GROUNDWATER EXPLORATION FOR AGRICULTURAL USE USING RESISTIVITY IMAGING IN PENINSULAR MALAYSIA

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GROUNDWATER EXPLORATION FOR AGRICULTURAL USE USING RESISTIVITY IMAGING IN PENINSULAR MALAYSIA

by

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Muhammad Kadri

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ABBREVATIONS

1-D	One Dimensional
2-D	Two Dimensional
3-D	Three Dimensional
Ann	Annual
BH	Borehole
MLD	Million Liters per Day
VES	vertical electrical sounding

SYMBOLS

a	Electrode spacing
C1,C2	Current electrodes
K	Geometric factor
mA	milli ampere
m	meter
m^2	meter square
m^3	meter cubic
p1, p2	Potential electrodes
r	distance between current electrodes and potential electrodes in general
s	second
R	resistance
V	voltage
ρ_a	apparent resistivity
ℓ	length
ρ_w	water resisitivity,
π	a constant (3.141593)
ρ	resistivity
m	cementation factor and
Φ	the fractional porosity
Ωm	ohm meter (unit of resistivity)

PENCARIGALIAN AIR TANAH UNTUK KEGUNAAN PERTANIAN DENGAN MENGGUNAKAN KAEDAH PENGIMEJAN KEBERINTANGAN DI SEMENANJUNG MALAYSIA

ABSTRAK

Air tanah ialah komponen sangat penting sebagai salah satu punca bekalan air. Penggunaan air tanah semakin meningkat dengan pertumbuhan penduduk. Aktiviti manusia dan industri menyumbang kepada pencemaran air dan sungai. Dalam pertanian, kecekapan dalam penggunaan air dalam pertanian adalah masih rendah. Kecekapan dalam hal pertanian kira – kira 40 sampai 50 peratus kerana hampir semua sistem pertanian ialah sistem terbuka yang telah dirancang untuk mengambil faedah daripada banjir. Dalam kajian air tanah ini dicadangkan untuk sebagai tambahan sebagai bekalan air alternatif bagi kegunaan pertanian. Di Malaysia kini hanya kurang dari 2% air yang digunakan dari air tanah. Untuk eksplorasi air tanah digunakan kaedah yang popular iaitu kaedah pengimejan keberintangan 2-D. Kaedah ini adalah kaedah yang sering digunakan untuk mencari air tanah. Air tanah adalah baik untuk keperluan pertanian. Terdapat lima kawasan kajian di Semenanjung Malaysia iaitu Johor, Terengganu, Perak, Kedah dan Perlis. Susunatur yang berbeza digunakan dalam tiap – tiap kawasan kajian yang berbeza. Di Pagoh, susunatur yang digunakan ialah susunatur Wenner Schlumberger, di Marang dan Ipoh digunakan susunatur Pole Dipole, mana kala di Pendang susunatur yang digunakan ialah susun atur Wenner dan Wenner Schlumberger dan terakhir di Chuping, susunatur yang digunakan ialah susunatur Wenner, Wenner

Schlumberger dan Pole Dipole. Tapak tinjauan di Pagoh menunjukkan adanya air bawah tanah. Hal ini ditunjukkan dengan nilai – nilai rintangan sekitar 10 sampai 100 ohm-m. Secara umum hasil menunjukkan bahawa bawah permukaan terdiri daripada alluvial dan tanah liat dan nilai – nilai rintangan lebih tinggi mula dari 1000 ohm-m yang dekat dengan permukaan adalah laterit dan kedalaman akhir dapat di ertikan sebagai campuran bahan yang terluluhawa atau juga batuan. Tapak tinjauan di Marang, menunjukkan adanya air bawah tanah. Secara umum hasil menunjukkan bahawa bawah permukaan terdiri dari batu pasir dan tanah liat dengan nilai rintangan kurang dari 100 ohm-m dan batu pasir dengan rintangan lebih dari 2000 ohm-m. Di semua zon boleh menjadi sumber air bawah tanah. Semua garisan di Ipoh menunjukkan adanya air bawah tanah. Umumnya dibawah permukaan bawah terdiri dari pasir dan tanah liat nilai rintangan kurang dari 100 ohm-m dan batu kapur dengan rintangan lebih dari 2000 ohm-m. Di Pendang Pula menunjukkan adanya bekalan air tanah, semua garisan tidak mengesan adanya bekalan air. Di Chuping hasil kajian menunjukkan adanya akuifer. Terdapat air tanah memenuhi rongga berlaku secara terpencil di kedalaman anggaran 7.7 m. kehadiran rongga tidak memungkinkan untuk memanfaatkan bekalan ini dengan kapasiti maksimum. Pada kedalaman 5 m terdapat batuan dasar dan dari kedalaman 27 sampai 30 m terdapat zon retakan. Ini menunjukkan bahawa zon retakan pada kawasan ini asal daripada kejadian air bawah tanah. Air bawah tanah boleh dikesan pada kedalaman 15 sampai 18 meter di kawasan ini.

GROUNDWATER EXPLORATION FOR AGRICULTURAL USE USING RESISTIVITY IMAGING IN PENINSULAR MALAYSIA

ABSTRACT

Groundwater is a very important component of water resources. The demand of water increases with increasing population growth. Human activities and industries contribute to pollution of stream and river. In agriculture, efficiency of water use in irrigation in general is low. Irrigation efficiency is in the range of 40 to 50 percent because almost all of the irrigation systems are open systems designed to take advantage of flooding. In this study groundwater is suggested to supplement as an alternative source of water for irrigation. In Malaysia only less than 2% of the present water used is developed from groundwater. 2-D resistivity imaging is used in order to determine the existence of usable groundwater. This method is the most commonly method that been used for groundwater exploration. The groundwater found is used for irrigation purposes. In this study there are five study areas in Peninsular Malaysia for groundwater exploration which are in Johor, Terengganu, Perak, Kedah, and Perlis. Different arrays were employed in the study at different site, for example the array used in Pagoh is Wenner Schlumberger. The array used in Marang and Ipoh are Pole dipole. The arrays used in Pendang are Wenner and Wenner Schlumberger and the site in Chuping the arrays used are Wenner, Wenner Schlumberger and Pole dipole. In Pagoh, the survey site shows the existence of groundwater. It is indicated by the resistivity values about 10 - 100 ohm-m. In general the results show that the subsurface is made up of alluvium and

