

WATER AND MINING: THE OCCURRENCE OF GROUNDWATER IN AUSTRALIA

By K. H. Morgan*

OCCURRENCE OF GROUNDWATER

Groundwater is water stored in the earth in the interstices in soil, sedimentary rocks, decomposed and weathered rock and in fractures and voids in crystalline rocks. Sections of interconnected water saturated rock are known as aquifers. The characteristics of groundwater occurrence can be separated into three groups: rock type, hydraulic style, chemistry (salinity). The broad features of these classifications as applied to the Australian continent are as follows.

Rock Type — Storage Control

Three broad classifications of groundwater occurrence based on rock type are recognised in relation to their control on the storage of groundwater.

CRYSTALLINE ROCKS

Crystalline rocks have limited water storage and disrupted continuity. They include igneous rocks such as granite, dolerite and basalt; metamorphic rocks such as schist, slate and greenstone; and crystalline sedimentary rocks such as cemented sandstones and crystalline limestone. These rocks form the large cratonic and structural blocks of Australia (Figure 1). Water can be stored only in joints, fractures, faults and leached zones such as provided by the solution of primary structures in volcanic rocks. The groundwater system may have poor continuity so that the groundwater storage may be divided into a number of isolated or poorly connected cells or separated aquifers. A common feature of crystalline rock groundwater storage is that both storage volume and rock permeability decrease markedly with depth. A sharp cut-off is usually present between the open fracture systems of the weathered oxidised zone and the unweathered rock. The supply from crystalline rock aquifers is often influenced by climate, *e.g.* decline in yield during drought periods.

SEDIMENTARY ROCKS

Sedimentary rocks have large storage and good interconnection. They occupy the large sedimentary basins of Australia (Figure 1) formed by depressions in the cratonic blocks. Sedimentary rocks such as sandstone within these basins can form large storages of water contained within the intergranular spaces. Some of these sedimentary sequences of

* B.Sc., FAusIMM, M.M.I.C.A., M.A.I.G., F.G.A.A.

large sandstone component not only occupy vast areas, such as the Great Artesian Basin, but also attain considerable thickness such as found in the Perth Basin (15,000 m). Water storages may have accumulated over a period of geological time (several million years) and in some cases may be poorly inter-connected, or are no longer connected to present day recharge (fossil waters). Sedimentary basins may provide large, long-term supplies of water that are not influenced by present day climate cycles.

REGOLITHS (SOILS AND SURFICIAL DEPOSITS)

Regoliths have intermittent storage and aquifer connection. They comprise soils, decomposed rock and colluvial-alluvial deposits. They generally form thin sheets of less than 20 m thick between areas of rock outcrop. In some places regoliths can form extensive sheets such as on the Yilgarn Block (Figure 1) or thick deposits such as in the Murray Darling Basin where they contain extensive aquifers. Regoliths generally have low storage, poor interconnection and storages are prone to decline in drought but respond to rapid recharge during wet seasons.

Hydraulic Style

Three principal types of hydraulic style groundwater are recognised and these relate to the amount of connection the saturated rock has with the atmosphere. The behaviour of the hydraulic characteristics is related as follows:

1. Phreatic (water table) aquifers, where the saturated rock has direct connection to the atmosphere, its barometric pressure changes, there is moisture interchange within the soil zone, evaporation and rainfall recharge (Figure 3).
2. Confined (artesian) aquifers do not have direct connection with the atmosphere. They often contain fossil water (stored from past geological periods). They respond to pressure changes, such as those imposed by earth tides, and may exchange water between adjoining aquifers separated by layers of low permeability as a result of pressure changes or major salinity gradients (Figure 5).
3. Semiconfined aquifers form an intermediate type between (1) and (2). The semiconfined layers are often formed by rocks such as siltstone whose fine grained fabric restricts rapid transfer of water (Figure 5). These aquifers are often the exchange system between phreatic and confined aquifers.

Chemistry

Chemistry of groundwater can be considered in several aspects. The first is total salinity referred to as total dissolved solids (TDS) and usually expressed in parts per million (ppm) or the similar milligrams per litre (mg/l). Total salinity defines the general usage of water, such as, less than 1000 ppm suitable for drinking or less than 14000 ppm suitable for sheep. The other aspects of water chemistry are the relative amounts of its common components, reaction or pH (1-14; 0-7 being acid and 7-14 being alkaline). The common components of groundwater are:

- 1 cations: calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+) and sodium (Na^+);
- 2 anions: chloride (Cl^-), sulphate (SO_4^-), carbonate (CO_3^{--}) and bicarbonate (HCO_3^{--}).

