TRAINING MATERIAL

FOR PRACTICAL SESSIONS

Advanced Center for Water Resources Development and Management

INDEX

I. Units of Measurements

There are a number of things that we measure in our day to day life. For example, height, weight, distance, temperature etc. All these have some system of measurements. The height of a person is measured in cm, m or in feet. Similarly weight is measured in kg, gram or pound. In India we use metric system for measurement. Metric system is a system of measurement which has three basic units: Meter, Kilogram and Second. This system is also called as SI system. In a watershed, there four major components are required to be computed or measured. These are **Length, Area, Volume and Discharge**.

Length: Length is measured to calculate the distance between any two points. This can help us in measuring the length of stream, depth of well, distance between two hamlets, height of the check dam and so on. The length can be measured using centimeter, meter, kilometer, mile, inch, feet or yard. In watershed, centimeter is the smallest unit of measurement while mile is the largest unit of measurement. Some simple conversions units are given in the table 1.

100 cm = 1m.	1000 m = 1km	1.60 km = 1 mile
12 inches = 1 foot	3.28 feet = 1 m.	1 m. = 1.09 yard

Table 1: Simple conversion units for length

Area: Area is calculated by multiplying length in to width. It is a two dimensional measure and is denoted as m^2, km^2, $feet^2$or $mile^2$. The area helps us in understanding the total expanse of the watershed, of the town or village and the patch of land. Acre and hector are the two additional units used for measuring area. Table 2 shows the conversion units for area.

1 m^2 = 10.76 feet	1 km^2 = 100 ha	2.5 acre = 1 Ha
1 acre = 40000 ft2	1000 ft^2 = 1 guntha	1 acre = 0.40 Ha

Table 2: Simple conversion units for area

Volume: Volume is calculated by multiplying length to width to height. It is a three dimensional measure and is denoted as m^3, cm^3 or ft^3. It is the measurement of amount of space contained within a three dimensional space. Volume helps us in understanding how much water is stored in a dam or a tank or a well. Liter is a common additional unit used for measuring volume. Table 3 shows the conversion units for volume.

1 m^3 = 1000 liter	1 m^3 =35.31 ft^3	1 ft^3 =28.31 liter

Table 3: Simple conversion units for volume

Discharge: Discharge is calculated as volume per unit time. It is used to measure the rate of flow of water in a watershed. The discharge is measured for the spring or for the water from the pumped well. Discharge is usually measured as m^3/min or lit/sec. In the earlier three measurements it is a direct calculation of length, area or volume. In case of discharge time is taken into consideration as the fourth dimension. So discharge can be calculated per second, per minute, per hour or per day. Therefore, if the discharge is 1 liter per second, it will be 60 liter per minute and 3600 liter per hour and 86400 liter per day. *Table 4* shows the conversion units for discharge.

$1m^3$/sec= 1000 liter/sec	1 ft^3 /min =28.30 lit/min	$1m^3$/hour=41 liter/hour

Table 4: Simple conversion units for discharge

The table of conversion for length, area, volume and discharge is readily available and given as annexure 1.

The other parameters measured in a watershed are rainfall and runoff. The rainfall is measured in mm. In some areas it is also measured in inches. Therefore, 1 inch of rainfall is equivalent to 25.5 mm. of rainfall.

If there is an area of 1 km^2 with 10 mm rainfall. Then the total volume of water generated in that area will be = 1 * 1000 * 1000 * 0.001 m^3

Volume = (**area * 1000 * 1000***(converting area from km. to m.)* * **rainfall** *(converting mm. to m.)*)

The volume of water = 1000 m^3

The runoff is measured as discharge which can be measured using a simple instrument called 'V' notch. This 'V' notch can be made of GI sheet. This instrument can be fabricated and installed at the narrowest part of the stream. During measurement following things should be ensured-

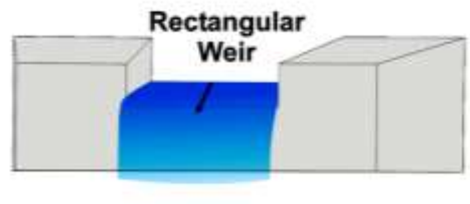
- The angle at the 'V' should be of 90°.
- All the water from the stream should pass through the 'V' and not outside the instrument.
- The height of the flowing water can be measured using a scale and recorded.
- The discharge can be measured using Thompson equation

$Q=0.8388H^{5/2}$

where, Q is discharge liter/min and H is the height in cm. of the water column.

- The discharge measurement table for 'V' notch can also be used to calculate the discharge from the stream. The table to measure the discharge from the stream is given as annexure 2.

Similarly, on a larger stream the discharge can be measured using rectangular weirs. In this method the rectangular weir can be constructed or any existing structure like a bridge side walls can be used to measure discharge. This method is used for slightly larger streams where discharge is more. During measurement from rectangular weir following things should be ensured-



- The length of the structure should be measured.
- The base of the surface should be uniform and smooth.
- The head of flowing water should be measured in inches.
- Francis equation can be used to measure discharge.