clay and the high resistivity values of more than 1000 ohm-m near the surface is due laterite and the end of the depth can be interpreted as mixture of weathered material or bedrock. In Marang, the survey site shows the existence of groundwater. In general the results show that the subsurface is made up of sand and clay (resistivity value of less 100 ohm-m) and sandstone with resistivity of more than 2000 ohm-m in all the sections. This zone can be a source of groundwater. In Ipoh all the two lines shows the existence of groundwater. Generally, the subsurface is made up of sand and clay (resistivity value of less 100 ohm-m) and limestone with resistivity of more than 2000 ohm-m. In Pendang, the results indicate there are no groundwater storage. In Chuping the results of the study showed that there is an aquifer. The water filled cavity occurred in an isolated manner at an approximate depth of 7.7 m. It was further observed that the cavity did not allow the harnessing of this resource to the fullest capacity. At a depth of 5 m there is bedrock and from a depth of 27 to 30 m there is a fractured zone. This is indicating that fractured zone in this area contains of groundwater. Groundwater is detectable at a depth of 15 to 18 meters in this area.

CHAPTER 1

INTRODUCTION

1.1 Background

In many countries of the world, there is a heavy dependence on groundwater as a source of primary drinking supply as well as for both agricultural and industrial use. The dependence on groundwater is such that it is necessarily important to always ensure the presence of significant quantities and qualities of groundwater in a given area. As in many countries in the world including in Peninsular Malaysia, groundwater exploration is necessary because the increasing number of population of the country and reducing of clean water. Water is one of the most basic needs and vital sources of life for all living beings. Water has become an important source for many purposes. Beside to human consumption and agriculture, water is also used for power generation, manufacturing, processing of goods, general cleaning products and much more. In Malaysia, the main water source comes from the earth's surface like a damning rivers, dams and so forth. Nevertheless, the groundwater in Malaysia is still yet to be exploited on a bigger scale to meet the increasing demand for various uses (Mohammed *et al*. 2009).

Many factors can possibly cause the water crisis in Malaysia. The factors that mostly evoked the crisis are the rapid population growth and the existence of climate change.

Many states in Malaysia, such as Perlis, Kedah, Negeri Sembilan, Johor and Sabah are experiencing in water crisis. It is a good example to inspect how climate will affect the consistency in water supply service (the Star online, 2010).

Therefore we need other alternatives in the use of water. One the alternative is the use of groundwater

Water crisis occurs especially during dry weather. Water crisis had occurred at some states in Malaysia, such as in Kedah, Negeri Sembilan, Johor and Sabah (the Star online, 2010). Water shortages will continue to grow caused by the increasingly rapid growth of population and the number of water pollution that occurs to the surface or due by the existence of global warming and it became increasingly more serious because of the demand of water in agricultural purposes is constantly on the rise every year. Malaysia used up 8.7 billion m^3 of water to irrigate paddy field in 1980 and rise up to 15.2 billion m^3 in 2000. In agriculture, efficiency of water use in irrigation in general is low. Irrigation efficiency is in range of 40 to 50 percent because almost all of the irrigation systems are the open systems designed to take advantage of flooding. In this study, groundwater is suggested to become an alternative water resource for irrigation that supplements the available water resources.

Figure 1.1 shows the distribution of agriculture area in Peninsular Malaysia.

