TRAINING MANUAL

SPRING HYDROGEOLOGY

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Cover photographs from ACWADAM's archive, showing some dimensions of groundwater in mountain regions.

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Contents

Introduction

Springs are a vital source of water supply to villages in the Himalaya. Rana and Gupta 2009 have stated that about 60% of the Himalayan population depends on natural spring water for fulfilling their daily domestic needs such as drinking water, sanitation and irrigation. The dependency of majority of the population on spring water means that with changing climatic conditions and rainfall pattern, a large number of villages, hamlets and settlements are facing potential drinking water shortage. Only systematic and detailed hydrogeological investigations can present any possible escape from the existing crisis and the impending peril. The springs have provided water to the mountain communities for centuries and the revival of this traditional source of water is extremely important for the region's sustainable growth.

Over the last few years many governmental and non-governmental organizations have initiated spring development programmes in the Himalayan states. Many watershed development schemes also include protection and development of springs. Failure of many such programmes is attributed to the lack of knowledge of the subsurface and the absence of hydrogeological input in the planning of recharge measures. Even if watershed interventions without geological input yield positive results and may be successful in saturating an aquifer, it may not contribute to rise in the spring discharge. This is because springs are controlled by diverse geological features which are not targeted by the conventional watershed development projects. The Himalaya is blessed with a large number of springs which have been quenching the thirst of mountain communities for centuries. Today with the stress of burgeoning population, adverse climatic factors and unchecked urbanization, springs are drying up or becoming seasonal. Although, the problem of over abstraction does not arise in mountain systems (where aquifers are untapped by wells) the quality of water is threatened from anthropogenic activities. Recharge plans for springs must also address quality issues which cannot be done without understanding the geological influence on the water. The pertinence of hydrogeology in spring development and management is almost undeniable.

Like surface water, water stored in aquifers is also in motion, although at marginal velocities. The movement of groundwater is controlled by the rock type and the geological structures affecting the rock bodies. Porosity and permeability of the aquifers also affect the storage and transmission of groundwater through the aquifers or rock bodies. Based on the mode of origin springs are classified into different types. Prior to formulating a recharge plan for any spring following factors need to be considered:-

1. Geology of the area (dip, strike of rocks and other structures)
2. Porosity and Permeability of the aquifer
3. Weather and rainfall in the area
4. Spring Discharge measurement and monitoring
5. Water quality monitoring

The recharge area of a spring is decided after considering all the above factors. However, recharge area may be identified by geological mapping and other field observations; confirmed later by spring discharge and water quality analysis.

Origin of springs

When groundwater from an aquifer or other water bearing bodies is released on the surface of the ground it is referred to as *springs* or *seeps*. This water may be released as a concentrated discharge, in other words, a point source of groundwater (released on to the surface) to form a *spring*. When there is no single source of discharge, but water is released from soil or rock over a small area, it is called *seep*.

Springs and *seeps* occur when down slope part of aquifers are exposed to the surface or when outcrops of aquifers are exposed along mountain flanks or valley sides. In areas where groundwater is present at shallow depths, the water table may intersect the ground surface forming a *spring*. *Springs* and *seeps* also form when dykes and faults introduce discontinuities in the flow of groundwater, which is forced along these barriers to rise up to the ground surface. In areas where the aquifers are fractured and fissured rainwater percolates through them and finally emerges at lower elevation as trickles or rivulets to form *springs* or *seeps*. Another way *springs* or *seeps* originate is when water oozes at the down slope parts of rock or soil debris at the foot of mountains. Springs also originate from chemically soluble rock types such as limestone which behave completely different from other types of springs.

Depending on the origin of the spring (its type), the discharge and water quality vary considerably. Apart from the mode of origin and nature of the aquifers (confined / unconfined), certain hydrogeological properties of the aquifer namely Storativity and Transmissivity also control the discharge and water quality of springs. Springs formed in the same way may exhibit different discharge and water quality due to above mentioned properties. These properties depend on the following-

- Lithology (rock type)
- Texture (framework of the grains or minerals in the rock) and the
- Structure of the rock formations (their geometrical orientation and disposition in the subsurface)

Therefore, learning rock types, their mineral constituents, textural and structural aspects of rock formations along with basic principles of hydrogeology are prerequisite to the development of thorough understanding of spring systems and mountain aquifers.

Geology

Types of Rocks

There are three main categories in which all rocks are grouped based on the nature of their formation.

Igneous Rocks

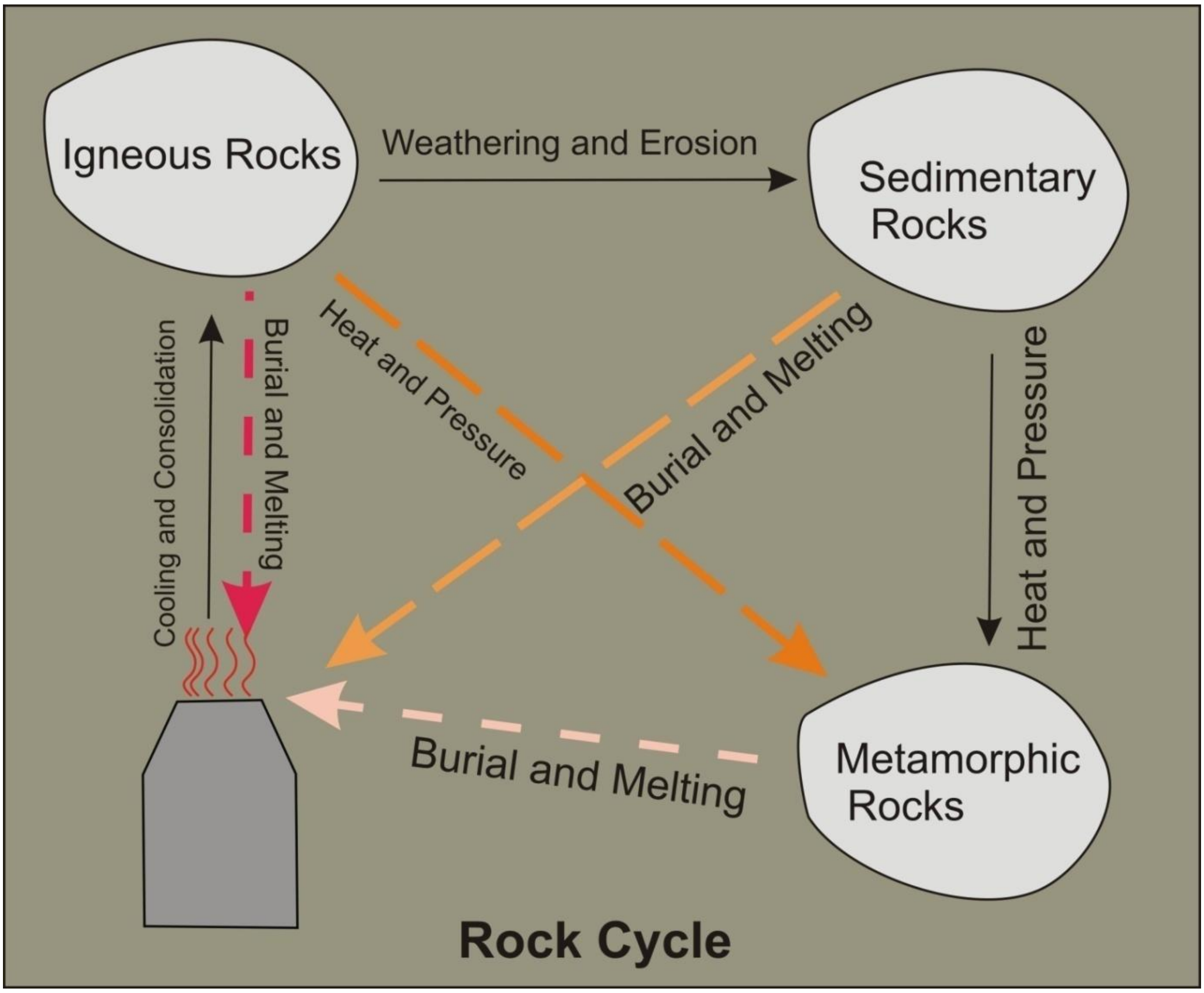
These rocks have formed from the cooling and solidification of molten rock material that has come to the surface from deeper earth. This molten rock material is referred to as *magma* when it is present below the ground and as *lava* when it reaches the surface. This molten rock material reaches the surface through *volcanoes* and *fissures* on the earth's surface where it cools and becomes solid (igneous rock). There are different types of igneous rocks e.g. basalt, gabbro, granite etc. They differ in their mineral content or chemical composition and are formed at different depths underground.

Sedimentary Rocks

They are formed due to *weathering, erosion, deposition* and *compaction* of sediments (rock particles) or mineral fragments. Earlier present rocks are weathered or broken down due to climatic processes. The product of *weathering* is then transported to a different place and deposited by water, wind or glaciers, which is referred to as *erosion*. The deposited sediments are compacted to form sedimentary rocks under the pressure of overlying material or later deposited sediments. E.g. conglomerate, sandstone, shale etc. As their material can be derived from different type of rocks (igneous, metamorphic or even sedimentary) their mineral content is highly diverse. Some sedimentary rocks form by precipitation of dissolved matter from water, e.g. limestone.

Metamorphic Rocks

Metamorphic rocks are formed by alteration of existing rocks due to changes in temperature and pressure conditions. Metamorphic rocks can be formed from igneous, sedimentary as well as pre-existing metamorphic rocks. Metamorphism results in the formation of new minerals and rock structures. The mineral and chemical composition of metamorphic rocks depends on the mineral and chemical composition of the original or parent rock. The texture and structure depends on the process of formation of the rock, that is, the dominant agent of metamorphism – temperature or pressure or both, e.g. quartzite, phyllite, schist, gneiss etc.


