hydrogeological unit. The groundwater yield and level in yuans depend upon the size of the yuan surface and the distance to gullies. The larger the yuan surface is, the bigger the storage capacity will be; and the shorter the distance to

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1) Yuan -- a high table-like plain with abruptly descending edges.

2) Liang -- an elongated loess mound.

3) Mao -- a round loess mound.

4) Taiyuan -- loess covering terraced landform.
(The term above is given by the local people).

the gullies, the deeper the water level. For example, the surface area of the Luochuan yuan is one-third smaller than that of the Xifeng yuan, consequently the daily discharge in the central part of the former is a half lower than that in the latter. The unconfined groundwater in loess deposits discharges in the form of descending springs into the gullies at the edges of the yuans. The water is chemically of bicarbonate type and contains a low content of total dissolved solids, generally less than 1.0 g/l.

The unconfined groundwater occurring in the loess taiyuan in the Feng-Wei, Taiyuan and Luoyang Basins is mainly supplied by meteoric water and locally by surface water and groundwater in diluvium, since the taiyuans are often adjoining to the piedmont diluvial aprons. In short, the quantity of unconfined groundwater in loess deposits in taiyuan areas is closely related to the size of the taiyuan surface, the structure of the loess deposits and the existence of the confining layer at the bottom. For example, the loess in part of the taiyuan areas north of the Weihe River directly lies on the limestone, but as there exists no confining layer, all the groundwater percolates into the underlying bedrocks. When the loess taiyuan has a wide surface with depressions on it, and the considerably thick deposits have a good confining bed at the bottom, and at the same time the annual precipitation is relatively ample, groundwater is generally copious and the yield per well may attain 200 - 800 m^3/day. However, in the case of the Taiyuan Basin it is quite the contrary. The loess taiyuan is thin in deposition and narrow in surface area, deeply incised by gullies. The annual precipitation is small, and the storage capacity of groundwater is very limited.

Discontinuous unconfined groundwater occurs mostly in the loess deposits of liang and mao areas as well as zhaang and zhang[1] land. The zhaangs and zhangs are often distributed in the surrounding areas of the Liupan and Baiyu Mountains. They are of very limited extent in the vast landform of ridges and mounds, generally covering only a few km^2. Besides, they are separated by liangs and maos, forming isolated units with no hydraulic interconnections to each other. The major aquifers, composed of loessal soils and silts, are generally 10 - 40 m thick. The water level is relatively deeply buried, and the well yield is generally very small. The water is of good quality, containing less than 1 g/l of total dissolved solids, locally 1 - 3 g/l. It belongs to bicarbonate or sulfate type.

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1) zhaang and zhang -- local terms for palm-shaped and branch-shaped loess land lying between liangs and maos.

Groundwater in liang and mao areas is distributed over vast areas beyond the loess yuans. As the terrains are strongly dissected by well-developed gullies and valleys, the area for groundwater replenishment by meteoric water is very small. Furthermore, as liangs and maos have steeply inclining edges and rainstorms are frequent in these areas, a large quantity of rainfall becomes surface runoff, resulting in very unfavourable condition for groundwater recharge and storage. Only in the saddle parts between liangs and maos can small amounts of water be collected, with the well specific yield only less than 0.04 m^3/h.m. The chemical types of groundwater are varied: in the area east of Zhewu Ridge it is of bicarbonate type, containing 1 g/l of total dissolved solids; while in the area to the west the chemical composition of the water becomes gradually complex in a S-N direction, changing from bicarbonate type to sulfate-chloride type and the content of total dissolved solids increases gradually from 1 g/l to 3 - 10 g/l.

3.4 Groundwater in Desert Areas

China has vast deserts, occupying almost one-ninth of the total area of the whole country. More than 90 % of the deserts are concentrated in the central parts of the interior basins in north and northwest China except a small part that lies on the interior plateau. The relatively large deserts include: the Taklamakan, Kurban-Tungut, Kumutako, Badan Jiryn, Tynferi, Ulanbuh, Kupuchi and Maowusu deserts. They are covered by sand dunes generally 10 - 25 m high, the highest may attain 100 - 300 m, and the low ones are less than 5 m. The climate is extremely dry. The annual precipitation over the majority of the areas is below 250 mm, reduced markedly towards the northwest, and coming down to less than 100 mm in the westernmost part. The evapotranspiration is intense, generally a few times higher than the rainfall. The surficial cover is very pervious. Almost no rivers are formed by local surface runoff within this area and only transit rivers and rivers replenished by melting snow and ice from the adjoining high mountains can be found. These are the main local water sources. Obviously there is a keen shortage of surface water in most parts of the deserts. And with regard to the groundwater often seen in deserts, two types can be recognized: fresh water lenses in sand dunes and pore water underlying the sand dunes.

(1) Unconfined sand-dune groundwater

Sand dunes are mainly composed of fine sands and fine silts, ranging in thickness from a few to some tens of meters, and having uniform grain sizes. In the above-mentioned deserts (the Taklamakan Desert excluded), fresh water lenses in sand dunes are very common, and unconfined water can often be found in low-lying depressions between various types of sand dunes. These depressions are of various sizes, ranging in area from a few to several tens of m^2. Their water-bearing conditions are related to the basement. For example, if the basement is a confining bed, the eolian sand dunes will form separate aquifers; and if the basement is highly permeable, the sand dunes and their underlying beds will form a unified aquifer. The source of groundwater recharge is mainly meteoric water and condensation water. Apart from the consumption through evapotranspiration, the groundwater discharge sometimes also replenishes the groundwater in lake basins through subsurface runoff. The levels of unconfined sand-dune groundwater generally are at the depths ranging from less than 1 m to 10 m, and become deeper with increasing height of sand dunes. For example, in the Kupuchi Desert, sand-dune aquifers are composed of silts and fine sands. The thickness of sand beds is 1 - 2 m at the edges of the sand dunes, and increases up to 10 - 20 m in the centers. Unconfined groundwater is generally found at depths of less than 1 m, the specific yields of wells are less than 1 m^3/h.m, and the water quality is good. In the depressions between sand dunes, the water level may be as deep as 10 - 15 m, but the amount of water is very small. In the Maowusu Desert, the sand-dune aquifers are mainly composed of medium and fine sands. The water level is generally 1 - 3 m in depth and has a very great seasonal fluctuation. The aquifer is hydraulically in close connection with the underlying alluvial and lacustrine deposits, constituting occasionally a unified aquifer of good water quality, with a discharge generally less than 10 m^3/h.m. The Taklamakan Desert which lies in the westernmost part is the largest in China. The climate there is very dry, and the shifting sand dunes are dominant. Except the belts along the banks of the rivers, the terrain is entirely covered by sand dunes. The big-sized sand dunes have very wide and open lands in between, generally 1 - 3 km in width and these open lands are in turn often separated by transverse sand dunes or ridges to form smaller closed depressions. Inside the depressions, the unconfined groundwater level is usually high, and the water quality is comparatively bad and changeable.

(2) Pore Water Underlying the Sand Dunes

In deserts, as fossil alluvial plains and fossil fluviolacustrine plains are buried at the edges of the deserts, there is generally a considerable thickness of early and middle Quaternary deposits underlying the sand dunes, originated on the one hand from the piedmont alluvio-diluvium extending towards the basin and on the other hand from the valley deposits plunging into the interior of the deserts and the alluviolacustrine deposits underlying the sand dunes. In these alluvial deposits, confined fresh water is often present. For example, at the northeastern edges of the Maowusu Desert, the upper part of the poorly permeable Jurassic sandy mudstones are covered by relatively thick lacustrine deposits, where spring groups often occur. the discharges of the springs of good water quality may sometimes reach as much as some tens of m^3 per hour. In the Kurban-Tungut Desert in the central part of the Dzungar Basin, high-head confined fresh groundwater is often tapped under the sand dunes. Besides, similar confined fresh water is also present in the Ulanbun and Badan Jiryn Deserts.

3.5 Groundwater in Karst Regions

Groundwater in karst regions refers to the groundwater occurring in carbonate rocks. Carbonate rocks are very widespread in China, but due to the difference in natural conditions, karst development varies markedly from area to area, and karst features are also different. Generally in south and southwest China, the karst landscape is marked by peak clusters, peak forests and corroded depressions. In the middle and lower reaches of the Changjiang River, hilly karst landscape is significant. And in the drainage areas of the Huanghe River, karst features are not prominent on the surface, presenting only ordinary landform.

Groundwater in karst regions is mainly of karst fissure-cavity water type, which is characterized by large quantity and relatively uneven distribution. This unevenness is displayed not only by areal distribution, but also by different depths, as well as by the sharp fluctuations of water level and water quantity during different times. The water quality changes slightly and the mineralization of water is relatively low. Chemically, karst water is mostly of calcium bicarbonate type, generally containing less than 0.5 - 1.0 g/l of total dissolved solids. Only in dolomite areas, coastal zones and sulfide deposit districts are the chemical types of groundwater a bit complex.

Owing to the difference in the burial depth of carbonate rocks, there are also appreciable differences in karst development, karst morphology and the properties of karst water. Accordingly, fissure-cavity water in karst regions can be classified into two types, the exposed and semi-exposed types and the buried type.

The exposed and semi-exposed karst fissure-cavity waters occur in the carbonate formations directly exposed at the surface or having a thin cover. In the exposed-type karst area, groundwater is mainly unconfined, and only under certain structural conditions does the confined groundwter occur locally. The distribution of groundwater is very uneven either in space or in time. On the basis of the karst development and the distribution of karst water in various areas, the waters can be classified into the following three types.

(1) Karst Fissure-Cavity Water in Peak-Cluster and Peak-Forest Area

Peak-clusters and peak-forests formed under tropical climatic conditions are mainly distributed in the subtropic Pearl River drainage area, including the south China region and Yunnan-Guizhou Plateau. There, the climate is hot and rainfall is plentiful. The mean annual precipitation is as much as 1500 - 2000 mm and the mean annual temperature is 20 - 22 °C. This is the area where karst is best developed in China. Its main features are as follows:

(a) Carbonate rocks are widespread, pure and very thick. For example, in the Guangxi Zhuang Autonomous Region, from the Middle Devonian to the Lower Triassic were deposited carbonate rocks with a total thickness of more than 8000 m, the exposed area making up 40 % of the total area. According to the statistics, in the Guilin area, more than 80 % of solution caves are developed in the Rongxian limestone of late Devonian age. The famous large caves such as the Reed-Flute Cave and the Seven-Star Cave are the case. As a saying goes, there is not a hill without a cave. In Guizhou Province, from the Cambrian through the Devonian up to the Tertiary were mainly deposited carbonate rocks with a total thickness of nearly 10 000 m, the exposed area making up approximately 70 % of the whole province. In eastern Yunnan Province carbonate rocks are very well developed, the exposed area making up 60 % of the whole area.

(b) Underground river systems are extensively developed. According to the preliminary statistics of the Guangxi Zhuang Autonomous Region, there are totally more than 100 underground rivers with a discharge greater than 180 m^3/h individually. The total low water flow is 360 000 m^3/h or so. For instance, the famous Disu underground river system in Duan County of Guangxi, more than 50 km long, has a recharge area of more than 1000 km^2.

As the main source of recharge is meteoric water, the discharges and water levels of the underground rivers are entirely governed by precipitation. In the Disu area, the mean annual precipitation is 1700 mm, while that in the rainy season (from April to September) accounts for as much as 85 %. Generally the minimum discharge in the low-water season is 14 000 m^3/h, while the maximum in the flood season is 1.4 million m^3/h; the latter is 100 times greater than the former. At various levels of the Yunnan-Guizhou Plateau, there are also many underground rivers which have substantial discharges and become the collecting points and discharge conduits of local groundwater flows. For example, the underground river system in the southern part of Dushan County has a total length of about 40 km, its recharge area is nearly 350 km^2 and its low-water discharge at the outlet is 4320 m^3/h.

What is worth mentioning is that when a rainstorm is over at a certain place, the flooding flow cannot be drained in good time, and the corroded depressions in the lower reaches are liable to be waterlogged; and furthermore as the surface drainage system is poorly developed and karst fissure-cavity water is relatively deep buried, karst areas are always seriously stricken by drought after rains.

Besides, on the Xisha Islands of the Nanhai (south China Sea) Islands of China, where carbonate rocks are extensively developed, coral limestones are up to more than 900 m thick, karst fissure-cavity water therein is relatively plentiful, and the well specific yield is 24 $m^3/h.m$, but the water is of poor quality, mostly saline, with 30 g/l of total dissolved solids.

(2) Karst Cavity-Fissure Water in Hilly Areas

Karst cavity-fissure water is mainly distributed in the middle and lower reaches of the Changjiang River, including eastern and southern Sichuan, Hubei, Hunan, northern Guizhou, Jiangxi, Zhejiang and southern Anhui. This region belongs to intermediate-subtropical humid climatic zone, with mean annual precipitation of 1000 - 2000 mm or so and mean annual temperature between 12 - 15 °C. Carbonate rocks are widespread. The landscape is mainly marked by karst hills and corroded depressions. Solution cavities and underground rivers are relatively well-developed, and the storage capacity of groundwater is very large. For example, the carbonate rocks in eastern and southern Sichuan have a total thickness of 1000 m or so. As the limestones along the axial zone of an anticline are usually corroded to form a ridge-trough landform, monadnocks and corroded depressions are often developed on them. Some of the caves in well-developed karst areas may be as big as 30 m in diameter and at a depth of 180 m. Big caves with a diameter of 1.8 m may also be encountered. Underground rivers cover a distance of a few thousand metres. In the Changxing Limestones in the southern part, the discharge of the underground river reaches 4212 m^3/h and the spring flow may reach a maximum of 432 m^3/h. But the groundwater distribution is very uneven. Some of the Permian Chanxing Limestones are often dry and contain no water. Other examples are the Lengshuiqiao and the Wangjiaping springs exposed in the Ordovician limestones in Hubei Province. The former has a discharge of 900 m^3/h, while the latter 180 m^3/h. Besides, the discharge varies greatly with seasons. For example, in the Xiling Gorge area of the Changjiang River the discharge of the Baimadong Spring in the Nanjinguan Limestone is 228 m^3/h in the flood period and 0.072 m^3/h in the dry season; and the discharge of the Carp Pond in the Shilongdong Limestone reaches a maximum of 1404 m^3/h in the flood period, while in the dry season it is only 10.8 m^3/h -- the difference between the two is about 130 times. In Hunan Province, carbonate rocks have a total tickness of more than 1000 m, covering an area of about 60 000 km^2 or more. The intermittent uplifting of the earth's crust results in the multi-layered nature of the karst development. Generally, the solution caves are developed within a depth of 100 m below the surface, and they are best developed at a depth of 50 m. According to the incomplete statistics, there are altogether more than 130 large springs and underground rivers having a discharge larger than 180 m^3/h; generally between 720 - 1080 m^3/h.

(3) Karst fissure-cavity water in mountainous areas

Karst fissure-cavity water is mainly distributed in the Huanghe drainage area, sporadically exposed in northeast and northwest China. The temperature in this area is low and the precipitaiton is insufficient. Karst phenomena, in consequence, at the surface are inconspicuous, only represented by corroded gullies and troughs, with the outcropped karst springs as the main feature. In north China, carbonate deposits are more than 1000 m thick. The forms of underground karst mainly include corroded pores and small solution cavities generally 0.5 - 0.2 m in diameter. There occur a large number of big karst springs. As the recharge area is of large extent, the discharge of the springs are correspondingly large and relatively stable. For example, the Niangzheguan spring group in the middle section of the Taihang Mountains consists of 11 major springs with a total discharge of 36 000 - 57 000 m^3/h. The discharge of the Fengfeng spring group is 21 000 - 32 000 m^3/h with a maximum of 138 000 m^3/h. Many big karst springs can often be found at the edges of the mountainous area in central Shandong. For example, near Jinan City there are more than 100 springs, of which 72 are famous, the total discharge being 15 000 m^3/h.

Buried karst fissure-cavity water is groundwater occurring in the carbonate strata underlying the overburden. The available exploration data indicate that karst fissure-cavity water buried within a depth of 400 m below the surface is usually abundant in quantity and good in quality and can serve as water sources for municipal, industrial and mining water supply. For example, in the Guanghua Basin in Guangdong Province, a thick carbonate stratum about 1300 m underlies the Quaternary sediments. The number of solution cavities and pores in the stratum is reduced with increasing depth. The solution caverns have a maximum height of more than 17 m, mostly filled with clayey and sandy materials. The water is mainly confined fissure-cavity water, the quantity of which is related to the filling materials. The wells yield 0.36 - 54 m^3/h.m of fresh water which belongs to bicarbonate type. In the northeastern part of the Jiang-Han Plain, well specific yields of buried karst fissure water are 0.36 - 28.1 m^3/h.m, and the discharge of the spring group is 60.5 - 263.5 m^3/h. The water is of calcium bicarbonate type. In the Zibo Basin in the central part of the Shandong Peninsula, there are three layers of buried carbonte rocks, and karst fissure water is relatively copious in the first and third layers, with well specific yield up to 72 m^3/h.m. In northern Guangdong, Jiangxi, Hunan, Hubei, Huaibei and the piedmonts of the Taihang Mountains, there occurs buried type of karst fissure water, of which the quantity is generally large.

3.6 Groundwater in Bedrock Mountainous Areas

China is a mountainous country. The exposed bedrock in mountainous areas makes up about two-thirds of the total territory of China. The bedrock mountainous area here denotes that constituted by various kinds of bedrocks, except carbonate rocks. The bedrock strata in mountainous areas of China include those of different times. The outcrops of bedrock may range from the Archeozoic to the Cenozoic. Among them granitic rocks are rather widespread, accounting for about one-third of the total exposed area of the bedrocks over the whole country. They often form the trunks of some mountain ranges.

The rock types in the areas include magmatic rocks, metamorphic rocks, and clastic rocks. In terms of the type of water-bearing formation, the water is mainly bedrock fissure water, and locally in clastic rocks is pore-fissure water. According to the regional distribution of different rock types, a summary is given as follows.

GROUNDWATER IN MOUNTAINOUS AREAS OF MAINLY MAGMATIC ROCKS

In the areas where magmatic rocks are distributed, the bedrock is compact, mostly massive or massoid and relatively weak in the resistance to weathering. In the surficial layer, fissures are quite well-developed, and the thickness of the weathered mantle is generally 10 - 30 m and in places greater than 30 m. Therefore, the strata at shallow depths often abound with unconfined water in weathered fissures. But the layers at depth contain little water or are impermeable. The groundwater of this type is mainly distributed in northeast China and in the coastal areas of southeast China.

In the areas of the Greater and Lesser Khingan Mountains in northeast China are mainly distributed Variscan granites and volcanic rocks. In these rocks, the degree of weathering is reduced gradually from east to west, and the burial depth of fissures increases from the mountain summits to the piedmont belt. The water quality is good, but the quantity of spring is small.

In the coastal areas of southeast China, especially in eastern Fujian and its coastal terrain, extensively distributed are the Jurassic volcanic rocks and Yanshanlan granites. The rocks are compact and hard, and the conditions for the occurrence of groundwater are relatively unfavourable. Descending springs, mostly seasonal, usually appear along the weathered crust in small flows, generally 0.03 - 0.9 m^3/h, and the well specific yields are 0.18 - 0.36 m^3/h.m. In the areas of volcanic rocks in eastern Zhejiang, the springs are relatively numerous, but their storage capacity is small, the discharge being merely 0.1 - 3.6 m^3/h. In the area of eastern Guangdong, as a result of frequent structural movements and multiple intrusions of magma, fissures are well developed in rocks and the weathered mantle is relatively thick. The discharge of spring is 1 - 3 m^3/h, but in places near the structural crushed zones the discharge may increase to 18 - 30 m^3/h. The wells generally yield less than 1 m^3/h.m.

Groundwater in magmatic-rock areas is generally of good quality. In most of these areas, it is fresh water of bicarbonate type, and only in the coastal terrain becomes highly mineralized due to sea water encroachment.

GROUNDWATER IN AREAS OF MAINLY METAMORPHIC ROCKS

Groundwater is mainly distributed in the metamorphic rock belts in the Tianshan, middle Kunlun and Qilian Mountains in northwest China as well as in the Qinling Mountains and the coastal areas in southeast China. The groundwater there is usually buried in structural fissures. The water-collecting capacity mainly depends on the characteristics of the structure, the combination of different formations and the filling extent of cementing materials in crushed zones.

In the mountainous areas in northwest China, fold-faults and fissures are very well developed and the replenishment of meteoric water and melting snow is copious. Under such a favourable condition, springs are relatively numerous, with a discharge usually of 5 - 30 m^3/h. The general regularity is that the discharge is larger in the west and gradually becomes smaller towards the east. However, the groundwater quality is commonly good both in the east and the west. In the areas in the Qinling Mountains where the metamorphic rock belts occur, though fold-faults are very well developed, the conditions for water storage and transmission in fissures and fault zones are generally poor, as the formations are mostly argillaceous. Springs can rarely be seen, if some, the discharge is only 0.04 - 0.6 m^3/h, though the water quality is good. In northern and western Fujian, the rocks are so compact and impervious that they hardly contain any water, and groundwater is exposed at the surface only in some places. The discharge of the springs are 0.05 - 0.03 m^3/h. In Jiangxi Province, metamorphic rocks are widespread, but the weathered mantle is thin and the water storage capacity is very low. The specific yields of wells are 0.7 $m^3/h.m$ and the discharges of the springs are less than 3 m^3/h.

Besides, in case marble beds are intercalated in metamorphic rocks, fissures and karst are often relatively well developed, and interlayer fissure water is often present. For example, in northeast and northwest Hubei, the metamorphic rocks have very poor water-bearing conditions, but the fault zones where gneisses are intercalated with marbles are relatively abundant in water. In the Dabie Mountains, the metamorphic rocks are poor water-bearers, the specific yield of wells being only 0.01 - 0.05 $m^3/h.m$, but in the places where marbles occur, the water is relatively abundant and locally artesian. The example is the spring at Longquansi, Hefei, Anhei Province, which has a discharge up to 2.7 m^3/h. The water is all low-mineralized fresh water of bicarbonate type.

GROUNDWATER IN MOUNTAINOUS AREAS OF MAINLY CLASTIC ROCKS

In China, clastic rocks are mainly distributed in the larger uplifted mountainous areas. As this kind of rock is generally compact, hard and brittle, and highly resistant to weathering, fissures produced by weathering are not quite well developed and the permeability is low. But under the effects of structural disturbances, far-extending structural fissures often appear, thus facilitating the concentration of groundwater and giving rise to water-abundant zones. Their storage capacity is directly related to the characteristics of the structural zones and geomorphology. Practice proves that if crushed and fissured zones are of large extent and far stretching, with close-spaced fissures and low-lying geomorphological position, the quantity of water will be relatively large. This type of water is mainly distributed in some mountainous areas of northwest China, the Nei Monggol Plateau, eastern Xizang (Tibet) and the mountainous area of western Sichuan.

In the Altai Mountains and the Dzungar mountainous area in northwest China are distributed clastic rocks of different geologic ages. Their storage capacity is relatively large, the water is of good quality with 1 g/l of total dissolved solids, and the discharges of the springs are 5 - 30 m^3/h. In the piedmont belt at the northern foot of the Tianshan Mountains, the water in clastic rocks is mainly confined, and locally artesian at depth. The specific yields of wells are greater than 10 m^3/h, and the mineralization of groundwater becomes higher with depth. In the piedmont belts at the southern foot of the Tianshan Mountains and the northern foot of the Kunlun Mountains occur mainly Mesozoic sandstones and conglomerates, which have relatively small storage capacity and poor water quality. The amount of the total dissolved solids is generally 1 g/l or so, but locally may be increased even up to more than 10 g/l. The chemical type of the water changes gradually from bicarbonate type to bicarbonate-sulfate type.

In the areas of the Qilian and Qinling Mountains, the clastic sediments consist mainly of interbedded mudstones, shales, sandstones and sandy conglomerates. The aquifers are mainly sandstones and sandy conglomerates, with moderate storage capacity. Under the control of the structural and geomorphological conditions, a number of intramontane artesian basins are formed in the mountainous areas. Within the basins, the discharges of the springs are generally 5 - 30 m^3/h. The water is good in quality, mostly containing less than 1 g/l of total dissolved solids. In the western Qinling and northern Qilian Mountains, sometimes the strata of clastic rocks occur with the association of carbonate rocks. Their storage capacity is generally moderate, but in a few individual favourable structural loci, the discharges of the springs may reach as much as 2800 m^3/h. The Ordos and northern Shaanxi plateaus belong to Mesozoic and Cenozoic structural basins, where aquifers of Jurassic, Cretaceous and Tertiary sandstones and sandy conglomerates are extensively distributed. The aquifers are of persistent distribution with relatively large quantities of good-quality water and often serve as the main sources for local water supply. In the western part of the northern Shaanxi plateau, the aquifers become gradually thin, the water quality deteriorates, and the mineralization becomes high.

In the western and southern parts of China, eastern Xizang, the western Sichuan mountainous area and the Sichuan basin, extensively distributed are the low-grade metamorphosed Mesozoic and Cenozoic sandstones, sandy conglomerates, mudstones and shales with sandstones. In the areas where alternating layers of sandstones and mudstones are exposed, groundwater is collected in sandstone fissures and interlayer fissures. In the structural basins in the mountainous areas, artesian aquifers are often formed in clastic rocks overlain by a thin bed of unconsolidated sediments. The water is generally not abundant in quantity, and belongs to low-mineralized fresh water except in the salt-bearing strata. Artesian water is very common at shallow depths in the fold zones of Sichuan, where sandstones are the main water-abundant section. The height of the artesian water head generally does not exceed 20 m, but in some cases may reach a maximum of 100 m. The artesian flow is generally 11 m^3/h or so. In western Guangxi, northwestern Hunan and the mountainous areas in northern Guizhou where the landform is high and steep, the drainage system is well developed, and the rocks consist mainly of sandy shales, sandstones, conglomerates and mudstones of Paleozoic and partly Mesozoic ages. The development of fissures varies from place to place. The storage capacity is relatively small, and only in local places are the discharges relatively large. In the folded mountainous areas in eastern Guangdong, the down-faulted laterite basins occur as paternosters set in the hills. Interlayer fissure water occurs quite copiously in the calcareous sandy conglomerates. In the central mountainous area and the adjoining hilly areas in Taiwan, there are also Mesozoic and Cenozoic clastic rocks with very low storage capacity. However, the water is low-mineralized water of bicarbonate type.

GROUNDWATER IN AREAS OF BASALTS

In the areas where volcanic lavas are distributed, there mainly occurs pore-fissure water in basalts with primary fissures and vesicles. In the Cenozoic strata in China, from the late Tertiary to the early Quaternary there are rather extensive eruptions of basaltic magmas, which mainly take place in eastern Jilin, Nei Monggol, the Leizhou Peninsula, western Yunnan and the Penghu (Pescadores) Islands. The process of the formation of basalts is often associated with well developed columnar joints and vesicular structures, which provide good spaces for groundwater gathering. The gathering of primary pore-fissure water depends upon burial condition, lithology and environments where the eruption of basaltic magmas occurs. In eastern Jilin, basalts with moderate storage capacity are exposed in the low-lying river valleys, replenished by meteoric water and surface water. At some places of the lava platforms in Nei Monggol, basalts directly overlie the impervious Tertiary laterite beds or Quaternary clay beds. As fossil valleys and gullies or depressions favourable for groundwater collection exist before the eruption of basaltic magmas, water-abundant zones are often formed therein. Sometimes sandy mudstones with basalts carry interlayer pore-fissure water; generally they have relatively large storage capacity. In the Leizhou Peninsula occur Quaternary basalts, with a confining bed at the basal part made up of weathered fossil laterite. And an artesian groundwater basin is formed, with aquifers of loose sands interposed with basalts. In the upper part occurs unconfined groundwater, while in the lower part the confined or slightly confined. They have a large storage capacity, and the water mostly belongs to low-mineralized water of bicarbonate type. In the Penghu Islands east of Taiwan, the superficial layer is composed of basalts, while at the bottom are alternating beds of sandstones, shales or sands and clays, which can be recharged by meteoric water percolating through the weaterhed zone of basalts capable of transmitting water but not storing water.

3.7 Groundwater in Permafrost Areas

China's permafrost is mainly distributed in the northern Greater Khingan, Lesser Khingan, Altai, Tianshan and Qilian Mountains and Qinghai-Xizang plateau, covering a total area of about 1.9 million km^2, about one-fifth of the whole territory of China. Its distribution accords laterally with the latitudinal zoning, and vertically with the vertical zoning. Thus the groundwater may be classified into the high-latitude mountain permafrost groundwater and the middle and low-latitude plateau permafrost groundwater.

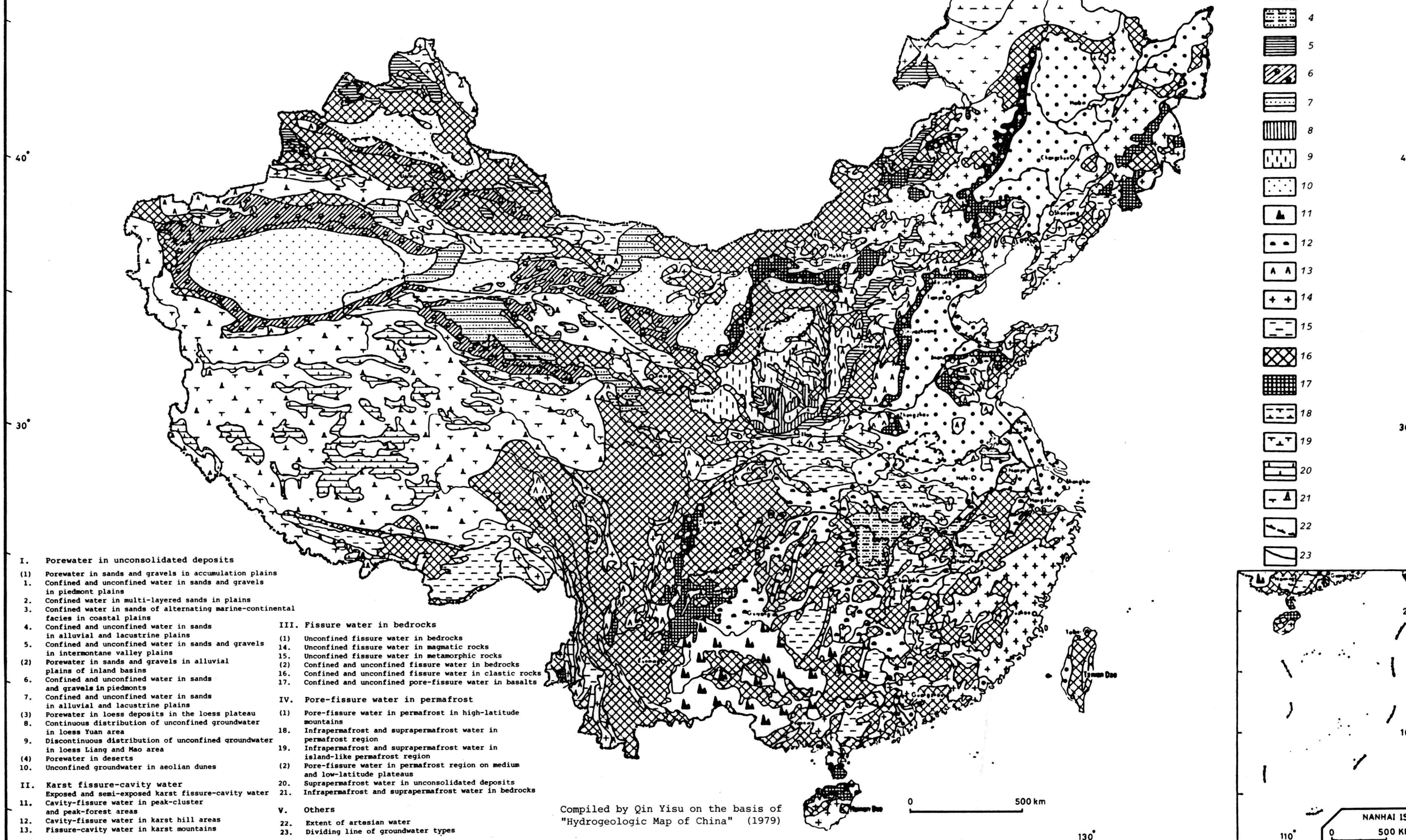
The high-latitude mountain permafrost groundwater is mainly distributed in the northern Greater and Lesser Khingan Mountains and the Altai Mountains. The permafrost there can be regarded as the southern-edge permafrost of the Eurasian Continent. The climate is frigid, with mean annual temperperatures of 0 - 4 °C. The Greater and Lesser Khingan Mountains are about 1500 m above sea level, composed mainly of volcanic rocks. The Altai Mountains are 1000 - 4000 m above sea level, mainly made up of volcanic rocks and clastic rocks. The distribution of the permafrost from north to south in the northern Greater and Lesser Khingan Mountains is characterized by: (a) the transition from continuous to discontinuous permafrost; (b) the decrease of thickness from 120 m to about 30 m; and (c) sporadic permafrost further southwards. Groundwater in permafrost areas differs in its mode of occurrence. According to its burial conditions, it may be classified as suprapermafrost water which occurs at shallow depth. Its quality is a little better than that of river water, but its quantity is not very large. Intra-permafrost water exists within the thawed zones of permanently frozen ground, where the thickness of aquifer is highly variable, but in general it is rather thin. The quality of intra-permafrost water is better than that of suprapermafrost water, but the quantity is relatively small. Subpermafrost water is usually confined groundwater of larger quantity than infra-permafrost water, yielding nearly 13 m^3/h.m, and of fairly good quality serving as a relatively reliable water supply.

Middle- and low-latitude plateau permafrost groundwater is mainly distributed in the Tianshan Mountains, the Qilian Mountains and the Qinghai-Xizang Plateau. Because of the extremely high altitude and the decreasing temperature with the rising relief the necessary conditions for the development of frozen ground are created. The mean annual temperature in this belt ranges between 0 - 12 °C. At the height between 3000 - 5000 m above sea level are the Tianshan and Qilian Mountains, with their main peaks over 5000 m in elevation. The mountains are of metamorphic rocks, clastic rocks, carbonate rocks and igneous rocks. The Qinghai-Xizang Plateau is averagely over 4000 m above sea level, within 14 peaks reaching the height of over 8000 m. It is the highest and largest plateau in the world, constituted by clastic rocks, carbonate rocks, igneous rocks and metamorphic rocks. On the northern Xizang Plateau loose deposits are extensively developed. The mountains are lofty with snow-clad peaks. As a result of repeated structural movements, fold-faults and structural faults are exceedingly well developed. Under these circumstances, the permanent snow and the plentiful precipitation provide good recharge conditions for groundwater. As the altitude of the plateau permafrost region is often higher than that of the lower freezing limit, the permafrost stretches continuously over vast areas, with only small, though numerous, patches of thawed ground. The total thickness of the permafrost is generally within the range from tens of metres to more than one hundred metres, and varies with relief. The permafrost is continuos in a vertical direction, and the thawed zone appears only in the structural fracture zones.

Suprapermafrost water in the plateau permafrost region is common, mostly occurring in the low-lying or sloping zones. It is mainly recharged by meteoric water or melting ice. Its quality is good, but the limited quantity is not available for water supply.

Subpermafrost water is mostly subject to hydrostatic pressure. The pressure is dependent on the thickness of the frozen layer and controlled by the geological structures. Therefore, some down-faulted valleys and basins often provide good spaces for the storage of subpermafrost water, which is exemplified by the down-faulted valley lying to the north of the Tangula Mountains, where confined or artesian water is commonly present beneath the frozen layer about 10 - 50 m thick. The well yields are 10.8 m^3/h. The

SCHEMATIC MAP SHOWING THE GROUND WATER TYPES IN CHINA



water is of calcium (magnesium) bicarbonate and sulfate type, containing less than 0.5 g/l of total dissolved solids. The subpermafrost water in bedrock fractures also occurs in relatively large amounts on the Qinghai-Xizang Plateau. For example, the unfrozen spring on the southern-facing slope of the Kunlun Mountains has a discharge of 89.6 m^3/h and a content of 0.7 g/l of total dissolved solids, belonging to chloride-magnesium bicarbonate type.

4. CONCLUDING REMARKS

On account of the integrated effects of physiographical and geological factors, the formation and regional distribution of China's groundwater have different features in different regions. According to the distribution and occurrence of groundwater, in this paper China is divided into seven groundwater regions and the groundwater is classified into four basic types (see the appended map). Groundwater is abundant in the great plains in the east, but the change of water quality is rather complicated. The Loess plateau and the bedrock mountainous areas are comparatively short of water. However, in recent years good results have been achieved through exploration in the sections with copious deep groundwaters. In karst areas, cavity-fissure water is abundant, but it is unevenly distributed. In local areas the land is arid, and there is a serious shortage of water. In recent years large amounts of work have been done in search of underground river systems, and very good results have been obtained. It is also promising to conduct hydrogeological investigations in deserts and permafrost areas.

Groundwater is one of the natural resources indispensable to the life of human being and production. For more than thirty years, substantial hydrogeological prospecting and study have been made; and as a result, the basic law of the regional distribution of China's groundwater has been preliminary elucidated. With further development of national economy, groundwater in such a vast territory as China should be studied and utilized in a more penetrative way, hence making due contributions to accomplishing the four modernizations.

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THE ASSESSMENT OF HYDROGEOLOGICAL FEATURES USING THE TECHNIQUE OF TERRAIN CLASSIFICATION

K.A. Styles and A.D. Burnett

ABSTRACT

This paper discusses the system of regional and detailed terrain classification used by the Geotechnical Control Office of the Hong Kong Government to assist the assessment of engineering feasibility for planning and land management purposes. The features of the mapping system which have hydrogeological applications are highlighted.

INTRODUCTION

In 1979, the Geotechnical Control Office (GCO) commenced a programme of terrain classification mapping, known locally as the Geotechnical Area Studies. The purpose of these studies is to provide engineering based terrain information for planning and land use management. This is necessary because of the high geotechnical constraints associated with the steep hillslopes and geologically complex terrain within the Territory of Hong Kong. The difficulty of undertaking development on this terrain is exacerbated by high annual rainfall which averages about 2500 mm (98 in.) most of which falls in a 6 month period from May to early November. Individual storms often result in excess of 250 mm (10 in.) of rain in a 24 hour period.

At an early stage in the programme it was decided that a systematic approach to data collection should be adopted, and terrain classification was selected as an ideal mechnanism to collect the physical land resource information required. Brand et al. (1982) describe the basic mapping programme.

The GCO recognised that, in order to assist Government's decision making process for land development information relevant to geotechnical engineering was required on a regional as well as on a more site specific basis. Terrain classification systems were therefore designed to provide reconnaissance data for use at both 1 : 20 000 and 1 : 2500 scales.

The terrain classification system used by the GCO is designed specifically for engineering purposes and, in particular, to highlight areas that contain or are subject to geotechnical constraints for development. Hydrogeological data is an important factor in engineering appraisal, particularly in geotechnics, and both regional and district terrain classification schemes incorporate a substantial amount of information regarding surface hydrology and possible groundwater flow. The purpose of the terrain classification programme is not necessarily to solve the geotechnical problems as such but rather to highlight areas of concern for further detailed assessment at project layout or design phase. The application for hydrogeological purposes are pitched at a similar level.

In addition to the terrain classification programme, the GCO is involved in a number of projects related to groundwater modelling,, predicition of subsurface flows and infiltration rates in volcanic, granitic and colluvial materials. Nash and Dale (in press) discuss the generalised flow paths of groundwater in a highly developed colluvial hillslope in Hong Kong. Leach and Herbert (1982) discuss the genesis of a groundwater model on steep terrain and Malone and Shelton (1982) review the effect of groundwater on landslides occurring in Hong Kong between 1978 and 1980.

In this paper, discussion is confined to the application of the terrain mapping to four of the major fields of interest outlined in the general brief for this meeting, namely:

(i) preparation of hydrogeological maps from geological maps complemented by little or no field data;

(ii) organization of mapping programmes relating to selection of priority areas, scale, legends and time schedule;

(iii) the relevance of hydrogeological maps for development; and

(iv) special problems associated with surface and subsurface flows in volcanic, granitic, colluvial, and man-made materials.

SYSTEMATIC TERRAIN CLASSIFICATION

Terrain classification is a technique which uses aerial photograph interpretation as a basis for systematic data collection. Aerial photographs when viewed stereoscopically enable the examination of the terrain as a three-dimensional image. The landform pattern can, however, be recorded in a two-dimensional form as a series of terrain units on a map or plan. A system of letter/number codes is used to describe the different features or attributes of the terrain and the product is known as a Terrain Classification Map. Examples of typical maps are presented at Fig. 1 and Fig. 7.

The type of observations relating to the nature and distribution of the terrain are determined by the purpose and the scale of the project. Examples of the data which can be collected and stored in a terrain classification map include: geology, slope gradient, aspect, relief, terrain component, terrain morphology, erosion/instability, slope condition, surface hydrology, rainfall, vegetation and land use. In most instances, it is essential that a terrain classification scheme is designed with specific project requirements in mind. Therefore, the size, shape and detail of the map units are directly related to the aims of the projects.

For geotechnical engineering purposes in Hong Kong, it was appropriate to aim at two very distinct levels of mapping detail. A generalized small scale (1 : 20 000) approach was adopted for regional assessment of relatively large areas, whilst a more detailed approach (1 : 2500) was essential for more site specific appraisal. Obviously, a major consideration in the design of terrain classification or any other mapping programme for that matter must relate to "economy-of-scale". A large scale (1 : 2500) survey requires more time and effort per hectare than a small scale (1 : 20 000) survey. In our experience, terrain classification mapping at a scale of 1 : 20 000 can be completed at a rate of approximately 300 hectares per day as opposed to 5 hectares per day at a scale of 1 : 2500. One of the major pitfalls in this work is to attempt to record too much information for the desired use. Over-classification results in a level of data in the terrain classification legend which cannot be reflected in the mapping. An extremely detailed classification legend (example at Fig. 2) is useless at 1 : 20 000 because the map base is too small to record or systematically map the variation of the attributes. There are many situations where time and effort are wasted because too much detail is sought for the problem in hand.

If maximum cost-benefit is to be achieved the regional survey should define the general location of problem areas before detailed terrain classification at a larger scale is applied to highlight individual features. The regional level can also double as an inventory of land resources which is not only suitable for problem related appraisal, as in the case of geotechnics, but also forms a mechanism for resource assessment. This type of information can be readily linked through a computer interface to form a data bank management system.

In order to demonstrate the application of terrain classification for hydrogeological mapping purposes, the Regional (1 : 20 000) and District (1 : 2500) mapping system in use in Hong Kong is summarised. Terrain classification is only the first phase of data gathering in a chain of progressively more intensive and more site specific investigation carried out within the GCO. It constitutes an organisational tool for effective management of landform data, existing site investigation data and fieldwork and can be applied to many tasks. Collection of data in a systematic manner enables comparison across regions or from site to site and hence, forms a basis for the formulation of models and further more detailed work.

HYDROGEOLOGY AND REGIONAL TERRAIN CLASSIFICATION

The legend of the Terrain Classification Map designed for use at 1 : 20 000 (Fig. 1) consists of three basic attributes, namely: slope gradient, terrain materials and erosion/instability. These attributes are divided into some 45 classes which describe the general character of the land surface. Hydrological or hydrogeological features of the terrain are reflected in almost every class contained in the classification system. An insight into the general behaviour of surface runoff and groundwater patterns can be gained from the interpretation of the terrain materials and erosion attributes. A few of the major hydrogeological features which are associated with terrain classes are presented:

(i) Hillcrest or ridge -- generally insitu materials associated with interfluvial terrain; usually occur as zones of surface runoff and dispersion; usually convex or planar in morphology; possible zone of infiltration in decomposed granite or highly jointed volcanics; groundwater behaviour subject to geological constraints.

(ii) Sideslope -- generally insitu material, hillslopes may be straight, concave or convex in morphology which influences surface runoff and infiltration; subsurface groundwater regime related to nature and structure of geological materials; granitic materials often subject to high infiltration and tunnel erosion; seepage is common along relict joints in granitic materials and along well developed joints in the volcanics.

(iii) Footslope -- generally colluvial material (debris accumulation); footslopes may be straight, concave or convex in morphology which influences surface runoff and infiltration; stratification of deposits is common and results in differential permeability of layers; tunnels and voids are common in colluvial layers; perched water tables are possible.

(iv) Drainage Plain -- colluvial deposits on footslope terrain which is subject to overland flow and periodic inundation; these areas are characterised by unusual groundwater regimes with severe problems for engineering and construction; perched water tables possible; these areas are not only zones of concentration for surface flow but subsurface flow as well, tunnels and voids up to 2 m in diameter are common within these deposits.

(v) Floodplain -- generally low lying alluvial plain which is subject to overland flow and regular inundation; probable zones of permanently elevated or fluctuating groundwater table.

(vi) Coastal and Alluvial Plain -- generally low lying alluvial deposits which are often associated with zones of high groundwater table; possible tidal response and saline intrusion.

(vii) Cut Slope -- areas of insitu or colluvial materials where natural groundwater regime may be disturbed by construction activity; seepage zones and spring lines are common in volcanics and decomposed granite.

(viii) Fill Slope -- man-made areas where natural drainage, runoff and groundwater patterns may be disturbed by construction activity; zones of perched water table are possible; fill may disrupt natural drainage lines; poorly compacted or inadequately drained fill may form water ponding areas and be subject to liquefaction.

(ix) Reclamation -- areas of possible high water table and differential settlement; water table may respond to tidal action; surface drainage and runoff is often poor.

(x) Sheet/Rill Erosion -- may correspond to zones of high infiltration depending on the nature of geological materials.

(xi) Gully Erosion -- may define natural drainage lines, zones of high infiltration or active groundwater regime depending on the nature of geological materials; may indicate areas subject to tunnel erosion.

(xii) Instability -- landslips or areas of slope failure are generally associated with zones of active groundwater regimes and often coincide with springs or seepage fronts.

At a scale of 1 : 20 000 it is possible to extract maps of a hydrogeological nature directly from the basic Terrain Classification Map and a general knowledge of the regional geology. Maps could be prepared for hydrogeological resource assessment or for more problem-oriented projects of an engineering or agricultural nature. For example, maps could be derived on the following themes:

- potential areas of groundwater concentration and high transmissivity associated with structural discontinuity;
- potential areas of high infiltration;
- potential areas of sheet and gully erosion;
- potential areas of high water table associated with alluvial deposits and floodplain;
- potential areas of natural tunnels and voids in colluvial materials;
- potential areas of concentration of surface and subsurface water flows;
- areas of drainage convergence or divergence; or
- catchment form and drainage pattern.

In the Geotechnical Area Studies Programme, the derivative maps which contain hydrogeological information at 1 : 20 000 scale are:

(i) Landform Map (Fig. 2). This map is extracted from the Terrain Classification Map and highlights the location of: floodplain, alluvial deposits, colluvial drainage plain, colluvial footslopes, disturbed terrain, cliff, reclamation, waterbodies, ponds, and littoral zone. In this map the slope gradient is shown together with the description of the terrain unit.
The Landform Map is designed specifically for the geomorphological assessment of engineering projects and could be used to review hydrogeological variation of the terrain.

(ii) Erosion Map (Fig. 3). This map is extracted from the Terrain Classification Map and highlights the location of important erosional and landslip features. It summarises the general distribution of sheet, rill, gully erosion and the location of large landslips and zones of general instability. This map could be applied to highlight erosional features which may be induced by hydrogeological factors.

(iii) Geotechnical Land Use Map (Fig. 4). This map is extracted from the Terrain Classification Map and presents in a non-technical manner the general level of geotechnical constraint associated with the terrain. Subclass IIS indicates the general level of geotechnical limitation associated with floodplain.

(iv) Physical Constraints Map (Fig. 5). This map is extracted from the Terrain Classification Map and presents the major physical constraints for development of the terrain. The map highlights a number of features which are important from a hydrogeological point of view. These are: colluvial drainage plains, colluvial footslopes, floodplain, disturbed terrain, zones of instability, waterbodies and severe gully erosion. This map could be applied to engineering assessment of general hydrogeological problems.

(v) Engineering Geology Map (Fig. 6). This map is partially derived from the Terrain Classification Map and partially from other geological sources. It displays the broad pattern of geological materials, structural discontinuities and general site investigation data. Structural discontinuities usually occur as zones of intense weathering which may act as locii for concentration of groundwater flow. They are shown on the map as photogeological lineaments. The Engineering Geology Map also delineates the major catchment and subcatchment boundaries and classifies them on the basis of Strahler's (1952) stream hierarchy.

A relatively detailed evaluation of the general drainage basin morphometry is completed for each study area. This information, combined with an interpretation of the general hydrogeological behaviour of the lithological units, provides a firm basis for evaluation of surface water and to some extent groundwater behaviour. Table 1 illustrates the type of drainage basin data derived in a regional survey and this data may be assessed in conjunction with rainfall data for the design of drainage measures during engineering appraisal.

The regional approach fulfills a particular aim and that is to highlight general target areas of potential or limitation. The next step in the planning process is to concentrate attention on the target areas themselves.

HYDROGEOLOGY AND DETAILED TERRAIN CLASSIFICATION

The legend of the Terrain Classification Map designed for use at 1 : 2500 (Fig. 7) consists of six basic attributes: slope gradient, terrain component, terrain morphology/materials, erosion/ instability, slope condition, and surface hydrology. These are divided into approximately 74 classes which describe the general features of the land surface in considerable detail. It is generally possible to delineate features such as springs, seepage front, landslips, and erosion.

Terrain classification at this scale represents an almost ten-fold increase in map scale over the regional level of study. Therefore, the information collected must reflect this change in detail. In fact, the average size of map unit at 1 : 2500 scale is approximately 30 m² on the ground as opposed to 5000 m² at 1 : 20 000 scale. Similarly, study areas are usually 100 to 150 hectares in size in comparison with the 10 000 hectares involved in a regional study.

Each of the 21 classes of terrain component are relevant to hydrological or hydrogeological interpretation. The classes are: hillcrest, ridge, sideslope, footslope, drainage plain, incised drainage channel, disturbed terrain, disturbed terrain/ drainage plain, rock exposure, alluvial plain, floodplain, coastal plain, stream course (perennial), stream course with rock exposure in bed (perennial), stream course with rock exposure in bed (ephemeral), man-made channels, water storage, swamp/marsh, reclamation, beach and dune. The attributes which record surface morphology/material distribution, erosion/instability and slope condition can also be applied to the characterization of surface runoff and general groundwater pattern.

The sixth attribute deals specifically with the surface expression of groundwater distribution. The classes relate to areas where unusual groundwater activity is apparent and these are often characterized by inlet zones, outlet zones or spring activity, water ponding areas and broad zones of surface water movement.

The Terrain Classification Map (Fig. 7) and legend (Fig. 8) form the basis of a number of derivative maps which are designed to highlight particular features for engineering use. Examples of some of the hydrogeological maps which could be derived from the terrain classification are:

-- potential areas of groundwater concentration and high transmissivity associated with structural discontinuity;
-- potential areas of high infiltration;
-- groundwater contour models based on terrain morphology;
-- potential areas of high water table associated with alluvial deposits and zones of saline intrusion;
-- potential areas of natural tunnels in colluvial material;
-- potential seepage areas associated with disturbed terrain;
-- areas of divergence and convergence of surface runoff;
-- runoff models associated with terrain angle and materials;
-- potential sites for piezometer installation;
-- summary of catchment characteristics and flow patterns;
-- potential areas of tunnel and gully erosion;
-- potential areas of instability associated with springs; and
-- potential areas of fillslope instability associated with disruption of natural drainage.

In the Geotechhical Area Studies Programme, the derivative maps which contain hydrogeological information at a scale of 1 : 2500 are:

(i) <u>Engineering Geology Map</u> (Fig. 9). This map is partially derived from the Terrain Classification Map and partially from other geological sources. It displays the general pattern of geological materials, structural dicontinuities, and associated information at a scale of 1 : 2500. The object of the Engineering Geology Map is to delineate the nature and extent of the geological constraints related to the terrain. The information which has application for hydrogeological investigations are: boundaries of major rock units and superficial deposits, major structural discontinuities, major topographic and geomorphological features, landslips and other erosional features, seepage zones and drainage paths, piezometer and borehole locations, and man-made slopes.

(ii) <u>Surface Hydrology Map</u> (Fig. 10). This map is partially derived from the Terrain Classification Map. It presents the basic pattern of surface hydrology at a scale of 1 : 2500. The map delineates catchment boundaries, natural drainage lines, man-made channels, predevelopment drainage, seepage zones, springs and other features associated with the surface expression of the groundwater regime.

(iii) Engineering Data Sheet (Fig. 11). This map supplements the Engineering Geology Map. It presents detailed factual information relating to previous site investigation, cutslopes, fillslopes, retaining walls and the location of observations made during fieldwork.

The engineering Geology Map and the Surface Hydrology Map highlight engineering constraints for development. These maps may be used to design drainage measures and as a framework for review of existing groundwater and catchment monitoring schemes. They could also be applied to the design of site investigation programmes for the location of piezometers and other instruments for monitoring of groundwater and surface runoff.

CONCLUSIONS

(i) Systematic terrain classification is an extremely powerful reconnaissance tool that can assist hydrogeological investigations. The technique has application for national inventory, regional assessment or can be oriented towards detailed investigation of a more site specific nature. Maps of a hydrogeological nature can be derived from the terrain classification system at 1 : 20 000 or 1 : 2500 scale.

(ii) The preparation of hydrogeological maps and the design of monitoring programmes can be expedited by the use of terrain classification maps in conjunction with existing geological data.

(iii) Detailed preliminary assessment of project requirements enables economy in data collection. It is necessary to indicate the minimum requirements for systematic coverage of a project area and to reflect this level of interest in the terrain classification. In general terms, a regional review should be completed prior to detailed site specific work. From a hydrological point of view it is quite pointless to select a trial catchment for monitoring if the catchment is not representative of other catchments in the area of interest.

(iv) The general format provided by the terrain classification approach at a regional level is relevant for the preparation of hydrogeological maps for resource development on the one hand and more specific problem solving on the other. Areas of potential for groundwater extraction could also be delineated using the terrain classification approach.

(v) General areas of problematical hydrogeology are delineated at the regional level and subsequently, individual problems can be pinpointed by detailed terrain classification for site investigation and monitoring.

(vi) Terrain classification provides a system for the preparation of land inventory and is well suited for developing countries because its application need not be restricted to a single purpose. The regional system described in this paper could be as readily applied to agricultural or urban capability classification, borrow resource estimation or materials assessment as it is to hydrogeological analyses or geotechnical suitability.