In regions of higher rainfall and higher potential rainwater recharge, water is fresher (Figure 4). In areas of low rainfall and high evaporation (deserts) the groundwater is usually brackish to saline. High intensity rain falls such as found in summer rainfall regions lead to concentrated recharge and groundwater water tends to have a lower salinity than the southern winter rainfall belts where rain falls over a longer time in low intensity falls.

Rainwater (H_2O) through the absorption of atmospheric carbon dioxide (CO_2) becomes acid ($\text{H}_2\text{O} + \text{CO}_2 = \text{H} + \text{HCO}_3$). This acid water causes the release of mineral matter from rock minerals in the zone of oxidation. Silicate minerals release calcium (Ca^{++}), magnesium (Mg^{++}), potassium (K^+), silicon dioxide (SiO_2^-), sodium (Na^+), iron (Fe^{++}) and other ions. Groundwater percolating through rocks is also involved in other chemical reactions. Mineral matter may be dissolved from the rocks or it may be deposited or precipitated from the percolating groundwater and added to the rock mass. Exchanges of one chemical element for another may take place, *e.g.* sodium (Na^+) may be taken up by the water and calcium (Ca^{++}) left behind in the rock making the groundwater richer in its relative amount of sodium and the clay richer in calcium.

Older waters are generally more saline, and relatively higher in chloride, magnesium and sulphate. Many desert groundwaters above the Tropic of Capricorn are high in nitrate to levels that may be dangerous to infant health. Older groundwaters have usually travelled a greater distance from the point of recharge; as a generalisation, waters near their rainfall intake points are fresher than those waters that have percolated over a long period of time, a considerable distance from their intake points. A generalised water chemistry scheme for inland aquifers in Australia is shown in Figure 4.

The chemistry of groundwater is determined by standard chemical tests either in the field or in the laboratory. Water chemistry also involves the determination of many minor or rare elements, particularly in pollution studies where special analyses involve two groups that may have significant effects on life:

1. organic matter hydrocarbons, pesticides and micro-organisms.
2. Heavy metals and other toxic chemicals mercury, lead, cadmium, zinc, fluoride, manganese, iron, aluminium, silica.

The age of waters is determined by the isotopes of hydrogen, carbon and chloride by the relationship

$$A = A_0e^{-gt}$$

Where A is the observed radioactivity
 A_0 is the radioactivity at the time of entry to the aquifer
 g decay constant
 t age of water
 e exponential

Hydrogen has an isotope tritium which is a natural isotope in the atmosphere as a result of cosmic radiation or as an increase spread worldwide after the atomic bomb explosions of 1954 and has entered the groundwater system through rainfall. This is a useful tool for measuring the ages of young waters. Tritium has a half life of 12.26 years (tritium to helium). Carbon has an isotope C14 with a half life of 5739 years and can be used to determine the ages of water to 50,000 years. Other isotopes of elements can be used for dating more ancient waters.

WATER RESOURCES

Water obeys the law of physics and chemistry; these principles can be used to measure the properties of water stored in the earth. Great progress has been made in the last few decades in the science of hydrogeology.

Hydrological Cycle

Prior to the eighteenth century, water was considered as an integral part of earth formation. During the seventeenth-century science renaissance the water cycle was recognised. Most water is derived from rainfall. Water is returned back to the atmosphere by evaporation and surface and subsurface flow (Figure 5). Most importantly, the water balance equation can be recognised; this is the basis for resource evaluation. This can be expressed as follows:

Rain = Sum of river flow + Evapotranspiration + Evaporation + Underground flow + Man and animals + Change in storage

Or

Change in storage = Inflows – Outflows

The various components of the equation can be evaluated in the following ways.

Rainfall	— meteorological records
River flow	— river gauging stations
Evaporation	— meteorological measurements
Evapotranspiration	— agricultural, forestry and botanical evaluation
Man and animals	— urban and rural records
Underground flow and change in storage	— hydrogeological evaluation

Groundwater Flow

The hydrogeologist is concerned with all the components of the water flow equation, but his particular role is in the determination of underground water storage and flow component of the above equation. In 1856 the French engineer Henry Darcy recognised that the amount of water (Q) flowing through a porous media (aquifer) is related to:

- pressure applied (hydraulic head) (i);
- cross sectional area (a) available to transmit the flow;

- the nature of the material the water is transmitted through which has a conductivity constant (k).

This equation is expressed as $Q = k.a.i.$ (Figure 6).