Igneous Rocks
Weathering and Erosion
Sedimentary Rocks
Heat and Pressure
Burial and Melting
Cooling and Consolidation
Burial and Melting
Heat and Pressure
Burial and Melting
Metamorphic Rocks
Rock Cycle

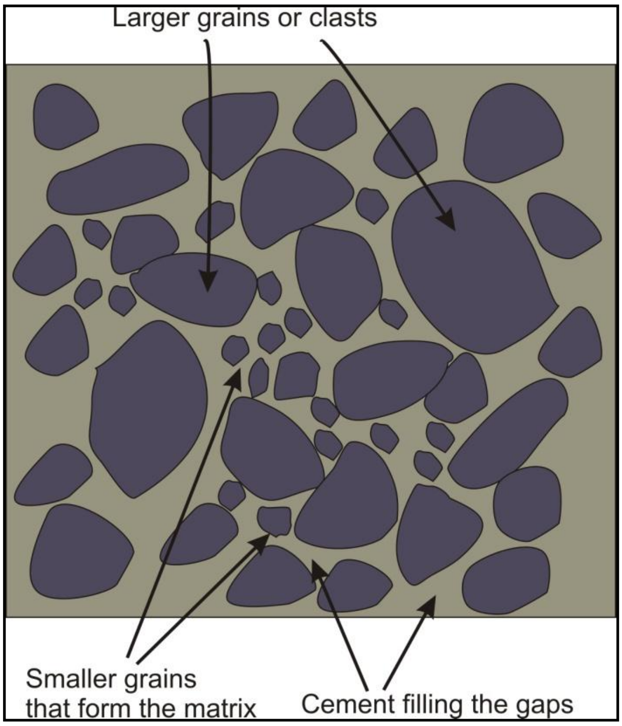
Rock textures and structures

Texture

Texture refers to the manner in which individual mineral grains or sediments in a rock are arranged in relation to each other. The hydrogeological property of different rocks is controlled by the texture of the rock. If the mineral or sediment grains in a rock are closely packed the porosity (and permeability) of the rock reduces considerably. Igneous rocks are formed from cooling molten rock material; the minerals formed share boundaries which results in them having low porosity. Many metamorphic rocks are also formed by heating of parent rocks and result in recrystallization of minerals. Thus, porosity and permeability of such rocks also tends to be less. Sedimentary rocks and metamorphic rocks formed only under the effect of pressure show variation in porosity and permeability depending on their grain size, shape and mineral content. Texture is thus an important factor controlling the storage capacity and Transmissivity of an aquifer or water bearing formation.

The essential textural elements of any rock include –

1. Larger grains or sediments
2. Smaller grains or sediments that fill up the voids between larger grains and
3. Cement (material precipitating in the voids of sedimentary rocks).



As explained above, the porosity and permeability of any rock body are merely the measureable characteristics of its mineral or granular framework. Porosity and permeability are generally established at the time of formation of the rock (*primary porosity*). However, there may be an increase in porosity (and permeability) after the formation of rocks, which is referred to as *secondary porosity*.

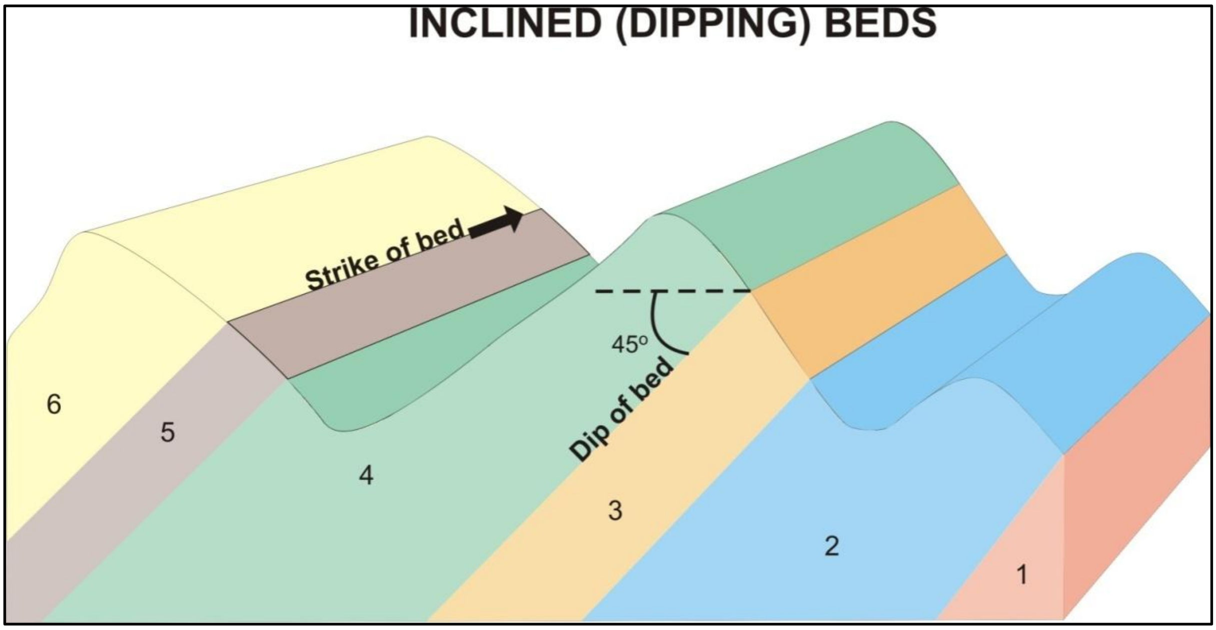
Rock Structures

Rock formations are often disturbed or deformed from their original state of formation. This deformation is the result of tectonic forces or crustal stresses. The deformation of the rock bodies produces different structures such as folds, faults and fractures. Metamorphic rocks show foliation structures such as schistosity and gneissosity which develop due to the presence of characteristic minerals. Igneous bodies form different kinds of structures depending on their relationship with the country rocks. Folds and faults are generally more conspicuous in sedimentary formations.

Identifying and understanding geological structures is an essential element of any hydrogeological study and the basis for further investigation. The orientation of geologic features in the subsurface is referred to as their *attitude*. Sedimentary formations are generally deposited as *beds or layers* which can be easily observed in the field. The deformation of sedimentary beds leads to tilting, folding and faulting of beds (which were horizontally deposited). The *attitude* has two essential components namely dip and strike which are described below.

Dip – It is the inclination of any planar geologic feature with respect to a horizontal plane. The amount of inclination is known as the *dip amount* and the direction in which the feature is inclined is the *dip direction* (with respect to north).

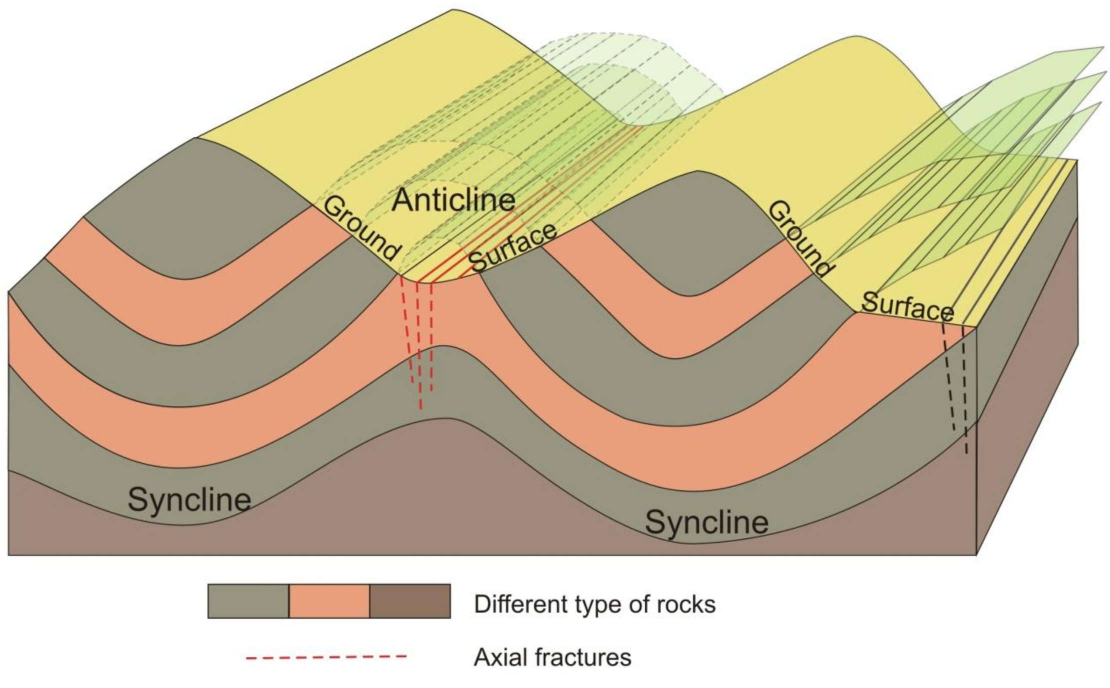
Strike – It is the line representing the intersection of a planar feature with the horizontal plane. The *strike direction* or the *trend* of the feature is also measured with respect to north.



Fold – When deformation of rock formations causes horizontal rock layers to be curved or bent they are referred to as folds. They are observed in the field as a stack of rock layers that have been bent along a common axis. Folds may be very small (observed within a small outcrop) or large (cannot be observed in a single outcrop and can only be deciphered after detailed geological mapping). Folds can either be an anticline or a syncline.

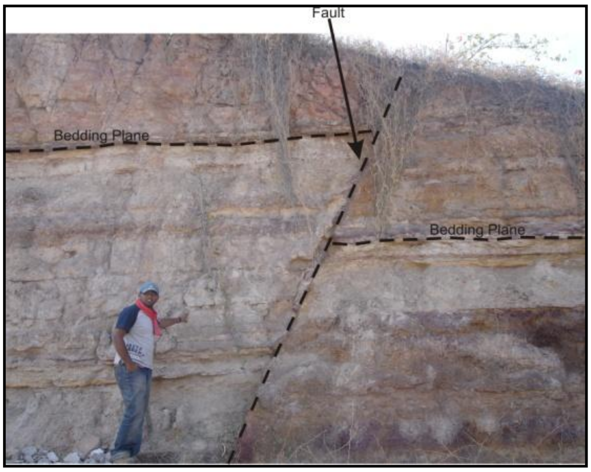
Anticline – It is a term used for folds which are convex upwards. The beds (the limbs) in an anticline slope downwards from a common crest (axis) in opposite directions.

