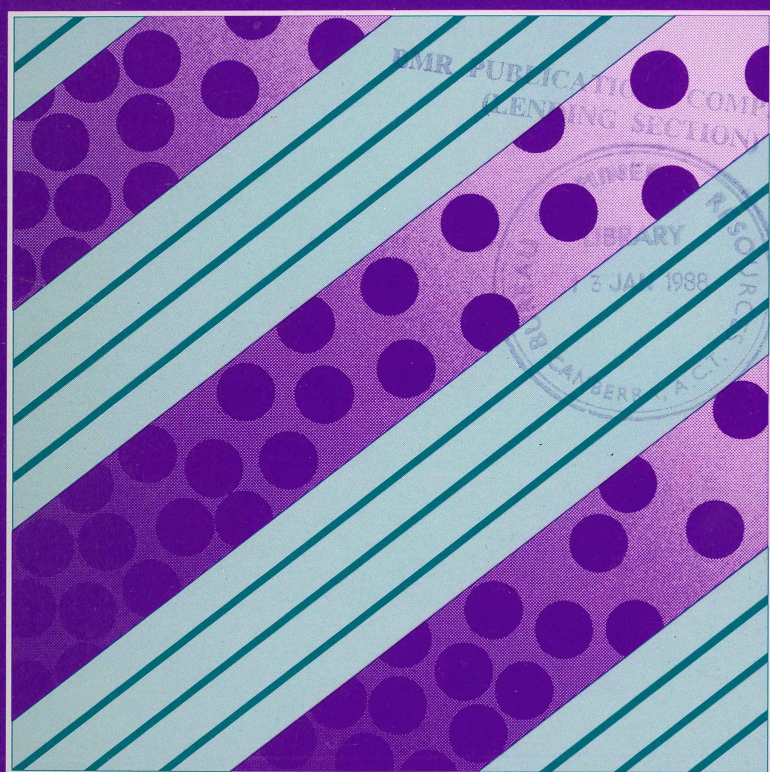
GROUNDWATER 8

Studies in Hydrogeology

AUSTRALIAN HYDROGEOLOGICAL MAPS — A DISCUSSION PAPER

G. JACOBSON, J. E. LAU, D. P. COMMANDER



BUREAU OF MINERAL RESOURCES,
GEOLOGY & GEOPHYSICS

DIVISION OF CONTINENTAL GEOLOGY

RECORD 1987/19

DEPARTMENT OF RESOURCES AND ENERGY
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS
DIVISION OF CONTINENTAL GEOLOGY

RECORD 1987/19

AUSTRALIAN HYDROGEOLOGICAL MAPS

-A DISCUSSION PAPER

by

G. JACOBSON, J.E. LAU, D.P. COMMANDER*

(*Geological Survey of Western Australia)

FOREWORD

In recent years there has been a significant increase in the level of interest in Australia in hydrogeological maps. However, only a limited number of such maps have appeared as yet and there are currently no agreed guidelines for legends. It was for this reason that the Groundwater Committee of the Australian Water Resources Council established a Working Group to develop guidelines, bearing in mind recent developments in computer-assisted cartography. The authors of this report were members of that Working Group.

A definitive set of guidelines has yet to be accepted by the Groundwater Committee. This report is produced as a contribution to the debate on hydrogeological maps and the depiction of data on such maps.

Peter J. Cook
Chief
Division of Continental Geology

CONTENTS

Figures

ABSTRACT

The development of hydrogeological mapping programmes in Australia requires some standardisation of style and symbolisation. A salinity/yield classification, has been the main feature of several published Australian maps aimed at communicating groundwater resources information to the public. However flexibility of approach is needed for more general hydrogeological maps, and an aquifer type/yield classification based on the International Legend is suggested. The use of computer graphics systems facilitates map compilation and editing, and adds a fourth dimension - the ability to update maps with time.

INTRODUCTION

Increasing awareness of groundwater throughout Australia has produced a demand for a knowledge of groundwater conditions for water supply, and for environmental planning, civil engineering, agricultural and pastoral activity. A basic understanding of groundwater conditions can be provided by hydrogeological maps. These also allow rapid evaluation of the hydrogeology of an area and fulfill a need for the dissemination of data. Their preparation may more readily expose deficiencies in data, which will stimulate further investigation.

The inception of hydrogeological mapping by State and Commonwealth authorities has given rise to a need for uniformity of approach. This report seeks to formulate guidelines for hydrogeological mapping using recent experience in compilation of a national hydrogeological map (Jacobson & Lau, 1987); State groundwater resources maps (Shepherd 1982; Nahm 1982); regional hydrogeological maps (Lakey & Tickell, 1980; Evans, 1984; Tickell & Humphrys, 1985; Ross & others, 1986;) and BMR's pilot project for national groundwater resources assessment (Kalf, 1985). The latter project is based on the compilation of hydrogeological maps using computer-assisted cartography.