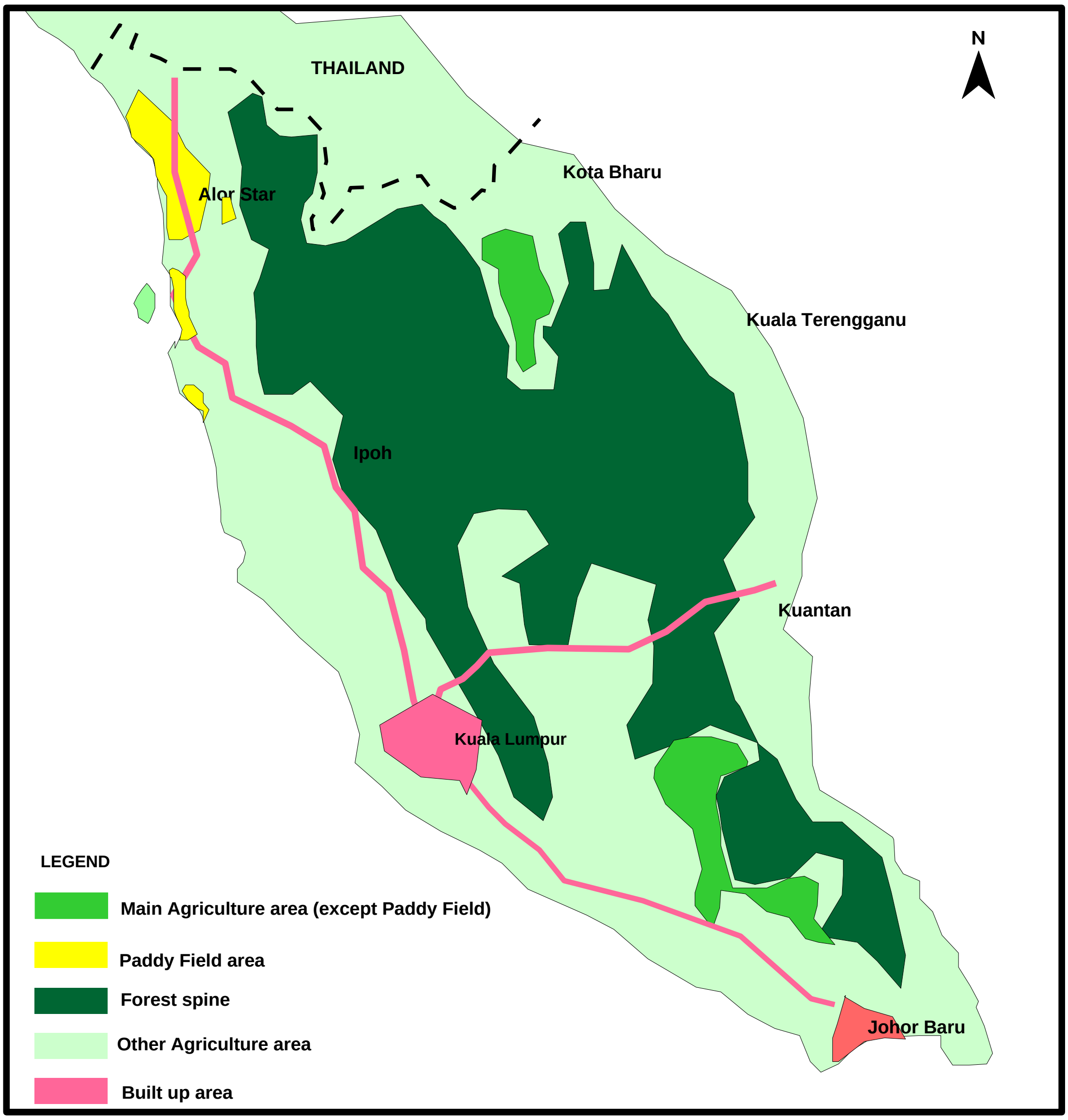


Figure 1.1 Agriculture distribution in Malaysia (www.townplan.gov.my).

Therefore it is important to explore groundwater for agricultural purposes especially for paddy field in Peninsular Malaysia. It is expected to increase the production of paddy field.

Over the years, there has been a tremendous increase in the application of geophysical methods for mapping and evaluating quantity and quality of groundwater resources. However, challenges often faced by geophysicists in adequately mapping a potential groundwater aquifer is largely dependent on the geologic formation, among other things, of the area under investigation and this further informs the choice of the appropriate geophysical method(s) to be adopted for the search of this natural resource.

Therefore it is necessary to explore groundwater by using geophysical method to prevent the water crisis becoming more severe.

Geophysical techniques have been applied to groundwater problem such as mapping the depth, thickness, and continuity of aquifers, fractured rock aquifers, individual bedrock fractures or fracture zone, saltwater intrusion into coastal aquifers, depth to consolidated bedrock, and buried valleys, as well as aquifer lithology, porosity, permeability, and the degree of weathering and jointing of an aquifer or water bearing rock mass (Kelly and Mares, 1993).

A variety of geophysical techniques have been successfully used for groundwater studies including electrical methods in Malaysia by Nawawi *et al.* (2001) and Umar *et al.* (2006). The electrical method is the most commonly utilized because of low cost as well as interpretation aids (Fitterman and Stewart, 1986).

1.2 Problem Statement

The dependence on water as a source of agricultural supply in Malaysia has increased recently. Because the water were used not only for agricultural purposes but also for many uses. Therefore it is necessary to explore groundwater as an alternative supply for agricultural uses. The exploration of groundwater was undertaken in several areas in Peninsular Malaysia. There are Pagoh, Marang, Ipoh, Pendang and Chuping. These five areas were chosen because it is able to represent the entire of Peninsular Malaysia and also these areas seem to have support for further reduced the water crisis in Peninsular Malaysia.

The exploration was carried out to find possible groundwater resources. 2-D resistivity imaging was utilized to explore the groundwater. Especially in Pendang and Chuping the result were then correlated with the provided borehole data in the corresponding survey area.

1.3 Objective of Study

1. To determine the existence of usable groundwater for agricultural purposes at several areas in Malaysia by using resistivity imaging
2. To investigate the groundwater potential for irrigation supply.
3. To study the characterization of water reservoir by using 2-D resistivity and borehole.

1.4 Layout of thesis

Chapter 1 of this thesis is concerned mostly with the reduction of water for domestic purposes, industry and agriculture caused by increasing population and decreasing supply of clean water due to contaminated water and due to climate change.It concerned with the strategy to overcome the water crisis occurred in some areas in Malaysia which are Pagoh, Marang, Ipoh, Pendang and Chuping. The 2-D resistivity imaging is a technique to be used to explore the groundwater especially in Pendang and chuping with comparisons to the corresponding borehole data, which are one borehole in in Pendang and two Boreholes in Chuping.

Chapter 2 is concerned with the literature review and the work of previous researchers on the role of geophysics and in particular, role of resistivity in groundwater prospecting.

Chapter 3 describes the method of investigation and the method that will be used in this research.

Chapter 4 describes general geology of the survey area including soil, climate and rainfall, water resources and also the description of the study area and it is also concerned with the field work and data processing and also explains the method that was used in this research.

Chapter 5 shows the result of the investigations.

Chapter 6 contains summary and conclusion of this research.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydrological Cycle

Water that we use every day experiences hydrologic cycle. The hydrologic cycle is the series of transformation that occur in the circulation of water from atmosphere onto surface and into the subsurface regions of the earth then back from surface to the atmosphere as shown Figure 2.1.

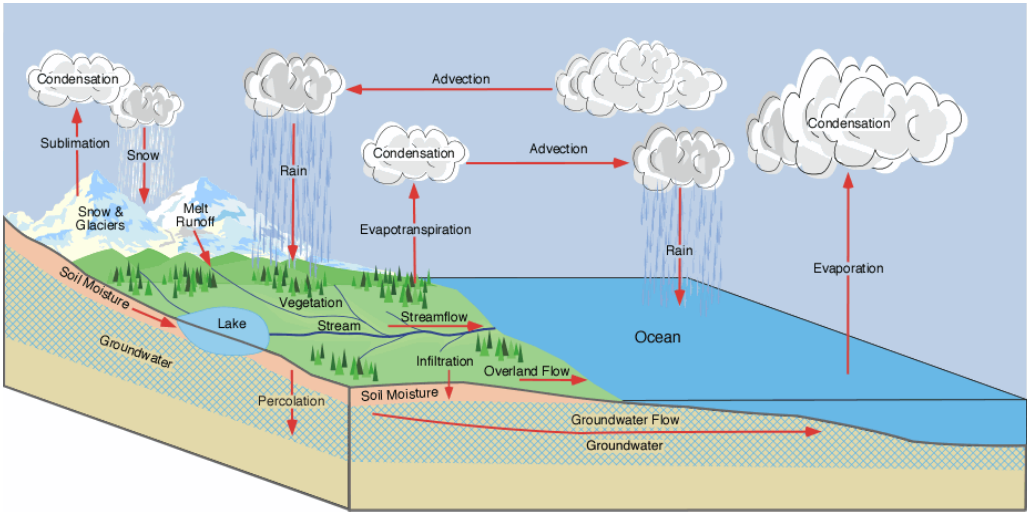


Figure 2.1 The Hydrogical cycle (after Pidwirny, 2006).