Syncline – It is a term used for folds which are concave upwards. The beds (the limbs) in a syncline slope downwards into a common trough (axis) towards each other.



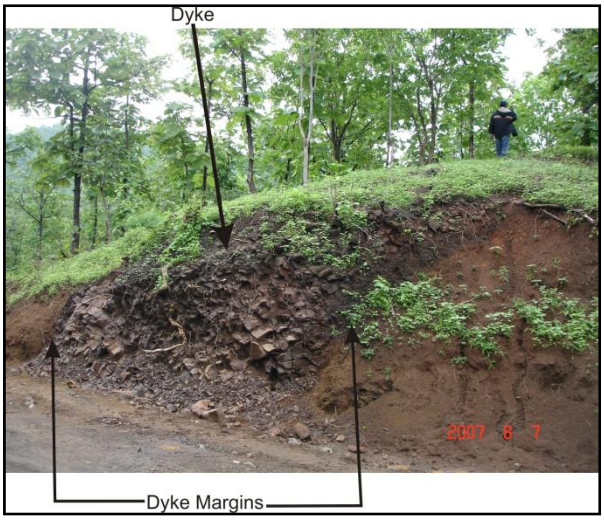
Folds

Fault – Due tectonic movements and crustal stresses rock masses may be fractured. When there is movement of a mass of rock along such a fracture or planar discontinuity, it is called a fault.



Fractures – Any planar or local discontinuity that separates a rock mass in to a number of parts is called as fracture. Fractures induce *secondary porosity* and increase permeability in a rock formation. This is often referred to as *fracture porosity*. Fracture openings may be horizontal, vertical or inclined.

Dyke – A dyke is an intrusive igneous body that bears a discordant relationship with the surrounding or country rocks. In simple words, it is a fracture or fissure cross – cutting a rock body that has been filled by a magmatic intrusion.



Geological Mapping and Development of Conceptual Model

The purpose of mapping the geology of a watershed is twofold – one is to acquaint oneself with the geology of the area and in the process understand intricately the extent, disposition, geometry of rock formations and other geological structures. Secondly, to represent the geology of the watershed in a convenient manner to facilitate the planning of recharge measures. Once the geology of an area is well understood and mapped, further, if the aquifer has been identified and delineated one can attempt to prepare a conceptual model. A conceptual model can be a two dimensional (or three dimensional if possible) geological section that facilitates one to understand how a particular groundwater system works. This serves as an additional use of hydrogeological mapping. The requirements for preparing the hydrogeological map of an area are –

1. Toposheet to understand the topography and drainage of the catchment. In most cases a topographic sheet is also the base map for preparing the geological map.
2. GPS for noting the elevation and marking key locations.
3. Hammer to expose rock surfaces (which aids in rock identification).
4. Satellite images if available and necessary for mapping and other purposes.
5. Clinometer compass for measuring the attitude of rock formations and other geological features.
6. Necessary stationary for recording field observation which includes pen, pencil, notebook etc.

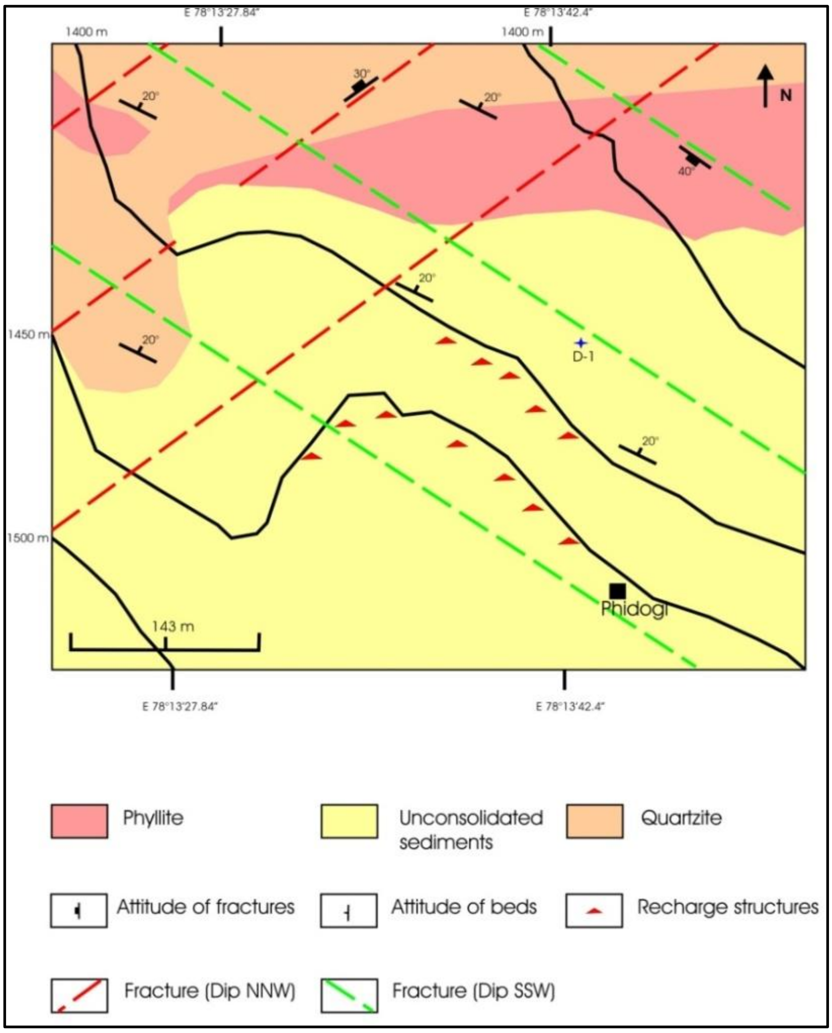
Hydrogeological mapping of a watershed is a fairly uncomplicated exercise. The following bullets highlight certain methods and techniques that are necessary to be kept in mind while mapping an area.

- The first step in geological mapping is the planning of the traverse. A traverse should be planned on the basis of availability of rock exposures. For example, good rock exposures are generally available along road or railway cuttings. If one is familiar with the terrain and the watershed, finding such sections should not be difficult. In mountain areas, deeply cut streams, rivulets or *Gadheras* often provide sections where rock exposures can be observed.
- In a new area or watershed, it is recommended that one must study toposheets and satellite images, if available. Not only can one gather information about the topography but location of streams and *Gadheras* can be understood.
- Traverses must be planned to cover the entire length of the watershed, particularly from the upstream to downstream where one encounters springs and seeps. The location of all the springs under consideration must be noted. Details such as village name, area, elevation,

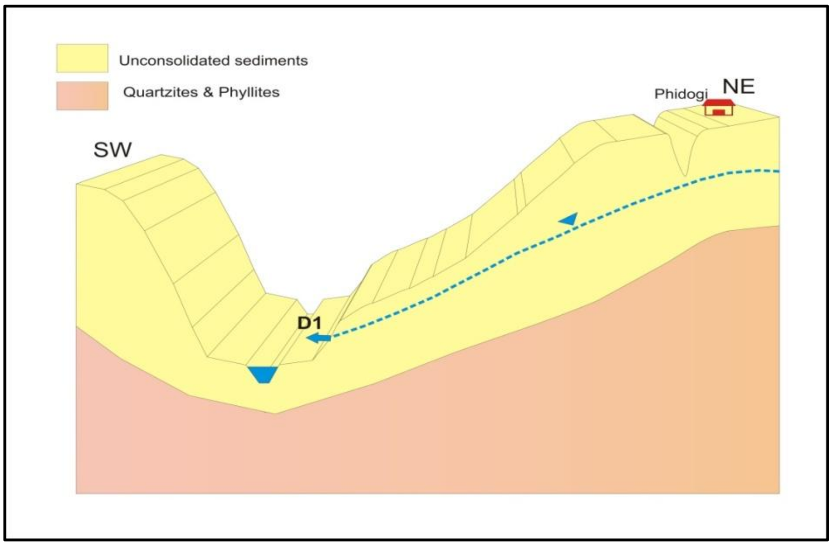
latitude and longitude must be noted. If toposheet is available, the location of springs and other observed features must be marked on them.

- At each exposure, the strike and dip of rock beds, fractures and joints must be noted. One must make it a point to compare the measurements at subsequent sections. This helps in understanding if there is any change in the attitude of geological features. Not so apparent geological features may be understood on the basis of these measurements. For example, large scale folds may not be visible in any section; however, by comparing attitude measurements a rough picture may be conceived.
- The main aim of the entire exercise is to understand the nature of the aquifer, identify the type of the spring and to demarcate the recharge area of the spring (or springs) in the watershed. The source region from where the spring issues must be carefully observed. If necessary, unwanted vegetation should be cleared, so that the rock formations from which the spring issues can be observed. When the rock formation that hosts the spring has been ascertained, the traverse must be planned to determine the continuity of the formation.
- Trends of fractures and joints must be noted as they conduct groundwater, especially in mountain areas and regions with hard impervious rocks. If a spring has been identified as a fracture spring, then the fracture along which the spring issues must be traced and potential recharge sites must be identified and marked.
- When there are changes in rock type along the traverse (or in other words section) the relative thickness of the beds should be given consideration. This will be helpful in the preparation of the conceptual model.
- It is imperative to denote the directions in the map and the two or three dimensional sections. The direction of flow of groundwater can also be shown on the conceptual model.
- While preparing conceptual models the direction of the section should be so chosen that the dip of the beds or fractures or faults is clear on the two dimensional plane of the paper. On the maps, however, as the dips will not be visible in any case, the strike or trend of beds or fractures or faults will be depicted.

One must understand that the hydrogeological maps and sections will be prepared on the information gained from specific traverses, it is imperative that short notes be added below maps and sections that describe the starting and end points of the traverse, the direction (E.g. N to S, SW to NE) in which the traverse progressed and whether the traverse was up the slope or down the slope (ridge to valley or valley to ridge). This is important for much more practical reason – person managing the spring recharge programme may change or there may addition of new members in the team who would benefit from the above given information. The details will allow uninformed team members to follow up quickly and acquaint oneself with the area and therefore ensure the continuity of the efforts.