Preliminary guidelines were drafted at a meeting of the Working Group on Hydrogeological Mapping, of the Groundwater Committee of the Australian Water Resources Council, held in Canberra in May 1985. In this paper, we have developed the guidelines to take into account the different styles of hydrogeological mapping current in Australia and to allow for the flexibility needed in mapping programmes.

AUSTRALIAN GROUNDWATER MAPS AND LEGENDS

The first coloured groundwater map published in Australia was the groundwater salinity map of Australia at 1:5 000 000 produced for the 1963 review of Australia's water resources (AWRC, 1965). This map distinguished five salinity classes in separate colours, and used full colour for porous rocks (sedimentary basins), dots for unconcolidated rocks and lines for fractured rocks. This legend was further refined for the series of maps produced in 1975 (AWRC, 1975), in which tones were introduced for two salinity classes to distinguish different yields and waters with high sodium hazards. Separate maps were used for the unconsolidated sediments, sedimentary rocks, and fractured rocks and this information was combined on a map of principal groundwater resources. State groundwater resources maps using this format have been produced for Queensland (Laycock & Wecker, 1961), Victoria (Nahm, 1982), and South Australia (Shepherd, 1982). Larger scale maps using a slightly different salinity-yield colour matrix, and carrying other hydrogeological data have been published in Victoria (Lakey & Tickell, 1980; Tickell & Humphreys, 1985) and in the Australian Capital Territory (Evans, 1984).

The first coloured hydrogeological map to emphasise rock units as groundwater flow systems was the Forbes 1:250 000 sheet published by the Water Resources Commission of NSW (Ross & others, 1986). This used a modification of the International Legend (Figs 1 and 2) whereby unconsolidated sediments are distinguished by a separate colour (yellow) to make the map compatible with the rock divisions used in the AWRC reviews. A simplified form of the International Legend has also been used on the 1:5 000 000 national hydrogeological map (Jacobson & Lau, 1987).

Table 1 lists the hydrogeological maps recently published in Australia.

Table 1 - Australian Hydrogeological Maps

Map	Scale	Aquifer Mapped	Parameter shown in solid colour	Purpose of map	Reference
Australia (Hydrogeology)	1:5 m	Principal	Aquifer type*	Groundwater resources	Jacobson & Lau, 1987
Forbes, N.S.W.	1:250 000	Principal	Aquifer type/yield	Groundwater resources	Ross, Williams & Woolley, 1986
Bendigo, Vic	1:250 000	Top	Salinity/yield	Salinity hazard	Tickell & Humphrys, 1985
A.C.T.	1:100 000	Principal	Salinity/yield	Groundwater resources	Evans, 1984
Victoria	1:1 m	Principal	Salinity*	Groundwater resources	Nahm, 1982
South Australia	1:2 m	Principal	Salinity*	Groundwater resources	Shepherd, 1982
Western Port,Vic	1:100 000	Principal	Salinity/yield	Groundwater management	Lakey & Tickell, 1980
Australia (Principal Groundwater Resources)	1:5 m	Principal	Salinity*	Groundwater resources	AWRC, 1975
Queensland	1:2.5 m	Two	Salinity	Groundwater resources	Laycock & Wecker 1971

*Limited information on yield

Engineering and environmental geology maps have also included information on groundwater. The 1:50 000 series covering the Perth metropolitan area published by the Geological Survey of Western Australia includes contours of depth to the water table, water table salinity, the positions of bores and selected well logs.

MAP PREPARATION

Types of Maps

Hydrogeological maps show the physical states of groundwater within a geological frame; other groundwater maps show physical and chemical characteristics (Day, 1983). A broader definition divides hydrogeological maps into general maps and special purpose maps (Struckmeier, 1985). Table 2 shows the relationship of these types of hydrogeological map to stages of groundwater development.

The "general" map presents the hydrogeological environment and groundwater regime in a geological framework, and its aim is to integrate all the hydrogeological and geological information as a legible synoptic picture. The general map emphasises all the features which are necessary to understand the hydrogeological setting of the mapped area and is essentially synthetic in character. The representation of coherent hydrogeological units is a most valuable feature.

The "special" map emphasises a particular aspect or combination of aspects, such as groundwater resources, aquifer systems, hydrochemistry, vulnerability to pollution, or geothermal resources. Special maps also include single parameter maps showing salinity, yield, abstraction, transmissivity, and depth to water table.

General maps may require some familiarity on the part of the user with hydrogeological concepts and practices, whereas special maps can be directed at the non-technical user.

