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GROUNDWATER NOMENCLATURE IN AUSTRALIA

by

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FOREWORD

This paper was originally submitted to the first meeting in April 1964 of the Technical Committee on Underground Water to provide a basis for discussion of groundwater nomenclature, from which may emerge more unified terminology in the investigation of groundwater in Australia.

The wide range of environments and problems facing the several organisations carrying out groundwater investigations in Australia and the lack of regular liaison between them in the past, have resulted in divergence in practice and terminology which makes it difficult to assemble data on groundwater in the continent as a whole. Divergence in terminology warrants special attention because it affects communication between individuals and organisations alike.

The present paper, although produced as a Bureau Record, sets out the terminology preferred by the author, not necessarily by the Bureau, although it has been discussed with other members of the Bureau who are engaged in groundwater studies. Divergence in meaning currently exists both within and between working groups. It is hoped that the distribution of this Record to a wide circle of groundwater geologists and engineers, will encourage criticism and comment, which should be sent to the Secretary, Technical Committee on Underground Water, C/- Bureau of Mineral Resources, Canberra.

SUMMARY

The groundwater terms currently used in Australia, and the meanings assigned to them, are a mixture from two distinct nomenclatures - one proposed by the Interstate Artesian Conference, the other developed overseas from that proposed by Meinzer.

In this paper some groundwater concepts are discussed, and terms and definitions suggested for these concepts. Some further inconsistencies and problems in nomenclature are indicated.

No standard Australian groundwater nomenclature can have wide and continued acceptance unless it is suitable to workers in related fields, is supported by adequate reference books, and is amended as necessary to accommodate advances in groundwater theory.

The appendix lists the definitions preferred by the Author, for aquiclude, aquifer, aquifuge, artesian water, bedrock, capacity, cone of depression, confined groundwater, discharge, drawdown, groundwater, groundwater basin, groundwater budget, hydraulic conductivity, infiltration, perched groundwater, percolation, permeability, piezometric surface, porosity, potential, potential gradient, potentiometric surface, pressure head, pumpage, recharge, safe yield, salinity, spring, storage coefficient, static level, sub-artesian water, unconfined groundwater, underground water, water bore, water table, water well, zone of aeration, and zone of saturation.

INTRODUCTION

The standardisation of Australian nomenclature relating to underground water was discussed at the 2nd Annual Meeting of the Underground Water Conference of Australia. The Bureau of Mineral Resources agreed to prepare a draft nomenclature, to be circulated to the other member organisations for comment.

At the present time in Australia, terms relating to underground water, and the meanings attached to them, are being taken from two distinct nomenclatures - the nomenclature adopted by the Interstate Artesian Conference (1912, 1928), and the American nomenclature which has developed from that proposed by Meinzer (1923). The comparison below of some corresponding terms from the two nomenclatures shows that the two nomenclatures cannot be used together without considerable explanation.

Interstate Artesian Conference (1928)	Meinzer (1923)
Underground water ?	Subsurface water
Underground water ?	Ground water
Ground water	Unconfined ground water
Pressure water	Artesian water
Artesian water	Flowing artesian water
Potential	Static level ?
Hydraulic surface	Piezometric surface
Bore (+ well ?)	Well

Terms, e.g.hydraulic surface, which belong to only one nomenclature add to the number of terms and definitions to be remembered but will not create ambiguities. Where the one term has both a restricted and a broad meaning, e.g. ground water, artesian water, and well, confusion must be expected.

The 1st Interstate Artesian Conference (1912) defined a number of underground water terms for use in Australia. This was the first Australian standard nomenclature, and with its adoption usage of underground water terms in Australia seems to have become more consistent than usage in most other countries at that time. This nomenclature was also consistent with the available groundwater theory. The 5th Interstate Artesian Conference (1928) reaffirmed the terms adopted by the 1912 Conference, with only minor changes in the definitions.

Before 1945-50 Australian usage of terms relating to underground water seems to have been almost completely in accord with the Artesian Conference definitions. Apparently, however, this nomenclature never received the attention it deserved from overseas workers in the groundwater field.

The American nomenclature has developed from the complete, and generally clearly defined, set of terms proposed by Meinzer (1923). This nomenclature has benefited from considerable published discussion, and some necessary amendments have received general acceptance. The discussion has been the more fruitful for the participation of workers with backgrounds in soils and petroleum and many of Meinzer's terms have been accepted in these related fields. American nomenclature has also been accepted in many other English-speaking countries (see, e.g. Dixey 1950), and many European ground water terms are direct translations from it (see Schieferdecker 1959).

The Artesian Conference nomenclature, on the other hand, has been the subject of little published discussion. Few, if any, of the terms for the more recently developed groundwater concepts are of Australian origin. As these new terms have been introduced in Australia with definitions using American nomenclature, and as suitable reference works are not available in the Artesian Conference nomenclature, workers requiring the new terms have become familiar with American nomenclature and have used it increasingly in their reports. This trend is most noticeable in quantitative studies.

The discussions of underground water in Australia by Ward (1950) and David (1950) consistently use the Artesian Conference nomenclature. Hills (1953) in "Reviews of research in arid zone hydrology" also used this nomenclature; his paper shows greater departure from the American nomenclature than any of the other papers in this Review, which includes contributions from workers in every continent.

The Artesian Water Investigation Committee (1954) quoted and used the Artesian Conference nomenclature, but found it necessary to introduce several new terms from the American nomenclature.

During the last ten years several Australian authorities have prepared articles or books on underground water for wide distribution e.g. Thomas (1955), Whiting (1955), S.Aust. Dept. Mines (1959). These use terms from both the American and Artesian Conference nomenclatures. This mixed nomenclature is also typical of most technical reports in recent years. A few workers are still consistently using the Artesian Conference nomenclature where it is appropriate; some others, most of whom received their hydrologic training overseas, are consistently using American nomenclature.

Recent glossaries, e.g. Economic Commission for Asia and the Far East (ECAFE) (1956), American Geological Institute (A.G.I.) (1960), which include groundwater terms are collections of previously published terms and definitions, with little or no attempt to develop consistent nomenclature or to revise long-standing definitions in the light of later advances in theory. The International Commission on Irrigation and Drainage (I.C.I.D.) draft definitions (undated) include numerous examples of contradictory definitions for terms.

There is little point in compiling a glossary of current Australian definitions and usage of underground water terms as most terms have been defined in more than one way, commonly using other terms each of which also has more than one definition.

This paper discusses several groups of related groundwater concepts, and the various terms and definitions suggested for these concepts. Compound terms of obvious derivation have not been included nor have rarely used terms which could be defined by the author in reports where they are necessary - one of the most frequent comments received was that most glossaries included numerous terms that did not merit inclusion in a standard nomenclature.

Many groundwater terms, as defined in published glossaries, are valid only for special cases e.g. equilibrium conditions of flow, completely impermeable boundaries etc. Where it is clear that general validity was intended modification of the definition is suggested rather than selection of a new term for the general case.

The preferred terms and definitions listed in the appendix represent an attempt to develop a consistent nomenclature, with a minimum of departure from present Australian usage. No new terms are proposed. The wording of the definitions of many terms has been modified from published definitions, in most cases only to maintain consistency in the use of terms. For a few terms the preferred definition differs from common usage as indicated by the literature.

Recommendations have not been made on standard units of measurement, but the need for standard units obviously accompanies the need for standard nomenclature, particularly when considering coefficients originally defined in units not commonly used in Australia. Further standardisation of symbols would also be helpful.

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The references listed include only those works quoted in the text for definitions and discussion of groundwater theory. Reference has been made to many other publications, particularly in checking the usage of terms in Australia. Several non-English sources have been consulted : some English terms have no equivalents in other languages, but the reverse is also true, suggesting that some groundwater concepts lack adequate expression in the English language.

GENERAL TERMS

A term is desirable to readily distinguish the water within the earth from that in the hydrosphere and atmosphere. I prefer the term UNDERGROUND WATER and suggest Tolman's (1937) definition: "All water occurring below the ground surface".

Combined water, and water forming a small proportion of a magma, would not be regarded as underground water.

The recommended definition is consistent with that adopted by the Interstate Artesian Conference (1928) : "The whole body of water existing beneath the surface of the ground, whatever may be its origin," although in the reports of the Artesian Conferences, the term was generally used in a more restricted sense.