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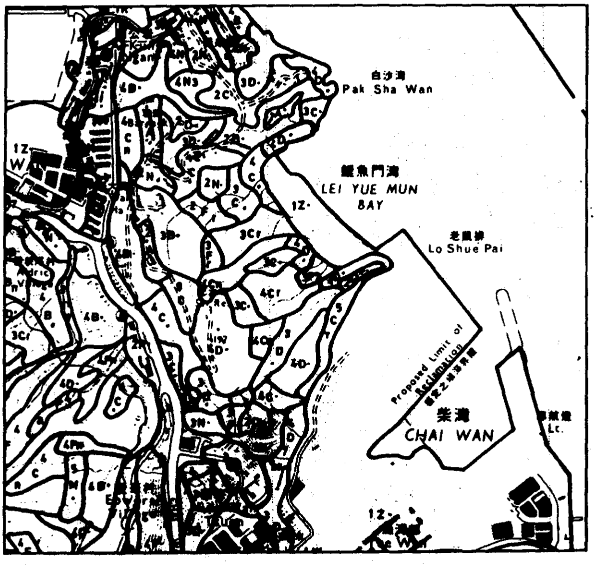


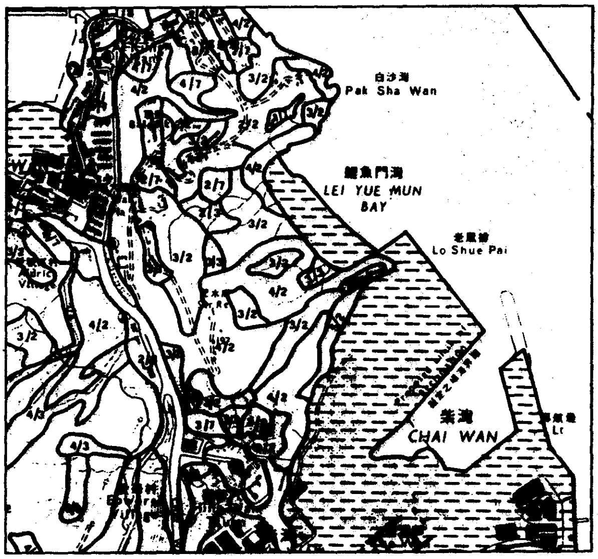
LEGEND FOR TERRAIN CLASSIFICATION MAP

SLOPE (degrees)	CODE
0 - 5	1
5 - 15	2
15 - 30	3
30 - 40	4
40 - 60	5
> 60	6

TERRAIN COMPONENT	CODE
Crest or ridge	A
Sideslope straight	B
concave	C
convex	D
Footslope straight	E
concave	F
convex	G
Drainage plain	H
Flood plain	I
Coastal plain	K
Littoral zone	L
Rock outcrop	M
Cut straight	N
concave	O
convex	P
Fill straight	R
concave	S
convex	T
General disturbed terrain	V
Reclamation	Z
Alluvial plain	X
Waterbodies (Natural stream	1
(Man-made channel	2
(Water storage dam	3
(Fish pond	4

EROSION	CODE
No appreciable erosion	.
Sheet erosion minor	1
moderate	2
severe	3
Rill erosion minor	4
moderate	5
severe	6
Gully erosion minor	7
moderate	8
severe	9
Well-defined recent landslip > 1ha in size	a
Development of general instability) recent	n
) relict	r
Coastal instability	w

SCALE 1 : 20 000	TERRAIN CLASSIFICATION MAP AND LEGEND	FIG. 1

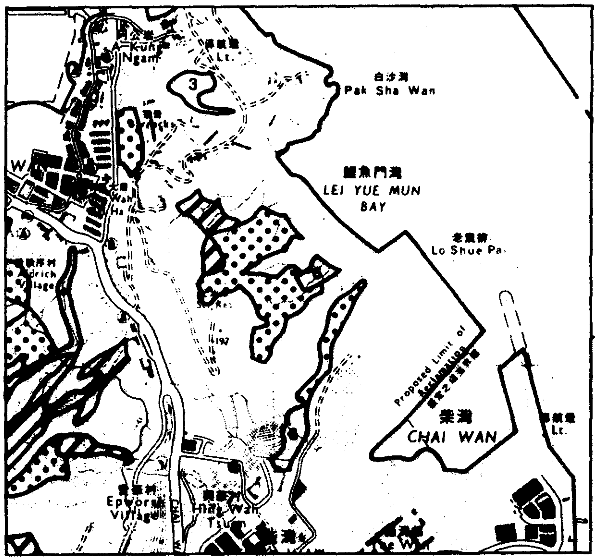


LEGEND FOR LANDFORM MAP

1	0 - 5° (gently sloping)
2	5 - 15° (gently-moderately sloping)
3	15 - 30° (moderately sloping)
4	30 - 40° (steep)
5	40 - 60° (mountainous)
6	> 60° (precipitous)

1	Crest or ridge
2	Sideslope - insitu
3	Footslope - colluvium
4	Drainage plain - colluvium subject to overland flow and regular inundation. Unusual groundwater regime.
5	Alluvial plain - includes raised terraces.
6	Flood plain - portion of alluvial plain subject to overland flow and regular inundation. Unusual groundwater regime.
7	Disturbed terrain - cut
8	Disturbed terrain - fill
9	Cliff and rock outcrop
	Reclamation
	Waterbodies
	Ponds
	Littoral zone

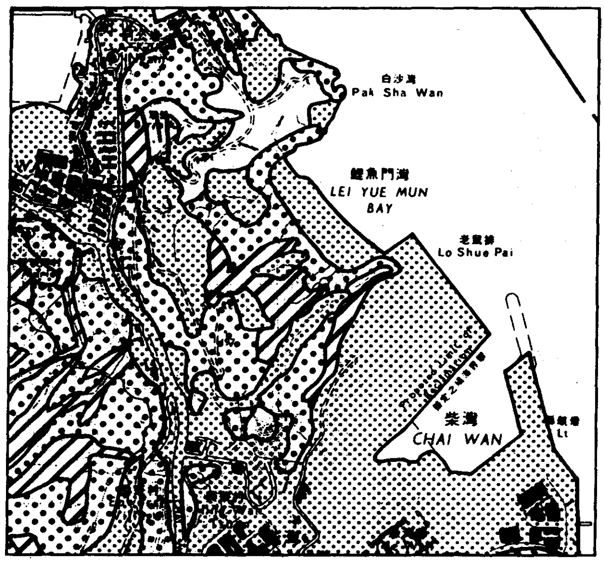
SCALE 1 : 20 000	LANDFORM MAP AND LEGEND	FIG. 2



LEGEND FOR EROSION MAP

Symbol	Description
(blank)	No appreciable erosion
1	Minor sheet erosion
2	Moderate sheet erosion
3	Severe sheet erosion
4	Minor rill erosion
5	Moderate to severe rill erosion
6	Minor gully erosion
7	Moderate to severe gully erosion
(dotted)	Zones of general instability associated with predominantly insitu terrain
(hatched)	Zones of general instability associated with predominantly colluvial terrain
	Waterbodies (streams, man-made channels, storage dams)
	Ponds
	Littoral zone (generally subject to tidal action)

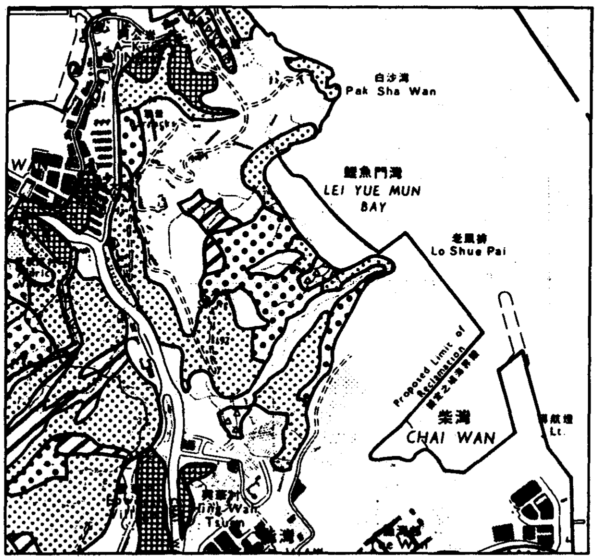
SCALE 1 : 20 000	EROSION MAP AND LEGEND	FIG. 3



LEGEND FOR GEOTECHNICAL LAND USE MAP

- Class I - Low Geotechnical Limitations
- Class II - Moderate Geotechnical Limitations
- Class IIS - Moderate Geotechnical Limitations (including flooding)
- Class III - High Geotechnical Limitations
- Class IV - Extreme Geotechnical Limitations

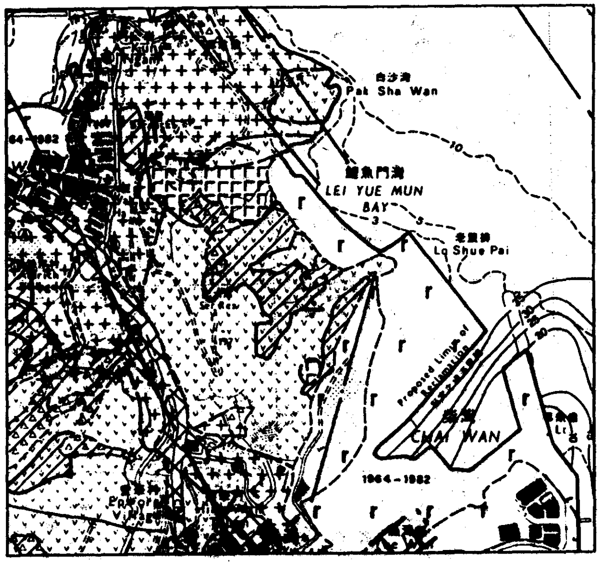
SCALE 1 : 20 000	GEOTECHNICAL LAND USE MAP AND LEGEND	FIG. 4



LEGEND FOR PHYSICAL CONSTRAINTS MAP

- Colluvium
- Zones of colluvium which are subject to overland flow and periodic inundation. Evidence of unusual groundwater regime (delineated as drainage plain on Landform Map)
- Floodplain - subject to overland flow and regular inundation. Evidence of unusual groundwater regime (delineated as floodplain on Landform Map)
- Zones of general instability associated with predominantly colluvial terrain
- Zones of general instability associated with predominantly insitu terrain
- Slopes on insitu terrain which are generally steeper than 30 degrees (other than those delineated as colluvial or unstable)
- Disturbed terrain - extensive cut and fill batters which generally exceed 30 degrees
- Instability on disturbed terrain
- Water bodies (streams, man-made channels, storage dams)
- Ponds
- Moderate or severe gully erosion (may be superimposed upon other constraints)
- Littoral zone (generally subject to tidal action)

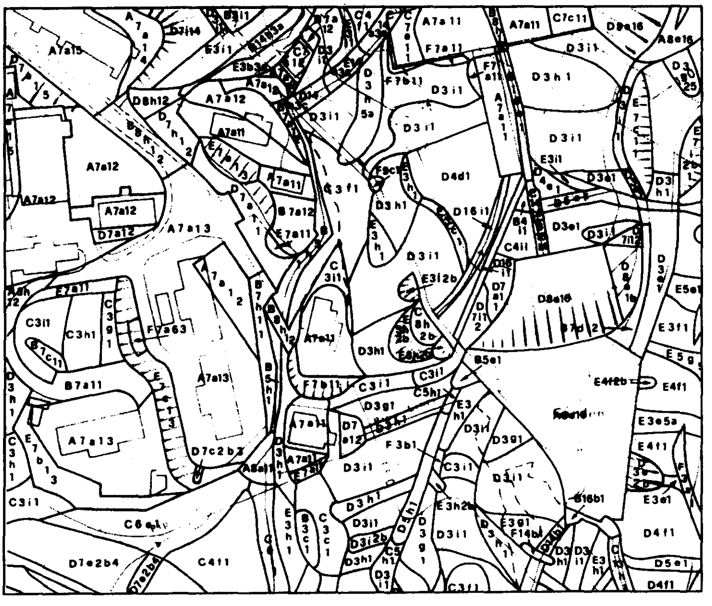
SCALE 1 : 20 000	PHYSICAL CONSTRAINTS MAP AND LEGEND	FIG. 5



LEGEND FOR ENGINEERING GEOLOGY MAP

- Fill
- Reclamation
- Littoral Deposits
- Alluvium (Undifferentiated)
- Colluvium (Undifferentiated)
- Hong Kong Granite
- Hong Kong Granite: fine grained porphyritic phase
- Hong Kong Granite: medium grained porphyritic phase
- Quartz Monzonite
- General Instability
- Feldspar Porphyry Dyke
- Quartz Porphyry Dyke
- Dolerite Dyke
- Geological Boundary (solid)
- Geological Boundary (superficial)
- Photogeological Lineament
- Fault
- Ma On Shan Granite
- Cheung Chau Granite
- Sung Kong Granite
- Granophyric Microgranite
- Undifferentiated Volcanic Rocks)
- Sedimentary Rocks and Water Laid Volcaniclastic Rocks)
- Acid Lavas) Repulse Bay Formation
- Coarse Tuffs)
- Dominantly Pyroclastic Rocks with some Lavas)
- Tai Po Granodiorite)
- Strike and Dip of Beds
- Strike and Dip of Schistosity
- Strike of Bedding - Dip Unknown
- Vertical Bedding
- G C O Rock Collection Sample Point
- Catchment Boundary

SCALE 1 : 20 000	ENGINEERING GEOLOGY MAP AND LEGEND	FIG. 6



SCALE 1 : 2 500	TERRAIN CLASSIFICATION MAP	FIG. 7

LEGEND FOR TERRAIN CLASSIFICATION MAP

Slope Gradient

Code	Description
A	0 - 5°
B	5 - 15°
C	15 - 30°
D	30 - 40°
E	40 - 60°
F	> 60°

Terrain Component*

Code	Description
1.	Hillcrest
2.	Ridge
3.	Sideslope
4.	Footslope
5.	Drainage plain
6.	Incised drainage channel
7.	Disturbed terrain
8.	Disturbed terrain/drainage
9.	Rock exposure
10.	Alluvial plain
11.	Floodplain
12.	Coastal plain
13.	Stream course (perennial)
14.	Stream course with rock exposure in bed (perennial)
15.	Stream course with rock exposure in bed (ephemeral)
16.	Man-made channels (including catchwaters)
17.	Water storage
18.	Swamp/marsh
19.	Reclamation
20.	Beach
21.	Dune

Terrain Morphology

Code	Description
a	Straight - insitu terrain
b	Concave - insitu terrain
c	Convex - insitu terrain
d	Straight - colluvial terrain (Relict d)
e	Concave - colluvial terrain (Relict e)
f	Convex - colluvial terrain (Relict f)
g	Straight - < 2m thick colluvium
h	Concave - < 2m thick colluvium
i	Convex - < 2m thick colluvium
j	Straight - corestones on insitu terrain
k	Concave - corestones on insitu terrain
l	Convex - corestones on insitu terrain
m	Straight - alluvial terrain (relict m)
n	Concave - alluvial terrain (relict n)
o	Convex - alluvial terrain (relict o)

* Minor disturbance of terrain is indicated by underlining the terrain attribute code. This is used in three situations :

(i) Squatter development on either natural terrain or terrain subject to major disturbance.
(ii) Development of minor roads, cemeteries or small lots, where the constituent components of cut and fill slopes and platforms are too small to be individually delineated.
(iii) Apparently natural terrain which may have been subject to a minor degree of disturbance during landscaping.

Erosion Classification (Terrain Denudation)

Code	Description	Code	Description
1.	No appreciable erosion		
2.	Landslip		
	Well defined landslip	a	Integral (Integral should only be used for rotational failures with minimal displacement)
		b	Scar
		c	Debris
	General evidence of instability on	d	Colluvial terrain (hummocky terrain, tension cracks or compression ridges etc.)
		e	Insitu terrain (terracetting, tension cracks or compression ridges without well defined failures.
3.	Sheet erosion (assessed from ground cover)	a	Minor - (1-10 percent bare ground)
		b	Moderate-severe - (11-40 percent bare ground)
		c	Very severe - (> 40 percent bare ground)
4.	Rill erosion	a	Minor - (incipient parallel rivulets - spacing generally > 2m apart)
		b	Moderate-severe - (deeply incised parallel rivulets - generally < 20cm in depth - spacing generally < 2m apart)
		c	Very severe - (deeply incised parallel rivulets - generally between 20-50cm in depth - spacing generally < 2m apart)
5.	Gully erosion	a	Minor - a single gully generally < 0.5m in depth
		b	Moderate-severe - a single incised gully which is generally 0.5 to 5m in depth or a multiple system of gullies.
		c	Very severe - a single deeply incised gully which is generally > 5m in depth and/or a multiple system of incised gullies.
6.	Highly jointed boulders or rock exposure, including cut slopes, with adverse jointing.		

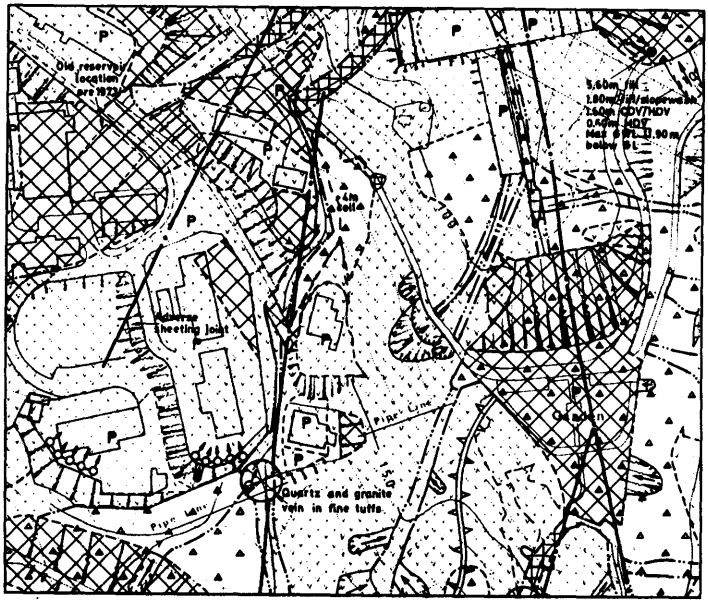
Slope condition

Description	Code	Height in metres
Cut	1	0 - 5
	3	5 - 10
	5	10 - 20
	7	20 - 30
	9	> 30
Fill	2	0 - 5
	4	5 - 15
	6	15 - 30
	8	> 30

Hydrology

Description	Code
Inlet zone	a
Outlet zone	b
Water ponding area	c
Surface groundwater movement	d

SCALE 1 : 2 500	TERRAIN CLASSIFICATION MAP LEGEND	FIG. 8



LEGEND FOR ENGINEERING GEOLOGY MAP

Symbol	Meaning	Symbol	Meaning
	Fill (made ground)		Slope failure
	Fill over alluvium		Zone of general evidence of instability
	Fill over colluvium		Boulders
	Colluvium (< 2 metres thick)		Spring
	Hong Kong Granite		Seepage line or front
	Repulse Bay Formation		Major areas of exposed rock
	Geological boundary (approximate)		Man-made slope
	Boundary of superficial deposits (approximate)	P	Man-made platform
	Photolineation		Borehole location with simplified borehole log
			Severe gully erosion

Major drainage channel (natural and man-made), subject to periodic flooding

Major joint orientation pattern at individual exposures, dip direction indicated.

Rose diagram giving regional trends of joint planes

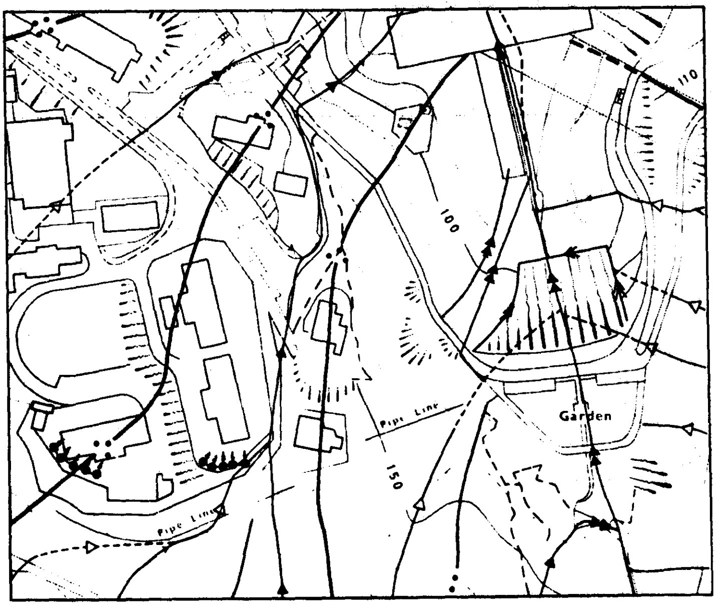
Convex break in slope)
Centreline of spur line) unaffected by development
Centreline of ridge crest)

Dv	Decomposed volcanics)	prefixed by weathering grades	(RS	Residual soil
			(C	Completely
Dg	Decomposed granite)		(H	Highly
			(M	Moderately
			(S	Slightly

e.g. CDv is completely decomposed volcanics

All	Alluvium (undifferentiated)	GL	Ground level
Coll	Colluvium (undifferentiated)	m	metre
GWL	Groundwater level	max	maximum

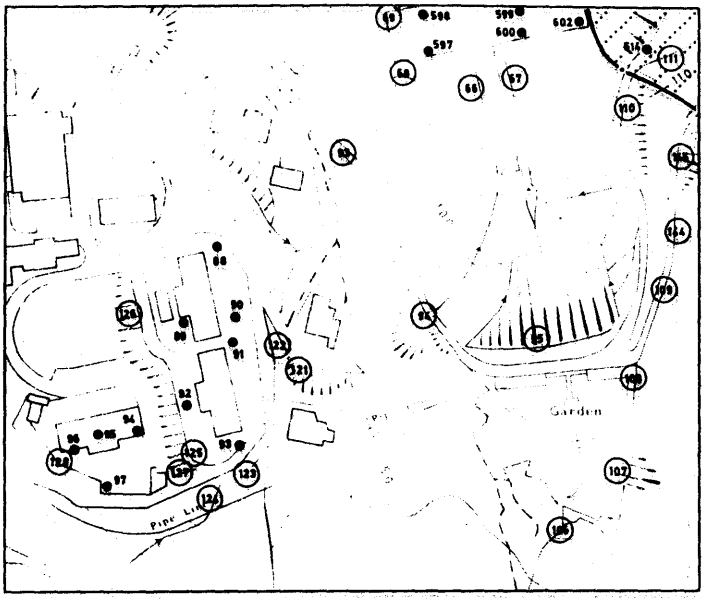
SCALE 1 : 2 500	ENGINEERING GEOLOGY MAP AND LEGEND	FIG. 9



LEGEND FOR SURFACE HYDROLOGY MAP

Existing	)	Catchment boundary
Predevelopment	)	
(number of dots refer to drainage order)		
Existing	)	Drainage line (ephemeral stream)
Predevelopment	)	
Existing	)	Drainage line (perennial stream)
Predevelopment	)	
Spring		
Water ponding area		
Man-made channels		

SCALE 1 : 2 500	SURFACE HYDROLOGY MAP AND LEGEND	FIG. 10



LEGEND FOR ENGINEERING DATA SHEET

90	Borehole location and number
93	Location and number of field observation
	Area affected by disused tunnel systems.
	Tunnel portal
14/11-SW-B 1923	Landslips and boulder falls registered by Geotechnical Control Branch (GCB), including approximate date of failure
	Landslide Study Phase IIA, Vicinity of 27 Barker Road (Altadena).
	Landslide Study Phase IIC, The Peak Area.
	Landslide Study Phase IIC, Mid-Levels East Area.
57/11-SW-D/C444	'CHASE' study slope and number - Existing Slopes Division, GCO.

SCALE 1 : 2 500	ENGINEERING DATA SHEET AND LEGEND	FIG. 11

DESCRIPTION \ LOCATION		CATCHMENTS: NORTHWARD DRAINING REGIME										CATCHMENTS: SOUTHWARD DRAINING REGIME				
		LO WU	HUNG LUNG HANG	LIN MA HANG	SHA TAU KOK	HANG TAU/ TAI PO	SHEUNG SHUI	FANLING	HOK TAU	NAM CHUNG	HAM HANG MEI	LAM TSUEN	FUNG YUEN	TING KOK	WANG SHAN KEUK	TAI PO KAU
Number of Streams per Order Nu	2	172	103	101	85	257	39	220	383	154	64	191	77	153	107	Only Minor Portion of Catchment lies within Study Area
	3	41	29	25	22	59	11	57	84	31	15	55	22	46	25	
	4	9	8	7	5	16	4	15	21	10	3	15	6	12	8	
	5	2	2	3	1	4	2	4	5	2	1	2	2	2	2	
	6	-	1	1	-	1	1	1	1	1	-	1	1	-	-	
	7	3	-	-	-	-	-	-	-	-	-	-	-	-	-	
	8	1	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Nu	228	143	137	113	337	57	297	494	198	83	264	108	213	142	
Total length of streams per order Lu (m)	2	26 600	17 000	22 800	24 000	55 000	9 800	43 000	65 600	35 400	14 000	44 000	12 300	37 000	24 400	
	3	12 600	7 200	11 400	10 500	25 200	3 200	20 800	23 400	8 800	5 200	27 600	5 400	22 400	10 000	
	4	4 800	10 800	6 600	7 300	9 400	1 200	10 700	17 000	7 800	4 200	15 400	2 100	7 300	4 900	
	5	4 000	6 400	4 000	1 400	6 200	3 900	4 800	9 600	5 000	300	3 800	1 000	3 400	4 300	
	6	-	900	7 400	-	7 900	2 800	5 000	8 900	1 000	-	5 800	1 100	-	-	
	7	11 600	-	-	-	-	-	-	-	-	-	-	-	-	-	
	8	8 800	-	-	-	-	-	-	-	-	-	-	-	-	-	
	Lu	68 400	42 300	52 200	43 200	103 700	20 900	84 300	124 500	58 000	23 700	90 600	21 900	70 100	43 600	
Mean length of streams per order Tu (ie) Lu/Nu (m/stream)	2	155	165	226	282	214	251	195	171	230	219	230	160	242	228	
	3	307	248	456	477	427	291	365	279	284	347	502	245	487	400	
	4	533	1 350	943	1 460	588	300	713	810	780	1 400	1 027	350	608	613	
	5	2 000	3 200	1 333	1 400	1 550	1 950	1 200	1 920	2 500	300	1 900	500	1 700	2 150	
	6	-	900	7 400	-	7 900	2 800	5 000	8 900	1 000	-	5 800	1 100	-	-	
	7	3 867	-	-	-	-	-	-	-	-	-	-	-	-	-	
	8	8 800	-	-	-	-	-	-	-	-	-	-	-	-	-	
Area of Subcatchment (km^2)	Au	14.12	11.08	9.49	8.15	18.49	7.03	15.38	21.38	7.34	3.86	18.23	4.17	13.20	6.2	
Length of Subcatchment (km)	Lb	6.3	3.74	6.30	2.06	7.12	4.34	5.42	6.78	3.86	2.54	5.44	2.04	2.84	3.04	
Bearing of Axis	θ	98°	131.5°	75.5°	317.5°	181.5°	168.5°	171.5°	108°	183°	183°	228°	334.5°	328°	251°	
Width of Subcatchment (km)	Br	6.00	5.08	3.28	5.60	4.10	2.82	4.96	7.64	2.56	2.50	4.70	3.34	7.12	2.98	
Bearing of Axis	θ	188°	221.5°	165.5°	47.5°	271.5°	258.5°	261.5°	198.5°	273°	273°	318°	64.5°	58°	341°	
Subcatchment Perimeter (km)	P	27.20	16.20	17.40	16.40	21.70	11.62	18.00	27.20	11.80	10.20	18.60	10.00	20.60	11.00	
Subcatchment Circularity = Au/area of circle with same P	Rc	0.240	0.531	0.394	0.381	0.493	0.654	0.597	0.363	0.662	0.466	0.662	0.524	0.391	0.625	
Subcatchment elongation = Diameter of circle with same P/Lb	Re	1.374	1.379	0.879	2.534	0.970	0.852	1.057	1.277	0.973	1.278	1.088	1.56	2.309	1.081	
Drainage Density Lu/Au	Du	4.844	3.818	5.500	5.301	5.608	2.973	5.481	5.823	7.902	6.140	5.299	5.252	5.311	7.243	
Stream Frequency (ie) Nu/Au No of streams per order/km	2	12.18	9.30	10.64	10.43	13.90	5.56	14.30	17.92	20.98	16.58	10.48	18.46	11.59	17.78	
	3	2.90	2.62	2.63	2.70	3.19	1.56	3.72	3.93	4.22	3.89	3.02	5.28	3.48	4.15	
	4	0.64	0.72	0.74	0.62	0.87	0.57	0.98	0.98	1.36	0.78	0.82	1.44	0.92	1.93	
	5	0.14	0.18	0.32	0.12	0.22	0.28	0.26	0.23	0.28	0.26	0.11	0.48	0.15	0.33	
	6	-	0.09	0.11	-	0.05	0.14	0.07	0.05	0.14	-	0.05	0.24	-	-	
	7	0.22	-	-	-	-	-	-	-	-	-	-	-	-	-	
	8	8	0.07	-	-	-	-	-	-	-	-	-	-	-	-	
	Fu	16.15	12.91	14.44	13.87	18.23	8.11	14.31	23.11	26.48	21.67	14.48	25.90	16.14	23.59	
Elevation of Highest Point on Watershed (mPD)	Z	185	340	492	480	565	255	470	630	630	340	800	440	630	600	
Elevation of Subcatchment Mouth (mPD)	z	0	10	10	0	10	10	10	10	0	0	0	0	0	0	
Basin Relief Z-z (m)	H	185	330	482	480	555	245	460	620	630	340	800	440	630	600	
Relief Ratio H/Lb	Rh	2.9	8.8	7.7	23.3	7.8	5.6	8.5	9.1	16.3	13.4	14.7	21.6	22.2	18.5	
Geology		Alluvium/ meta-sediments	Alluvium/ Pyroclastic	mainly Pyroclastic	mainly Pyroclastic	Alluvium/ Colluvium Pyroclastic	Alluvium/ Colluvium Pyroclastic	Mainly Pyroclastic	Mainly Pyroclastic	Sediments	Sediments	Superficial Pyroclastic Granodiorite	Pyroclastic	Pyroclastic	Pyroclastic	
Vegetation/ landuse		Grassland/ Cultivated	Grassland/ Cultivated	Grassland	Grassland/ Cultivated	Cultivated/ Grassland/ Shrubland	Cultivation/ Development	Grassland/ Shrubland/ Development	Grassland/ Shrubland	Grassland/ Shrubland	Cultivation	Cultivation/ Shrubland	Shrubland	Shrubland	Shrubland/ Grassland	

SURVEY OF MAJOR CATCHMENTS IN THE STUDY AREA — Table 1

Hydrogeological Mapping in Asia and the Pacific Region
Proceedings of the ESCAP-RMRDC Workshop, Bandung, 1983

GROUNDWATER RESOURCES DEVELOPMENT AND MANAGEMENT IN INDIA

B.D. Pathak

1. INTRODUCTION

In recent years, growing recognition of the role of groundwater in providing an assured water supply for irrigation, domestic and industrial requirements has led to its accelerated development in India during the past two decades. At present, 43 % of irrigation water requirements are met from groundwater. Dependence on this resource has recently increased due to the introduction of high-yielding crop varieties and the adoption of multi-cropping patterns, for both of which a timely and reliable irrigation water supply is a pre-requisite. Groundwater-resource utilization in canal-command areas offers a means of stabilizing the water table as well as of correcting the imbalance in the groundwater system which causes water-logging problems.

2. THE HYDROGEOLOGICAL SETTING IN INDIA

The Central Ground Water Board has covered in its regional hydrogeological surveys an area of 1.77 mill. km², which is a little more than half of the area of the country. To investigate the groundwater potential of certain areas as well as to evaluate aquifer parameters, over 4500 exploratory boreholes in the depth range of 200-700 m have so far been drilled, employing a fleet of 59 drilling rigs. To reassess the groundwater conditions periodically, the areas covered under the hydrogeological surveys are subjected to reappraisal studies every third to fifth year. As a result of these studies an area of over 0.5 mill. km² has so far been found worthy of groundwater development in the country.

3. WATER BALANCE STUDIES

3.1 Unconsolidated Formations

Studies in five basins covering an area of about 200 000 km² were undertaken by the Central Ground Water Board in the arid, semi-arid and sub-humid climatic zones of West and Northwest India. The studies revealed that the recharge from rainfall in the semi-arid areas was about 5 % and in the sub-humid regions 14-18 %. The contribution of return flow from applied irrigation, though somewhat complex to assess, was estimated to vary form 20-35 %, and specific yield had an average value of 8 % in the alluvial formations comprising fine to medium sands and clays. These values were also found to apply to the aeolian deposits of the western desert of India, where the total annual precipitation is limited to about 250 mm.

The percentage values of rainfall infiltration were, however, found to be higher in the sub-humid areas bordering the foothills of the Himalayas, where these vary from 18 to 35 %. The seepage from canals in these areas was estimated at 1.8 to 2.5 m^3/s per km^2 of irrigated area. The norms calculated from the studies constitute an authentic base for the evaluation of resources of basins with similar hydrogeological and hydroclimatic settings in other parts of the country. The consolidated formations were found to be suitable for constructing shallow, medium and deep tube wells with an average yield of 50-200 m^3/h at economically feasible drawdowns. On the basis of these studies, plans for further development and management of the resources were drawn indicating the design criteria and spacing and intensity of structures in the various areas.

3.2 Consolidated rocks

In the hard rock formation of the southern peninsula, the Central Ground Water Board undertook five water balance studies and calculated the various norms for the estimation of the potential. The results obtained indicated that the contribution of rainfall to groundwater storage was 5 % in the discharge and 15 % in the recharge area. The seepage from surface storage tanks was estimated at 9-10 % and return flow from irrigation at 10-12 %. The average effective porosity for the hard rock formations comprising granites and gneisses was computed at 3 %. The studies undertaken by deep drilling down to a depth of 280 m proved the existence of artesian conditions in the underlying limestone of the southern peninsula. The discharge from the tube wells varied from 2 m^3/h to 100 m^3/h in certain favourable areas.

3.3 Semi-consolidated formations

Studies of these formations comprising Tertiary sandstones show that the effective porosity varies from 1-7 % depending upon the level of consolidation.

4. HYDROGRAPH NETWORK MONITORING PROGRAMME

With a view to assessing periodically the behaviour of the groundwater system and changes in the chemical regime, the country has been covered by a national groundwater network of about 5000 observation stations in the various basins and sub-basins. Each station at present is responsible for about 700 km², which is considered to be rather disproportionate. Thus, the number of these stations is proposed to be increased to about 10 000 by 1985 to make the observations more intensive. The observations from these stations are at present recorded 5 times a year, and the chemical quality tests are performed twice a year in the pre- and post-recharge periods. A programme for monitoring the behaviour of the deeper aquifers by installing small-diameter piezometers and equipping these with self-recording facilities has already been launched. This permits a precise monitoring of the effects of possible periods of deficit rainfall and enables suitable suggestions to be made regarding the installation of tube wells for providing water supply during period of drought. Based on the observations recorded, annual and decade reports are being brought out for planning and development by the user agencies and also for persuing scientific research in the development and conservation of the resources.

5. TRAINING FACILITIES

To meet the need for trained man-power in the country, regular training programmes on the techniques of hydrogeological surveys and on the exploration and evaluation of groundwater potential and its development and management are being organized. A 12-week course is conducted during the winter season for the young in-service officers of federal and state organizations. This course primarily takes the form of class-room lectures on theoretical and applied aspects in the disciplines of hydrogeology, drilling, geophysics, hydrology, hydrochemistry, and remote sensing techniques for 6 weeks and intensive field training for a further period of 6 weeks. Under this programme over 500 in-service officers have so far been trained.

Special short-term programmes for the in-service officers of Asian, African and other countries are also being organized. The Board has also deputed a number of officers to the African and Middle-Eastern countries to render guidance in field operations and to conduct training of counterpart personnel.

Training of middle- and top-level scientists is also being undertaken by organizing seminars, symposia and workshops on various subjects. A seminar on assessment, development and management of groundwater resources was held very recently on April 29th and 30th, 1983.

6. EQUIPMENT

The country has launched an organized programme of research and development of equipment to meet growing needs. Although it has at present the necessary technical know-how for manufacturing all drilling equipment of various types and capacities, emphasis is being laid on the manufacture of rigs having a capacity to drill down to 500 m, to which depth most of the production tube wells are generally drilled. The general depth of heavy-duty tube wells in the alluvial areas is at present 200-300 m except in certain areas where drilling to the depth of over 700 m has been carried out. In addition, small-capacity "down the hole" hammer rigs (200 m) and percussion and combination rigs (500 m) are being manufactured in the country. The number of drilling rigs of various types available in the country at present exceeds 1000.

As an aid to studies in borehole geophysics, a multi-channel electric logger has also been developed, and production has already started. The country is also producing medium-duty compressors, heavy-duty pumps as well as very low-capacity ejector-type pumps for use in the small water-supply tube wells for public health purposes. The India Mark II hand pump has internationally been accepted as a pumping device for village water-supply schemes.

In order to cope with problems posed by the general energy crisis the world over, alternative means of energy are being developed and utilized. Solar pumps, windmills and biogas plants are being produced to provide energy for pumping devices of low-capacity tube wells. In addition, defluoridization and desalinization equipment is also being produced for use in areas where groundwater contains fluoride and chloride in quantities beyond permissible limits.

7. GROUNDWATER DEVELOPMENT -- STATUS, POLICY AND PROGRAMME

Of late, groundwater investigation and development have gained momentum not only in our country but throughout the world in order to cope with the increasing demand for a greater quantity and assured supplies of fresh water caused by population expansion and industrial and agricultural growth.

The Government of India attaches great importance to the joint use of ground- and surface water resources in a coordinated, planned manner; thus, while exploitation of groundwater can, to a certain extent, reduce the level of the water table, it must also be recognized that surface-water irrigation will add to the groundwater potential. In other words, development of both ground- and surface waters is complementary, and there is need for an integrated planning of the use of the two so that an optimum balance between them can be struck.

An additional area of 13,76 mill. ha is proposed to be brought under irrigation in the period 1980-1985. Of this, 7 mill. ha will be irrigated by groundwater. In addition, increased water supply will be needed for industrial growth and for meeting the requirements of several hundred urban centres and of the rural population of India. Groundwater could be a major source of supply for industrial and public health purposes. Of the country's 572 000 villages nearly half have still to be provided with protected water supplies. For the majority of these villages, water will have to be supplied from the groundwater resources. Under the International Water Supply and Sanitation Decade Programme, safe drinking water will be made available to all the villages in the country before 1990.

The full development of the resources may pose a number of management problems. Studies on all possible aspects including artificial recharge, optimum water use, recycling of waste water and prevention of groundwater pollution are already being undertaken to equip the scientists, engineers and planners with a high level of knowledge and proficiency so that they can manage the situations likely to arise in future.

Hydrogeological Mapping in Asia and the Pacific Region
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HYDROGEOLOGICAL PROBLEMS OF HARD ROCK AREAS OF SOUTHERN INDIA

K.C.B. Raju

Nearly two-thirds of the Indian subcontinent is composed of hard rocks. Wide variation in climatic conditions, physiographic features and in rock types of southern India produces a complicated hydrogeological setting and makes its assessment problematic.

The southern part of the peninsula of the Indian Subcontinent is geographically divided into 4 distinct physiographic units, namely, the coastal plains, the Eastern Ghats, the Western Ghats, and the Central plateau. Between the Western Ghats and the Arabian Sea lies a narrow coastal strip, while between the Eastern Ghats and the Bay of Bengal there is a broader coastal belt. The area is drained by 4 major rivers: Godavari, Krishna, Pennar and Cauveri. It receives rainfall both from southwest and northeast monsoons. The presence of the Western Ghats directly in the path of southwest monsoon currents has a significant effect on the rainfall distribution over the area. The Western Ghats and the region to the west are humid with very heavy rainfall, ranging from 1000-3000 mm with highest annual rainfall of more than 8000 mm at Augumbe in Karnataka. In contrast, the area to the east is comparatively dry and semi-arid with rainfall of 450 to 1000 mm except in the eastern coastal regions, which receive rainfall from the northeast monsoon and the depressions and cyclones during April-May and October-December. The rain-shadow effect of the Western Ghats extends inland to a distance of more than 200 km. This belt is more than 1000 km long and includes areas with an annual rainfall of less than 600 mm. The annual potential evaporation exceeds 1800 mm in Andhra Pradesh and Tamil Nadu and amounts to less than 1400 mm in the coastal belt.

Geologically speaking, South India presents a broad spectrum of rock types belonging to various formations ranging in age from Archaean to Recent. However, it is predominantly underlain by the Archaean crystalline complex with a wide range of rock types of different metamorphic grades. Granites and gneisses are the most common rock types encountered. Gneissic rocks are banded and widespread, while granites stand out as prominent ridges and are highly jointed. The gneisses are well foliated with the major foliation directions varying from NW-SE to NE-SW and E-W. These have been traversed by basic and acid intrusives.

The charnockites are confined to the territory of the Eastern and Western Ghats and adjacent areas. The khondalites are well foliated with a N-S or NNE-SSW trend and steep dips and are intensely weathered.

The Dharwarian schists and the associated formation occur as patches and bands within the gneissic complex in parts of Karnataka, Tamil Nadu, Kerala, and Andhra Pradesh. They are high-grade metamorphic rocks with foliation trends ranging from NNW-SSE to N-S with steep dips.

The crystalline limestones are associated with khondalites and sillimanite gneisses in the Eastern and Western Ghats. These are fractured and have well-developed solution channels.

The peninsular shield is the oldest stable block of the subcontinent which has not been affected by orogenic processes since the close of the Pre-cambrian era. However, it has suffered normal and block faulting with the result that some portions have been uplifted. Rocks of the Archaean crystalline complex, the Dharwar schists and the Precambrian sediments have been tectonised and deformed in many ways and have, for example, been deeply eroded over the great span of geological time.

STRUCTURES

All the major rock types encountered in the area show moderate to pronounced, vertical to sub-vertical gneissic foliation. Charnockites are more massive than gneisses. The granites show pronounced foliations at their contact with the gneisses but become more massive away from the contact zone. Joints parallel to the foliation are very common in almost all rock types. However, fewer joints occur, on average, in charnockites than in gneisses. Sheet joints are common in granites as well as in charnockites but they become widely spaced, tight and infrequent with depth. Tension joints perpendicular to the fold axis have been observed in areas where rocks have been folded.

Most of the lineaments and major fractures can be grouped into three directions:

viz. 1. NE-SW or Eastern Ghat trend,
2. NW-SE or Dharwarian trend,
3. E-W.

Some of the major river courses follow the major lineaments along parts of their courses.

Investigations indicate that the lineaments in the area are connected with the tectonics. As regards groundwater productivity, the NW-SE trending lineaments and fractures supply the highest yields, whereas moderate yields are obtained from the E-W trending lineaments and the lowest from the NE-SW lineaments. It was also concluded from the detailed studies that the outputs are higher in areas of tension fractures.

Groundwater development in hard rocks was generally confined to the weathered mantle. However, the increase in withdrawal has resulted in the decline of the water table. This has necessitated exploring deeper fracture aquifers by means of drilled wells. Groundwater extraction by means of open dug wells has become costlier, whilst the drilling of deep boreholes is gaining momentum due to the implementation of D.T.H. air rotary rigs.

The open wells, which were easy to construct and hitherto cheaper, have become more costly due to the increase in excavation depth necessitated by the decline of the water table. These structures occur in their millions. The determination of the hydraulic parameters of fracture aquifers by pumping tests in large-diameter open wells is still to be perfected. Similarly, the analysis of pumping test data from boreholes is to be refined in order to give reliable hydraulic parameters of the hard rock aquifers.

Special multi-disciplinary water-budget projects have been constituted on a prototype basis in order to assess the total water resources of the hard-rock basins. The results of the projects are intended to serve as guidelines for future groundwater management on a planned and scientific basis and in evolving standards, methodology and procedures which can be applied over wider areas with a similar hydrogeological setting.

The hydrogeological map and other special maps prepared for the Noyil-Amaravati-Ponnani river basin are described below.

HYDROGEOLOGICAL MAP OF THE NOYIL, PONNANI AND AMARAVATI RIVER BASINS, TAMIL NADU AND KERALA, INDIA (C.G.W.B.)

This map at a scale of 1 : 253 440 covers an area of 8150 km² and lies mainly within the Archaean crystalline complex. The various rock types, i.e. alluvium, basic and ultrabasic rocks, magnetite-quartzites, syenites, granites, hybrid gneisses, hornblende-biotite gneisses, charnockites, calc-granulites and associated crystalline limestones and garnetsillimanite gneisses, are distinguished by separate symbols in grey instead of brown as recommended in the International Legend (Section D), since the "regions generally with very local groundwater" are also to be represented in brown colour (Section F 17 of the International Legend).

The various rock types have been represented separately by symbols instead of grouping them as intrusive rocks or metamorphic rocks. It has been our experience that certain rock types have higher potential groundwater yields the reason for which, however, is in certain cases disputed, hence the need to classify them separately. The geological boundaries and structural details are shown in black as recommended. Details with regard to 'Hydrography' and 'Groundwater Hydrology' are also presented as recommended in the International Legend. With respect to the 'character of the aquifer', the porous formations include alluvium/colluvium and weathered (hard rock) zones. The colour codes recommended for porous formations, fissured formations and regions generally without groundwater have been used. The hydrogelogical map also includes lineaments and fractures as observed from aerial photographs. Wherever feasible the shear fractures and tensile fractures have been identified and shown accordingly in the map in view of their relevance for groundwater occurrence, movement and availability.

In addition to the hydrogeological map, three more special maps, namely the hydrological and hydrometeorological map, groundwater recharge and balance map, and hydrochemical map have been compiled to represent groundwater and allied aspects in order to obtain an overall picture of the groundwater regimen, the assessment of resources and development prospects. The groundwater recharge and balance map shows average annual recharge contours, while the shades of green in it indicate the groundwater balance available for future development as well as over-developed areas. Brown shows the hilly areas. In this map the hydrography and groundwater contours conform to the International Legend. In the hydrochemical map the groundwaters are classified on the basis of the dominant anions. The colours used (blue for bicarbonate water, green for chloride water, yellow for sulphate water and violet for mixed water) broadly conform to the International Legend. Water-quality hazard areas have been shown in striped colours. More than one water-quality hazard can be found in certain areas, thus giving a criss-cross/interlocked appearance. This naturally cannot figure in the legend of the map.

Hazards to water quality can, perhaps, be better represented on an overlay or as a separate map to avoid such a complicated representation.

SUGGESTIONS

As already explained above, with regard to hard-rock terrain, the groundwater yield often depends on the rock type and, to a certain extent, on the grade of metamorphism. Therefore, from the hydrogeological point of view, it is important that the hydrogeological map distinguishes in some detail between the different rock types and between different grades of metamorphism. In the case of some rock types, it is even difficult to determine the mode of origin, i.e. whether metamorphic or intrusive; for example, the origin of charnockites and certain granites is disputed. The potential groundwater yields of metamorphic rocks vary greatly, ranging from gneisses, on the one hand, to schists on the other, the gneisses generally being more prolific.

The hard rocks have invariably undergone tectonic deformation, resulting in fractures, though the degree of fracturing varies from place to place. Most hard rocks have an identifiable fracture pattern that can be related to geological history. Observations of fracture patterns at a number of places in a given rock unit can be synthesised by means of statistical analysis. Of the many methods adopted in this connection, the strike-frequency diagrams of joints/fractures in the case of rocks exclusively with vertical or near-vertical fracture systems and stereographic projections in rocks with fractures varying in magnitude of dip hold considerable promise for groundwater studies as they give a three-dimensional perspective of fracture systems, direction of maximum intersection and degree of anisotropy. The photogeological studies will enable us to prepare strike-frequency diagrams and stereographic projections in the case of macro-fractures. In view of their relevance in the hard rocks, it is stressed that in future the hydrogeological maps should also include the statistical analysis of joints and fractures, both micro and macro-fractures.

THE STATUS OF HYDROGEOLOGICAL MAPPING IN INDONESIA IN 1983

R. Soekardi and Sutrisno, S.

1. INTRODUCTION

Activities in the field of hydrogeology in Indonesia started approximately a century ago. Up to the end of the Second World War the activities were mainly conducted in connection with domestic water supply and small scale irrigation purposes. After this period, the same activities were still continued. However, intensive hydrogeological investigation had just been started since 1969, the first year of Indonesia's Five Year Development Plan (Repelita I).

The following paper describes in brief the historical development of hydrogeological investigation in Indonesia and reviews activities as well as the state of art of hydrogeological maping carried out by the Directorate of Environmental Geology.

2. HYDROGEOLOGICAL INVESTIGATION

Before the Second World War the aim of the hydrogeological investigation was mainly to solve water supply problems, especially for drinking water pruposes. The earliest investigation was carried out by van Dienst (1870) in the Bogor-Jakarta area in connection with the first unsuccessful water well drilling at Prince Frederik, Jakarta, in 1845. This activity was conducted to investigate the presence of artesian water in the city of Jakarta and based only on the inferred geological map. The "Dienst van het Grondpeilwezen", the predecessor of the present Water Well Drilling Section, was built then, due to the successful artesian drilling in the Jakarta area in 1872.

Since then more investigations were conducted, especially in connection with water well drilling for supplying water to the military camps at various places such as at Cilacap, Semarang, and Gresik. Hydrogeological investigations were then conducted also to solve municipal, rural, industrial, and irrigation water supply problems. In addition, hydrogeological investigations were also carried out to see the possibilities of collecting spring water such as those conducted at the vicinities of Rewut Binangun spring (Malang), Cipaniis spring (Cirebon), and Ronggojalu spring (Probolinggo).

Activities at that time were organized by the "Bureau der Geologisch Technische Onderzoekingen", the predecessor of the present Engineering Geology Division. Until the end of the Second World War, the investigations were not carried out in detail. They were conducted only to obtain the general hydrogeological conditions of the study areas.

Up to 1958, activities in hydrogeological investigation were performed by the Engineering Geology Division and later by the Hydrogeological Section of the former Geological Survey of Indonesia (GSI). During this period, this Section, at the beginning in cooperation with the German Bundesanstalt für Bodenforschung, has performed several hydrogeological surveys in limestone terrains of Madura and Gunungkidul (1961) and Sumba (1964); the results have been compiled in the form of reconnaissance hydrogeological maps. Since then investigations were carried out throughout the Indonesian islands, although they were frequently conducted locally.

Intensive activities in hydrogeological investigation have been carried out by GSI since the first year of the First Five Year Development Plan. The activities include systematic hydrogeological mapping and groundwater resources evaluation. Since GSI was reorganized in 1978, the Directorate of Environmental Geology (DEG), Directorate General of Mines, Department of Mines and Energy, now pursues the hydrogeological investigation project.

Apart from the DEG, a number of institutions are also concerned with hydrogeological investigation, especially in the groundwater development aspects. The Directorate General of Water Resources Development is concerned primarily with all aspects of irrigation, whereas the Directorate General of Housing, Building, Planning and Urban Development, Ministry of Public Work is responsible for designing and supervising the construction of all major urban and small city water supplies and sewerage projects. Through the Directorate of Hygiene and Sanitation, the Directorate General of Communicable Deseases Control is responsible for all aspects of environmental sanitation, including rural community water supply.

3. HYDROGEOLOGICAL MAPPING

3.1 Historical Background

Before the first year of the First Five Year Development Plan (1969), activities on hydrogeological mapping carried out by GSI were still limited. In 1960, GSI published the "Tentative Groundwater Map of Java and Madura", scale 1 : 1 000 000. Later on, in cooperation with the West German Bundesanstalt für Bodenforschung, the Hydrogeological Maps of Madura (1961) and Sumba (1968) were published. Following Indonesia's First Five Year Development Plan in 1969, GSI carried out more extensive hydrogeological investigation, mainly hydrogeological mapping and groundwater resources evaluation. These activities resulted in a great number of internal reports which either have been published in the GSI or DEG annual activity report series or as separate booklets of the different sections of the Hydrogeology Sub-Directorate. Most of the reports generally contain the results and observations of one field season, mainly data on springs, drilling, irrigation, etc., as well as an outline on the geological and

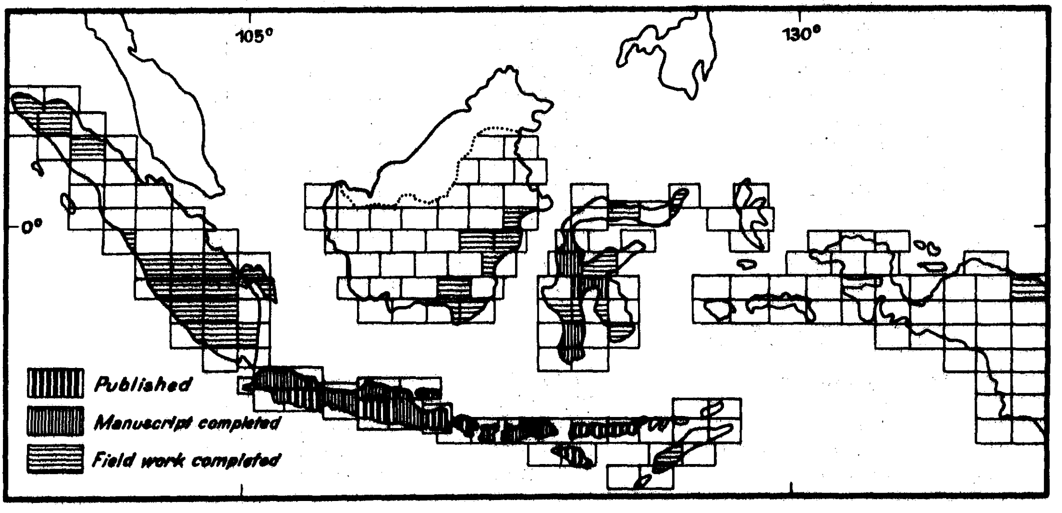

Fig. 1. Status of hydrogeological mapping in Indonesia by the end of November 1983.

hydrogeological setting of the surveyed area. Maps depicting lithological rock units or information on groundwater (e.g. equipotential lines, isolines of ion content, groundwater potential) are also included.

Table 1. Status of Hydrogeological mapping in Indonesia in 1983

Scale : 1 : 250,000

No.	Sheet of map	Year prepared	S t a t u s
1	2	3	4
	J A V A		
1.	Sheet Jakarta (I)	1972/1973	Edited
2.	-"- Cirebon (II)	1972/1973	Edited
3.	-"- Ujung Kulon (III)	1972/1973	Edited
4.	-"- Pelabuhanratu (IV)	1972/1973	Edited
5.	-"- Bandung (V)	1983	Published
6.	-"- Pekalongan (VI)	1973/1974	Edited
7.	-"- Semarang (VII)	1973/1974	Edited
8.	-"- Surabaya (VIII)	1973/1974	Edited
9.	-"- Yogyakarta (IX)	1982	Published
10.	-"- K e d i r i (X)	1973/1974	Edited
11.	-"- Jember (XI)	1981	Published
	S U M A T R A		
12.	Sheet Kutaraja	1975/1976	Fieldwork Completed
13.	-"- Lhok Suemawe	1975/1976	Fieldwork Completed
14.	-"- C a l a n g	1977/1978	Fieldwork Completed
15.	-"- Meulaboh	1977/1978	Fieldwork Completed
16.	-"- Langsa	1978/1979	Fieldwork Completed
17.	-"- Pakanbaru	1975/1976	Fieldwork Completed
18.	-"- Muarasiberuk	1975/1976	Fieldwork Completed
19.	-"- P a i n a n	1975/1976	Fieldwork Completed
20.	-"- Muaratebo	1977/1978	Fieldwork Completed
21.	-"- J a m b i	1977/1978	Fieldwork Completed
22.	-"- P. Bangka	1979/1980	Fieldwork Completed
23.	-"- Palembang	1979/1980	Fieldwork Completed
24.	-"- Banghulu	1977/1978	Fieldwork Completed
25.	-"- Parabumulih	1979/1980	Fieldwork Completed
26.	-"- B a n g k o	1981/1982	Edited
27.	-"- S o l o k	1982/1983	Fieldwork Completed
	K A L I M A N T A N		
28.	Sheet Balikpapan	1980/1981	Fieldwork Completed
29.	-"- Longiram	1980/1981	Fieldwork Completed
30.	-"- Samarinda	1980/1981	Fieldwork Completed
31.	-"- Sangata & Sabang	1981/1982	Fieldwork Completed
32.	-"- Sanggau	1982/1983	Fieldwork Completed

Table 1 cont.

1	2	3	4
	S U L A W E S I		
33.	Sheet Manado	1975/1976	Fieldwork Completed
34.	-"- Tilamute	1976/1977	Fieldwork Completed
35.	-"- P a l u	1980/1981	Edited
36.	-"- Pasangkuyu	1980/1981	Edited
37.	-"- Malili	1980/1981	Edited
38.	-"- Majene	1977/1978	Fieldwork Completed
39.	-"- Palopo	1977/1978	Fieldwork Completed
40.	-"- Pare-Pare	1979/1980	Edited
41.	-"- Watampone	1979/1980	Edited
42.	-"- R a h a	1977/1978	Fieldwork Completed
43.	-"- Ujungpandang	1980/1981	Edited
44.	-"- Bulukumba	1980/1981	Edited
45.	-"- Poso & Ampana	1981/1982	Etited
46.	-"- Gorontalo & Sidate	1982/1983	Fieldwork Completed
	BALI & NUSA TENGGARA		
47.	Sheet B a l i	1970	Published
48.	-"- P. Lombok	1972	Published
49.	-"- Sumbawa	1974/1975	Edited
50.	-"- Flores	1983	Published
51.	-"- S u m b a	1965	Published
52.	-"- P. Timor Barat	1975/1976	Fieldwork Completed
	IRIAN JAYA		
53.	Sheet Jayapura dsk.	1981/1982	Fieldwork Completed

Although nearly 20 % of the country were already covered by hydrogeological mapping in 1978, the number of printed hydrogeological map sheets was rather low. The hydrogeological map of Bali was published in 1970 and the map of Lombok -- again in cooperation with the West German Bundesanstalt für Bodenforschung -- in 1972. Table I and Fig. 1 show the status of hydrogeological mapping by the end of November 1983. It can be seen that some 25-30 % of the country has been covered by systematic hydrogeological mapping.

3.2 Aims and Purpose of Systematic Hydrogeological Mapping

Due to an increasing demand of water for many purposes (drinking water, irrigation and industry) the country needs more information on groundwater resources as an alternative for water supply. Thus, hydrogeological maps are required for regional development planning, since they provide basic data on the occurrence of groundwater, aquifer productivity, groundwater quality and other groundwater related information.