Table 2: Hydrogeological maps and other representation: relationship to stages of groundwater development (after Struckmeier, 1985)

	Reconnaissance Coherent representation of available data on a topographic base	Planning Semi-quantitative determination and representation of data relevant for the project quantity and quality	Management Exact quantitative assessment of available water resources (surface and groundwater),
Hydrogeological maps (various scales)	General hydrogeological map (project map)	Special hydrogeological map (parameter map)	Detailed
Representation of groundwater dynamics	Regional groundwater systems represented on maps and sections	Sub-regional groundwater systems on maps and sections	Local groundwater systems on maps and sections
3D-groundwater models	Conceptual groundwater model	Semi-quantitative groundwater model	Quantitative model, time and space variable

(large)	<————	Area of representation	————> (small)
(small)	<————	Amount of data per area	————> (large)
(low)	<————	Reliability	————> (high)
(low)	<————	Cost per unit area	————> (high)
(small)	<————	Scale	————> (large)

A map and section provide the best impression of a hydrogeological environment, but it is a simplified model of the facts, and the complexity can never entirely be represented. The degree of simplification depends mainly on the purpose and scale of the map, the relative importance of specific parameters, the accuracy of the information and on the techniques of representation used (UNESCO, 1976).

Purpose

A hydrogeological map aims to give a basic understanding of the hydrogeological conditions in a particular area. Such an understanding may have important and far reaching consequences - generating decisions with respect to water resource management and utilisation, land use planning, waste disposal management, civil engineering and environmental matters, and basic and applied research in environmental and earth sciences (Stein & Toth, 1974). It can help to encourage industrial and agricultural development by providing knowledge of groundwater resources and help to avoid costly errors by discouraging development in areas with insufficient resources, with high potential for pollution or salinisation, or with high potential for sterilization of agricultural land having significant groundwater resources.

Hydrogeological maps can present a clear and easily legible picture of groundwater conditons not only to hydrogeologists and engineers but also to a much broader group of potential map users such as planners, politicians and the interested public. In this way the advantages of a non-verbal delineation can be used to link groundwater specialists with users lacking a technical background, who normally think along different lines.

Maps produced by government agencies can assist the private sector to provide the necessary groundwater orientated services and reduce demand on government. Dissemination of groundwater information in map form will also remedy some of the deficiencies in communication identified in the Water 2000 study (DRE, 1983).

Scale

One of the more difficult decisions to be taken in 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. It also depends on the hydrogeological complexity of the area and the amount of information available. In general, the economies of map production will demand that maps be published on a scale no greater than is essential for the purpose (Bestow, 1985). Where publication is not required, computer graphics systems can enable the manipulation of map scales for particular purposes.

Small scale maps of 1:1 000 000 or less can be useful to depict the broad hydrogeological features of a state or region and to give an overview of hydrogeological conditions and groundwater resources.

A medium scale of 1:250 000 can be used to display summarized aquifer information and the general pattern of groundwater salinity. This scale is particularly important in Australia as there is complete coverage of topographic maps and almost complete coverage of geological maps at this scale. It is also possible in pastoral areas and some agricultural areas to display the distribution of boreholes at this scale.

Large scale maps of 1:100 000 or greater are usually confined to areas of high development potential and bore density. Such maps are useful for detailed water supply planning and management, and for the solving of site specific problems - either the determination of groundwater conditions at a specific site or the location of a site with particular groundwater conditions.

The terms 'large', 'medium', and 'small' scale, however, mean different things to different users, and the question as to whether a map can solve a site-specific problem is more a function of the hydrogeological complexity than the scale.

Compilation

Hydrogeological maps cannot be produced without basic data and the collation and evaluation of relevant existing information is a necessary preliminary to the implementation of a mapping programme (Day, 1985).

A data base is a prerequisite for the compilation of medium or large scale hydrogeological maps. The data base must contain details of bore locations, aquifers intersected, water levels, water quality and yields. The data base may be in the form of a card index or, increasingly, in digital form. Where an existing data base is insufficient, a field survey will have to be carried out to provide the required spread of data, depending on the scale and purpose of the map. Ideally the map compiler should have some familiarity with the area and with the collection of field data. It is often convenient to compile the data as single parameter maps which can then be combined with a geological base to form a hydrogeological map.

Bore locations on a graphics system may also be linked directly to a digital data base. With the use of a computer graphics facility, such as the Intergraph system used in the hydrogeological mapping pilot program (AGC, 1986) and in the production of the 1:5 000 000 national hydrogeological Map of Australia (Jacobson and Lau, 1987), these single parameter maps can be compiled in separate layers, then printed off in various combinations as required.

Advantages of the computer graphics (CAD-CAM) systems are the ability for interactive editing and the facility for obtaining proof plots of various combinations of parameters. Emphasis can easily be changed by varying line weights and symbolisation. Maps can readily be produced as fairdrawn ready for scribing and colour printing or can be distributed as black and white or coloured overlays.