It is only in modern times that considerable advances have been made in the techniques of field measurement of the value of k and storage (S) measurements of large aquifers by means of controlled pumping tests and from the evaluation of regional hydrogeological data. Through these methods the evaluation of the through flow (or the natural balance of recharge) and the volume of storage in any aquifer can be determined. This information can be used to assess 'safe yield' or to allow the prediction of long-term effect on an aquifer of a given rate of abstraction. Safe yield has an important bearing on factors such as long-term use of an aquifer, seawater encroachment, saline intrusion, and coastal subsidence of the ground.

WATER REQUIREMENTS IN MINING

Uses of Groundwater

Groundwater is used in mining operations as a transport medium for materials (slurries, suspension); to physically break up materials (jetting); as a medium to which chemicals and heat are added for chemical extraction (extractive metallurgy); as a gravity separation medium (sluicing jigging, centrifuging); for dust suppression in machines, plants and drills; at the work face and on haulways; for cooling; and for infrastructure such as potable water for new mining towns.

Magnitude and Quality

The amount and quality of water required varies widely between different types of mines and the physical, legal and economic restraints imposed on the operation at any particular location. In nearly all situations, low salinity (fresh) water is preferred. Poorer quality water is used when geological and legal access restraints prevail. In most extractive metal mines (gold, copper, lead *etc.*) a crude rule of thumb is that one tonne of ore mine requires one tonne of water for metallurgical processing. A general guide to mine water quality and quantity requirements appears in Table 1.

Groundwater Exploration and the Proving of a Water Resource

The procedure taken to establish a resource is in three steps. The first step is to establish the required rate of usage and the expected life of the mine. (Most mines have finite reserves and therefore a limited life.) The second step is Regional evaluation: geology, ground access, possible present and future conflicts. During this phase a number of options are researched. The third step is access and hydrogeological evaluation, which includes:

1. land tenure, government approval to search for water;

Table 1
Mine Water Requirements

Principal Usage	
Ore treatment	— transport medium, chemical metallurgy
Dust suppression	— haulways, washing, drilling
Potable	— people, town, recreation
Examples	
<i>IRON ORE MINE</i>	— 80,000t day ore production
5,000 people	— 5,000 to 20,000m ³ water day potable (less 1,000 ppm TDS and soft)
Process requirements:	
Volume	— 20,000t mostly dust control
Quality	— variable main restraint corrosion
<i>BASE METAL MINE</i>	— 3,000t day ore production
1,000 people	— 1,000–5,000m ³ day potable water
3,000 to 5,000 tonnes of industrial water	5,000 to 30,000 ppm concentrator, smelting refining
<i>ALLUVIAL OPERATIONS</i>	
	— Gold, tin, tantalite, diamond, etc.
Quality	— can use very saline water, main problem is corrosion and frothing of highly saline water
Quantity	— 3 to 10m ³ water per m ³ gravel
<i>GOLD MINES</i>	
	Open cut and underground hard rock ore
	Weathered and clayey decomposed rock ore
	Tailings dumps
Process:	Crushing, grinding, roasting, floatation, carbon-in-pulp, heap leaching
Water requirement:	1 to 1.5m ³ water per tonne of ore depending on efficiency of tailings returns and clay generation
Quality:	Can use up to 200,000 ppm TDS. Restraints on high salinity water are pH and calcium magnesium content. Lime or sodium hydroxide is added to adjust cyanide solution to pH 8 to 9. High salinity or low pH results in high chemical use and carbonate deposition and clogging of process.