Meinzer's (1923) term 'subsurface water' is not well known in Australia and its introduction would not help the confusion between 'groundwater' and 'underground water'. The term 'groundwater' (see p.4) has never been defined as including all water below the ground surface.

Before defining further concepts relating to underground water it is necessary to adopt terms which describe the medium in which underground water occurs.

A rock is defined in the A.G.I. Glossary (1960) as "Any naturally formed aggregate or mass of mineral matter, whether or not coherent, constituting an essential and appreciable part of the earth's crust".

This definition is accepted in the following discussion, but is taken to include only solid mineral matter. Weathering products, including soil, may be included as rock. In some circumstances it could also be convenient to regard man-made mineral aggregates as 'rock'.

The rock is characterised not only by the presence of mineral aggregates but also by the arrangement of these aggregates. An interstice has been defined (Meinzer, 1923) as "a space in a rock that is not occupied by solid mineral matter".

Todd (1959), largely following Meinzer (op. cit.), comments on interstices: "Typically they are characterised by their size, shape, irregularity, and distribution. Original interstices were created by geologic processes governing the origin of the geologic formation and are found in sedimentary and igneous rocks. Secondary interstices developed after the rock was formed; examples include joints, fractures, solution openings, and openings formed by plants and animals. With respect to size, interstices may be classed as capillary, supercapillary, and subcapillary. Capillary interstices are sufficiently small so that surface tension forces will hold water within them; supercapillary interstices are those larger than capillary ones; and subcapillary interstices are so small that water is held primarily by adhesive forces. Depending upon the connection of interstices with others, they may be classed as communicating or isolated".

The storage and movement of underground water are essentially restricted to interstices. However, underground water contained in rock interstices is not regarded as a characteristic of the rock.

Zones of Saturation and Aeration

Meinzer (1923) discussed the zones of fracture and flowage within the earth's crust. Fixing a precise lower limit to the zone of fracture would be difficult in practice but generally this limit lies much deeper than the depths reached in the search for underground water. Therefore the following discussion relates only to the zone of fracture.

Within the zone of rock fracture Meinzer (op. cit.) defined the 'zone of saturation' as "the zone in which the functional permeable rocks are saturated with water under hydrostatic pressure".

Later definitions of the zone have followed the sense of this definition, and only this term is commonly used for this concept. The following wording is suggested for the definition of the ZONE OF SATURATION:

<u>The zone in which interconnected interstices are filled with water</u>.

Meinzer (op. cit.) defined the 'zone of aeration' as "the zone in which the interstices of the functional permeable rocks are not (except temporarily) filled with water under hydrostatic pressure; the interstices are either not filled with water or are filled with water that is held by capillarity".

According to Meinzer's definitions thick shale sequences in which the interstices are filled with water would be regarded as being in the zone of aeration. I would prefer to regard all rocks in which the interstices are filled with water as belonging to the zone of saturation, and suggest the following definition for the ZONE OF AERATION:

<u>The zone in which interconnected interstices are filled with air or partly with air and partly with water held or suspended by molecular forces</u>.

This definition closely follows that of ECAFE (1956).

The boundary between the two zones and its significance in groundwater studies are discussed further on page 12.

Groundwater

It is essential to have a term distinguishing between all water below the ground surface and the water in the zone of saturation - the water from which bores and springs are fed. The term and definition of Meinzer (1923) are recommended: "Ground water is the water in the zone of saturation".

This is contrary to the definition of ground water by the Interstate Artesian Conference (1928), where the term is applied to part only of the water in the zone of saturation. However in at least half the Australian publications checked, groundwater is used in the sense recommended, and this use of the term seems to be increasing. All overseas glossaries consulted include this usage, and most indicate that it is strongly preferred. Any future 'international' nomenclature will be certain to include this term with this definition.

The term has been variously spelt - ground water, ground-water, and groundwater; Meinzer's usage was ground water (noun) and ground-water (adjective). Certainly GROUNDWATER is the simplest, used as both noun and adjective:

<u>The water in the zone of saturation</u>.

Only terms and definitions relating to groundwater are discussed in the following sections. Some terms discussed, e.g. salinity, potential, are also used in other disciplines and wherever possible the definition has been made consistent with usage in these disciplines.

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Salinity

Water is used in this paper in the sense of 'natural water' of Meinzer (1923) - materials dissolved in chemically pure water are regarded as part of the water. 'Salinity' has been used for:

(1) the measured, or calculated, content of sodium chloride in water, e.g. Wiebenga (1955). This usage has become less common with increasing recognition of the importance of other ions.

In the petroleum industry conductivity is often expressed as equivalent p.p.m. NaCl. This may be a satisfactory approximation for brines, but for better-quality groundwaters the conductivity is better expressed in the units in which it is determined.

(2) the total content of dissolved solids, or salts, in water, e.g. "The salinity of an underground water is the total of the mineral salts it contains in solution", (S. Aust. Dept Mines, 1959).

This second usage is strongly preferred.

The distinction between dissolved salts and dissolved solids is generally not great. As most analyses give the total dissolved solids I would prefer the following definition of SALINITY:

The total content of dissolved solids of groundwater.

It is expressed as the ratio between the weight of the solids content and the weight of the water including the dissolved solids.

THE CONTAINERS OF GROUNDWATER

Groundwater occurs within rock bodies and the extent and properties of these rock bodies are major factors in the distribution and movement of groundwater.

Porosity

The term porosity is invariably used in the sense of the following definitions:

"The porosity of a rock is its property of containing interstices. The porosity of a rock or soil can be quantitatively expressed as the ratio of the aggregate volume of its interstices to its total volume". (Meinzer 1923).

"Porosity: The physical property of rock or earthorn materials that defines the degree to which they contain interstices and is expressed as the ratio of the volume of interstices to the total volume of the rock or earth materials". (Inter. Comm. Irrig. Drain).

The following definition of porosity is suggested:

The property of a rock that defines the degree to which it contains interstices.

Specific Yield

Meinzer (1923) defined 'specific yield' and 'specific retention' which together comprise the porosity. "The specific yield of a rock or soil, with respect to water, is the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume..... The specific retention of a rock or soil, with respect to water, is the ratio of (1) the volume of water which, after being saturated, it will retain against the pull of gravity to (2) its own volume".

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The main difficulty arising from these definitions is that the drainage of water from a rock continues for an infinite period - presumably specific yield is yield at infinite drainage time. As such there is often limited practical value in specific yield.

A recently introduced term in the United States is 'gravity yield', which is useful in computing usable storage:

"The gravity yield of a rock or soil after saturation or partial saturation is the ratio of (1) the volume of water it will yield by gravity to (2) its own volume, during the period of ground-water recession" (Rassmussen and Andreason, 1959).

The I.C.I.D. Draft Glossary defines 'effective porosity' as "The ratio between (1) the volume of water that a pervious material previously saturated with water, will yield in specified hydraulic conditions and (2) the total volume of the material". Meinzer's specific yield is clearly a particular case of effective porosity as thus defined.

'Effective porosity', as determined by the interpretation of geophysical logs, is certainly less than the (total) porosity, but its relation to specific yield and gravity yield is uncertain. Similar comment can be made about short-term laboratory determinations of the proportion of water in a rock that is available for extraction. The term 'effective porosity' has also been used in relation to fluids other than water.

If a definition of effective porosity is required for use in groundwater studies, that of I.C.I.D. given above is recommended.

There is no simple solution to the problems posed by limited and variable periods of drainage. Statements on the proportion of water which will drain from a rock need to include the method of determination and period of drainage.

Permeability

Meinzer (1923) wrote: "A permeable or pervious rock, with respect to subsurface water, is one having a texture that permits water to move through it perceptibly under the pressure ordinarily found in subsurface water. Such a rock has communicating interstices of capillary or super-capillary size". Later he defined a co-efficient of permeability (see Ferris et al., 1962) as the flow of water through unit cross-sectional area under unit hydraulic gradient. This co-efficient is clearly a function of the properties of both medium and fluid.

However the report on permeability of the Committee on Ground Water of the American Geophysical Union (Jacob et al., 1946) strongly favoured the use of 'permeability' for the properties of the medium alone. In studies involving two fluids in the one medium, e.g. air/water in the zone of aeration or oil/water in the zone of saturation, it is essential to have a term for "the facility with which a given rock or material transmits fluids", which is Hubbert's (1940) definition of permeability.