The graphics system is also potentially useful in areas of intensive groundwater use or where new information necessitates updating portions of the map. The map becomes a method of depicting the groundwater data base, and segments or levels of information can be extracted for modelling or analysis as required.

Cartographic Representation

Some hydrogeological maps published overseas have suffered from overloading with hydrogeological data to the point of being unreadable even by specialists. The skill of a map maker lies in showing as much as possible of the available information while maintaining clarity.

The representation of multi-aquifer systems is a particular problem with hydrogeological maps where only a single sheet can be published. The decision must be made as to which aquifer is to be shown on the map face according to the purpose of the map. The concept of 'principal aquifer' used on the groundwater resources maps of Australia (AWRC, 1975) has been retained on the national hydrogeological map (Jacobson & Lau, 1987) where it has been defined as the aquifer which produces the best quality water at highest yield from the shallowest depth. However this concept does not show aquifer systems well because 'principal aquifer' boundaries are arbitrary and often cut across groundwater systems.

The International Legend (UNESCO, 1983) allows for the representation of potentiometric head, salinity and structure contours of concealed aquifers by means of dashed or dotted lines.

Cross-Sections

Cross-sections are essential to any hydrogeological map of layered aquifers. They should clearly show vertical aquifer relationships, especially the relationship of the main aquifer shown on the map to subsidiary overlying or underlying aquifers.
The horizontal scale of the cross-section should generally be the same as that of the map, although it may be appropriate to use larger scale cross-sections of major aquifers which constitute only a small proportion of the area. The vertical exaggeration should be clearly labelled, since over-exaggeration may present a misleading picture of aquifer geometry and hydrodynamics. A bar scale of altitude (vertical scale) at each end of the section is necessary. 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, and the labelled section lines printed in black upon the map face.

The lines, symbols and ornaments used on the cross-section should be the same as those used upon the map.

Lines of individual well sections may also be used, or details of typical or index wells given in the map surrounds.

Diagrammatic cross-sections and block diagrams illustrating aspects of the hydrogeology can be shown on the map surrounds or in accompanying explanatory notes.

Explanatory Notes

Explanatory notes are a desirable adjunct to a hydrogeological map although to be effective the map must stand on its own without notes. Small scale maps produced for educational and overview purposes (ie national and state maps) may suffice with annotated legends on the face of the map, but it is frequently desirable to accompany hydrogeological maps with explanatory notes in booklet form. The booklet form is preferable for reasons of easy perusal and reference as a published work.

Where possible, compilation of explanatory notes should be an integral part of the compilation of a map since a hydrogeological map is essentially interpretative, and a systematic written description will force more thought about the implications of the map itself. Both explanatory notes and the map can be continually revised as the data are interpreted.

Explanatory notes should include an introduction which describes the geology, physiography, climate, surface hydrology and land use in the area, and a section in which each aquifer is systematically described as to its hydraulic characteristics, the groundwater flow regime, groundwater quality, and the existing and potential development and groundwater resources. Sections on bore siting and construction, salinisation, groundwater pollution and modelling studies may also be appropriate.

Tables can be used to present climatic data, stratigraphic columns or selected bore logs, typical chemical analyses, bore data and statistical information on yields. Diagrams can be used to show correlations between bores, graphical representations of chemical analyses, and representative hydrographs.

Subsidiary maps may be included in the explanatory notes or on the face of the map. Suggested themes are aquifer systems and groundwater province boundaries, surface hydrology and drainage basins, climatic parameters, reliability of data and borehole distribution; and various measured and derived hydraulic parameters such as isopachs, abstraction, transmissivity and recharge.

A reference list or bibliography of relevant publications should be included. Microfiche may be used to provide additional bore data such as strata logs, graphic logs, chemical analyses and bore location plans where bores are not shown on the map face. An annotated bibliography with abstracts or keywords could be included if available from an information data base.

LEGENDS

Selection of appropriate legend

Selection of an appropriate map legend depends on the purpose of the map and to a lesser extent on the scale and available information. Full colour is the most outstanding feature on the map face and should be used to highlight the most important aspects of the map.

Groundwater salinity and aquifer yield are important parameters in the Australian groundwater setting, and several Australian maps have used a salinity/yield matrix to emphasise these parameters. Some published Australian maps emphasising aquifers and non-aquifers have used the International Legend or a modified form of the International Legend (Ross & others, 1986; Jacobson & Lau, 1987).

Future development and standardization of colour schemes may be required for maps showing aquifer systems (BRGM, 1980), hydrochemistry (UNESCO, 1975), vulnerability to pollution, and other parameters (UNESCO & WMO, 1977).