Hydrogelogical maps transfer hydrogeological knowledge to a broader public, e.g. delivering fundamental, mainly groundwater related information to all users who are interested in the hydrogeological setting of an area. These may be local government planners, public authorities, water supply companies, or private users. The map, therefore, may serve as a general hydrogeological basis for further investigation, planning, and compilation of interpretive maps for special purposes.

The map sheets, scale 1 : 250 000, generally cover 1°30' longitude and 1° latitude, i.e. an area of more than 18 000 km². The scale of 1 : 250 000 was determined to be the most appropriate for the map, because it copes best with the following aims and boundary conditions:

-- clear and exact representation of the hydrogeological data for fairly large areas,
-- ability to complete the maps by reasonable means and in relatively short time,
-- availability of recent topographic and geological base maps.

The whole map series of the hydrogeological map of Indonesia will comprise more than 150 sheets (see Fig. 1). Each sheet is to be accompanied by an Explanatory Note, either printed on the map itself or in a separate leaflet. The maps are published in two languages, both in Bahasa Indonesia and English.

The legend of the map series is based on "A Proposal for a General Legend for the Hydrogeological Map of Indonesia 1 : 250 000" which itself was inspired by the "General Legend for the International Hydrogeological Map of Europe 1 : 1 500 000 (Bundesanstalt für Bodenforschung-UNESCO).

Editing of the sheets is done in the hydrogeological mapping sections of DEG, whilst cartographic production and print is conducted by the publication section of Geological Research and Development Centre (GRDC).

3.3 Recent Publications

Sheet XI (JEMBER) of the 1 : 250 000 map series has been chosen as a pilot or model sheet and was published in 1981. It has been edited in cooperation with the German Hydrogeological Advisory Group, Technical Cooperation Project of the Federal Republic of Germany (CTA-40). In 1982, Sheet IX (YOGYAKARTA) has been published, followed by Sheet Flores (in two parts) printed in 1983. Sheets I (JAKARTA) and X (KEDIRI) of Java are under final preparation for printing. They will be published in early 1984.

Copies of the published hydrogeological map sheets are available at the Direktorat Geologi Tata Lingkungan, Jln. Diponegoro 57, Bandung.

Some ten sets of sheet manuscripts are about to be completed and are planned to be published in the near future. First priority is given to the sheets covering Java and the population centres outside Java, as well as to sheets in relatively dry areas.

Besides systematic hydrogeological mapping, scale 1 : 250 000, the draft of a hydrogeological map at the scale of 1 : 5 000 000 has been prepared in 1981 as the Indonesian contribution to the Commission for Geological Map of the World, Sub-Commission for South & East Asia. However, it was recognized that a hydrogeological map at the very small scale of 1 : 5 000 000 is not appropriate to the archipelago country of Indonesia.

A national Hydrogeological Map of Indonesia, scale 1 : 2 500 000 is likely to be more suitable for the country, since it presents in a clear and easily readable way a general outlook on the hydrogeological setting of the whole country. This map will serve as the first basis for country-wide planning, e.g. transmigration projects. In addition, the whole country will be represented in a coherent way and in a relatively short time. Lastly, the expenses for the map will be rather low, and in several remote areas in which large scale hydrogeological mapping is less important, the map will present the only hydrogeological document available in the near future.

The legend of this map is based on a generalized classification into lithological rock units and groundwater potential areas ranging from very high to very low. Important hydrogeological features like great springs, artesian or heavily pumped areas are also shown.

The map is being prepared as a collaboration project of the hydrogeologists of the Hydrogeology Sub-Directorate. It is hoped that up-to-date information can be claimed from the remainder DEG staff and GRDC. The map is scheduled to be published in late 1983.

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REVIEW OF GROUNDWATER IN THE REPUBLIC OF KOREA

Dong Woo Lee

ABSTRACT

Almost 70 % of the Korean peninsula is covered with Precambrian metamorphic rocks and various Mesozoic igneous rocks. The average total annual rainfall is estimated at 114 billion m^3 (114 x 109 m^3). Of this total, 15.3 billion m^3 are utilized, and of this amount 60 % or more is used for agricultural irrigation.

The increase in population together with rapid industrialization, great urban growth and an improvement in the standard of living in Korea will continue to produce higher water consumption and increased demands; therefore, there is an urgent need to develop groundwater resources.

Accordingly, KIER has been carrying out water resources development projects on a national scale since 1967, mainly focusing on the study of hydrogeological aspects of the four river basin areas.

1. INTRODUCTION

Almost 70 % of the Korean peninsula is covered with Precambrian metamorphic rock, mainly granitic gneisses and granitic schists, and with Mesozoic granites. Sedimentary rocks mainly comprise Palaeozoic and Mesozoic formations, whilst Tertiary sedimentary rocks cover the remaining 3 % of the area.

Geomorphologically speaking, the Korean peninsula is a mountainous country with mountains covering about 70 % of the area.

Elevations on the peninsula tend to decrease from north to south and from east to west.

There are five major river basins, two of which drain to the west and three to the southwest.

2. HYDROLOGY

The greatest part of the annual precipitation of the Korean Peninsula falls during the three summer months while very little falls during other seasons. Due to the seasonality of the rainfall coupled with evaporation and the discharge into the sea, the availability of water for exploitation is severely restricted.

The total rainfall of Korea averages 114 billion m^3/a. Of this amount 66 billion m^3/a run off (40 billion m^3 as flood flow and 26 billion as ordinary flow). The remaining 48 billion m^3 is accounted for by evapotranspiration and by recharge to the aquifers and groundwater base flow. It is estimated that 27 billion m^3 is evaporated and that 21 billion m^3 goes to recharge the aquifers.

Of the total annual rainfall (114 billion m^3), the amount available for use is 15.3 billion m^3 (14.1 billion m^3 as runoff and 1.2 billion m^3 as groundwater); of this amount 60 % or more is used for irrigation.

The population of the Republic of Korea now numbers 40 million and by the year 2000 the population could be 50 million. The increase in population coupled with rapid industrialization, great urban growth, the increased standard of living and the use of irrigation water means that water consumption and water demand will continue to rise, with the result that by the year 2000 the total river flow may have been utilized. Thus, a more rational and intensive development of groundwater as an alternative water source is essential.

KIER, affiliated to the Ministry of Science and Technology, is responsible for groundwater resources assessment and survey, and ADC (Agricultural Development Corporation) for the development of groundwater and surface water for irrigation.

The following table shows the projected increase in groundwater demand. It can be seen that in the year 2001 it is likely to be twice that of the present day.

Water Demand

(million cubic meters)

Year	1978	1981	1986	1991	1996	2001
Domestic use	1,915	2,727	3,871	5,021	6,087	6,847
Industrial use	717	1,019	1,689	2,289	2,705	3,300
Agricultural use	10,193	11,113	13,118	13,738	14,357	14,983
Channel storage	3,049	3,049	3,049	3,049	3,049	3,049
Total	15,874	17,908	21,727	24,277	26,198	28,179

3. GROUNDWATER

Groundwater survey and development projects in Korea started in 1960 and have been continued by KIER up to the present day. The National Organization of Groundwater Development was founded in 1969 as a result of the drought of 1968. ADC, the agency for groundwater development for irrigation, was established in 1970 and has continued its activities up to the present time.

Groundwater storage in Korea occurs in two main aquifer types, in alluvial deposits and in fissured bedrock.

A) Alluvial deposits

-- Average base of alluvium: 7 m.
-- Average thickness of aquifer: 4 m.
-- Average effective porosity: 14 %.
-- Water level varies according to rainfall, resulting in a variation of well output of ± 15 %.

B) Bedrock

Favourable storage conditions in the bedrock are found occurring in the following:

-- in the volcanic region of the Jeju Island where groundwater circulates in columnar joints and at interfaces of volcanic rocks;
-- in zones of sedimentary deposits where groundwater occurs in openings such as limestone caves, in bedding planes of sandstone and shale and in tectonic zones;
-- in areas of igneous and metamorphic rock where groundwater is stored in tectonic fracture zones.

4. PREPARATION OF HYDROGEOLOGICAL MAPS

Hydrogeological mapping in Korea has been undertaken by KIER from 1967 to the present day and has been conducted in the following four areas:

i) Anseong River basin,
ii) Upper Jinwi River basin,
iii) northeastern part of Daejeon,
iv) Boseong-Yeosu area.

Summaries of the explanatory texts for the hydrogeological maps of the four areas published by KIER appear in the Appendices.

5. FUTURE ACTIVITIES OF KIER

A groundwater resources survey will be carried out in a pilot-study area during the next 3 years by KIER in conjunction with UN/DTCD. The aim is to acquire an adequate knowledge of groundwater resources for multi-purpose development and for their exploitation.

The objectives of the project are as follows:

-- to establish a data bank relating to groundwater by means of a data collection/storage/retrieval programme,
-- to increase the expertise of KIER in the fields of groundwater survey and development,
-- to carry out pilot studies in the field so as to assess the groundwater potential to the principal water-bearing formations.

APPENDIX 1

EXPLANATORY TEXT FOR THE HYDROGEOLOGICAL MAP OF THE ANSEONG RIVER BASIN

Jeong Ung Lim and Chang Ju Cho

ABSTRACT

This report is concerned with the results of hydrogeological studies in the Anseong River basin located in the central part of the Korean peninsula. The geology of the area mainly consists of biotite granites,

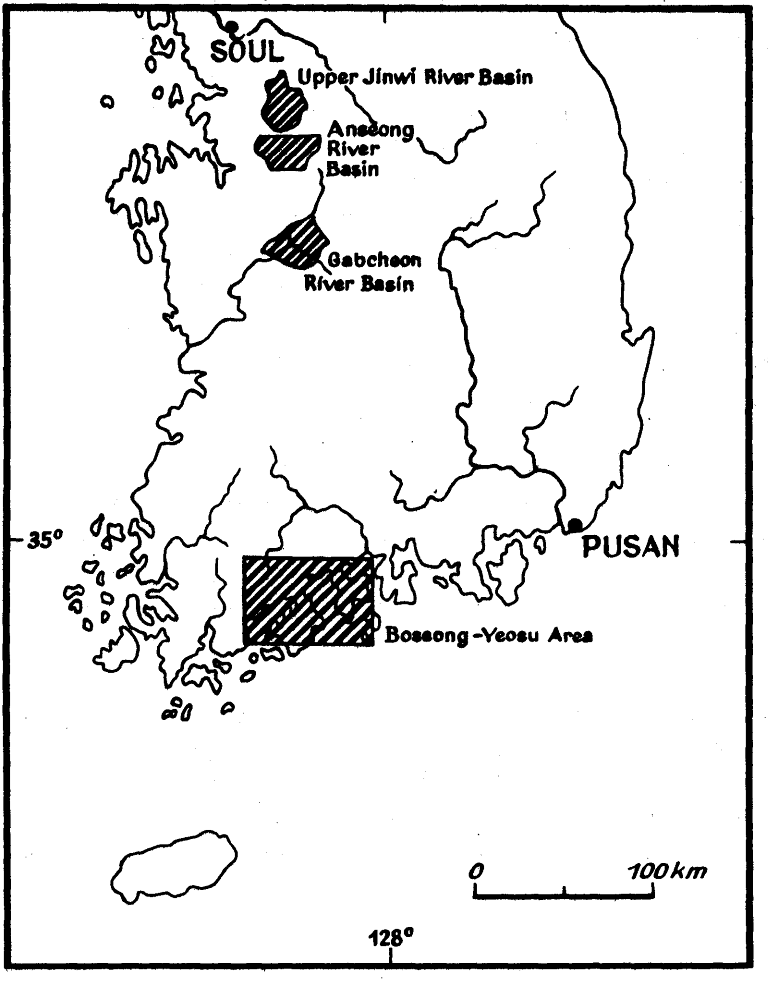


Fig. 1. Status of hydrogeological mapping in the Republic of Korea by 1983.

gneisses and mica schists, of which the probable age ranges from Precambrian to Cretaceous. Investigations have revealed that the occurrence of groundwater in the bedrock itself is not sufficient to make extraction feasible except from the highly weathered zone.

The main aquifers of the Quaternary formations in this basin are either lacustrine deposits or valley fills. The lacustrine deposits in the Pyeongtaek plain are mainly distributed over low-lying areas with altitudes of less than 17 or 18 m a.s.l., while the valley fills are spread along the Anseong River valley. The former, which consist of silty sands, silts and clays, contain a large proportion of organic materials. The beds under these formations, which consist of primary detrital material, in the river valley contain sands or sandy gravels, serve as aquifers. Along the inner part of the valley, the predominant materials are sand and gravel which is considered to be carried at the time of the river valley deposition, but the others generally composed of clay and sandy clay or gravel are regarded as aquicludes. The alluvial deposits reach up to ca. 9 m in thickness in the vicinity of Anseong town and 12 m in the Pyeongtaek area.

In order to determine the hydraulic parameters in this basin, more than 20 aquifer tests were carried out during the investigation. The results show that, in terms of exploitation potential, the most favourable area of the basin is the central part of the Pyeongtaek plain. Here, the transmissibility is 0.8 to 3 m^2/min, and well outputs of more than 500 m^3/d are assured.

Potential total groundwater exploitation rates in this basin could amount to more than 630 000 m^3/d minimum in a year of average annual precipitation and at least 1 100 000 m^3/d during the irrigation season. However, there is no difficulty in imagining that the above values would only reach 470 000 m^3/d and 800 000 m^3/d, respectively, in a water drought striken year.

APPENDIX 2

EXPLANATORY TEXT FOR THE HYDROGEOLOGICAL MAP OF THE UPPER JINWI RIVER BASIN

Jeong Ung Lim and Jin Won Kim

ABSTRACT

This study was carried out during 1970 and 1971 and describes the groundwater in the upper part of the Jinwi River basin, an area of 357 km^2 in the central part of the Korean peninsula.

Quaternary deposits along the valley from the principal aquifer in the drainage basin, in particular in the central zone of the lower reaches of the river channel, where they show a transmissivity coefficient of 500 m^2/d (= 0.35 m^2/min.), with a potential well output of at least 800 m^3/day.

The colluvium in the uppermost reaches of the valley and the weathered zone of bedrock does not show high permeability, but it is a broad enough reservoir to be a good source of groundwater.

Generally speaking, the chemical properties of groundwater and surface water show a relatively low electrical conductivity of less than 200 µS/cm and total hardness of less than 100 ppm. In towns the shallow groundwater usually has higher values of electrical conductivity due to groundwater contamination.

APPENDIX 3

EXPLANATORY TEXT FOR THE HYDROGEOLOGICAL MAP OF THE NORTHERN PART OF DAEJEON (GABCHEON RIVER BASIN)

Jeong Ung Lim

ABSTRACT

The lower reaches of the Gabcheon River basin occupy a wide valley plain in the areas of Daedeong-Gun and the northern part of Daejeon city.

Hydrogeological research was carried out in the drainage basin of the Gabcheon River and its tributaries during 1978 and 1979, and a hydrogeological map was drawn.

The bedrock in this area mainly consists of two Mesozoic mica granites, with gneissic granites of unknown age and Precambrian schists occurring locally.

In the central part of the drainage basin a deep weathered zone has formed as a result of in-situ weathering of the two-mica granites.

Within the drainage basin of the River Gabcheon, Quaternary deposits are widely distributed in the main river valley. This is not the case in the tributary valleys, where sandy gravel and silt deposits reach thicknesses not greater than 10 m. The principal aquifers are sand and gravel deposits with clay interbeds in the Gabcheon River valley.

The average transmissivity is 0.07 - 0.4 m^2/min., and maximum well outputs can safely be estimated at 800 m^3/d. In contrast, wells tapping groundwater at depths of 25 - 40 m in the weathered zones have outputs of 100 m^3/d.

According to the fluctuation of groundwater levels shown on the groundwater contour map, the zone of groundwater movement near the Galmaheon and the Samcheondong areas has a width of about 300 m and a hydraulic gradient of about 1/500.

In other areas, groundwater moves directly to the river channel, i.e., perpendicular to the groundwater contour line. As regards water quality, the conductivity under natural conditions measures 100 - 200 μS/cm, rising to 1000 μS/cm in the contaminated zone.

Unusually, the Udeung-cheon discharge below the city of Daejeon has become highly polluted, so that its toxic effluents travel considerable distances.

In terms of chemical composition, most groundwater has a carbonate and/or non-carbonate hardness.

In dry seasons, the specific runoff in rivers is, on average, 400 - 500 m^3/km^2, which is equal to 16 % of the annual precipitation.

APPENDIX 4

EXPLANATORY TEXT FOR THE HYDROGEOLOGICAL MAP OF THE BOSEONG-YEOSU AREA

Sang Kyu Yun, Dong Young Lee and Chang Eun Lim

ABSTRACT

This survey was carried out to explain the general features of the hydrogeological conditions prevailing in the Boseong and Yeosu areas. The first trial mapping engendered many discussions and suggestions about the methods of data collection, mapping scale, presentation of the data and its eligibility for general utilization. The previous feasibility study in 1979 made it possible to choose the appropriate mapping scale and the methodology for collecting the necessary hydrogeological data with the intention of continuing this kind of mapping throughout the country. The data representation was based on the symbols established by UNESCO.

Investigation for this reconnaissance mapping consisted of collecting data about the present water demand, utilization of groundwater, and representative well inventories, mapping of aquifers, measuring hydraulic and hydrological characteristics and analysing the chemical composition of the groundwater. In addition, data collected from various organizations was examined in detail.

After analyzing the data, this reconnaissance hydrogeological map was compiled to show the distribution and composition of the aquifers and their hydrogeological parameters, the effective yields of wells and aquifers, the interrelation between surface water and groundwater, and the quality of groundwater in the various aquifers, etc.

Hydrogeological Mapping in Asia and the Pacific Region
Proceedings of the ESCAP-RMRDC Workshop, Bandung, 1983

STATUS OF HYDROGEOLOGICAL MAPPING IN PENINSULAR MALAYSIA

Ang Num Kiat

ABSTRACT

In recent years there has been an upsurge of hydrogeological activities in Malaysia, due to the greater need to exploit groundwater as a source of water supply. As a step towards the systematic assessment of the groundwater potential of the country, and to facilitate the planning and implementation of various hydrogeological progammes, a hydrogeological map of the peninsula was published. The problems and limitations involved in the preparation of the map are discussed.

In view of the importance of such maps, a new approach is being adopted in recent hydrogeological programmes giving due emphasis to the mapping aspect.

INTRODUCTION

Although groundwater has been used for some time now as the source of municipal water supply in Arau in the northwestern state of Perlis and in Kota Bharu and several other towns in the northeastern state of Kelantan, the general concept of large scale groundwater development and exploitation is relatively new in Malaysia. The country had in the past been dependent almost entirely on surface sources for its domestic, industrial and agricultural water supplies. It is only in the last two decades or so that groundwater studies and development have been accorded a greater emphasis because of increased water demands due to rapid population and industrial growth coupled with physical constraints in some of the existing surface supply systems. Factors such as drought, pollution, human interference with catchment areas and other environmental problems, have also created a strain on the present surface water sources.

With the new dimension given to the role of groundwater, there has been a corresponding upsurge in activities related to hydrogeological planning, exploration and research. An important aspect of these activities concerns hydrogeological mapping. As a step towards the systematic assessment of the groundwater potential of the country, and as an aid towards the planning of groundwater resources investigations, a first edition of the hydrogeological map of the peninsula was published in 1975. Since then a number of detailed hydrogeological investigations have been completed or are in various stages of completion, and a wealth of information has been acquired. These have contributed significantly towards the understanding of the hydrogeological features and occurrences of groundwater in the country.

THE HYDROGEOLOGICAL MAP OF PENINSULAR MALAYSIA

The decision to compile a hydrogeological map of the country was made at the 8th Joint Session of the Working Group of Senior Geologists, and the Subcommittee on Mineral Resources, held in Bandung, Indonesia, in August 1970. The map, besides fulfilling the objectives outlined earlier, was also part of an exercise to produce a regional hydrogeological map of the then ECAFE region. The responsibility of preparing the map of the country was entrusted to the Geological Survey of Malaysia. Technical guidance was provided by a senior ECAFE hydrogeologist.

The first hydrogeological map of Peninsular Malaysia was published in 1975, on a scale of 1 : 500 000. This map was the first attempt at synthesizing hydrogeological data available then at the archives of the Geological Survey of Malaysia and was based on four main aspects, namely:

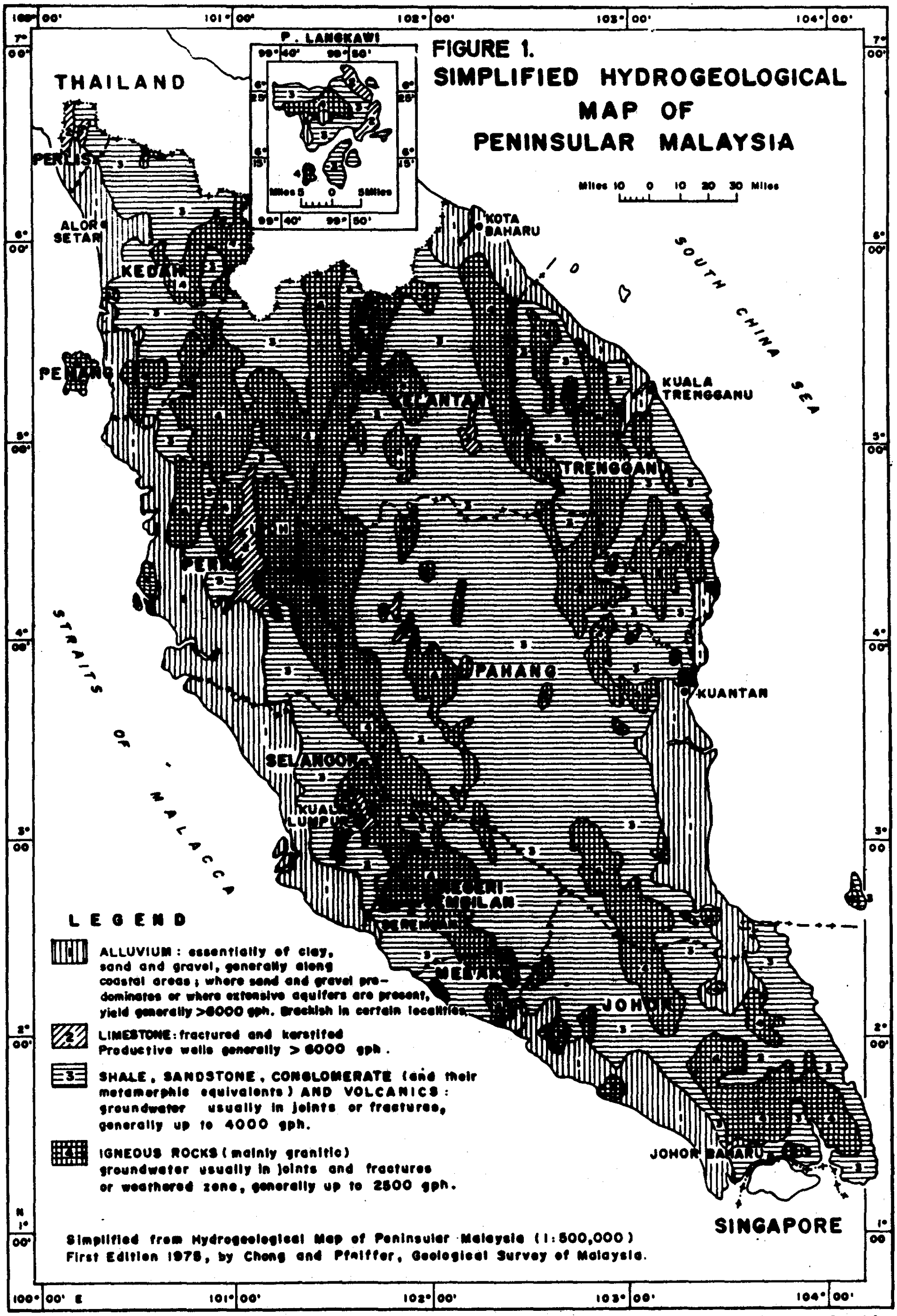
(i) Lithology: this was based to a large extent on the geological map of the country, published by the Geological survey in 1973. Attention in the main was given to the lithological differences, and areal distribution of the main rock types.

(ii) Structural/tectonic elements: consideration was also given to the occurrence and degree of fracturing and jointing, and other factors that contribute to secondary porosity in the rocks.

(iii) Topography: consideration was given to its influence on the recharge and flow of the groundwater.

(iv) Available borehole and well data.

Besides the above, relevant information such as annual rainfall, perennial streams, stream flows, thermal springs, irrigation structures, tidal gaugstations, major surface water divides, and the location and capacity of reservoirs were also depicted on the map.



PKM (Hy)-8-31-80 A

The map was prepared, as far as possible, following the legend and colour scheme adopted by UNESCO/IAH (1970).

The map attempted to depict the various hydrogeological zones, highlighting their respective general characteristics, and quantifying, in a broad manner, the expected potential of each of these zones. A simplified version of the hydrogeological map is shown in Figure 1.

The hydrogeological map has been useful in that it has contributed significantly towards the understanding of the general features and characteristics of the groundwater occurrence of the country. It has served as a valuable source of information for both students of hydrogeology and practising hydrogeologists. The map has also been useful to several other government agencies involved in water resources development and management, and environmental control programmes. In recent years the government has implemented several groundwater exploration programmes, and also several water resources studies in which the aspect of groundwater availability was also incorporated. The hydrogeological map was utilised as a reference for the preparation, planning and implementation of these studies. The map has also been widely used by several private drillers and individuals in selection of sites for boreholes and wells for groundwater exploitation.

PROBLEMS AND LIMITATIONS IN HYDROGEOLOGICAL MAPPING AND PREPARATION OF HYDROGEOLOGICAL MAPS

In the preparation of the first hydrogeological map, there were several problems and limitations. The main problem was the lack of relevant hydrogeological data, such as well and borehole information. This was because a great amount of information was not forwarded to the Geological Survey. Since then, however, there has been better cooperation, and the department has been able to acquire substantial amount of useful hydrogeological information. The problem of lack of data was further aggravated by the incomplete nature of the information that was available. Data may be incomplete in that certain vital information, such as detailed geological log, well parameters, yield, location, water quality, etc., were omitted. This was largely due to the fact that most of the earlier investigations were not systematic in approach, and not enough emphasis was placed on the recording of information. In many instances, the information available was not uniform in presentation and description, and this made correlation work difficult. This is particularly true in cases where the hydrogeological information was received from private drillers, who generally do not engage qualified technical personnel to undertake recording of the field data. Under such circumstances, some form of generalisation, and some sacrifice to detail were unavoidable.

In so far as the mapping aspect is concerned, it can be said that most of the earlier hydrogeological investigations that had been carried out in the country were not designed specifically for hydrogeological mapping purposes. The investigations were geared more towards the objectives of immediate exploitation of the groundwater for crash programmes to ease problems of shortage in the existing water supply. As such the aspect of hydrogeological mapping was generally not given as much emphasis as it should have been.

The Geological Survey, however, is aware of the importance of the mapping aspect. In its recent groundwater investigation programmes, besides the objectives of establishing a well field for exploitation purposes, the element of mapping was also incorporated to gather as much information as possible to build up a repository of hydrogeological data.

STATUS OF HYDROGEOLOGICAL INVESTIGATION (SINCE 1975)

Since the first edition of the hydrogeological map was published, several regional hydrogeological investigations have been completed, and as a result a substantial amount of additional data is now available. A summary of these investigations is given below (Fig. 2).

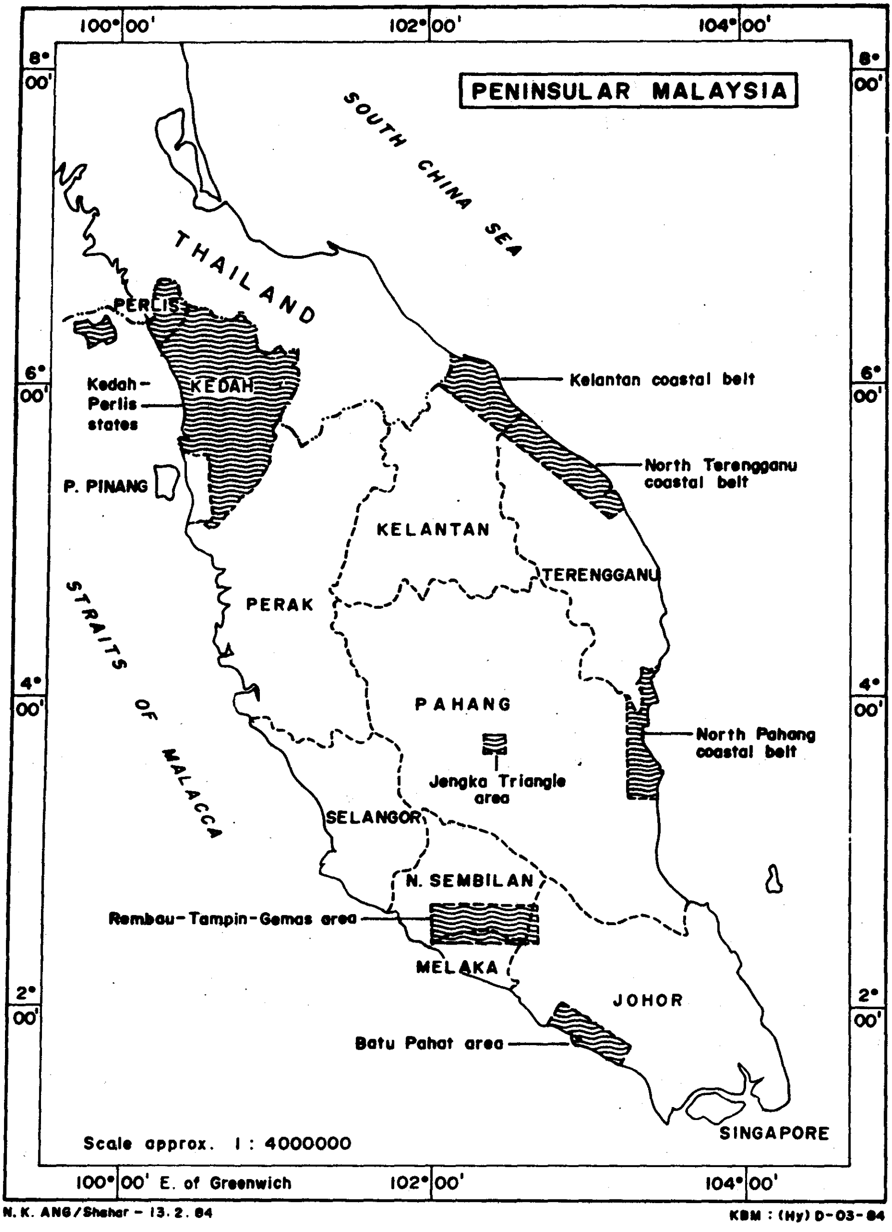
1. Malaysian-German Hydrogeological Mission

The project was undertaken from 1974-1977 by the Geological Survey with technical assistance from the Federal Republic of Germany. The project involved the sinking of about 240 exploration boreholes and test wells in the coastal alluvial areas in the east coast states of Kelantan, Trengganu, and Pahang. Substantial hydrogeological information, including subsurface distribution of aquiferous zones, water quality, saline water intrusion, regional groundwater flow, hydraulic parameters such as permeability, specific capacity, and others were obtained during this project.

2. Kedah-Perlis Water Resources Management Study

The study was undertaken by the Government of Malaysia between 1978 and 1980, and part of it included a systematic groundwater development feasibility study. One hundred and nine wells were drilled and test-pumped to determine the various hydraulic parameters and aquifer characteristics. Subsequent to this, a programme of development of 250 production wells was implemented by the Ministry of Works and Public Utilities. When this is

FIGURE 2. AREAS WHERE DETAILED HYDROGEOLOGICAL INVESTIGATIONS HAVE BEEN UNDERTAKEN SINCE 1975



completed in 1983, it is anticipated that a hydrogeological map for these two states will become available.

3. Batu Pahat Area, Johore

A detailed study of the subsurface hydrogeological conditions and groundwater occurrence was undertaken from 1981-1983. Forty-two exploration boreholes and wells were drilled. The wells were test-pumped, and various hydraulic and hydrogeologic studies were conducted.

4. Rembau-Tampin-Gemas Area, Negeri Sembilan

A programme of well drilling and related hydrogeologic studies are presently being undertaken as part of the 4th Malaysian Plan project. About 60 wells will be drilled into the various geological environments to ascertain the hydrogeological characteristics of the area. The project will be completed by 1985.

5. Other Studies

Besides the above major hydrogeological studies, there are several other water resources investigation projects in which hydrogeological investigations play a significant role. Of these, the most important is the National Water Resources Study -- a joint programme undertaken by the Government of Malaysia and the Government of Japan to study the overall water resources in the country. In addition, the Public Works Department has implemented several river basin water resources studies which include groundwater investigations as well. The Drainage and Irrigation Department has also undertaken several groundwater investigation programmes as part of its efforts to locate more water for irrigation purposes.

With the data obtained from these investigations, a wider and deeper understanding of the hydrogeology of the various parts of the country has emerged. This will greatly facilitate future attempts in the preparation and updating of hydrogeological maps.

FUTURE PLANS FOR HYDROGEOLOGICAL MAPPING

With the greater emphasis being accorded to groundwater exploitation, and with the gathering of more information, it is envisaged that periodic upgrading of the existing hydrogeological maps will be undertaken to further contribute to the understanding of the hydrogeology of the country. The immediate plan is to prepare large-scale hydrogeological maps based on information obtained from the various regional groundwater investigation programmes (Chong, personal communication).

It is also intended that a second edition of the hydrogeological map of the country be prepared when sufficient information has been collected to enable a more meaningful improvement. In this connection, special hydrogeological mapping programmes may have to be implemented. Meanwhile, the Geological Survey of Malaysia is in the midst of finalising a Quaternary map of the country on a scale of 1 : 250 000. The Quaternary deposits are of special hydrogeological interest as they offer a relatively good potential for groundwater development. The preparation of the Quaternary map thus serves as a valuable reference in updating an important part of the hydrogeological map. In addition, new information obtained from the routine regional geological mapping programmes undertaken by the department in the various parts of the country will also contribute significantly towards the improvement of the maps.

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NOTES ON THE HYDROGEOLOGICAL MAP OF SARAWAK

Yogeswaran Mailvaganam

ABSTRACT

The Hydrogeological Map of Sarawak has been prepared using the guidelines set out in the "General Legend for the International Hydrogeological Map of Europe, Hannover, 1974". Some amendments and additions have been introduced into the 'General Legend' to take into account the varying local conditions and needs.

The knowledge of groundwater resources in Sarawak is sparse. This situation is mainly due to the abundance of surface water resulting from the heavy precipitation which amounts to more than 3000 mm/year. Consequently, the demand for groundwater and the need for groundwater research have been very low. This situation is changing and interests in this aspect of water resources are gaining momentum, especially in the coastal areas of Sarawak where the surface supplies are unable to cope with the demand for fresh water during the drier months of the year.

The map was compiled by Y. Mailvaganam and S.P. Chen. In preparation of the map, the authors relied greatly on geological data and the little hydrogeological data that are available.

The following three hydrogeological classes are recognised:

I) Groundwater in porous (commonly unconsolidated) rocks.
II) Groundwater in jointed rocks, including karstic rocks.
III) Only local occurrence of groundwater (in porous or fissured rocks) or area with insignificant groundwater resources.

In the map, information is also given on the individual characteristics of groundwater in accordance with the 'General Legend', on surface water, on artificial works for the utilization of groundwater and surface water and on some geological data.

INTRODUCTION

The hydrogeological map has been prepared as an aid for groundwater resources planning, management as well as for groundwater exploration and exploitation, especially at this time when various Government and private agencies in Sarawak are realising the potential of obtaining at least part of their water supply from the ground. Extraction of fresh water from the ground through drilled wells was first initiated in 1954 (no earlier known records are available), and in this respect hydrogeology is a new science in Sarawak. Unfortunately, the three areas Sarikei, Binatang and Simanggang, where groundwater was utilised for their water supplies faced the phenomenal problem of saline water intrusion due to a variety of reasons, overpumping being the primary cause. Other information than the lithological profiles, the initial discharge rates, well construction and some water analyses, data on changing water-levels and pumping test results are not available from those wells. When preparing the Hydrogeological Map of Sarawak, the authors were faced with the availability of only limited hydrogeological data. As a topographical and geological base, the Sarawak series No. 8 (1980) and the Geological Map of Sarawak, 1 : 500 000 (1982) have been used. Some minor corrections have been made to the Geological Map of Sarawak, and also some modifications and additions to reflect the importance of the Recent and Pleistocene deposits for groundwater occurrence.

Recent groundwater exploration and exploitation in Belawai, Kabong, Bintulu, and Kuala Lawas have provided useful data which greatly aided in the categorising of the various rock sequences according to their groundwater potential. In areas where no drillholes or wells are present, the geology was compared with other geologically similar areas where data are available, and the rock sequences were categorised accordingly. Drilling data from various economic mineral investigations and engineering geology studies have been greatly made use of in the preparation of the map.

Compilation of the Hydrogeological Map of Sarawak on a scale of 1 : 500 000 was initiated by S.P. Chen in 1974 using the guidelines set out in the "Recommendations for Symbols for Use in the Compilation of Hydrogeological Maps in the Member Countries of the ECAFE Region". The map in its present format was compiled by Y. Mailvaganam and S.P. Chen between 1981 and 1983. In the preparation of the map, the authors were guided by the following works: "General Legend for the International Hydrogeological Map of Europe, Hannover 1974", the maps and the explanatory notes of Sheet B4 (London), Sheet C3 (Oslo), Sheet B3 (Edinburgh), Sheet E3 (Moskva) and

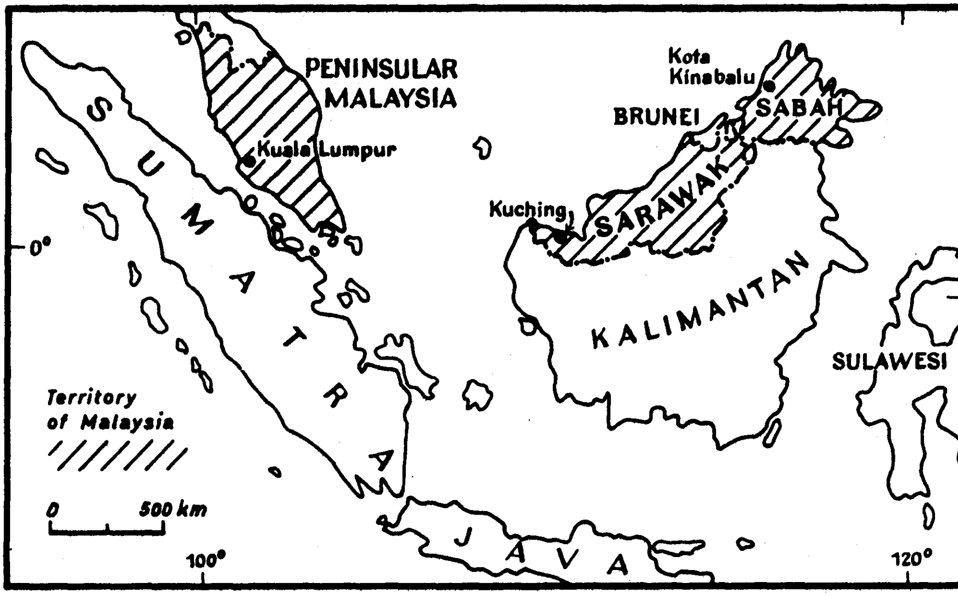

Fig. 1 Locality map

the maps of Sheet C5 (Bern) and Sheet C4 (Berlin). It was felt necessary to introduce certain amendments and additions into the 'General Legend' to take into account the varying local conditions and needs.

REMARKS ON THE LEGEND

Representation of Lithology and Occurrence of Groundwater
(Section I-III of the Legend)

Basically, three hydrogeological classes are recognised:

I. Groundwater in porous (commonly unconsolidated) rocks.
II. Groundwater in jointed rocks, including karstic rocks.
III. Only local occurrence of groundwater (in porous or fissured rocks) or area with insignificant groundwater resources.

The representation by areal colours is based on an estimation of the groundwater potential of rock bodies, with particular regard to their lithological compositions and their modes of occurrence. The knowledge of groundwater resources in Sarawak is sparse. This situation is mainly due to the abundance of surface water resulting from the heavy precipitation which amounts to more than 3000 mm/year. Consequently, the demand for groundwater and the need for groundwater research have been very low. In recent years, however, interests in this aspect of water resources have been gaining momentum, especially in the coastal areas of Sarawak where there are frequent shortages of fresh water for the villages during the drier months of the year. During these months, streams either dry up or, due to low river discharge, the sea water intrudes upriver into areas where the intake points of water supplies are situated.

Groundwater investigations conducted by the Geological Survey Department in some of these areas have yielded encouraging results and these have acted as an impetus for the further search and development of the groundwater resources.

The first two hydrogeological classes refer to aquifer systems or aquifers in which the flow is through porous, fissured or fissured-porous rocks. Here the aquifer system refers to a water-saturated rock body, the rocks comprising the body being similar in their genesis and hydrogeological properties. An aquifer is the sum total of beds and lenses, similar in their lithological composition making up a single body within some particular intervals of a lithological profile. In the map, no distinction has been made between aquifer systems and aquifers.

The third hydrogeological class refers to locally aquiferous rocks and practically non-aquiferous rocks. The locally aquiferous rocks (IIIa) represent layers and lenses of porous rocks and zones of fissured rocks in non-aquiferous bodies. These layers, lenses and zones vary in their thickness and areal extent, but they contain a significant amount of groundwater which may be of importance locally. The practically non-aquiferous rocks are characterized by negligible porosity or fracturing. They may, however, contain thin layers, lenses or zones of water-bearing rocks which can still meet the water requirements of a small community. Some rocks with significant porosity and fissuring have also been placed in this third category because of their limited extent and their proximity to the sea.

The following classes of rocks appear in the legend under the title "Occurrence of Groundwater". Their lithological properties are indicated by symbols:

1. Porous (commonly unconsolidated) rocks: In the 'General Legend' two units are distinguished according to their productivities: extensive

and highly productive aquifers/systems (dark blue colour, Ia), and local or discontinuous productive or moderately productive aquifers/ systems (light blue colour, Ib). Only Ib is represented in the Hydrogeological Map of Sarawak, as the hydrogeological data so far available are insufficient to classify any area under Ia, although some areas do indicate their great potential as extensive and highly productive aquifers.

2. Jointed rocks, including karstic rocks: Distinction is again made between highly productive aquifers/systems (dark green colour, IIa) and the local or discontinuous productive or moderately productive aquifers/systems (light green colour, IIb). Although no known drilled wells are located in the karstic limestone areas, they are classified as highly productive aquifers based on their known geological structures which include numerous solution openings, joints and faults. The Serin Arkose Member has been classified under IIb (light green) based on the data from existing wells. For the areas coloured light green well data indicate flows of generally less than 5 l/s, and this figure is often taken as a conventional limit between productive and highly productive aquifers/systems on the one hand, and moderately and low productive aquifers on the other.

3. The locally aquiferous (porous or fissured) rocks (light brown, IIIa) and the practically non-aquiferous rocks with their insignificant groundwater resources (dark brown, IIIb) are placed under this section. The lack of sufficient hydrogeological data, especially areal, has relegated a number of rock bodies to these groupings. This was felt prudent, especially so for a map of this scale. The various igneous bodies in west Sarawak, although coloured dark brown, can show a variation in the productivity from area to area as some prominent faults and joint systems with their associated secondary porosities have been mapped in these bodies. The metamorphic aureoles around igneous intrusives can be prolific water producers but due to their limited extent they have not been shown in the map.

   Much of the Sejingkat Formation, as in Muara Tebas, is highly fractured and would be a good water producer, but due to their presence as small exposures and their proximity to the sea they have been shown in light brown.

   The sandstones of the Plateau Sandstone have been classified under IIb, but where they occur at high altitudes as along the Klingkang Range, and underlain by rocks with very poor groundwater potential, they have been represented in dark brown as they are being left 'high and dry'.

Explanation of Hydrogeological and Geological Features of the Map
(Section IV-VII of the Legend)

Section IV of the legend comprises symbols reflecting some individual characteristics of groundwater in accordance with the 'General Legend'. Only four such symbols are indicated because insufficient data do not allow the representation of other information on the scale of the map prepared. Due to the lack of extensive aquifers, or rather due to the localised uses of groundwater at the moment, no groundwater contours are included.

Section V of the legend contains symbols for surface water. Some new symbols have been included into this section and these have been adopted mainly from the 'Symbols Recommended for Use in the Compilation of Hydrogeological Maps in the Member Countries of the ECAFE region' which was issued in 1972. The new symbols are as follows:

(a) areas with seasonal marsh;
(b) areas prone to flooding (based on the 1962 and 1963 flood records);
(c) isohyets (their reliability decreases inland);
(d) tidal and back-water extent along major rivers;
(e) maximum upstream flow of saline/brackish water during periods of low river discharge.

The representation of these features is of practical importance, especially in the planning and locating of groundwater works. Due to extensive development work upstream, the base flow contribution to the river discharge has been greatly curtailed, and during periods of extended dry weather the low river discharge is not able to hold the sea-water intrusion along the rivers to their normal areas. This has resulted in the sea water/brackish water to intrude into areas previously unaffected by these high-salinity waters. Surface waterworks which are located in these newly intruded areas have been affected, and in recent years water with salinity higher than the recommended levels has been supplied to the consumers. Some other streams dry up completely during the dry season. Villagers who rely on the waterworks located in the small streams face a shortage of fresh water during the drier months, and the State Government has to mobilise a great number of vehicles and vessels to ferry fresh water to these consumers. However, some of these areas have now resorted to the use of groundwater, which has been successfully located as a result of the hydrogeological investigations undertaken in the areas.

Section VI comprises symbols for artificial works for the utilization of groundwater and surface water. Some modifications of the symbols in the 'General Legend' and some new symbols have been introduced into this section, such as the following:

(a) dug wells and drilled wells have been distinguished;
(b) groundwater pumping stations have been distinguished as presently operating stations, proposed stations, and abandoned stations;
(c) surface-water abstraction works have been included and these are distinguished as major waterworks and rural waterworks.

Section VII contains geological symbols. Faults that have been mapped out in the field and postulated major faults that have been deduced from aerial photographs and satellite imageries have been classified under a single symbol in the map.

EXPLANATORY NOTES

Explanatory notes for the Hydrogeological Map of Sarawak will accompany the map and this is being prepared mainly to provide more information especially in areas where detailed groundwater investigations have been conducted. It is impossible to represent all this information on the map sheet if the legibility of the map is to be preserved.

In the explanatory notes detailed information is provided regarding the groundwater chemistry in the coastal areas of Sarawak. No representations on the quality of water have been made in the map.

A chapter will also be included on the occurrence of groundwater in the coastal sands of Sarawak. This is especially significant because in the coastal areas there are frequent shortages of freshwater and there are plans to exploit the groundwater for the villages in order to meet the objective of the International Drinking Water Supply and Sanitation Decade. Its objective is to provide ready access to safe drinking water and adequate sanitary facilities for the whole population by 1990.

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WATER RESOURCES AND HYDROGEOLOGICAL MAPPING IN THE MONGOLIAN PEOPLE'S REPUBLIC

Luvsannamjilin Tumur

GEOGRAPHICAL FEATURES

The Mongolian People's Republic is situated in the central part of Asia and covers an area of 1.56 million km², thus being the fifth largest country in Asia.

Mongolia is a predominantly mountainous country with an absolute elevation above sea level averaging 1580 m. Mountains dominate in the west of the country, while the eastern and southeastern areas are characterized by flat relief. The territory of Mongolia is divided into the following four large natural provinces, differing in relief, climate, hydrography, hydrogeology, and vegetation:

(i) Hangay-Hanteę mountain province,
(ii) Altai mountain province,
(iii) Flat steppe province,
(iv) Gobi province.

Geographically speaking, Mongolia is remote from seas and oceans, the nearest coastline of the Yellow Sea Bay lying some 1300 km from its centre. An extremely continental climate, comparatively dry air, insignificant precipitation and characteristically abrupt seasonal and even daily temperature variations are conditioned by the fact that Mongolia lies within the continental region of the temperate belt. The mean annual temperature measures -5 °C in the north and +4 °C in the south. The summer maximum is +40 °C, the winter minimum -50 °C.

Average annual precipitation measures 200 to 220 mm. The highest precipitation (550 mm) falls in the north, while the lowest value (50 mm) is encountered in the southerly regions. During the summer period most precipitation falls as heavy showers. A thin snow cover does not provide adequate protection of the soil which freezes to depths of over 3 m during severe frosts. Short summers and long winters are responsible for the presence of permafrost throughout the northwest of the country. Frosts, which frequently occur in late spring and early autumn, impede the growth of many agricultural crops. The natural conditions in Mongolia are fairly varied. The northern part of the country belongs to a mountainous, wooded steppe zone, which develops southwards into a zone of high mountain steppes replaced further south by semi-deserts (the Gobi).

WATER RESOURCES

The territory of the Mongolian People's Republic possesses abundant surface and groundwater resources. Surface water constitutes the greatest part of the national water budget.

Total runoff of surface water formed within the territory amounts to 28 200 million m^3 per year; taking into account the inflow from abroad it reaches 34 300 million m^3 per year.

The availability or absence of surface water governs water resources development and other economic activities in every region of the country and will remain decisive in future.

Such forms of surface water as swamps, glaciers, and snowfields are not of much significance for the water budget except for the glaciers and snowfields of the Mongolian Altai Mountains feeding the rivers of this region.

The Mongolian rivers are incorporated in the world basins of the Arctic and Pacific Oceans as well as in the closed basin of Central Asia. The majority of rivers with considerable drainage basin areas, lengths and flows belong to the Arctic Ocean basin, occupying about 25 % of the MPR territory. The rivers of this basin make up 57 % of the total surface runoff, while the rivers flowing into the Pacific Ocean basin account for 11 %. Only 32 % of the total surface runoff drains into the Central Asian basin, covering 64 % of Mongolian territory, as half of it is under the Gobi desert. This fact explains the extremely uneven distribution of water resources over the country.

The rivers of Mongolia are found predominantly in mountains; they are characterized by clear waters, variable runoff and rapid currents. Apart from rivers with permanent flow, seasonal streams are typical for the southern Gobi part of the country. On the whole, the river network is characterized by the availability of permanent streams in mountainous stretches and their gradual drying up as they flow out into a piedmont area or a plain. The total length of the permanent river network in the country is about 65 000 km. One of the valuable properties of Mongolian rivers is their low mineralization. In terms of its chemical composition the river water may be classed into bicarbonate and sulphate types. Mongolian lakes store a large amount of the surface water resources. There are some 3500 lakes with a surface area exceeding 0.1 km^2. The total area of lake surfaces is approximately 15 640 km^2, which consitutes 1 % of the overall territory of the country. Uneven distribution of lakes over the country is the result of different climatic and geological conditions. Surface water resources are distributed unevenly, not only over area but also seasonally. By and large, only 4 % of the annual precipitation falls within the cold period of the year, as against 96 % during the rest of the year.

This testifies to the necessity of providing regulating reservoirs both for territorial and seasonal redistribution of water, depending on the needs of the national economy.

Mongolia is rich in mineral, medicinal and thermal waters which have been used by the local population for medical purposes for quite a long time. At present, over 400 mineral and thermal springs are available. According to the chemical composition of the waters, they are divided into the following main types:

(i) Acidic carbon-dioxide cold mineral water,
(ii) Hydrogen-sulfide and nitrogen thermal water (up to +100 °C),
(iii) Sodium-chloride mineral water with a high dissolved solids content.

The present knowledge of mineral, medicinal and thermal water in terms of geology and hydrogeology does not permit the assessment of these resources in Mongolia on a regional basis.

It was only in the 1940s that groundwater studies were initiated.

Consequently, as far as hydrogeology is concerned, the country is neither evenly nor adequately investigated.

In the early 1960s, the Ministry of Geology began to collect data and in 1971 published the first hydrogeological map of Mongolia at a scale of 1 : 1 500 000 on the basis of the geological map of Mongolia. More recently we began to carry out hydrogeological mapping at the scale of

1 : 500 000. The map has been set up on the principle of regional and zonal groundwater. In addition, we are compiling large-scale (1 : 10 000 - 1 : 100 000) hydrogeological maps for technical projects and city planning.

The data available so far show that the total volume of usable groundwater resources of Mongolia amounts to 6000 million m^3/a. Groundwater occurring in river flood-plains has a close hydraulic connection with the river, which is why it can be referred to as either a ground or surface water resource. Groundwater which is not drained by a river network can be used without limitation. It is not hydraulically connected with streams and is therefore independent of surface water resources. The hydraulic connection with surface resources being absent, groundwater featuring a more or less uniform yield throughout the year is a reliable source of water supply, this being particularly important for the south of the country, where no surface runoff is available. Groundwater is mainly recharged through precipitation and infiltration during the summer-autumn period.

Hydrogeological Mapping in Asia and the Pacific Region
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THE HYDROGEOLOGY OF THE BUTWAL - BHAIRAHWA AREA, LUMBINI ZONE, NEPAL

G.S. Thapa and Y.L. Vaidya

ABSTRACT

The area is a part of the Lumbini Terai located within the Rupandehi District in the western Terai at an altitude of about 100 m a.s.l.

The hydrogeological picture of the region has been built up from surface observations and from the investigation of more than 150 boreholes. These show a succession of alluvial sediments of different grain size from gravel and sand to silt and clay. The proportion of coarser sediments in the section decreases, in general, from north to south, with a corresponding increase in the proportion of finer-grained deposits.

In the north, on both sides of the Tinau River, there extends a zone built up mainly of coarse-grained sediments known as the Bhabar zone. Beyond its periphery and also beneath the coarse-grained Bhabar sediments there is a gradual transition towards finer-grained materials. The sediments of generally finer-grained texture are termed Gangetic sediments.

Aquifers in the area are of both the phreatic and confined types. Phreatic aquifers are to be found in the Bhabar zone and in the near-surface layers of the Gangetic sediments. Confined aquifers exist along the periphery and south of the Bhabar zone. Most of the groundwater recharge takes place in the Bhabar zone by infiltration of rainfall and surface flow in streams. The change in groundwater storage in the Bhabar zone over the monsoon period as estimated from the rise in water level measures about 130 million m^3. Groundwater flow in the confined aquifers of the area under the existing hydraulic gradient is tentatively estimated to be about 60 million m^3/a. Recharge of the phreatic aquifers of the Gangetic sediments through infiltration from rainfall and from water ponded on the paddy fields is not yet known.

1. INTRODUCTION

The hydrogeological analysis of the area is based on existing data principally drawn from the US AID Report on the Ground Water Investigation of Lumbini Terai, the Tahal Report on the feasibility study of the Bhairahwa Lumbini Ground Water Project, and from the well logs and pumping test records of the Bhairahwa-Lumbini Ground Water Project.

The study area, which is located within the Rupandhi District of the Lumbini zone in the western Terai at an altitude of about 100 m, lies between the Kothi River in the west, the Roheni River in the east, the Churia (Siwalik) Hills to the north and the India/Nepal border to the south.

The climate is of the monsoon or sub-tropical type, with a rainy season from mid-June to late-September. Precipitation during the other months is relatively small. Mean annual rainfall is around 1400 mm. The topography of the area is that of a flat, or nearly flat plain, sloping in a general NW to SE direction with an average gradient of 0.1 to 0.2 %. Elevations range from about 120 m in the northeast to about 90 m in the southwest. The area is underlain by alluvial deposits, which increase in thickness southwards and merge into the deposits of the Ganges plain proper. In the central part of the area, the alluvium is more than 450 m thick. Coarse sediments predominate in the sections towards the northern edge of the area adjacent to the Churia Hills, forming what is termed the Bhabar zone. Southwards, the proportion of fine material in the alluvial sequence increases, and there is a transition to the Gangetic zone of sediments, in which beds or lenticles of coarse sediments alternate with beds or lenticles of silt or silty clay. The permeable materials contained in the alluvial deposits of the region constitute a complex aquifer system. It is recharged in its phreatic part by rainfall and stream flow infiltration. The sediments of the area are typical alluvial deposits and are characterized by abrupt vertical and horizontal changes between different-sized pebbles, sand, silt and silty clay sediments.

Three distinct hydrogeological units can be identified in the area. These hydrogeological units can be recognized in the N-S geological section prepared on the basis of the lithological and electric well logs. These three units are:

(i) The phreatic aquifer of the Bhabar sediments.
(ii) The confined aquifer of the Gangetic sediments.
(iii) The phreatic aquifer of the Gangetic sediments.