Other definitions of permeability include "characteristic of porous material which allows it to transmit water" (ECAFE, 1959), and"the capacity of a rock or earth material to transmit water through its pores; also the quantitative expression of this capacity; the permeability of a material is a constant dependant only on the nature of that material and not on the fluid". (I.C.I.D.). The following is suggested as the basis for a formal definition of PERMEABILITY:

<u>The capacity of a rock to transmit fluids through its interstices.</u>

In the definition of permeability it is assumed that the

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The coefficient of permeability is further discussed under "Bores and wells".

Aquifer

A distinction is necessary between rock bodies according to their ability to store and to transmit groundwater, especially the latter. Distinction is made between bodies that transmit water freely, bodies that transmit water slowly, and those that are, for practical purposes, impermeable.

The term aquifer is almost universally used for units that transmit water freely. The following definitions of 'aquifer' are representative:

"Formation, group of formations, or part of a formation that is water-bearing". (Meinzer, 1923).

"Stratum or zone below the surface of the earth capable of producing water as from a well". (A.G.I. Glossary 1960).

"Rock formation or stratum that is relatively permeable and will yield water in sufficient quantity to be of consequence as a source of supply". (Queensland Artesian Water Committee, 1954).

It is generally accepted that water will drain from the interstices of an aquifer at a rate which is of economic value. Meinzer states, "The term water-bearing is a relative term used to designate a formation that contains considerable gravity water. It is commonly used with more or less reference to the economic value of the formation as a source of supply".

The suggested definition of AQUIFER is:

<u>A body of rock containing a system of interstices that will yield groundwater at sufficient rate to be of local consequence as a source of supply</u>.

The system of interstices constituting the aquifer may be either fractures or intergranular voids, and the rock body in which it occurs may not be identical with a rock body which is a convenient unit for stratigraphic studies. Provided their system of interstices are similar two adjacent rock units may be grouped as one aquifer, although they may be of quite different age. A minor zone within a thick rock unit of generally consistent lithology may, on the other hand, be separated as an aquifer although the only difference from the rest of the unit is a slightly greater interconnection between interstices, if this zone is of importance as a source of supply.

Most definitions of aquifer have clearly restricted it to the zone of saturation, and this has been followed in the definition suggested above. There would, however, be some advantages in having the one term for permeable rock bodies which occur in both the zones of saturation and aeration. (The same comment applies to aquiclude but the zones of saturation and aeration have no meaning in an aquifuge.)

The definition of aquifer by the Interstate Artesian Conference (1928) "most commonly a bed of porous sediments, but may be a fault zone, a single joint-plane or crevice, or, in some cases, a system of interconnected joints or fractures traversing dense and non-porous rocks" does not refer 'aquifer' to either zone.

Ferris et al. (1962) wrote of the "saturated zone of the aquifer" and clearly implied that the aquifer could extend into the zone of aeration, and some other writers appear to have used aquifer in this extended way.

The distinction between groundwater and its container has not been clearly drawn in many Australian groundwater studies. The properties of a rock body (porosity, elasticity, permeability, etc) are essentially

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fixed, at least within periods of less than, say, 100 years. The groundwater contained in the rock body may, on the other hand, be constantly changing - water is added to and removed from it, and pressure and salinity may vary. A body of groundwater has therefore to be defined in time as well as in space.

French hydrologists use the term 'nappe' for the body of groundwater saturating a permeable rock body:

"In hydrogeology it is convenient to introduce the concept of a 'nappe'. By it is meant the body of underground water occupying a region throughout which there is easy intercommunication. The most typical example is that of the water saturating a permeable formation between two impermeable beds.

"But the position is not always so clear, and at times disagreement can exist about the correctness of the term, or the limits to be assigned to it: can the body of water saturating the weathered zone of a granite, or the scree on a slope be considered to belong to a nappe? The various units which constitute such formations can be practically isolated from each other, so that there is no real interconnection: but in each of these units the water is under the same conditions and it may be useful to emphasize this unity. There may be similar differences of opinion in the case of a limestone, within which there are a number of distinct series of caverns, between which interconnection could be doubtful.............

The idea of nappes, implicitly supposed to be independent of each other, is only a first approximation. To go further it is necessary to consider the interconnection between different nappes". (translation from Goguel, 1959, p.124).

It is suggested that further consideration be given to the desirability of restricting 'aquifer' to the rock body thus making this term valid in both the zones of saturation and aeration. Perhaps a new term - not necessarily 'nappe' - could be established for the body of groundwater contained in an aquifer (or aquiclude).

<u>Aquiclude and aquifuge</u>

Rock bodies which are less permeable than the aquifers which they overlie or underlie have been defined as 'confining beds' (Meinzer 1923). Confining beds have been divided into aquicludes and aquifuges.

Aquiclude was defined by Tolman (1937) as a "formation which, although porous and capable of absorbing water slowly, will not transmit it fast enough to furnish an appreciable supply for a well or spring". At a locality with numerous highly permeable gravel beds a bed of silty sand might be rightly regarded as an aquiclude but at another locality a similar silty sand overlying thick tight shales could well be of significance as a source of supply. The suggested definition of AQUICLUDE is:

<u>A body of rock which contains an interconnected system of interstices saturated with water but which will not yield groundwater at a sufficient rate to be of local consequence as a source of supply.</u>

Tolman (op. cit.) defined an aquifuge as a "formation which contains no interconnected openings or interstices and therefore neither absorbs nor transmits water". Some workers have not recognised the distinction between aquiclude and aquifuge. Very few rock bodies are aquifuges in the strict sense of the definition. Rock salt is an aquifuge and many other rocks may in certain circumstances be conveniently treated as aquifuges, e.g. metamorphic basement below a major sedimentary basin. Retention of both terms is recommended, with the following definition of AQUIFUGE:

<u>A body of rock that does not contain an interconnected system of interstices.</u>

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Bedrock

In groundwater studies the term bedrock has been used in two distinct senses, illustrated by the following definitions:

"Any solid rock exposed at the surface of the earth or overlain by unconsolidated material". (A.G.I., 1960)

"The limit below which there is no reasonable expectation of obtaining commercial supplies of water". (Interstate Artesian Conference, 1928).

The first definition is that used in many other branches of geology and engineering, and also in groundwater studies in some parts of Australia. If there is to be only one definition of bedrock it has to be in this sense, which makes it a term of convenient description rather than exact definition. An author using the term would need to state the rock units to which it referred in all but the most obvious of cases.

Alternatively both definitions could be retained with authors using, or abusing, each as they saw fit.

It has been suggested that the term should be discarded because it is indefinite. But it often serves a useful purpose and if discarded would probably be replaced in due course by another equally indefinite term. It is suggested that the use of BEDROCK be continued, in the sense of the following definition:

<u>Any solid rock exposed at the surface of the earth or overlain by unconsolidated material.</u>

GROUNDWATER HYDRAULICS

Pressure Head

"The hydrostatic pressure at a given point in a body of water at rest is the pressure exerted by the water at the point. The hydrostatic pressure of ground water is generally due to the weight of water at higher levels in the same zone of saturation. Ground water is generally in motion, but except where the conditions are artificially modified the motion is generally so slow that no appreciable error is involved in regarding the pressure which it exerts as hydrostatic...........

"The pressure head of water at a given point in an aquifer is its hydrostatic pressure expressed as the height of a column of water that can be supported by the pressure". (Meinzer 1923).

Meinzer noted that the presence of gas bubbles in the water column lowers the specific gravity of the water and a higher column of water can be supported by the hydrostatic pressure than if the gas were not present. He did not mention the more common case in which the specific gravity of the water is increased by the presence of dissolved solids and the column of water which can be supported is lower than for pure water.

Meinzer's term 'pressure head' is very useful but I think it would be even more valuable if specifically stated as the column of pure water which could be supported by the hydrostatic pressure. It is suggested that the definition of PRESSURE HEAD be amended to:

<u>The height of a column of pure water that can be supported by the hydrostatic pressure against the pressure of the atmosphere, at a given point, in a groundwater body.</u>

Static Level

'Static level' was defined by Meinzer (op. cit) as "the level that passes through the top of a column of water that can be supported by the

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hydrostatic pressure of the water at a given point in an aquifer". He stated "it can be expressed with reference to any convenient datum - for example, it is proper to say that the static level is a certain number of feet above or below the land surface, the water table, or mean sea level".