Geological Map



Conceptual model

Any geological map must contain –

1. Scale for measuring the distance.

2. Directions for understanding the orientation. Preferably N marked at the top of the map.

3. All the symbols and colours used must be represented in the legend or the index.

For preparing a geological map one needs a *base map.* A toposheet must be used as a base map if available. Few simple steps may be followed while preparing the geological map.

1. Mark the locations where lithological contacts were measured on the base map.

2. Now join the points of lithological contacts to trace the junctions.

3. Similarly trace the junctions of various beds after marking the outcrop locations on the map. Various contacts will be observed in the map depicting different lithologies or rock types.

Conceptual models can be prepared by drawing the topography roughly and depicting the beds (rock layers) based on elevation difference between the beds as shown.

Hydrogeology

Hydrogeology is the science of understanding the movement and occurrence of water below the ground. It includes the study of physics, chemistry and environmental relationship of water in the subsurface. In other words, it is the study of groundwater and its links with surface water. Although, springs are surface water sources, they are tapping the groundwater resource. Springs are a classic example of surface and groundwater links. Often groundwater feeds streams and rivers through *springs* and *seeps*, known as *base flows*. Before developing a comprehensive understanding of springs, it is essential to learn the basic concepts in hydrogeology and definitions of technical terms.

Aquifer – A saturated geological formation which yields sufficient quantity of water to wells and springs.

Confined Aquifer – An aquifer where water is stored under pressure due to the presence of an overlying impermeable layer or formation.

Unconfined Aquifer – It is a partially saturated aquifer which is not overlain by an impermeable bed and whose water table is free to fluctuate under atmospheric pressure.

Porosity – It is the total volume of pores or voids in a rock or aquifer. The total volume of pores will be the maximum capacity of fluid (air or water) that can be stored in the rock material.

Primary Porosity – Porosity developed in a rock body at the time of its formation.

Secondary Porosity – Porosity developed in a rock body after its formation due to weathering, fracturing etc.

Permeability – It is the total volume of the interconnected pores or voids present in a rock body or aquifer. It is the measure of a rock body's ability to transmit fluids (air or water) through it.

Storativity / Storage Co-efficient – It is the estimate of quantity of water that can be stored in the rock body or aquifer. It is the measure of amount of available groundwater stored in the aquifer.

Transmissivity – It is the ability of an aquifer to transmit groundwater through its entire thickness. It is measured in m^2 / day.

As mentioned earlier porosity and permeability of the rocks forming the aquifers are the two important properties that influence the discharge of springs and their water quality. Aquifers with higher porosity and low permeability will yield to springs with a slow rate of discharge that is sustained throughout the year. While highly permeable aquifers will have high discharge springs that may be seasonal in nature. Discharge of springs may also reflect the nature of the aquifer; as water is stored under some pressure (*hydrostatic pressure*) in confined aquifers, springs from these aquifers may yield at a higher rate of discharge.

The discharge of springs is directly dependant on the availability of water in the aquifer which depends on the recharge to the aquifer, in other words, on the amount of rainfall received by the region. Not all the rainwater enters the aquifer, however, generally a direct correlation between rainfall and spring discharge can be established. Spring discharges are known to increase after a rainfall event. The relationship between rainfall and spring discharge also has a time factor associated with it. The behaviour of springs after rainfall can be used to estimate aquifer properties like Transmissivity and Storativity. For example, if the spring shows increase in discharge immediately after rainfall, it can be said that the aquifer is highly transmissive in nature. On the other hand, aquifers with high storage and low Transmissivity may not show any significant change in the spring discharge after rainfall. The type of spring or its origin is also reflected in its discharge pattern. Sedimentary depression springs are likely to respond immediately to a high rainfall episode with increase in discharge, whereas fracture springs may not show a significant rise in discharge even after a heavy downpour.

Similarly, analysis of spring water quality may also help in understanding the spring type, aquifer type and make assumptions on the lithology of the aquifer (when the aquifer is not mappable in the field). For example, springs issuing from soluble rocks such as limestones are expected to yield water with higher TDS content, whereas those issuing from *weathering resistant* rocks such as quartzites and sandstones will in most cases yield water with low TDS. Analysis of spring discharge and water quality data helps considerably in understanding the hydrogeological regime in an area. Such analysis is also helpful in verifying the extent of the recharge area of a spring. Contamination of spring water from anthropogenic sources can also be ascertained by continuous monitoring of springs.

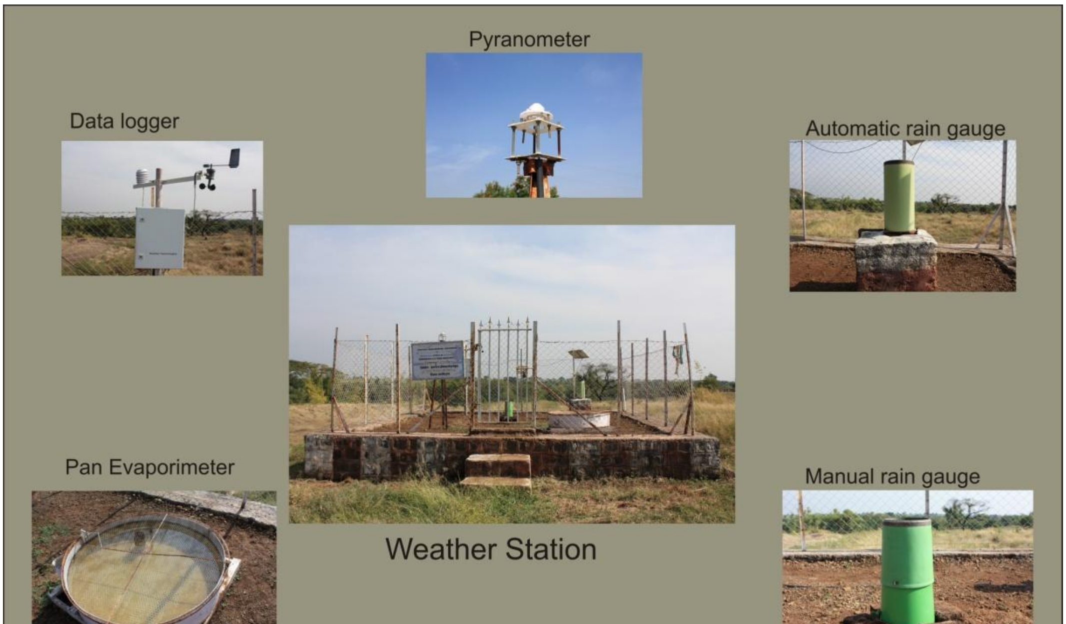
Understanding spring hydrology requires collection of data and regular periodic monitoring of –

1. Weather
2. Spring Discharge
3. Water Quality

Weather Monitoring

Weather is the specific condition of the atmosphere at a particular place and time. The average weather over a period of time in an area is called climate. Weather may vary from hour to hour, day to day and season to season. Wind, relative humidity, temperature, atmospheric pressure, cloud cover and precipitation are the measurable parameters of weather. The weather of an area depends on the altitude of the area, geographic location, surface features and terrain.

Weather monitoring is possible by installing a weather station in an area. Satellite data is also used for weather forecasting. The weather station may be automatic (data is automatically measured and recorded in a data recorder) or manual (data is measured and recorded manually). A weather station consists of the following equipments –



Components of weather station

1. Rain gauge - Rainfall
2. Evaporimeter - Evaporation
3. Wind anemometer – Wind speed
4. Wind vane – Wind direction
5. Pyranometer – Solar Radiation
6. Thermometer – Temperature
7. Humidity sensor or Wet and Dry thermometer - Humidity
8. Barometer or Pressure sensor – Pressure

Rain gauge and evaporimeter are the most commonly used equipments in any spring-shed or watershed development programme. In a spring recharge programme, measurement of rainfall is of utmost importance, as the behaviour of a spring is directly influenced by precipitation. Other weather parameters like evaporation, humidity, evapotranspiration etc. are important to measure when calculating the water balance of an area. For all practical purposes, rainfall measurement is easy and the most pertinent in the context of spring monitoring. Rainfall may be measured using a recording rain gauge which records rainfall data continuously every hour. A non – recording rain gauge may also be used to measure rainfall, in which case rainfall is measured preferably every morning at 8.30 IST.

The interrelation between rainfall, rate of spring discharge and water quality has already been highlighted in the previous section. The format for recording rainfall data has been provided in Box no.1.

Box no.1: Format for recording daily rainfall

Location of Weather Station	Write the name of the Location			
	Year			
Date	**January**	**.**	**.**	**December**
1	...mm	...mm	...mm	...mm
.	...mm	...mm	...mm	...mm
.	...mm	...mm	...mm	...mm
.	...mm	...mm	...mm	...mm
30	...mm	...mm	...mm	...mm
31	...mm	...mm	...mm	...mm
Total	...mm	...mm	...mm	...mm
Year Total	...mm			

Format for recording monthly rainfall for a year

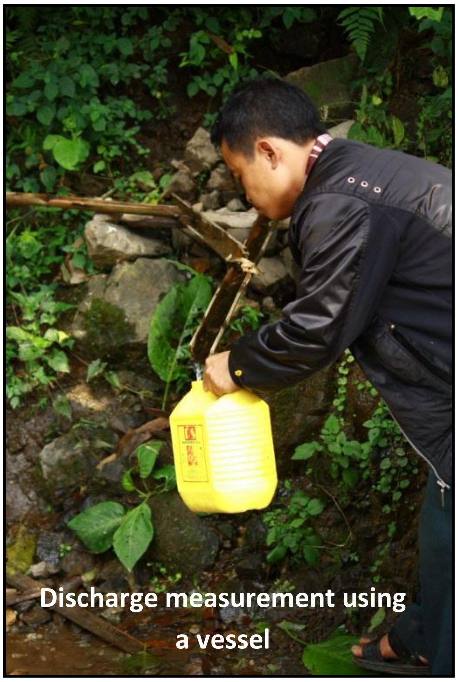
Month and Year	**Rainfall in mm**
January, Year	...mm
February, Year	...mm
March, Year	...mm
April, Year	...mm
May, Year	...mm
June, Year	...mm
July, Year	...mm
August, Year	...mm
September, Year	...mm
October, Year	...mm
November, Year	...mm
December, Year	...mm

Amount of rainfall is to be recorded in **mm**.