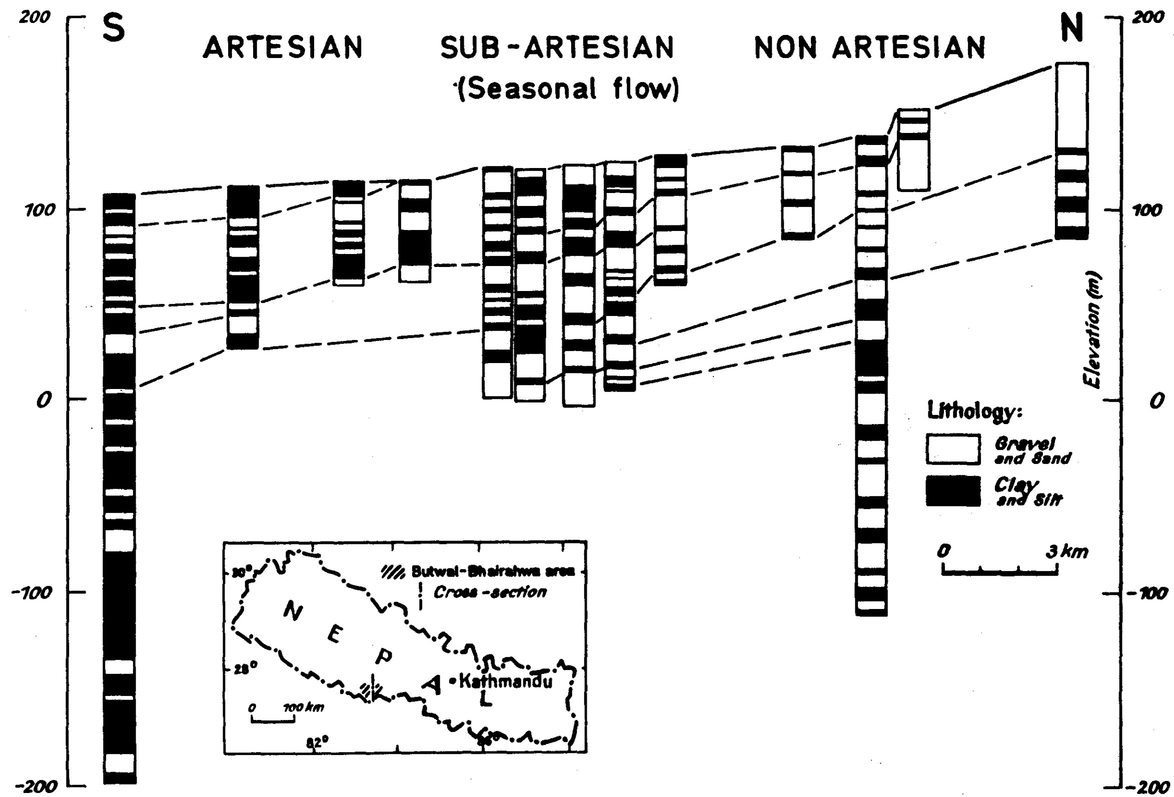

Figure 1. Section across the Butwal-Bhairahwa area

2. THE PHREATIC AQUIFER OF THE BHABAR SEDIMENTS

2.1 General

Bhabar sediments is the term applied to coarse-textured alluvial sediments in the north of the area, fanning out around the Tinau River from Butwal and extending to the vicinity of Anandaban covering an area of about 100 km². Southwards, these sediments pass gradually into the finer-grained Gangetic sediments.

The coarse clastic nature of the upper part of the Bhabar zone sediments with a high proportion of boulders, cobbles, pebbles and coarse sand bears out the high effective porosity of this phreatic aquifer. The proportion of coarse material and its grain size diminish both horizontally from the centre of the zone towards the periphery and vertically with increasing depth, the boundaries being gradational. The thickness of the aquifer is about 100 m at Butwal.

A transition area of inter-fingering exists where the fringes of the Bhabar zone adjoin the Gangetic zone. The progressive confinement of sub-units of the Bhabar aquifer to the south results in a sub-artesian belt characterized by seasonally flowing wells.

The phreatic Bhabar aquifer is recharged mainly by infiltration from precipitation on its surface and by direct infiltration from the Tinau and Dano Rivers, as demonstrated by the disappearance of flow in the Tinau River channel downstream of the Tinau Canal headworks. With the seasonal rise of the water level, springs appear further downstream in the river channels and lowlands.

2.2 Groundwater levels and flow directions

In the majority of the Bhabar zone wells, a rise in water leels occurs during the first six weeks of the monsoon period, the rise is quite rapid and reaches its maximum in September. The decline to the seasonal minimum is gradual with minor fluctuations. Minimum levels are observed in the period between late-May to early-July. Annual water-level fluctuations are betwen 5.5 m and 16.5 m. The direction of groundwater flow is generally from north to south and towards the periphery of the Bhabar zone, i.e. to the southsoutheast and southsouthwest. The hydraulic gradient of the Bhabar zone aquifer varies from 0.004 in the wet season to 0.002 at the end of the dry season. The steeper gradients in the wet season indicate the effect of rapid recharge from rainfall and stream flow. Gradients in the northern part of the Bhabar zone are much higher than in the south. Part of the groundwater discharges into the Tinau and Dano Rivers or through springs along the spring line, in the transition zone to the confined aquifer of the Gangetic sediments. The rest flows into the aquiferous layers of the confined aquifer system.

2.3 Aquifer characteristics

Transmissivity values obtained from the phreatic aquifer of the Bhabar sediments are in the order of magnitude of thousands of m^2 per day. The results are consistent with the lithological character of the layers and their thickness. Lower values obtained in some wells are due to the different lenghts and depth of installation of the screens. The permeability calculated on the basis of the thickness of the screened zone provides better comparable indications for the hydrological character of the aquifer.

Wells penetrating the upper part of the section, which consists of very coarse material, have a very high discharge with a specific capacity of 100-250 m^3/h.m drawdown. It is estimated that in this zone, properly constructed wells with a depth of 60 m could yield 400 m^3/h or more with a 5 m drawdown.

2.4 Present exploitation

Present exploitation of the phreatic aquifer of the Bhabar sediments does not exceed 0.3 million m^3/a.

2.5 Water quality

Water samples from wells in the Bhabar zone have low electrical conductivity (between 320 and 510 micromhos/cm) and SAR values between 0.17 and 1.82, corresponding to the water quality class C_1-S_1 or C_2-S_2 of the US Salinity Laboratory Classification. Water of this quality is considered to be of low to moderate salinity and low sodium content with practically no limitations for irrigation.

3. THE CONFINED AQUIFER OF THE GANGETIC SEDIMENTS

3.1 General

Gangetic sediments spread across the entire region from the foot of the Churia range to as far as the Indian border, possibly with the exclusion of the northernmost part of the Bhabar zone. They are a sequence of generally fine-grained, alluvial, deltaic and fluvial sediments, formed in a fresh-water environment. The Gangetic sediments are known from boreholes all over the area. The deepest borehole in the region drilled to a depth of 460.8 m (Semri 6/6) did not penetrate the entire thickness of this unit. No clear-cut break between the Gangetic sediments and the Bhabar zone sediments can be defined in the north of the area, the transition between the two zones being gradual. The Gangetic sediments consist mainly of clay and silt intercalated with layers and lenses of gravel and sand. The clays are yellow and grey, occasionally black-brown or green. The pebbles, which are of various sizes, are mainly angular, sub-rounded to rounded. Calcareous pebbles predominate in the northern part of the area. The sands are fine- to coarse-grained. The aquiferous horizons in this unit are those composed of sand and coarse-grained material. The uppermost unit is phreatic, while deeper units are confined.

It is evident from the typical N-S cross-section that the combined thickness of the aquiferous layers diminishes from north to south. In addition, the thicker permeable sub-units split up into numerous thinner ones with the appearance of more and more intercalated clayey layers. Some boreholes do not conform to the above-mentioned tendency, probably due to local palaeo-geographic irregularities.

The general hydrogeological pattern shows the set of individual aquiferous units dipping south, becoming progressively more confined. The confined aquifer of the Gangetic sediments is recharged mainly by groundwater flow from the phreatic aquifer of the Bhabar sediments. There may also be some contribution from the lower Churia formations.

Analyses of the results of 51 wells drilled to depths ranging from 101 to 184 m in the Bhairahwa-Lumbini Ground Water Project area show that the proportion of coarse-grained sand and gravel below a depth of about 40 m ranges from 42 to 85 % and averages 63 %. An exploratory well drilled at Lumbini in the southsouthwestern part of the area demonstrates that the section between 45 and 225 m depth contains 38 % aquiferous material.

Table I. Hydraulic Properties of Bhabar Zone Wells

Location	Maximum discharge (m^3/h)	Q/S Specific capacity ($m^3/h/m$)	T Coefficient of transmissivity (m^2/d)	K Permeability (m/d)	Storage coefficient
Manigram	129.8	223.8	18,550	927	
			9,800	490	
Manigram			3,900		5.0×10^{-2}
			1,700		5.3×10^{-2}
Naya Mill	104.1	5.7	1.350	117	
			1,515 - 3.140	132-273	
Jogikuti	107.8	85.0	13,550	452	
			5,770	192	
Manigram Irrigation Well	124.9	140.3	14,800		
Butwal	190.0	15.0	4,500	122	

3.2 Groundwater levels and flow directions

Water-level records generally show minimum water levels in June and maximum levels in September-October. Annual fluctuations between minimum and maximum levels range from 1.5 to 3 m.

The groundwater flow is from north to south and to the southsoutheast in the central part of the area, from north to southeast in the eastern part and from north to southwest in the western part.

As for the hydraulic gradients, these are low in the central part, though they become steeper in the vicinity of and south of Bhairahwa as the proportion of aquiferous material within the alluvial section and transmissivity values decline.

Gradients in the eastern and western parts of the area are also low though higher than in the central part. The gradients increase towards the southern boundary of the area.

In general, it appears that gradients in the central area range from 0.0006 to 0.0014, in the eastern part of the area from 0.001 to 0.0015, and in the west from 0.0007 to 0.0013.

3.3 Aquifer characteristics

Transmissivity values obtained in the confined aquifer of the Gangetic sediments are generally in the order of hundreds of m^2 per day; this is in agreement with the composition of the layers and their thickness. Only part of the aquiferous layers is screened in the wells which were used for pumping tests, and, therefore, the transmissivity values obtained were related only to that particular layer in the confined complex in which the well was screened.

Exceptionally high values of mean permeability, greater than 100 m/d, were obtained for the confined aquifer in the immediate vicinity of the transition zone from the phreatic aquifer of the Bhabar zone to the confined aquifers of the Gangetic zone.

Low values of mean permeability in the order of 10 to 20 m/d occur in the southern part of the area. This is confirmed by the steepening hydraulic

Table II. Hydrogeological Parameters in the Bhairahwa Lumbini Project Area

Well	Depth (m)	Permeable layers (m)	Perçentage of permeable layers	Transmissivity T (m^2/d)	Permeability K (m/d)
Farsatikar	115.3	83.6	72	3153 - 8600	121 - 330
Jura	122.3	75.3	61		
Bhulwari	118.6	78.7	66		
Sakuwani	125.7	74.1	59		
Parshawal	107.4				
Kotihawa	119.9	76.2	64		
Karaunjia	113.5	68.9	61	26,200	570
Pathar Danda	111.3	65.3	59		
Muriyari	120.2	86.0	71	23,440	416
Jahada	110.1	83.6	76		
Karaiya	116.2			22,926 - 39,600	565 - 975
Semra	101.4	71.1	70	15,312	335
Pahuni (West)	110.4	70.5	64		
Supauli(North)	125.9	78.1	62		

gradient observed on the piezometric maps and concurs with the finer composition of the aquiferous layers.

Storage coefficients calculated from interference tests conducted in wells in the confined aquifer show values in the range of 10^{-3} to 10^{-5} and are consistent with the confined nature of the aquifers. An average storage coefficient of 2×10^{-4} is considered to be representative of the confined complex.

Boreholes in the confined aquifer of the Gangetic sediments located near the transitional area adjoining the phreatic Bhabar zone are characterized by high capacities. The highest free-flowing discharge was obtained in the fully screened wells drilled in the area of the Bhairahwa Lumbini Ground Water Project, where discharges of 300 - 400 m^3/h with specific capacities of more than 100 $m^3/h.m$ are common. The much lower specific capacity in wells situated in the south of this region is mainly a result of the limited length of the screen.

3.4 Present-day exploitation

Most of the artesian boreholes in the region, including the privately owned, small-diameter, flowing artesian wells and large-diameter, damaged investigation wells, are flowing continuously throughout the year. The only wells with controlled discharge are those incorporated in irrigation schemes. The estimated annual discharge of privately owned flowing wells is estimated to be about 14.3 million m^3. A few large-diameter artesian wells drilled under the Ground Water Investigation Programme in the area are at present used for domestic water supply and irrigation. The total annual yield of these artesian wells is estimated at 5.1 million m^3.

About 30 large-diameter wells of the Bhairahwa Lumbini Ground Water Project have recently become operational for irrigation, and the estimated annual discharge from these wells (both pumped and free flowing) is about 28 milliom m^3. The project is estimated to utilize 60 mill. m^3 groundwater at full development (64 tube wells).

3.5 Water quality

Water samples taken from wells drilled into the confined aquifer within the area gave electrical conductivity values ranging from 300 - 500 micromhos/cm and SAR values generally of less than 1. Most of the water

Table III. Well Design and Production Data
Bhairahwa Lumbini Ground Water Project

Well no.	Total depth (m)	Pump chamber (m)	Screen (m)	Sand screened (m)	Total sand (m)	Production string (m)	Sand % in production string	Yield (m^3/h)	Drawdown (m)	Specific capacity (m^2/h)	Unit specific capacity1) (m/h)	Depth to static water level (m)
1	115	52	35	29	29	63	46	286	5.9	48	1.37	-7.7
2	122	46	44	44	50	76	66	223	2.5	89	2.03	+3.7
3	119	43	34	34	52	76	68	409	4.1	100	2.94	+0.26
4	126	42	55	47	47	84	56	382	15.9	24	0.44	+2.0
5	107	38	39	39	53	69	77	409	6.4	64	1.64	+1.0
6	120	37	42	42	52	83	68	---	---	--	----	---
7	113	35	36	36	46	78	59	409	2.98	137	3.81	-1.4
8	111	41	44	43	43	70	61	409	6.01	68	1.55	+3.3
9	120	38	51	51	56	82	68	409	2.32	176	3.46	-1.3
10	110	32	48	48	57	78	73	400	2.5	160	3.33	-0.9
11	116	35	51	41	41	81	51	409	3.49	117	2.86	-1.78
12	101	38	46	46	46	63	73	409	3.85	106	2.31	-1.6
13	110	29	40	40	47	81	58	409	2.79	147	3.66	-4.6
14	126	45	47	47	50	81	62	432	3.8	114	2.42	-4.7
15	119	44	37	37	47	75	63	392	6.9	57	1.54	+0.5
16	139	45	40	40	63	94	67	400	17.5	23	0.57	-2.4
17	123	45	40	40	45	78	58	470	7.2	65	1.63	-1.6
18	118	43	42	42	48	75	64	450	5.7	79	1.88	+2.2
19	140	44	35	35	49	96	51	500	9.2	54	1.54	-4.2
20	118	46	41	41	49	72	68	545	6.0	90	2.20	-2.5
21	140	47	49	49	79	93	85	396	5.6	71	1.44	-8.0
22	141	45	41	41	65	96	68	370	5.4	68	1.66	-3.2
23	121	44	42	42	62	77	81	386	3.9	99	2.36	-7.7
24	130	45	41	41	65	85	76	525	4.0	131	3.12	-3.5
25	132	45	48	48	64	87	74	432	4.1	106	2.21	-4.0
26	141	41	42	42	42	100	42	450	4.7	96	2.21	-2.0
27	137	45	42	42	46	92	50	405	6.3	65	1.55	-4.4
28	130	41	42	42	--	89	--	409	3.17	129	3.07	+3.7
29	126	44	43	45	51	82	62	432	3.2	135	3.00	+2.9
30	149	43	53	53	58	106	55	345	3.2	108	2.04	-1.7
31	136	43	48	48	62	93	67	386	2.6	148	3.08	-0.9
32	136	46	47	47	61	90	68	386	2.2	175	3.73	-2.0
33	143	46	50	50	66	97	68	386	2.2	175	3.51	+0.5
34	165	42	59	59	70	123	57	320	3.1	102	1.73	+4.0
35	151	41	50	50	60	110	55	455	2.0	159	3.18	+1.38
36	184	40	50	60	67	144	47	470	6.0	78	1.39	-0.73
37	162	50	56	56	60	112	54	---	---	--	----	-----
38	190	48	48	48	80	142	56	---	---	--	----	-----
39	164	43	57	57	65	121	54	---	---	--	----	-----
40	175	38	47	47	65	137	47	---	---	--	----	-----
41	176	54	60	60	70	122	57	---	---	--	----	-----
42	169	43	77	77	100	126	79	475	3.7	130	1.69	+3.37
43	164	41	85	70	90	123	73	530	7.4	72	1.02	+0.66
44	161	43	--	--	68	118	59	415	2.7	154	----	-1.65
45	163	47	67	67	80	116	69	---	---	---	----	-----
46	151	41	70	70	72	110	65	395	2.6	150	2.14	-5.18
47	160	48	63	63	70	112	63	---	---	---	----	-----
48	164	43	60	60	78	121	64	435	4.2	104	1.73	+0.1
51	164	47	63	--	--	117	--	---	---	---	----	-----
52	158	43	77	77	78	115	68	385	3.3	117	1.52	+2.95
53	154	46	81	75	90	108	83	---	---	---	----	-----

Statistical Summary of Important Characteristics

Characteristics	Average value	Range from	Range to	Sample size
Sand screened (m)	49	29	77	49
Total sand in production string (m)	59	29	100	49
Sand % in production string	63	42	85	49
Yield (m^3/h)	414	223	545	40
Specific capacity (m^2/h)	107	23	176	40
Unit specific capacity (m/h)	2.2	0.44	3.81	40

1) Unit Sc is Yield/Drawdown/Length of sand screened -- this is an aquifer permeability indicator.

can be classified as C_1-S_1 and in a few cases C_2-S_1 and is considered suitable for irrigation without restriction.

4. THE PHREATIC AQUIFER OF THE GANGETIC SEDIMENTS

4.1 General

The phreatic aquifer of the Gangetic sediments covers the whole area surrounding the Bhabar zone and overlies the confined aquifer of the Gangetic sediments. The Gangetic phreatic sediments increase in thickness southwards from about some 30 m in the northern part (Manglapur 5/13, R 1/1) to a thickness of some 80 m at the southern border. Generally speaking, 5 to 15 m of the section are composed of aquiferous layers. Proceeding N-S, individual phreatic horizons become gradually confined, semi-artesian or even artesian, while other shallow phreatic horizons take their place. These horizons are recharged by lateral groundwater flow and by precipitation.

4.2 Groundwater levels and flow directions

The groundwater flow is N-S oriented, following the regional trend of land elevation. In most areas annual water-table fluctuations are within the range of 1 - 5 m below ground level. This suggests a thin aquiferous layer as well as low storage capacity and transmissivity.

4.3 Aquifer characteristics

The hydraulic properties of the shallow, phreatic aquifer have not been tested properly since no drilled wells exist. However, the thinness of the aquiferous layers precludes the possibility of high-yielding wells, and it may be assumed that shallow wells with a depth of 40 m could yield 20 - 30 m^3/h with a probable drawdown of 10 m.

4.4 Water quality

A survey of hand-dug wells during an investigation of the area indicates that the total mineral concentration is higher than that in the water from deeper wells, mainly due to the higher chloride and sulphate content. The high TDS content is due to low transmissivity (prolonged solution processes) and a shallow water table, and the high chloride and sulphate content is the result of contamination in the wells.

4.5 Present exploitation

Shallow and hand-dug wells are numerous and are used mainly for domestic supply. Annual extraction is estimated at 0.2 million m^3. In the southwestern part of the area (Marchawar) there is a particular concentration of thousands of shallow hand-dug wells being used for irrigation, sometimes a well for every paddy field. The total annual discharge from these hand-dug wells is estimated to be around 5 million m^3/a.

5. RECHARGE-DISCHARGE RELATIONSHIPS

The Bhabar zone is recharged by infiltration of rainfall, by seepage losses from water ponded on the paddy fields and by transmission losses of flows in the river beds. Marked changes in groundwater levels occur in the Bhabar zone during the monsoon. Water-level rises of up to 18 m have been recorded. Water-level change maps permit an estimate to be made of changes in groundwater storage. Change in storage in this Bhabar zone during the monsoon period is estimated to be about 130 million m^3. This estimate does not represent total recharge as discharge by lateral flow is not accounted for in the change in the storage balance.

The proportion of this recharge retained by the groundwater system under present conditions is not accurately known. It is estimated that the confined aquifers in the Gangetic zone in the area may transmit about 60 million m^3/a under the existing hydraulic gradients. Therefore, it appears that nearly half of the total potential recharge into the Bhabar zone can be accounted for as lateral flow into the Gangetic sediments, and the balance is rejected from the Bhabar aquifer as effluent supply to the surface drainage. Water-level rises in the monsoon period in the phreatic part of the Gangetic sediments indicate that this part also receives recharge from rainfall and from water ponded on the paddy fields. However, the amount of this recharge is not yet known.

It is not possible to provide an accurate estimate of the potential recharge under development conditions because the hydrodynamic situation in the aquifer system will be profoundly changed. Water levels will decline, and hydraulic gradients will slacken in the south (outflow) and steepen to the north (inflow). Some vertical infiltration from the phreatic part to the deeper aquifers of the Gangetic sediments may also be induced.

Total well discharge in the area from the confined aquifers of the Gangetic sediments, excluding the discharge from Bhairahwa-Lumbini irrigation wells, is presently estimated to be about 19.4 million m^3/a, but about 50 % of this water will return to the phreatic part of the system, making net abstraction from the system about 9.7 million m^3/a. At full development, the Bhairahwa-Lumbini Ground Water Project wells will require a gross abstraction of 60 million m^3/a. Again assuming that 50 % of the water will recirculate to the aquifer system, net abstraction from the aquifer will be 30 million m^3/a. These abstraction estimates refer to a total area of about 400 km^2.

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PAKISTAN -- STATUS REPORT

Syed Rashid Ali

1. INTRODUCTION

Pakistan is a land of great scenic contrast, varying from the snow-capped peaks of the Himalayas in the north to the arid deserts in the south. It can be broadly divided into three distinct geographical regions: (i) the mountainous north and northwest, (ii) the tableland of Baluchistan to the west of the mountainwall and (iii) the plain of the Indus River basin, which stretches from the foothills in the northeast and northwest to the Arabian Sea in the south. The plain of the Indus basin, the principal agricultural region of the country, is equipped with one of the largest integrated irrigation networks in the world, comprising some 38 000 miles (61 142 km) of canals, and commands a cultivatable area of some 33.6 million acres.

Pakistan covers a total area of 307 374 sq. miles (896 099 km^2) and is composed politically of the provinces of Baluchistan, Punjab, Sind and North West Frontier (N.W.F.P.), federally administered tribal areas and the federal territory of Islamabad. Baluchistan occupies 43.6 % of the total area, followed by the Punjab (25.8 %), Sind (17.7 %), N.W.F.P. (9.4 %) and the federally administered areas (3.5 %). The total surface area of the country amounts to approximately 198 million acres (80.13 million hectares), of which about 36 % can be cultivated; however, only 48 million acres (19.43 million hectares) or 28 % is currently under cultivation. Of the cultivated area, two-third is irrigated and one-third depends on rainfall.

Pakistan lies wholly outside the tropics, and although its climate is generally classified as "tropical monsoon", it is in fact continental in character. Rainfall is low, ranging from 5 inches (127 mm) in the south-west to about 30 inches (762 mm) in the north. Both diurnal and annual ranges of temperature are considerable. During the summer, day temperatures are quite high everywhere in Pakistan, often exceeding 110 °F (43 °C). In the winter the cold is relatively intense. The mean January temperature is less than 55 °F (12.8 °C) and is below freezing point in the northern and western areas of Pakistan.

Agriculture is the largest single sector of Pakistan's economy, contributing about 36 % of the gross domestic product. In the arid and semi-arid environments, which prevail over a part of the country, the availability of adequate surface-water supplies at the appropriate time provides the key to progressive agriculture. However, for the most part, land is abundant while water is scarce. Water being a "limiting factor", the emphasis in planning has continued to be on the prudent exploitation of the water resources in order to provide the basic environment for agricultural development.

Apart from water shortages, the problems of irrigated areas are ones of restricted drainage and unchecked seepage to aquifers resulting in the continuous rise of the water table creating waterlogging and salinity over vast tracts of agricultural lands. In other areas, inadequate water supplies have become a serious impediment in the planning and programming of agricultural and industrial development.

2. HYDROGEOLOGICAL CLASSIFICATION

Broadly speaking, three main regions in Pakistan have been identified on the basis of hydrogeological studies, viz.: (i) the mountainous northern region, (ii) the vast flatlands traversed by river systems including the Indus Plain and (iii) the sub-mountainous regions of Baluchistan with its basin-and-range topography.

The thick alluvial deposits of the Indus basin constitute a large groundwater reservoir. The depth of this alluvium varies. At a few places it is pierced by the basement, but, on the whole, boreholes drilled to over 1500 ft (257 m) in depth have found no evidence of bedrock. The alluvium is of Pleistocene and Holocene age and generally consists of the usual mixture of well-sorted, fine- to medium-grained micaceous sand with bands and lenses of silt and silty clay typical of sediments carried down by water over great distances.

In the mountainous areas of N.W.F.P. and the sub-mountainous region of Baluchistan, the unconsolidated valley-fills between the ranges constitute the aquifer units. These deposits are composed of rock material derived from the adjacent mountain ranges. The consolidated rocks have not been investigated for groundwater development as they are considered far poorer in storing and transmitting water than the unconsolidated deposits.

3. HYDROGEOLOGICAL INVESTIGATION

The menace of waterlogging and salinity, as is well-known, is an inherent problem of irrigation agriculture in the arid as well semi-arid regions of the world. In Pakistan, this problem is perhaps felt to a worse extent than anywhere else because it has the oldest and the biggest weir-controlled, gravity-flow irrigation system.

The water table over most of the irrigated area rose to within 10 feet (3.05 m) of depth to groundwater from an original depth range of 40 to over 90 feet within about 40 years. The evapotranspiration from the high water table resulted in a steady accumulation of salts in the soils and in the irrigation water occurring within the root zones, thus adversely affecting the growth of crops. A programme of hydrogeological investigation was expanded (1959 - 66) to cover the entire canal-irrigated areas of the country. In the provinces of Punjab and Sind groundwater investigations were conducted by the Water and Power Development Authority (WAPDA) through its Water and Soils Investigation Division (WASID). The main objectives of these in-vestigations were:

1. to determine the distribution and extent of fresh groundwater zones and to assess the potential yield of groundwater for agricultural domestic and industrial use;

2. to establish the feasibility of tube well drainage in areas where water table control is essential; and

3. to study the general geology and groundwater hydrology of the Indus basin.

Hydrogeological investigations have indicated that the entire Indus plain is underlain to depths of 1000 ft or more with unconsolidated sediments of alluvial origin. The alluvium comprises a single more or less water table aquifer which under pre-development conditions was saturated to within a few feet of the ground surface. The sediments have been found to vary in texture from medium-grained sand to silty clay, but sandy sediments predominate, and gravel-packed wells tapping groundwater at 200 - 400 ft deep can yield up to 5 cusecs (0.14 m^3/s) or more.

A total of 1530 test holes have been drilled and 223 test tube wells installed. The investigations provided the basic data for project planning and implementation of projects, such as SCARPS (Salinity Control and Reclamation Project). During the past decade the scope of groundwater investigation has been extended to include non-irrigated areas. Groundwater investigation in the mountain region of Baluchistan and N.W.F.P. has been development oriented. These investigations were completed during 1973 - 83 and cover an area of about 30 000 square miles in Baluchistan by drilling about 212 test holes and 84 production wells. Encouraging results have been found.

4. METHOD OF INVESTIGATIONS

Outline of operational steps as practiced.

i) The level of investigation is determined by the amount of funds, availability of equipment with logistical support, infra-structure and conditions of work.

ii) The first step is to carry out a hydrogeological reconnaissance survey to establish the nature and magnitude of the various parameters that will be the object of subsequent investigations and to form a first opinion about the likely groundwater conditions of the area.

iii) Geophysical studies of selected areas are undertaken to complement the geological information and to add a more realistic third dimension (depth) to the parameters, thereby enabling a closer estimate of the magnitude of work and expenses involved.

iv) A detailed report is prepared recommending a thorough investigation involving a certain number of test holes, up to 50 % of which may be converted into tube wells.

v) Test holes are drilled and pumping test performances are recorded at selected wells.

vi) Analysis of the data and preparation of a detailed report are completed prior to undertaking project planning work and to the implementation of a development scheme.

vii) Project development includes the installation of the required number of tube wells and the creation of ancillary facilities.

5. HYDROGEOLOGICAL MAPS

5.1 Preparation

Various types of hydrogeological maps are prepared of an area on the basis of the studies as follows:

i) Reconnaissance type, involving preliminary surveys, geophysical surveys, studies of geological maps and photo interpretation.

ii) Detailed investigation, involving exploratory drilling, well installation and supplementary geophysical studies.

5.2 Scale

The topographic survey sheets at scales of 1 : 50 000 and 1 : 250 000 provide the base for the maps. The use of base maps at these scales enables (i) the direct transfer of data, e.g. topographic features onto the map under preparation from other maps, (ii) easy interpretation and correlation of information and (iii) the identification of any site in the field with reference to a map of a particular hydrogeological environment.

5.3 Classification

A variety of hydrogeological maps are prepared based on field investigation. Such maps can be very useful for the evaluation of different hydrological parameters, the identification of promising or potential areas for groundwater development, and the assessment of groundwater quality and are also useful in planning a development programme for land and groundwater resources.

The end-product of a hydrogeological investigation is a report containing the results and providing the following hydrogeological maps as an aid to future planning:

1) Physiographic maps, depicting various physiographic units, e.g. mountains or highlands, valley flats and other morphological features. Identification of areas of recharge and discharge.

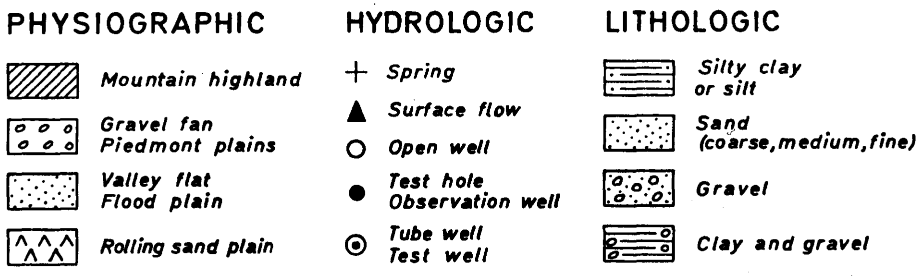

Fig. 1. Legend used for hydrogeological mapping in Pakistan

2) Preliminary hydrogeological maps showing existing hydrological points and their status, e.g. springs, wells, surface flow, zones or areas suitable for detailed investigation.

3) Depth-to-water maps. Provided sufficient data are available, the depth-to-water map is prepared with a contour interval of 10 ft; this shows the configuration of the upper zone of saturation.

4) Water-table elevation maps require levelling surveys of hydrogeological points. Contour interval of 10-20 ft. Useful in calculation of hydraulic gradients, between ground- and surface water. Also textural changes.

5) Water quality maps represent both horizontal and vertical changes in groundwater quality using contours or zones to show chemical composition in terms of total dissolved solids content. It also shows areas underlain by fresh groundwater and possible causes of mineralization.

6) Groundwater availability maps are prepared subsequent to the interpretation of data. They show zones or areas where adequate supplies of usable groundwater could be available for development.

Hydrogeological Mapping in Asia and the Pacific Region
Proceedings of the ESCAP-RMRDC Workshop, Bandung, 1983

HYDROGEOLOGICAL MAPPING IN THE PHILIPPINES

Romeo M. Luis

BACKGROUND

Groundwater geology investigations in the Philippines were conducted as early as 1917, when a Philippine geologist made an assessment of the groundwater potential of Manila and its suburbs. Since then, several local and foreign geologists and engineers have conducted surveys for groundwater in specific areas.

The systematic assessment of the country's groundwater resources was started by U.S. army engineers and geologists prior to and during the second world war. The main objective of their study was to determine potential sources of potable water in strategic places in the Philippines as part of their military planning and preparation for war.

In 1955, the then Bureau of Public Works (now a part of the Ministry of Public Works and Highways) with technical and commodity assistance from the United States initiated groundwater studies in the country. The activities consisted primarily of the collection of available data, groundwater geological surveys, well drilling, electrical logging, water sampling and analysis and data evaluation. Eight major river basins were covered during the period of study (1956 - 1970). During this period, many deep wells were drilled throughout the country, the data of which were used in subsequent hydrogeological studies.

RECONNAISSANCE HYDROGEOLOGICAL STUDIES

In the early 1960s, the Philippine Bureau of Mines and Geosciences (BMG) started a continuous program of assessing the whole country's groundwater resources using reconnaissance methods. Existing geological and hydrological data are being collected and are supplemented by additional information in the field. Data from field activities are supplied by well inventories, pumping tests, geological mapping, water sampling for quality analysis and aerial photointerpretation. Due to the lack of well drilling equipment, no drilling was conducted during these investigations. BMG hydrogeologists usually rely on data of existing public and private wells. The collected data are then evaluated and analysed to produce hydrogeological or groundwater availability maps and reports. These maps and reports are kept as open-file reports by the BMG while some are published as Reports of Investigations or as Technical Information Series.

As of December 1983, around 70 % (Figure 1) of the Philippines have been covered by reconnaissance hydrogeological surveys. Map scales are usually 1 : 250 000, but recently the BMG has been producing hydrogeological maps at a scale of 1 : 50 000. The rest of the country is coverd by "Regional Water Resources Development Study" (REWARDS) reports which are based mainly on the evaluation of existing geological and hydrological data.

DETAILED HYDROGEOLOGICAL STUDIES

In addition to reconnaissance hydrogeological surveys, the BMG also conducts detailed groundwater studies when requested by private entities and other government agencies with no experience on this field. The objectives of such studies are the assessment of the available water resources in any specific area and the location of best possible sites for groundwater exploration and development. In these studies, BMG hydrogeologists are now applying some knowledge of Quaternary geology in locating sites underlain by more permeable sediments such as abandoned river channels and alluvial fans.

Apart from the BMG, there are other government agencies and corporations engaged in water resources studies. Since these studies are for a particular purpose and cover a specific area, they are usually conducted in detail with the help of local and/or foreign consulting firms as well as international organizations.

The Metropolitan Waterworks and Sewerage System (MWSS) is in charge of the water supply of Metro Manila and lately has brought out a report on the "Groundwater Development, Manila Water Supply Project II" done by Electrowatt Engineering Services Ltd. (a Swiss firm) and Engineering Geo-Sciences (a local firm). The Local Water Utilities Administration (LWUA) is responsible for the promotion and development of water districts throughout the country. To determine the viability of a proposed water district, LWUA with the assistance of foreign or local consulting firms conducts a feasibility study of the area. With regard to water resources, the potential

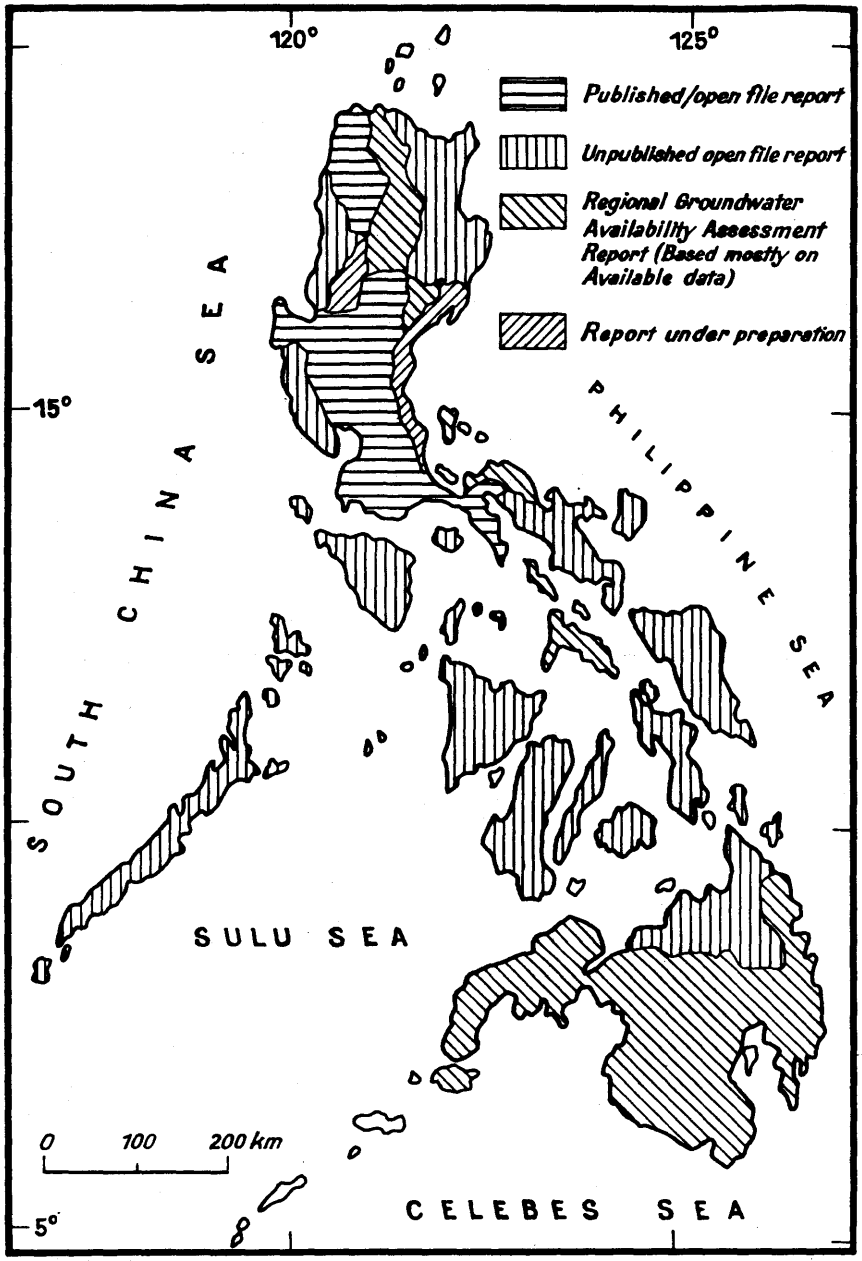

Fig. 1. Status of hydrogeological mapping as of December 1983. Philippine Bureau of Mines and Geosciences.

sources of water supply (surface and groundwater) are thoroughly studied. Most of the urban centers of the country are now covered by such studies.

The National Irrigation Administration (NIA), as its name implies, is responsible for irrigation water. In the 1970s, it conducted hydrogeological studies of selected areas with assistance from UNDP to determine the possibilities of using groundwater for irrigation purposes. The agency has drilled a lot of successful deep wells, but due to the high cost of operation and maintenance, the idea of using groundwater for irrigation has been temporarily suspended.

In sugar-growing areas of the country, the Philippine Sugar Commission (Philsucom) through its Water and Weather Division are also conducting detailed water resource studies in search for water for irrigation, domestic and industrial purposes.

Other government agencies involved in water resource studies for domestic purposes, though to a limited extent, are the Ministry of Local Government (MLG) and the newly created Rural Waterworks Development Corporation (RWDC). The MLG implements the Barangay Water Program (BWP) in cooperation with USAID. This program covers provinces included under the Provincial Development Assistance Project. The RWDC, like the BWP, is responsible for the provision of water supply systems in the rural areas not served by MWSS and LWUA.

GROUNDWATER AVAILABILITY MAP OF THE PHILIPPINES

Based on the results of the reconnaissance hydrogeological surveys of the BMG and the regional water assessment studies, a preliminary groundwater resources report and availability map of the whole Philippines are being prepared. This report and map are going to be a part of the Mineral Resources volume of the BMG publication "Geology and Mineral Resources of the Philippines". The scale of the map is 1 : 2.5 million.

In the groundwater availability map, the various geological formations are subdivided into three major groups based on the mode of occurrence and movement of groundwater. These are:

I. Rocks in which flow is intergranular,
II. rocks in which flow is through fractures and solution openings,
III. rocks with local or no groundwater.

The rock units in the first group generally consist of granular deposits wherein groundwater occurs and moves through pore openings between individual grains. They are usually the most productive aquifers. This group was further subdivided into three sub-groups based on the extent and productivity of the formations.

The second group refers to the limestone formations and highly fractured volcanic rocks that store and transmit water through interconnected fissure systems and solution openings. Success or failure of wells drilled into these rocks, therefore, largely depend on the well encountering such water-bearing openings. This group is further divided into two sub-groups based mostly on the age and productivity of the formation.

The third major group generally refers to the hard rocks, the igneous and metamorphic rocks and older, well-consolidated sedimentary rocks. In this group, groundwater is usually limited to the leached overburden and locally fractured zones. Although these rocks usually occupy the rugged mountains and are therefore mostly untested, an attempt was also made to group them into two hydrogeological sub-units. The sub-groupings are based mostly on their potentials for groundwater development which are in turn dependent on the age of the formation and ruggedness of the topography. Rocks in valleys and gentle mountain slopes are generally considered to have a thicker leached overburden.

Hydrogeological Mapping in Asia and the Pacific Region
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DEVELOPMENT OF GROUNDWATER RESOURCES IN SRI LANKA

A.G.Nihal Wijesekera

ABSTRACT

In Sri Lanka the groundwater resources are widespread throughout the country due to abundant rainfall. However, the varied geological, topographical and climatic conditions on the island give rise to differing groundwater potentials.

Of the total surface area, 90 % comprises crystalline hard rock. Only recently, exploitation of groundwater in these hard rock areas was given priority. Many districts are presently being studied on a regional basis. The capacities of tube wells are adequate only for basic human consumption and small-scale agriculture.

The remaining 10 % of the island consists of deep sedimentary formations in the northern and northwestern coastal belt, where karst aquifers occur in Miocene limestone formations. Systematic exploration of these aquifers, with the aim of assessing their parameters and characteristics, and water balance studies will enable the preparation of hydrogeological maps.

1. INTRODUCTION

Sri Lanka is an island in the Indian Ocean to the east of the southern tip of India, from which it is separated by the Palk Strait. The island lies between latitudes 5°55' and 9°50' N and longitudes 79°42' and 81°52' E, measuring 440 km in length N-S and 226 km in width at its broadest part.

The total area of Sri Lanka amounts to 65 610 km², of which the southern central mountain zone covers 10 900 km² and inland waters 958 km².

The land rises gradually from all sides into a mountainous mass in the southern central region, with the highest peak reaching an elevation of 2575 m a.s.l. A sectional view across the southern central mountains in an E-W direction indicates several peneplained structures at an average elevation of 165 m and 500 m, respectively. The lowland coastal plains with elevations of less than 165 m form a narrow belt around the southern coast of the island, while the entire northern region shows essentially a flat topography except for isolated hillocks, which remain as old erosional residuals.

Rainfall is practically the only source of fresh water in Sri Lanka, and its distribution over the island is connected with the two regular monsoonal seasons in the year. During the northeast monsoon, which prevails from October to February, rainfall is to be found over the entire island, but during the southwest monsoon, which lasts from about April to September, the southwestern areas receive heavy rainfall. Appreciable rainfall also occurs during inter-monsoonal periods due mainly to the local convection currents producing afternoon thunderstorms. The average annual rainfall over the entire island measures about 2000 mm. The isohyets indicate a climatic division between the dry zone and the wet zone based mainly on the rainfall pattern. The dry zone, which covers nearly two thirds of the island, receives an average annual rainfall as high as 1448 mm with only one rainy season, experiencing long periods of drought causing arid and dry conditions. The wet zone, which also encompasses the high mountainous mass, receives an average annual rainfall of 2413 mm. It often has over 5000 mm in some mountainous areas and generally experiences two monsoonal rainy seasons. The drainage pattern of the island, which is essentially radial, is mostly influenced by the topographical and geological characteristics and the intensity and distribution of rainfall, while the occurrence and availability of groundwater depends chiefly on infiltration, retention (storage) and flow conditions within the ground.

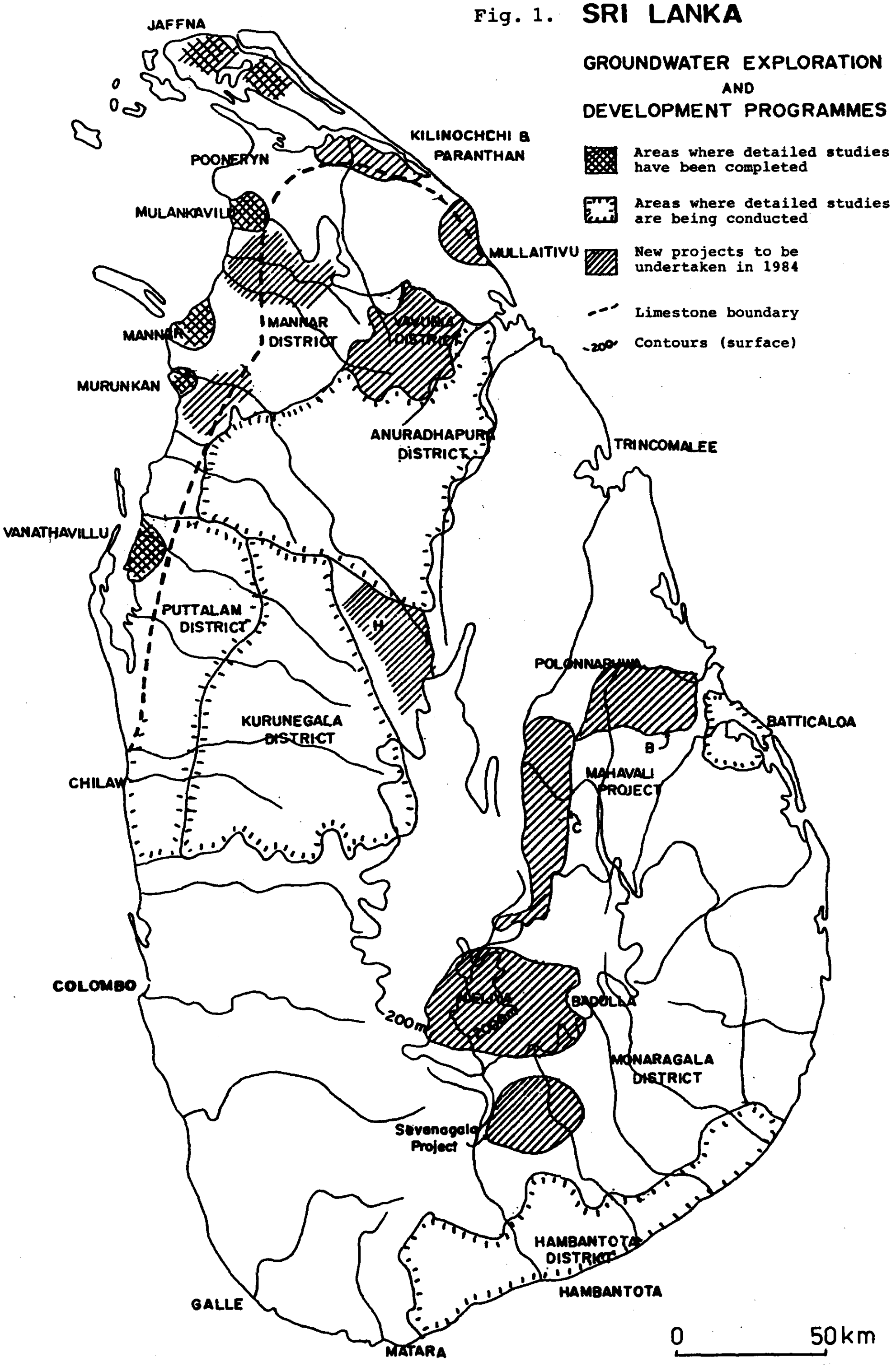
Geologically, nine-tenths of the island are underlain by impermeable crystalline rocks of the Precambrian basement complex. Due to the development of secondary porosity in fissured, fractured and decomposed basement rocks, overlain by an irregular, thin soil mantle, aquifers are locally developed but are inadequate in their potential for the successful development of large-scale agriculture.

The remaining one-tenth of the island consists of a sequence of sedimentary formations confined to the northern and northwestern coastal belt, where the Miocene limestone formations provide the major karst aquifers.

2. GROUNDWATER IN CRYSTALLINE ROCKS

Systematic hydrogeological investigations are being conducted in the areas of Kurunegala, Hambantota, Puttalam, Anuradhapura and Batticaloa. The

Fig. 1. **SRI LANKA**



crystalline rocks do not lie close to the surface; thus, the occurrence and flow of groundwater in them depends mainly on the porosity and permeability caused by discontinuities, such as bedding planes, joints, foliation, etc., along which water circulates. Essentially, the unweathered crystalline rocks are relatively impervious and non-porous. Porosity and permeability, however, are developed to an appreciable extent where joints and fissures are concentrated in zones, as in fault zones or in particular rock types such as quartzites, crystalline limestone, etc. The groundwater yield from large open fractures is fairly reliable during dry seasons, the aquifer being unaffected by evapotranspiration and other losses and the fractures being fed by large areas of decomposed rock. The groundwater in the unweathered crystalline regions does not form a continuous water body with a high water table, but rather exists in localised zones with varying groundwater potentials. Hence, the outputs of the tube wells in these areas are very low -- in the region of 0.32 l/s (5 gal/min) to 1 l/s (15 gal/min). Deep weathered zones with a substantial local recharge have mean yields of as much as 3.15 l/s (50 gal/min) and are recommended for small-scale agriculture. Variations in yield within a given area are large, but on the whole, yields are low with only a limited number of high yields and are recommended for drinking and domestic use only.

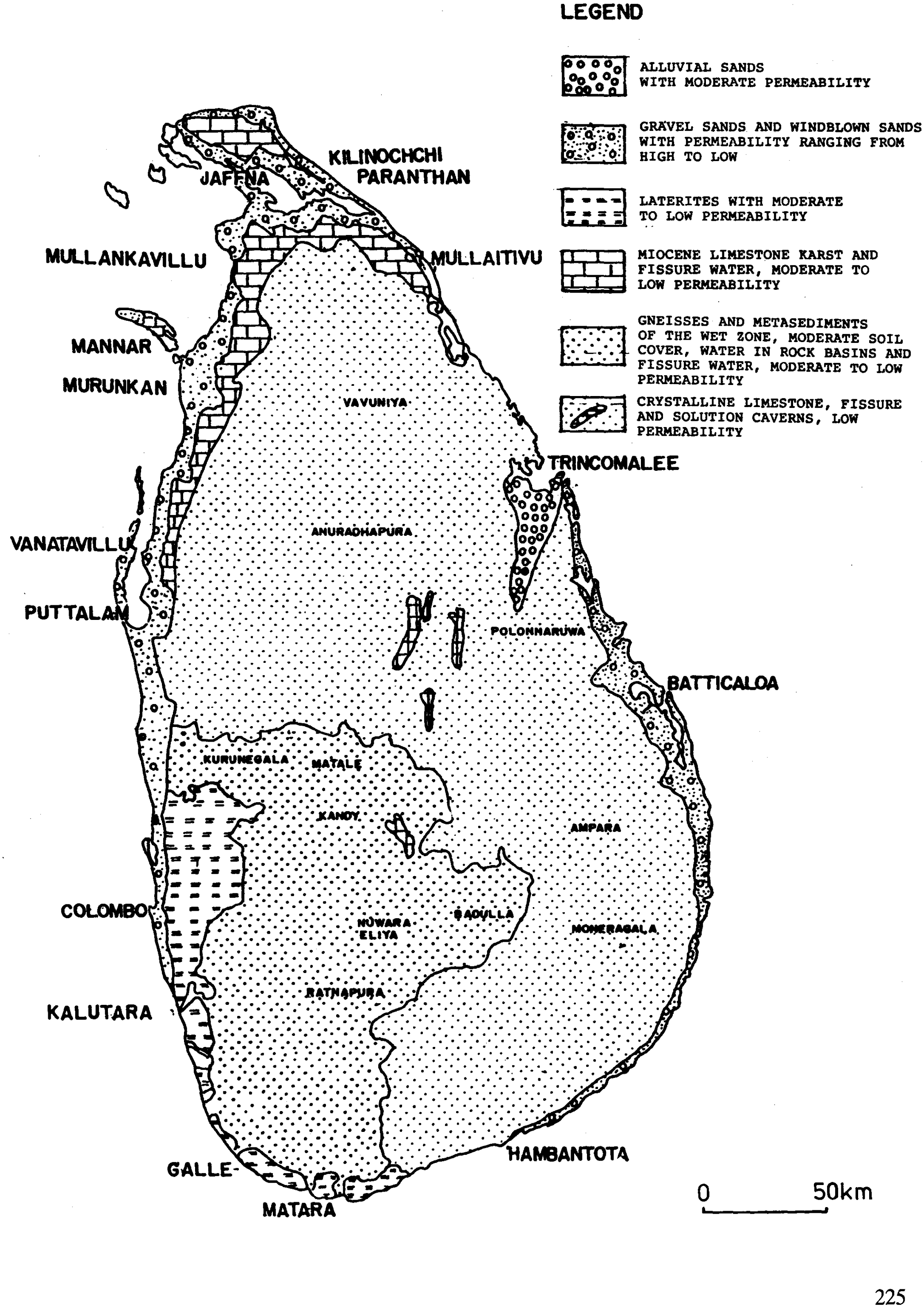
The chemical quality of water from crystalline rocks is always almost excellent. Exceptions are encountered in arid regions where salinization may be encountered in the recharge water due to evaporation and in the coastal reaches due to sea water intrusion into the rock fractures. In addition, saline water left behind in rock formations during marine transgressions in past geological periods may also be encountered in some regions. Water hardness in crystalline limestone, marble and dolomite is moderate to high. However, in certain areas of the Hambantota district, studies indicate that saline water has invaded the crystalline rocks here.

3. GROUNDWATER IN SEDIMENTARY FORMATIONS

The sedimentary formations in the northern and northwestern coastal belt are of great importance as far as groundwater prospection is concerned for several reasons. Firstly, the deposits are many times thicker than in other areas and lie wedge-shaped over the crystalline rocks, ranging in thickness from about 15 m to over 225 m towards the coast. Secondly, the unconsolidated sediments in this belt are underlain by cavernous (karst) Miocene limestones and Jurassic sandstones, which contain many deep seated aquifers. Thirdly, the conditions of porosity and permeability in almost

Fig. 2

GROUNDWATER POTENTIAL AREAS IN SRI LANKA



all sedimentary units give rise to high specific capacities in deep tube wells. Fourthly, and perhaps most important, are the implications for the development of the vast extent of undeveloped fertile land in the dry zone belt, where good quality water is scarce.

The northwestern coastal sedimentary belt is essentially flat lying, generally below 23 m a.s.l. and occasionally up to about 60 m a.s.l. in isolated hillocks. Geomorphological units, such as older sand dunes, are much altered due to erosional processes, and young coastal plains are commonly found in this region. Flat lagoon deposits and vast alluvial deltaic plains traverse the coastal plains on account of the meandering drainage patterns, the flood plains of which are identified. These units of loose sediments act as intensive recharge zones of the deep aquifers in the sedimentary basins. The recharge is generally from runoff from the peneplained basement and direct infiltration of precipitation.

The Miocene limestones, which contain the most productive aquifers owing to their extensive karstic nature, extend from south of Puttalam to Pooneryn and then sweep east up to Mullaitivu, underlying the entire Jaffna peninsula. Many different hydrogeological features have been recorded in the limestone strata, giving rise to varying aquifer conditions. The limestones are generally thickly covered in the south, surfacing in places around Mannar-Pooneryn and outcropping extensively in the Jaffna peninsula.

Detailed hydrogeological studies have been undertaken in the basins of Vanathavillu, Murunkan, Mulankavil. Priority was given to these basins because prospects for the development of groundwater for agriculture are favourable. In Vanathavillu, two significant water-bearing formations are present: (i) the Vanathavillu limestone strata of Miocene age and (ii) a series of Quaternary clays and sands of the Moongil Aru formation. These two water-bearing formations appear to be rather independent of each other; however, extensive leakage of groundwater is thought to occur from the Moongil Aru formation to the underlying limestone in the centre of the basin. The major water-bearing zone of the Miocene strata is the upper part of the limestone, which is highly karstic. The average depth of the tube wells is about 100 m, and aquifer parameters have been obtained from pumping test results. The safe yield in most of these wells is about 20 l/s. The water quality is most acceptable (about 100 to 400 ppm Cl) and the soils are suitable for the irrigation of a wide range of crops.