Australian usage has usually, but not invariably, been to measure static level from a measuring point at or near the ground surface. Nevertheless there is no obvious objection to leaving the selection of datum open.

The main use of 'static level' is in the recording and discussion of measured water levels in bores. It is suggested therefore that STATIC LEVEL should be clearly expressed as referring to the water in the groundwater body at a particular point by the definition:

<u>The level that passes through the top of a column of water that can be supported, against the pressure of the atmosphere, by the hydrostatic pressure of the water at a given point in a groundwater body, the water in the column having the same density as that in the groundwater body at that point.</u>

'Static level' is also used for observed water levels in bores open to a large part of the thickness of an aquifer, or even to more than one aquifer. Such 'average' levels are of considerable value, but in determining the groundwater flow pattern it must always be recognised that use of 'average' levels may obscure evidence of a vertical component of flow.

Potential

The Interstate Artesian Conference (1928) defined 'potential' as "the height above an assumed datum (usually sea-level) to which subartesian water would rise in a bore, or to which artesian water would rise under its own natural pressure in a vertical pipe erected above the casing, and which can be ascertained by observation of the pressure at the bore-head when closed", i.e. as a synonym of 'static level'.

Hubbert (1940) discussed the analogy between the flow of groundwater and electricity, and independently introduced 'potential' into groundwater nomenclature. He discussed the significance of the density of the fluid in expressing fluid pressure as a 'pressure head'.

If the elevations of the points in a groundwater body to which pressure heads refer are related to a common datum (generally but not necessarily sea level) then POTENTIAL may be defined:

<u>The sum of the pressure head of the groundwater at a given point and the elevation of that point above a selected horizontal datum.</u>

The I.C.I.D. Glossary defines 'total head' of groundwater as being the sum of the pressure, elevation and velocity heads. In general the rate of movement of groundwater and the resistance of the rock medium to flow are such that the velocity head may be ignored, and 'total head' is identical with potential as defined.

The term 'static level' has usually been used only for levels which are not influenced by artificial discharge or recharge of groundwater. Certainly however groundwater has a 'potential' both within and beyond areas influenced by artificial recharge and discharge. The potentials in a groundwater body may vary in three dimensions (see Hubbert, 1940)

Potential gradient

Much of the earlier groundwater literature (containing definitions still widely quoted) stated that groundwater flow was in the direction of pressure gradient. Meinzer (1923) stated: "The hydraulic gradient, or pressure gradient, of an aquifer at a given place in a given direction is the rate of change of pressure head per unit of distance at that place and in that direction". The I.C.I.D. Glossary attempts to distinguish between the 'pressure gradient' of confined groundwater and the 'hydraulic gradient' of unconfined groundwater.

Hubbert (1940) showed that groundwater flow is in the direction of potential gradient,+ a conclusion implied if not stated in the Interstate Artesian Conference (1928) definition: "The hydraulic grade in any portion of an artesian basin must be measured in a direction normal to the isopotential passing through that locality, and is consequently the line of steepest grade in the hydraulic surface at that place".

POTENTIAL GRADIENT may be defined:

The rate of change in potential at any point in a groundwater body; where no gradient direction is specified, the direction is that of maximum gradient.

Potential gradient may be in any direction in a vertical as well as the horizontal plane.

Potentiometric Surface

Potentials vary in three dimensions but within one groundwater body lateral differences in potential may be more marked than vertical. It is then convenient to consider the potentials corresponding to a horizontal, or near-horizontal surface in the groundwater body, and these potentials may be spoken of as the potentiometric surface of the groundwater body. The following definition of POTENTIOMETRIC SURFACE is recommended:

An imaginary surface defined by the potentials at all points on a given plane in a groundwater body.

This term has been used very little in hydrological studies but has received wider acceptance in the petroleum industry where important differences in fluid density are common (salt water/fresh water/oil/gas).

The flow lines of groundwater are perpendicular to the equipotential surfaces in the groundwater body. Microscopically the flow lines are very irregular but in homogeneous aquifers, when the field examined is very much larger than the interstices and distances between interstices, the macroscopic flow lines will be smooth. Where groundwater movement occurs only in sparse fissures in an otherwise impermeable rock the flow lines may be irregular even in the macroscopic view.

Isopotential lines are the lines of intersection of equipotential surfaces with other surfaces, e.g. with the upper surface of an aquifer.

Piezometric surface

Meinzer (op.cit.) defined a 'piezometric surface' as "an imaginary surface that everywhere coincides with the static level of the water in an aquifer".

The 'hydraulic surface' of the Interstate Artesian Conference (1928) is a synonym of piezometric surface.

Unfortunately piezometric surface implies 'pressure surface' but the term is very well established overseas and widely used in Australia and it is unlikely that it would be displaced by another term.

Strictly, the piezometric surface, like potentiometric surface,

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\+ It has been observed (Petroleum Research Corporation, unpublished notes) that, with large salinity differences, electro-osmosis can be important in determining the direction and rate of groundwater flow. This is not considered in the nomenclature discussed.

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should be referred to a particular surface within a groundwater body, but it is often convenient, where the major component of flow is horizontal, to speak of the piezometric surface of a groundwater body. The piezometric surface may then be defined by the use of 'average' static levels. The suggested definition of PIEZOMETRIC SURFACE is:

An imaginary surface defined by the static levels at all points on a given plane in a groundwater body.

The piezometric surface is of direct interest, e.g. in determining whether there will be artesian flow at a particular place, but the use of the piezometric surface to determine direction of groundwater flow is based on the assumption that the piezometric surface is a reasonable approximation to the potentiometric surface. It has been suggested that where the 'piezometric surface' cannot be referred to the full thickness of the groundwater body it may be preferable not to use this term.

Water Table

The term 'water table' is well established in the literature; the following definitions are representative:

"The upper surface of the zone of saturation except where that surface is formed by an impermeable body". (Meinzer 1923)

"The free upper limit of the body of groundwater, and represents the level at which the water stands in a well sunk into the rocks saturated with ground water". (Artesian Conference 1928).

"The upper free surface of ground water; locus of points in soil water at which the hydraulic pressure equals the atmospheric pressure". (Food and Agricultural Organisation 1960).

Lohman (U.S. Geol. Survey, unpublished notes) in a discussion of the water table has written, ".... only one precise definition of the water table is possible .... that isobaric surface at which hydrostatic pressure is atmospheric. This surface is defined by the level at which unconfined water stands in non-pumped wells. It is not the upper surface of the zone in which all interstices are saturated, except in materials having only very large (supercapillary) openings".

Meinzer, and many later writers, have drawn a distinction between the water table and the piezometric surface but the water table is a particular case of the piezometric surface - it is where the piezometric surface in the groundwater body to which they refer.

If there is a vertical component of groundwater movement a single groundwater body may have a water table near (or at, using Meinzer's definition) its upper surface and a different piezometric surface for a plane deeper in the groundwater body. The following definition of WATER TABLE is recommended:

The surface within a groundwater body at which the hydrostatic pressure is equal to atmospheric pressure.

Confined and unconfined groundwater

The terms 'confined' and 'unconfined' have been applied both to aquifers and to the water contained in aquifers.

Meinzer (1923) defined the 'confining bed of an aquifer' as a bed "which, because of its position and its impermeability or low permeability relative to that of the aquifer, gives the water in the aquifer either artesian or subnormal head". The confining bed could overlie or underlie the aquifer. He did not, in that paper, use 'confined water' or 'confined aquifer', but these terms have been widely used by later workers, generally without precise definition.

Confined water has been used as a synonym of 'pressure water' but the deeper part of a groundwater body will behave as 'pressure water' if there is an upward component of flow, and in a natural syphon the groundwater is confined but is not 'pressure water'.

Recent usage of 'confined' and 'unconfined' is typified by Chapman (1936)+: "Ground-water can be classified according to the nature of the top boundary. In confined flow the upper boundary is the limit of a region of negligible permeability, while in unconfined flow the boundary is not fixed _a priori_ but is a surface of constant pressure (slightly below atmospheric pressure and corresponding to the upper limit of the essentially saturated zone)." The co-efficient of storage (defined under 'Bores and wells') is perhaps the best indication of whether the groundwater in a particular part of an aquifer is confined. Many aquifer test results indicate that confinement is very local, or partial only - the terms 'semi-artesian' and 'semi-confined' have been used as loose descriptions of conditions. Because of the inhomogeneity of rock bodies there is a degree of "confinement" in all aquifers - 'unconfined groundwater' is perhaps an ideal case.