Monitoring Spring Discharge

The amount of water discharged by the spring varies with time and depends on both recharge to the aquifer and hydrologic properties of the aquifer. Periodic monitoring of spring discharge helps in understanding the behaviour of the spring under varying conditions of recharge. Spring discharge is measured as the volume of water issuing from a spring within a given period of time. *It is the measure of the volume of water discharging from a spring in unit time*. The volume of water issuing from a spring may vary from only a few litres per minute (lpm) to a few hundred litres per minute. The magnitude of change in spring discharge reveals sizeable information about the aquifer's condition and type. The nature of a spring's origin can also be ascertained from the discharge pattern of a spring.

Spring discharge can be measured using a simple bucket or container of known volume and a clock or stopwatch. Discharge can be measured as the time taken for the spring to fill up the bucket or container. The discharge measured will be expressed as X (volume of the container) litres of water in Y (time taken to fill the container) seconds. Discharge measurements should be repeated to obtain a mean value and should be expressed either as litres per minute (lpm) or litres per second (lps), preferably the former.



Discharge measurement using a vessel

Monitoring spring discharge involves regular measurement and recording of data. It is advisable to measure spring discharge at least twice every month and finally compile annual data. Discharge can be measured within the first and the last week of each month. This is essential to obtain a mean estimate of average monthly discharge of a spring.

Recording spring discharge data is crucial and a simple format must be followed that will aid in easier and faster analysis of the data. The sheet must also include information such as spring code, spring name, location name, latitude, longitude and details of geology and spring type if available. The format for recording spring discharge data is presented in Box no.2.

Box no.2: Format for Recording Spring Discharge Data

Spring Name/Code	Spring Location	Spring Type	Geology	Latitude	Longitude
Write the name and code	Write the name of the area	Contact, fracture etc.	Sandstone, phyllite etc.	N deg° min' sec''	E deg° min' sec''

Year			
Month	**Start of the month** (Fixed date)	**End of the month** (Fixed date)	**Mean Discharge for the month**
January	...lpm	...lpm	...lpm
February	...lpm	...lpm	...lpm
March	...lpm	...lpm	...lpm
April	...lpm	...lpm	...lpm
May	...lpm	...lpm	...lpm
June	...lpm	...lpm	...lpm
July	...lpm	...lpm	...lpm
August	...lpm	...lpm	...lpm
September	...lpm	...lpm	...lpm
October	...lpm	...lpm	...lpm
November	...lpm	...lpm	...lpm
December	...lpm	...lpm	...lpm

Discharge to be recorded in litres per second (lps) or litres per minute (lpm), preferably in litres per minute (lpm). An additional column of rainfall can be added for the purpose of analysis.

Water Quality Monitoring

Monitoring spring water quality is just as important as monitoring spring discharge. Even in cases where measuring spring discharge may prove to be cumbersome, the water quality of a spring can be easily measured. Frequently, it has been observed that the lithology of an aquifer can be inferred from water quality data. Such inference not only serves to corroborate the information gained from hydrogeological mapping, but provides insight into the aquifer geology when mapping is not feasible in an area. Seasonal variation in water quality can also be assessed to understand aquifer characteristics and its temporal response to rainfall (recharge).

Water quality measurements require collection of water sample and chemical analysis in a laboratory. In situ water quality analysis is possible with portable water quality test kits and digital meters. The most commonly measured water quality parameters are –

1. pH
2. Total Dissolved Solids (TDS) measured in mg/l or *ppm*
3. Salinity measured in mg/l or *ppm*
4. Electrical Conductivity (EC) measured in micro Siemens (μS)
5. Water Temperature measured in °C

Spring water quality must also me measured and recorded regularly. Water quality can also be measured during the first and the last week of every month. It is advisable to measure water quality each time the spring discharge is measured.

The collected data must be recorded in proper format to assist in faster and better analysis. Other information such as spring code, spring name, location name, latitude, longitude and details of geology and spring type should also be included. The format for recording water quality data is presented in Box no.3.

Water quality measurement using a pocket tester

Box no.3: Format for Recording Water Quality Data

Spring Name/Code	Spring Location	Spring Type	Geology	Latitude	Longitude
Write the name and code	Write the name of the area	Contact, fracture etc.	Sandstone, phyllite etc.	N deg° min' sec''	E deg° min' sec''

Year				
Month	pH	TDS	Salinity	Electrical Conductivity
January		...mg/l	...mg/l	µS
February		...mg/l	...mg/l	µS
March		...mg/l	...mg/l	µS
April		...mg/l	...mg/l	µS
May		...mg/l	...mg/l	µS
June		...mg/l	...mg/l	µS
July		...mg/l	...mg/l	µS
August		...mg/l	...mg/l	µS
September		...mg/l	...mg/l	µS
October		...mg/l	...mg/l	µS
November		...mg/l	...mg/l	µS
December		...mg/l	...mg/l	µS

An additional column of rainfall can be added for the purpose of analysis.

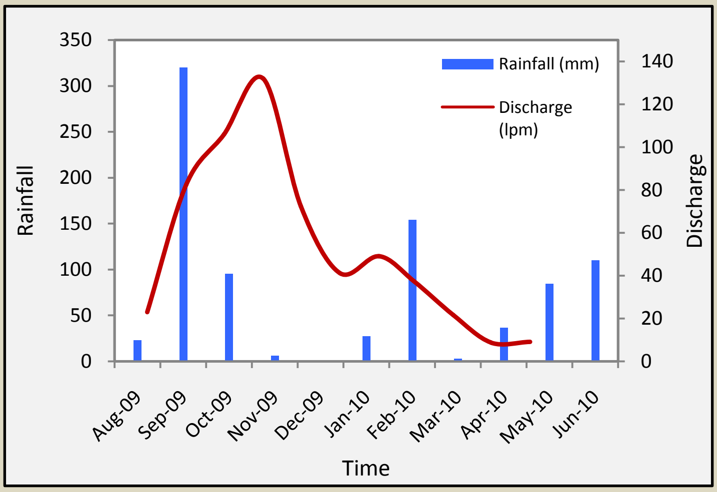
Analysis of Spring Discharge and Water Quality Data

The analysis of spring discharge and water quality data begins with graphical representation of the recorded data. The data can be plotted manually on a graph paper or through common office application software available such as MS Excel. While graphically plotting spring discharge or water quality data, the parameter (water quality parameters or spring discharge) is to be plotted on the Y (vertical) axis and time is to be plotted on the X (horizontal) axis.

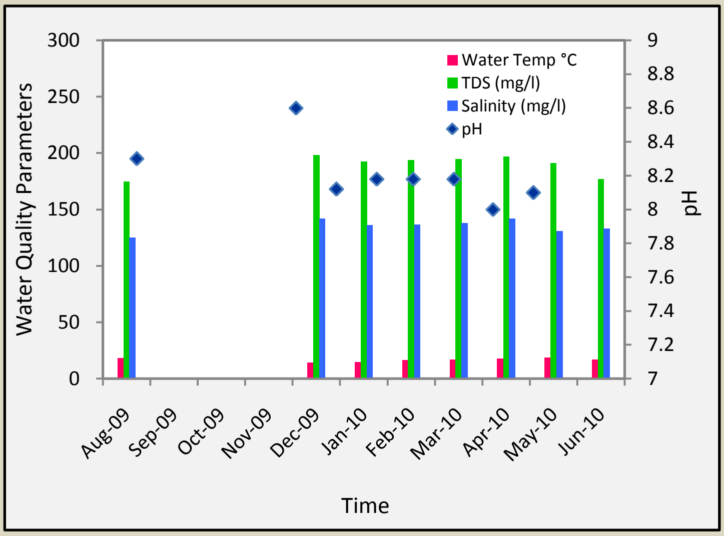
The generation of the *hydrograph* is the most important output from the spring discharge data. A *hydrograph* is a graph depicting the variation in spring discharge with time. Incredible amount of information can be obtained from a *hydrograph* applying mathematical principles. However, for spring recharge programmes the most important information revealed by a hydrograph is the behaviour of the spring in different seasons. The response of the aquifer to rainfall events can be assessed based on the hydrograph. For this reason, the rainfall data of a spring's catchment is also plotted along with the spring discharge data.

Water quality data can also be plotted similarly with rainfall to understand the changes in the groundwater chemistry with rainfall. The TDS and salinity of water are controlled by the pH of the water. The relationship between pH and TDS or pH and salinity can also be drawn from such graphs. The water quality of a spring may be helpful in defining the recharge area as well. Due to seasonal variation in rainfall and therefore recharge to the aquifer, the spring may tap different water sources in different seasons. Intricacies of the groundwater network in mountain areas can also be understood by interpreting water quality changes.

Once the water quality and spring discharge data have been plotted against rainfall, much of the above discussed information can be extracted from the graphs. Examples of plotted discharge and water quality curves are given below.



Spring Discharge Curve Plotted against Rainfall



Water Quality Curve with Four Parameters

From the spring discharge curve above it can be said that there is a time lag between rainfall and increase in spring discharge. Such delayed response is an indicator of low aquifer Transmissivity and/or high storage capacity. In the above case, however, the reason for the delayed response is quite different. The delay may be because of the aquifer's highly water unsaturated condition. The October rainfall was the monsoon rainfall event in the area of the year 2009. The aquifer must saturate itself to a minimum threshold level, after which the additional water recharged to the aquifer may be discharged to springs. The *hydrograph* clearly shows that the discharge of the spring falls immediately after the cessation of rain. Such abrupt change in discharge in response to rainfall can be interpreted to be due to the aquifer's high Transmissivity and low Storativity. The extent of the recharge area and its proximity to the spring can also be estimated approximately.