The equation is **$Q=3.33(L-0.2H)H^{1.5}$** ***Where.***

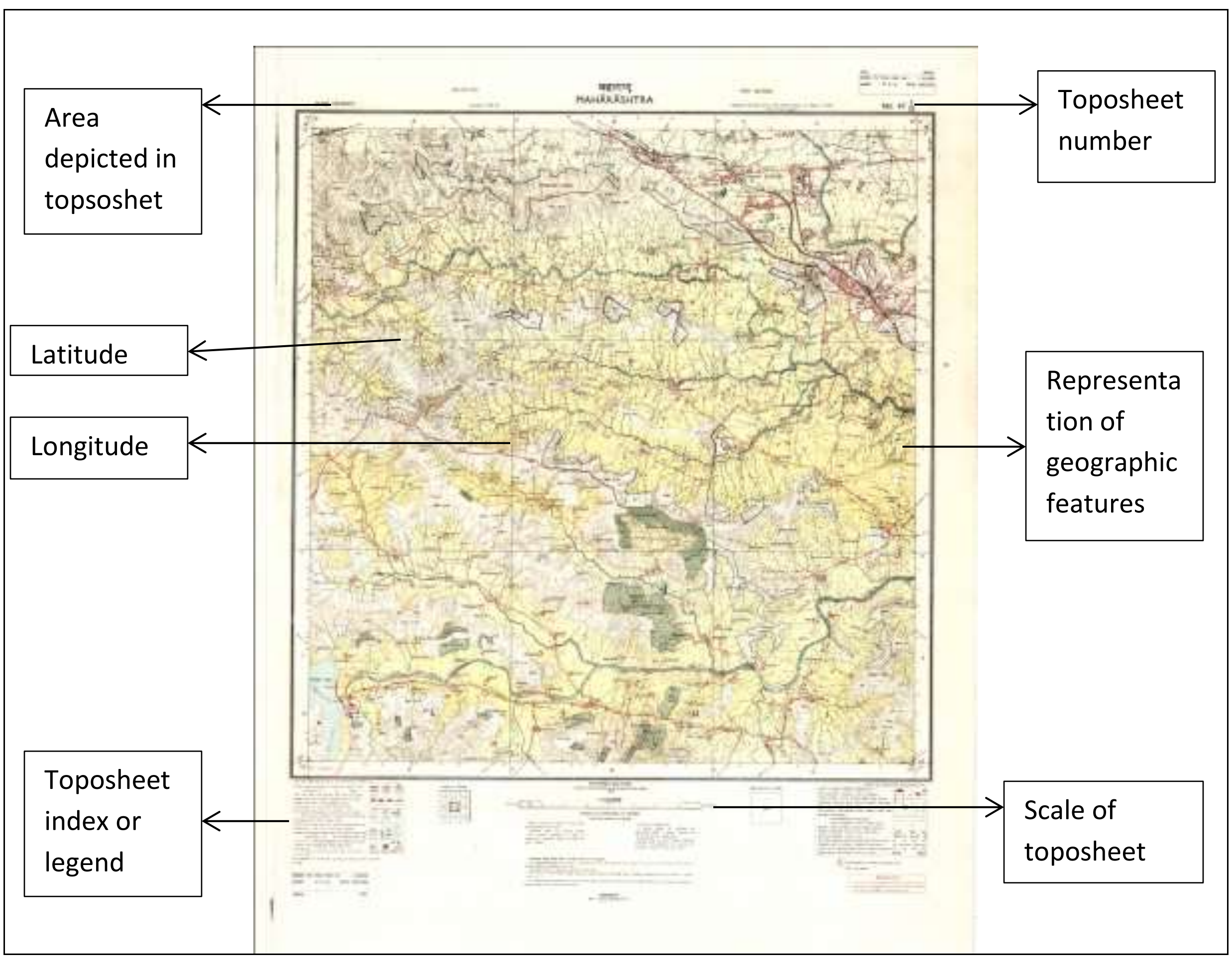
- ***Q= Flow of water in ft3/sec; L= Length of weir in ft & H= Head of weir in ft.***

The discharge measurement table can also be used for calculating the discharge from the rectangular weir. The table is given as annexure 3.

II. Reading Toposheets

Toposheet is a shortened name for topographic sheet. It is a map depicting information about topographic features like contours & drainage, land use features like agricultural land & forest land along with information about roads, settlements etc. The topographic map on a sufficiently large scale to enable the individual features shown on the map to be identified on the ground by their shape and position. In watershed work. Topographic maps can be used as sources of detailed information about a particular territory and as a reliable means of orientation on the terrain. Therefore, toposheet is used as a base map. One can get a reasonable idea about the area by referring to the toposheet before going to the actual area.

The toposheets are available in varied scale from 1:250000 scale to 1:10000 scale. The 1:250000 sheets are called as small scale maps while 1:10000 sheet are called a large scale maps as maps with smaller scale will give more details than the maps with larger scale. Toposheet are prepared using a suitable projection and contain information about latitude and longitude. Each toposheet has a unique number which helps in identification of the exact toposheet for the particular area. Every toposheet has an index which can be used as a reference.