Saturation of the soil above aquifers which would generally be regarded as unconfined can cause a 'temporary confinement' during which bore water levels respond to changes in atmospheric pressure.

With some hesitation the following definitions are proposed for CONFINED GROUNDWATER:

Groundwater occupying the full thickness of an aquifer overlain by an aquifuge or saturated aquiclude.

And for UNCONFINED GROUNDWATER:

Groundwater of which the upper surface is formed by surface water or by permeable rock containing air at atmospheric pressure.

'Unconfined' seems to be a unnecessarily complex term but the alternative sometimes used, 'free', can imply the opposite of 'charged for' or of 'fixed' and is not recommended.

Artesian Water

The static level (and potential) of groundwater may be above, at, or below the upper surface of the groundwater body, and the static levels of groundwater body may be higher than, equal to, or lower than the static levels of overlying or underlying groundwater bodies. Terms for many of these possibilities were discussed by Meinzer (1923) but only two are considered here - static level above the ground surface, and static level above the upper surface of the groundwater body but below the ground surface.

The derivation of 'artesian' (from Artois, France, where flowing bores were first scientifically described) suggests that the characteristic of artesian water is that it flows at the ground surface. But many different definitions have been published, of which the following are representative:

"Ground water that is under sufficient pressure to rise above the zone of saturation". (Meinzer 1923).

"Subsurface water under sufficient pressure to cause it to rise above bottom of fissure or other opening in confining bed that overlies the aquifer". (ECAFE Glossary 1956).

+ "Effects of ground-water storage and flow on the water balance". (Paper C3 to Nation Symposium on Water Resources, Use and Management, Australian Academy of Science, 1963).

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"Ground water that is under sufficient pressure to rise above the level at which it is encountered in a well, but which does not necessarily rise to or above the surface of the ground". (A.G.I. Glossary 1960).

"When pressure water is struck in bores it may rise above the surface of the ground, in which case it is termed "artesian water". (Interstate Artesian Conference 1928).

"Water that will rise to the surface, or even flow, when penetrated by drilling", and

"Water which rises in a bore hole or well when tapped, and may or may not produce a surface flow". (South Aust. Groundwater Handbook 1959, p.9 and p.22).

The usage of the Interstate Artesian Conference, which is general throughout Australia, is preferred and the following definition of ARTESIAN WATER suggested:

<u>Groundwater of which the static level is above the ground surface</u>.

'Artesian aquifer', if used at all, can only mean an aquifer containing artesian water but it is doubtful if the term could describe only that part of an aquifer containing artesian water. The possibility of artesian flow makes no difference to rock properties.

The Interstate Artesian Conference (1928) definition of sub-artesian water required that it be confined but David (1950) and some later writers seem to regard the position of the static level above the upper surface of the groundwater body as the essential point in defining sub-artesian water. The following definition of SUB-ARTESIAN WATER is recommended:

<u>Groundwater of which the static level is above the upper surface of the groundwater body but below the ground surface</u>.

Using this definition a vertical component of flow can give rise to sub-artesian water without the presence of a confining bed.

Pressure Water

'Pressure water' is the traditional Australian term for 'artesian water + sub artesian water'. It was defined by the Interstate Artesian Conference (1928) as "...... (underground water) which is confined and is under pressure exceeding that of the atmosphere".

The continued use of 'pressure water' which is an obvious misnomer, cannot be recommended but 'artesian water' (American nomenclature) is the only published alternative term. Accordingly, no term for the concept is recommended in this paper.

The term 'non-pressure water' has been used for groundwater which is neither artesian nor sub-artesian but has found little favour.

Perched Groundwater

"Groundwater is said to be perched if it is separated from an underlying body of groundwater by unsaturated rock. Perched water belongs to a different zone of saturation from that occupied by the underlying ground water". (Meinzer 1923).

The ECAFE Glossary (1956) defines perched water as "ground water supported by relatively impervious material above the prevailing water table of the region".

A relatively impermeable bed supporting the perched groundwater is a general feature, but the presence of permeable, but unsaturated, rock below this impermeable bed is the characteristic of perched groundwater. The following definition of PERCHED GROUNDWATER is suggested.

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Groundwater separated from an underlying body of groundwater by unsaturated rock.

Where a groundwater body has higher potentials than those of an underlying groundwater body, from which it is separated by a relatively impermeable bed although both bodies form part of the one zone of saturation, the overlying body has been referred to as 'semi-perched' (Meinzer, 1923). This term is very rarely used in Australia and its inclusion in formal nomenclature is probably not necessary, although the conditions to which it refers are common in areas of groundwater recharge.

'Perched artesian basin' and 'perched groundwater area', as defined by the Interstate Artesian Conference (1928), refers to the superposition of rock units and have no necessary association with 'perched groundwater' as defined above.

The Limits of the Zone of Saturation

The recommended definition of the zone of saturation requires that all interstices in the zone be saturated with water under hydrostatic pressure. There are many exceptions to these ideal requirements:

Some air may be trapped in the zone of saturation. In the zone of water table fluctuation the air content of the zone of saturation may be considerable.

Oil and natural gas are other fluids which occur locally in the zone of saturation. These normally occur at potentials consistent with those of the adjacent groundwater, after allowance is made for capillary effects.

Most water in the zone of saturation moves so slowly that the assumption of hydrostatic pressure is a reasonable approximation. However in large caverns and adjacent to points or lines of concentrated recharge and discharge (bores, springs, streams, etc.) there may be radical departure from hydrostatic conditions. Some of the concepts for which terms and definitions are discussed in this paper are not valid where hydrostatic conditions do not apply.

If a groundwater body is sealed from the general system of groundwater circulation by an aquifuge, e.g. rock salt, then this groundwater may be under pressures much greater than the weight of the water column, with the pressure approaching the weight of the overlying rock column in extreme cases. In areas of contemporary tectonism, too, thick sequences of relatively impermeable beds may contain groundwater under pressures greater than "hydrostatic" - under these conditions even steep potential gradients may not have operated for sufficient time to remove all the groundwater 'available' for release by compaction.

However these exceptions do not appear to have destroyed the usefulness of the term.

The zone of saturation was arbitrarily limited by Meinzer (1923) to the zone containing water with hydrostatic pressure greater than atmospheric pressure. Hubbert (1940) pointed out that in an artificial medium (e.g. sand of uniform fine grainsize) in a transparent container there is a clearly visible limit of saturation quite distinct from the water table which can be measured in a supercapillary tube open through the medium. In natural media, commonly anisotropic and inhomogeneous, the upper limit of saturation may not be readily defined. Nevertheless groundwater flow does occur in that part of the zone of saturation above the water table - the capillary fringe.

The limit of saturation is a close approximation to the water table in beds in which all interstices are of supercapillary size. Elsewhere the limit of saturation does not closely correspond to a potentiometric surface.

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Geophysical methods determine the limit of saturation. They may therefore be used for approximate determination of the water table under unconfined conditions but cannot determine the piezometric surface of confined groundwater.

Some European nomenclatures include terms, e.g. verkhovodka and sickerwasser, which apparently refer to the water in (temporary)zones of saturation formed during movement of water from the ground surface to the (permanent) zone of saturation.

GROUNDWATER IN THE HYDRAULIC CYCLE

Movement of underground water comprises:

(i) movement of water from the surface of the ground into the zone of aeration

(ii) from the surface of the ground directly into the zone of saturation

(iii) within the zone of aeration
(iv) from the zone of aeration into the zone of saturation
(v) within the zone of saturation
(vi) from the zone of saturation into the zone of aeration
(vii) from the zone of saturation directly to the surface of the ground
(viii) from the zone of aeration to the surface of the ground.

Distinction is also to be made between movement through macro - and micro - interstices.

The terms infiltration, recharge, discharge, seepage, and percolation are among those which have been applied to one or more of these phases.

Infiltration

Infiltration seems to be generally used for the movement of atmospheric or surface water through the ground surface into either the zone of saturation or the zone of aeration. The I.C.I.D. Glossary defines infiltration as:

" (i) The flow or movement of water through the surfaces into the soil or ground.