Abstraction of groundwater from the Moongil Aru formation is currently limited to small quantities from hand-dug wells for domestic use. In addition to these dug wells, domestic water supplies could be obtained by constructing shallow boreholes fitted with hand pumps in the Moongil Aru formation.

In the Murunkan basin, some 300 km² are underlain by a thick sequence of predominantly calcareous Miocene sediments rapidly thinning out to the east, where Precambrian basement strata crop out. These limestones have been subjected to several periods of "karstification", weathering and large-scale block faulting. The highly irregular surface of the limestone has been covered by a thick deposit of estuarine alluvium, which ranges in texture from clay to coarse grits. There are over 100 tube wells constructed in this basin with an average depth of about 30 m and a yield of around 10 l/s. These wells provide a supplementary water supply for rice production.

The Mulankavil-Vellankulam area, covering 140 km², rises gently from sea level in the west to an elevation of 30 m in the east. The geological sequence consists of a latosol ground cover, typically 6-12 m thick, overlying an up to 60 m thick sequence of limestone, which becomes sandy with depth. About 50 tube wells have been constructed in these settlement areas with an average depth of 30 m and safe yields of 8 l/s. These are used for irrigating subsidiary crops. Groundwater recharge into this area takes place by means of infiltration of rainfall through the predominantly forest-covered, highly permeable latosols of the Vellankulam area.

Further investigations have been carried out on a small scale in the Mullaitivu-Paranthan area, indicating a very deep sedimentary coastal belt, which increases in thickness from about 60 to 250 m. In most parts of these sediments the marine sands and clays are intercalated with thinner beds of fossiliferous limestones and sandstones. The crystalline basement, which lies within 30 m of the ground surface in the region between Kilinochchi and Paranthan, indicates an abrupt drop (probably a fault) by about 60 m giving rise to thick Miocene limestone formations.

Investigation boreholes drilled to the north of Puthukkudiyiruppu struck the crystalline basement rock around 250 m. Groundwater of good quality was encountered only at depths in the region of 150-200 m below ground surface. It was observed that the fresh water aquifer exists under considerable hydrostatic pressure -- just sufficient to overflow above the ground surface. The extent of this artesian basin and its potential have yet to be defined by further detailed studies.

In the Jaffna peninsula the groundwater situation has been studied to a great depth in detail because of its special interest for many scientists and engineers in this field. The peninsula is almost an island and measures about 1070 km^2, being divided further into smaller areas by inland lagoons. The whole peninsula and its islands are formed of Miocene karst limestones and sandstones with a total thickness of around 275 m. However, the occurrence of the fresh water is typical of that on any island with groundwater lenses floating over sea water. The uniformity of such lenses of fresh water is greatly dependent on the highly cavernous limestones influencing the general groundwater flow conditions.

Recharge of the fresh aquifers follows from rainfall, and it has been estimated that with the rainy season the peninsula receives an annual recharge volume ranging from about 9.87×10^7 m^3 to about 22.2×10^7 m^3. However, 75 % of this water is discharged into the sea due to the rapid outflow from groundwater mounds as a result of the numerous karst conduits in the limestones. Herein lies a definite problem of the Jaffna peninsula since the aquifer comprises large coastal areas affected by saline water intrusion, while the central regions in which the fresh water lenses are rapidly reducing in thickness, only allow limited groundwater development.

Over 100 000 dug wells have been constructed in this area to depths ranging from 5 to 10 m, which are used for small scale agriculture. There are over 1500 wells monitored every month for their water quality and water levels. This function will be carried out continuously over a long period in order to evaluate the hydrogeological characteristics fully. Only then can any realistic solution be suggested to overcome the difficulty of retaining the large volume of fresh water that is being discharged rapidly into the sea.

4. OTHER AREAS OF INVESTIGATION

There is a very distinct hydrogeological unit in the coastal belt with a high potential for groundwater extraction, varying greatly in thickness and width. On the eastern coast this unit covers a wide area and extends as a continuous belt from Hambantota to the northern tip of the Jaffna peninsula, while in the western coastal belt this unit extends down to the Katunayake free trade zone areas, where the yields from tube wells vary from 1.5 to 5 l/s.

In the laterite region in the southwestern part of the wet zone, there are also good aquifers featuring moderate to high permeability. The behaviour of groundwater in the laterite deposits is of special importance in view of the fact that the southwestern sector is the most densely populated part of the island. Due to the high infiltration capacity of the laterite outcrops, groundwater builds up very rapidly after heavy rains but drains off quickly into marshes and streams. Therefore, siting of the tube wells is mainly recommended towards the valley edge, while in most cases dug wells are recommended in the laterite regions.

5. HYDROGEOLOGICAL MAPPING

In the districts where detailed hydrogeological investigations are being carried out, an attempt is being made to produce a hydrogeological map for each district. Initially, data is collected, such as information relating to water levels, hydrochemistry, geology, structure, geomorphology, climatology, and hydrological features, which include rivers, surface water divides, springs and lakes.

With this data to hand, it is possible to evaluate hydrogeological features, such as water table contours, piezometric contours, direction of groundwater flow, area of artesian flow, and aquifer potential, in order to understand the hydrogeological setting in proper perspective and to project it onto the map.

These systematic hydrogeological investigations will be extended to the remaining districts with a view to covering the entire island, so that eventually a hydrogeological map of Sri Lanka can be produced in the same format as that of the hydrogeological map of India, which is based on the standard UNESCO/IAH International Legend for Hydrogeological Maps, 1970.

6. CONCLUSIONS

With the large-scale development of groundwater by the said projects for domestic, industrial and agricultural needs, it has become essential to monitor the behaviour of the groundwater systems in all parts of the country by extending systematic investigation to areas where no work has yet been done, with a view to ensuring that the systems are not over-developed. Over-development of the resources in addition to changes in the groundwater regime also raise the problems of water quality deterioration.

It is very essential that for all areas where systematic surveys have been completed and tube wells sunk, a hydrogeological map be prepared showing all the information on occurrence, movement, quantity and quality of groundwater.

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STATUS OF HYDROGEOLOGICAL MAPPING IN THAILAND

Somchai Wongsawat

ABSTRACT

The first hydrogeological map of Thailand, scale 1 : 500 000, was published in 1975, covering an area of 200 000 km² in the northeastern part of the country. The map was prepared from analyses of existing data obtained from hydrogeological investigations since 1955 and geological, geophysical and hydrological surveys; lithology, stratigraphy, structural geology, geomorphology, drilling logs, pumping tests, and monitoring of water levels and water quality, etc., have been taken into account. Various attempts have been made at hydrogeological mapping in other parts of the country since 1965. The hydrogeological maps, scale 1 : 500 000, of the northern, central, eastern, western and southern regions were published in mid-1983. The hydrogeological maps covering the whole country of Thailand at a scale of 1 : 500 000 in 4 separate sheets are available for distribution. The single-sheet hydrogeological maps, scales 1 : 1 000 000 and 1 : 2 500 000, have already been drafted and are being printed.

The hydrogeological map at the scale of 1 : 500 000 was chosen as the national standard scale for planning of water resources development in the regions. The legend and symbols used here were based on UNESCO recommendations and the hydrogeological map of England and Wales, scale 1 : 625 000, published in 1977. Detailed hydrogeological maps at scales of 1 : 100 000 and 1 : 50 000 for each provincial area are planned.

1. INTRODUCTION

Thailand is located in the tropical monsoon region of Southeast Asia. It has an area of 514 600 km² lying between the latitudes 6°N and 21°N and the longitudes 97°E and 106°E. It has a maximum length of 1650 km and a maximum breadth of 800 km. The country is bounded on the west and the northwest by Burma, on the northeast and east by Laos, on the southeast by Kampuchea, and on the south by the Gulf of Thailand and Malaysia (Fig. 1).

Groundwater is assuming an increasingly important role in the solution of water problems in Thailand. The increasing demand for groundwater results primarily from the national programme to provide clean water for rural communities. In many cases, groundwater is also required in areas where surface water resources are limited and unreliable or polluted. Groundwater investigation and development in Thailand has been carried out by the Department of Mineral Resources (DMR) since 1955. The results of investigations have been compiled in hydrogeological maps. The maps were prepared with the following objectives:

1) As a preliminary step towards the systematic assessment of groundwater potential.

2) To aid in the planning of groundwater development.

This report attempts to describe the status of hydrogeological mapping in Thailand, the legend and scales used in the preparation of hydrogeological maps, and some problems in hydrogeological mapping in Thailand.

2. HISTORICAL BACKGROUND

The Groundwater Exploration Project in Thailand was set up in 1955 under joint cooperation of the government of Thailand and the United States of America. The project provides for basic geological and hydrological studies and exploratory drilling in northeastern Thailand. Studies planned under the project were considered necessary for evaluating groundwater resources of the areas and essential for preparation of plans for the ultimate systematic development of groundwater supplies for domestic, municipal, livestock, industrial and possibly irrigation use. After expiry of the contract between the two governments in 1961, the Department of Mines, now named the Department of Mineral Resources, continued both the investigation and development phases under the newly assigned name of the "Groundwater Exploration and Development Project". Since 1964, this project has expanded beyond the northeastern part to cover the entire country under the programme of the provision of clean water for rural communities in the National Economic and Social Development Plan. The project objective is to provide sufficient water from both surface and groundwater resources for domestic consumption in all villages of the country. To comply with this objective, the Department of Mineral Resources, the Office of Accelerated Rural Development, the Department of Public Works, and the Department of Health are responsible for the development of groundwater in villages where surface water resources are not available or insufficient.

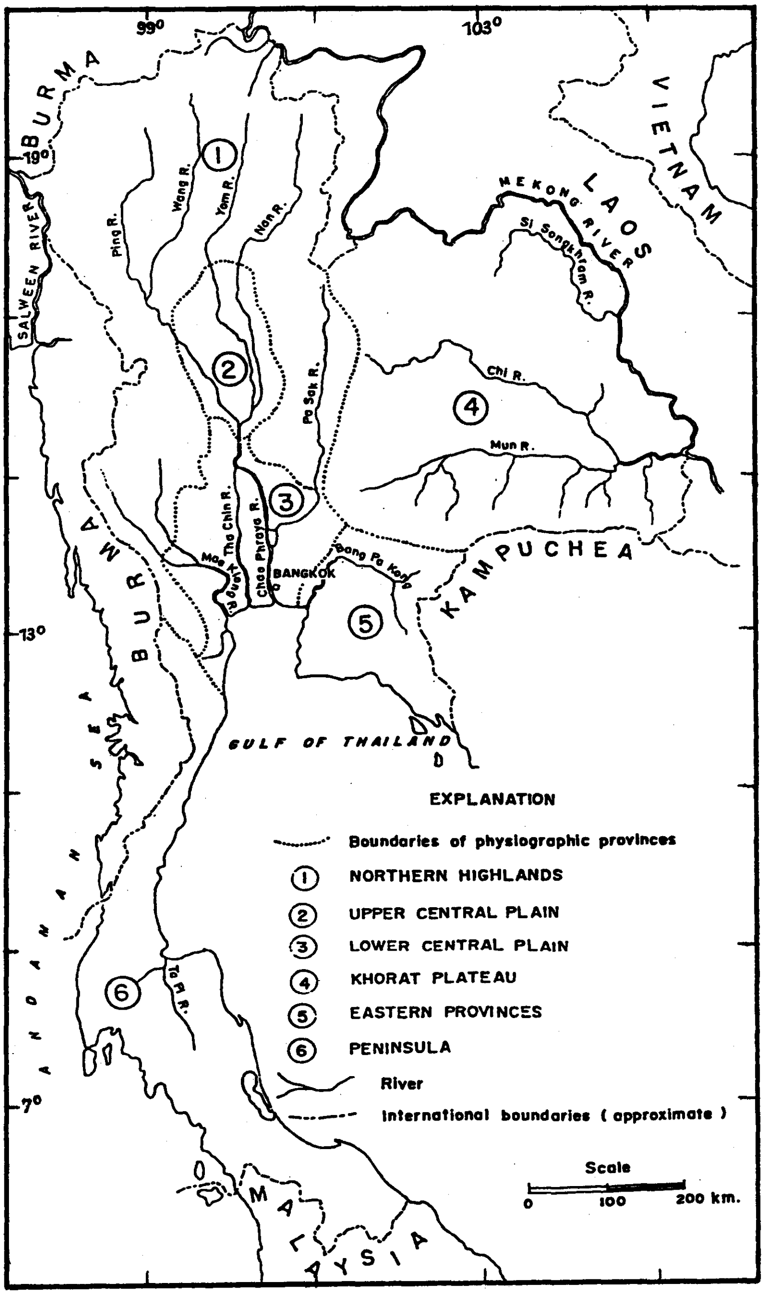


Figure 1. Location Map of Thailand

Recently, the National Security Command, through its Engineering Division, joined these four agencies in developing groundwater for areas affected by political unrest near the national borders.

During the period of groundwater exploration between 1955 and early 1961, conducted by the Department of Mineral Resources in collaboration with the United States Geological Survey (USGS), data was obtained from geological surveys, test drilling, well logging, pumping tests, and water quality analyses. Basic and interpreted data were presented in the Groundwater Bulletin No. 2, published in 1966, in which geological maps and groundwater availability and groundwater quality maps at the scale of 1 : 750 000 were included. Several thousand wells have been drilled, and more information has been obtained from hydrogeological investigations since 1961. The results of the investigations have been compiled in hydrogeological maps. The regional hydrogeological map of northeastern Thailand at a scale of 1 : 500 000 was compiled in 1973 and published in 1975. Later on, in 1975, the regional hydrogeological map of northern Thailand at a scale of 1 : 500 000 was compiled, and published in 1983. The regional hydrogeological map of central, western and eastern Thailand, compiled as a single sheet at the same scale in 1976, and the hydrogeological map of southern Thailand, compiled in 1979, have already been published in mid-1983 and are available for distribution. Due to the urgent need for the planning of groundwater resources development for refugees in the eastern part of Thailand, the hydrogeological map of this region, scale 1 : 250 000, was drafted in 1978; more information has now been collected and the map is expected to be published in 1984. The hydrogeological map of the Upper Chao Phraya Basin, an area of high potential for groundwater resources for irrigation purposes, was compiled at a scale of 1 : 250 000 in 1980 and published in 1982. The hydrogeological map of the Chian Rai-Phayao Basin at the same scale was compiled in 1982 and published in mid-1983.

At present, single-sheet hydrogeological maps of the whole country, at the scales of 1 : 1 000 000 and 1 : 2 500 000, have already been drafted and are at the printers.

Moreover, the Department of Mineral Resources has prepared detailed hydrogeological maps at scales of 1 : 100 000 and 1 : 50 000 for provincial areas or for specific areas, such as the Chiang Mai Basin, Lampang Basin, Phuket Island and Phattaya City; these maps are in the process of final drafting. Maps of the other provincial areas are planned.

3. FRAMEWORK OF HYDROGEOLOGICAL MAPPING

3.1 Base Map

Topographic maps, series L708 and L7017 (scale 1 : 50 000) and series L509 and 1501S (scale 1 : 250 000), have been used as base maps in hydrogeological mapping. The topographic maps mentioned were published by the Army Map Service (KC), Corps of Engineers, U.S. Army, Washington D.C., and printed by the Royal Thai Survey Department.

3.2 Geological Information

In the preparation of hydrogeological maps, geological and hydrological data is needed. The geological data should give details of lithology, stratigraphy, structural geology, and geomorphology. The information can be obtained from geological surface survey and drilling. The geological surface mapping in Thailand has been carried out by the Geological Survey Division, Department of Mineral Resources, at scales of 1 : 250 000 and 1 : 50 000. However, many areas have been rechecked and surveyed by hydrogeologists.

3.3 Hydrogeological Information

The hydrogeological information obtained from borehole drilling for production wells and test drillings by the government agencies concerned consists of drilling logs, aquifer characteristics, such as yield, water level and water quality.

In compiling hydrogeological maps, existing data and information from hydrological and geological investigations pertaining to the exploration of groundwater are analysed. The Hydrogeological Map of Northeastern Thailand, scale 1 : 500 000, was prepared from the data of 2500 drilled wells. The Hydrogeological Map of Northern Thailand, scale 1 : 500 000, was prepared on the basis of data from 1500 drilled wells. The Hydrogeological Map of Central, Western and Eastern Thailand, and the Hydrogeological Map of Southern Thailand, scale 1 : 500 000, were prepared from data taken from 1700 and 650 drilled wells, respectively.

4. HYDROGEOLOGY

4.1 Precipitation

Thailand receives abundant rainfall during the southwest monsoon season, which prevails over the central, northern and northeastern parts of the country from May to October. The mean annual rainfall in the northern region averages 1200 mm in the western part, gradually increasing to 1600 mm towards the Mekong River in the east. Intense rainfalls are found on the southern half of the Peninsula during November to January with a higher mean annual rainfall of about 1800 mm and 2500 mm over the east and west coasts of the peninsula, respectively.

4.2 General Lithology

Since the lithological characteristics of rocks influence their water-bearing properties, it is justified for hydrogeologists to classify the rocks on the basis of their lithology. The following classification is independent of the conventional stratigraphy and applies mainly to rock types and their structural features. Furthermore, the identification of the principal aquifers is based on this classification.

4.2.1 Metamorphic Rocks

The oldest rocks in Thailand are metamorphic rocks mainly consisting of high-grade schists, and paragneisses of Precambrian age, low-grade schists, phyllites, slate and quartzites of Cambrian to Devonian age. The para-gneisses are generally intensely folded whereas the oldest schists are well foliated and lineated. The Lower Paleozoic metamorphic rocks are mostly well bedded, complexly folded, and in places crumpled or even over-turned.

4.2.2 Metasedimentary Rocks

This group of rocks consists mainly of thickly bedded quartzitic sand-stones, feldspathic sandstones, phyllitic to slaty shales, graywackes, and conglomerates of Carboniferous to Permian age. The metasediments are mostly strongly folded, jointed or cleaved, and exposed over both large and small areas all over the country except in the northeastern part of Thailand.

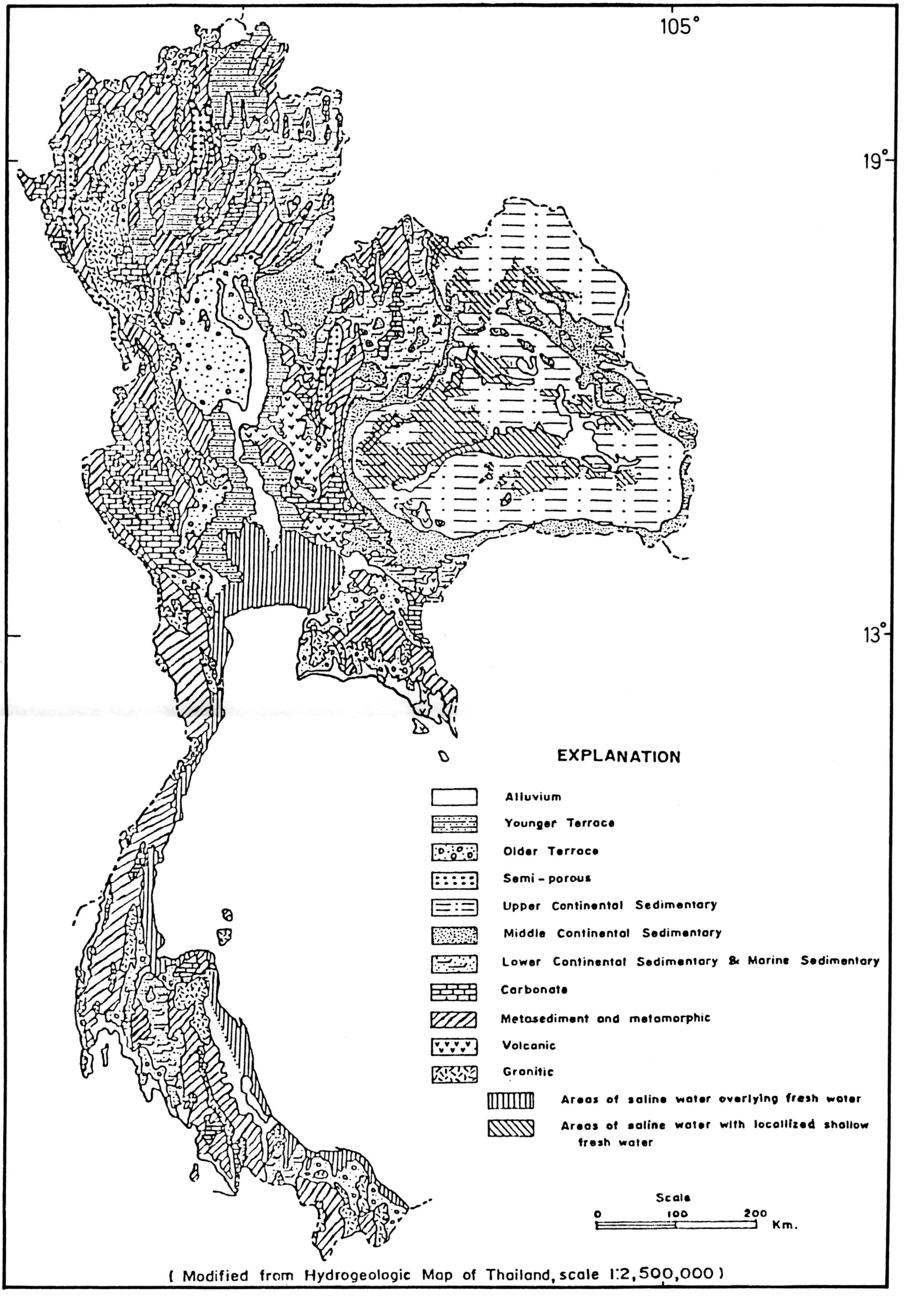


FIGURE 2: MAP OF THAILAND SHOWING PRINCIPAL AQUIFERS

4.2.3 Carbonate Rocks

The carbonate rocks in this group consist of Triassic, Permian and Ordovician limestones. The Ordovician limestone is characteristically thinly bedded, often sandy or argillaceous, light gray to dark gray. The Permian limestone is light gray to gray, cavernous and massive. The Triassic limestone exists only in the northern part of the country and is similar to the Permian limestone.

4.2.4 Marine Sedimentary Rocks

These rocks consist mainly of thick sequences of dark gray shale, thinly bedded, fine-grained sandstone, and intercalated limestone, with reddish-brown shales and sandstones or conglomerates in the upper parts. The shale is typically indurated and features ellipsoidal and conchoidal fractures.

4.2.5 Continental Sedimentary Rocks

This group of rocks is limited to the Upper Triassic to Cretaceous terrigene deposits of the Khorat group, which consists lithologically of three units: the upper, the middle, and the lower Khorat group. The upper Khorat group is composed of red to reddish-brown and grayish-brown, soft shales, siltstones, and sandstones of the Salt and Khok Kruat formations. The middle Khorat group consists of yellowish-gray to grayish-pink, massive sandstones and conglomerates of the Phu Phan formation on the top; grayish-red to olive-gray to white, massive, thickly bedded quartzose sandstones of the Phra Wihan formation at the bottom; and dark reddish-brown to brownish-gray shales and siltstones of the Sao Khua formation in between. The lower Khorat group comprises dark brown to grayish-brown or variegated shales and soft, slabby, micaceous sandstones of the Phu-Kradung formation and sequences of siltstones and thick, resistant sandstones and some conglomerate of the Nam Phong formation.

4.2.6 Semi-Consolidated Rocks

The semi-consolidated rocks include Tertiary lacustrine and fluviatile sediments in the intermontane basins of the north, west and south. They consist of limestones, marls, carbonaceous to oily shales, mudstones and lignite beds.

4.2.7 Unconsolidated Rocks

The unconsolidated rocks in Thailand can generally be divided into two types, i.e. the terrace sediments and the alluvial sediments. The terrace sediments, probably of Upper Tertiary to Pleistocene age, can be found along the peripheries of the basins or within the basins where flood plains are absent. The formations consist of clay, sand and gravel and are generally unconformably overlying Tertiary sediments or older rocks.

The alluvial sediments, generally of Quaternary age, are usually formed along flood plains or meander belts. The thickness of the Holocene alluvial deposits rarely exceeds 50 m.

The other type of unconsolidated rock is colluvium, referring to loose and incohensive deposits usually at the foot of mountain slopes or cliffs and strongly subject to gravitational movement. It consists of poorly sorted rock fragments, sand, and gravel.

4.2.8 Granitic Rocks

Granitic rocks can be found all over the country. The rocks are fine to coarse-grained to porphyritic, and have been subjected to weathering to some extent. The rocks in many places have also suffered deformation and fracturing or faulting.

4.2.9 Volcanic Rocks

Volcanic rocks of various ages occur in Thailand, the rocks older than Tertiary being mostly andesite, rhyolite, tuff, and agglomerate. The Tertiary or Pleistocene volcanic rocks are mainly basalts. Andesites, rhyolites, and tuffs are generally massive and poorly bedded but in places intensively fractured. The Tertiary or Pleistocene basalts are vesicular to amygdaloidal and fairly massive.

4.3 Principal Aquifers and their Hydrogeological Characteristics

The principal aquifers in Thailand can be classified into two main groups: porous and jointed rocks.

4.3.1 Aquifers of Porous Rocks

The alluvial aquifers (temporarily named Chao Phraya aquifers) consist in most places of poorly to moderately sorted clay, silt, sand and gravel. The sandy to clayey deposits normally yield less than 20 m^3/h of good quality water. The sandy to gravelly deposits can be expected to yield up to 50 m^3/h. Within the central parts of the upper and lower Central Plains, where multiple productive aquifers are present, wells with yields of more than 100 m^3/h are common. In the lower part of the lower Central Plain, the alluvium and deltaic sediments with minor estuarine deposits occur at a maximum depth of about 120 m. Along the coastal plain of the Gulf, the alluvial aquifers occur at depths varying from only a few to about 100 m, and average yields for production wells are about 7 - 25 m^3/h.

The colluvial aquifers normally extend from the ground surface to a depth of 10 - 50 m, yielding up to about 5 m^3/h of relatively good quality water to most shallow wells.

The younger terrace aquifers (temporarily named Chiang Rai aquifers) generally form relatively low, flat surface terraces in the basins of central and northern Thailand. The aquifer sediments are composed of thick sequences of clay and a wide variety of clastic sediments including unsorted sand or gravel lenses. Their thickness generally exceeds 100 m in some basins in the north, rarely exceeding 50 m in the Central Plain. Wells drilled in these aquifers normally give an average yield of about 7 - 10 m^3/h of potable water.

The older terrace aquifers (temporarily named Chiang Mai aquifers) are present in most large and small basins with a thickness ranging from not less than 100 m in many parts of the country to more than 500 m in the lower Central Plain. The aquifers are considered to be the most productive of the country and are so permeable and extensive that groundwater is available even in badly constructed wells. The transmissibility coefficient of aquifers is relatively high, with maxima ranging from about 1200 $m^3/d/m$ in the north to 2000 $m^3/d/m$ in the coastal plain to 2400 $m^3/d/m$ in the upper Central Plain, and 3000 $m^3/d/m$ in the lower Central Plain.

Semi-porous aquifers (temporarily named Mae Sot aquifers) are composed of Tertiary deposits, which do not form significant water-bearing units. Water wells drilled into the Tertiary sediments always give low yields, from meagre to about 7 - 8 m^3/h of potable water.

4.3.2 Aquifers of Jointed Rocks

In the continental sedimentary aquifers (commonly known as the Khorat aquifers), groundwater occurs mainly in cracks, joints, and bedding planes of shales, siltstones, and sandstones. No primary porosity of these rocks exists for groundwater storage since the primary permeability of the coarse-grained sandstones has been tested at 8 10^{-5} m/d or less.

According to the lithological classification mentioned above, the Khorat rocks can be divided into three sub-aquifers: the upper Khorat, the middle Khorat, and the lower Khorat aquifers.

The shales and siltstones that constitute the upper Khorat aquifers are generally soft but locally hard and brittle. Wells drilled in these rocks, if not producing salty water, will yield only a small quantity of water. Drilling in the indurated shales normally produces a considerably higher yield, up to 30 m^3/h or more. The sandstones of the middle Khorat aquifer yield 0 to about 5 m^3/h of potable water. The fractured shales and slabby sandstones of the lower Khorat aquifer form a peneplain-type topography. The depth of productive or fracture zones does not generally exceed 60 m. Wells drilled into these zones may yield from 5 - 25 m^3/h of good quality water, but in many places yields of more than 50 m^3/h can be obtained.

The rocks of the marine sedimentary aquifers (temporarily named Lampang aquifers) are generally indurated and readily broken when exposed. Large quantities of groundwater cannot be expected from jointed systems since they are not well interconnected. Wells drilled into the aquifers generally have outputs ranging from very few to about 10^3/h of potable water.

Rocks forming the carbonate aquifers are the Triassic, Permian, and Ordovician limestones. Wells penetrating the cavernous zones of Permian limestone mostly yield more than 25 m^3/h of moderately hard to hard water, and outputs as high as 100 m^3/h with less than 10 m drawdown are common. The Triassic and Ordovician limestones are not as productive as the Permian limestones due to an absence of potential solution openings. The fracture zones and bedding planes forming openings in these limestones usually yield less than 25 m^3/h of usable water.

The aquifers in metasedimentary and metamorphic rocks are similar in their water-bearing characteristics and are not successfully exploited as groundwater resources in the country. The aquifers are made up of Upper Paleozoic metasediments and Middle to Lower Paleozoic metamorphic rocks, as previously mentioned. Of the many rock types mentioned, the metamorphosed shales or slaty shales are significant for the metasedimentary aquifers. They normally yield 3 - 10 m^3/h of potable water to wells. The phyllites and schists of the metamorphic aquifers rarely yield more than 3 m^3/h and dry wells are commonly found. The quartzitic sandstones and quartzites may yield some 10 m^3/h at one well and yield nothing at other wells nearby.

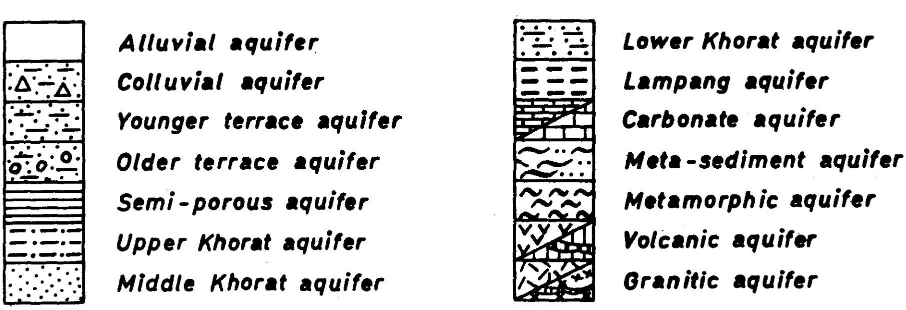
Groundwater of the volcanic aquifers occurs only in secondary openings such as joints and fractures. Wells penetrating the openings usually yield a sufficient quantity of water, up to 15 m^3/h, for domestic requirements of a community. Higher yields, up to 30 m^3/h, have been obtained in areas of favourable hydrogeological conditions.

Groundwater in granitic aquifers can only be found in joint or fissure systems and decomposed zones where yields average 2 - 5 m^3/h, although in some areas yields of up to 8 m^3/h have been obtained. Water quality is generally good but locally inferior due to high iron content.

5. STANDARD LEGEND TO BE USED IN THE PREPARATION OF HYDROGEOLOGICAL MAPS

5.1 The legend used in preparation of the Hydrogeological Map of Thailand, scale 1 : 500 000, is based on the standard legend recommended by UNESCO, IAH, IASH and IHD. However, some additions have been made to the leged to represent certain special hydrogeological conditions.

5.1.1 Lithology: Line and dot patterns symbolizing the lithological composition of aquifers are printed in brown. The various patterns have been used as follows:



5.1.2 Character of aquifers: Colours are used to distinguish the hydrogeological characteristics of aquifers, while productivity of aquifers of the same hydrogeological character is differentiated by colour tones. A darker tone indicates a high degree of productivity.

Dark blue -- highly productive porous aquifers (aquifers in which flow is intergranular).

Light blue -- less productive porous aquifers.

Dark green -- highly productive fissured aquifers.

Light green -- less productive fissured aquifers.

Dark brown -- local groundwater resources in fissured rocks in which groundwater may be present at great depth.

Light brown -- local groundwater resources in fissured rocks in which groundwater is absent, even at great depth.

5.1.3 Geology: Geological features are represented by line and dot patterns and by symbols and names in black.

5.1.4 Groundwater Hydrology: Hydrological information relating to groundwater, such as water-level contour lines, direction of groundwater flow, groundwater divides, etc. is shown in violet.

5.1.5 Hydrochemistry: Orange is recommended as the colour for lines representing hydrochemical composition; the same colour has also been used to indicate hydrochemical features in the Hydrogeological Maps of Thailand, scales 1 : 1 000 000 and 1 : 250 000.

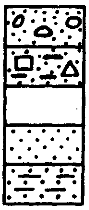
2.1.6 Hydrography: All natural surface water features are coloured blue.

5.1.7 Artificial works: All artificial works are indicated in red.

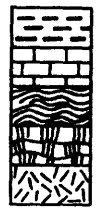
5.2 The standard legend mentioned above has been adopted for the Hydrogeological Maps of Thailand, scale 1 : 500 000. One exception is the

Hydrogeological Map of northeast Thailand, in which special patterns for local geochemical and lithological features have been added, as shown below.

5.2.1 Lithology:



Unconsolidated aquifer
Semi-consolidated aquifer
Upper Khorat aquifer
Middle Khorat aquifer
Lower Khorat aquifer



Lampang aquifer
Ratburi limestone aquifer
Meta-sediment aquifer
Volcanic rocks
Granitic rocks

5.2.2 Character of aquifers

5.2.2.1 Groundwater in porous rocks: Local but productive aquifers are represented by blue, greater productivity of aquifers being indicated by a darker tone.
Local and less productive aquifers are represented by light green and orange.

5.2.2.2 Groundwater in jointed massive rocks: Extensive and productive aquifers are represented by dark green to light green.
Extensive but less productive aquifers are represented by four tones of orange and brown.
Regions generally without or with only local groundwater are represented by dark and light violet.

6. PROBLEMS IN HYDROGEOLOGICAL MAPPING

The problems encountered in hydrogelogical mapping are mainly those of financial support and personnel. The national budget for the drilling of wells for village water supplies and for increasing the personnel engaged in drilling is normally sufficient, but the number of increasingly qualified personnel for the investigations is very limited. Inadequate budgeting will eventually create the problem of inadequate numbers of hydrogeologists and trained staff. Generally speaking, the diversity of geological formations with their very varied lithology and chronology, the complex tectonic framework, and the hydrochemical conditions which prevail throughout the country present those involved with the preparation of hydrogeological maps at small scales with a difficult task.

7. A FUTURE PROGRAMME FOR HYDROGEOLOGICAL MAPPING

Fortunately, regional hydrogeological maps at a scale of 1 : 500 000 have already been published and maps at scales of 1 : 1 000 000 and 1 : 2 500 000 covering the whole country have already been drafted and are being printed. The hydrogeological maps already published are considered as a preliminary step, and the results still need to be quantified. The data available so far is insufficient to plan in a rational manner the extensive development of groundwater resources. To cope with this problem, the proposed programme for hydrogeological mapping aims towards a quantitative approach with the compilation of more detailed hydrogeological maps. The standard scales chosen are 1 : 100 000 and 1 : 50 000 for each provincial area. Thailand consists of 73 provinces; thus, the detailed hydrogeological maps will appear on 73 sheets covering the whole country.

8. CONCLUSIONS

Hydrogeological mapping in Thailand was started at the same time as the groundwater development programme, in 1955. The first study concentrated on the northeastern region, but since 1964 the programme has been expanded to all areas of the country. The objectives of hydrogeological mapping could be summarized as making a preliminary step in the systematic assessment of groundwater potential and in the planning of groundwater resources development. The methods of hydrogeological mapping consist of the compilation and analysis of existing data from geological surface studies and from records of drilled water wells. For areas with insufficient data, hydrogeological mapping programmes have been set up and teams of hydrogeologists then sent out to conduct field surveys. For such purposes, field officers are required. The hydrogeological map at the scale of 1 : 500 000 has been chosen as the national standard scale for planning the groundwater resources development of each region. The single-sheet hydrogeological maps of Thailand, scales 1 : 1 000 000 and 1 : 2 500 000, have been prepared as a general review of the hydrogeological setting in the whole country. The legend used in the hydrogeological maps is based on UNESCO, IAH, IASH and IHD recommendations.

Complex structures and the wide variety of rock types have created very diverse groundwater conditions. Detailed hydrogeological maps at scales of 1 : 100 000 or 1 : 50 000 are necessary to assist in the planning of groundwater resources development in the provinces.

The regional hydrogeological maps covering the entire country at a scale of 1 : 500 000 were completed in mid-1983. Maps at scales of 1 : 100 000 and 1 : 250 000 have already been drafted, and the preparation of detailed hydrogeological maps at larger scales is planned, too.

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Proceedings of the ESCAP-RMRDC Workshop, Bandung, 1983

HYDROGEOLOGICAL MAPPING IN THE SOCIALIST REPUBLIC OF VIETNAM

Nguyen Dong Lam

Hydrogeological mapping is being conducted with increasing intensity in the Socialist Republic of Vietnam with the aim of exploring groundwater, mineral water and thermal water resources, thus benefitting the national economic planning. This task has been carried out during the last decade and extended, so that today it encompasses the whole country and has achieved a number of encouraging results.

1. VARIOUS TYPES OF HYDROGEOLOGICAL MAPS MADE IN VIETNAM

Hydrogeological maps at a small scale (1 : 500 000), medium scale (1 : 200 000) and large scale (1 : 25 000 - 1 : 50 000) are being compiled in Vietnam, in addition to hydrogeological maps, scale 1 : 3 000 000, for the National Atlas.

1.1 NATIONAL HYDROGEOLOGICAL MAP, SCALE 1 : 500 000

This map was begun during the last few years and is expected to be completed in 1984-85. The map has been based on the principles of hydrogeological stratigraphy in six hydrogeological regions, representing the complexes and zones of groundwater. So far, the results enable the Vietnamese hydrogeologists to understand the general hydrogeological features of the country as a whole, the basic properties of regional hydrogeological structures, the distribution of stratigraphic units and hydrochemical features, and the salinity of coastal areas. At the same time, the achievements indicate the success of mineral-water and thermal-water prospecting in Vietnam. The results also lay down guidelines for larger-scale hydrogeological mapping as well as for groundwater exploration.

1.2 HYDROGEOLOGICAL MAP, SCALE 1 : 200 000

These maps have been compiled on the principles of hydrogeological stratigraphy showing details of aquifers. Three separate sheets, covering about 10 % of the national area, have been completed, two of which belong to the Red River delta area and one of which belongs to the central plateau region. It is expected that more than 30 % of the national territory will be covered by 1986.

For the Red River delta and a part of the hilly region, the maps show all hydrogeological features: the aquifers (mainly sand and gravel aQ_{IV} and gravel aQ_{II-III} layers, called the Hanoi aquifer), the main hydrogeological parameters, groundwater areas of interest for further exploration and the boundaries which have been the subject of investigation of saline-water regions. The maps also show groundwater areas and deposits of calcium carbonate (karst marble) of C-P, D_2 and T_2a stratigraphical age. It is difficult to find fresh-water resources in a number of saline and arid coastal deltas in central Vietnam. As a preliminary step, hydrogeological mapping has indicated a number of regions for groundwater exploration, specific exploitable deposits being the amQ_{IV} sands, karst limestones of Devonian and Triassic age and fractured Jurassic rocks. The exploitation of groundwater reserves in these regions measures ten of thousands cubic metres per day, thus meeting a portion of the population's requirements.

The medium-scale hydrogeological maps have also been completed for the northern region of the central plateau, representing the hydrogeological features of various stratigraphical units on the high plateau together with the groundwater storage capacity of the Bazal rock (N_2Q_I), thus laying the foundation for groundwater exploration and evaluation.

1.3 HYDROGEOLOGICAL MAP, SCALE 1 : 25 000 - 1 : 50 000

A part of the 1 : 25 000 map has been completed for the Quang Ninh mining region during recent years, and at present it is being extended to cover other mining and industrial regions.

To sum up, in the field of hydrogeological mapping in Vietnam, definite results have been achieved, thus progressing in the task of geological research and groundwater exploration and meeting the requirements of national economic development.

2. FUTURE POLICY OF HYDROGEOLOGICAL MAPPING IN VIETNAM

Tasks to be carried out during coming years in the field of hydrogeological mapping in Vietnam are as follows:

-- National hydrogeological maps at scales of 1 : 500 000 and 1 : 3 000 000 to be completed and published.

-- Hydrogeological mapping at the scale of 1 : 200 000 to be intensified, starting at the deltas and working towards the mountainous regions, and finally covering the entire country.

-- Preparation for the hydrogeological mapping at scales of 1 : 25 000 - 1 : 50 000 of a number of economically important and populous areas.

In order to enhance the quality of hydrogeological mapping, the Vietnamese hydrogeologists have to continue to study and perfect various methods in drawing, representation, illustration, explanation, and remote sensing as well as to conduct pilot surveys.

Hydrogeological mapping in Vietnam is a newly developing field, lacking both experience and technical equipment, chiefly with regard to hydrogeology and geo-engineering. Therefore, the Vietnamese hydrogeologists are seeking cooperation with the International Hydrogeological Society and similar associations from developed and developing countries, above all from countries within ESCAP, with a view to exchanging experiences and mutual support and in order to increase the wealth of hydrogeological data of the country as well as to enhance the people's lives.

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THE INTERNATIONAL LEGEND FOR HYDROGEOLOGICAL MAPS -- PRINCIPLES AND APPLICATION

W. Struckmeier

ABSTRACT

Early attempts at a standardization of the graphical representation on hydrogeological maps originate from the 1950s and were first published in 1963 in an "International Legend for Hydrogeological Maps" (Unesco).

The present paper expounds the usefulness of a standard legend for hydrogeological maps and outlines its development from the first theoretical considerations of the 1963 legend to the representation scheme of the revised legend of 1983, which has been tested in practice over large areas of Europe and in various environments.

By and large, the legend applies to general hydrogeological maps which integrate information on groundwater resources, geology (lithology, structures) and hydrogeological features (groundwater and springs, water quality and temperature, surface water, karst, permafrost, horizon contours, man-made features). A large number of signs and symbols are also recommended for use on more specialized and detailed hydrogeological maps. It is recognized, however, that these detailed maps frequently require special representations to underline their special purpose.

General hydrogeological maps can be used for many purposes and by numerous map users, such as administrators, economists, engineers, technicians, scientists, teachers, farmers and private individuals.

The important role of the standard legend as a common legend mediating between the specialists in the field of hydrogeology the technical level and the interested public is stressed. The legend, meanwhile internationally accepted, is used in many hydrogeological mapping projects at regional, national or international scale and in industrialized or developing countries, as many recent examples reveal.

1. INTRODUCTION

The branch of hydrogeology as a modern science is relatively young although the first hydrogeological maps were already produced some hundred years ago. The number of hydrogeological maps has been increasing strongly, especially during the past two decades. At present, there is only a small number of countries in the world that have not yet prepared any hydrogeological maps for at least part of their territory.

Attempts at a standardization of the representation on hydrogeological maps were launched in the late 1950s, when it was recognized that the individual style of each hydrogeological map author made a comparison of the maps almost impossible and gave rise to confusion among the map users.

This paper presents a review of the historical background, principles and usefulness of a standard legend, and its application to hydrogeological maps.

2. DEFINITIONS, LIMITATIONS AND PURPOSE

A hydrogeological map, in the broad sense, is any graphical representation, to scale and on a flat medium, of hydrogeological features in relation to the surface of the earth.

Within the system of graphical representation used in the field of hydrogeology, hydrogeological maps form only one section (Table 1). At present, this group is the most important since the representation of water systems and 3D-groundwater-models are still in their infancy.

Hydrogeological maps can be classified in many ways and by the use of various criteria (1), a selection of which is presented at the bottom of Table 1. The most useful and practicable classification seems to be one referring to the purpose that the map is intended to serve and, thus, to the recipient functional system which works with the hydrogeological map. Three subgroups of hydrogeological maps can be identified:

-- general hydrogeological maps, which refer to the reconnaissance system,

-- specialized hydrogeological maps or project maps, which refer to the planning system, and

Table 1. System of graphical representation in hydrogeology

Functional system using graphical representation / Type of graphical representation	Reconnaissance system Coherent representation of available data on a topographic base	Planning system Semi-quantitative determination and representation of data relevant for the project	Management system Exact quantitative assessment of available water resources (surface and groundwater), water quantity and quality
Hydrogeological maps (various scales)	General hydrogeological map	Specialized hydrogeological map (project map)	Detailed hydrogeological map (parameter map)
Representation of GW-dynamics	Regional GW-systems represented on maps and sections	Sub-regional GW-systems on maps and sections	Local GW-systems on maps and sections
3D-GW-models	Idealized GW-model	Semi-quantitative GW-model	Quantitative model of the water system, time and space variable
Type of graphical representation / Variation of parameters of representation	(large) ◁—— Area of representation —— (small) (small) —— Amount of data per area ——▷ (large) (low) —— Reliability ——▷ (high) (low) —— Cost per unit area ——▷ (high) (small) —— Scale ——▷ (large)		

-- detailed hydrogeological maps or parameter maps, which refer to the management system.

The latter two groups of maps comprise a wide variety of representations in order to display the specialized hydrogeological information which is needed by technicians, planners and engineers. The aim of a general hydrogeological map, however, is to integrate all the hydrogeological and geological information in a way which presents a clear and easily legible synoptic picture not only to technicians and engineers but also to a much broader group of potential map users, such as politicians and the interested public. In this way, the advantages of a non-verbal delineation are used to link the technicians with the users without a technical background, who normally think along different lines.

A general hydrogeological map, therefore, should emphasize all features which are necessary to understand the hydrogeological setting of the mapped area. Their character is synthetic, whereas specialized and detailed hydrogeological maps are necessarily analytic.

A general hydrogeological map can serve a wide range of purposes and a variety of map users (2). For professionals in hydrogeology and for planners it serves as a basis for further work, frequently revealing questions and identifying problems which have only been recognized through the work on the map. For politicians and the interested public the representation of coherent hydrogeological units is most valuable despite their "artificial" boundaries.

The International Legend for Hydrogeological Maps is especially recommended for use on general hydrogeological maps. However, even if the representation on specialized and detailed hydrogeological maps differs from the general map because of their more specialized contents, a number of graphical elements of the international legend may be used also on these maps instead of newly invented symbols. Nonetheless, it is obvious that only those graphical elements should be used which apply to the hydrogeological setting of the map area.

In addition, the definitions of the graphical elements and their grouping under thematic headings provide a methodology or programme for the preparation of general hydrogeological maps. A further advantage of a multilingual legend is its use as a kind of multi-lingual dictionary of hydrogeological terms.

3. PRINCIPLES OF THE LEGEND

A legend aiming at international recognition has to apply a fairly general classification in order to become universally applicable under widely differing climatic, geographical and hydrogeological conditions.

All hydrogeological map representations have to meet two basic requirements: firstly, to present a large amount of exactly defined hydrogeological information and, secondly, to preserve utmost clarity for the map user. It is evident that even the most sophisticated cartographic techniques will fail to show all the complex water-related information on one single general hydrogeological map if it is to remain legible. Therefore, a part of the available information has to be shown on supplementary "insert" maps or in an explanatory text accompanying the map.

The representation methodology recommended in the International Legend for Hydrogeological Maps comprises four main groups of information which together compose the general hydrogeological map*):

A. Background topographical information.
B. Characteristics of hydrogeological units.
C. Lithology.
D. Detailed hydrogeological data.

Colours are used to portray the most imporant information on the map, i.e. the character of hydrogeological formations and whether they contain large, medium or small amounts of groundwater or essentially no groundwater.

3.1 BACKGROUND TOPOGRAPHICAL INFORMATION

The background information should ensure an easy use of the map. Thus, it goes without saying that all background information should be represented in the most up-to-date form. A hydrogeological map printed on an antiquated topographical base map will be obsolete immediately as no map user will find it acceptable.

The precise drainage network, which is supplemented by important surface hydrology features further specified under section D, should be printed in blue.

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*) It should be mentioned that the complete map can be printed with only eight colours, i.e. in two runs of a four-colour-offset printing machine.

Topographical information on roads, railroads, towns and settlements, and all geographical names are shown in dark grey or black. On very small-scale maps it may be justified to omit altitude contours, but generally they are of great value to the map user. They should be printed in a grey tone.

The grid, preferably referring to international rather than national coordinates, should be always in black.

3.2 CHARACTERISTICS OF HYDROGEOLOGICAL UNITS

Since general hydrogeological maps are recommended to be produced in a relatively early phase of hydrogeological reconnaissance, sufficient weight will be placed on geological information. However, the colours blue, green and brown, as used on the map, do not refer to the age of rock units (as was proposed and applied by many map authors in the 1960s), but rather to the hydrogeological character of the formations.

All outcropping strata appear in colour on the map, whether aquifers or non-aquifers. Aquifers in which flow is mainly intergranular (mostly unconsolidated material) are coloured blue; fissure aquifers, including karst aquifers, are coloured green. In each case a dark tone of the colour indicates extensive and large groundwater resources and a high productivity of the aquifer, while a lighter tone indicates local and smaller resources and a lower productivity of the aquifers. Formations containing only limited or local groundwater resources are coloured light brown, while strata with essentially no groundwater are coloured dark brown. The colours, therefore, combine information on the occurrence of groundwater with information on groundwater flow regimes. This information is essential to recognize the hydrogeological units occurring in the mapped area.

Hatching with fine, vertical, brown stripes is used where thin covering layers of low permeability overlie major aquifers or groundwater systems.

3.3 LITHOLOGY

The lithology of the outcropping strata is represented by grey screen patterns. These symbolize in a general way the main components of the strata. Screens representing sedimentary strata are recognizably laminar and are arranged horizontally where strata are gently inclined or horizontal, while steeply inclined or folded areas are represented by vertical screen patterns.

Aquifer systems composed of a number of superimposed layers of different lithology which are too small to be split up into different units are usually represented by a mixed type of screen pattern.

3.4 DETAILED HYDROGEOLOGICAL INFORMATION

Information on hydrogeological data is illustrated by the use of symbols or lines printed in various colours on the map, each colour symbolizing a particular group of hydrogeological features:

i -- violet for information on groundwater and springs,
ii -- orange for information on groundwater quality and temperature,
iii -- blue for information on surface water and karst hydrology,
iv -- red for all man-made features and alterations of the natural groundwater regime,
v -- dark green for horizon contours and permafrost,
vi -- black for geological information.

It is up to the map author to decide how much detailed information is to be presented on the main map or on insert maps. However, even a general small-scale hydrogeological map should contain the most important features which reduce groundwater development prospects, such as poor quality of the water or insignificant recharge.

4. APPLICATION OF THE LEGEND

Since the first publication of an international legend for hydrogeological maps in 1963 (3) and the amended, multi-lingual version in 1970 (4), the legend has provided the basis for the preparation of many hydrogeological maps both inside and outside Europe and on a national or international scale. A sketch on the historical development of the legend written by H. Karrenberg is included in the revised legend of 1983 (5).

4.1 INTERNATIONAL HYDROGEOLOGICAL MAP OF EUROPE

The revised legend is closely associated with the International Hydrogeological Map of Europe, scale 1 : 1 500 000, since, for the most part, the same experts have contributed to both projects under the aegis of the IAH Commission on Hydrogeological Maps. Moreover, the European map was intended to serve as a practical test for the application of the representation methodology presented in the legend. Thus, the legend draws upon the experience of more than 200, mainly European, hydrogeologists.

In the preparatory phase of the project of the International Hydrogeological Map of Europe, four different models were developed and printed as a practical test of the proposed representation (6). Part of the Sheet C 5 (Bern) was selected as the prototype since it covered a region with varied geology and for which a large amount of data was available.

Models 1 and 2, printed in 1964, were basically geological maps containing some hydrogeological information and the colours still corresponded to the geological timescale. Neither model gained general acceptance.

Model 3, produced in 1965, presented a classification of good, moderate and poor aquifers expressed by different colours. However, well yields as a basic criterium for the classification were criticized, and no agreement was found as to what constituted "good", "moderate" and "poor".

Thus, Model 4 introduced for the first time the aquifer productivity and groundwater resources concept, whereby the occurrence and distribution of groundwater in the strata was expressed by the colours blue and green for extensive and large amounts of groundwater and brown for local or essentially no groundwater. Two tones of each colour are used for further specification. Additional colours and graphical elements were printed to represent detailed hydrogeological information.

Model 4 was accepted as the prototype of the series of the International Hydrogeological Map of Europe and the final version of Sheet C 5 (Bern) was published in 1970.

Subsequently, the methodology was described in detail (7) and a general legend was prepared for the whole project and distributed to all contributors (8).

By the end of 1983, at the time of writing, 18 sheets out of the series of 30 have been printed (see Fig. 1). Nine sheets are published together with their explanatory notes. Complete map manuscripts of eight further sheets are awaiting cartographic processing and printing.

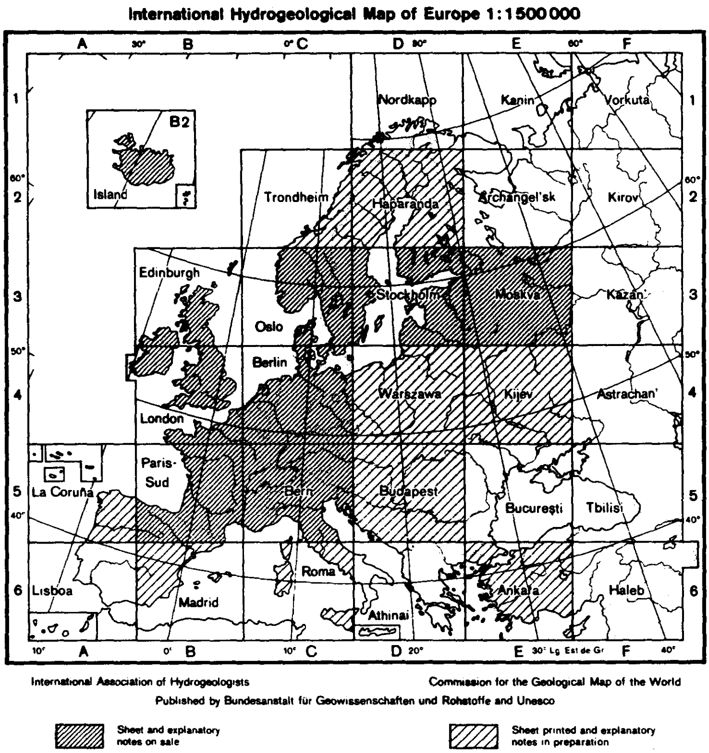

Fig. 1: State of preparation of the International Hydrogeological Map of Europe 1 : 1 500 000. Date: end of 1983.

The size of the area covered by the map, the variety of climatic, geographical and geological environments, and the large number of experts cooperating in the project have made the International Hydrogeological Map of Europe into an outstanding example for small-scale general hydrogeological maps.

This project has, directly or indirectly, brought to life numerous other hydrogeological map projects, on both international and national scale.

4.2 INTERNATIONAL AND CONTINENTAL MAP PROJECTS OUTSIDE EUROPE

The importance of international hydrogeological mapping is being recognized throughout the world. Consequently, small-scale hydrogeological maps are being developed on all continents of the earth to produce coherent base maps which display the hydrogeological units in their full extent.

Prominent examples of continental or international hydrogeological maps outside Europe are:

- the Hydrogeological Map of South America (in compilation),
- the International Hydrogeological Map of South and East Asia (in compilation),
- the Water Resources Map of the Arab States (in print), (9), (10),
- the project of the International Hydrogeological Map of Africa (in preparation), and
- the Hydrogeological Map of Australia (in preparation).

All these ongoing or planned projects are based on the cooperation between many hydrogeologists from many countries, and agreement on the mapping methodology had to be reached before printed maps became available. In general, the International Legend was a very helpful contribution to all the projects mentioned above.

4.3 NATIONAL MAPS

It is a striking feature that a request for international scientific co-operation pushes forward national research programmes. For example, co-operation in Europe for the hydrogeological map has initiated the first nation-wide inventories and national hydrogeological mapping in many European countries, such as Iceland, the Skandinavian countries, U.K., Ireland, Portugal, Italy, Greece, Turkey, Romania, Czechoslovakia and several others.

A non-exhaustive list of references to national general hydrogeological maps at scales smaller than 1 : 200 000 is included in the 1983 Legend (5).

As more and more countries recognize the value of hydrogeological maps for development, the number of national hydrogeological maps will grow rapidly. For these multipurpose hydrogeological maps the international legend can provide a suitable working tool.