Salinity/yield classification

The salinity/yield colour matrix is recommended for the purposes of communicating groundwater resources information to the general public or in areas where salinity is a particular concern. A considerable level of information is required for development of these maps (Fig. 3).

The recommended salinity categories to be used are related to potential water use and follow those adopted for the 1963 and 1975 reviews of Australia's groundwater resources (AWRC, 1965; 1976).

Additional classes for salinity of 0-500, 500-1000 and 1000-1500 mg/L have been added to the previous classes of 0-1000 and 1000-3000 mg/L, because of the need to represent drinking water standards. At the high salinity end of the scale, classes for 14000-35000, 35000-100 000 and >100 000 mg/L have been added to enable subdivision in areas where brines are important. Each salinity class should be represented by a distinct colour (Fig. 3).

TABLE 3: RECOMMENDED SALINITY CATEGORIES

SALINITY (mg/L TDS)	DESCRIPTION	POTENTIAL USE
>500	Fresh	All purposes, domestic and irrigation
500-1000	Marginal	Most purposes
1000-1500	Brackish	Most purposes, upper limit for drinking
1500-3000	Brackish	Limited irrigation, all livestock
3000-7000	Saline	Most livestock
7000-14000	Saline	Some livestock
14000-35000	Saline	Limited industrial use, ore processing
35000-100 000	Hypersaline	Limited industrial use, ore processing
>100 000	Brine	Brine production, ore processing

Salinity is usually expressed as mg/L total dissolved solids, and is derived by chemical analysis, evaporation to dryness or from the electrical conductivity. Where differences between reporting methods are significant, it may be appropriate to specify the derivation.

The terms 'fresh', 'marginal', 'brackish' and 'saline' have been used in Australia (AWRC, 1975) to refer to the salinity categories in Table 1, but these terms are used in a different sense elsewhere in the world (UNESCO, 1978). The term 'brackish' in particular is often used to refer to salinities up to 10,000 mg/L.

The recommended yield categories are `0.5, 0.5-5, 5-10 and >50 litres/second (L/s). Each yield category should be represented by a tone of colour used to represent salinity (Fig. 5).

Aquifer type/yield classification

A fourfold classification of aquifers and non-aquifers in full colour has been adopted for general hydrogeological maps to be produced in Western Australia (Fig. 2). This style of map is likely to be of particular use in regions of complex or little-known hydrogeology, or sparse bore data. The International Legend (UNESCO, 1983) uses a threefold subdivision into porous aquifers (blue), fissured aquifers (green) and areas of limited groundwater resources (brown) (Fig. 1). In order to conform more closely with the classifications used in the assessment of groundwater resources in Australia (AWRC, 1965, 1976), surficial, alluvial and coastal plain aquifers can be shown in yellow to distinguish them from aquifers in sedimentary basins (blue).

Tones are used to represent yield subdivisions in each of the aquifer classes. Suggested yield subdivisions are given in Figure 2. A statistical approach towards aquifer yields similar to that of the 1:5 000 000 national hydrogeological map (Jacobson & Lau, 1987) could be used. There is considerable flexibility especially with lower yielding rocks as to whether they should be shown as aquifers, in yellow, blue or green, or as non-aquifers, in brown. This will depend on the relative importance in a particular area.

Brown stripes can be used to indicate that an aquifer is overlain by a confining bed to or by a non-aquifer.

SYMBOLS, LINES AND ORNAMENTS

Common to all groundwater maps are symbols, lines and ornaments (see Appendix 1 for definitions). Recommended colours for these are shown in Table 4 and are described in detail below. These are based on the International Legend for Hydrogeological maps (UNESCO, 1970, 1983).

TABLE 4: COLOURS FOR SYMBOLS. LINES AND ORNAMENT

COLOUR	FEATURE
Grey or black	Background information, geographical detail
Gray or black	Geology, lithology ornament
Blue	Surface hydrology
Violet	Potentiometry and groundwater flow
Orange	Groundwater quality and temperature
Red	Man-made features, boreholes, alteration to groundwater regime
Dark green	Structure contours, isopachs, subsidiary aquifer boundaries

Background information

Background information comprising geographic detail such as major roads, railways and towns and topographic contours on medium to large scale maps is shown in grey or screened black. Lines of latitude and longitude and, on medium or large scale maps, lines of the Australian Map Grid should also be shown.

Background information should be subdued so as to highlight hydrogeological data and should be as up to date as possible.

Geological, lithological and stratigraphic information

Lithology is indicated by a grey ornament which is a graphical representation of the strata or rock type (Fig. 4). Symbols indicating the goelogical structure (Fig. 5) are shown in black. Both ornaments, symbols and stratigraphic symbols (Fig. 6) should conform to established Australian practice (BMR, 1974, 1978) but may be varied slightly for cartographic clarity.