(ii) The absorption of liquid water by the soil, either when it falls as rain, or when applied as irrigation, or from a stream flowing over the ground.

(iii) Flow from a porous medium into a channel, pipe, drain, reservoir or conduit.

(iv) The infiltrated water, as infiltrate.

Note - The distinction between infiltration and percolation is that the latter is the movement of water or moisture within the soil through the saturated zone".

Langbein and Iseri (1960) define it as:

"The flow of liquid into a substance through pores or small openings. It connotes flow into a substance in contradistinction to the word percolation, which connotes flow through a porous substance".

The term is usually restricted to movement through small interstices and to laminar flow, e.g. water falling into a limestone sink is not infiltration. Infiltration does not include all water moving into the ground. The following definition or INFILTRATION is suggested:

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The movement of water through the ground surface into small interstices in either the zone of aeration or the zone of saturation.

Percolation

The definitions of infiltration quoted above contrast it with percolation, which is stated as the flow of water through porous media and is, in the I.C.I.D. definition, restricted to the zone of saturation. Tolman's (1937) definition of percolation, "a type of laminar flow occurring in interconnected openings of saturated granular material under hydraulic gradients commonly developed underground" is also quoted in the I.C.I.D. Glossary with the comment, "the difference between percolation and seepage is that the latter is through unsaturated material while the former is through saturated material".

Meinzer (1923) defined percolation as "the movement, under hydrostatic pressure, of water through the interstices of the rock or soil, except the movement through large openings such as caves". He contrasted it with 'capillary migration' and apparently intended it to apply only in the zone of saturation.

The ECAFE (1956) definition, however, "downward movement of water within the soil after infiltration", implies that perolation also occurs in the zone of aeration.

I would prefer to restrict PERCOLATION to the zone of saturation, using the following definition:

The flow of groundwater in the zone of saturation, under conditions in which the rate of flow is proportional to the potential gradient.

Recharge and Discharge

RECHARGE has been consistently used in the use of the following recommended definition:

The addition of water to the zone of saturation, either directly from the ground surface or from the zone of aeration.

Intake is a synonym of recharge, but the latter has been more generally used in recent publications.

Meinzer (1923) defined both groundwater discharge and vadose-water discharge. Only the former is included in the definition of DISCHARGE recommended; it may be desirable in places to use groundwater discharge to avoid ambiguity:

The removal of water from the zone of saturation, either to the ground surface or to the zone of aeration.

Seepage

The term seepage is commonly used as the converse of infiltration (as defined above) e.g. "the movement of water through the ground or other porous media to the ground surface or surface water bodies" (Todd, 1959). Meinzer (1923) defined both influent seepage (= infiltration) and effluent seepage (= seepage, of Todd), The I.C.I.D. definition of percolation, quoted above, contrasts percolation with seepage which is there used for water movement in the zone of aeration. Others appear to have used seepage for movement of water in the zone of saturation, or for movement in both the zones of saturation and aeration.

In groundwater studies Todd's usage is probably the most common, but it is felt that no recommendation should be made on preferred usage without further consideration of the use of the term in soils and irrigation studies.

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Spring

Ward (1950) wrote "where underground water issues in a stream or where water stands in a pool replenished from an underground source, such an occurrence is called a spring. In some cases there is a defined point of emergence and in others a distributed seepage from some water-bearing rock". He pointed out that water must be visible at the ground surface before the term spring applies.

Some definitions of spring, e.g. Todd (1959) require that there should be a "current of flowing water" but Ward's definition seems closer to most Australian usage. The following definition is suggested for SPRING:

<u>A place of natural discharge of groundwater as a liquid</u>.

BORES AND WELLS

American nomenclature regards all man-made holes sunk to obtain groundwater as wells. In Australia and many other countries distinction has been made between bores, which are drilled, jetted or augered, and wells which are dug. This difference in construction techniques is commonly, though not necessarily, supplemented by difference in size and in manner of completion.

No published definitions were found + which expressed the Australian usage of these terms, and the following definitions are suggested for WATER BORE:

<u>A hole which is drilled, jetted or augered to withdraw or replenish groundwater, or to obtain information about groundwater</u>.

And WATER WELL:

<u>A hole which is dug, manually or mechanically, to withdraw or replenish groundwater, or to obtain information about groundwater</u>.

Excavations, such as ditches or tunnels, which permit groundwater discharge by lateral flow, are not included as wells. Bores (and wells) are qualified, where necessary, as recharge bores, observation bores, etc. The definitions proposed do not require that a hole contain groundwater to be included as a bore or well.

When confusion with oil wells, etc. is not likely to arise, the terms bore and well may obviously be used for water bore and water well.

Drawdown

Water withdrawn from a bore is, within the limits set by aquifer properties and bore development, replaced by groundwater moving to the bore from the aquifer. This movement requires the development of potential gradients in the groundwater body, i.e. a lowering of potentials towards the bore++, which is usually observed as a lowering of the level

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+ <u>Footnote</u>

O'Shea (1961 unpubl.) suggested that the diameter of the hole was the commonly used criterion for distinguishing wells from bores - wells having a diameter greater than about one foot.

++ <u>Footnote</u>

Near the discharging bore, the assumption that potential is the sum of (hydrostatic) pressure head and elevation may not be valid.

at which groundwater stands. This lowering of potential has invariably been termed DRAWDOWN, and the following definition is suggested:

<u>The lowering of potential at a given point in a groundwater body, resulting from the withdrawal of water from a bore.</u>

One of the I.C.I.D. definitions of drawdown, "the lowering of the water table or piezometric surface caused by the discharge of groundwater through wells, springs or other openings", would widen the scope of the term considerably. Generally, however, the lowering of potentials about a spring would not be regarded as drawdown, the term being used, for practical convenience, for the lowering of potential as a result of man's activities. It may even be restricted to cases in which the level from which 'drawdown' has occurred and the duration of discharge can be established.

The increase in potential with recharge of groundwater through a bore is the converse of drawdown.

Cone of Depression

The lowering of potential during discharge from a bore have been used to define a 'cone of depression', e.g. "A cone-shaped depression in either the water table in unconfined flow, or the piezometric surface in confined flow developed around a well which is being pumped at any given rate of discharge. It has its apex in the well and its base in the water table or piezometric surface". (I.C.I.D.)

If negligible vertical flow occurs the cone of depression is identical for all surfaces perpendicular to the bore within the groundwater body. In many cases, e.g. partially penetrating bores, no single cone of depression can be defined. In practice the cone of depression at the upper surface of the groundwater body is often assumed to be the only cone of depression, or the cone of depression is determined from measured levels in bores open to the full thickness of the aquifer. Only one 'cone of depression' is then apparent but the possible importance of vertical flow cannot be assessed. Where a significant vertical component of flow is known or suspected the use of this term with its implication of two-dimensional flow would be best avoided. The following definition of CONE OF DEPRESSION is suggested:

<u>The depression in a potentiometric surface resulting from the withdrawal of water from a bore. It varies in size and shape with the rate and duration of withdrawal.</u>

Several glossaries, e.g. I.C.I.D., contain definitions of equilibrium drawdown, equilibrium cone of depression, etc., all of which imply that at constant withdrawal rate the cone of depression stabilises after a limited time, in distinction to stabilisation of the shape of the cone of depression which is the basis for aquifer tests. These terms are not recommended, being likely to cause further confusion regarding the capacity, drawdown, etc. of bores.

Capacity

Meinzer (1923) defined capacity as "The rate at which a well will yield water .... The <u>total capacity</u> of a well is the maximum rate at which it will yield water by pumping after the water stored in the well has been removed ..... The <u>tested capacity</u> of a well is the maximum rate at which it is known to have yielded water without appreciable increase in drawdown ...... The <u>artesian capacity</u> of a well is the rate at which it will yield water at the surface as the result of artesian pressure ..... The <u>Specific capacity</u> of a well is its rate of yield per unit of drawdown. The term is applied only to wells in which the drawdown varies approximately as the yield".

The capacity of a bore is effected by the duration of pumping,

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secular fluctuations in water level, interference from other bores, and distance to recharge point.