At the same time, the need for reliable information about special hydrogeological features in detail and at a larger scale will multiply the number of specialized hydrogeological maps. These maps will have to use very varied graphical representation to meet their requirements and constraints in the most appropriate way.

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DATA REQUIREMENTS FOR HYDROGEOLOGICAL MAPS

Klaus D.W. Krampe

ABSTRACT

The content of groundwater maps has been reviewed with special regard to the importance of hydrogeological parameters.

The data have been classified as essential, very important and desirable data. The significance of all relevant data and parameters has been described at some length. Three types of groundwater maps have been distinguished: single-parameter maps, comprehensive hydrogeological maps and groundwater potential maps.

In addition to field inventories, data acquisition from lithological logs and hydrochemical analyses has been explained. A series of 13 figures has been inserted.

Finally, recommendations have been made for the preparation of maps with reference to the hydrogeologist's role. Remarks on data plotting and how to augment the amount of data have been included.

1. INTRODUCTION

The present paper is aimed at the very first steps of hydrogeological mapping. Therefore, it relates to several basic questions dealt with at the workshop, such as concerning the scope of groundwater maps, organization of mapping, types and scales of maps, and data collection and presentation.

Hydrogeological maps may be said to serve two main purposes: (i) to provide description about the occurrence and the type of groundwater resources, and (ii) to aid the utilization of groundwater potential. Hydrogeologists are preparing their maps for either hydrogeological professionals, who are familiar with the hydrogeological terminology, or planners, who often are decision-makers and non-specialists in groundwater matters.

Although the representation of hydrogeological information is different for each type of map or category of user, there is a basic set of data, indispensable for all groundwater mapping.

2. THE CONTENT OF GROUNDWATER MAPS

2.1 A review

In order to prepare groundwater maps we need a relatively limited number of parameters. The information about them mainly derives from measurements and, additionally, from certain observations. These data are expressed in measures of length (distances, altitudes), area, volume, concentration of chemical contents, in a few dimensionless values, and also in several values over time.

Since groundwater exists principally without the influence of man upon it, groundwater maps primarily contain and summarize information about:

-- depth, altitude, quality, distribution of groundwater and groundwater occurrences;
-- the geological framework (type and extent of aquifers, tectonic structures);
-- the hydrological network as a possible source of groundwater discharge or recharge;
-- other topographical features (morphology, vegetation).

For such maps the relationship between all relevant parameters has to be worked out as clearly as possible.

Based on, and in connection with this picture, the interaction between human activities (groundwater extraction, endangerment, planned withdrawal) and natural groundwater conditions has to be described.

2.2 Map types

The scope of a hydrogeological map determines its content. With regard to the variety of parameters represented, several types of groundwater maps can be distinguished:

(a) single-parameter maps,
(b) comprehensive hydrogeological maps,
(c) groundwater potential and basic planning maps.

The parameter map shows with much exactitude a specific set of data concerning groundwater, its occurrence, extent and magnitude. Examples of such maps are those showing "groundwater contours", "depth-to-groundwater", "groundwater salinity", specific "ion content" (e.g. chloride, fluoride, iron, nitrate), "thickness of saturated sediments" and "thickness of aquifers".

It should be noted that the representation of a single parameter has to take into account its relationship to at least one other parameter; e.g. a "groundwater contour map" can not neglect the location, topographic setting and runoff regime of a river.

The basic maps of "observation points" and "topographic surface" principally belong to the single-parameter maps. This also is true for the representation of further parameters, such as transmissivity, coefficient of permeability, storage coefficient, field capacity, infiltration rates, fluctuation of groundwater table, hydraulic head characteristics and so forth.

Single-parameter maps often serve for the presentation of many details and may, therefore, require the use of larger scales. If necessary, values or data may be reported on the map. It can then easily be extended or revised. Such maps are only appropriate for use by hydrogeologists.

Comprehensive hydrogeological maps contain a combination of various parameters. They give a review of hydrogeological conditions in more general terms and have, therefore, to demonstrate the interdependence of a number of parameters.

"Classical" hydrogeological maps of this type usually show groundwater contour lines, areas of salinity ranges and depth to groundwater, and sometimes information about aquifers (type and/or thickness); the content of the basic maps (observation points and topographic surface) is also included.

Such maps are prepared on either large or small scales, depending on their use. However, the comprehensive hydrogeological maps also require to be interpreted by hydrogeologists.

Groundwater potential maps, the third type, are more generalized. They are more adapted to the planner's need and are not intended to be a comprehensive hydrogeological map. Such maps must be prepared on scales adequate to review the possibility and limits of groundwater development where it is planned. Maps of this type are usually produced for water master plans, feasibility studies, etc.

To mention a few examples of maps of the third type, there are those showing "groundwater yield", "groundwater quality" and "groundwater vulnerability".

2.3 Type of data used

Independent of the scope of the maps, a minimum amount and a specific series of data are indispensable for the preparation of all types of maps.

One may distinguish between "essential data", "very important data" and "desirable or other useful data", as explained below.

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

An orderly data collection is also indispensable for hydrogeological mapping. It is the basis for further effective data elaboration, data evaluation and data presentation (see Fig. 1, Review of the treatment of hydrogeological data).

3. SIGNIFICANCE OF DATA

3.1 Hydrogeological field inventory

For the orderly collection of data, well-inventory forms or well schedules are necessary. There is a large number of different forms and formats. Reference is made to discussions on the occasion of various RMRDC hydrogeological advisory services (see Krampe, September 1978; January 1979; March 1979; August 1979; June 1980; November 1980).

The well-inventory form reported in Fig. 2 was developed in 1978 for the purpose of manual data processing. It is principally based on a well schedule of the Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR), 1969-1976 (see Fig. 3), which was developed for both easy field inventory and subsequent electronic data processing (EDP). Figure 4 was designed in the BGR afterwards on the basis of Fig. 3. The well-inventory forms reported in Figs. 5 and 6 adapt the experiences from the aforesaid forms. They are especially designed for the requirements of a feasibility study to improve the rural water supply in Central Java (see Ploethner, 1984).

3.2 Essential data

A number of hydrogeological data can be considered "essential data" since without them the most important hydrogeological maps (showing groundwater contours, salinity and depth-to-groundwater) could not be prepared:

-- Well number leads to an orderly storage, retrieval and plotting of information.

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

-- Altitude of land surface is necessary for computing the elevation of the groundwater table.

-- Elevation of groundwater table is essential for the construction of groundwater table maps, which enable the hydrogeologist to recognize the direction of groundwater flow, its gradient, and, together with topographical data, (surface water) recharge and discharge areas. A groundwater table map is one basic requirement, together with figures on transmissivity, to compute the quantity of groundwater flow.

-- Depth to groundwater (sometimes called "static water level") is necessary to compute water table elevation in order to obtain hints at possible processes acting from the land surface on the groundwater (evapotranspiration).
Fig. 7 is given in order to illustrate the interdependence of well location, elevation of land surface, depth to groundwater and elevation of groundwater table.

-- Type of well gives a first hint at the number of aquifers.

-- Source of data may roughly describe the reliability of the data.

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

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

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

-- Salinity (to deduce from field measurements of electrical conductivity) is a basic datum which informs about groundwater suitability.

-- Date informs about the date of observations of either one's own field investigations or of previous observers (but does not necessarily correspond to the date of filling in the survey form).

-- Recording sequence is required to inform about the number of data sheets prepared or available for the same observation point. More than one recording sequence will occur if several field visits were undertaken, if data from different periods are available or if the content of a block taken at the same time varies. This latter may be valid in the case of varying depths (e.g. several aquifers, lithological descriptions) or ranges of quantity (e.g. step drawdown tests), or quality (e.g. electrical conductivity or temperature by depth), or diameter (e.g. due to reductions of casing and screen). The block for "Recording sequence" should consist of two positions.

3.3 Very important data

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

A list of very important data comprises the following:

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

-- Lithology of aquifer or aquifers and also type of overlying strata hints, among other things, at hydraulic characteristics of strata (permeability).

-- Base of aquifer or aquifers, obtained by a similar subtraction method as in top of aquifer.

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

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

-- Specific capacity, computed value from yield and drawdown, both obtained from pumping tests, which suggests groundwater productivity and under certain circumstances helps to intensify data frequency on transmissivity.

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

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

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

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

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

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

3.4 Desirable and other useful data

Additional subjects may be classified as "very desirable", such as:

-- Map sheet, very useful to support the ordering of observation points.

-- Province and/or other administrative unit or subdivision, for the same reason as given for "map sheet" and also to recognize or to prove the density or existence of data in various areas.

-- Well use, for a similar reason as for the two subjects mentioned above.

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

-- Diameter of well, desirable for interpreting pumping tests, planning pumping tests (lowering the pump, moving the flow meter during test), planning other geophysical well measurements, and reasons mentioned under "date of termination" (distinction of wells!).

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

-- Duration of pumping; to be connected with blocks "Yield" and "Drawdown" and giving an idea of the reliability of data on specific capacity and transmissivity.

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

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

-- Mode of extraction or groundwater withdrawal; its regional survey contributes to an assessment of the status of groundwater development.

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

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

-- Altitude of land surface determined by means of...; distinction between estimate using more or less precise topographical maps and determination by land surveyors using various means.

Certain data obtained by groundwater surveys may be classified as "useful" to facilitate map preparation and to appraise the reliability of essential, very important and desirable data. There is a wide range of useful data. Their importance may be judged variously due to different conditions of environment and of groundwater development status. A list of such data may comprise:

-- Map scale; may inform about precision of well location or availability of topographical maps at the time of survey.

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

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

-- Ownership of well may give an indication about groundwater development status, accessibility to information on wells, and others.

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

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

4. DATA ACQUISITION FROM BOREHOLES AND ANALYSES

4.1 Lithological data

These data may derive from sampling or be deduced from geophysical measurements. In the following only the use of samples will be dealt with.

The source of data is based on lithological descriptions of cuttings or cores carried out usually not by geologists but by drillers or auxiliary technical staff.

Each description is subject to a number of factors which may cause possible errors. Some of these factors might be listed as follows:

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

-- moisture content of the sample;
-- too generalized description at an early stage of study (either in the field or during data storage or plotting of well logs).

For registering lithological data we use abbreviations for grain sizes of major and minor constituents including remarks on colours, specific minerals and other contents. All information should be reported (listed) on special forms. These can either be adapted for the use of EDP or transcribed on diagrams (lithological or well logs) as described below.

Fundamentally, lithological data can be utilized for map preparation in two ways:

(a) Plotting of primary data from each log on the respective location on the map. These data are not adjusted to or correlated with neighbouring logs before plotted.
It is important to insert comparable data only, that is to say, values over the same depth or the same thickness, etc. The data may be grouped and the classes marked by colours or symbols. The observation points can then visually be reviewed and possibly combined in areas.

(b) Plotting of data obtained from a correlation of logs: a visual comparison is also used for this method, however, previous to the plotting of data. As to the correlation of logs more explanations are given below.

It is, however, recommended to use both methods complementarily.

The <u>preparation of well logs</u> is necessary for their correlation. But this is simply the initial step and does not constitute the correlation itself. Such logs may be prepared on diagrams as shown in Fig. 8. For the data transcription lithological symbols are used; in Fig. 9 a selection of such symbols is shown.

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

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

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

Two main steps of correlation are described in the following: (1) the initial comparison between various logs (Fig. 10 and 11) and (2) the synopsis or more generalized (regional) picture (Fig. 12). To simplify matters, the number of logs is reduced to three, the distances and depths being for illustration only.

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

The initial step (Fig. 11) comprises a discussion of certainty (cf. letters a, b, c, d):

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

(b) The correlation is probable. The boundaries indicated by this letter correspond to divisions between thick series which are characterized by different predominant grain sizes in the various logs. Less attention is paid to the direct correlation of descriptive terms such as "coarse sand" with "coarse sand" or "fine sand" with "fine sand".
Firstly, characteristic changes or sequences are studied within each log separately.
Secondly, similar sequences (e.g. fine to coarse) are recognized in neighbouring logs.
The certainty is supported by the fact that no material described had to be omitted from the correlation.

(c) The correlation is possible. By jumping one log, good (regional) correlation has been obtained. The boundary in log no. 2 between "coarse and with medium sand" below and "fine with coarse sand and medium sand" above shows the same sequence from coarser to finer material and at a similar level as in logs no. 1 and 3.

(d) The correlation is problematic. The separation of a lower coarse fraction from an upper finer part in logs 1 and 3 remains problematic, because the coarse layer in log 3 has been tapped over a very limited thickness. This layer may only represent a thin intercalation as known from the same log and log no. 1. The correlation should be omitted.

(e) The correlation is impossible due to lacking information.

Figure 12 shows a generalized transverse section in which two main types of hydrogeologically relevant formations are distinguished by using diagonal hatching (for main aquitards) and dots (for main aquifers A, B and C).

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

4.2 Hydrochemical data

Laboratory data are registered either in special forms by analyses individually or in comprehensive data sheets, both types being useful for the hydrogeologist.

Comparable with the handling of lithological data, the hydrochemical data, too, can be treated in various ways before being plotted on the map. However, the processing of previously correlated data is preferable.

The diagram after Schoeller which serves to report analysis data in a graphical form is a very useful tool for such a correlation (Fig. 13). If the analyses are represented individually and on translucent diagram paper, the ordering of analyses can be much facilitated.

5. MAP PREPARATION

5.1 Some requirements for data plotting

In the follwing section, some additional remarks are made on the preparation of working maps.

First and foremost, a base map (on a transparent plastic sheet) has to be prepared in a most scrupulous way. Apart from topographical information (amongst other things, an exact, continuous grid!), it contains:

-- well locations,
-- well numbers,
-- well types.

Especially the location of each well has to be plotted as exactly as possible.

This well location map should be used in identical format for all subsequent single-parameter draft maps and for the comprehensive hydrogeological draft map. It is, therefore, necessary to make transparent (heliographic or photo) copies of the base map. This will facilitate further adjustments between several maps, which is always necessary.

Data plotting is usually preceded by the retrieval of data from various storages. This may be achieved by concentrating data in working lists (or print-outs in the case of EDP).

The data retrieval and/or concentration in lists should be done under the surpervision of the hydrogeologist responsible for the map. This hydrogeologist should be the same one who carried out the field inventory and data collection from archives. He should also participate actively in the plotting of data.

For some parameters the grouping of data may be a necessary step before values are plotted. This has been described under 4.1 (lithological data) and mentioned under 4.2 (hydrochemical data). Data grouping may also apply for values of depth to groundwater, groundwater fluctuations, infiltration rates, and others. The choice of ranges for each group has to be decided upon by the hydrogeologist on the basis of professional criteria.

It is evident that the construction of contours and areas of ranges, and the adjustment of parameters are the exclusive task of the hydrogeologist. During this work it may be desirable to increase the data for some parts of the map.

5.2 Increase of data

This is related to the problem of how hydrogeologists can provide reliable hydrogeological maps derived from a small amount of field data.

Some suggestions are given in the following concerning data on depth to groundwater and groundwater salinity areas. Additional data relating to both parameters can be obtained through hydrogeological interpretation of aerial photographs, satellite photos and topographical maps.

For augmenting the data on <u>depth to groundwater</u>, the hydrogeological interpretation of runoff conditions in rivers and creeks, and vegetation areas, and the height of steep slopes in flatlands may help.

(a) Runoff conditions usually vary by season. However, if there is a relationship between surface water and groundwater, the depth to groundwater would be zero at the river bank, providing the runoff is longer than just occasional. A problem may consist in determining elevations or heights for specific points on the river bank. However, with the help of good topographical maps (equidistances!, height points) approximate values may be estimated. In case the runoff is discontinuous or occasional, the contours showing depth to groundwater have to pass beneath the river bed.

(b) Since the presence of certain plants may depend upon determined ranges of depth to groundwater, it is necessary to observe the distribution and density of the type of vegetation; examples: swampy lands; rims of foothill areas; vegetation cover in wadis and/or on river banks (e.g. date-palms); types of forest.

(c) The steep slope is the measure from the surface of the flat plain perpendicularly down to the river bed. Such height values may be contained in topographical maps, and yet it could often be necessary to adjust them or augment their number by dip-meter measurements. If we admit a relationship between runoff and groundwater, the steep slope roughly indicates the depth to groundwater below the flat plain in the area surrounding a river. According to the conditions of runoff (either occasional or continuous), the value of depth to groundwater has to be estimated as greater or less.

The distinction of areas of saline/brackish groundwater can be facilitated by mapping soil salinity, soil type (grain-size distribution, field capacity) and halophytic vegetation. Such an investigation has to be based on the interpretation of aerial (and satellite) photographs combined with observations on the ground. Additional information, such as relates to infiltration rates, extent of shallow groundwater, etc., also has to be considered.

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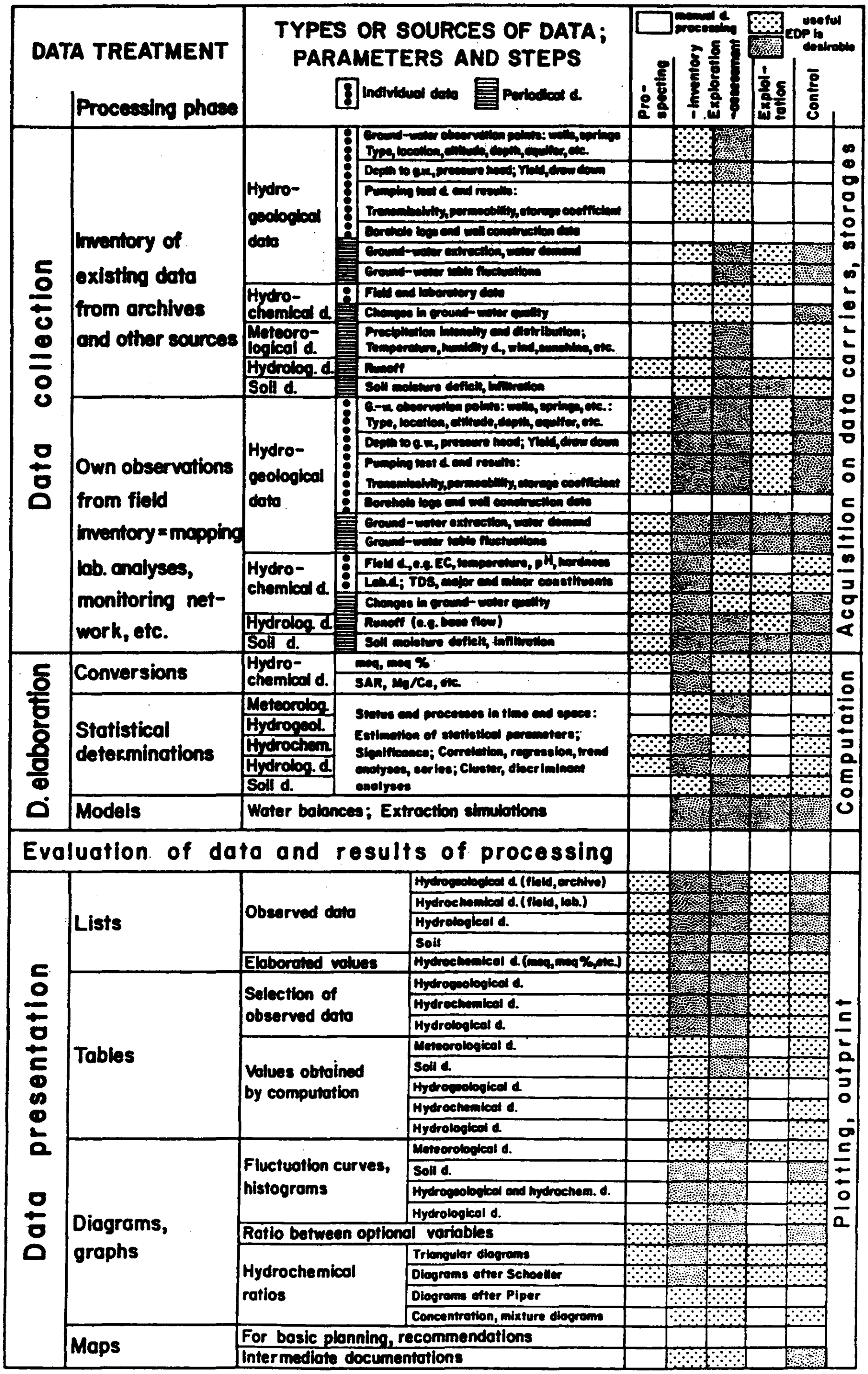


Figure 1: Review of the treatment of hydrogeological data
Source: KRAMPE, Jan. 1979

WELL INVENTORY

Project: .... ; (Provisional Well No.: ....); Well number: _ _ _ _ _ _ ;

Source of data: (1) field observation, (2) oral information, (3) driller's log, (4) documents, archives, (5) report ...., (6) map .... [ ]

Name: ....;

District or municipality: ....; Province: ....;

Ownership: (G) governmental, (M) municipal, (C) Community, Assoc., (F) family, (F) Firm, Comp., (O) other [ ] Well use: (P) public, (D) domestic, (I) irrigation, (F) industry, (A) animals, (S) investigation, (O) observation, (U) unused [ ]

Latitude: _ _ ° _ _ ' _ _ " Longitude: _ _ _ ° _ _ ' _ _ "; Topogr. map: ....;

Well type: (1) bore hole cased, (2) bore h., open hole, (3) dug well, pit, (4) dug well deepend by drill, (5) spring, (6) river, creek, (7) lake, (8) other [ ]

Drilled by: ....; Date of completion: d _ _ m _ _ y _ _ ;

Method drilled: (1) hydraulic rotary, (2) reverse rotary, (3) rotary other, (4) percussion, (5) jetted, (6) augered, (7) other [ ]

Number of aquifer exploited or described: (A) shallowest (= dug wells), (B) second, (C) third, etc., (S) several, (U) unknown [ ]

Lithology, Geophysical measurements, Well completion (diameters, filter, gravel etc.): use separate forms ;

Altitude: determined by: (L) instrum. level, (M) estim. after map, (A) altimeter, (O) other [ ]

Land surface (LS): _ _ _ _ _ . _ _ m ;

Depth to Water level: above LS use sign + _ _ _ _ . _ _ m ;

Elevation water table: below sea level use sign − _ _ _ _ _ . _ _ m ;

Level, head characteristic: (Q) outflow, (U) above LS, (C) confined aquif., (F) free water table, (U) unknown [ ]

Depth of:

Aquifer tapped: (.........') _ _ _ _ . m ;

1st Filter perfor.: (.........') _ _ _ _ . _ m ;

Casing bottom: (.........') _ _ _ _ . _ m ;

Bore hole: (.........') _ _ _ _ . _ m ;

Top of aquifer: below sea level use sign − _ _ _ _ _ . m ;

Base of aquifer: _ _ _ _ _ . m ;

Type of extraction (or pump): ....;

Yield or Discharge: (.........gpm, ...unit) _ _ _ _ _ . _ _ l/sec ≙ _ _ _ _ _ . _ _ m^3/h ;

measured by: (L) bailer, (B) bucket, barrel, (C) current-meter, (O) other device ...., (S) orifice, (T) tank, pond, (E) estimated, (U) unknown [ ]

Drawdown: (.........) _ _ _ _ . _ _ m ; Duration of pumping: ....hours ;

Pump test equilibrium: (A) achieved, (N) not achieved, (U) unknown, (T) uncertain, (X) well exhausted, [ ]

Specific capacity: (..........unit) _ _ _ . _ _ $m^3/h \cdot m$;

Hydraulic aquifer characteristics: ....(specify units);

Sampling by/at: (P) pumping ....hrs., (H) hand pump, (F) outflow, (B) bucket, bailer, (O) other device .... [ ]

Sample for labor. analysis: ....; Electrical conductance: _ _ _ , _ _ _ _ µS;

Hydrochemical labor. analysis: use separate form ;

Inventory recorded by: ....; Date of observation or information: d _ _ m _ _ y _ _ ;

RMRDC 3/78

Figure 2: Well inventory form designed for manual data processing (Reduced size).
Source: KRAMPE, Sept. 1978

WELL SCHEDULE

Bundesanstalt für Bodenforschung

Record by: ____________ Date: ___ d . ___ m . ___ yr

Well number: ____ (provisional) — Recording sequence:

Source of data: (1) field observation, (2) oral inform., (3) field observ. and oral inform., (4) driller's log, (5) documents (agency), (6) report, (7) maps, (8) synthesis

Latit.: N/S — Longit.: E/W

Grid: zone, square, east m, north/south m

Map: 1: ______ .000

Name (owner, local well No.): (name according to map)

Province, District: ______

Well type: borehole: (1) (2) cased, (3) open hole, dug well: (4) (5) concrete or masonry, (6) conventional design, (7) open hole, spring: (8) (9) natural state, (0) improved, (E) emergence, (G) gallery, (Ø) other

Ownership: (1) Federal, (2) Provincial, (3) District, (4) City, (5) Corp., Co., (6) Private, (7) Agency, (8) other ______, (9) unknown

Well use: water supply (1) public, (2) domestic, (3) irrig., (4) industr., (5) stock, (6) mixed, (7) investig., (8) observat., (9) unused, (0) other ______

Depth of well: (below land surf.) m measured / reported; Profile / Log (by): ______ 1: ______ (scale)

Method drilled: (boreholes) (1) augered, (2) driven, (3) cable tool, (4) jetted, (5) rotary, (6) hydraul. rot., (7) reverse rot., (8) air rot., (9) other ______

Date of completion: m yr

Inside diameter or Smallest casing: ______ in. — m dm

Depth cased: (first perforations) m;

Number of aquifer(s): (S) several, (U) unknown

Aquifer: Order: (A) major, (I) minor, (U) unknown, (S) seepage

Lithology: — Origin: ______

Geolog. age (syst., series, member, form. or group):

Dimension: (L) local, (P) principal, (R) regional, (U) unknown

Topographic setting: (L) lake / swamp / marsh, (R) offshore, (T) terrace, (V) valley flat, (C) stream channel, (H) hilltop, (S) hillside, (P) pediment, (D) local depression, (W) undulating, (F) flat surface, (U) unknown, (Ø) other ______

Altitude: (referred to sea level) determined by: (L) instrum. level, (A) altimeter, (M) estim. after map, (U) unknown, (Ø) other ______ **B**

Reference point (RP): (at well) ______ m ______ description (sketch on backside)

Land surface (LS): ______ m; ______ m above / below RP; [below sea level use sign — in front of figures]

[redacted]

Water level: ______ m above / below RP; ______ m above (+) / below LS; (F) free water table, (C) confined aquifer, (P) perched aquifer, (H) pressure head above LS, (A) artesian flow, (U) unknown

Elevation: [below sea level use sign —] Water table: ______ m; Fluctuation magnitude: due to... after... ______ m;

Top of aquifer: (confined) ______ (depth) m ______ m; Base of aquifer: ______ (depth) m ______ m;

Yield or Discharge: ______ m³/h / l/sec; measured by: (B) bucket or barrel, (R) orifice, (P) propeller-type meter, (T) tank or pond, (L) bailer, (W) weir, (Ø) other device ______ or (E) estimated, (U) unknown

Rate of flow: (discharge) (1) low, (2) medium, (3) high, (4) minim., (5) average, (6) maxim, (7) const., (8) unknown, (9) intermittent spring;

Draw-down: ______ m; (M) measured, (E) estimated, (U) unknown, or pumping test equilibrium (A) achieved, (T) uncertain, (N) not achiev., (X) well exhausted; Specific capacity: ______ m³/h;

Coefficient of permeability (k): ______ × 10⁻ ______ m/s;

Transmissivity (T): ______ × 10⁻ ______ m²/s; Storage coefficient (S): ______ × 10⁻

Quality of water: (field determinations) Sampling by/at: (B) bucket, (P) pumping ______ hrs., (Ø) other device ______ (below water table: m), (F) outflow, (U) unknown

Odor: (1) none, (2) mouldy, H_2S (3) faint, (4) medium, (5) strong, (6) NH_4, (7) phenol, (8) unknown, (9) other ______

Color, turbidity, taste, etc.: ______;

Temperature: ______ °C; Carbonate hardness: ______ °dH; Total hardness (TH): ______ °dH; [1 °dH = 10 mg CaO/l]

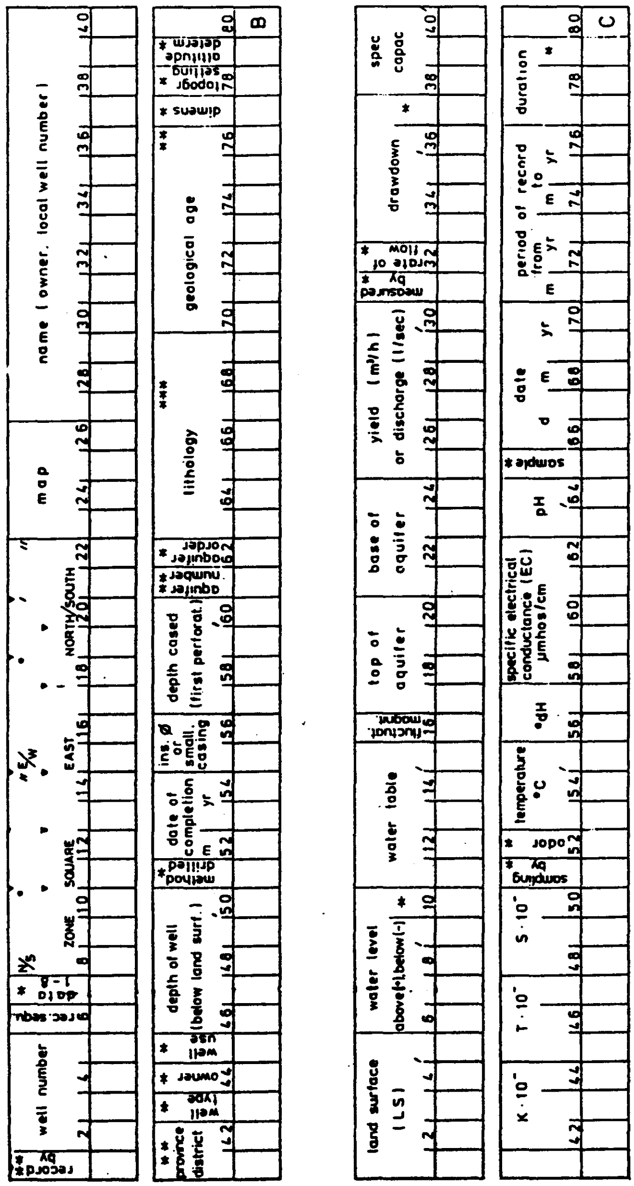
Specific electrical conductance (EC): (at field water temperature) microsiemens = micromhos/cm; NO_2: ______

pH: ______; Sample for labor. analysis: (0) none, (1) major constituents, (2) ______, (3) ______; Date: d m yr

Period of record: from ______ d m yr to ______ d m yr; Duration: (H) hrs., (M) months, (D) days, (Y) years **C**

* develop own code
** see code table

Figure 3: Well schedule; I (original shape), used for EDP



* see code table

** develop own code

*** see code table " AQUIFER LITHOLOGY "

Figure 4: Well schedule; II (actual shape), used for EDP
Source: Bundesanstalt für Geowissenschaften und Rohstoffe, 1969 - 1976

KABUPATEN: ____________________

KECAMATAN: ____________________

WELL INVENTORY
FOR
CENTRAL JAVA RURAL WATER SUPPLY PROJECT
WHO/GTZ/DINAS KESEHATAN/GTL

WELL NO.	COORDINATES EAST	COORDINATES SOUTH	TOPOGR. MAP 1 : 50 000 NO.	TOPOGR. MAP 1 : 50 000 I-IV	NAME (OWNER, LOCAL WELL NUMBER)	WELL *) TYPE	LITHOLOGY *) (*) see code table)

WELL NO.	TOTAL DEPTH m,	LAND-SURFACE (LS) m ± MSL	WATER LEVEL m ± LS,	WATER TABLE m ± MSL,	FLUCTU-ATION MAGNIT. m	DISCHARGE l/s,	TEMPE-RATURE °C,	SPEC. ELECTR. CONDUCTANCE at 25°C µmhos/cm	pH,	SAM-PLE +/- YES/NO	DATE D	DATE M	DATE Y

Figure 5: Well inventory form designed for manual data processing; reduced type A, for a special project
Source: PLOETHNER, 1984

R U R A L W A T E R S U P P L Y P R O J E C T
C E N T R A L J A V A
WHO/GTZ - GTL/CTA 40
GROUNDWATER INVESTIGATIONS

DATE OF RECORD:

1. DESA : Kecamatan :
   Dukuh : Kabupaten :
   Elevation (m) : Population (19) :
   Coordinates : E , N
   Map : Scale : 1 : 50.000

2. MORPHOLOHY[1] : plain, terrace, valley, undulated, moderate slope, steep slope, ridge.

3. GEOLOGY[1] : volcanic rock, basalt/andesite, breccia, lahar, tuff; massive, loose, weathered; sediment; clastic, carbonate, consolidated, unconsolidated, semiconsolidated, weathered.

4. AQUIFER[1] : fissured, fractured, karstified, porous.
   PERMEABILITY[1] : very low, low, medium, high, very high.

5. EXISTING WATER SUPPLY[1] :
   Springs: no. : , max. distance (km) :
   Dug wells: no. : , total depths from to m, dry:
   Tube wells: no. : , total depths from to m,
   Handpumps in dug and tube wells: no. : broken: no.:
   Rainfall collection : no. of tanks :
   total volume (m^3) :
   Irrigation channel : deriving from spring/river/reservoir
   River : max. distance (km) :
   Tank lorry : distance of water transport (km) :
   Details see well inventory no. :
   map :
   Sample taken from no. :
   REMARKS :

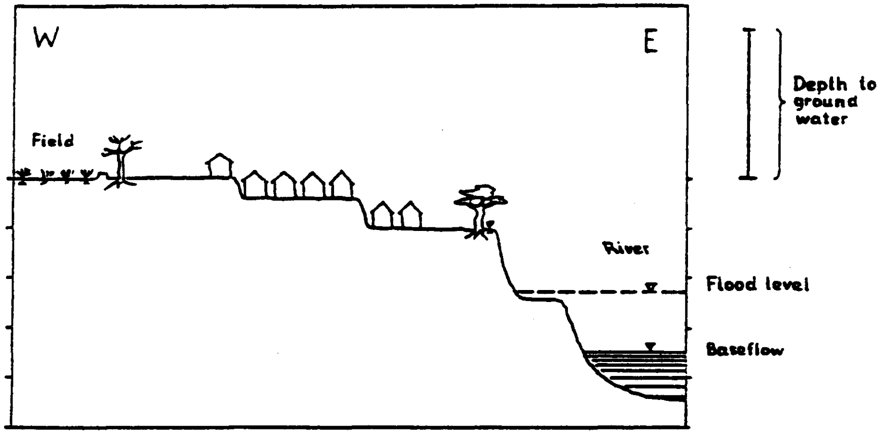
6. POSSIBILITIES OF WATER SUPPLY
   6.1. Spring : Elevation (m) :
   no. of well inventory : (location see map)
   discharge (l/s) : (estimated, measured)
   EC[2] (µmhos/cm) : T (°C) : pH :
   Remarks :
   6.2. Shallow tube well
   total depth (m) :
   depth to water level (m) : diameter : "
   EC[2] (µmhos/cm) : T (°C) : (pH) :
   Remarks :
   6.3. Deep tube well
   total depth (m) : diameter : "
   depth to water level (m) :
   EC[2] (µmhos/cm) : T (°C) : (pH) :
   Remarks :
   6.4. Rainfall collection
   Precipitation (19 - 19) mm/a
   minimum : mm/a, maximum : mm/a
   duration of dry season : month below 100 mm
   6.5. River :
   Discharge (l/s) : (estimated, measured)
   EC[2] (umhos/cm) : T (°C) : pH :

7. CONCLUSIONS
   Classification of possibilities :
   1.
   2.
   3.
   Remarks :

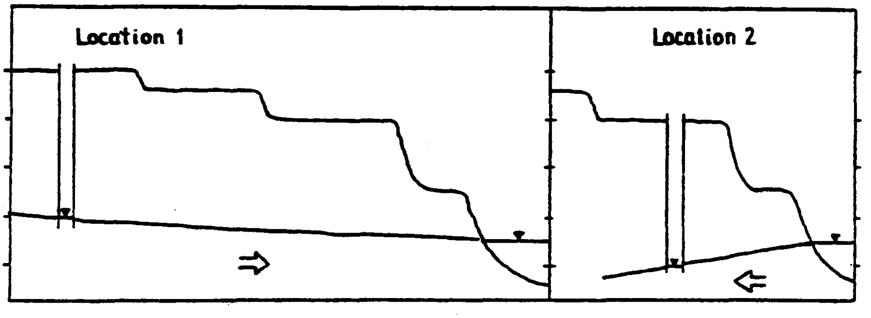
1) Underline applicable term: if more terms apply, underline more

2) EC at 25°C

Figure 6: Well inventory form designed for manual data processing; reduced type B, for a special project
Source: PLOETHNER, 1984



Upper sketch section: A village has one well. Its exact location is not known. It could be located either E or W of the village. Only the depth to ground water was measured.



Lower sketch sections: If location 1 is chosen: the ground-water table must be constructed dipping towards the river. (The river is effluent in respect to ground water). If the well would be located as shown in location 2: the ground-water flow is directed away from the river (influent river).

Figure 7: The significance of exact well location
<u>Source:</u> KRAMPE, Nov. 1980

WELL RECORD

Name:	Well Number:
Position: y ______ m, x	Altitude: Landsurface: ______ m; Reference Point: ______ m
Date of Completion: d / m / y	
Drilling Company:	Method drilled:
Total Depth: m	
Date of Record: d / m / y	
Scale: 1 : 200	

Thickness m	Depth m	Section	Lithology	Formation		Depth to Aquifer Water Level	Casing, Filter 14 10 6 2 2 6 10 14

Figure 8: Well record sheet
Source: KRAMPE, Sept. 1978, modified from BGR 1969 - 1976

GRAIN SIZE (in mm)	NAME	ABBRE-VIATION (example)
	Clay	T
0.002		
	Silt	U
0.06		
	Sand:	S
	fine sand	fS
0.2		
	medium sand	mS
0.6		
	coarse sand	cS
2		
	Gravel:	G
	fine gravel	fG
6.3		
	medium gravel	mG
20		
	coarse gravel	cG
63		
	Stone, boulders	B

ADDITIONAL SPECIFICATIONS (selection)

- Concretions
- Mica, micaceous
- Gypsum or other evaporite
- Rootes
- Breccia

LITHOLOGIC SYMBOL

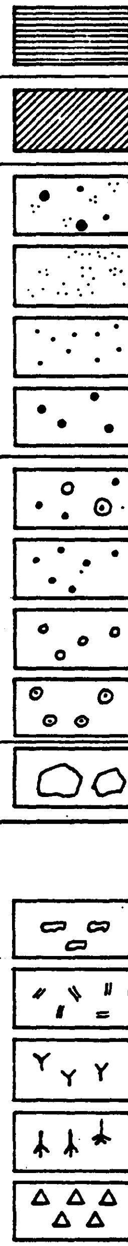


Figure 9: Lithological symbols to represent unconsolidated sediments
Source: KRAMPE, Sept. 1978, modified from BGR, 1969 - 1976

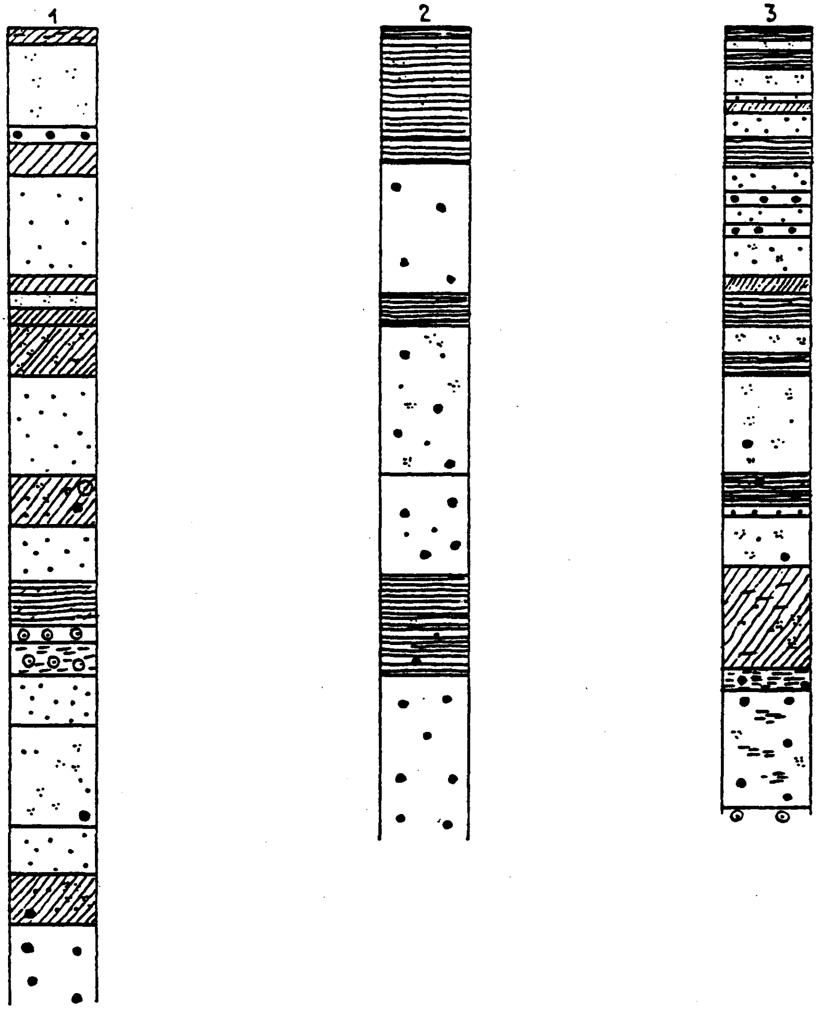


Figure 10: Lithological logs after being represented in well record sheets.
(These examples will be served for correlation in Fig. 11 and 12).
Source: KRAMPE, Nov. 1980

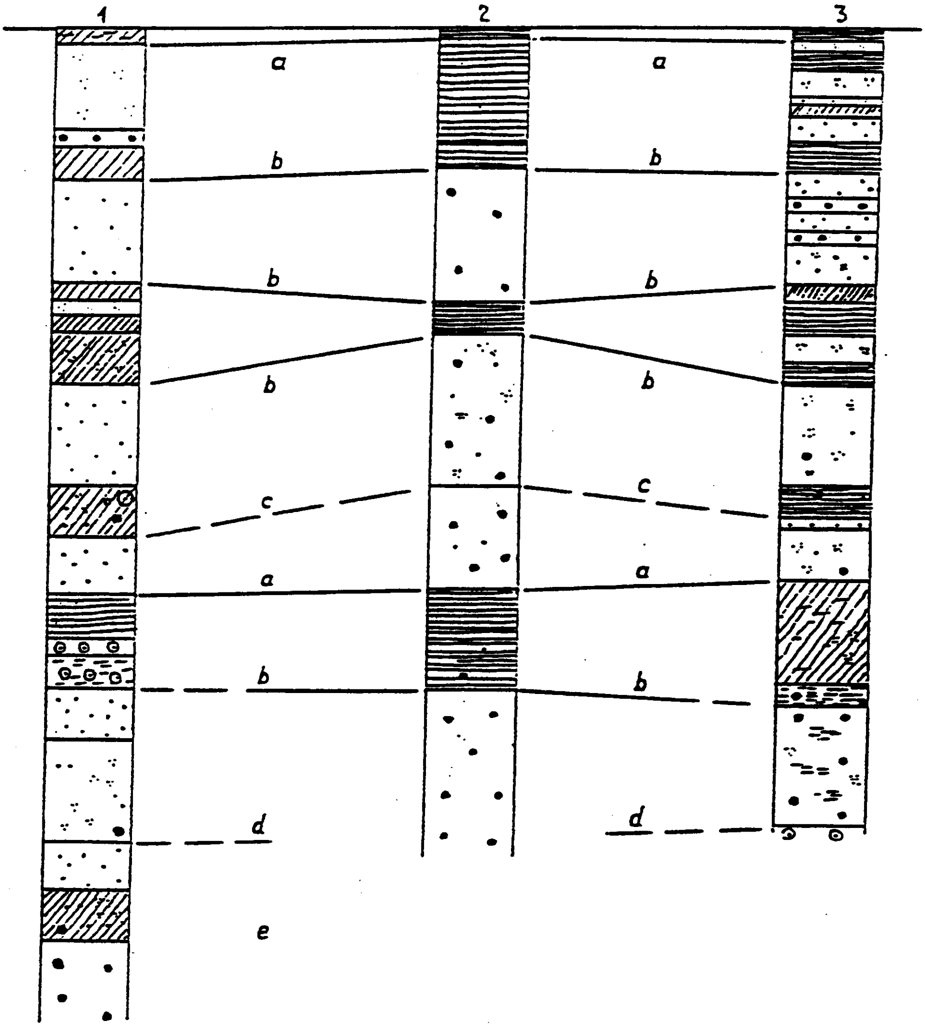


Figure 11: Correlation of lithological logs.
Initial step: discussion of certainty, see explanation in chapter 5.1.
Source: KRAMPE, Nov. 1980

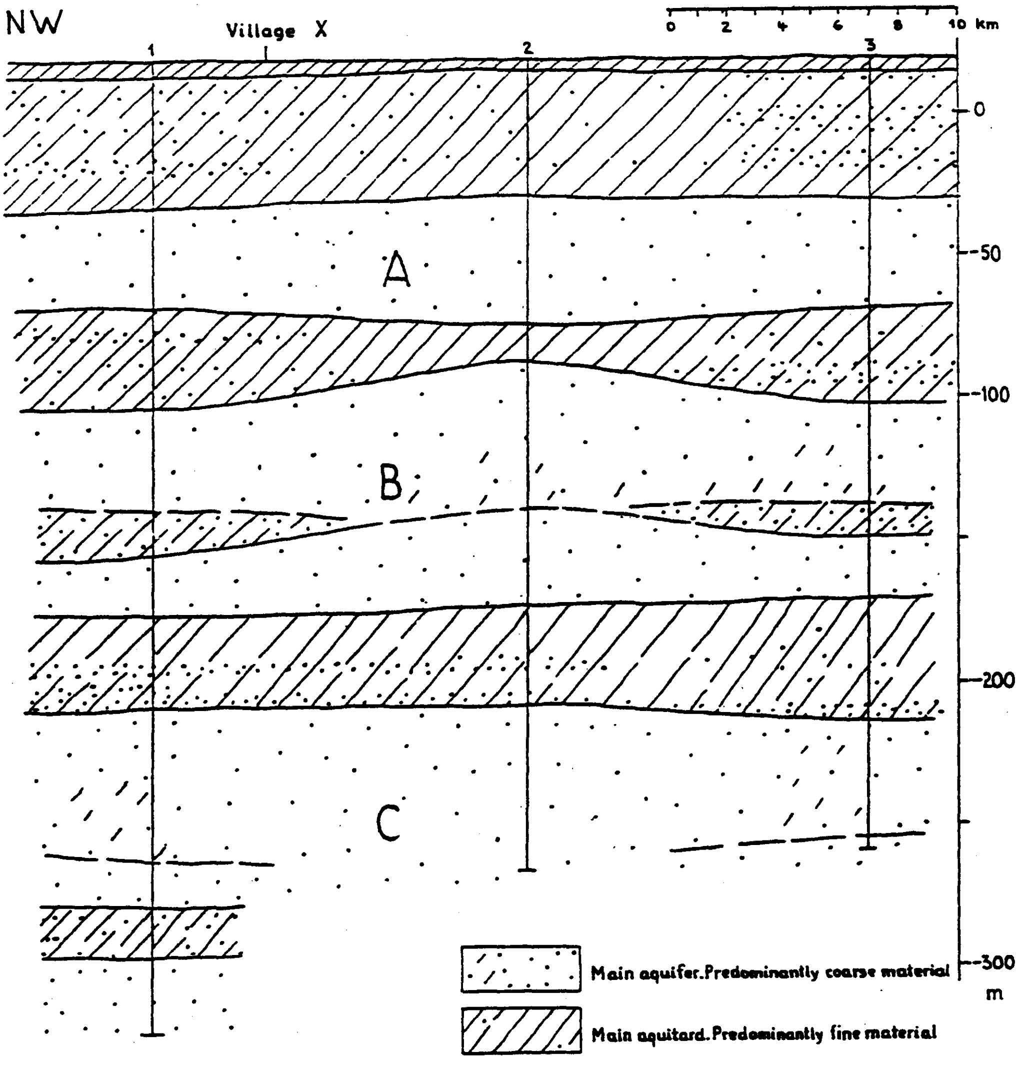


Figure 12: Correlation of lithological logs.
Synopsis: Generalized transverse section, see explanation in chapter 5. 1.
Source: KRAMPE, Nov. 1980

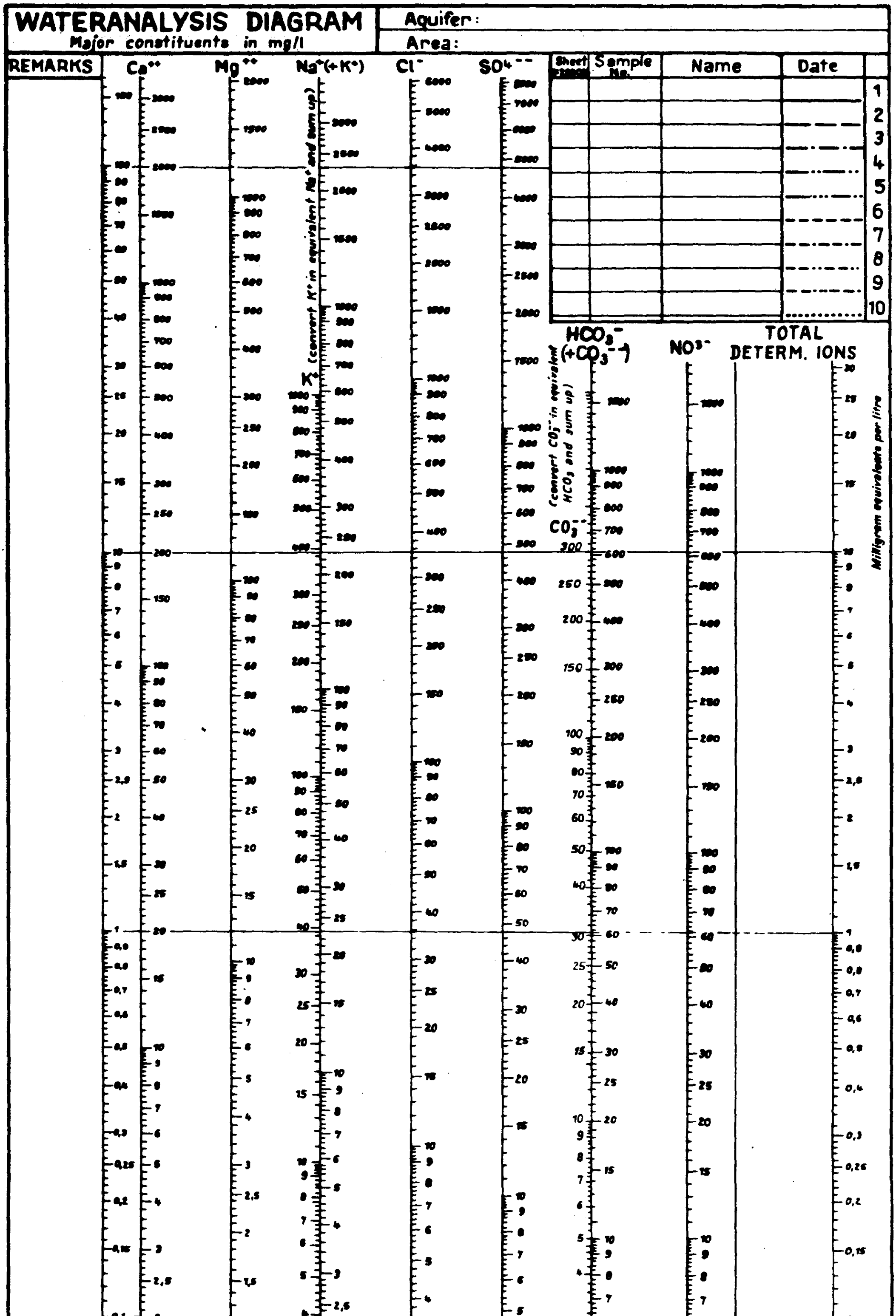


Figure 13: Diagram after SCHOELLER for representing and grouping water analyses data

Hydrogeological Mapping in Asia and the Pacific Region
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THE ORGANIZATION OF HYDROGEOLOGICAL MAPPING PROGRAMMES

Trevor T. Bestow

ABSTRACT

Hydrogeological mapping supports development and its cost is small in relation to the long term benefits. Programme planning must take account of priorities and the availability of geological and groundwater information. The objectives should be clarified in order to optimise the data to be included in the final publication and its style. Compromise and data selection is necessary if maps are to retain clarity. Scales must be chosen in relation to objectives, data availability and the hydrogeological environment.

INTRODUCTION

Hydrogeological mapping should be regarded as one of a series of tools to be used in support of a country's development. Quite obviously it is primarily undertaken for the purpose of groundwater resources assessment and hence ultimately meeting water supply needs in the area covered. In any activity involving the use of scarce expertise or resources it is necessary to undertake the work on a priority basis starting with areas of the most immediate need and finishing with areas of longer-term development potential. Criteria for the selection of priorities will also have to include the presence of surface water sources and their suitability in terms of quality and quantity to meet anticipated demands. An area possessing developable usable surface water will clearly merit a lower priority for hydrogeological mapping than one in which it is seasonal or lacking. The exception to this rule is where there are prospects for the conjunctive use of groundwater and surface water.

Where a number of areas exist, each having an equal need for hydrogeological mapping for which some may have geological maps and others not, it would be prudent to give priority to those areas which have geological maps to provide essential background data.

It is worth pointing out that hydrogeological mapping constitutes an intermediate stage in the process of national groundwater resources evaluation in that before these maps are produced, there must be a certain minimum amount of basic information, including basic geology.

Hydrogeological maps are also intermediate in the sense that they seldom represent the results of extensive exploration providing precise quantitative assess-ments of throughflow in the separate aquifers which is generally the last stage of resource evaluation.

When developmental needs dictate that a hydrogeological map should be produced of an area lacking a primary geological map, it will be necessary to allow a substantial amount of time in the organization of the mapping programme for the necessary field survey. A hydrogeological map is essentially the presentation of the physical state of groundwater within a geological framework. However, if one attempts to present just the physical and chemical characteristics of groundwater without the geology, the resultant map becomes only a groundwater map. This might include water points, chemical quality and bore yield but without presenting the geological environment in which the water occurs, the map would not be usable for conventional groundwater resources assessment.

MAPPING OBJECTIVES

Having decided on a particular area for hydrogeological mapping in terms of priority, the next question to be addressed is to define the objectives of the map. On these will depend its published scale and the type of information to be displayed. The prime objective of providing a better understanding of the hydrogeological regime is obvious but coupled with that will be desire to display the magnitude and characteristics of the groundwater resources over the area. These are not only of value to specialist hydrogeologists but also to engineers, planners and economists interested in the development potential of the area. We should also not forget that there is increasing interest on the part of the public in groundwater as part of the environment or a source of private water supply. In Perth, Western Australia, there are some 60 000 private boreholes used largely for watering gardens and there is a corresponding awareness of the importance of groundwater. This is shared by farmers in the rather dry agricultural areas of the State where groundwater is used as a supply for sheep and cattle. Hydrogeological maps may also be used by owners of large or small areas of land either as a means of eventually planning the development of the land in relation to water sources or even the selection of sites for boreholes themselves.

Despite increasing interest in groundwater and appreciation of its importance, there is widespread ignorance with respect to its occurrence below ground and one should realise that hydrogeological maps are a vehicle for public education, particularly if they are accompanied by clear explanatory notes.

METHODOLOGY

The planning of hydrogeological mapping must commence with a review of all relevant existing information. A topographic map is not only necessary to provide a base plan for the mapping but also to provide reference detail for positioning the natural or man-made features on the final map. Clearly the amount of topographic information available varies between one country and another as does the availability and scale of maps.

A geological map is a basic necessity for providing the physical framework of groundwater occurrence and movement and is perhaps the most important source of data in hydrogeological mapping. However, it is unusual for a mapping programme to be mounted specially to record the geology and it is more usual for hydrogeological mapping to be confined to areas over which basic geological mapping has already been completed.

In countries where comprehensive records are kept of boreholes drilled for water, it is not uncommon for most of the collation of data and actual map preparation to be undertaken with a minimum of field work. However, this does depend on the amount and reliability of the data.