The sun, which drives the water cycle, heats water in oceans and seas. Water evaporates as water vapor into the air. Ice and snow can sublimate directly into water vapor. Evaporation is water transpired from plants and evaporated from the soil. Rising air currents take the vapor up into atmosphere where cooler temperature causes it to condense into cloud. Air currents move water vapor around the earth's cloud particles collide, grow and fall out of the sky as precipitation. The precipitation in Malaysia is relatively high as shown in Table 2.1. Some precipitation falls as snow or hail and can accumulate as ice caps and glaciers, which can frozen water for thousands years. Most water falls back into oceans or onto land as rain, where the water flows over the ground as surface runoff. A portion of runoff enters rivers in valleys in the landscape, with stream flow moving water toward the oceans. Runoff and groundwater are stored as freshwater in lakes. Not all runoff flows into rivers, much of it soaks into the ground as infiltration. Some water infiltrates deep into the ground and replenishes aquifers, which store freshwater for long periods of time. Some infiltration stays close to the land surface and can seep back into surface-water bodies and the ocean as groundwater discharge.

Groundwater is stored in and moves slowly through layers of soil, sand and rocks called aquifers. Groundwater flows depend on the size of the spaces in the soil or rock and how well the spaces are connected.

The part of precipitation that fall into the soil piled on top of a bed waterproof and saturated pore space available to form the body of underground water is called an aquifer. Water contained in the aquifer and the groundwater component contributes of the cycle from which the natural flow reaches rivers and streams, wetlands and ocean.

Table 2.1 Summary of monthly precipitation in some states of Malaysia (after Zakaria, 2008).

Subregion name		West coast	Selangor	Terengganu	Kelantan	Pahang	Perak	Kedah	Johor
Maximum monthly precipitation (mm)	Historical	600.0	564.1	1271.2	929.7	633.6	722.9	626.7	591.7
	Future	560.3	525.7	1913.9	1128.5	684.6	767.8	705.3	538.2
	Diff	-39.7	-38.4	642.7	198.8	51.0	44.9	78.3	53.5
	(%)	-6.6	-6.8	50.6	21.4	8.0	6.21	12.5	-9.0
Mean monthly precipitation (mm)	Historical	179.2	190.2	289.0	221.8	198.5	192.9	173.6	187.3
	Future	176.2	180.9	299.0	239.5	208.4	199.4	176.6	180.0
	Diff	-3.0	-9.3	10	17.7	9.9	6.5	3.0	-7.3
	(%)	-1.7	4.9	3.5	7.9	4.9	3.4	1.7	-3.9
Minimum monthly precipitation (mm)	Historical	12.4	12.2	33.6	15.4	24.5	9.0	2.1	13.3
	Future	7.9	8.3	14.0	10.9	16.6	4.1	1.1	5.2
	Diff	-4.5	-3.9	-19.6	-4.5	-7.9	-4.9	-1.0	-8.1
	(%)	-36.3	-32	-58.3	-29.2	-32.2	-54.4	-50	-60.9

The land contained in the water beneath the land surface between the unsaturated zone below the ground, a suburb of capillaries beneath the water and that beneath the water table as shown in Figure 2.2.

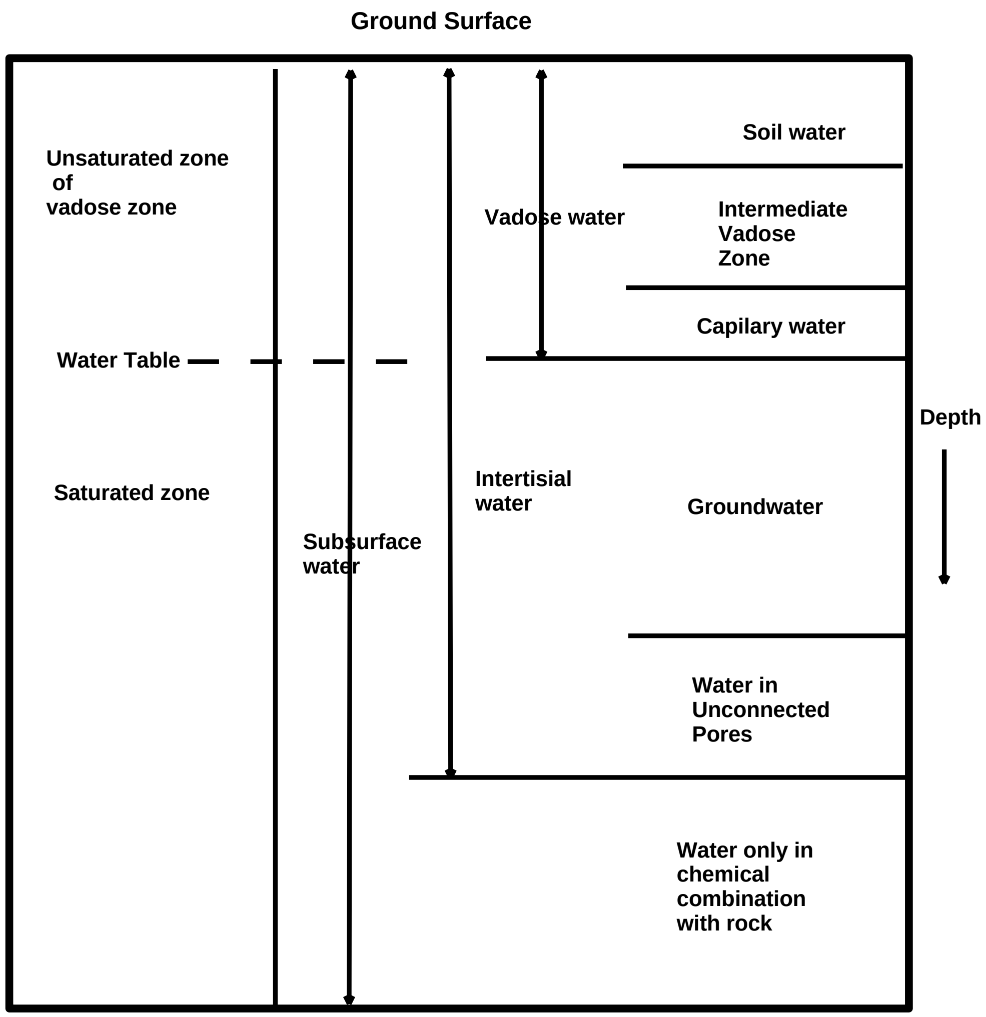


Figure 2.2 Layer of soil (modified from Driscoll, 1986).