At least one of "continuous withdrawal without appreciable increase in drawdown", "constant drawdown without appreciable decline in yield", and "withdrawal for the greatest likely duration of pumping" is implied in all statements of capacity. It is not possible to give a precise general statement of "appreciable" and "likely".

The following definitions are suggested.

TESTED CAPACITY : The maximum rate at which withdrawal from a well or bore is known to have been sustained.

TOTAL CAPACITY : The maximum rate of withdrawal from a well or bore that can be sustained for the greatest likely duration of discharge.

SPECIFIC CAPACITY : The capacity of a well or bore per unit drawdown.

The specific capacity of a bore may vary with both the rate and duration of a withdrawal. If the variation is great, then the term is not appropriate.

Due to the effects of interference between pumping bores, induced recharge, etc., longterm assessments are now related to conditions in the groundwater body as a whole rather than the capacity of individual bores.

The term 'pumpage' is widely used in America for the amount of water obtained from a bore (or group of bores) e.g. "The quantity of water withdrawn from a well by means of pump". (I.C.I.D.) The term is convenient and the adoption of PUMPAGE for use in Australia is recommended. The period during which the pumpage is measured must be stated:

The amount of water withdrawn from a bore or group of bores during a stated period.

The term 'yield' has been used in many ways in groundwater studies:

yield	- rate of withdrawal (synonym of capacity).
yield	- content of water withdrawn (synonym of pumpage).
safe yield	- limiting rate of withdrawal from a groundwater body.
specific yield	- ratio of volume of available water to volume of container.

Where ambiguities may arise the term 'yield' is best avoided. In particular 'specific yield' should not be used as a synonym of 'specific capacity'.

Hydraulic Conductivity

The 'co-efficient of permeability' has been mentioned in the discussion of permeability. Both a standard (laboratory) co-efficient and a field co-efficient have been used, but a 'co-efficient of permeability' expressed in any other than field conditions is probably less useful than 'permeability' - the property of the medium alone.

A 'co-efficient of permeability' which is dimensionally different to 'permeability' could be confusing, and other terms have been suggested for this combination of rock and fluid properties, the most popular probably being 'hydraulic conductivity'. HYDRAULIC CONDUCTIVITY may be defined as:

The rate of flow of groundwater through a given rock under unit potential gradient at field temperature.

A 'co-efficient of transmissibility' has also been defined (see Ferris et al. 1962) which is the hydraulic conductivity multiplied by the thickness of the saturated aquifer. There seems no reason to use 'co-efficient of' and the term transmissibility could be adopted.

Storage Co-efficient

Ferris et al. (1962) defined the co-efficient of storage of an aquifer as "the volume of water it releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface", but the storage of co-efficient is a dimensionless co-efficient, as are porosity and specific yield.

I would prefer to define STORAGE CO-EFFICIENT as:

<u>The ratio of (1) the volume of water released from or taken into storage in a prism of aquifer of unit surface area and the f[illegible] thickness of the aquifer to (2) the volume of the aquifer prism, per unit change in the component of pressure head normal to that surface.</u>

Implicit in the concept of storage co-efficient is the assumption of either "instantaneous release from storage" or "infinite drainage time". For confined conditions the storage co-efficient is a function of the elasticity of the aquifer, and the assumption of instantaneous release has proved reasonable.

Ferris et al. (op.cit.) stated that "for a water table aquifer" the storage co-efficient is sensibly equal to the specific yield. However the storage co-efficient of an unconfined aquifer, as calculated from aquifer tests consists of two components - (1) elastic yield from the full thickness of the aquifer, and (2) gravity drainage from the dewatered part of the aquifer. The calculated storage co-efficient of an unconfined aquifer is therefore partly dependent on the ratio of the thickness drained to initial saturated thickness in the particular test. If the elastic yield of the aquifer can be estimated independently it is possible to calculate the 'gravity yield' (of Rassmussen and Andreason, 1959) but the correspondence between this and the 'specific yield' (infinite drainage time) remains indefinite.

GROUNDWATER RESOURCES.

'Groundwater resources' includes the quantity of groundwater, defined in terms of storage, recharge, and discharge, together with the quality of the water and its availability for human use.

Groundwater Basin

It is impracticable to study the groundwater resources available to a single bore, particularly in areas of heavy development from closely spaced bores. Studies are best made of areas (volume) of rock, selected as having geologic and hydraulic boundary conditions suitable for quantitative analysis. The term 'Groundwater basin' is widely used for such an area (volume). The most obvious groundwater basins, and therefore these first described, are these that are close approximations to sedimentary, structural or topographic basins, but some recent usage indicates that close approximation to either geologic or a topographic basin is not a necessary condition for recognition of a groundwater basin.

Todd (1959) defined a 'groundwater basin' as "A physiographic unit containing one large aquifer or several connected and interrelated aquifers".

He qualified this definition by the following notes.

"In a valley between mountain ranges the drainage basin of the surface stream closely coincides with the ground water basin. In limestone and sand hill area, the drainage and ground water basins may have entirely different configurations", and

"The term <u>basin</u> is used very loosely in practice, and, because of its vagueness, has no clear general definition; however, it implies an area containing a ground water reservoir capable of furnishing a substantial water supply".

With an ideal groundwater basin there would be no groundwater flow into or from the basin. In practice the units treated as basins are those which most clearly approach this ideal. Lithologic, structural and topographic features may all be considered in defining a groundwater basin; however, a groundwater basin does not necessarily correspond to a drainage, sedimentary, or structural basin, but is commonly an approximation to one, two or all three of these types of basin.

As no basins are completely isolated any groundwater basin must be adequately defined in terms of the geologic and hydraulic boundaries assumed. In many cases the groundwater basin does not even approximate a discrete unit which can be considered apart from its interconnection with other basins, although wherever possible the main recharge and discharge zones of the groundwater body would be included within the basin.

The concept of GROUNDWATER BASIN is difficult to define but the following is suggested.

<u>A body of rock, containing a groundwater body or group of groundwater bodies, which has geologic and hydraulic boundaries convenient for description and analysis</u>.

If it is considered desirable to restrict groundwater basins to units which are co-extensive with either geological or topographic basins then the desirability of adopting a new term for other convenient working units in groundwater studies could be considered.

'Artesian basin' is a particular case of groundwater basin and has been defined as:

"A geologic structural feature or combination of such features in which water is confined under artesian pressure". (Meinzer, 1923), and

"The whole of an area within which pressure water exists and from which artesian or sub-artesian water is obtainable by boring, together with the area occupied by the groundwater contained in the upper and marginal portion of the water-bearing beds". (Interstate Artesian Conference 1928).

It has been generally recognized that the boundaries of an artesian basin cannot be logically placed at the change from confined to unconfined aquifer, or at the limits of artesian and sub-artesian water.

Even in Australia, 'artesian basin' has never been restricted to basins containing artesian water (in the usage suggested here for 'artesian'). However such a wide definition of artesian basin would include all the larger, and many of the smaller, groundwater basins in Australia. The general term 'groundwater basin' appears to be adequate for all purposes.

Among the terms defined by the Interstate Artesian Conference are several for minor basins tributary to or overlying larger basins. These terms do not appear to merit inclusion in a standard nomenclature.

<u>Groundwater Budget</u>

Groundwater is generally to be regarded as a continuing, renewable, resource, unlike most other mineral deposits which are regarded as non-renewable on the human time-scale, and are 'mined'. It is therefore necessary to have data on replenishment as well as storage, as expressed in the following:

"Hydrologic budget - An accounting of the inflow to, outflow from, and storage in, a hydrologic unit, such as a drainage basin, aquifer, soil zone, lake, reservoir, or irrigation project. (Langbein and Iseri,1960).

"Groundwater inventory - A detailed estimate of the amount of water added to the groundwater reservoir of a given area (recharge) balanced against estimates of amounts of withdrawals from the groundwater reservoir of the area". (Inter. Comm. Irrig. Drain).

The word inventory has, perhaps, been more commonly used, but budget suggests more clearly the joint consideration of 'income, expenditure, and capital reserves'. The following definition is suggested for GROUNDWATER BUDGET:

An accounting of the recharge to, discharge from, and storage of groundwater in, a subsurface hydrologic unit such as an aquifer or groundwater basin.