The water quality curve also reveals some important information about groundwater system. In the example above, it can be observed that the TDS and salinity remain fairly constant throughout the year irrespective of the fluctuation in discharge. This suggests that the aquifer is made up of fairly insoluble material such as sandstone or sedimentary deposits like alluvium. Comparing the water quality graph with the spring discharge curve and rainfall pattern, it can be observed that the pH of the water increases anomalously in December when both rainfall and spring discharge drop steeply. At times when only water quality data is available, the reverse conclusion can be arrived at. For example, in an alluvial or sedimentary aquifer if there is an anomalous increase in the pH and/or TDS it can be presumed to be because of reduced spring discharge.

The simple procedure or code for plotting and analyzing rainfall, spring discharge and water quality data can be outlined as follows -

- Plot the available data on the co-ordinate axes. Plot time on the horizontal axis and other parameters on the vertical axis.
- Spring discharge and water quality data can be plotted in isolation and analysed. It is advisable to include rainfall data especially with spring discharge data for improving the analysis.
- It is important to note the following aspects of the spring discharge curve or the *hydrograph* – the pattern of the graph i.e. variation in discharge throughout the year, response of the spring to rainfall events.
- Variation in water quality parameters with rainfall and spring discharge.
- At an advanced level the curves can be used to quantify water contribution from an aquifer, calculate the water balance in an area etc.

Types of Springs

Springs have been classified on the basis of their origin, geological structure, discharge and other factors. Excluding hot or thermal springs, all springs can be classified as gravitational springs i.e. flow of groundwater under gravity produces these springs. The origin of springs has been discussed in the introduction. Five different types of springs have been identified on their mode of occurrence or origin and geological control -

1. ***Depression Springs***

   They are formed when the groundwater table is shallow enough and intersects the ground surface at topographic lows. Local discharge zone is formed resulting in the formation of a spring.

2. ***Contact Springs***

   When permeable water bearing rock body (aquifer) overlies a less permeable rock formation that intersects the ground surface, springs may arise at the contacts and are termed as contact springs. Such springs are often associated with perched mountain aquifers.

3. ***Fault Springs***

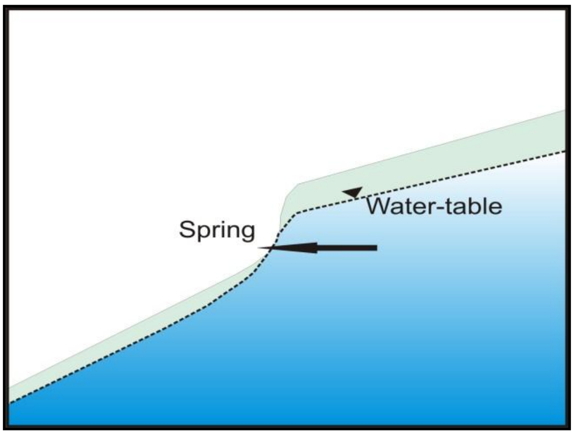
   Faulting may also give rise to conditions favourable for spring formation. Groundwater under hydrostatic pressure can move up along faults such as in confined aquifers. Along faults the aquifer may come in abrupt contact with impervious layers, groundwater issues along such discontinuities to form springs.

4. ***Fracture Springs***

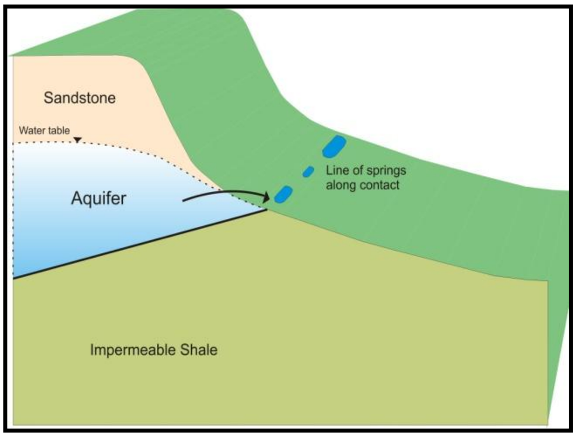
   When rock bodies are sufficiently jointed or fractured groundwater may find easy passage through these fractures. Such fractures may tap shallow as well as deep aquifers. When they intersect the ground surface, groundwater issuing from these fractures forms springs.

5. ***Karst Springs***

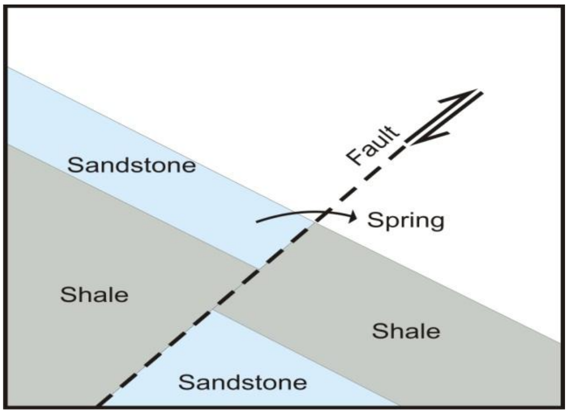
   These are special kind of springs that are formed only in areas where there are water soluble rock formations such as limestone, dolomite etc. Cavities and conduits formed in the rock formation due to dissolution conduct water through interconnected channels. The water finally emerges from similar cavities at lower topographic elevations to form springs.



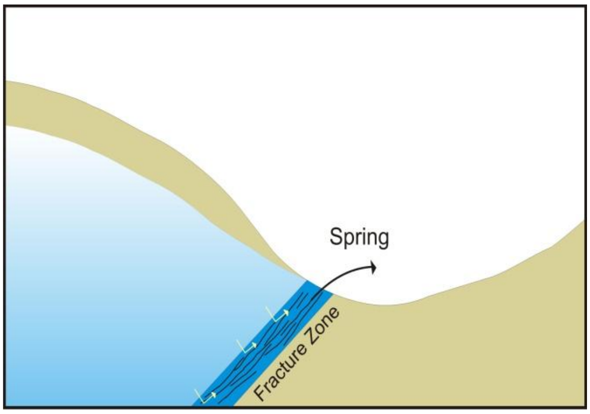
Depression Spring



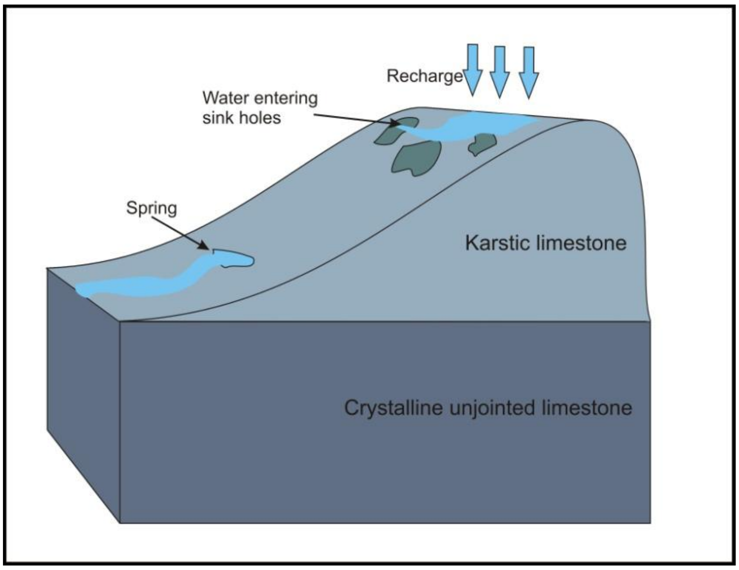
Contact Spring



Fault Spring



Fracture Spring



Karstic Spring

Spring Recharge Zones: Different Geological settings

Post geological mapping and aquifer delineation, the recharge zone of a spring can be demarcated and treatment of the catchment area can commence. The geological setting of the area controls the recharge to springs; the attitude of rock formations, joints or fractures, faults and other structural features influence the groundwater flow and are vital in demarcating the recharge area. Based on the type of the spring, the type of aquifer, the lateral extent of the aquifer and the topography in the region, the recharge area may vary. In mountainous regions, the location of the spring (whether on dip slope or scarp slope) is also a factor that defines the area of recharge. The recharge area of a spring may be in close vicinity of the source or may be several kilometres from the source.

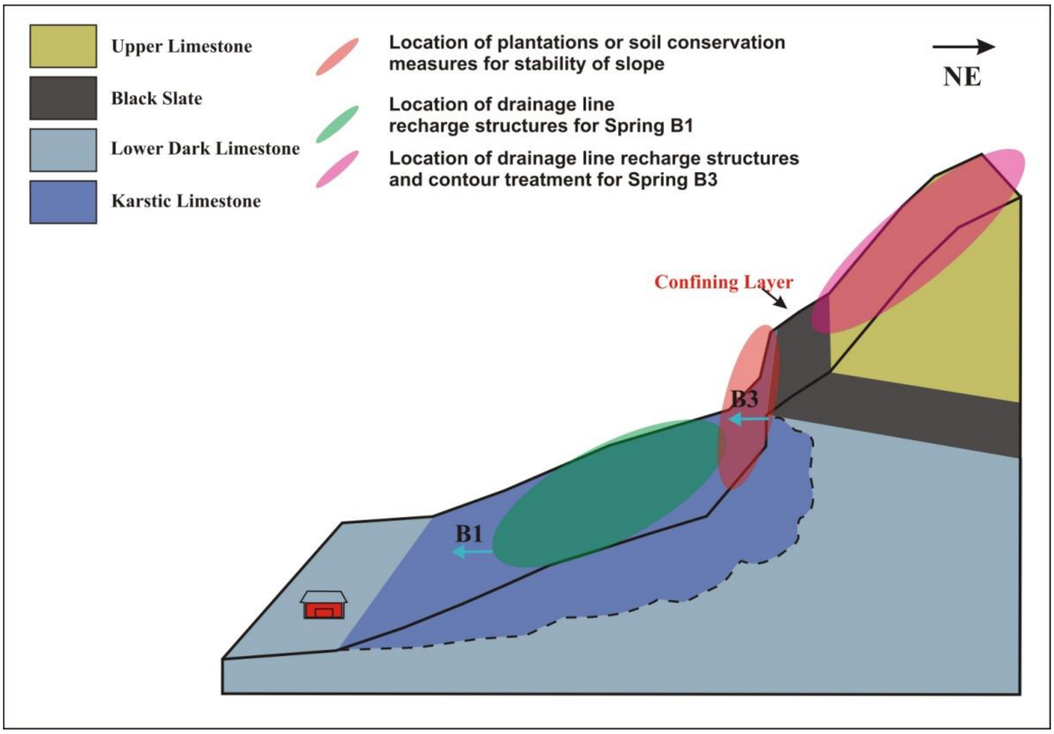
When there are depression springs in an area issuing from unconfined aquifers, it is expected that the recharge area for such springs would be large covering several kilometres. However, if the unconfined aquifer is composed of unconsolidated debris covering certain slopes of a mountain flank, the area of recharge will be limited to the higher reaches of the mountain slopes. Thus, in case of unconfined aquifers, the aerial extent of the aquifer and the topography are the vital factors that determine the area of recharge of a spring.