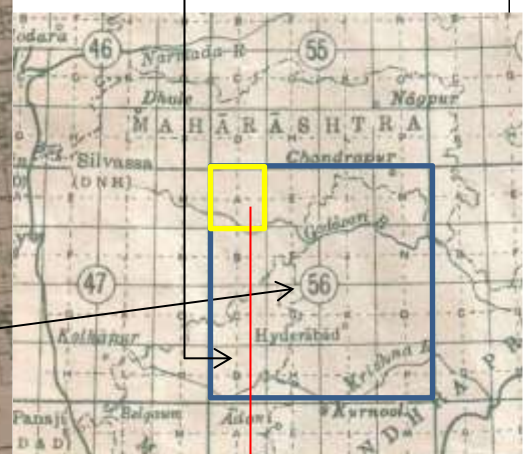


Toposheet number

Each Toposheet has a unique number which is related to the scale of the Toposheet. The layout and numbering of all toposheets (1: 50000 and 1:250000) are based on 1: 1000000 (1 Million) India and adjacent countries series maps. Each 1 Million map is divided into sixteen 1:250,000 maps. Each 1: 250,000 map is further divided into sixteen 1:50000 maps. The numbering is explained further in the diagram given below.

1 Million sheet depicting India divided in various numbers. The number 46,47, 63….indicates the number of 1: Million sheet. This is further divided into 16 1:250000 scale maps.

Each 56 A to 56 P map has a scale of 1:250000.



1: 250,000 sheet

1:50,000 sheet

Thus, the 1: 50,000 sheet has a Toposheet number like 56 A/10 or 47 F/14. Using this toposheet number, the numbers of the surrounding toposheets can be found out.

Example: Toposheet No. 56 A/6 will have toposheet no. 56 A/5 to the north, 56 A/7 to the south, 56 A/2 to the west, 56 A/10 to the east and so on.

Scale

Scale represents the relationship between the distance on the map and corresponding distance on the ground. The map scale can be represented either as ratio or representative fraction (RF) or graphical scale or word statement. The three methods of scale representation are shown below.

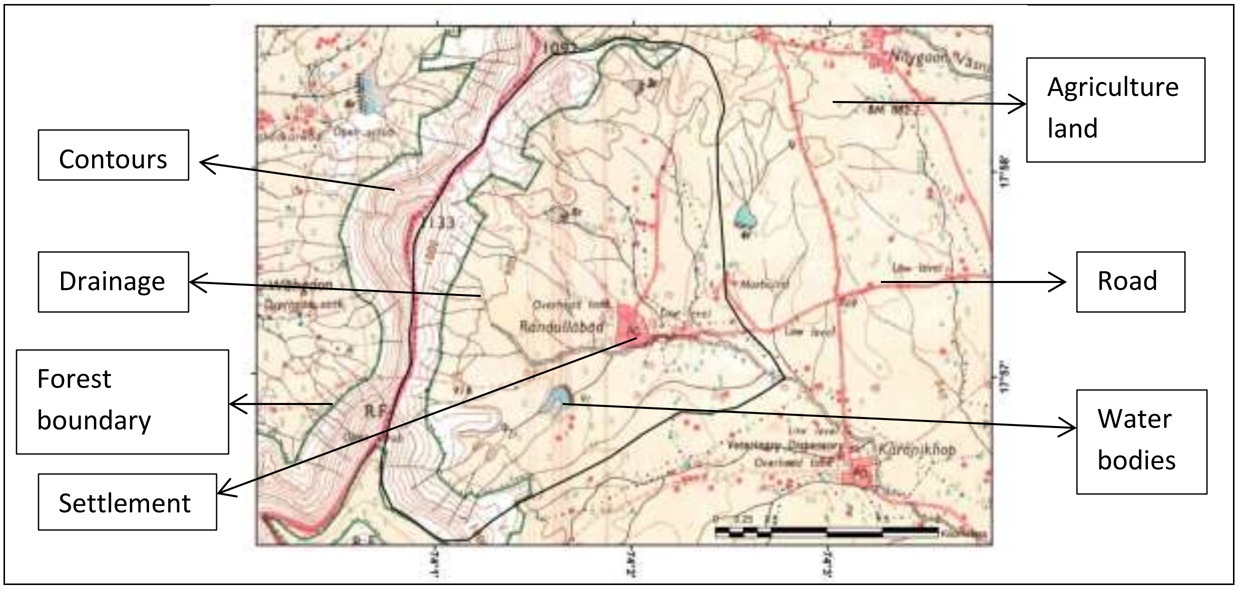
Ratio or Representative Fraction (RF)	**Graphical scale**	**Word statement**
1: 50000 scale Means, 1 cm on map represents 50000 cm on the ground. So 1 cm= 50000 cm or 1 cm = 500 m.		It simply states what is the scale. Example: 1 cm is 500 m.

The most commonly used scale is the **graphical scale** in a map as this scale gets automatically reduced or enlarged with the enlargement or reduction of a map. The scale of 1:50000 toposheet is 1 cm = 500 m. This scale is used to measure the distance between any two points on the toposheet.

Maps are often divided as small scale map and large scale map. The small scale map gives lesser details as the scale is large. On the contrary, large scale map gives more details as the scale is small. Example: 1: 1000 map is a large scale map as 1 cm on map represents 10 m on ground. This map will be able to represent features with greater accuracy. As against this 1:250000 map is small scale map as 1 cm on map represents 2.5 km. on ground. This map can show larger area with very little details. Depending upon the details required, the maps with appropriate scales are selected.