Therefore, groundwater refers only to water in water saturated zone under the water table and column totals for water under the earth surface is usually called the water below the surface. Saturated and unsaturated zone actually connected. The position of water table seasonally fluctuates from time to time (Schmoll, 1996).

2.2 Groundwater

Groundwater is water located beneath the earth's surface. Groundwater is water that can be consumed by living things and it is the most widely on the percentage of water that can be consumed as compared to other edible water. It is very important to explore groundwater as alternative water from existing water right now. Groundwater is that part of precipitation that infiltrates through the soil to the water table. The unsaturated material above the water table contains air and water in the spaces between the rock particles and supports vegetation. In the saturated zone below the water table, ground water fills in the spaces between rock particles and within bedrock fractures.

The area where water fills these spaces is called the saturated zone of a geologic formation. The top of this zone is called by water table.

Groundwater has been exploited for domestic use, agriculture, livestock and irrigation since the earliest times. Although the precise nature of its occurrence was not necessarily understood, successful methods of bringing the water to the surface have been developed and groundwater use has grown consistently ever since. It is, however, common for the dominant role of groundwater in the freshwater part of the hydrological cycle to be overlooked.

Groundwater is easily the most important component and constitutes about two thirds of the freshwater resources of the world and, if the polar ice caps and glaciers are not considered, groundwater accounts for nearly all usable freshwater. Even if consideration is further limited to only the most active and accessible groundwater bodies then they constitute 95% of total freshwater. Lakes, swamps, reservoirs and rivers account for 3.5% and soil moisture accounts for only 1.5% (Freeze and Cherry, 1979).

Distribution of water on earth is divided into two main divisions, saltwater and freshwater. There are about 97% of all water is salt water of water from the sea, while the remaining 3% is fresh water. Fresh water is divided into 68.7% glaciers and icecaps, while the remaining 30.1%, 0.3% and 0.9% are groundwater, surface water and others respectively. Surface water is divided into the lake is 87%, swamps is 11% and rivers is 2% as shown in Figure 2.3 (Gleick, 1996).

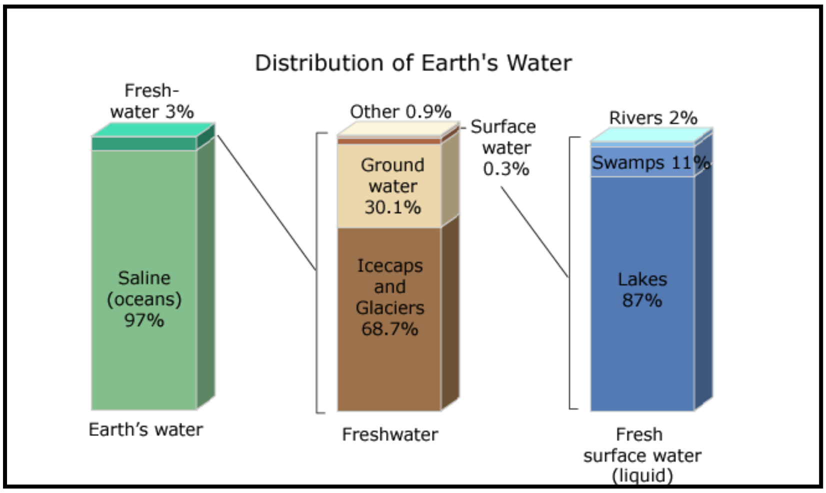


Figure 2.3 Distribution of earth's water (after Gleick, 1996).

The amount of water on the surface of the earth is basically no change either under or above the earth's surface. Although a small amount of water vapor will come out into space. Table 2.2 shows the estimated volume of various types of water, above and below the earth's surface 1,338,000,000 km^3 of sea water (Maidment, 1993). Thus, fresh water makes up only 3% of all water on earth but not all this water available for human use. Water ice at the poles, other forms of ice and snow, soil moisture, swamp, systems biology, and the atmosphere is not available for human use. As a result only 10.53 million km^3 of groundwater, 91,000 km^3 of fresh water in the lake, and 2120 km^3 of water in the river is considered affordable to use and consist of a total of 10,623,120 km^3. As a result, groundwater comprises 99% of available fresh water of the earth (Gleick, 1996).

Table 2.2 Estimates of relative volumes of water of various kinds on earth (after Gleick, 1996).

Item	area 10^6 km^2	Volume km^3	Percent of total water	Percent of fresh water
Oceans	361.3	1,338,000,000	96.50	
Groundwater: Fresh Saline	 134.8 134.8	 10,530,000 12,870,000	 0.76 0.93	 30.10
Soil moisture	82.0	16,500	0.0012	0.05
Polar ice	16.0	24,023,500	1.7	68.6
Other ice and snow	0.3	340,600	0.025	1.0
Lakes: Fresh Saline	 1.2 0.8	 91,000 85,400	 0.007 0.006	 0.26
Marshes	2.7	11,470	0.0008	0.03
Rivers	148.8	2,120	0.0002	0.006
Biological water	510.0	1,120	0.0001	0.003
Atmospheric water	510.0	12,900	0.001	0.04
Total water	510.0	1,385,984,610	100	
Fresh water	148.8	35,029,210	2.5	100

2.3 Occurrence of groundwater

Rock materials may be classified as consolidated rock often called bedrock and may consist of sandstone, limestone, granite, and other rock, and as unconsolidated rock that consists of granular material such as sand, gravel, and clay. Two characteristics of all rocks that affect the presence and movement of groundwater are porosity (size and amount of void spaces) and permeability (the relative ease with which water can move through spaces in the rock).