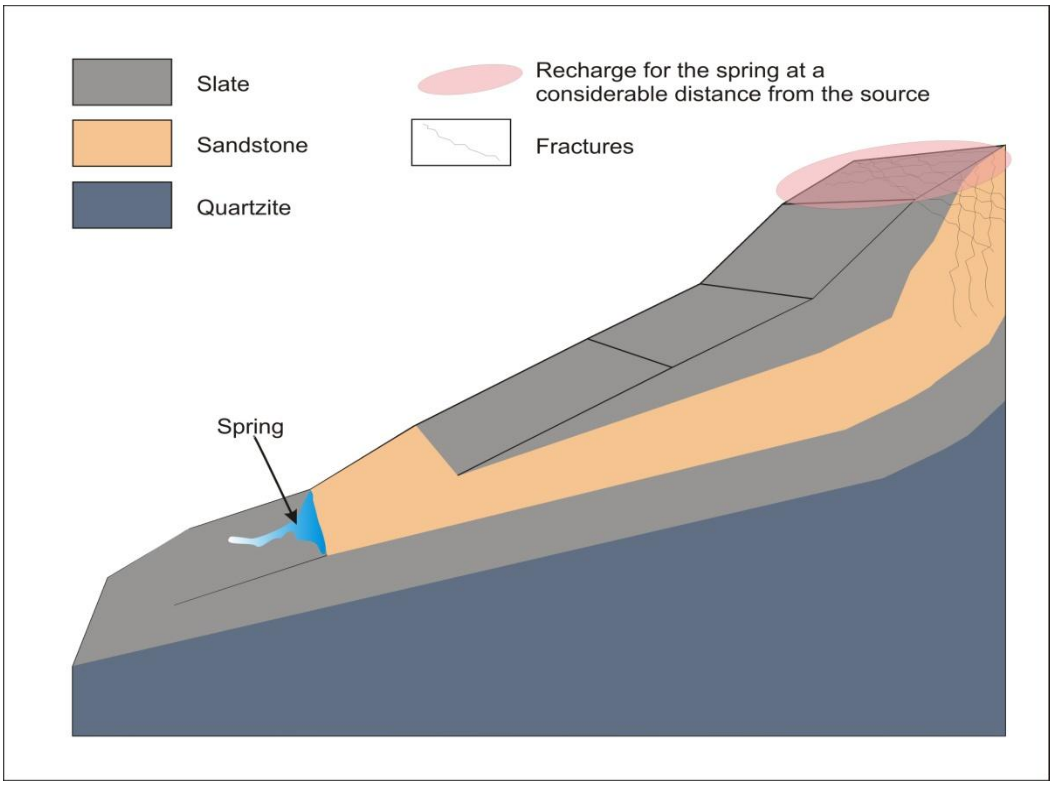
In case the spring issues from confined aquifers along a lithological contact, the recharge area of the spring system would be limited to the aerial extent of the confined aquifers, that is, the area of the aquifer that is exposed or available for recharge. Such conditions are more likely to be encountered in layered formations that may or may not have undergone structural disturbance and metamorphism.

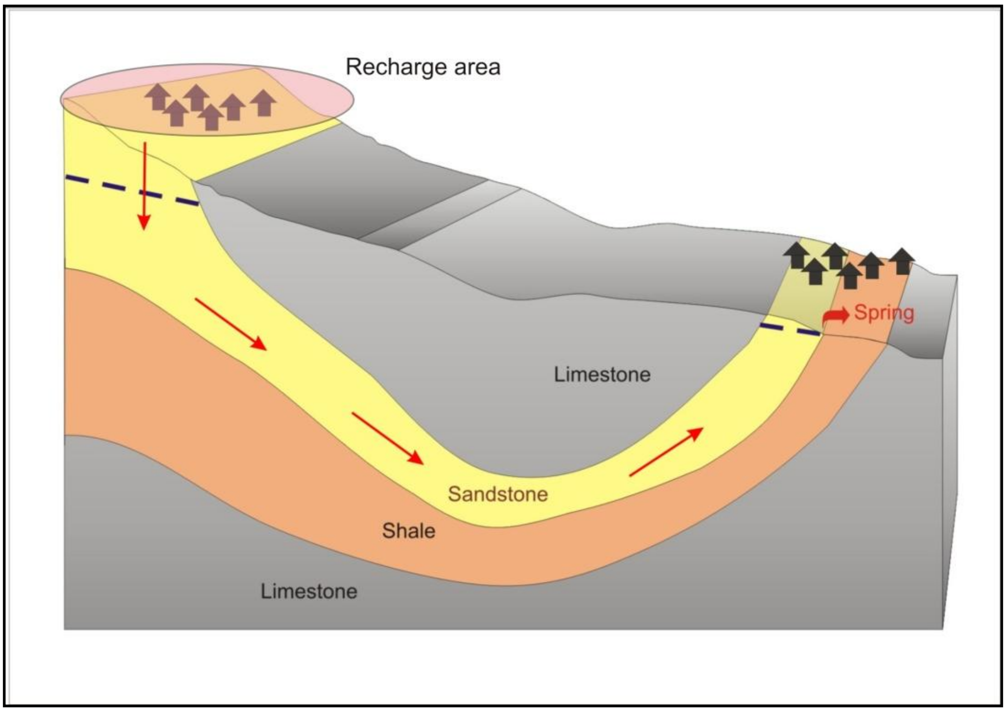
When springs originate from fractures or faults that cut across different rock layers, the recharge to the springs may not be from a definite aquifer. These springs receive water from higher reaches of the terrain where water is able to percolate down through these fractures and eventually emerge from the spring openings. In general, there are two components of recharge to such springs – one is water that directly enters these fractures from the ground surface and second, water from surrounding formations may slowly enter these fractures and contribute to recharging the springs in the system.

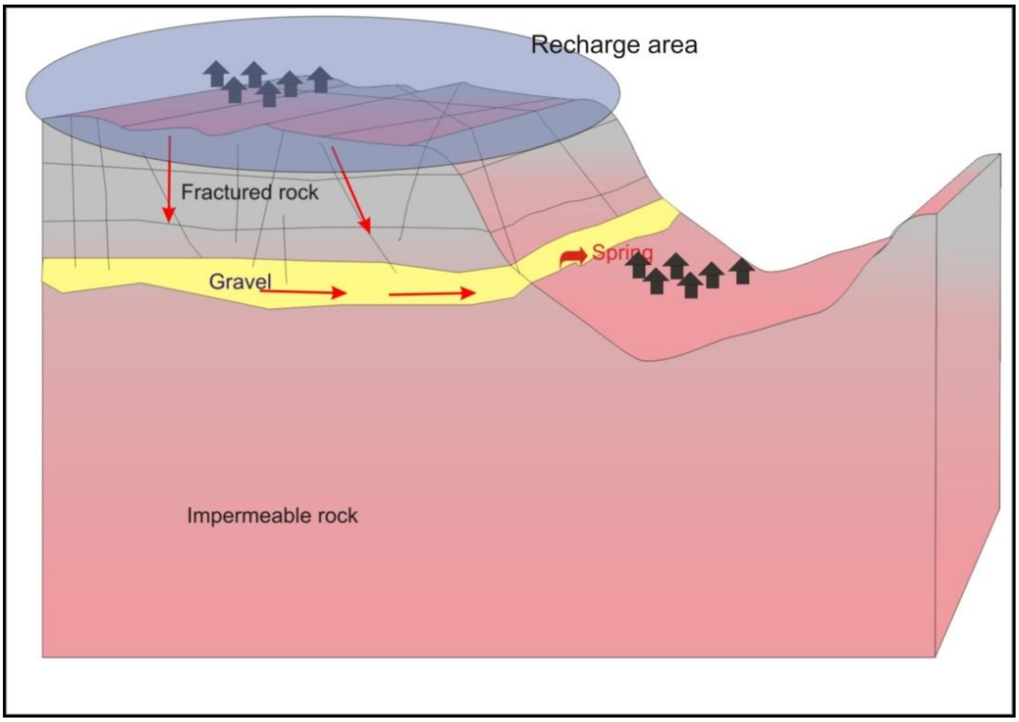
Varied and complicated relationship may exist between the springs (discharge zone of a watershed) and the zone of recharge for the springs or the watershed. Hydrogeological mapping, discharge and water quality measurements help in understanding this relationship in a hydrological as well as in a spatial context.

The spatial relationship between springs and their recharge zones in varied geological environments is illustrated in the following pictorial representations.






Recharge area
Spring
Limestone
Sandstone
Shale
Limestone


Recharge area
Fractured rock
Spring
Gravel
Impermeable rock

Spring-shed Management

The fundamentals of geology, the principles of hydrogeology and the analytical methods essential in spring-shed management have been discussed and elaborated in the previous chapters. For a spring development or spring recharge programme to be successful, there should be a systematic approach to the treatment of the spring catchment and development of the resource. Hydrogeology is an indispensable, but often ignored component of planning when it comes to dealing with groundwater systems. Therefore, systematic and detailed hydrogeological study facilitates in the formulation of an effective plan for spring-shed management. This chapter puts forth guidelines along which spring development programmes can be planned.