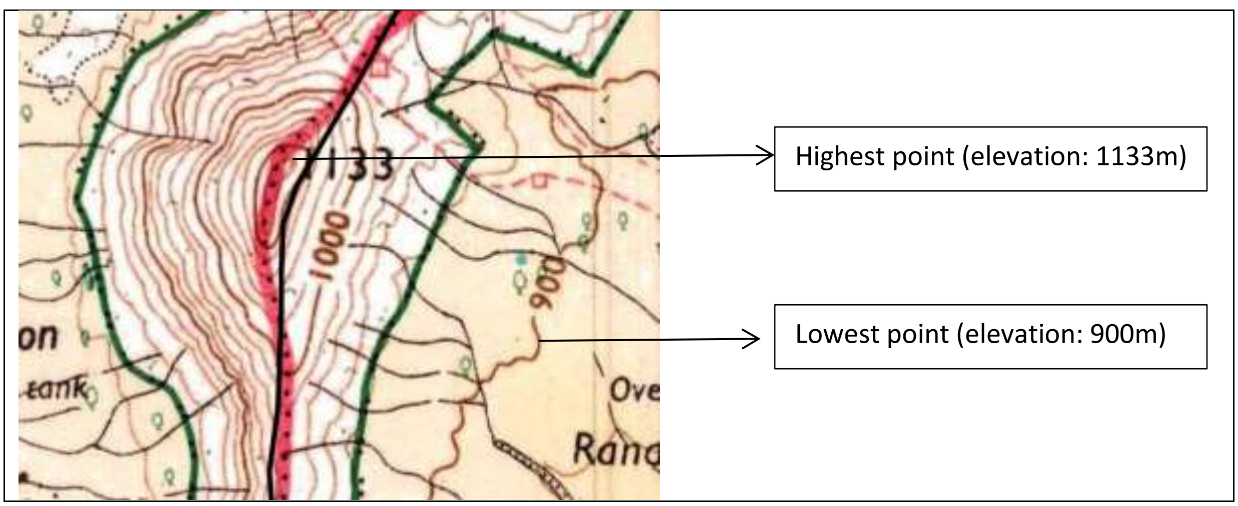
Index or legend

Each toposheet has an index or a legend which is given at the bottom left and bottom right corner of the toposheet. The index will have details of each and every symbol used in the toposheet. There is a colour code used for depicting various features. The colour codes are as below.
Blue is used for water features
Red for roads and settlements
Green for wooded area
Yellow for cultivation
Brown for contour and cliffs, etc
Black for outline and typescript
Grey for hill shading



Contour

Contour line is an imaginary line showing area of same elevation. In a toposheet, contour lines are shown with brown colour. The closely spaced contours show rapid change in the elevation indicating hilly area. The sparsely spaced contours show little change in elevation indicating plain area. Each toposheet has a specific contour interval. Example: 1:50000 toposheet has a contour interval of 20m. while 1:25000 toposheet has a contour interval of 10m. Using this information the exact elevation difference can be calculated using the maximum and minimum contour value.



Settlements

Settlements are shown in red colour. The size of the settlement indicates how big or small the settlement is. The smaller hamlets are shown as small rectangle while larger towns are shown with bigger red rectangles. In some toposheets information like the market day, civil amenities present in the village are also given.

Drainage

The first, second and third order drainage is usually shown in black colour. The rivers are shown in blue colour. The rivers which are dry or have lot of sedimentation are shown with black colour. The dams or ponds are also shown in blue colour with the sedimentation in black colour.

Administrative boundary

All the administrative boundaries are shown in the toposheet. The taluka boundaries, district boundary and state boundary is clearly depicted in the toposheet. If the toposheet is showing area of two districts or states, it is shown in the square at the bottom right corner of the toposheet.

Most of the toposheets are easily available at the Survey of India offices across India. However, there are some restricted toposheets which are not available mainly due to security purpose. A special permission has to be obtained to procure these toposheets. At present, the toposheet catalogue is available on the internet. One can easily find the toposheet number from the internet and that toposheet can be obtained from the SOI office at cost. The toposheets are available in the soft as well as hard copy format.