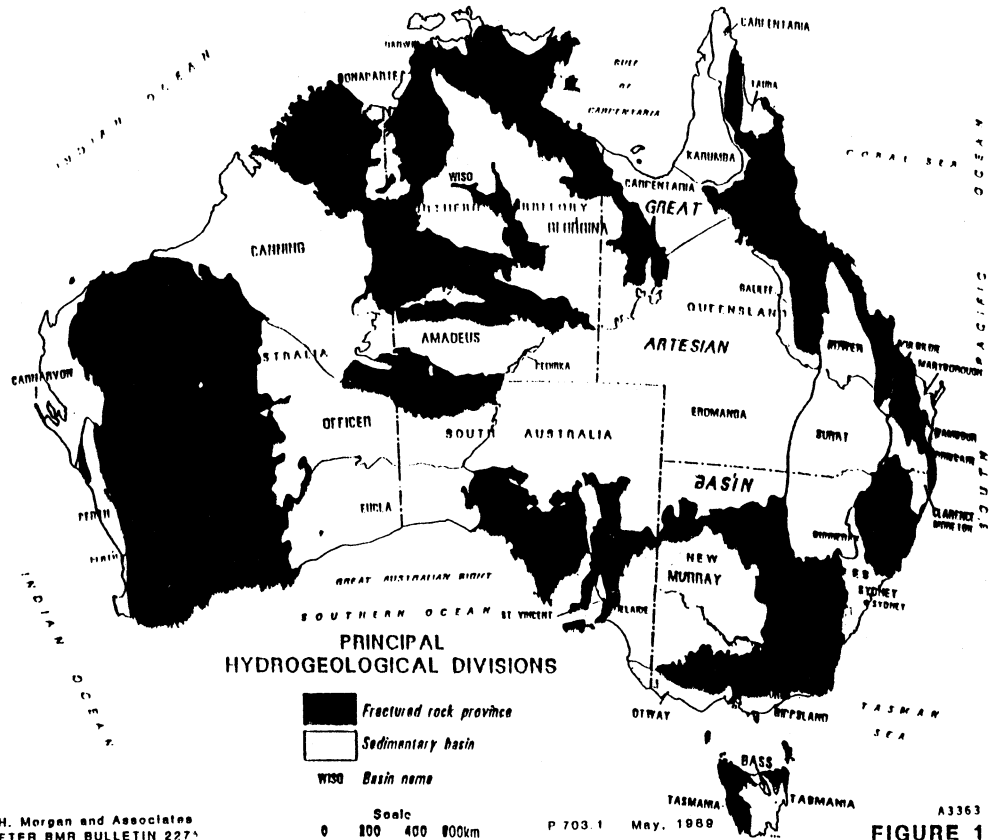
- 2 geological evaluation by data research, remote sensing (satellite), geological mapping, geophysics, drilling, hydraulic testing, resource evaluation, wellfield, pipeline and storage design;
- 3 approvals by mine planning, government agencies;
- 4 extraction management as a requirement of laws, mine management, forward predictions and planning.

Legal and Economic Restrictions

The attitudes to water supply as a component to mine planning have varied considerably in Australia over the last 50 to 100 years. In the early mining years (turn of the century development where technology

was a major restraint), the lack of water, or indeed in many cases too much water, was often a factor in the failure of a mining operation. From the 1930s to the last few decades, development and technology have been highly advanced, competition for resources has been relatively weak and legal restraints little enforced (Water, Land, Forestry, National Parks, Environmental Protection, Aboriginal legislation). During this period mines accepted that water could be readily supplied to any proposed mining operation. In the last few decades this has changed: mine planners now realise that the provision of a water supply may be a major factor in mine feasibility, despite improvement in the technology to locate and prove water resources. The minefield of negotiations required to gain access to areas containing a potential water resource may now take more time and cost expenditure than the cost of technical work involved in proving and the construction of the water supply system. The time involved in these negotiations can be longer than the whole mining plant and infrastructure construction.

Planning a water supply should begin immediately a potential mineral resource is recognised and not after the ore reserves have been proven. At this stage, outside competition may have already become the overriding factor, apart from the time factor involved in government procedures. The parameters that govern the selection of the particular water source used are distance, quantity, quality and access. Distance is not a linear cost. Distance can result in an almost exponential cost increase due to the increase in the number of access factors involved such as private land, government reserves, physical barriers and environmental restrictions. It may be better to establish a more difficult to manage saline source closer to the mine site. Water quality may create economic restraints such as poorer metallurgical extraction, higher treatment or chemical additive requirements, desalination and provision for environmental protection of the area due to saline spillage and seepage. The direct cost of acquiring access or the time taken to negotiate access or to wait for government procedures such as additions to Parliamentary Acts (ministerial reserves) may govern the selection of the water source.