The reference should clearly explain whether the ornaments and symbols refer to outcropping or to concealed or partially concealed aquifers.

Representation of detailed data

Surface Hydrology

Surface hydrological features are shown in blue. A list of standard symbols is given in Figure 7. Perennial streams and lakes are defined as those which register flow at least nine years out of ten.

Potentiometry and groundwater flow

Hydrodynamic features are shown in violet (Fig. 8). Potentiometric contours should be shown wherever data are available, depending also on the scale and purpose of the map.

Groundwater quality and temperature

Features relating to groundwater quality and temperature are shown in orange (Fig. 9). On aquifer type/yield maps, groundwater salinity may be shown by isohalines in aquifers where the salinity distribution is systematic and directly related to groundwater flow systems. The concentrations shown in Table 1 should be used on isohalines but in addition intermediate isohalines such as 250 mg/L and 5000 mg/L may be used where appropriate for illustrating the salinity pattern.

Where the groundwater salinity variations are complex it may be more appropriate to use areal shading of the salinity ranges shown in Table 1. This is recommended to be done by means of orange hatching on general hydrogeological maps (aquifer/type yield). The hatching should increase in intensity with increasing salinity (see Cuff & Mattson, 1982, for discussion of choropleth maps).

Man-made features

Man-made features and alterations of the groundwater regime are shown in red Figure 10 . More detailed classification of bores and wells may be necessary for larger scale hydrogeological maps, and a range of additional symbols is available if required (e.g. Qureshi, 1985). Where scale permits, bores used as data points should be shown on the map face to permit reinterpretation and updating.

Horizon contours

Horizon contours, isopachs, subsidiary aquifers and other concealed geological or hydrogeological features may be shown in dark green (Fig. 11).

REFERENCES

AGC, 1986 - Hydrogeological mapping pilot program - Ballarat 1:250 000 explanatory notes. Australian Groundwater Consultants Pty Ltd Report for Bureau of Mineral Resources, Australia.

AWRC, 1965 - Review of Australia's water resources, 1963. Australian Water Resources Council, Canberra.

AWRC, 1975 - Groundwater resources of Australia. Australian Water Resources Council, Canberra.

AWRC, 1976 - Review of Australia's water resources, 1975. Australian Water Resources Council, Canberra.

BESTOW, T.T., 1985 - The organization of hydrogeological mapping programmes. In Proceedings, United Nations Workshop on Hydrogeological Mapping, Bandung, 1985. International Contributions to Hydrogeology, 293-300.

BMR, 1975 - Australia: standard colour scheme and stratigraphic symbols for geological maps. Bureau of Mineral Resources, Australia.

BMR, 1978 - Symbols used on geological maps. Bureau of Mineral Resources, Australia.

BRGM, 1980 - Carte hydrogeologique de la France - systemes aquiferes. Bureau de Recherches Geologiques et Minieres, Orleans.

CUFF, D.J. & MATTSON, M.T., 1982 - Thematic maps - their design and production. Methuen, New York.

DAY, J.B.W., 1983 - The role of hydrogeological maps in groundwater resource evaluation and development. In Papers, International Conference on Groundwater and Man, Sydney, 1983. Australian Water Resources Council, Conference Series, 8, 1, 51-68.

DRE, 1983 - WATER 2000 - A perspective on Australia's water resources to the year 2000. Department of Resources and Energy, Australia, Canberra.

EVANS, W.R., 1984 - Hydrogeology of the Australian Capital Territory and environs (1:100 000 scale map). Bureau of Mineral Resources, Australia.

JACOBSON, G. & LAU, J.E., 1987 - Hydrogeology of Australia (1:5 000 000 scale map). Bureau of Mineral Resources, Australia.

KALF, F.R., 1985 - National groundwater data base inventory. Australian Groundwater Consultants Pty Ltd. Report for Bureau of Mineral Resources, Australia.

LAKEY, R. & TICKELL, S.J., 1980 - Hydrogeological map of Western Port Basin (1:100 000 scale map). Geological Survey of Victoria, Melbourne.

LAYCOCK, J.W. & WECKER, H.R.B., 1971 - Groundwater resources of Queensland (1:2 500 000 scale map). Geological Survey of Queensland and Irrigation and Water Supply Commission, Brisbane.

NAHM, G.Y., 1982 - Groundwater resources of Victoria (1:1 000 000 scale map). Geological Survey of Victoria, Melbourne.

QURESHI, H., 1985 - Guidelines for symbols on hydrogeological maps. Water Resources Division, Northern Territory Department of Mines & Energy, Report.