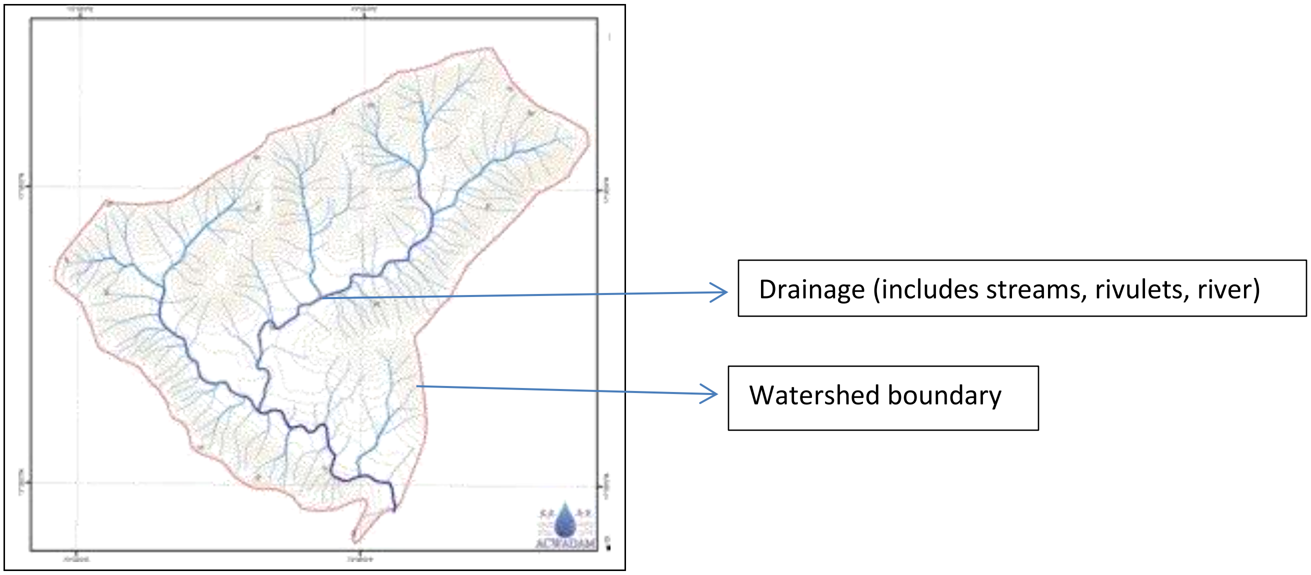
III. Drainage analysis

Common treamtments done in the watershed development programme

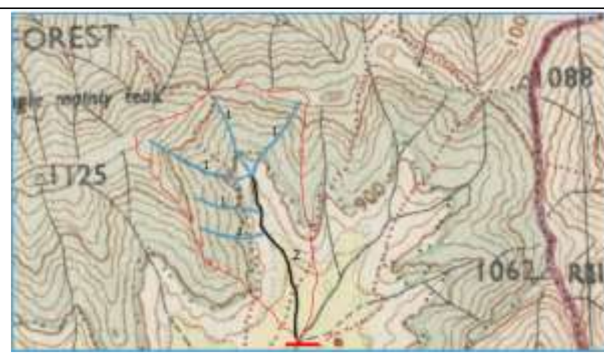
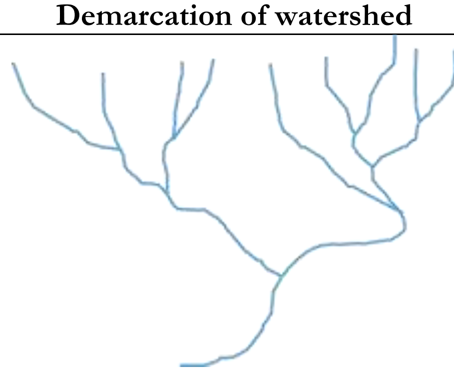
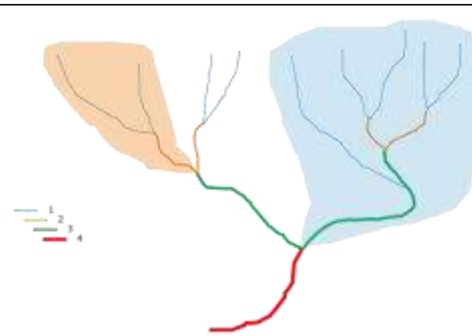
Watershed treatments

Feasible measures	**RIDF 1,2,3**	**RIDF 4,5,6**	**RIDF 7**	**RIDF 8**
Soil conservation	Most areas above 300m (asl) have steep slopes – soil conservation (trenches/bunds) – staggered, wherever possible and gully plugs along small gullies	Most areas above 300m (asl) have steep slopes – soil conservation (trenches/bunds) – staggered, wherever possible and gully plugs along small gullies	Mostly Low lying area with lateritic plateau soil conservation - trenches/bunds and in some places gully plugs along small gullies	Mostly Low lying area with lateritic plateau soil conservation - trenches/bunds and in some places gully plugs along small gullies
Drainage line treatment	165 to 260 m (asl): water conservation, to control flow velocities (could be low, concrete structures or even gabion, where slopes are relatively gentler)	To control flow velocities &water conservation treatment is to construct check dam (which may be of concrete, loose boulder or earthen bund)	Small check dam, loose boulder dam, earthen dam for water conservation treatment,	Water conservation, to control flow velocities construct check dam (which may be of concrete, loose boulder or earthen bund) gabion, where slopes are gentler.
Percolation tanks	120 to 160 m (asl): wherever such sites exist along drainage lines	120 to 250 m (asl): wherever such sites exist along drainage lines	120 to 160 m (asl): wherever such sites exist along drainage lines	120 to 250 m (asl): wherever such sites exist along drainage lines
Water harvesting structures	Below 110 m (asl): Wherever such sites exist along drainage lines	Below 110 m (asl): Wherever such sites exist along drainage lines	Below 110 m (asl): Wherever such sites exist along drainage lines	Below 110 m (asl): Wherever such sites exist along drainage lines
Decentralized water harvesting structures	NO SCOPE	Especially along second order drainage	Many of the places possibilities of decentralized water harvesting structures.	Many of the places possibilities of decentralized water harvesting structures
Spring water management	Scope along certain zones, especially in areas aligned with fracture zones (Chirani, Mohane, Khandat villages).			