Consolidated rock may contain fractures, small cracks, pore spaces, spaces between layers, and solution openings, all of which are usually connected and can hold water. Bedded sedimentary rock contains spaces between layers that can transmit water great distances. Most bedrock contains vertical fractures that may intersect other fractures, enabling water to move from one layer to another. Water can dissolve carbonate rocks, such as limestone and dolomite, forming solution channels through which water can move both vertically and horizontally. Limestone caves are a good example of solution channels. Consolidated rock may be buried below many hundred feet of unconsolidated rock or may crop out at the land surface. Depending upon the size and number of connected openings, this bedrock may yield plentiful water to individual wells or be a poor water-bearing system.

Unconsolidated material overlies bedrock and may consist of rock debris transported by glaciers or deposited by streams or deposited in lakes. It also may consist of weathered bedrock particles that form a loose granular or clay soil. Well-sorted unconsolidated material can store large quantities of groundwater; the coarser materials which are sand and gravel readily yield water to wells.

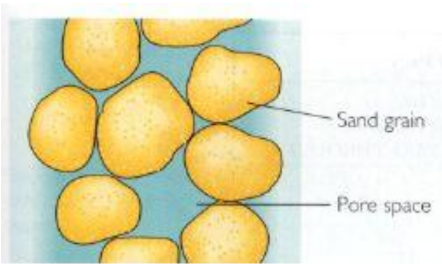
A close look at the rocks exposed in road cuts and along streams will show the types of openings in which ground water can occur. Especially noticeable in bedrock exposures are spaces between layers that can extend for miles-the void spaces between rocks particles contain water that percolates into these spaces between the layers. In most sand and gravel deposits, water occupies and moves freely within granular material.

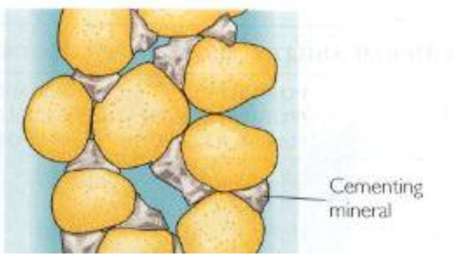
2.3.1 Porosity

The porosity is the ratio between the volumes of the pores and that of the rock. When dealing with saturated layers (under the water level, that is to say under the vadose zone where the pores are filled with air and with water), the water content is equal to the porosity.

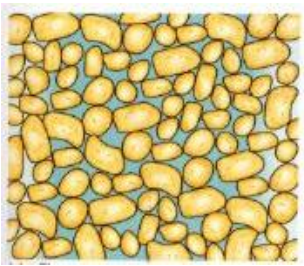
Porosity = (volume of pores) / (volume of the rock)

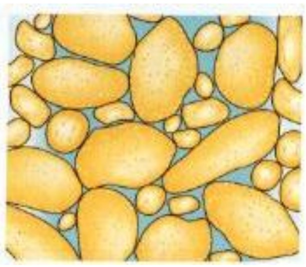
Being a ratio, the porosity is expressed in %. The total porosity also includes the water located in clay, even if clay is impermeable. For the exploitation of water, it is important to determine the porosity of free water, and hydrogeologists speak of the effective porosity which is the ratio of the volume of the pores which are interconnected to the volume of the rock. As an order of magnitude, the effective porosity can be for instance 80% of the free water porosity. The porosity of a fissured rock can be a few percents, that of a gravel or a sand of the order of 30 percents. Figure 2.4 shows the porosity of various stones.



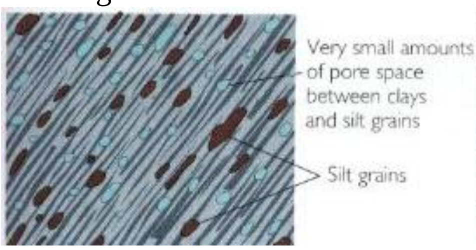


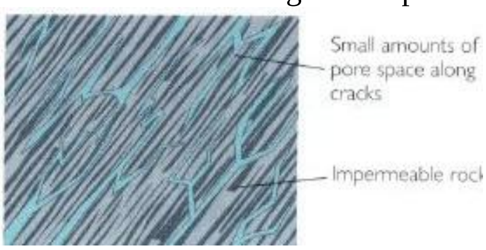
a. Porous sandstone b. Cemented sandstone





c. Fine grained sandstone d. Sandstone with irregular shapes





e. Unfractured shale f. Fractured shale

Figure 2.4 Porosity of various stones (after Todd, 1980).

Soil and rock are composed of solids and voids or pores. Groundwater can fill up and flow through pores. Pores formed at the same time as the rock such as in sand, gravel, and lava tubes in basalt, are called primary openings. Pores formed after the rock was formed are called secondary openings. Examples are fractures in massive igneous rocks like granite and the caves and caverns in limestone. The pore sizes vary and may not be filled with water. The ratio of volume of the pore space to the total volume of the soil or rock is called porosity. Table 2.3 shows the properties of soil and rocks and Table 2.4 shows the porosity of some geological materials.

Table 2.3 Porosity of some physical properties of soil and rocks (after Domenico and Schwartz, 1990).

Lithology	Porosity (%)
Unconsolidated	
Gravel	25–40
Sand	25–50
Silt	35–50
Clay	40–70
Glacial Till	10-20
Indurated	
Fractured Basalt	5–50
Karst Limestone	5–50
Sandstone	5–30
Limestone, Dolomite	0–20
Shale	0–10
Fractured Crystalline Rock	0–10
Dense Crystalline Rock	0–5

Table 2.4 Porosity of geological materials (after Freeze and Cherry, 1979).

Material	Porosity (%)
Unconsolidated sediments	
Gravel	25 – 35
Coarse sand	30 – 45
Fine sand	26 – 50
Silt	35 – 50
Clay	45 – 55
Sand and Gravel	20 – 30
Glacial till	20 – 30
Consolidated sediment	
Sandstone	5– 30
Siltstone	20 – 40
Limestone and dolomite	1 – 25
Karstic limestone	5 – 35
Shale	1 – 10
Igneous and metaporhic rocks	
Vesicular basalt	10 – 40
Fractured basalt	5 – 30
Tuff	10 – 55
Fresh granite and gneiss	0.01 – 3
Weathered granite and gneiss	5 – 25

2.3.2 Permeability

Permeability is a measure of the degree to which the pore spaces are interconnected and the size of the interconnections. It is actually the hydraulic conductivity is the ability of a material to let some water current flow through it when a hydraulic pressure is applied, can be defined on a sample of rock by the Darcy law:

$$\text{Permeability} = \frac{\text{Yield / Section}}{\text{Pressure gradient}}$$

The yield being expressed in m^3s^{-1}, the sample section in m^2 and the pressure gradient (difference of water pressure/sample length) in m/m, the unit of permeability is ms^{-1}.