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FIGURE 1

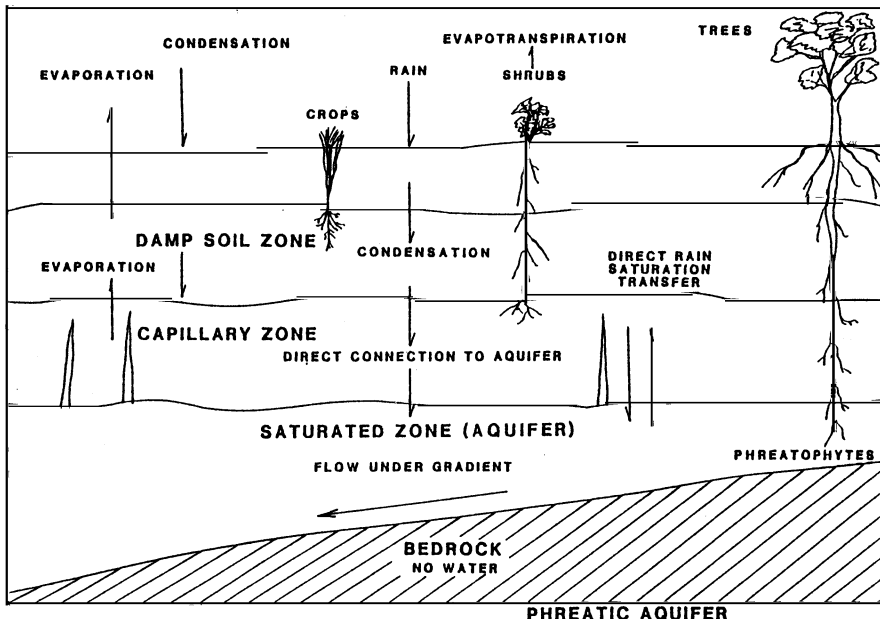
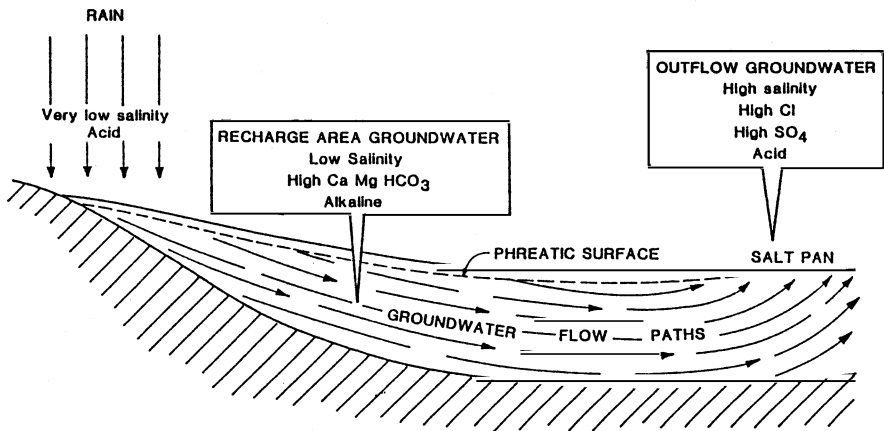


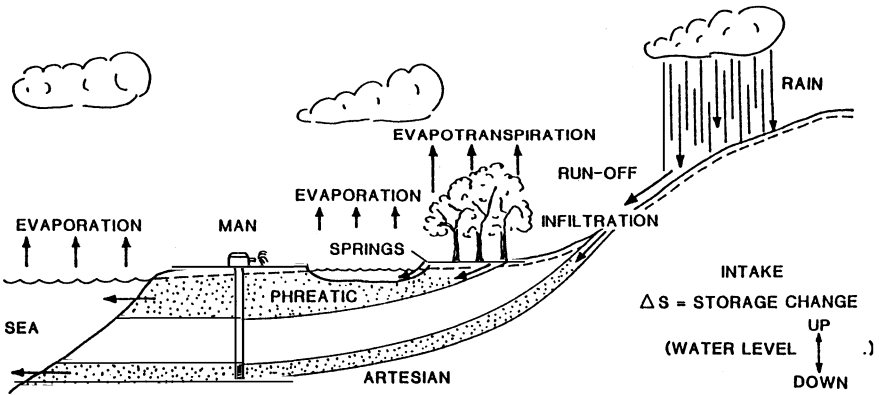
FIGURE 3



**GROUNDWATER
FLOW AND CHEMICAL TRENDS
IN A SEMIARID - ARID REGIONS**

FIGURE 4

HYDROLOGICAL CYCLE



$$\text{RAIN} = \text{RUN-OFF} + \text{EVAPORATION} + \text{EVAPOTRANSPIRATION} + \text{STORAGE CHANGE} + \text{GROUNDWATER FLOW} + \text{USE BY MAN AND ANIMALS}$$

$$\text{CHANGE IN WATER STORAGE} = \text{SUM OF INFLOWS} - \text{SUM OF OUTFLOWS}$$

FIGURE 5

DARCYS LAW

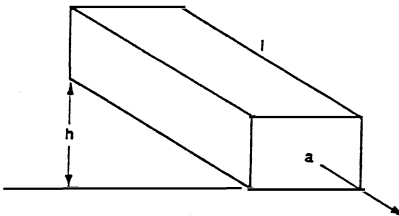
Henry Darcy - French hydraulic engineer, 1856

$$Q = ka i$$

k = coefficient or constant of permeability

a = area transmitting water

i = gradient of head = $\frac{dh}{dl}$



$$Q = ka \frac{dh}{dl}$$

$$V = \frac{Q}{A} = k \frac{dh}{dl}$$

FIGURE 6