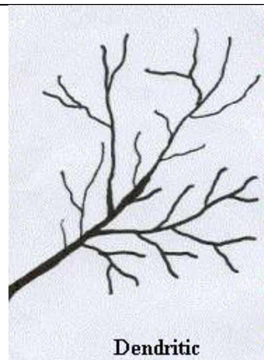
Drainage and watershed

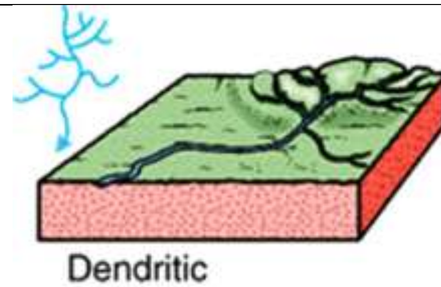


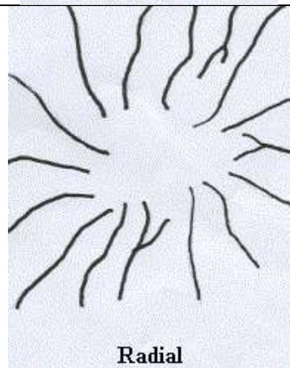
Demarcation of watershed

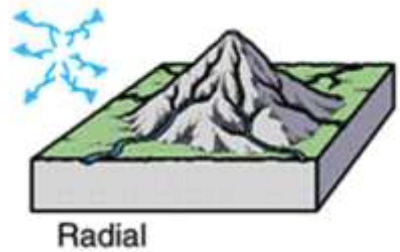
 Demarcation of watershed	 Stream ordering (Straler's method)
 Drainage	 Stream ordering and watershed demarcation

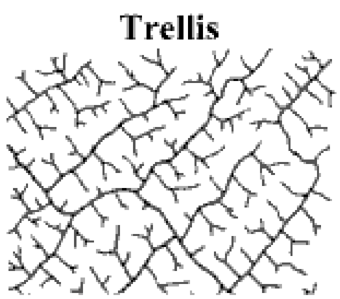
Drainage patterns

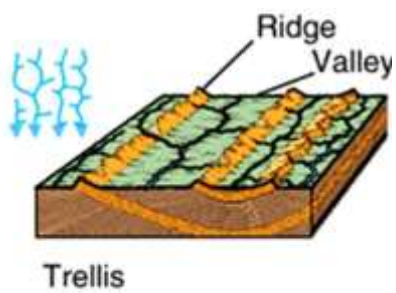


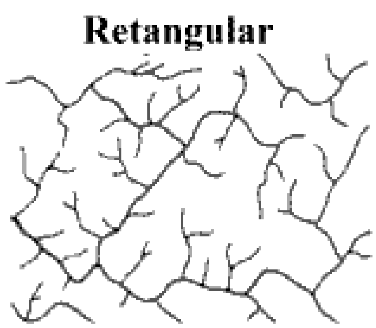


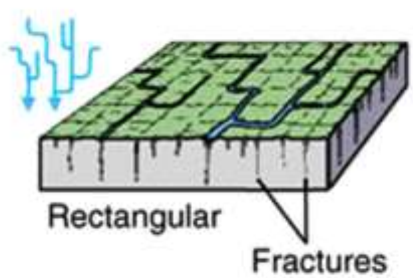


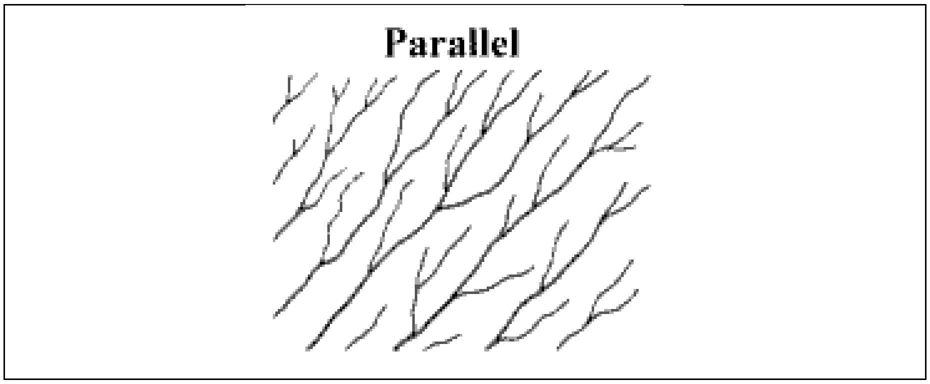












Parameters required for drainage analysis/morphometric analysis

- Area of watershed: The watershed area in km^2
- Stream numbering: Stream ordering by the Strahler's method
- Number of streams: Total number of streams (total of first, second ….n^{th} order of streams)
- Length of stream- Total length of stream