Hydrogeological mapping

The study of the spring-shed's geology and geomorphology must be the first step. Hydrogeological mapping exercise is conducted to understand the types of rocks, the attitude of rocks and other geological features in the area. The geomorphology or topography (landforms) of the spring-shed must also be studied as the landforms define the drainage in the area. By studying the drainage system in an area, the flow and accumulation of water in the spring-shed can be understood. The basic procedure for hydrogeological mapping has been described exhaustively in the previous chapters.

Aquifer delineation

Hydrogeological mapping must be exhaustive enough to promote the delineation of the aquifer in the spring-shed. Delineation of aquifer simply means that one must identify the rock formation or in some cases rock formations that yield water to springs. The aquifer or the water bearing rock body is surrounded by impermeable layers that inhibit the flow of groundwater. For recharge plans to be successful, it is imperative that the extent of the aquifer and the impermeable beds be established.

Classification of springs

Once the aquifer has been delineated and the geological features responsible for the origin of springs understood, the spring can be classified into the different types described in the previous chapters. The different types of springs are depression, contact, fracture, fault and karst springs. The classification of springs is critical as the recharge area of a spring is largely controlled by the mode of its origin; in other words, the type of the spring. Discharge and water quality analysis can be later used to confirm the classification.

Identifying the recharge area

The delineation of the aquifer and classification of a spring helps in the identifying the recharge area of the spring. The location of springs and the recharge area for the springs should be marked carefully on the hydrogeological map and the conceptual model. Different zones can be identified such as the direct recharge zone, recharge protection zone and zone of soil conservation etc. The zones can also be marked on photographs of the spring-shed, if available.

Conceptual model of the spring

The conceptual model of a spring is a two dimensional or three dimensional layout of the spring-shed depicting the subsurface geology and the groundwater regime. The model must include details such as rough topography, dip of rocks, dip of fractures, recharge area and discharge area in the spring-shed.

Setting up of a monitoring system and impact assessment

As described previously, discharge and water quality data convey large amounts of information. Therefore, an organized system must be set up for periodically measuring the spring discharge and water quality. Monitoring the spring prior to the implementation of recharge structures is useful in verifying the map and conceptual models developed. Post implementation monitoring helps in the understanding whether the spring-shed measures have technically proven beneficial for the sustainability of the springs. The benefits of the measures could be increase in the recharge to the aquifer or a significant increase in the spring discharge. There may be changes in the water quality which can only be addressed if significant data is available.

Structure to store and measure spring discharge

Planning treatment measures

Once the hydrogeology of the spring-shed has been understood, the aquifer delineated, conceptual models prepared, recharge area identified and most important of all a monitoring system has been setup, the treatment measures for the catchment can begin. Recharge areas are not controlled by administrative and communal factors.

Mobilizing Partners

Therefore, it is very likely that catchment for the springs may lie in private lands, forest areas, agricultural lands etc. Sometimes the recharge area may simply be inaccessible due to topographic constraints. The planning for catchment area treatment must thus consider all the administrative and communal specificities. The community mobilization by teaching the basic principles of hydrogeology and groundwater will help in the making implementation that much easier. Community participation ensures the completion of the project and often plays a more dominant role in shaping the spring-shed programmes. However, building awareness among various stakeholders - administrative and communal – about the science of groundwater will be significant a step in securing the projects objectives.

Mobilizing Community

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Spring Inventory Data Sheet

Spring No: Spring Name:

Study Area: Village:

Lat: Long: Elevation with GPS: m

Location with prominent landmarks:

Topo-sheet no.: Ownership: Private / Govt. Owner's Name:

Type of Spring: *Naula* / *Dhara* / Any other

Dimensions of Spring (Length x Breadth x Depth in case of ***Naula*** or pipe diameter in case of ***Dhara***) :

Geology:-

Rock Type: Loose-unconsolidated / weathered rock / fractured-vertical / fractured-horizontal / hard & unfractured / any other…………

Other characteristics:

Other Structural features:

Type of Spring: Depression / Contact / Fracture or Fault / Karst /Dip related

Seasonality of Spring: Seasonal / Perennial

If Seasonal, what is the period of flow:

Temperature of water: hot / warm / cold /normal ………° C

Measuring Point from Ground level: m Reduced Level: m

Spring Water Use: Domestic / Irrigation / Industrial / Community water supply

Nearest surface water source: Stream / Tank / Canal

Approximate Distance of source: m

Page 1

For '*Dhara*' and 'Flowing *Naula*'

Date	Time of measurement	Discharge in litres per minute

For 'Non-flowing *Naula*'

Date	Time of measurement	Static Water Level from measuring point

Water Quality

Date	pH	Electrical Conductivity (µSiemens/cm)	Total Dissolved Solids (mg/l)	Salinity (ppm)	Nitrate (mg/l)	Bacteria

Water sample: collected / not collected

Water sample ID: Observed by

Page 2

Igneous Rocks

Name of the Rock	Description	Grain Size	Minerals Present	Metamorphosed to	Porosity	Permeability	Water Quality
Basalt	Very hard rock, black to greenish in colour.	Mineral fragments are very fine, not visible to the naked eye.	The rock contains dark coloured minerals such as augite, feldspars etc. which are rich in iron, magnesium and calcium.	A dark coloured rock that is difficult to distinguish from basalt.	Low	Low	Salinity and TDS will tend to be high.
Gabbro	Very hard rock, black to greenish in colour.	Mineral fragments are coarse grained and visible to the naked eye.	The rock contains dark coloured minerals such as augite, feldspars etc. which are rich in iron, magnesium and calcium.	A dark coloured rock that is difficult to distinguish from basalt and gabbro.	Low	Low	Salinity and TDS will tend to be high.
Granite	Very hard rock. Light coloured rock with dark coloured minerals distributed unevenly.	Mineral fragments may be coarse to fine grained.	The rock contains dark coloured and light coloured minerals like quartz, mica, feldspar and hornblende which are rich in potassium, sodium and silica.	Generally forms gneisses.	Low	Low	Salinity and TDS will tend to be low.

Sedimentary Rocks

Name of the Rock	Description	Grain Size	Minerals Present	Metamorphosed to	Porosity	Permeability	Water Quality
Conglomerate and Breccia	Rock composed of pebble sized or larger fragments of different rocks held together by fine grained matrix and/or cement.	Very large grains or clasts	Various; may contain quartz, clay, calcite and others.	Depends on the composition of the larger grains (clasts) and the grains filling the gap between larger grains (matrix).	Depends on the matrix material. Sand – High Clay – Low Precipitated cement – Lowest	Depends on the matrix material. Sand – High Clay – Low Precipitated cement – Lowest	Will depend on the abundance of water soluble minerals. Generally, low to medium TDS and Salinity.
Sandstone	It is composed of sand sized grains that have been consolidated or *lithified*. Matrix is made up of finer clay size particles. Cement may be of iron, silica or calcium.	Coarse to fine grained	Dominantly quartz. Feldspar and other minerals are also present.	Quartzite	Generally high	Generally high	Will depend on the abundance of Feldspar and other water soluble minerals. Generally, low to medium TDS and Salinity.
Mudstone / Claystone / Shale	Completely composed of clay sized grains.	Very fine grained	Clay, Chlorite and Mica.	Slate to Phyllite to Schist. First slate forms with coarse partings. On further metamorphism Phyllite forms with finer partings. Schist forms at the highest level and contains large recryatllized Mica.	Highest Porosity	Lowest Permeability	Will depend on the abundance of Feldspar and other water soluble minerals. Generally, low to medium TDS and Salinity.
Limestone/ Dolomite	White to dark coloured rock. Chemically precipitated rock.	Coarse to fine grained	Calcite and Dolomite.	Marble	Generally low	Generally low	Generally high Salinity and TDS.

Metamorphic Rocks

Name of the Rock	Description	Grain Size	Minerals Present	Metamorphosed from	Porosity	Permeability	Water Quality	
Slate	Soft to hard rock. Colour varies depending on the mineral content. Characterised by widely spaced parting surfaces.	Mineral fragments are very fine, not visible to the naked eye.	Contains large amount of clay. Mica, Chlorite and some feldspar may also be present.	Mudstone/Claystone /Shale	Low to moderate.	Low. However, open partings will increase the permeability.	TDS will generally tend to be low. pH and TDS will increase if feldspar and other water soluble minerals are present.	
Phyllite	Soft to hard rock. Colour varies depending on the mineral content. The parting surfaces are very close.	Mineral fragments are very fine, not visible to the naked eye.	Contains large amount of clay. Mica, Chlorite and some feldspar may also be present.	Mudstone/Claystone/ Shale	Low to moderate.	Low. However, open partings will increase the permeability.	TDS will generally tend to be low. Salinity, pH and TDS will increase if feldspar and other water soluble minerals are present.	
Schist	Soft to hard rock. Colour varies depending on the mineral content. The parting surfaces are extremely close. The rock has a bright sheen due to presence of mica.	Minerals are medium to coarse grained.	Generally the clay content reduces. Mica is the dominant mineral in schists. When Chlorite forms the schist, the colour is green.	Mudstone/Claystone/ Shale	Low to moderate.	Low. However, open partings will increase the permeability.	TDS will generally tend to be low. Salinity, pH and TDS will increase if feldspar and other water soluble minerals are present.	
Gneiss	Hard rock that often resembles granite. Contains alternate layers that resemble schist sandwiched between large granulose grains.	Minerals are medium to coarse grained.	Contains Quartz, Mica, Feldspars and other minerals.	Generally from granite.	Low	Will depend on the grain size and the openings of schistosity.	Salinity, pH and TDS will increase if feldspar and other water soluble minerals are present.	
Quartzite	Hard rock with varying colours. The grains are fused together	Minerals are medium to coarse grained.	Completely made of Quartz. Other minerals may be present as impurities.	Sandstone.	Low	Low	Salinity, pH and TDS will tend to be low.	
Marble	Soft to hard rock. Colour varies depending upon impurities.	Minerals are medium to coarse grained.	Completely made of Calcite and/or Dolomite. Other minerals may be present as impurities.	Limestone and Dolomite.	Low	Low	Salinity, pH and TDS will tend to be high.