Safe Yield

Many investigations of groundwater basins aim to estimate, quantitatively, the water available for human use. Apart from the range of properties of the aquifers throughout their extent, and variations in the recharge, discharge and quality of water, the distribution of withdrawal points, intended use of the water, and the cost which can be paid for it must all be considered in determining the available water resources. The most-used term for expressing this complex of factors is 'safe yield':

"Safe yield of a groundwater basin is the amount of water which can be withdrawn from it annually without producing an undesired result". (Todd 1959).

Safe yield is employed to designate the rate at which water can be withdrawn from an aquifer for human use without depleting the supply to such an extent that withdrawal at this rate is no longer economically feasible". (Meinzer 1923).

"Maximum dependable draft which can be made continuously upon a source of water supply (surface or groundwater) over a period of years during which the probable driest period or period of greatest deficiency in water supply is likely to occur". (ECAFE Glossary 1956).

"With reference to either surface-water or groundwater supply, the rate of diversion or extraction for consumptive use which can be maintained indefinitely, within the limits of economic feasibility, under specified conditions of water-supply development". (I.C.I.D. Glossary).

The I.C.I.D. Glossary also includes definitions of 'economic yield' and 'potential yield':

"Economic Yield: The maximum rate at which water can be artificially withdrawn from an aquifer throughout the forseeable future without depleting the supply or altering the chemical character of the water to such an extent that withdrawal at this rate is no longer economically possible. The economic yield varies with economic conditions and other factors such as recharge, natural discharge, pumping head, etc. The term may be applied with respect to the economic feasibility of withdrawal from the standpoint only of those who artificially withdraw water or from the standpoint of the economy of a river valley or other longer area to which the aquifer contributes water".

"Physical Yield Limit or Potential Yield: The greatest rate of artificial withdrawal from an aquifer which can be maintained throughout the forseeable future without regard to cost of recovery. The physical yield limit is, therefore, equal to the present recharge, or that anticipated in the forseeable future, less the unrecoverable natural discharge".

'Economic Yield' is equivalent to the 'safe yield' of Meinzer and Todd and clearly distinguished from the concept expressed by 'potential

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yield'. The following definition of SAFE YIELD is suggested:

The maximum rate at which water can be artificially withdrawn from a groundwater basin without causing depletion or deterioration to the extent that withdrawal at that rate is no longer economically feasible.

It must be stressed that 'safe yield' is not a fixed figure, but must be related to all physical, economic and technical factors at a given time. It offers, of course, a basis for the prediction of future resources, but only insofar as continuity of these factors can be assumed, or changes in them anticipated. It may not be practicable in many cases to consider groundwater resources separately from surface water resources.

'Safe Yield', as defined above, is best not applied to a single bore or even a group of bores.

CONCLUSIONS

Australian usage of groundwater terms has been compared with overseas usage and considered in relation to some developments in groundwater theory since the terms were first defined. Terms, and definitions, have been recommended for some groundwater concepts but problems and inconsistencies remain, e.g. the proper use of 'aquifer' and 'potentiometric surface'.

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APPENDIX

ALPHABETIC LIST OF PREFERRED TERMS, WITH DEFINITIONS

The page numbers given are those of the text discussion of each term. References for definitions quoted, or paraphrased, from other sources are given in the text.

Aquiclude (p.8)

A body of rock which contains an interconnected system of interstices saturated with water, but which will not yield groundwater at a sufficient rate to be of local consequence as a source of supply.

Aquifer (p. 7)

A body of rock containing a system of interstices that will yield groundwater at sufficient rate to be of local consequence as a source of supply.

Aquifuge (p. 8)

A body of rock that does not contain an interconnected system of interstices.

Artesian Water (p. 14)

Groundwater of which the static level is above the ground surface.

Bedrock (p. 9)

Any solid rock exposed at the surface of the earth or overlain by unconsolidated material.

Capacity (p. 20)

Specific capacity

The capacity of a well or bore per unit drawdown.

Tested capacity

The maximum rate at which withdrawal from a well or bore is known to have been sustained.

Total capacity

The maximum rate of withdrawal from a well or bore than can be sustained for the greatest likely duration of discharge.

Cone of depression (p. 19)

The depression in a potentiometric surface resulting from the withdrawal of water from a bore. It varies in size and shape with the rate and duration of withdrawal.

Confined groundwater (p. 13)

Groundwater occupying the full thickness of an aquifer overlain by an aquifuge or saturated aquiclude.

Discharge (p. 17)

The removal of water from the zone of saturation, either to the ground surface or to the zone of aeration.

Drawdown (p. 19)

The lowering of potential at a given point in a groundwater body in or adjacent to a bore, resulting from the withdrawal of water from the bore.

Groundwater (p. 4)

The water in the zone of saturation.

Groundwater basin (p. 22)

A body of rock containing a groundwater body or group of groundwater bodies, which has geologic and hydraulic boundaries convenient for description and analysis. Generally both the recharge and discharge zones of the groundwater body lie within the basin.

Groundwater budget (p.23)

An accounting of the recharge to, discharge from, and storage of groundwater in, a subsurface hydrologic unit such as an aquifer or groundwater basin.

Hydraulic conductivity (p. 20)

The rate of flow of groundwater through a given rock under unit potential gradient at field temperature.

Infiltration (p. 16)

The movement of water through the ground surface into small interstices in either the zone of aeration or the zone of saturation.

Perched groundwater (p. 14)

Groundwater separated from an underlying body of groundwater by unsaturated rock.

Percolation (p. 17)

The flow of groundwater in the zone of saturation, under conditions in which the rate of flow is proportional to the potential gradient.

Permeability (p. 6)

The capacity of a rock to transmit fluids through its interstices.

Piezometric surface (p. 11)

An imaginary surface defined by the potentials at all points on a given plane in a groundwater body.

Porosity (p. 5)

The property of a rock that defines the degree to which it contains interstices.

Potential (p. 10)

The sum of the pressure head of the groundwater at a given point and the elevation of that point above a selected horizontal datum.

Potential gradient (p. 11)

The rate of change in potential at any point in a groundwater body: where no gradient direction is specified, the direction is that of maximum gradient.

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<u>Potentiometric surface</u> (p. 11)

An imaginary surface defined by the potentials at all points on a given plane in a groundwater body.

<u>Pressure head</u> (p. 9)

The height of a column of pure water that can be supported by the hydrostatic pressure, against the pressure of the atmosphere, at a given point in a groundwater body.

<u>Pumpage</u> (p. 20)

The amount of water withdrawn from a bore or group of bores during a stated period.

<u>Recharge</u> (p. 17)

The addition of water to the zone of saturation, either directly from the ground surface or from the zone of aeration.

<u>Safe yield</u> (p. 24)

The maximum rate at which water can be artificially withdrawn from a groundwater basin without causing depletion or deterioration to the extent that withdrawal at that rate is no longer economically feasible.

<u>Salinity</u> (p. 5)

The total content of dissolved solids of groundwater.

<u>Spring</u> (p. 18)

A place of natural discharge of groundwater as a liquid.

<u>Storage coefficient</u> (p. 21)

The ratio of (1) the volume of water released from or taken into storage in a prism of aquifer of unit surface area and the full thickness of the aquifer to (2) the volume of the aquifer prism, per unit change in the component of pressure head normal to that surface.

<u>Static level</u> (p. 10)

The level that passes through the top of a column of water that can be supported, against the pressure of the atmosphere, by the hydrostatic pressure of the water at a given point in a groundwater body, the water in the column having the same density as that in the groundwater body at that point.

<u>Sub-artesian water</u> (p. 14)

Groundwater of which the static level is above the upper surface of the groundwater body but below the ground surface.

<u>Unconfined groundwater</u> (p. 13)

Groundwater of which the upper surface is formed by surface water or by permeable rock containing air at atmospheric pressure.

<u>Underground water</u> (p. 3)

All water occurring below the ground surface.

<u>Water bore</u> (p. 18)

A hole which is drilled, jetted or augered to withdraw or replenish groundwater, or to obtain information about groundwater.

Water table (p. 12)

The surface within a groundwater body at which the hydrostatic pressure is equal to atmospheric pressure.

Water Well (p. 18)

A hole which is dug, manually or mechanically, to withdraw or replenish groundwater, or to obtain information about groundwater.

Zone of aeration (p. 4)

The zone in which interconnected interstices are filled with or partly with air and partly with water held or suspended by molecular forces.

Zone of saturation (p. 4)

The zone in which interconnected interstices are filled with water.