Calculations

- Bifurcation ratio =

  No. Of streams of order n / No. Of streams of order (n+1)
- Drainage density =

  Σ Stream Length / Area of watershed
- Stream frequency =

  No. of streams / Area

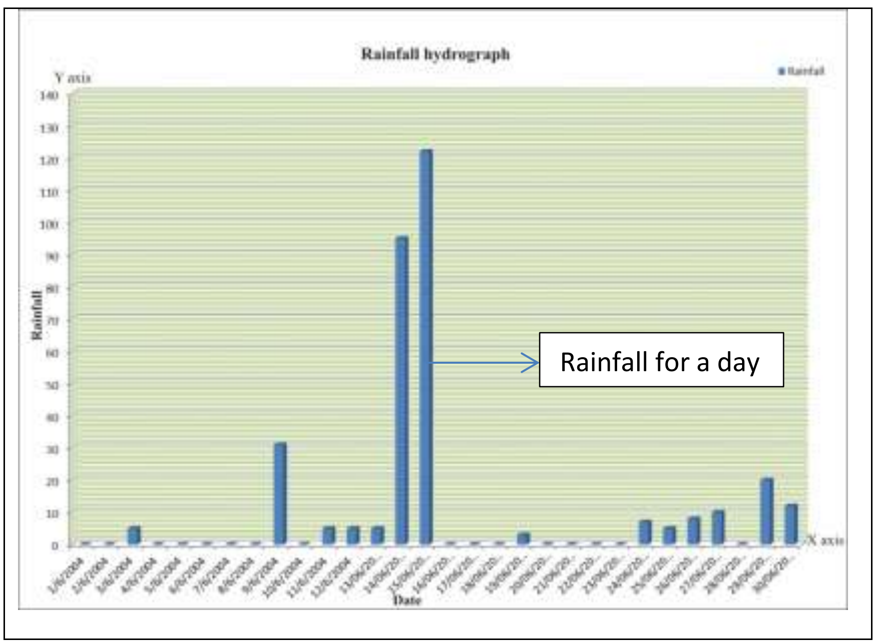
IV. Integration of weather data in Hydrogeological studies

In hydrogeological studies different types of data is collected. For example, the weather data like rainfall & evaporation, water level data, water quality data etc. All this data is analysed and interpreted. The hydrogeological studies involve collection of data for a longer period (at least one hydrological cycle i.e. one year) It is easier to plot and analyse this huge data set. Besides, the graphical presentation is always easy to understand than the description. Therefore, simple graphs can be prepared using graph paper or using MS Excel. These graphs speak for themselves and there is very little need to explain in detail. We will see how two different data sets are plotted on the same graph and how they are interpreted.

There are two data sets; one for rainfall data and other for water level for a month. These two data sets can be plotted on the same graph paper. This is how it is done.

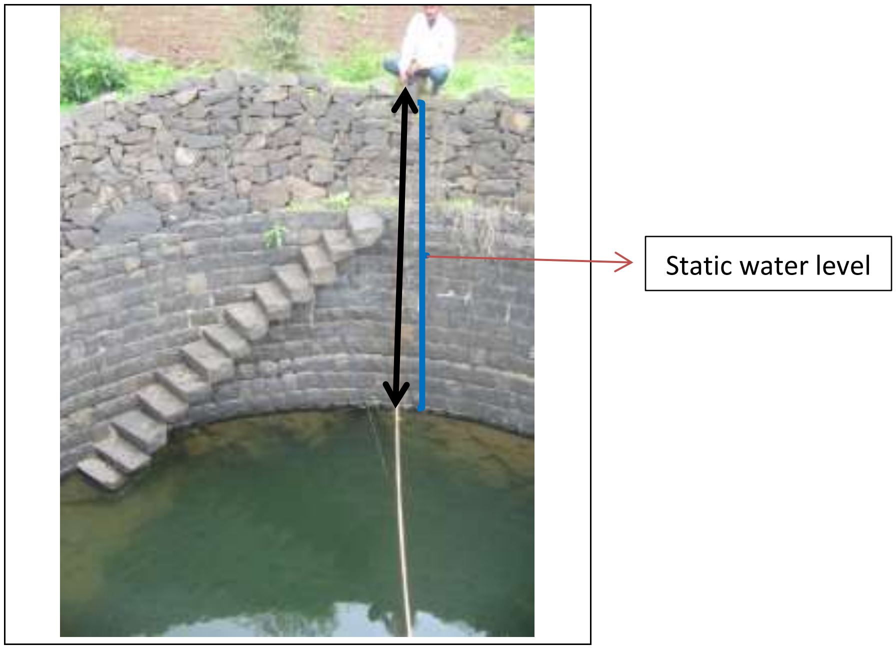
Plot a hydrograph indicating daily rainfall for a watershed

- The rainfall data is plotted on 'Y' axis while the date is plotted on the 'X' axis using appropriate scale.
- This graph will represent the exact distribution of rainfall over the time.



Graph representing distribution of rainfall over a month

Similarly data is collected for the water levels for the selected wells in the watershed. The Static water level is collected for every well at a stipulated time interval (8days/ 15 days/ one month). The static water level is level of water in the well measured from the top. *(shown in the photograph below)*



This static water level is the water level for that particular well. There are more than 10 wells in a watershed and if the water level of all these wells is to be plotted, there is a need of a common datum. This common datum is the mean sea level. The elevation of each well will give the location of each well with respect to mean sea level. On the basis of Elevation and Static water level, reduced water level is calculated for each well. The reduced water level will be the level of water in the well with respect to mean sea level.