If the porosity is almost zero the permeability is necessarily also very weak. But the porosity can be high, such as in the case of a clay layer, and the permeability very weak. The permeability already includes the information of the porosity for determining the volume of water which can be extracted from the ground. The permeability is linked not only to the volume of the available water, but also to the size of the pores: for a given value of the porosity, large size pores lead to a higher permeability than small size pores, as the water flows more easily in the first case than in the second one. The permeability of a clay layer can be as low as 10^{-10} ms^{-1}, of a weakly permeable layer 10^{-6} ms^{-1}, of a highly permeable layer 10^{-2} ms^{-1} (www.Geo-Hydrology.com).

The property of permeability is related to porosity. In qualitative terms, permeability is expressed as the capacity of a porous rock or soil to transmit a fluid. Large interconnected pore openings are associated with high permeability, while very small unconnected pore openings are associated with low permeability. Sand and gravel with large interconnected pore openings have high porosity and permeability.

Clay tends to have high porosity, but the very small openings tend to inhibit the passage of water. Therefore, clay displays low permeability.

2.4 Water table

Water table is the surface water level in unconfined aquifer at which the pressure is atmospheric as shown Figure 2.5. It is the level at which the water will stand in a well drilled in an unconfined aquifer. The water table fluctuates whenever there is a recharge or an outflow from the aquifer. In fact, the water table is constantly in motion adjusting its surface to achieve a balance between the recharge and the out flow. Generally, the water table follows the topographic ridge and the water table ridge may not coincide and there may be flow from one aquifer to the other aquifer, called watershed leakage. Wherever the water table intersects the ground surface, a seepage surface or a spring is formed.

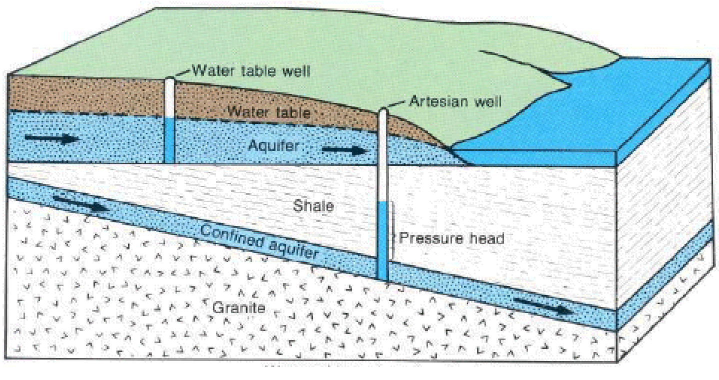


Figure 2.5 Water-table (after Waller, 2005).

2.5 Aquifers

Most of the void spaces in the rocks below the water table are filled with water. Wherever these water-bearing rocks readily transmit water to wells or springs, they are called aquifers.

An aquifer that is sandwiched between two impermeable layers or formations that are impermeable is called a confined aquifer if it is totally saturated from top to bottom.

Although ground water can move from one aquifer into another, it generally follows the more permeable pathways within the individual aquifers from the point of recharge (areas where materials above the aquifer are permeable enough to permit infiltration of precipitation to the aquifer) to the point of discharge (areas at which the water table intersects the land surface and water leaves an aquifer by way of springs, streams, or lakes and wetlands). Where water moves beneath a layer of clay or other dense, low-permeability material, it is effectively confined, often under pressure. The pressure in most confined aquifers causes the water level in a well tapping the aquifer to rise above the top of the aquifer. Where the pressure is sufficient, the water may flow from a well Saturated rock or soil units that have sufficient hydraulic conductivity to supply water for a well or spring are aquifers. Aquifers transmit water from recharge areas to discharge areas, such as springs, lakes, and rivers. Typical aquifers are gravel, sand, sandstone, limestone, and fractured igneous and metamorphic rock. Those subsurface rock or soil units that do not transmit water readily and cannot be used as sources of water supplies are called aquicludes. Typical aquicludes are clay, shale, and unfractured igneous and metamorphic rock. Aquicludes that exist between aquifers are confining beds; the water moves only within the aquifers. Figure 2.6 shows the Schematic cross-section illustrating confined and unconfined aquifers

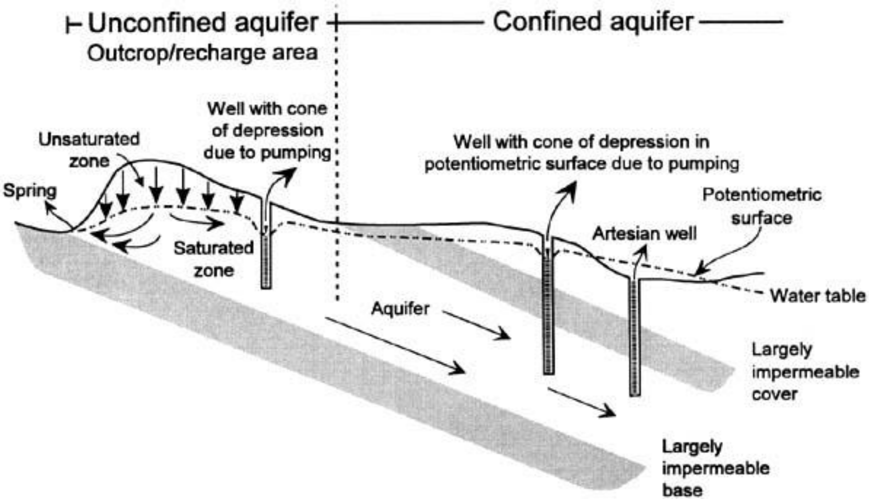


Figure 2.6 Schematic cross-section illustrating confined and unconfined aquifers (after Prentice Hall, 1979).