Borehole records are the second most important source of data in hydrogeological mapping and if, for any reason, these are not recorded at some central agency, it is necessary to gather that information by undertaking a field census of bores and wells throughout the area. This would include visits to local government bodies responsible for water supply and also all known drilling contractors. If there are no statutory obligations requiring either landowners or drillers to provide information to a central government water authority, the researcher may have to exercise persuasion to gain access to records. If contractors seek a commitment to keep information confidential then this should be respected.

All basic data should be carefully checked and drillers logs reinterpreted or compared with sample logging by a geologist, and stratigraphic or aquifer boundaries defined.

The range of hydrogeological data required includes the distribution of rainfall over the area mapped and its seasonal or areal variability. Evaporation figures should also be known as these influence the rainfall deficit or excess for groundwater recharge. Where river-flow data are available, the dry-season base flows should be studied with a view to identifying the locations of losses or gains and hence corresponding areas of groundwater recharge or discharge. It is obvious that the positions of lakes and the courses of rivers are essential positional as well as hydrogeological information to include on hydrogeological maps.

It is important to assess spring flows as these may constitute key groundwater discharges. Their elevations should be surveyed and related to groundwater levels in the area. Where hydrographic records of boreholes are kept, these should be reviewed as they may not only indicate variable rates of groundwater recharge over an aquifer but also relationships between groundwater and river stages. At least one set of synoptic water level measurements should be taken on each set of bores tapping an aquifer. It is generally necessary to reduce depth to water table measurements to elevation above datum with an appropriate survey. The information may then be contoured to present the pattern of groundwater movement.

The hydrochemical data available from file records is seldom adequate to characterise the groundwater in the separate aquifers present in an area and it is commonly necessary to collect samples from wells, bores and springs specially for chemical analysis of major dissolved ions. The field measurement of pH may be desirable to eliminate changes during the transportation of samples back to the laboratory.

INFORMATION FOR PRESENTATION

Although the scope for presenting the widest possible range of information is narrowed when small map scales are used, it is true to say that to maximise the usefulness of the map, it should present as much hydrogeological information as possible without reducing the overall clarity of the picture presented. Thus the map constitutes a visual summary of the hydrology of the area. It is normal, indeed it is almost essential, for colour to be used on hydrogeological maps. These are not uncommonly printed in up to 12 basic colours, each requiring a separate printing plate and various screens to provide a range of shades of each colour.

An alternative approach is to print separate maps in a single color to show each hydrogeological feature within a particular area. By this means one can build up an atlas of maps of that area and although bulky and expensive to print and distribute, has the merit of great clarity and allows rather cheaper printing techniques because of avoiding the need to register colour plates. Apart from cost, one disadvantage is some increased difficulty of relating one parameter to another on a different plan. Thus, changes in salinity on the hydrochemical map may be unrelated to the flow lines or potentiometric contours presented on another map.

The need to maintain a reasonable clarity of presentation necessarily limits the amount of information which appears on the principal map and it is usual to present additional information as marginal inset maps. These illustrate such parameters as hydrochemistry which may include contours of T.D.S. and pie diagrams at data points or hystograms. Where data are sparse it is perhaps better to use the latter technique than to attempt contouring. The reason for this is that contouring could involve the gross extrapolation of data over areas where later information may prove it to be wrong. Marginal information may include well hydrographs also horizontal and vertical sections with due emphasis on aquifer disposition.

Specialist maps may be desirable for groundwater or waste disposal management or land planning purposes. These can be regarded as second stage maps and may include assessments of aquifer vulnerability to pollution and major or minor ion hydrochemistry. Other special maps may be related to shallow and deep geothermal resources, groundwater abstraction and transmissivity.

MAP SCALE

Perhaps one of the more difficult decisions to be taken in the planning of mapping is the selection of a suitable published scale. This will depend on the primary purpose of the map and the extent of the area to be covered. However, it also depends on the hydrogeolgical complexity of the area including the presence of multiple aquifers, as in sedimentary terrain, and the amount of information available. In general, the economies of map production will demand that maps be produced on a scale no greater than is essential for the purpose. Thus a small scale map of 1 : 500 000 or more would be used to depict the broad hydrogeological features of the State.

They generally represent gross generalisations and tend to be based on adaptations of geological maps and may have a bias in their presentation towards either displaying aquifers or salinities such as the Australian Commonwealth map of 1978. The format of the International Map of Europe has much to commend it as it can present most hydrogeological conditions including hard-rock or shield areas, sedimentary basins, fold belts, and volcanic terrains.

A medium scale of between 1 : 200 000 to 1 : 500 000 can be used to display an open distribution of boreholes, summarised aquifer information and the generalised pattern of groundwater quality. Where large States have to be covered, such as Western Australia, a scale of 1 : 250 000 is a useful compromise to adopt as it is possible to depict the positions of most boreholes and represent aquifer detail without overcrowding. However, it is not possible to show salinity variations satisfactorily because of the very short distances over which changes may occur in any area. Medium-scale maps have little scope for the presentation of interpretive material unless the topography is subdued and the geological structure is simple. In these instances it may be possible to include some structural or potentiometric contours.

Large scale maps or plans on scales of less than about 1 : 200 000 are usually confined to areas of high development potential and bore density. They are required for purposes of detailed water supply planning, borefield design and in the case of Western Australia to provide advice to the public interested in sinking their own boreholes. We also commonly include water table contours on urban geology maps published on a scale of 1 : 50 000. We will probably be producing hydrogeological maps of the Perth metropolitan area on this or a larger scale. This would be required not only to separately show the positions of the many private bores but to pinpoint the positions and elevations of proposed drilling sites in order to estimate target depths to provide a particular yield.

It may not be practical to optimise the map scale in relation to all the data to be presented because to do so would involve the use of a large scale and a corresponding large number of maps would be needed to cover a region. In consequence of this, production costs could outweigh the returns from the sale of maps. This raises a particularly controversial matter in the production of any specialised map such as a hydrogeological map. Its value cannot be assessed wholly in financial terms but must be judged by its value for planning or specialist use, also its value to the population as a whole -- either directly or indirectly. It is an unfortunate fact that such maps cannot be produced in large print runs to provide a cost advantage in numbers of maps sold. It can nevertheless often be claimed that the cost of hydrogeological mapping can form only a small proportion of the overall cost of a major groundwater development and is frequently minor in the context of the capital cost of the bores drilled in the area.

CONCLUSIONS

The essential understanding provided by hydrogeological mapping should permit the orderly planning of groundwater development and, perhaps more important in terms of value, decision making in land management. Thus an area known to provide recharge to potable groundwater should not be used for industrial waste disposal. Similarly an area of irrigation development potential should not be sterilized by industrial or other use. It is better to promote industrialisation in areas of poor soils and limited groundwater resource potential.

Water resources are the lifeblood of every nation and hydrogeological maps provide an essential tool for the conservation as well as the development of groundwater resources.

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REPORT ON HYDROGEOLOGICAL MAPS OF KARSTIC TERRAINS

H. Paloc and J. Margat

ABSTRACT

This report is largely inspired by the work which has been devoted for almost a quarter of a century to hydrogeological mapping, especially the mapping of certain limestone regions in Europe, work which has for the most part been published in the form of maps and explanatory notes.

Using some of these documents as examples, the report sets out the various standards and forms of representation which can be adopted for limestone rocks, in view of their specific hydrogeological features and according to the various types of information that different users are entitled to expect.

1. INTRODUCTION

Mapping productions in the field of hydrogeology have developed during the last two decades thanks especially to the recommendations of IAH, IASH and UNESCO, as well as those of numerous geological organizations throughout the world.

The comparisons which can be made between the different types of maps and the various methods of representation adopted by their authors, the interest which they have generated, but also occasionally the criticisms expressed by a good number of their users, recent suggestions that such documents should satisfy a larger variety of objectives -- some of a more scientific, others of a more practical nature -- lead us today to propose additional legends complementary to those which have until now been most frequently used.[1]

It is not our purpose here to re-examine the diverse problems posed by hydrogeological mapping in general, as these problems are themselves to be discussed during other sessions of this workshop.

It is rather a question of examining in what way we can understand and employ forms of representation more specially adapted to the specific hydrogeological features of limestone terrains: these terrains constitute in fact, in numerous areas, aquiferous reservoirs of great economic interest, the particularities of which, in relation to other geological formations, call for special attention.

In this report we propose which data, of the numerous data that can be mapped, are the most useful to map, and what are the most suitable forms of representation. Several examples will allow us to illustrate, with slides, the sort of map one can consult, according to its subject, its scale and its desired use, and the various objectives which must be attributed, prior to production, to such documents.

2. MAPPABLE DATA IN LIMESTONE TERRAIN

The form of a map, its contents and its scale, are dependent upon the data at one's disposal. If these data are sparse, only imprecise maps can be produced, elaborated mainly for purposes of planning.

On the other hand, if the data are abundant and diverse, it will sometimes be necessary to be selective. The selection of data will be determined by the intended use of the map.

In fact it is a question of supplying the users of the map with whatever data are relevant to their needs: data of a more scientific or a more technical nature depending upon whether the map is designed for teachers, engineers, well-diggers, hygienists, etc.

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1) See in particular:

-- UNESCO: International legend for hydrogeological maps; Paris 1970.

-- J. Margat: Hydrogeological map of France, aquifer systems, at 1 : 1 500 000, with explanatory notes; BRGM, Orléans 1980.

-- ACSAD: Legend for the water ressources map of the Arab countries; Damascus 1982.

2.1 Criteria for selection

It is especially desirable that the three particular types of data that constitute the common basis of all hydrogeological mapping should be known: these are the data relating to the porosity, the geometry and the hydraulic regime of the aquiferous reservoir; we shall call this the "basic data".

2.2 Basic data

The presence of underground water in rock is quite obviously a function of the cavities which the rock contains. In limestone rocks the existence, the importance and the distribution of these cavities are variable and depend upon three factors: the original facies of the limestone, its state of fissuring, and the degree of karstic action to which it has been subjected.

Three types of porosity -- interstices, fissures, and channels -- may therefore be found either combined or not, and in any proportion. Thus it would seem that the hydrogeological conditions of limestone rocks can be extremely diverse, infinitely more complex than in other types of aquiferous reservoirs, for example in alluvial deposits.

The first objective of limestone mapping should therefore be to try to collect information about the aquiferous possibilities of the limestone under study, i.e. about its aptitude to receive water and the distribution of cavities in the terrain.

But the presence of cavities does not necessarily indicate the presence of underground water; it is also necessary that the cavities should be able to receive and to retain this water.

Such a condition is dependent upon both the possibilities of water being supplied and transferred to the limestone rock and upon the existence of areas favourable to its accumulation. A map should therefore include all information relating to:

-- the definition of the boundaries of the aquiferous systems under study, specifying their nature and their function (watertight boundaries, feeding fronts, drainage areas;

-- the potential groundwater recharge (whether by effective rain, by infiltration of surface water, or by hydraulic contact with neighbouring non-limestone aquifers);

-- the possibility of the accumulation of water and its retention, specifying the position, the depth and the extent of the saturated part of the aquifer.

Finally, as the exploitation of an aquiferous reservoir is dependent upon the volume of water that can be extracted and which will renew itself, it is important that we can depict upon the map the data necessary for an understanding of the underground water regime, so that predictions concerning the rational exploitation of the reservoir will be possible.

In total, it is highly desirable that we should be able to depict this basic data on the map, as this would produce an appropriate synthesis of the principal information required by the majority of users.

However, it is still rather difficult to produce a complete representation of this information, since this would require a high level of knowledge of the terrain, a level which only in exceptional cases is attained after the preliminary studies -- studies too often conducted with insufficient means.

While striving to attain the goal of completeness, a map can in fact only represent the information that has actually been gathered.

Among the maps already available -- and notably most large-scale maps -- many reflect the general desire to express this same basic data. If notable differences exist between these documents that are to be explained more by the varied state of the information available than by a widely differing regime only if there are enough gauging stations at our disposal, we can delimit the saturated part of the aquifer only if its structure is sufficiently well known.

2.3 Other data

If the preceding data are to be considered as essential, then there are other data which equally ought to be, or which can usefully be, regarded in the same way.

The choice of these data, which can be highly diverse, should be made with the consideration of providing only information which will improve the map with regard to its given objectives.

In this category of data we can include: topographical and morphological data, the latter often allowing useful deductions to be made about structure and permeability of the aquifer and about groundwater flow; complementary hydrological data; climatic data; hydrochemical data; data concerning constructions for water abstraction, etc.

3. FORMS OF REPRESENTATION

What we must strive for when expressing the data, which has been selected according to the objectives of the map, is clarity of representation, so that the map will be easy to read.

We must therefore avoid overburdening the map with a systematic expression of all the data, especially when this is very abundant. Instead we should represent only those data which are the most significant and the most compatible with the chosen scale and the given objective. As for the other data, they can either become the subject, as we have seen, of special insets presented on the margin, or they can be appended to the explanatory notes, the production of which is in any case desirable. One would reserve for the latter variable data which could be represented in the form of graphs or tables.

Special importance should be given to the provision of a topographic base sufficiently precise to allow the location of sites of hydrogeological significance, to give an account of the morphological aspect of the region under study and to assess useful dimensional data such as the depth to the water table, the thickness of a limestone layer, etc.

For large-scale maps this base will be constituted in most cases by the reproduction of the existing topographic map.

The expression of the whole range of data will be made possible by the use of colours, markings and symbols: thanks to the various combinations which these allow, we shall be able to aim for a clear and evocative representation, while at the same time endeavouring as far as possible to keep down the costs.

3.1 Different types of maps

3.1.1 Maps of a scientific inclination (called "general maps")

Two approaches to medium and small-scale mapping have been proposed, one more "hydrogeolithological", the other more "hydrogeodynamic". In spite of their appreciably different forms of expression the fact remains that these two approaches are complementary. The first led to the creation of the UNESCO International Legend; the second to the proposal of a new legend and to the production of a "prototype" map of the aquifer systems of France (see J. Margat, op. cit.). In both cases the concern was to institute a form of expression common to all specialist users (hydrogeologists, hydraulic engineers, water authorities) and to facilitate both the preparation and the use of maps. The selection was not made haphazardly, but took into account common experience in this field.

3.1.1.1 The International Legend of UNESCO has defined a certain number of mapping norms, juxtaposing three sorts of information

- -- a translation of the geological map into lithological classes signifying permeability,
- -- data concerning groundwater flow (piezometry),
- -- various information about water-courses, springs, the harnessing of the water and hydraulic constructions.

Today these norms are for the most part well-tried and tested: they can serve as the basis for the elaboration of any new map, while still allowing the map-drawer a certain latitude for what he wishes, or is able, to display more particularly.

As we are unable to discuss this legend in detail -- in itself an important work on hydrogeological mapping in general, which any author of a new map would do well to consult -- we should remind ourselves of its essential features with regard to the hydrogeology of limestone terrains.

The following examples of hydrogeological mapping at different scales present a suitable illustration of the most frequently used markings and symbols conforming to the international legend.

As a general rule, the colours reserved for the hydrogeological classification of terrains have until now been chosen to provide stratigraphic information, and have been derived from the norms adopted for geological maps (e.g.: violet for Triassic, blue for Jurassic, green for Cretaceous).

The examples given here conform to this rule, with the exception of the International Map of Europe at 1 : 1 500 000 in which colours are used to distinguish the main classes of aquifer permeability. Furthermore, it will be observed that apart from this one map, the colours which are "flat", which shade off gradually, are reserved preferably for terrains that are either impermeable or of only mediocre permeability, whereas the symbols for limestone terrains consist almost exclusively of rectangles and squares of a wide variety of sizes.

As for dolomites, they are represented either by their usual symbol (parallelograms), or -- particularly to indicate the extension of dolomitisation in a limestone series -- by punctuations of different sizes and densities: this is the case for the 1 : 200 000 map of the Grands Causses. In this map oblique hatching is used for representing the expansion of the permanent flooded areas in the karst, hatching of different shades according to the age of the aquiferous reservoir; but such procedures will only be possible if the necessary shades are already being used on the map so that the cost should not be increased too much.

Finally, we must emphasize the importance of a classification, according to the flow-rates at low water, of both the hydrographic network and the springs, such as has been produced for the maps of the Paris basin and the Grands Causses. Such a classification enables us indeed to show the effect of groundwater recharge on base flow to streams, and more generally the nature and importance of the relationship between groundwater and surface water. N.B.: A special symbol for palaeokarsts, that is not used in the examples on Slide 1, was also recommended in the international legend.

The symbols presented in Figure 1 are based on the results of a speleological study of several karst areas; they correspond in fact to all types of karstic solution openings that are encountered in nature; however, they are used in their entirety only in very large-scale maps (up to 1 : 100 000); the colour of the symbol is blue or violet, or more rarely black (cavities without drainage).

Information relating to the regime of springs (variability and rate of flow) can be provided either by varying the size of the symbol or by placing around it one or more concentric circles; such information will be most interesting since it will be possible to express on the map the features of the surface drainage regime.

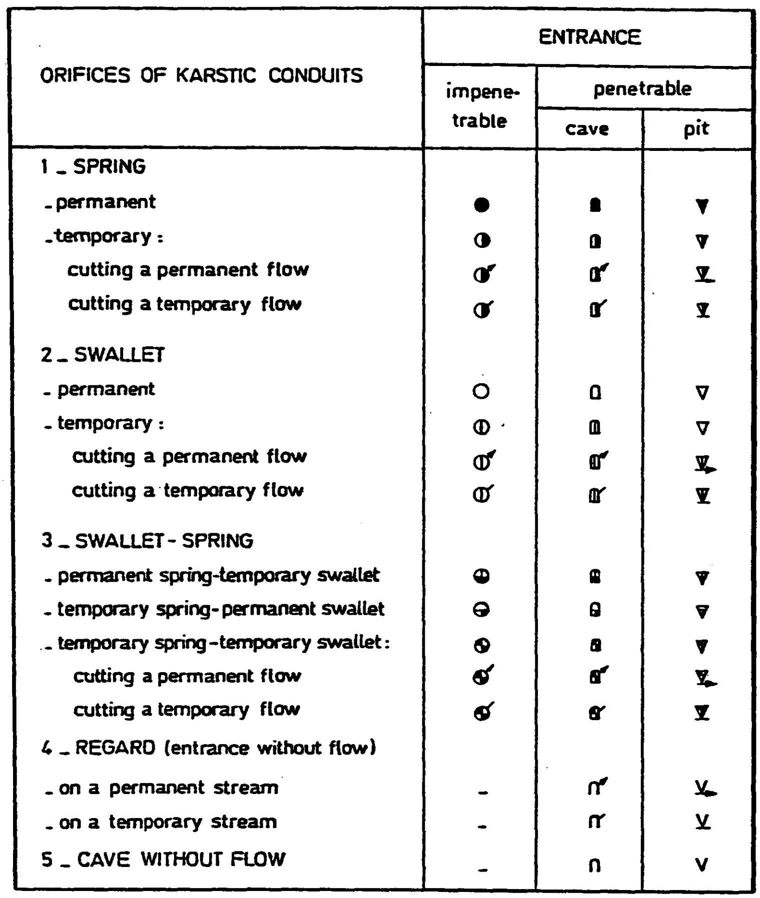

Figure 1. Symbols recommended for large-scale maps

It is quite clear that this will have to be simplified for smaller scales, as it has been the case for the maps of various scales from which we have taken the examples on Slide 1: moreover, this simplification can easily be achieved without introducing new symbols of a type different from those presented in Figure 1.

The other symbols that are used (mineral springs, wells, boreholes, gauging stations, etc.) are identical to those recommended by the international legend for non-limestone aquifers.

3.1.1.2 The new legend proposed by J. Margat was inspired by the methods of schematization that are used to create simulation models. To this end it brings together information about

-- the constitution of the aquifer systems definable at the adopted scale, -- small for the map of France, but which can be medium or large with the possible inclusion of the punctual data used in conventional maps -- based upon the distinction between, and disposition of, the principal bodies (whether aquiferous, semi-permeable capacitive or not, impermeable) which compose them or delimit them by forming more or less complex systems (mono-layers, bi-layers, multi-layers).

-- the conditions at the boundaries of these systems. This description is based principally upon two distinctions:

1) The direction of the water flow at these boundaries, which can be positive (water entering the system), negative (water leaving the system), or neutral (no flow).

2) The distinction between the potential conditions -- i.e. at an imposed level -- and flow conditions.

This information is depicted in the following manner:

Colours

a) Information about the passive characteristics of aquiferous reservoirs, about boundaries, natural hydrological conditions and surface hydraulic constructions which have no influence upon groundwater:
(depicted in dark grey):

Impermeable geological boundaries (boundaries of an aquiferous reservoir), structure contours of the impermeable roof or wall of an aquiferous reservoir, a lake, reservoir or stream without hydraulic contact with groundwater, a drainage divide, an inactive karstic cavity; a dam, a dyke, an underground dam; channels, aqueducts, watertight pipes, canals, abandoned or non-productive wells or boreholes, other abandoned constructions for the harnessing of water, boreholes for geological research or mining surveys.

b) Information about the feeding of aquiferous reservoirs (depicted in red)

Feeding water-course, drainage of surface water, absorbent karstic cavities, limits of feeding, a lake or reservoir forming a feeding front; isohyets and information about precipitation; flood areas, areas of preferential infiltration; constructions for artificial recharge, infiltration basins, recharge wells and boreholes; feeding channels, irrigation networks and perimeters, areas of water spreading.

c) Information about the emergence, discharge and withdrawal of groundwater (depicted in blue).

Draining water-courses, springs, areas of groundwater emergence, sea shores or banks of lakes representing areas of emergence, a karstic cavity emitting water; areas of evapotranspiration; constructions of any sort to harness and exploit water (production wells and boreholes, pumping stations, channels or underground drainage galleries).

d) Information about surface water that is without hydraulic contact with groundwater: water-courses, natural or artificial stretches of water (depicted in green).

e) Direct information about underground water and its dynamics (depicted in dark blue).

Piezometers and information about piezometric levels, isopiezometric curves (or hydroisohypses), lines delimiting confined or unconfined groundwater conditions, limits of artesian areas, groundwater divides, groundwater flow lines or other information about the direction of water flow; "manhole" karstic cavities within an aquifer; underground rivers, links discovered by tracers, the general axis of the underground drainage.

Markings

a) Continuous and discontinuous markings

Continuity in the markings signifies a continuity in space:

unbroken line: continuous limit
solid colour: continuous environment (aquifer).

Discontinuity in the markings signifies a discontinuity in space:

broken line (dots, dashes): discontinuous limit
"graphic" markings (squared, etc.): discontinuous environment (aquifer)

b) Solid or open markings

Continuity and discontinuity in time is represented preferably by solid or "open" markings (lines, punctual symbols). For example: permanent springs or emissions will be represented by solid symbols, and temporary springs or discharges by "open" symbols.

c) "Jagged" lines

These designate flow condition limits, whereas straight lines represent potential condition limits.

d) Additional stripes

-- Horizontal stripes provide information about surface hydrodynamic conditions: feeding (red), emission (blue) or no flow (black). Thus they are superimposed mainly on the marking for free surface aquifers.

-- Vertical stripes provide information about the hydrodynamic conditions at the roof of a non-surfacing aquifer, in general semi-confined, with the colour of the stripe specifying the exchange of water with a superior aquifer, or a semi-permeable covering, with reference to the deeper aquifer: red stripes for a descending flow signifying a supply of water, blue stripes for ascending flow signifying an emission of water.

The stripes can be superimposed either upon free aquifers, or upon semi-permeable coverings.

3.1.1.3 Other maps

We shall take as example two recently produced maps which represent a compromise in relation to the two above-mentioned approaches, and whose legends are considerably simplified.

On the Water Resources Map of the Mediterranean Karsts in France, scale approx. 1 : 750 000 only surfacing karstic formations and, in part, their extension beneath the covering terrains are shown. The aquiferous systems are distinguished according to the existence of permanent reserves. Only three categories of boundaries have been expressed: impermeable boundaries, limits between unconfined and confined conditions, surface water in contact with groundwater. The feeding potential has been calculated for the principal systems (expressed in millions of cubic meters), according to the values of the effective rain and the coefficients of infiltration measured in experimental basins. Finally, different symbols have been used to allow the importance of the renewal of water in each system to be appreciated renewal either by a spring, or by boring: a symbol specifies which of these supply points are harnessed.

The Water Resources Map of the Karsts of Lebanon, scale 1 : 400 000 is even more simplified than the previous one, as it includes neither distinctions between the limits of the system, nor evaluation of the feeding potential. Moreover, it does not specify which of the springs shown on the map are harnessed.

3.1.2 Specialist maps

These are maps with more obviously practical objectives. Considering the diversity of the subjects which can be approached, and the various scales which can be used, generally large or very large, it is difficult to propose norms for these maps. We shall take as examples three maps with different subjects recently produced in the south of France:

-- Fracturation Map of the Karsts in the Vidourle Basin, scale approx. 1 : 10 000.

This is a map which specifies, by indicating all the fractures revealed in different surfacing parts of an aquiferous limestone reservoir, the relationship between fracturation and the development of karstification: it depicts especially the density of the fractures in the various limestone beds and facies, with histograms of fractures providing the synthesis of the observations for each of the areas distinguished in this way.

-- Map of the Susceptibility of Underground Water to Pollution, scale 1 : 250 000.

This map displays the limestone regions' great vulnerability to pollution by linking with a symbol for fractured and intensely karstified regions in the areas which are mostly exposed to the infiltration of pollutants and the directions in which a possible pollution would spread towards harnessed springs.

-- Map of the Suitability of Soils for Individual and Collective Purification, scale 1 : 25 000.

This map locates, in a terrain formed essentially by highly fractured and karstified limestone rock, the areas of diverse pedological characteristics which determine the possibility or otherwise of putting into operation an individual or collective purification project.

The map itself includes a text and diagrams specifying the methods of operation of purification projects dependent upon geopedological distinctions.

3.2 Other documents

There is good reason to list in this category the complex documents such as hydrogeological atlases: their aim is to divide up into various plates, each devoted to a particular subject, the data collected in different fields, in which the information contributes to a complete understanding of the aquifers under consideration. We are provided with a very good example of this by the atlas at the scale of 1 : 100 000 of the karstic region of Miskolc in Hungary.

The following subjects are successively examined:

1 -- Topographical sketch-map of the protection zone;
2 -- Hydrogeological map;
3 -- Hydrological map;
4 -- Map of the pollution - sensitivity of the protection zone;
5 -- Map of pollution sources - communal sewage and wastes;
6 -- Map of pollution sources - animal breeding;
7 -- Map of pollution sources - forestry and agriculture;
8 -- Map of pollution sources - mining and industrial activities;
9 -- Map of the proposed measures for water pollution control.

Slide no.	For maps: title, country, scale, author, edition.
1	Examples of hydrogeological mapping at various scales.
2	International Hydrogeological map of Europe (1 : 1 500 000), Sheet B5, by H. Karrenberg and O. Deutloff, Hannover 1975.
3 and 4	Hydrogeological Map of the "Grands Causses" Area, France (1 : 200 000), by H. Paloc, BRGM-CERGA, Montpellier 1972.
5	Table of symbols recommended for large-scale maps.
6 and 7	Hydrogeological Map of the Karstic Area at the North of Montpellier, France (1 : 80 000), by H. Paloc, BRGM, Paris 1964.
8	Hydrogeological Map of Lot Department and of the Quercy Karstic Area, France (1 : 100 000), by J.C. Soulé, BRGM, Toulouse 1977.
9	Hydrogeological Map of the Vercors Karstic Area, France (1 : 50 000), by P. Rousset, Dolomien Institute, Regional Park of Vercors, Grenoble 1982.
10	Project of a new legend for hydrogeological mapping based upon the classification and the conditions at the limits of aquifer systems, by J. Margat, BRGM, Orléans 1975.
11 and 12	Hydrogeological Map of France -- Aquifer Systems (1 : 1 500 000), by J. Margat, BRGM, Orléans 1980.
13	Water Resources Map of the Mediterranean Karsts in France (1 : 750 000), by C. Drogue, A.M. Laty and H. Paloc, USTL-BRGM, Montpellier 1983.
14	Water Resources Map of the Karst of Lebanon (1 : 400 000), by S. Zaatiti, USTL, Montpellier 1982.
15	Fracturation Map of the Karst in Vidourle Basin, France (1 : 10 000), by J.C. Grillot, USTL, Montpellier 1975.
16	Map of the Susceptibility of Underground Water to Pollution, Sheet Valence, France (1 : 250 000), by M.F. Parascandola, USTL-BRGM, Lyon 1979.
17	Map of the Suitability of Soils for Individual and Collective Purification (1 : 25 000), SIVOM of Pic St. Loup, France, BURGEAP 1982.
18	Hydrogeological Atlas of the Environmental Protection Zone of Miskolc City, Hungary (1 : 100 000) by T. Bocker and G. Vecsernyes, Budapest 1983.

Table 1. Documents presented on slides

4. CONCLUSION

Cartographic documents in the field of karstic hydrogeology should facilitate, as should hydrogeological mapping in general, communication and transmission of knowledge between specialists; but it should also, more and more, provide those who are non-specialists in the field of underground waters with the information which the latter need for their particular work. Thus it is desirable, on the one hand, that the recent effort displayed in all countries towards the goal of a general hydrogeological cartography, for essentially scientific purposes, should be continued and extended to the territories not yet covered by this type of map, and that it should rely on the norms that we have dealt with in this report; but, on the other hand, it is desirable that hydrogeological mapping should address itself to specialized subjects, in order to provide information of more direct interest to developers and decision-makers. An appropriate selection of data should be the rule, with a certain latitude being allowed to map-drawers in the choice of their form of representation. In both cases mapping is a profitable undertaking, as the services which a well-produced map can provide, whether for a scientific or an applied purpose, and especially the savings it allows its users to make, are incomparably superior to the outlay necessary to produce it. All organizations should therefore seek to facilitate the production of such maps.

Hydrogeological Mapping in Asia and the Pacific Region
Proceedings of the ESCAP-RMRDC Workshop, Bandung, 1983

HYDROGEOLOGICAL MAPPING IN COASTAL AREAS

S. Jelgersma and E. Romijn

1. INTRODUCTION

A revised draft of the International Legend for Hydrogeological Maps published in 1970, will be presented during this meeting.

The explanatory note of the revised draft discusses its main purpose, which is to facilitate the preparation of hydrogeological maps, regardless of scale, in standardized form.

The original legend was used to prepare small scale maps with the aim of representing quality and quantity of groundwater as it occurred in a region. Accordingly for rural water supply this small scale map gives excellent general information.

For the water supply of big cities with industry and a large population, also for irrigation, hydrogeological maps are needed to a larger scale. These maps should lay stress on the amount and quality of available groundwater, location of recharge areas and give hydroclimatological data such as precipitation, runoff, infiltration and evaporation. If sufficient hydrological data is available in such areas it is advisable not to put all the data in one map, as was done in the small scale maps of Europe, but to make one background map with supplementary maps showing one class of data. The thickness, lithology and physical and chemical characteristics of surface layers situated on top of the aquifer should be presented in such a supplementary map. This map can be of great importance which regard to problems of groundwater pollution. In large scale maps it may also be of importance to distinguish the occurrence of different aquifers separated by aquitards and aquicludes superposed on each other. The International Hydrogeological Legend does not give a solution for these special problems (see explanatory note).

However, many coastal plains are underlain by subsiding basins which hold a thick accumulation of Cenozoic sediments below surface. In those areas different aquifers separated by aquitards and aquicludes can be present. The geological background of these basins will be given in Section 2. The aim of this article is to propose a refining of the International Legend for use on large scale maps in coastal areas where there is an important demand for water supply (irrigation areas and large cities with industries) and where several aquifers are present (see Section 6). The importance of collecting hydrological and hydrogeological data and their storage in a data bank is stressed. The construction of a hydrogeological map out of the data bank is only an application of the various purposes of the data bank (Section 5). A special problem of aquifers in coastal areas can be the quality of the groundwater and, in particular, the occurrence of salt and brackish water. These problems will be discussed in Section 3. One of the most disastrous man-induced geological hazards in coastal areas is land subsidence due to groundwater withdrawal. A discussion of the problem is given in Section 4.

2. GEOLOGICAL SETTING

Evidence is available that many coastal and deltaic plains are underlain by tectonically subsiding basins. Such basins are the sites of a heavy accumulation of Cenozoic sediments, sometimes several thousand metres thick.

The position of the shoreline in these basins depends on the rate of subsidence and the rate of influx of sediments. These two factors varied in geological time and caused alternating periods of shoreline regression and transgression. During the Quaternary a third factor played a role, namely eustatic sea-level changes which were the result of alternating glacial and interglacial periods. In general, it is accepted that during a glacial period a drop of sea level of more than 100 m occurred while during an interglacial period the sea level stood slightly above or near the present level. Because of these factors there are often alternating marine and alluvial deposits buried below surface of many coastal areas. These different deposits show various lithologies; in general, marine deposits are fine-grained in contrast to the alluvial deposits which are coarser grained. It is also clear that the pore water of marine deposits was originally saline or brackish and that the alluvium originally contained fresh water (for more details see Section 3).

At many places the deepest part of the basins is found offshore, as in the North Sea Basin in Western Europe (3500 m deep) and the Bengal Basin in SE Asia (about 6000 m below sea level). In SE Asia many subsiding basins are present both offshore and onshore.

The Bangkok and the Jakarta basin (onshore) are examples of basins situated in highly populated areas with important and extensive fresh water aquifers in the underlying sediments.

3. SOURCES OF BRACKISH GROUNDWATER

Two different sources of brackish and saline groundwater can be distinguished in coastal aquifers:

(i) The original pore water content of marine sediments and (ii) the intrusion of seawater, both through surface water and underground flow. It has been noted above that the stratigraphic units in the subsurface of coastal basins represent, in many cases, an alternation of marine and alluvial environments.

Marine sand and clay layers may, in some cases, have an important salt content long after their deposition. In other cases the salt may be partly or fully removed either by flushing with fresh water or, in case of a clay layer, by compaction due to superincumbent load.

The transition from fresh to brackish to saline groundwater in coastal plains may lie between several metres and several hundred metres below the surface. The location and nature of this transition zone is related to the geological history and environment of the surface and subsurface deposits, the hydrologic regime of recharge areas, the infiltration capacity of surface layers and the groundwater flow and gradient.

In the Dutch part of the North Sea Basin the salt-fresh water boundary is situated at shallow depths in the coastal area. This is thought to be caused by recent marine transgression. Outside the coastal area the salt-fresh water boundary is situated between depths of 100 and 500 metres. In these areas the original salt water of the marine deposits of Pliocene and Early Pleistocene age is due to groundwater flow redistributed by fresh water.

In the northern part of the Mississippi delta the fresh-salt water boundary is situated at more than 1000 m below surface. It is clear that heavy withdrawal of groundwater will cause this salt-fresh water boundary to rise close to the surface.

Heavy groundwater withdrawal in coastal aquifers connected to the sea can result in salt water intrusion. This overdraft condition will cause a lowering of the watertable which can reduce or reverse the natural gradient sloping downward to the ocean. This condition will favour the intrusion of seawater in the aquifer.

4. LAND SUBSIDENCE DUE TO GROUNDWATER WITHDRAWAL

A serious man-induced geological hazard is land subsidence due to overdraft of groundwater in areas underlain by Cenozoic basins. The main purpose of this section is to give an outline of the principles and problems concerned; detailed information can be derived from the proceedings of the first and the second International Symposium on Land Subsidence.

Surface and subsurface layers of subsiding basins in coastal areas consist of young unconsolidated material deposited in alluvial, lacustrine and shallow marine environments. These environments have alternated due to changes in influx of sediments, tectonics and sea-level changes. Depending on the lithology of the subsurface layers the permeability may be very low to high.

Accordingly, the hydrological schematization of the subsurface layers gives an alternation of confined or semiconfined aquifers consisting of gravel and sand of high permeability and low compressibility and aquitards of low vertical permeability and high compressibility under primary stress. Groundwater withdrawal will cause artesian head decline resulting in compaction due to increased effective stress. The compaction of these aquifers is immediate and is chiefly recoverable if fluid pressure is restored.

The above-mentioned compaction is small compared to the compaction that occurs in the aquitards, due to time dependent pore-pressure reduction in these fine-grained sediments. The decrease in head in the aquifer creates a hydraulic gradient from the clays of the aquitards to the aquifers. It must be realised that these fine-grained beds have low hydraulic conductivity and high compressibility. Therefore, the vertical escape of water and the consequent decrease in pore pressure and increase in effective stress are slow and time-dependent.

The occurring compaction is large and irreversible. Summarizing it may be concluded that the compaction in the aquifers occurs directly if pore pressures decay but the amount is small. Compaction in the aquitards is much more time-dependent due to the slow vertical escape of water but the ultimate compaction is large and mostly permanent.

The problems associated with subsidence due to groundwater withdrawal are various. The most important in coastal areas is that of the tidal encroachment which can cause salt water intrusion in the aquifer and flooding of settlements.

Other problems are differential changes in elevation and gradient of stream channels, drains, canals and failure of pipelines. In water wells casings may fail due to compressive stresses caused by compaction of aquifers. These problems have to be taken into account if heavy withdrawal is allowed to take place.

This can occur in deltaic areas with heavy population and intense industrial development which then must be protected from inundation by construction of an extensive system of dikes, flood walls, locks and pumping stations. It is clear that the costs of such construction works are very high.

In these areas it is advisable to have an annual geodetic survey to monitor ground movements and to install a network of piezometers to check pressure heads in the exploited aquifers. Measurements of compaction in the aquifer itself can be done by extensometers in boreholes.

Investigations of permeability, grain size, clay chemistry and compressibility of aquifers and aquitards should be made to give information on the physical properties of the subsurface formations. These data should be used to build up a numerical model, simulating the compaction of the groundwater reservoir caused by groundwater withdrawal. Based on the results of these investigations withdrawal of groundwater in coastal plain aquifers should be controlled by the authorities concerned.

5. DATA BANK

Those data related to the hydrogeological system should be collected in inventory archives. These may contain data such as:

(i) Borehole records, with careful descriptions of the samples, depth of wellscreens and geophysical borehole measurements. The abovementioned data give an impression of the occurrence of aquifers and their porosity and permeability and the alternating aquitards.

(ii) Chemical analysis of groundwater samples in the various aquifers give information about the quality of the groundwater.

(iii) Pumping tests in the different aquifers give evidence of transmissivity of the aquifer and the hydraulic resistence of the aquitards. Collection of data on the elevation of the watertable, piezometric head, gives an indication of the groundwater flow and the influence of groundwater withdrawal. The available data on physico-chemical properties of the subsurface layers should also be included in the archives as they can be useful in calculating compaction. The first step in collecting the above-mentioned data should be the organization of national inventory archives. It is a heavy task to collect all data available as they are stored by various sources, such as water supply companies, drillers, engineering bureaus, public agencies, etc. But if it is not done by the authorities concerned the available data will be lost in the future. The main problem is not the first set-up of such a national inventory archive but to keep it up to date.

It is evident that the above-mentioned inventory can be put in an automatized system i.c. a data bank.

6. HYDROGEOLOGICAL MAPS

Some problems may arise if large scale hydrogeological maps in coastal areas are compiled for special purposes as mentioned in the introduction. First of all it is difficult to present all relevant hydrogeological data on one map.

A second problem is how to present the occurrence of various aquitards and aquifers in the subsurface. It must be concluded that next to a main map several single property maps are needed to present all available information. Not presented on the main map but given in separate maps may be:

(i) The lithology and thickness of the surface layers, with a relevant cross-section.

The postglacial rise in sea level has caused important sedimentation in low lying coastal areas. The geotechnical properties of these young deposits are different from the underlying older layers. Accordingly, a map of the lithology and the thickness of these surface deposits may give information on compaction due to piezometric head decline, infiltration capacity and vulnerability with regard to pollution from the surface. If possible it is advisable to combine this map with the map of the surface water, relevant artificial works and isohypses.

(ii) Mean annual rainfall together with the rainfall gauging stations. This map can be presented at a small scale.

(iii) Maps of the most important aquifers and aquitards in the subsurface should be constructed.
A top and base contour of the aquifer or isopach lines together with the hydraulic conductivity and information about the quality of the groundwater will be given. From the most important aquitards data according to depth, thickness and hydraulic resistivity must also be mapped.
The main map will express the number of aquifers present in the subsurface. This can be done by using different densities of stippeling. We propose the use of the following densities:

one aquifer	⁘
two aquifers	••
three or more aquifers	°°

Three colour shades of blue will be used to express the productivity of the whole water-bearing strata concerned. These colours will indicate the presence of

highly	productive	aquifers	(dark blue)
moderate	"	"	(lighter blue)
low-moderate	"	"	(light blue)

A depth contour line of the fresh-salt water boundary, the line of saltwater intrusion and the depth of the total bearing strata should also be presented on the main map.

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HYDROGEOLOGICAL MAPS FROM THE VIEW-POINT OF THE USER

E. Romijn

INTRODUCTION

Hydrogeological maps are produced for different purposes. They may serve science and education, evaluation of groundwater resources or land use planning. This paper deals with hydrogeological maps directed to practical use by engineers or planners in preparing decisions of practical importance.

After a summing-up of data, needed for applied hydrogeological purposes, an evaluation is made on scale of mapping. Data should be collected in a data bank. The latter may be automatized.

AIMS OF APPLIED HYDROGEOLOGY

Applied hydrogeology aims at evaluating the (natural) groundwater resources, the suitability for effective land use and the prediction and prevention of possible wrong use of the landsurface or the groundwater. It is important to realize that land use and the groundwater regime are strongly connected.

This follows from the decisive role of the land surface and soil in the hydrological cycle (Figure 1). The land surface determines the division of the precipitation into evapotranspiration, surface runoff and infiltration. The soil as contact layer between atmosphere, hydrosphere and biosphere generates an important series of physical and (bio)chemical processes and stays under strong impact of man's activities, both of which influence the groundwater regime.

THE HYDROLOGICAL SYSTEM

From the preceding paragraph it becomes clear that applied hydrogeology deals with complicated problems. Therefore a systematic approach is necessary which means that the hydrological system should be analysed carefully. By definition a system Σ is a whole that can be separated more or less from its surroundings and that consists of a set of elements B and a set of relations C between these elements B

$$\Sigma \triangleq < B,C,g >$$

where g are functions which prescribe how relations C are attributed to elements B. In Figure 1 the elements (rectangles) represent reservoirs and the connections (arrows) the flows betwen the reservoirs.

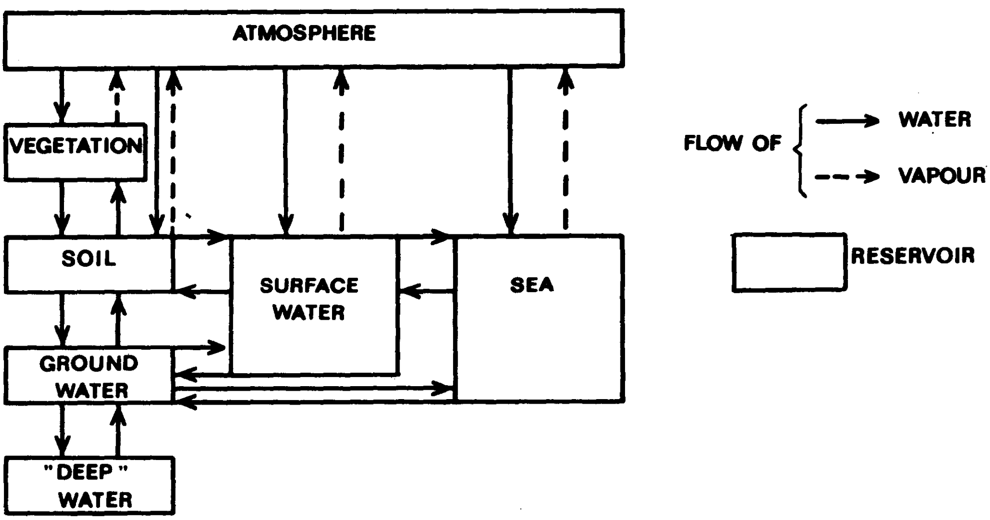

FIGURE I. A HYDROLOGICAL SYSTEM

An important class of systems are the dynamic systems, which are characterized by state variables. State variables describe completely the relevant history of the system, they are often called the "memory" of the system. Examples are the hydraulic head (h) and the Darcy groundwater velocity or specific discharge (q). They are connected by the well known law of Darcy.

$q = -K \frac{\partial h}{\partial s}$ where s is the flow direction and $\frac{\partial h}{\partial s}$ the gradient of the hydraulic head.

The connecting element K, the hydraulic conductivity, is called a parameter. Although it may change in time, in a first approximation it can be taken as a constant. Immediately the question arises: should parameters and state variables be mapped or should they only be collected in a data bank. In the next paragraph, a short list of important variables and parameters will be given first of all.

INTERIOR AND SURROUNDINGS OF THE HYDROLOGICAL SYSTEM

Characteristics of the system may be grouped as follows:

1. The subsystem of groundwater itself

-- the matrix parameters depending on rock type

a) hydraulic parameters like porosity, permeability (hydraulic conductivity), hydraulic resistance (e.g. of clay layers), storage coefficient, compressibility, dispersivity, drainage resistance, etc.;

b) physico-chemical properties like dissolvability, adsorption isotherm, colloidal and swelling properties of clay minerals, etc.

-- the groundwater flow
   a) water table, piezometric head,
   b) flow rate and flow direction;

-- the groundwater quality
   a) physical characteristics like temperature, electrical conductivity;
   b) general physico-chemical characteristics like acidity (pH) and redox potential (Eh);
   c) chemical composition including isotopes, organic compounds, micro organisms, special pollutants.

2. The relation between the subsystem groundwater and its surroundings

-- natural boundaries of groundwater
   a) with the atmosphere: infiltration, evapotranspiration,
   b) with surface water: influent rivers and effluent seepage,

c) with the sea: submarine springs, seawater intrusion,
d) with deeper parts of the earth: magmatic (volcanic) activity;

-- groundwater in relation to soil processes
   a) soil forming processes depending on averaged precipitation excess or evaporation excess,
   b) horizontal soil transport: erosion, landslides, sedimentation depending on wetness of soil and surface runoff,
   c) vertical soil movements, land subsidence: consolidation, karstification, shrinkage, oxidation of organic material, geodynamical processes related to groundwater flow and pressure;

-- human influence on groundwater
   a) abstraction or artificial recharge of groundwater,
   b) level control by systematic drainage or polderworks,
   c) level control by pumping mines, excavations, civil engineering works,
   d) change in quality by pollution from the land surface or by attracting groundwater of other quality from surrounding aquifers.

RELATION OF THE GROUNDWATER SYSTEM TO LAND USE

Different kinds of human influence were already mentioned in the preceding paragraph. These are directly related to different forms of land use. Should the land use be mapped on a hydrogeological map? Some examples of relations follow:

a) housing: in low areas level control, abstraction for drinking water, pollution hazard by sewerage systems,
b) industry: as housing, abstraction for process and cooling water,
c) agriculture: drainage or irrigation systems, pollution hazard by fertilizers or pesticides,
d) recreation, medical treatment: use of mineral-thermal springs
e) traffic, pipelines: soil mechanical properties in relation to groundwater level, pollution hazard,
f) mining, excavations: pumping of water excess, pollution hazard,
g) energy production: use of thermal waters or -- with heat pumps -- "normal" groundwater,
h) waste disposal: use of purification properties of the soil, pollution hazard.

MAPS AND DATABANKS

The next problem is whether all those variables and parameters mentioned above should be mapped and stored in databanks. Generally, many data will be collected in special research programs and published in reports, stored in archives or described in internal (unpublished) papers both of public agencies or engineering bureaus, drinking water companies, drillers, etc. It is a very heavy task to collect all data in a national databank, but if this is not done, the data will be absolutely lost sooner or later.

A first step cold be the organization of national "inventory archives". Such archives have been set up in the Netherlands. For each km² it gives information about which kind of data are present (but not the values of the data) and where more information can be obtained on these data. Therefore, for example information is given about the presence of a borehole and the rain gauge. The main problem is not the first set up of such an information system but keeping it up to date.

Data which are collected by specialized institutes (like Geological Service, Soil Science Institute, water companies, public works) are mostly directly available for hydrogeological mapping purposes. Full use may be made of existing geographical and topographical maps and of geological and soil maps and maps on land use, water works, irrigation systems and the like. Although much work has recently been done on the automatization of such maps, this is not the first problem for hydrogeologists. The main problem is whether the scarcely available hydrogeological data permit the construction of maps on a specific scale, or in other words, permit interpretation in regions where data is lacking.

Another scale problem is related not to the availability of data but to the necessity of detailed information. In order to investigate a local pollution or soil mechanical problem, a detailed survey is necessary and a large scale map (of about 1 : 5000) whereas for regional planning purposes small scale maps will do.

HYDROGEOLOGICAL MAPS OF DIFFERENT SCALES

1. Small scale maps (1 : 500 000 to 1 : 5 000 000).
   Maps at this scale will often give more or less integrated information (single value maps on this scale are not readable). From the scientific point of view they are very useful to learn to distinguish larger units (hydrogeological provinces), which may be studied as a system on itself and combined with this, to supply an overall system of sym-

bols for mapping. From the planning point of view, these maps may serve as tools to communicate with politicians. For technical purposes these maps have less value. Good examples are the UNESCO/IAH Hydrogeological Map of Europe 1 : 1 500 000 and the Groundwater Maps of the F.R. Germany 1 : 1 000 000.

2. Intermediate scale maps (1 : 100 000 to 1 : 500 000).
Maps at this scale may be excellent tools for regional (town and country) planning and water management planning. Single property maps on this scale are possible (e.g. transmissivity values of aquifers, distribution of clay layers, boundary zone of fresh and sea water in the underground). On this scale it becomes clear which parts on the map are still "white" and what are the needs for further mapping. As an example may serve the Hydrogeological Map of Guelderland and Flevoland (Netherlands) at a scale of 1 : 250 000.

3. Large scale maps (larger than 1 : 100 000).
Maps at this scale are real tools for data collection, local research programs, mathematical modelling of hydrogeological systems, planning of technical systems (irrigation, waterworks, etc.) and city planning. Hydrogeological maps will be used in connection with large scale topographical, geological and soil maps.

DATA BANK AND DATA BASE

A data base may be defined as a data bank with sufficient programmed facilities to serve for different purposes such as digital mapping, statistical calculations, time series analyses, etc. This means that the data base connects data banks and hydrogeological maps. In many cases perhaps still futuristic, hydrogeological data bases will sooner or later be established all over the world and will serve mankind not only for their basic needs of water, food and housing but also for industrial development and recreational purposes in the broadest sense.

Report of Working Group 1:

MINIMUM DATA REQUIREMENTS FOR THE PREPARATION OF HYDROGEOLOGICAL MAPS, AND PROBLEMS OF SMALL ISLAND NATIONS

Chairman: D.R. Tappin
Rapporteur: G. Jacobson

In the spectrum of groundwater development, it is necessary to start with a topographic base map and a geological map. A census of bores and wells should be undertaken in order to provide water-level and possibly chemical data, as well as the vital information on the occurrences of aquifers. A preliminary hydrogeological map at this stage can form the basis of successive stages of:

- Groundwater investigation, including geophysical surveys, drilling, aquifer testing, chemistry;
- Groundwater resources assessment, including water balance calculations, integration of meteorological and streamflow data;
- Groundwater management, including monitoring, consideration of demand, and the legal framework.

Hydrogeological maps are needed at these successive stages in order to summarize data and present it in an easily appreciated form, especially for decisionmakers. Progressively more information will become available for compilation.

Discussion focussed on aspects of groundwater investigation, assessment and monitoring, especially as they affect the small island nations, and considering appropriate and available technology. Geophysics, especially the resistivity technique, may provide a tool for rapid delineation of the freshwater lens. A portable conductivity meter can provide data for the rapid assessment of water quality. Hand augering and pitting can provide access for water-level measurement. The chloride balance can be used for water-balance calculations.

Groundwater is a dynamic resource and monitoring is essential for management. Presentation of data in map form is an integral part of the process of groundwater development.

Report of Working Group 2:

A REGIONAL HYDROGEOLOGICAL MAP OF SOUTH AND EAST ASIA

Chairman: B.D. Pathak
Rapporteur: W.H. Gilbrich

On 1 December 1983, a working group met to discuss salient futures of the project of a regional small-scale hydrogeological map of South, Southeast and East Asia. The meeting was attended by representatives of Bangladesh, China, India, Indonesia, Japan, Malaysia, Nepal, Pakistan, Rep. of Korea, Thailand and Vietnam, Unesco and IAH.

Mr. Gilbrich introduced to the meeting the various regional mapping projects in the world pointing out briefly their special features and problems.

Mr. Struckmeier explained the purpose, scope and utility of regional maps as they depict the hydrogeological situation irrespectively from political borders. The aim is to obtain an idea of the rechargeable water resources in order to avoid "mining" of the groundwater resources.

Most country representatives took the floor and described the mapping progress in their countries and expressed their support to a regional mapping project. Pakistan requested consultancies for evaluating their date resources and insisted much in a uniformity of approach and legend for the whole regional project. China was informed of the project only during the Bandung meeting but would readily participate. Bangladesh emphasized the need for a transfer of knowledge, data and information and for regional cooperation. Nepal requested experts from RMRDC to assist them in the main compilation. The representative of Malaysia felt that the intended scale of 1 : 5 000 000 was too small for his country and would prefer a scale of 1 : 2 500 000. The Republic of Korea would appreciate recovering data from neighbouring countries. Vietnam has embarked on a national map 1 : 500 000. Japan emphasized the need for socio-economic and agricultural viewpoints to be considered. Thailand reported on a Unesco-financed mission to Indonesia, Malaysia and the Philippines. The report will be available in early 1984. Unesco funds for exchange of information, consultancies and coordinating meeting is requested.

Mr. Struckmeier urged for project coordination within the region. He referred to the role of the IAH, CGMW and Unesco, not to set up any new organizational body but to entrust all coordination activities to the CGMW subcommission for Hydrogeological Maps in South and Southeast Asia, headed by Mr. Pathak. Any duplication of work must be avoided, and the existing infrastructure should be strengthened.

Mr. Pathak then introduced the "Progress Report" describing the background and present status of the regional project. He pointed out the endeavour to base all mapping activities on the "Unesco legend". The Progress Report, having been approved by the working group with one minor modification.

SCALE

Previous discussions assumed a scale of 1 : 5 000 000 and the Geological Map as well as the Oil and Natural Gas Map of Asia have been issued also on this scale. The meeting realized that doubling the scale to 1 : 2 500 000 results in quadripulation of data, work and cost.

The meeting considered the area to be covered and decided to maintain the numbers of countries and the area of the above maps. The meeting considered another cut of the sheets in order to be able to reduce primary costs (the above maps have been printed on four sheets while the omission of marginal areas could lead to two large sheets only). Any deviation from the layout of existing maps should be only hydrogeologically justified but not by ideas of saving preparatory time or of temporary absence of data from the one or other country.

The meeting agreed to a scale of 1 : 5 000 000. Where a difficult hydrogeological situation needs to be described or small countries wish to provide more detailed information, space will be given in the explanatory notes which will accompany each map sheet. Another possibility is to use insert maps.

LEGEND

The map will follow the "International Legend" which will be published by Unesco in 1984. Copies will be put at the disposal of all collaborators in the map project, free of charge. The meeting realised that the term "productivity" is relative and should not be defined rigidly ((exact figures in l/s) but should be seen in the context of the region. For small scale maps a greater uniformity is required.

The meeting discussed the use of colours. There was no problem concerning blue and green colours but there were two interpretations for brown colour where dark brown means lowest productivity (Unesco approach) or relatively high productivity in a non-aquifer. The meeting agreed to adopt, in this respect, the Unesco legend to utilize dark brown for the lowest degree of productivity.

Report of Working Group 3:

DISCUSSION ON THE REVISED INTERNATIONAL LEGEND FOR HYDROGEOLOGICAL MAPS

Chairman: W.F. Grimmelmann
Rapporteur: W. Struckmeier

The new Unesco legend for hydrogeological maps was discussed in the plenum of the ESCAP-RMRDC Workshop on 1 December 1983.

Mr. Struckmeier emphasized the aim of the Unesco legend. The legend is intended as a means for the coherent representation of groundwater resources and groundwater-bearing rocks with all features determining the regime, quality and utilization of groundwater. The Unesco legend provides a catalogue of symbols, signs and colours which are recommended to be used on hydrogeological maps. This also implies that additions to or deviations from this legend may be justified whenever required.

Mr. Bestow suggested using figures characterizing the groundwater balance in the aquifers. However, the difficulty was recognized that this would require much additional information.