ROSS, J.B., WILLIAMS, R.M. & WOOLLEY, D.R., 1986 - Forbes hydrogeological map (1:250 000 scale map). Water Resources Commission of New South Wales, Hydrogeological Series, Sheet. SI 55-7.

SHEPHERD, R.G., 1982 - Groundwater resource map, South Australia (1:2 000 000 scale map). Geological Survey of South Australia, Adelaide.

STEIN, R. & TOTH, J., 1974 - The hydrogeological maps of Alberta: rationale and use. Alberta Research Council, Edmonton.

STRUCKMEIER, W., 1985 - The international legend for hydrogeological maps - principles and application. In Proceedings, United Nations Workshop on Hydrogeological Mapping, Bandung, 1983. International Contributions to Hydrogeology, 7, 251-261.

TICKELL, S.J. & HUMPHRYS, W.G., 1985 - Hydrogeological map of Bendigo and part of Deniliquin (1:250 000 scale map). Geological Survey of Victoria, Melbourne.

UNESCO, 1970 - International legend for hydrogeological maps. UNESCO, Paris.

UNESCO, 1975 - Legends for geohydrochemical maps. UNESCO, Paris.

UNESCO, 1976 - Engineering geological maps, a guide to their preparation. UNESCO/IAEG, Paris.

UNESCO, 1978 - International glossary of hydrogeology. UNESCO, Paris.

UNESCO, 1983 - International legend for hydrogeological maps. Revised edition. UNESCO, Paris.

UNESCO & WMO, 1977 - Hydrological maps: a contribution to the International Hydrological Decade. UNESCO/WMO, Lausanne, Switzerland.

APPENDIX 1

DEFINITIONS

Certain terms are used rather loosely in both hydrogeology and cartography, and it is easy for misunderstandings to arise. A short list of definitions is here included which refer to the usage in these guidelines.

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 (isopach), or similar parameters.

Colour: a colour refers to an even "wash" of constant tone. It may be used for lines, symbols or ornaments as well as for emphasizing 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.

FIGURE 1

UNESCO aquifer type-yield classification (after UNESCO 1983)

1 INTERGRANULAR AQUIFERS

Ia *Extensive and highly productive aquifers*

Ib *Local or discontinuous productive aquifers, or extensive but only moderately productive aquifers*

2 FISSURED AQUIFERS, INCLUDING KARST AQUIFERS

IIa *Extensive and highly productive aquifers*

IIb *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

IIIa *Strata with local and limited groundwater resources*

IIIb *Strata with essentially no groundwater resources*

IIIc *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*

NOTE *Certain aquifers combine intergranular and fissure characteristics. In such cases the relevant colours described in sections 1 and 2 should be used depending on which characteristic is dominant.*

FIGURE 2

Modified aquifer type-yield classification used for Western Australia and New South Wales hydrogeological maps.

1 UNCONSOLIDATED SEDIMENTS WITH INTERGRANULAR POROSITY

Bore yields > 5 L/s

Bore yields 0.5-5 L/s

Bore yields 0.05-0.5 L/s

Bore yields < 0.05 L/s

2 SEDIMENTARY ROCKS WITH INTERGRANULAR POROSITY

Bore yields > 5 L/s

Bore yields 0.5-5 L/s

Bore yields 0.05-0.5 L/s

3 FISSURED AND KARSTIC ROCKS WITH APPRECIABLE SECONDARY POROSITY

Bore yields > 5 L/s

Bore yields 0.5-5 L/s

Bore yields 0.05-0.5 L/s

4 FRACTURED AND WEATHERED ROCKS WITH LIMITED GROUNDWATER RESOURCES

Undifferentiated suites of rocks containing water-bearing zones which yield up to 0.5 L/s

Rocks with generally very low yields in restricted areas

FIGURE 3

Recommended salinity/yield colour matrix

SALINITY mg/L TDS		BORE YIELD L/s < 0.5	0.5-5	5-50	> 50
PANTONE REFLEX BLUE	< 500	10%	20%	35%	60%
PANTONE PROCESS BLUE	500-1000	10%	20%	40%	70%
PANTONE GREEN	1000-1500	10%	20%	40%	70%
PANTONE 375	1500-3000	15%	30%	60%	SOLID
PANTONE 145	3000-7000	10%	20%	40%	70%
PANTONE 175	7000-14000	10%	20%	35%	60%
PANTONE 165	14000-35000	10%	20%	40%	70%
PANTONE 192	35000-100 000	10%	20%	35%	60%
PANTONE 246	> 100 000	10%	20%	35%	60%