2.5.1 Confined

Confined aquifers as shown in Figure 2.6 are the aquifers that are completely filled with water and are overlaid by a confining bed. The water level in a well supplied by a confined aquifer will stand at some height above the top of the aquifer. Water that flows out of the well is called flowing artesian. Water rises because of the pressure that the overlying materials exert on the water and the height of the column of water driving the water through the interconnecting pores of the aquifer. The height of the column of water that is driving water through the aquifer is the head. The height that the water will rise to inside a tightly cased artesian well is the potentiometric surface and represents the total head of the aquifer.

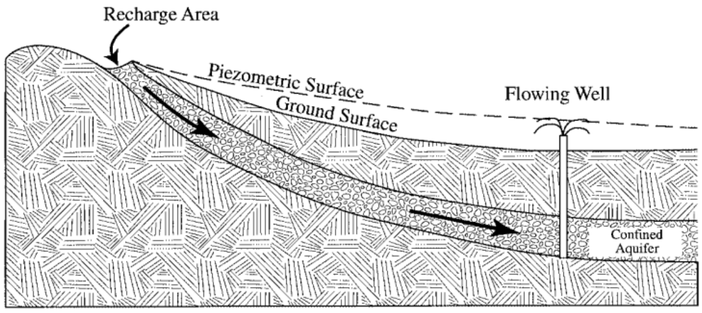


Figure 2.7 Confined aquifer (after Delleur, 1999).

2.5.2 Unconfined

Unconfined aquifers as shown in Figure 2.7 are the aquifers that are partly filled with water, have fluctuating water levels, and can receive direct recharge from percolating surface water. Wells drilled into an unconfined aquifer are called water-table wells.

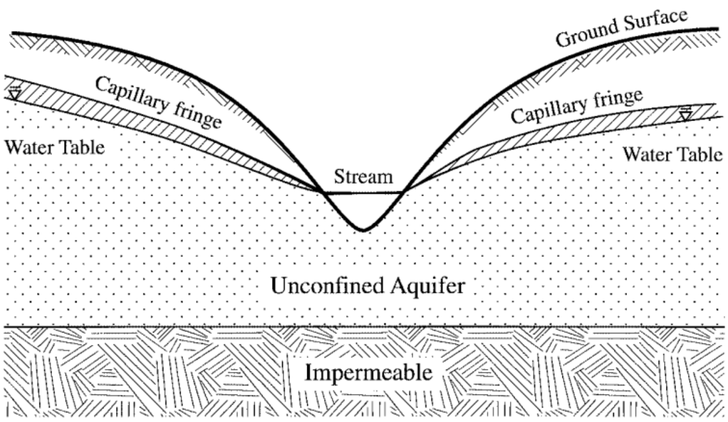


Figure 2.8 Unconfined aquifer (after Delleur, 1999).

2.5.3 Perched

These aquifers lie above an unconfined aquifer and are separated from the surrounding groundwater table by a confining layer. The aquifers are formed by trapping infiltrating water above the confining layer and are limited in extent and development. In some arid environments, perched aquifers form sources of shallow and easily developed groundwater.

2.5.4 Catchment

This is formed where impervious rock underlies a zone of fractured rock or alluvium that serves as a reservoir for infiltrated water. A catchment can be a special type of perched aquifer. Catchments cannot provide large quantities of water, but they may provide easily developed groundwater for small demands or temporary supplies for drilling operations.

2.5.5 Aquifer Material

These aquifers occur in unconsolidated deposits. Examples of sediment deposits and their sources are:

- Alluvium, which comes from running water.
- Glacial drift, which comes from flowing ice.
- Sand dunes, which come from blowing winds.

The overall goal of a groundwater quality assessment program, as for surface water programs, is to obtain a comprehensive picture of the spatial distribution of groundwater quality and of the changes in time that occur, either naturally, or under the influence of man (Wilkinson and Edworthy, 1981). The benefits of well designed and executed programs are that timely water quality management, and/or pollution control measures, can be taken which are based on comprehensive and appropriate water quality information. Each specific assessment program is designed to meet a specific objective, or several objectives, which are related in each case to relevant water quality issues and water uses.

Two principal features of groundwater bodies distinguish them from surface water bodies. Firstly, the relatively slow movement of water through the ground means that residence times in groundwater are generally orders of magnitude longer than in surface waters. Once polluted, a groundwater body could remain so for decades, or even for hundreds of years, because the natural processes of through-flushing are so slow. Secondly, there is a considerable degree of physico-chemical and chemical interdependence between the water and the containing material. The word groundwater, without further qualification, is generally understood to mean all the water underground, occupying the voids within geological formations. It follows, therefore, that in dealing with groundwater, the properties of both the ground and the water are important, and there is considerable scope for water quality to be modified by interaction between the two scope for such modification is in turn enhanced by the long residence times, which depend on the size and type of the groundwater body. To appreciate the particular difficulties of monitoring ground-water bodies, it is necessary first to identify and to discuss briefly those properties of ground and water that are relevant to the occurrence and movement of groundwater. This is done in the following sections. Only a brief summary is possible, but further information is available in Price (1985) which gives a general introduction to the subject. Comprehensive descriptions of hydro are given by (Freeze and Cherry, 1979; Todd, 1980 and Driscoll, 1986).

2.6 Fracture Zone

Fracture zone develop due to stresses imposed on the crust of the earth. Nearly every volume of rocks from a hand specimen to a continent has fractures. The fractures represent zone of increased porosity and permeability. They may form networks that extend sub continental distances and therefore the fractures are able to store and carry vast amount of water.

2.7 Limestone

Wherever the land is underlain by relatively soluble bedrock, natural waters on and below the land surface slowly dissolves that bedrock. The dissolution increases with increase in the acidity of the water. A landscape in which the bedrock is shaped or sculpted by dissolution is referred to as karsts. The most common type of rock in karsts terrain is carbonate rock, which includes limestone and marble.

The peculiarity and uniqueness of limestone lies in its solubility in even slightly acidic water example of which is carbonic acid which is formed when carbon dioxide dissolves in water. The dissolution of limestone is usually associated with the formation of karstic features such as cavities, caves, solution slots, etc. Furthermore, the dissolution can also lead to disrupted surface drainage due to loss of surface water to the subsurface and presence of closed depressions known as sinkholes.

Apart from environmental problems such as the groundwater pollution, presence of cavity and other karstic features can cause subsidence and other related problems during borehole development in this geologic terrain and consequent upon which property and life can be lost. In order to ensure an appropriate borehole