Mr. Jacobson asked for an adequate representation of the chemical composition of the groundwater to provide necessary information on possible limitations for groundwater use. This information would be essential for arid areas. It was recognized that information on groundwater chemistry could be represented on the map by using different hatching in orange, symbolizing salinity or ion content ranges. However, any overloading of the map by the excessive use of hatching should be avoided. A line around areas of high salinity may be more appropriate in many cases. Mr. Krampe emphasized that only comprehensive classes of relatively uniform hydrochemical character require depiction on a general hydrogeological map.
Mr. Gilbrich referred to the Unesco legend for geohydrochemical maps (1976) which may provide additional information for this special type of hydrogeological map.

Mr. Struckmeier stated on the request of Mr. Pathak that the main difference between the Unesco legend published in 1970 and that distributed in 1983 is the change from a hydro'stratigraphic' to a more hydro'geological' representation, i.e. different colours were used in the 1970 edition to represent the stratigraphy and the age of hydrogeological units, whilst in the later edition different colours were used to emphasize the occurrence of groundwater and subordinate symbols to represent the stratigraphic units.

Mr. Bestow requested the depiction of river discharge classes on hydrogeological maps as in the aquifer system map of France (Margat, 1980). However, adequate data on long-term runoff may be lacking in many parts of the world and thus this decision should be left to the map author. It should be considered also that the proposed representation requires total redrawing of the drainage network.

The significance of the areal colours was discussed whereby it was suggested using an additional colour in areas where the proportions of groundwater flow in fissured and porous aquifers are nearly the same.

It was agreed that, in order to give map authors as much freedom as possible, numerical values defining the colour classes should not be used in the International Legend. Clearly, each author can best judge the relative importance of the different hydrogeological units in his area.

In general, "static" groundwater resources (reserves) and "dynamic" groundwater resources (recharge) should be distinguished. The proposed line around areas of insignificant recharge may prove to be of practical value and should be shown on the map.

Working Group 4:

HYDROGEOLOGICAL PROBLEMS IN COASTAL AREAS

Chairman: S. Rashid Ali
Rapporteur: S. Jelgersma

Editors' note:

Discussions of the Working Group on Hydrogeological Problems in Coastal Areas centered around the following subjects:

-- Hydrogeology of deltas.
-- Occurrence of salt-water in unconsolidated and consolidated rocks.
-- Geophysical investigations in coastal areas.

No report was produced by Working Group 4.

ANNEX I: LIST OF PARTICIPANTS

AFGHANISTAN

Mr. Nassir Ahmad FORMOLI,
Vice President,
Institute for Survey and Project Planning,
Ministry of Irrigation,
KABUL

AUSTRALIA

Mr. Trevor T. BESTOW,
Supervising Hydrogeologist,
Geological Survey of Western Australia,
Department of Mines,
66 Adelaide Terrace,
PERTH,
Western Australia 6000

Mr. Gerry JACOBSON,
Senior Hydrogeologist,
Bureau of Mineral Resources,
Geology and Geophysics,
P.O. Box 378,
CANBERRA CITY, A.C.T. 2601

BANGLADESH

Mr. Muhammed SIDDIQUE Ali,
Geologist,
Bangladesh Mineral Exploration
and Development Corporation,
Planning Division BMEDC,
HBFC Building,
22 Purana Paltan,
DHAKA-2

BRUNEI

Mr. Abdul GHANI bin Haji Ahmad,
Head, Cartographic Unit,
Mapping Division,
Survey Department Brunei,
BANDAR SERI BEGAWAN Negara Brunei Darussalam

CHINA

Mr. CHEN Mengxiong,
Senior Hydrogeologist, Scientific Adviser,
Advisory Committee on Geol. Science and Technology,
Ministry of Geology and Mineral Resources,
BEIJING, Xisi

Mrs. JIAO Shuqin,
Hydrogeologist,
Deputy Chief of Regional Hydrogeology Section,
Institute of Hydrogeology and Engineering Geology,
Ministry of Geology and Mineral Resources,
ZHENDING,
Hebei Province

FIJI

Mr. Alfred T. SIMPSON,
Principal Geologist,
Department of Mineral Resources,
Private Mail Bag,
G.P.O., SUVA

FRANCE

Mr. Henri Marie PALOC,
Chairman, Commission on Hydrogeology of Karst,
International Association of Hydrogeologists (IAH),
1039, Rue de Pinville,
34000 MONTPELLIER

GERMANY (FRG)

Mr. Klaus D.W. KRAMPE,
Senior Hydrogeologist,
Federal Institute for Geosciences
and Natural Resources (BGR),
P.O.B. 51 01 53,
3000 HANNOVER 51

Mr. W. STRUCKMEIER,
Chairman,
Commission on Hydrogeological Maps,
International Association of Hydrogeologists (IAH),
c/o Federal Institute for Geosciences
and Natural Resources (BGR),
P.O.B. 51 01 53,
3000 HANNOVER 51

Mr. Bernt SOEFNER,
Senior Hydrogeologist,
German Hydrogeological Advisory Group,
c/o Directorate of Environmental Geology,
Jl. Diponegoro 57,
BANDUNG, Indonesia

Mr. Manfred HOBLER,
Hydrogeologist,
German Hydrogeological Advisory Group,
c/o Directorate of Environmental Geology,
Jl. Diponegoro 57,
BANDUNG, Indonesia

HONG KONG

Mr. Kevin Ashley STYLES,
Senior Geotechnical Engineer,
Geotechnical Control Office,
68 Mody Road,
Empire Centre,
Tsim Sha Tsui,
KOWLOON

INDIA

Mr. Bhan Datt PATHAK,
Chairman,
Central Ground Water Board,
Ministry of Irrigation,
236, Bishi Bhawan,
NEW DELHI

Mr. K.C.B. RAJU,
Director,
Central Groundwater Board,
Sadhana Building, Hyderguda 3-6-291,
First Floor,
HYDERABAD 500 029

Mr. N.N. SETH,
Director,
Geological Survey of India,
Special Projects (geothermal),
3 Gokhle Marg,
LUCKNOW

INDONESIA

Mr. Karsono ADISAPUTRA,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. DJAENDI,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. GUSTIAR,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. HADI Darmawan Said,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. HERMAWAN,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. Wayan MUDIANA,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. Puryanto REPOJADI,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. R. SOEKARDI Puspowardoyo,
Chief,
Hydrogeological Survey Division,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. Dodi SOLEH,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. SUKRISNO,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

Mr. Soekiban SUTRISNO,
Directorate of Environmental Geology,
Jalan Diponegoro No. 57,
BANDUNG

JAPAN

Mr. Masaaki UEDA,
Hydrogeologist,
Ministry of Agriculture and Fishery, Japan,
DPMA -- Bandung,
Directorate of Water Research,
Ministry of Public Works,
Jl. Ir. H. Juanda 193,
BANDUNG

KOREA

Mr. Dong Woo LEE,
Principal Researcher,
Applied Geology Division,
Korea Institute of Energy and Resources (KIER),
219-5, Garibong-dong,
Kuro-gu,
SEOUL

MALAYSIA

Mr. Num Kiat ANG,
Hydrogeologist,
Hydrogeology Division,
Geological Survey of Malaysia,
Jalan Scrivenor,
P.O. Box 1015,
IPOH,
Perak

Mr. YOGESWARAN Mailvaganam,
Geologist,
Hydrogeology Section,
Geological Survey of Malaysia,
P.O. Box 560,
KUCHING,
Sarawak,
East Malaysia

MONGOLIA

Mr. Luvsannamjilin TUMUR,
Hydrogeological Engineer,
Ministry of Water Economy,
Gudamj Natsagdorjyn 13,
ULAN BATOR

NEPAL

Mr. Gopal Singh THAPA,
Senior Geologist,
Department of Mines and Geology,
Lainchour,
KATHMANDU

Mr. Yadab Lal VAIDYA,
Chief Geologist,
Dept. of Irrigation,
Hydrology & Meteorology (HMG/N),
Groundwater Section,
Babar Mahal,
KATHMANDU

NETHERLANDS

Mrs. Saskia JELGERSMA,
Senior Geologist,
Geological Survey/IAHS,
P.O. Box 157,
Sjaarne 17,
HAARLEM

Mr. Erik ROMIJN,
Secretary-General of the International
Association of Hydrogeologists (IAH),
P.O.B. 9090,
6800 CX ARNHEM

PAKISTAN

Mr. Syed Rashid ALI,
Senior Hydrogeologist,
Directorate General of Hydrogeology,
Water and Power Development Authority (WAPDA),
430 - Tariq Block,
New Garden Town,
LAHORE

Mr. Muhammed ISMAIL,
Junior Hydrogeologist,
Hydrogeology Directorate,
WAPDA,
94-Ferozepur Road,
LAHORE

PHILIPPINES

Mr. Romeo M. LUIS,
Chief,
Hydrogeology,
Engineering and Quaternary Geology Section,
Bureau of Mines and Geo-Sciences,
P.O. Box 1595,
MANILA

SOLOMON ISLANDS

Mr. Stephen James BOOTH,
Senior Geologist,
Ministry of Lands, Energy and Natural Resources,
P.O. Box G24,
HONIARA

SRI LANKA

Mr. A.G. Nihal WIJESEKERA,
Acting Deputy General Manager,
Groundwater Division,
Water Resources Board,
2A, Gregory's Avenue,
COLOMBO 7

THAILAND

Mr. Paiboon PRAMOJANEE,
Geomorphologist,
Soil Survey Division,
Land Development Department,
BANGKOK 10900

Mr. Somchai WONGSAWAT,
Chief,
Groundwater Investigation Section,
Groundwater Division,
Department of Mineral Resources,
Rama VI Rd.,
BANGKOK 10400

TONGA

Mr. David R. TAPPIN,
Government Geologist,
Ministry Lands,
Survey and Natural Resources,
P.O. Box 5,
NUKUALOFA

VANUATU

Mr. Richard J. MARKS,
Applied Geologist,
Department of Geology, Mines
and Rural Water Supplies,
G.P.O., PORT VILA

VIET NAM

Mr. NGUYEN Dõng Lãm,
Senior Hydrogeologist,
General Department of Geology,
6 Pham Ngu Lao Street,
HANOI

UNESCO

Mr. Wilfried H. GILBRICH,
Programme Specialist in Water Sciences,
Unesco,
Place de Fontenoy,
75700 PARIS,
France

RMRDC

Mr. Jacques BECKER,
Uranium and Industrial Minerals Specialist,
Jl. Jend. Sudirman No. 623,
BANDUNG, Indonesia

Mr. Wolfgang F. GRIMMELMANN,
Senior Hydrogeologist,
Jl. Jend. Sudirman No. 623,
BANDUNG, Indonesia

Mr. Haruo KISHI,
Analytical Chemist, Geochemist,
Jl. Jend. Sudirman No. 623,
BANDUNG, Indonesia

ANNEX II: LIST OF MAPS DISPLAYED AT THE WORKSHOP

AUSTRALIA

Hydrogeological Map of Western Port Basin, Victoria.
R. Lakey & S.J. Tickell, Victorian Department of Minerals and Energy, 1980, 1 : 100 000.

Groundwater Resources Map of Victoria.
G.Y. Nahm, Victorian Department of Minerals and Energy, 1982, 1 : 1 million.

Groundwater Resources Maps of Australia.
Four sheets at 1 : 1 million, Australian Water Resources Council, 1975.

CHINA

1. Hydrogeologic Atlas of the People's Republic of China, Insitute of Hydrogeology and Engineering Geology, State Bureau of Geology, People's Republic of China, 1979.

2. Hydrogeologic Map of China (Photo), 1 : 4 000 000, Institute of Hydrogeology and Engineering Geology, Ministry of Geology and Mineral Resources, PRC, 1983.

3. Regional Hydrogeologic Maps

    Hydrogeologic Map for Amelioration of Salinized Soils in the Huang-Huai-Hai Plain, 1 : 1 000 000, Bureau of Hydrogeology and Engineering Geology, Ministry of Geology, 1965.

    Map Showing the Depth of Water Table in the Huang-Huai-Hai Plain, 1 : 1 000 000, Bureau of Hydrogeology and Engineering Geology, Institute of Hydrogeology and Engineering Geology, Ministry of Geology, 1965.

    Map Showing the Regionalization of Groundwater Resources in Hexi Corridor of Gansu Province, Bureau of Geology of Gansu Province, 1979.

Map Showing the Conditions of Groundwater Exploitation and the Rational Distribution of Well-irrigated Districts in Hexi Corridor, Gansu Province, 1 : 1 000 000, Bureau of Geology of Gansu Province, 1979.

Hydrogeologic Map of Shallow Fresh Water in the Huang-Huai-Hai Plain, 1 : 2 500 000, Geological Bureaus of Shandong, Hebei, Anhui, Henan, Jiangsu, Beijing, Tianjin Provinces (cities), 1979.

Appended Hydrogeologic Map of the Huang-Huai-Hai Plain, 1 : 4 500 000, Geological Bureaus of Shandong, Hebei, Anhui, Henan, Jiangsu, Beijing, Tianjin Provinces (cities), 1979.

Map showing the Groundwater Hydrochemistry in the Arid Region of Northwest China, 1 : 6 750 000, Geological Bureaus of Gansu, Ningxia, Xingjiang, Nei Mongol, Qinghai Provinces (Autonomous Regions), 1979.

Hydrogeologic Map of Loess Region in the Middle Reaches of the Huanghe River (Yellow River), 1 : 2 500 000, Geological Bureaus of Shaanxi, Gansu, Shanxi, Henan Provinces and Ningxia Autonomous Region, 1979.

Map Showing Hydrogeologic Regionalization for Agriculture in the Songliao Plain, 1 : 2 700 000, Geological Bureaus of Lianoning, Jilin, Heilongjiang Provinces, 1979.

Hydrogeologic Map of Karst Region in South China, 1 : 3 600 000, Geological Bureaus of Hunan, Guizhou, Guangdong, Hubei, Jiangxi, Sichuan, Yunnan Provinces and Guangxi Autonomous Region, 1979.

Hydrogeologic Map of Permafrost Region on the Qinghaixizang Plateau, 1 : 6 500 000, Geological Bureau of Qinghai Province, 1979.

Hydrogeologic Map of the Guanzhong Basin, 1 : 800 000, Geological Bureau of Shaanxi Province, 1979.

Hydrogeologic Map of the Huitengxili Lava Platform, 1 : 600 000, Nanjing University, 1979.

Hydrogeologic Map of the Leiqong Artesian Basin, 1 : 600 000, Geological Bureau of Guangdong Province, 1979.

Hydrogeologic Map of Jilin Province, 1 : 500 000, Geological Bureau of Jilin Province, 1983.

4. A Series of Maps Showing the Hydrogeology in Districts

4.1 Maps Showing the Hydrogeology in some Districts of Hebei Province, Geological Bureau of Hebei Province, 1982.

Map Showing the Moduli of Base Flow in the Mountainous Area and Transmissivities in the Plain Area of Hebei Province, 1 : 1 800 000.

Map Showing the Depth Available for Well Construction in Cangzhou District, 1 : 550 000.

Maps for the Part of Hebei Plain South of Beijing and Tianjin, 1 : 950 000:

-- Map Showing the Lithology and Thickness of the Deep Fresh Water Aquifer.
-- Map Showing the Buried Depth of the Bottom of Saline Water.
-- Sketch Map Showing the Deep Fresh Water Quality for Irrigation.
-- Hydrochemical Map of Shallow Fresh Water.
-- Map Showing the Buried Depth of the Bottom of Shallow Fresh Water.

4.2 A Group of Sketch Hydrogeological Maps for Developing Well-irrigation in Shangqiu District, Henan Province, 1 : 500 000, Geological Bureau of Henan Province, 1982:

Map Showing the Hydrogeologic Regionalization of the Shallow Aquifer.

Map Showing the Regionalization of Buried Depths of Shallow Water Table on the Basis of Long Term Balancing.

Map Showing the Regionalization of Water Supply Conditions and Exploitation of Shallow Aquifer.

Map Showing the Regionalization of Calculated Shallow Water Evaporation.

Map Showing the Regionalization of Replenishment Resources for Shallow Aquifer on the Basis of Long Term Balancing.

4.3 A Set of Hydrogeological Maps of Shanghai, 1 : 750 000, Shanghai Geological Department, 1983.

Map of Regional Hydrogeological Classification.

Map of Groundwater Resources.

Map Showing the Penetration of Precipitation and Recharge Module.

Map of the Buried Limestone under Cenozoic Sediment.

Map Showing the Correlation of Land Subsidence, Pressure Head and Exploited Quantity in Shanghai Urban Area.

Map Showing the Transmissivities of the Second Confined Aquifer.

Map Showing the Water Storage Capacity and Mineralization of the Second Confined Aquifer.

Map Showing the Elastic Reserve of the Second Confined Aquifer.

Hydrochemical Map of the Second Confined Aquifer.

Map of the Appraisal of Water Quality of the Second Confined Aquifer for the Use of Industrial Boiler.

Map of the Contour Lines of the Water Table and the Bottom of Phreati Aquifer.

Map of Exploitable Resource of Phreatic Aquifer.

Map Showing the Pollution of Phreatic Aquifer by Zinc and Phenol.

Map of Transmissivities of Phreatic Aquifer.

Map of Chemical Types of Phreatic Aquifer.

4.4 Hydrogeological Maps of the Plain Area of Beijing, 1 : 430 000, Geological Bureau of Beijing, 1980.

Map Showing the Distribution of the Shallow Quaternary Aquifer.

Map Showing the Distribution of Deep Aquifers.

Map showing the Isobars and Buried Depths of Confined Water during the Dry Season in 1978.

Map Showing the Contour Lines and the Buried Depths of the Water Table during the Dry Season in 1978.

5. A Set of Sample Hydrogeological Maps (1 : 200 000) of Different Regions Published in Separate Sheets.

6. Standards of Regional Hydrogeological Mapping, State Bureau of Geology, PRC, 1975.

Standard of Regional Hydrogeological Mapping in Plain Area.
Standard of Regional Hydrogeological Mapping in Hilly Area.
Standard of Regional Hydrogeological Mapping in Coastal Area.
Standard of Regional Hydrogeological Mapping in Karst Area.
Standard of Regional Hydrogeological Mapping in Loess Area.
Standard of Regional Hydrogeological Mapping in Permafrost Area on Plateau.

7. The Method of Compilation and Legends for Comprehensive Hydrogeological Maps, State Bureau of Geology, PRC, 1979.

8. Karst in China, Institute of Hydrogeology and Engineering Geology, Chinese Academy of Geological Sciences, 1976.

9. Wudalianchi Volcanoes in China, Geological Museum, State Bureau of Geology of the People's Republic of China, 1979.

FIJI

Provisional Hydrogeological Map of Viti Levu, 1 : 500 000 (Manuscript), 1983. Department of Mineral Resources, Fiji, and ESCAP-RMRDC.

HONGKONG

Geotechnical Area Study Programme -- Schematic Representation of Terrain Classification at a scale of 1 : 2500 -- District Study Stage I.
Geotechnical Control Office, Engineering Development Department, Hong Kong Government, 1983.
Poster with example maps at 1 : 2500.

Geotechnical Area Study Programme -- Schematic Representation of Terrain Classification at a scale of 1 : 20 000 -- Regional Study.
Geotechnical Control Office, Engineering Development Department, Hong Kong Government, 1983.
Poster with example maps at 1 : 20 000.

Engineering Geology Map -- North West New Territories Geotechnical Area Study. Scale 1 : 20 000.
Geotechnical Control Office, Engineering Development Department, Hong Kong Government, 1980.
(This map includes information on surface hydrological features and drainage basin morphometry.)

Surface Hydrology Map -- Shau Kei Wan Geotechnical Area Study. Scale 1 : 2500.
Geotechnical Control Office, Engineering Development Department, Hong Kong Government, 1981.
(This map delineates surface hydrological features and drainage system morphometry.)

INDIA

Hydrogeological Map of India, 1 : 5 000 000 scale, published by Central Ground Water Board, 1976.

Revised Hydrogeological Map of India, 1 : 5 000 000 scale, published by Central Ground Water Board, November 1983 (Draft).

Central Ground Water Board Map of Noyil -- Ponnani -- Amaravati River Basins:

Hydrogeological Map -- 1 : 253 440 scale, published by Central Ground Water board, 1980.

Hydrogeological and Hydrometeorological Map -- 1 : 253 440 scale, published by Central Ground Water Board, 1980.

Ground Water Recharge and Balance Map -- 1 : 253 440 scale, published by Central Ground Water Board, 1980.

Hydrochemical Map -- 1 : 253 440 scale, published by Central Ground Water Board, 1980.

INDONESIA

Hydrogeological Map of the Isle of Sumba, 1 : 250 000; Geological Survey of Indonesia, 1965.

Reconnaissance Hydrogeological Map of Bali, 1 : 250 000; Geological Survey of Indonesia, 1972.

Hydrogeological Map of Indonesia, 1 : 250 000, Sheet XI Jember;Directorate of Environmental Geology, Bandung, 1981.

Hydrogeological Map of Indonesia, 1 : 250 000, Sheet IX Jogyakarta; Directorate of Environmental Geology, Bandung, 1982.

Hydrogeological Map of Indonesia, 1 : 250 000, Sheets Flores East and Flores West; Directorate of Environmental Geology, Bandung, 1983.

Hydrogeological Map of Indonesia, 1 : 250 000, Sheet V Bandung; Directorate of Environmental Geology, Bandung, 1983.

Hydrogeological Map of Indonesia, 1 : 2 500 000; Directorate of Environmental Geology, Bandung, 1983.

JAPAN

Hydrogeological Maps of Japan 12: Southwestern Part of Hyogo Prefecture, Scale 1 : 100 000; Geological Survey of Japan, 1967.

Hydrogeological Maps of Japan 16: The Coastal Region of Bay of Sendai, Scale 1 : 100 000; Geological Survey of Japan, 1968.

Hydrogeological Maps of Japan 30: The Kofu Basin, Yamanashi Prefecture, Scale 1 : 50 000; Geological Survey of Japan, 1980.

Hydrogeological Maps of Japan 32: The Takada Plain, Niigata Prefecture, Scale 1 : 50 000; Geological Survey of Japan, 1982.

KOREA

Jeong Ung LIM and Chang Ju CHO:
Hydrogeological Map of Anseong River Basin.
Geological Survey of Korea, 1969.

Jeong Ung LIM and Jin Won KIM:
Hydrogeological Map of Upper Jinwi River Basin.
Geological Survey of Korea, 1972.

Jeong Ung LIM:
Hydrogeological Map of the Northern Part of Daejeon (Gabcheon River Basin).

Yun, Sang Kyu, Lee, Dong Young and Lim, Chang Eun:
Hydrogeological Map of Boseong-Yeosu Area.

MALAYSIA

Hydrogeological Map of Peninsular Malaysia 1 : 500 000, Geological Survey of Malaysia, 1975.

Hydrogeological Map of Sarawak 1 : 500 000. Final Draft, 1983; D. Santokh Singh, Director General, Geological Survey of Malaysia.

PAKISTAN

Status of Groundwater Investigation in Pakistan. Scale 1 : 2 million; Directorate General of Hydrogeology, WAPDA, 1981.

SRI LANKA

Groundwater Potential Areas in Sri Lanka. Scale 1 : 2 million; Water Resources Board, Colombo, 1983.

THAILAND

1. Hydrogeological Map of Northeastern Thailand, scale 1 : 500 000, by Chareon Phianchareon, 1973, Department of Mineral Resources, Bangkok, Thailand.

2. Hydrogeological Map of Northern Thailand, scale 1 : 500 000, by Chareon Phianchareon et al., 1983, Department of Mineral Resources, Bangkok, Thailand.

3. Hydrogeological Map of Central, Western, and Eastern Thailand, scale 1 : 500 000, by Chareon Phianchareon et al., 1983, Department of Mineral Resources, Bangkok, Thailand.

4. Hydrogeological map of Southern Thailand, scale 1 : 500 000, by Somchai Wongsawat et al., 1983, Department of Mineral Resources, Bang-kok, Thailand.

5. Hydrogeological Map of Thailand (Draft), scale 1 : 2 500 000, by Somchai Wongsawat and O. Dhanesvanich, final draft 1983, Department of Mineral Resources, Bangkok, Thailand.

EUROPE

International Hydrogeological Map of Europe, scale 1 : 1 500 000 (sheets and explanatory notes).
Ed. IAH/CGMW/UNESCO/BGR, 1970, Hannover/Paris.

-- Sheet A5 La Coruña, 1983; Explanatory Notes in preparation.
-- Sheet B2 Island, with Explanatory Notes (English), 1980.
-- Sheet B3 Edinburgh, with Explanatory Notes (English), 1980.
-- Sheet B4 London, 1976; Explanatory Notes (English), 1978.
-- Sheet B5 Paris-Sud, 1975; Explanatory Notes (French), 1978.
-- Sheet B6 Madrid, 1978; Explanatory Notes in preparation.
-- Sheet C3 Oslo, with Explanatory Notes (English), 1979.
-- Sheet C4 Berlin, with Explanatory Notes (French), 1977.
-- Sheet C5 Bern, 1970; Explanatory Notes (French), 1974.
-- Sheet D3 Stockholm, 1981; Explanatory Notes (English), 1982.
-- Sheet D4 Warszawa, 1981; Explanatory Notes in preparation.
-- Sheet D5 Budapest, 1982; Explanatory Notes in preparation.
-- Sheet E3 Moskva,with Explanatory Notes (English), 1979.
-- Sheet E4 Kiev, 1983; Explanatory Notes in preparation.
-- Sheet E6 Ankara, 1978; Explanatory Notes in preparation.

FRANCE

Hydrogeological Map of the "Grands Causses" Area, France (1 : 200 000), by H. Paloc, BRGM-CERGA, Montpellier 1972.

Hydrogeological Map of the Karstic Area at the North of Montpellier, France (1 : 80 000), by H. Paloc, BRGM, Paris 1964.

Hydrogeological Map of the Department of Lot and the Karstic Area of Quercy, France (1 : 100 000), by J.C. Soulé, BRGM, Toulouse 1977.

Hydrogeological Map of the Karstic Area of Vercors, France (1 : 50 000), by Ph. Rousset, Dolomien Institute, Regional Park of Vercors, Grenoble 1982.

Hydrogeological Map of France, Aquifer Systems (1 : 1 500 000), by J. Margat, BRGM, Orléans 1980.

Water Resources Map of the Mediterranean Karst in France (1 : 750 000), by C. Drogue, A.M. Laty and H. Paloc, USTL-BRGM, Montpellier 1983.

NETHERLANDS

S. Jelgersma and W.A. Visser:
Hydrogeological Map of the Netherlands, 2 sheets (scale approx. 1 : 1 500 000), Geol. en Mijnbouw, Vol. 51, 1972.

ANNEX III

INTERNATIONAL ASSOCIATION OF HYDROGEOLOGISTS (IAH)

INTERNATIONAL ASSOCIATION OF HYDROLOGICAL SCIENCES (IAHS)

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION (UNESCO)

International Legend for Hydrogeological Maps

- Revised preliminary version, 1983 -

FOREWORD

The large and growing number of hydrogeological maps throughout the world is evidence of the general tendency to present both data and their interpretation in map form. This method of presentation permits a rapid areal evaluation of the hydrogeology linked to the advantages of a topographic base. There is, however, likely to be a considerable variation in the amount of information depicted upon a given map, depending both upon the chosen scale and upon the purpose the map is intended to serve.

This Legend is intended to be a guide to the preparation of hydrogeological maps at any scale to a uniform standard. A list is given of the symbols, ornaments and colours which have specific meanings and that are internationally recognised.

This present Legend is based upon the International Legend for Hydrogeological Maps published jointly in 1970 by the International Association of Hydrogeologists, the International Association of Hydrological Sciences, UNESCO, and the Institute of Geological Sciences (London). Used in many mapping projects throughout the world, the 1970 Legend is now out of print, and a revised edition is being prepared. As a preliminary step, a simple and inexpensive version has been produced here as a UNESCO document in English language only, and without colour illustrations. At some future date, after adequate review and trial of this revised Legend, it is intended that a definitive and multi-lingual version with colour illustrations will be published.

For the compilation of the 1970 Legend, working groups were set up within the International Association of Hydrogeologists (IAH) and the International Association of Hydrological Sciences (IAHS). The recommendations of these working groups have come to fruition with the continuing publication of the various sheets of the International Hydrogeological Map of Europe on a scale of 1 : 1 500 000, a project largely carried out by the IAH Commission on Hydrogeological Maps and published jointly by UNESCO and BGR (Federal Institute for Geosciences and Natural Resources of the Federal Republic of Germany). For this reason, that Commission was given the task of preparing the revised Legend, taking into account nearly two decades of experience in hydrogeological mapping. In making this revision, the Commission has collaborated with IAHS and with UNESCO and was supported by BGR.

As a consequence of the application of the original Legend to widely differing environments, varying from tropical climates to permafrost regions, a number of amendments and additions have been proposed. Nevertheless, the basic techniques proved to be universally applicable and have led, in Europe in particular, to a useful degree of uniformity. This successful outcome has encouraged the Commission to press for the continued general acceptance of the Legend as a basis for the preparation of hydrogeological maps.

This revised Legend is intended to provide for the requirements of a general hydrogeological map rather than one produced solely to emphasize one or more particular aspects. Such specialized maps may of necessity use non-standard symbols, ornaments or colours. Suggestions for legends for certain specialized maps have been published, for example, Hydrogeology of Karstic Terrains (IAH, IAHS and UNESCO, 1976) and Legend for Geohydrochemical Maps (UNESCO, 1978). However, the Commission strongly recommends the preparation of a general hydrogeological map before any attempt to produce specialized maps.

The revised Legend contains a list of all the hydrogeological maps known to the Commission which have been published after 1970 at a scale of 1 : 200 000 or less. The exhaustive bibliography on the methodology of hydrogeological mapping that was included in the 1970 Legend has been omitted from the revised version.

Final editing of the revised Legend was carried out by a panel consisting of the following members:

W. Struckmeier (Chairman, IAH)
R. A. Monkhouse (IAH)
S. Jelgersma (IAHS)
W. H. Gilbrich (UNESCO)

The Commission would be glad to receive criticisms and suggestions for amendments or additions to the revised Legend from hydrogeologists throughout the world. These should be addressed to the Chairman of the IAH Commission of Hydrogeological Maps.

G. CASTANY	H. KARRENBERG	W. STRUCKMEIER
President of IAH	Advisor to IAH	Chairman of the IAH Commission on Hydrogeological Maps

1. HISTORICAL DEVELOPMENT OF THE INTERNATIONAL LEGEND FOR HYDROGEOLOGICAL MAPS

The first hydrogeological maps were produced in several countries during the two decades from 1940. 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 (Grahmann, 1952 - 57) and even smaller. These maps were intended to serve as a basis for the water resources planning required to satisfy the generally increasing demand by agriculture, industry and public supply, particularly so since the groundwater resources were not limitless. 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 basis.

The numerous and diverse ideas of the map-makers were demonstrated at an exhibition held in Helsinki in 1961 during the general meeting of the International Association of Hydrological Sciences (IAHS). Approximately 200 hydrological and hydrogeological maps wre displayed, with an extraordinary variety of map content, of colour, and of ornament and symbol use. During 1960 and 1961, the International Association of Hydrogeologists (IAH) attempted a survey of the techniques used in the preparation of such maps by circulating a questionnaire to hydrogeologists in many countries.

The replies received were revealing. Apart from the widely varying opinions expressed, largely due to a concentration on individual projects to the neglect of universally acceptable concepts, great weight was generally placed on theoretical considerations which altogether ignored the practical difficulties of expressing such matters on a two-dimensional map.

In short, there was a complete lack of uniformity, whereby a symbol, an ornament or a colour would 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 would be significant on a regional or international rather than a local basis. Above all, there were no specialists in the preparation and production of hydrogeological maps.

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

Two international scientific bodies in particular, IAH and IAHS, concerned themselves with these problems. After many discussions, IAH had established in 1959 the Commission for Hydrogeological Maps with a remit first to prepare a Legend of recommended symbols, ornaments and colours, and secondly to plan the production of a series of small scale maps to cover the whole of Europe (Karrenberg, 1964). A Working Group was set up within the Commission to provide co-ordination on these projects. Simultaneously, IAHS established within their Commission for Unterground Water a Permanent Standing Committee on Hydrogeological Maps. Contacts were established with UNESCO, with FAO, and with interested parties of many nationalities. As a starting point, both the Working Group and the Standing Committee considered the legend that had been produced for the hydrogeological maps of Morocco (Ambroggi and Margat, 1960).

A joint meeting of the IAHS Committee and the IAH Working Group was held in Paris 1962 under the auspices of UNESCO. Representatives of the latter organisation and of FAO attended. Agreement was reached on a draft legend for hydrogeological maps, and this was published by UNESCO in the following year (Anon, 1963). The purpose of the legend was stated in the preface to be to "facilitate the work of all those, whether specialists or not, who are concerned in the problem of water resources".

Since part of the draft Legend was based more on theoretical considerations rather than on practical experience, the IAH Commission used the preparation of the series of hydrogeological maps for Europe, named the International Hydrogeological Map of Europe, as a practical test. Part of the Sheet C5(Bern) was selected for the prototype since it covered a region with very varied geology and for which a large amount of data was available. The scale was 1 : 1 500 000. Hydrogeologists from Austria, Czechoslovakia, the Federal Republic of Germany, France, Italy, Switzerland and Yugoslavia were involved in the compilation of this map from 1962 to 1964. 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. The printing costs were borne by the Deutsche Forschungsgemeinschaft (as part of the German contribution to the International Hydrological Decade) by the International Union of Geological Sciences, by the Bundesanstalt für Bodenforschung, and by the Geologisches Landesamt Nordrhein-Westfalen.

Models 1 and 2 were presented at the International Congress 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 source yields in the different formations. Neither model proved generally acceptable.

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 on what constituted "good", "moderate" and "poor". In consequence, Model 4 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 dominant intergranular flow. Brown was reserved for those strata not generally considered to be aquifers. 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 Model 3 had departed from being a simple geological map with hydrogeological additions, Model 4 had moved away from the concept of well yield into that of aquifers and groundwater resources. Even at the present day, more than a decade after the first appearance of such a map, the world at large barely appreciates the importance of groundwater resources and their distribution as against the mere ability of a well to yield water, the latter often no more than a measure of technical efficiency in well construction. 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, financed primarily by contributions from UNESCO and from the Bundesanstalt für Bodenforschung,predecessorof the Federal Institute for Geosciences and Natural Resources (BGR).

Much of theinformation 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 adviseable to prepare a volume of Explanatory Notes, limited to not more than 100 pages on an 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 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 the United Kingdom under the supervision of the Institute of Geological Sciences. The publication was in colour, and the text was printed in English, French, Spanish and Russian. An interesting feature was the deliberate incorporation of a wide margin in which a manuscript translation of the text in any other language could be inserted.

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, to illustrate groundwater flow, and to accomodate ideas on aquifer protection. A special additional list of these symbols and ornaments was prepared in 1974 for use by the editors of the European map series (KARRENBERG et al, 1974), but it was not published for general use.

Since its publication in 1970, the Legend has provided the basis for the preparation of many hydrogeological maps, both inside and outside Europe. Although now out of print, the Legend is still in demand, and serious thought has been given to its reprinting. However, in its 1970 form, the Legend already contained some supplementary information appended to the main text, and work both on the European map series and elsewhere had suggested the need for further modifications and additions. To publish a new Legend in a definitive form containing these changes would, nevertheless, have been inappropriate before the latter had been tested in practical map production. The IAH Commission has, therefore, decided upon the production, with the co-operation of UNESCO and IAHS, of this revised Legend as a single language, mono-colour publication at minimum cost. The intention is that, after a trial of a few years in practical use, a fully revised version in colour and with a multi-lingual text will be published.

References

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Grahmann, R., et al. 1952-1957. Hydrogeologische Übersichtskarte 1 : 500 000 and 1 : 1 000 000, maps of the Federal Republic of Germany, Bundesanst. f. Landeskunde, Remagen.

Karrenberg, H. 1964. Der Plan der A.I.H. bezüglich einer hydrogeologischen Karte von Europa 1 : 1 500 000. Mem. Assoc. Int. Hydrogeol., Athens, V, 386-393.

Karrenberg, H., O.Deutloff and C. v. Stempel 1974. General Legend for the International Hydrogeological Map of Europe 1 : 1 500 000. Bundesanst. f. Bodenforschung/UNESCO, Hannover, 49 pp.

2. INTRODUCTION

This legend has been compiled in order to present an internationally agreed means of displaying hydrogeological information in map form.
Hydrogeological maps are maps upon which are depicted the extent of aquifers, together with such geological, hydrogeological, meteorological and surface water features that may be necessary for an understanding of the groundwater regime. Such maps may be international, national, regional or local, and may vary from small (1 : 1 000 000, or smaller) to large (1 : 250 000, or greater) in scale.

Hydrogeological maps are of importance to hydrogeologists and groundwater specialists. They are of use also to non-specialists such as administrators and economists, engineers in the fields of town and country planning, technicians in agriculture and horticulture, as well as to farmers, schoolteachers and private individuals.

Purpose of hydrogeological maps

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 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.

Scales

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, 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.

Definitions

Certain terms are used rather loosely in both hydrogeology and cartography, and it is easy for misunderstandings to arise. A short list of definitions is here included which refer to the usage for this Legend.

Ornament: a pattern of marks, lines or other symbols 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.

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.

Sign: a sign may consist of a line, a symbol, or an ornament, or a combination of any or all of these.

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.

Background information (Section A of the Legend)

This comprises largely geographical detail such as major roads, railways, the larger conurbations, and so forth. Relief is generally not shown on the map since it tends to obscure hydrogeological detail, but insert maps can be used for the purpose. The international grid (UTM grid-Universal Transversal Mercator projection - is suggested), a national grid, or lines of latitude and longitude should be shown.

Background information is generally printed in grey with the grid or latitude-longitude lines in black. Regional and town names may also be printed in black, but the type faces should be clearly different from those used for the stratigraphic symbols (see Section E).

Aquifers and non-aquifers (Section B of the Legend)

All strata that appear in outcrop upon the map, whether aquifers or non-aquifers are shown in plain colour. 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 (see Sections B.I and B.II).

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 (see Section B.III, a and b).

Where it is considered to be particularly important to show the continuation of an aquifer beneath a thin but persistent 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 (see Section B.III c). The legend normally printed in the margin of the map sheet should state the order of maximum thickness of the drift cover.

Lithology (Section C of the Legend)

The lithology of the strata in outcrop is represented by ornament printed in grey beneath the colour. Where the ornament indicates recognisably stratified bedrock, the ornament itself is also recognisably laminar: when the ornament is arranged horizontally (in an east-west orientation upon the map), it indicates horizontal or gently inclined strata, and arranged in a vertical position (a north-south orientation upon the map) indicates steeply inclined or folded strata.

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

Representation of detailed data (Section D of the Legend)

Detailed hydrological information is shown by the use of symbols, and occasionally of lines and 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

Stratigraphy (Section E of the Legend)

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. The symbols, printed in black, are listed in Section E, and are taken from the International Geological Map of Europe 1 : 1 500 000 scale. On large scale hydrogeological maps, it may prove adviseable to use symbols of more local than international significance.

Climatology (Section F of the Legend)

It is rarely possible to include meteorological information on a hydrogeological map without obscuring more pertinent data. It is, therefore, recommended that climatological information be presented either in insert maps upon the margins of the hydrogeological map, or as figures in any accompanying text.

Vertical sections (Section G of the Legend)

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 detail 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.

3. International Legend for Hydrogeological Maps

A <u>Background information</u>

1. All background information is printed in screened black with the exception of the simplified topographic base map which is printed in <u>dark grey</u> (60% black). It presents mainly the

   location and names of important localities and the geographic names (streams, lakes, mountains, etc.), international and administrative boundaries.

2. The actualized drainage network is printed in <u>blue.</u>

3. Grids or lines of longitude and latitude are printed in <u>black.</u>

4. Additional background information to topography and orography where required is presented in the explanatory notes or on insert maps.

B <u>Groundwater and rocks</u>

1. Intergranular aquifers

blue	1.1	Extensive and highly productive aquifers
screened blue	1.2	Local or discontinuous productive aquifers or extensive but only moderately productive aquifers

2. Fissured aquifers, including karst aquifers

green	2.1	Extensive and highly productive aquifers
screened green	2.2	Local or discontinuous productive aquifers, or extensive but only moderately productive aquifers

3. Strata (intergranular or fissured rocks) with local and limited groundwater resources or strata with essentially no groundwater resources

screened brown	3.1	Strata with local and limited groundwater resources
brown	3.2	Strata with essentially no groundwater resources
brown stripes	3.3	Where there is an extensive aquifer immediately underlying a thin cover the option be used of continuing the appropriate aquifer colour crossed by brown stripes (one mm wide and three mm separation)

<u>Note</u>:
Certain aquifers combine intergranular and fissure characteristics. In such cases the relevant colours described in sections 1 and 2 should be used depending on which characteristic is dominant. Further explanation, if required may be added to the map legend.

C Lithology

Ornament indicating the lithology is printed in grey.

The orientation of the ornament indicates the type of bedding:

Horizontal = unfolded horizontal or gently inclined strata

Vertical = folded strata

The following list contains ornaments which indicate general lithological types as well as some combinations to symbolize strata of varying lithology.

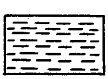
Note:
The ornament represents the lithology of the strata which is shown on the map. The exact lithological composition may be explained in detail in the map legend. Where combinations of ornaments are required, examples are shown in section C 3.
Combination of more than two ornaments is not recommended.

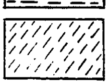
The identification numbers given below are purely for convenience and do not refer to any commercial listings.

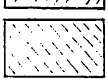
Additional ornaments other than listed here can be used for special purposes.

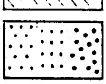
Recommended ornaments:

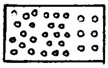
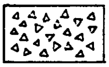
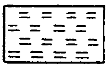
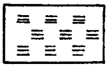
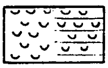
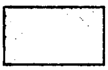
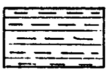
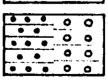
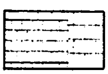
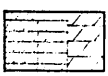
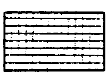
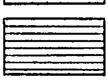
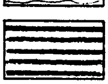
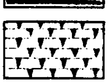
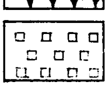
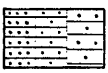
1. Lithology of sedimentary rocks

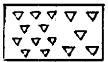
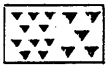
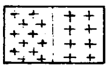
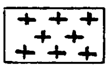
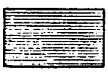
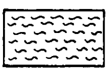
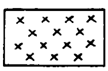
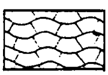
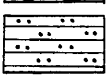
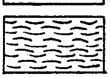
1  clay, clayey loam, mud, silt, marl

2  clayey-loamy alteration products

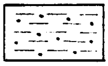
3  loess

4  sands (units can be distinguished by variation of thickness of points)

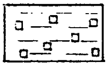
5		gravels (distinction by variation of the arrangement of circles)
6		moraines
7		peat
8		lignite
9		pyroclastics
10		made ground
20		claystone, siltstone, shale
21		sandstone (distinction by variation of size)
22		conglomerate
23		limestones (distinction by variation of rectangle size)
24		dolomites (distinction by variation of parallelogram size)
25		travertine
26		marlstone
27		flysch
28		complex alternation of different lithology
29		radiolarite, lydite, siliceous shale
30		rock salt
31		gypsum

2. Lithologies of igneous and metamorphic rocks

40		acid to intermediate extrusives (distinction by variation of triangle size)
41		basic extrusives (distinction by variation of triangle size)
42		ultrabasite, serpentinite
43		acid to intermediate intrusives (distinction by variation of arrangement of crosses)
44		basic intrusives
45		slate, phyllite, mica schist, etc.
46		gneiss
47		gneiss and granite, undifferentiated
48		marble
49		quartzite
50		metamorphic rocks, undifferentiated

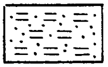
3. Examples of combined types

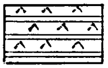

1+4

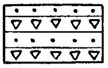

2+4+5

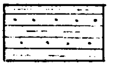

1+30

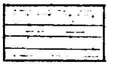

4+9

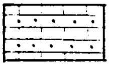

4+7

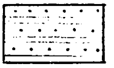

26+31

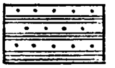

21+40

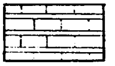

20+21


20+23


21+23


21+26


21+45


23+26


23+45

Distinction between different geological formations may be made by varying the size of the ornament.

D <u>Representation of detailed data</u>

Signs are printed in several colours grouped as shown below:

1. <u>violet:</u> groundwater and springs

2. <u>orange:</u> groundwater quality and temperature

3. <u>blue:</u> surface water and karst hydrography

4. <u>red:</u> man made features and alterations of the natural groundwater regime

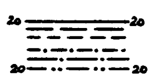
5. <u>dark green:</u> horizon contours (isopachytes) and limits of certain features, such as permafrost

6. <u>black:</u> geological information

Detailed examples of internationally used colour charts* are given in brackets to standardize the colours.

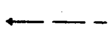
1 <u>Groundwater and springs</u>

Colour: violet (ITC No. 062, RCC)

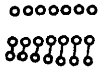


1.1 Contours of the potentiometric surface (solid or broken lines with height relative to reference level)

1.2 Direction of groundwater flow

a)
b) 

1.3 Connection between karstic loss and resurgence a) proven, b) inferred

a) ooooooo
b) 

1.4 Groundwater divide a) stationary, b) periodically changing

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*) ITC Colour Chart (1982), ITC Journal 1982-2, Enschede
Rock Colour Chart(1963), Geological Society of America, N.Y.

1.5 Limit of area with confined groundwater

1.6 Limit of area of artesian flow

1.7 Lens of fresh water surrounded by salt water

1.8 Limit of area with insignificant natural replenishment to the groundwater (50% screen colour)

average discharge of a) less than 100 l/s
b) 100 - 1000 l/s,
c) more than 1000 l/s

a) b) c)

1.10 Spring
1.11 Perennial karst spring
1.12 Submarine spring
} Fresh water

1.13 Spring
1.14 Perennial karst spring
1.15 Submarine spring
} Brackish water

1.16 Group of springs (relevant symbols are enclosed of circles)

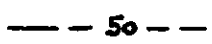
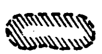
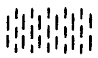
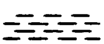
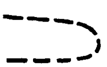
1.17 Temporary karst spring (large: 0 - less than 1 m^3/s, small: 0 - more than 1 m^3/s)

.... 1.18 Line of springs

1.19 Groundwater seepage area

2 Groundwater quality and temperature

Colour: orange (ITC No. 650, RCC)

	2.1	Boundary of saline groundwater in an aquifer
	2.2	Isolines of equal groundwater salinity
	2.3	Contours of the interface between fresh and saline groundwater, in m below reference level
	2.4	Area of sea water intrusion
	2.5	Limit of mineralization of shallow groundwater inland
	2.6	Area of mineralized groundwater inland
	2.7	Area with mineralized water overlying fresh groundwater
	2.8	Limit of continental mineralization
	2.9	Stream with mineralized water (blue stream with orange band)
	2.10	Lagoon or lake with saline or brackish water (blue shore line with orange band inside)
	2.11	Periodical salt-water lake (broken blue shore line with orange band inside)
	2.12	Shotts (playas) with epidosical water (dotted blue shore line with orange band inside)

2.13	Salt marsh	
2.14	Limit of formations containing minerals susceptible for groundwater quality deterioration (grey line with orange band)	
cf. 1.13	Spring	Brackish water (circles in violet, centres in orange)
cf. 1.14	Perennial karst spring	
cf. 1.15	Submarine spring	
2.15	Cold mineral spring	
2.16	Thermomineral spring	
2.17	Thermal spring	
2.18	Area of increased geothermal heat	
2.19	Meltwater chamber beneath glacier	
2.20	Glacier burst from meltwater chamber beneath glacier	

3 Surface water and karst hydrography

Colour: blue (ITC No. 006, RCC No)

3.1 Stream with perennial runoff

3.2 Stream with intermittent runoff

3.3 Dry valley, possibly with episodical runoff (ephemeral stream)

3.4 Sander

3.5 Stream ending in inland depression

cf. 2.9 Stream with mineralized water (blue stream with orange band)

3.7 Karstic loss in river valley

a) a) perennial flow downstream

b) b) seasonal flow downstream

c) c) no flow downstream

3.8 Aven

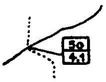
3.9 Doline filled with water

3.10 Dry doline

3.11 Limit of karst area

3.12 Main surface water divide

3.13 Secondary water divide

 3.14 Flow gauging station

$$\frac{\text{mean annual runoff}\,[m^3/s]}{\text{catchment area}\,[.\ 1000\ km^2]}$$

 3.15 Glacier

 3.16 Glacier burst from ice dammed lake

 3.17 Waterfall

 3.18 Fresh water lake

 cf. 2.10 Lagoon or lake with mineralized water (blue shore line with orange band inside)

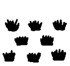
 cf. 2.11 Periodical salt-water lake (broken blue shore line with orange band inside)

 cf. 2.12 Shotts (playas) with episodical water (dotted blue shore line with orange band inside)

 3.19 Periodical fresh water lake

 3.20 Dry lake with only episodical water

 3.21 River marsh

 3.22 Bog

4 Man made features and alterations of the natural groundwater regime

Colour: red (ITC No. 660, RCC No.   )

4.1 Well, shaft or borehole, with phreatic or confined groundwater

4.2 Group of wells or boreholes, with phreatic or confined groundwater

4.3 Well or borehole, artesian flowing

4.4 Group of wells or boreholes, artesian flowing

4.5 Mineral water well

4.6 Thermomineral water well

4.7 Thermal water well

4.8 Injection well

average quantity of discharge or pumping (categories at the discretion of the author, e.g.

a) 3 - 30 million m^3/year

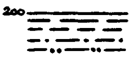
b) 30 - 300 " " "

c) more than 300 million m^3/year)

a) b) c)		
	4.9	Pumping station, pumped well
	4.10	Pumping station from spring (red square with violet dot inside)
	4.11	River intake
	4.12	Pipeline
	4.13	Aqueduct
	4.14	Storage reservoir or pond
	4.15	Dam or weir, with capacity of the reservoir in million m^3
	4.16	Levee or coastal dike
	4.17	Flood-tide barrage or tidal power plant
	4.18	Groundwater recharge site
	4.19	Installation for desalination
	4.20	Oasis cultivation
	4.21	Limit of area of intensive groundwater exploitation
	4.22	Area of underground mining effecting the natural groundwater regime
	4.23	Area of open cast mining effecting the natural groundwater regime

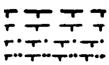
5 <u>Horizon contours (isopachytes) and limits of certain features, such as permafrost</u>

Colour: dark green (ITC No. 606, RCC No.)

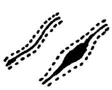


5.1 Horizon contours or isopachytes (solid or broken lines with depth in m relative to reference level)

30 5.2 Thickness of aquifer in m



5.3 Limit of permafrost area (variation of broken lines for continuous, discontinuous and isolated distribution)



5.4 Talik (unfrozen zone) under a river, lake or reservoir (river or lake in blue, green dots surrounding)

6 Geological information

Colour: black

6.1 Geological or hydrogeological boundary

6.2 Fault, certain (solid line) or inferred (broken line)

6.3 Overthrust, certain or inferred

6.4 Boundary of infilled erosional channel

6.5 Fractured belt of hydrogeological importance

cf. 2.14 Limit of formations containing minerals susceptible for groundwater quality deterioration (grey line with orange band)

6.6 Salt plug (diapir)

a) near surface,

b) at depth (dotted line)

6.7 Area and edge of solution chambers formed in salinar formations (subrosion)

6.8 Volcanic cone

6.9 Volcanic crater

6.10 Line of cross-section

E Stratigraphic symbols

Simple stratigraphic symbols are printed in black.

They help to identify the unit which is represented on the map, whenever it is not characterized unequivocally by the combination of areal colour and screen. With the knowledge of the stratigraphy, the map reader can recognize the geological structures in an easier way.

It is recommended to use the stratigraphic symbols according to the general legend of the "International Geological Map of Europe and the Mediterranean Region 1 : 1 500 000, Hannover 1962" for areas built up of sedimentary strata. In magmatic and metamorphic areas, however, the age determination is often problematically. It is, therefore, up to the author to decide whether or not it is necessary to present stratigraphic symbols in those areas, since the combination of areal colour and screen is often sufficient.

Note: Stratigraphic symbols are to be used sparingly on hydrogeological maps. The representation of hydrogeological features is in any case predominant.

List of stratigraphic symbols

Symbol		Name	Era
q	-	Quaternary undifferentiated	q+m-Cenozoic
qh	-	Holocene	
qp	-	Pleistocene	
m	-	Tertiary undifferentiated	
m4	-	Pliocene	
m3	-	Miocene	
m2	-	Oligocene	
m1	-	Eocene and Paleocene	
c	-	Cretaceous undifferentiated	ms-Mesozoic
c2	-	Upper Cretaceous	
c1	-	Lower Cretaceous	
j	-	Jurassic undifferentiated	
j3	-	Upper Jurassic	
j2	-	Middle Jurassic	
j1	-	Lower Jurassic	
t	-	Triassic undifferentiated	
t3	-	Upper Triassic	
t2	-	Middle Triassic	
t1	-	Lower Triassic	

p	-	Permian undifferentiated	pl-Paleozoic
p2	-	Upper Permian	
p1	-	Lower Permian	
h	-	Carboniferous undifferentiated	
h2	-	Upper Carboniferous	
h1	-	Lower Carboniferous	
d	-	Devonian undifferentiated	
d3	-	Upper Devonian	
d2	-	Middle Devonian	
d1	-	Lower Devonian	
s	-	Silurian	
o	-	Ordovician	
cb	-	Cambrian	
eo	-	Eocambrian	
pr	-	Pre-Cambrian	

F Climatology

Maps showing climatological features, e.g. precipitation, evaporation, temperature or other climatological features, should be presented separately from the hydrogeological map, either as an insert map on the main map or as figures in an accompanying explanatory text.

G **Vertical cross-sections**

It is standard practice to illustrate the geology and hydrogeology at depth by the use of vertical cross-sections. These sections may be printed upon the margin of the map, or alternatively within an accompanying explanatory text.

The lines along which the sections are drawn should be clearly indicated by lines printed in black upon the map. The significance of these lines should be clearly explained in the sheet legend and labelled, also in black, with the number identifying the particular section.

The horizontal scale of the cross-section should generally be the same as that of the map. The vertical scale is often exaggerated; however, the vertical exaggeration should be limited to that necessary to illustrate the required detail since over-exaggeration, expecially upon large scales, may present a grossly misleading picture.

The lines, symbols and ornament used upon the cross-section should be the same as those used upon the map.

The end-points of each section, together with any point of importance along the section, should have their locations specified, preferably by the use of grid references. A bar-scale of altitude (vertical scale) at each end of the section is compulsory.

4. SELECTED LIST OF HYDROGEOLOGICAL MAPS

A. International and Continental Hydrogeological Maps

Groundwater in Africa, 1:17,000,000, New York 1973.

Hydrogeological Map of South America, 1:2,500,000, Rio de Janeiro, in preparation.

International Hydrogeological Map of Europe 1:1,500,000, IAH/Unesco/BGR, Hannover/Paris, 1970 - .

Water Resources Map of the Arab Countries 1:1,000,000, ACSAD, Damascus, in preparation.

B. National Hydrogeological Maps

AFRICA

Algeria

Cartes hydrogéologiques, 1:200,000 et 1:1,000,000, several sheets, Alger, 1973 - .

Botswana

Hydrogeological Reconnaissance Map, 1:500,000, 11 sheets, Lobatse, 1979 - .

Chad

Carte hydrogéologique, 1:500,000, 1972.

Ghana

Carte hydrogéologique, 1:1,000,000, 1972.

Ethiopia

Hydrogeological Map, 1:250,000, in preparation.

Madagascar

Hydrogeological Map, 1:500,000, 1972.

Marocco

Cartes hydrogéologiques, 1:200,000, 1:500,000 et 1:1,000,000, Rabat, 1960 - .

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The increasing worldwide demand for water makes it imperative that hydrogeological maps are available as a basic tool for assessing, managing and conserving groundwater resources in both industrialized and developing countries. There has been a considerable increase in hydrogeological mapping over the last two decades, mainly due to the support this subject has received from international organisations.

The ESCAP-RMRDC Workshop on Hydrogeological Mapping in Asia and the Pacific Region was the first of this kind involving the whole ESCAP region. It was intended to be a review of achievements as well as a source of information on different subjects.

The Proceedings of the workshop include reports from 21 countries, 6 general papers, 3 reports of ad hoc working groups, a list of published maps and the revised version (1983) of the International Legend for Hydrogeological Maps (IAH, IAHS, UNESCO). The wealth of information presented in this volume will be of value to water resources specialists both within the ESCAP region and elsewhere.

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