FIGURE 4
Lithology

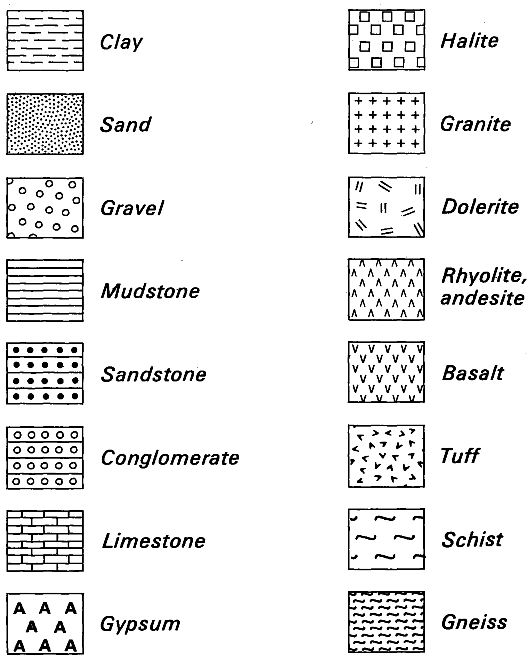
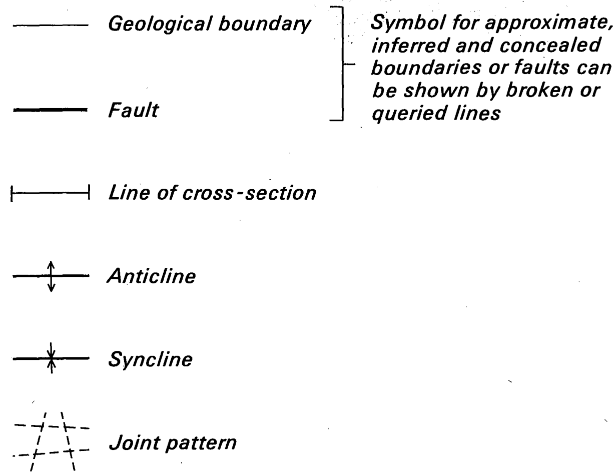


FIGURE 5
Geological information



Other geological symbols as required may be used (see BMR, 1978)

FIGURE 6
Stratigraphic symbols (after BMR 1974)

- **PHANEROZOIC**
  - **CAINOZOIC** Cz
    - QUATERNARY Q
      - Holocene Qh
      - Pleistocene Qp
    - TERTIARY T
      - Pliocene Tp
      - Miocene Tm
      - Oligocene To
      - Eocene Te
      - Paleocene Tl
  - **MESOZOIC** M
    - CRETACEOUS K
    - JURASSIC J
    - TRIASSIC R
  - **PALAEOZOIC** Pz
    - PERMIAN P
    - CARBONIFEROUS C
    - DEVONIAN D
    - SILURIAN S
    - ORDOVICIAN O
    - CAMBRIAN Ꞓ
- **PRECAMBRIAN** p-Ꞓ
  - **PROTEROZOIC** P
  - **ARCHAEAN** A

FIGURE 7
Surface water

- Perennial stream
- Intermittent stream

Discharge may be indicated by line thickness

- Storages, including lakes so used
- Perennial lake
- Intermittent lake
- Swamp
- Surface water divide
- Sinkhole
- 50 / 4.1 — Flow gauging station showing mean annual runoff (m^3/s) / catchment area (1000 km^2)
- Dam

FIGURE 9
Groundwater chemistry and temperature for aquifer type-yield maps

- 500 — Contours of equal groundwater salinity (ticks optional, to point to fresher water)
- -50 — Contours of the interface between fresh and saline groundwater (m below reference level)
- Area of salt water intrusion
- Area with high salinity overlying fresh groundwater
- 10 — Water temperature (°C)

FIGURE 11
Horizon contours and subsidiary aquifers

- 100 — Horizon contours or isopachs (solid or broken lines with depth in m relative to reference level)
- 30 — Thickness of aquifer (m)
- Boundary of subsidiary aquifer
- K — Age of subsidiary aquifer (for stratigraphic symbols see Figure 6)

FIGURE 8
Potentiometry and groundwater flow

- 20 — Contours on the potentiometric surface (m)
- Direction of groundwater flow
- Groundwater divide
- Limit of area with confined groundwater (ticks point toward confined area)
- Limit of area of artesian flow
- Spring
- Group of springs
- Groundwater seepage area
- 640 — Radiometric age of groundwater (thousands of years BP)

FIGURE 10
Man made features and alterations of the natural groundwater regime

- Bore
- Bore with windmill
- Artesian bore
- Bore, abandoned

Bore yield may be indicated by varying size of symbol

- Well
- Pipeline
- Bore drain or irrigation channel
- Storage reservoir
- Groundwater recharge site
- Desalination plant
- Area of underground mining
- Area of open cut mining
- Boundary of groundwater control area
- Liquid waste disposal or landfill site
- Rising water table and salinisation

19-2/9