The Reduced water level is calculated as-

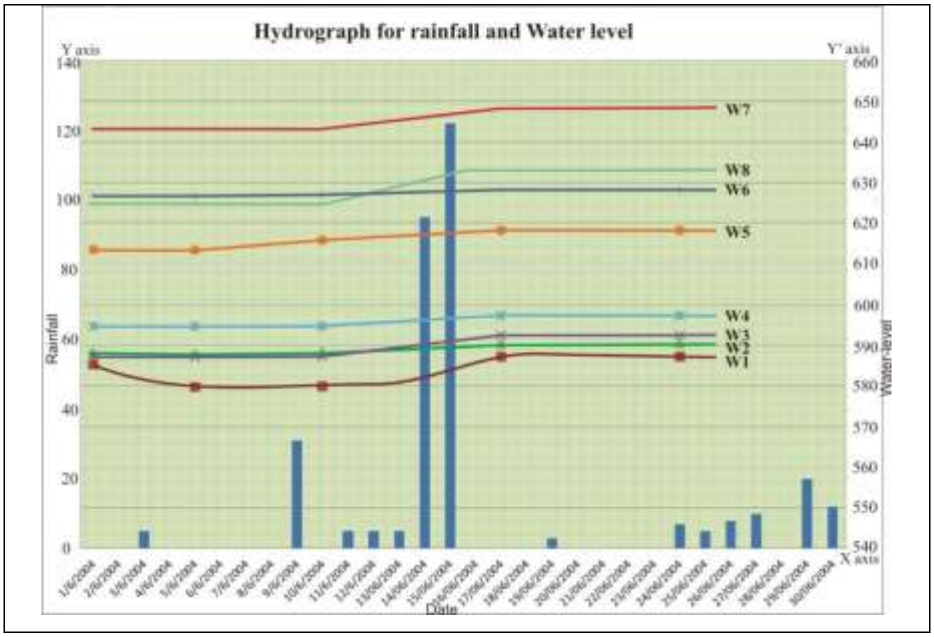
Reduced water level = Surface elevation of the well *(GPS Reading)* – Static water level

If the Elevation of the well is 600 m. above msl and static water level is 5.5 m.

Then the Reduced water level (RWL)= 600 – 5.5 = **594.5 m.**

The reduced water level (RWL) can be plotted on the rainfall plot to understand the effect on rainfall on the well water level.

For this another Y' axis is plotted to the right hand side of the graph. This is called as Secondary axis. The reduced water level for each well is plotted on that axis against the date. (which is common for both, rainfall and water level) This graph will give an idea about the increase in the water level with respect to rainfall as shown in figure below.



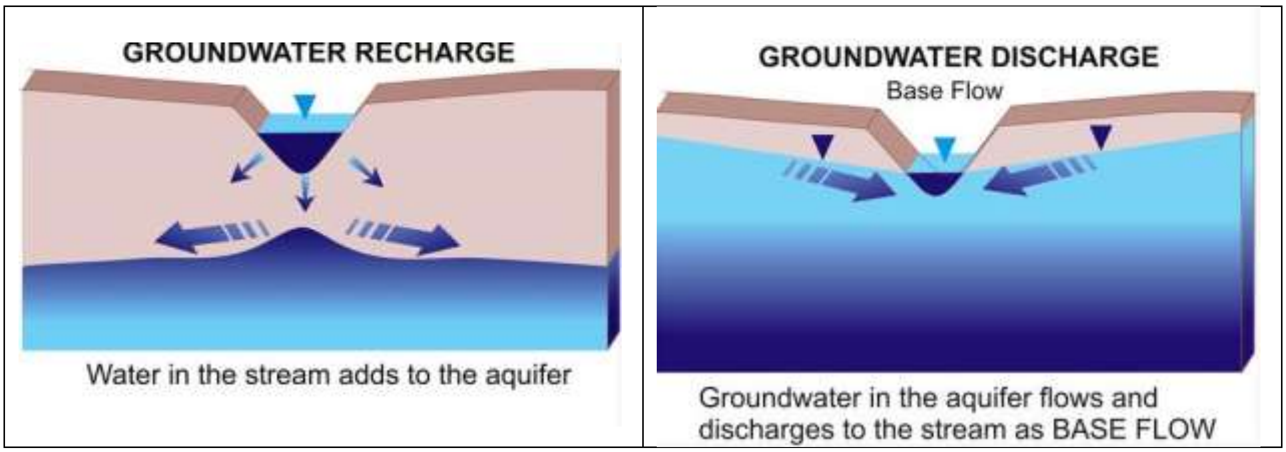
This graph, when plotted for a longer duration data (8 to 12 months) will help in understanding the behavior of the well. A precaution should be taken the well water level should be the natural state condition and not pumping water level. Some inferences can be derived using the well water level data and rainfall. The inferences are as follows.

- The wells showing maximum fluctuations in water-level during rainfall represents the wells in recharge zone
- The wells showing minimum fluctuations in water-level represents the wells in discharge zone
- Wells showing Fluctuations in water-level irrespective of rainfall events are pumping water levels.

V. Water table contour map

Water table contours are topographic lines on a map which essentially represent "elevations" of the water levels. These elevations are also called the hydraulic heads which help in understanding the groundwater flow in a region. Water table contours represent areas of equal head. These water table contours lines are also called equipotential lines. Lines drawn perpendicular to the water level contours indicate the groundwater flow direction and are called groundwater flow lines.

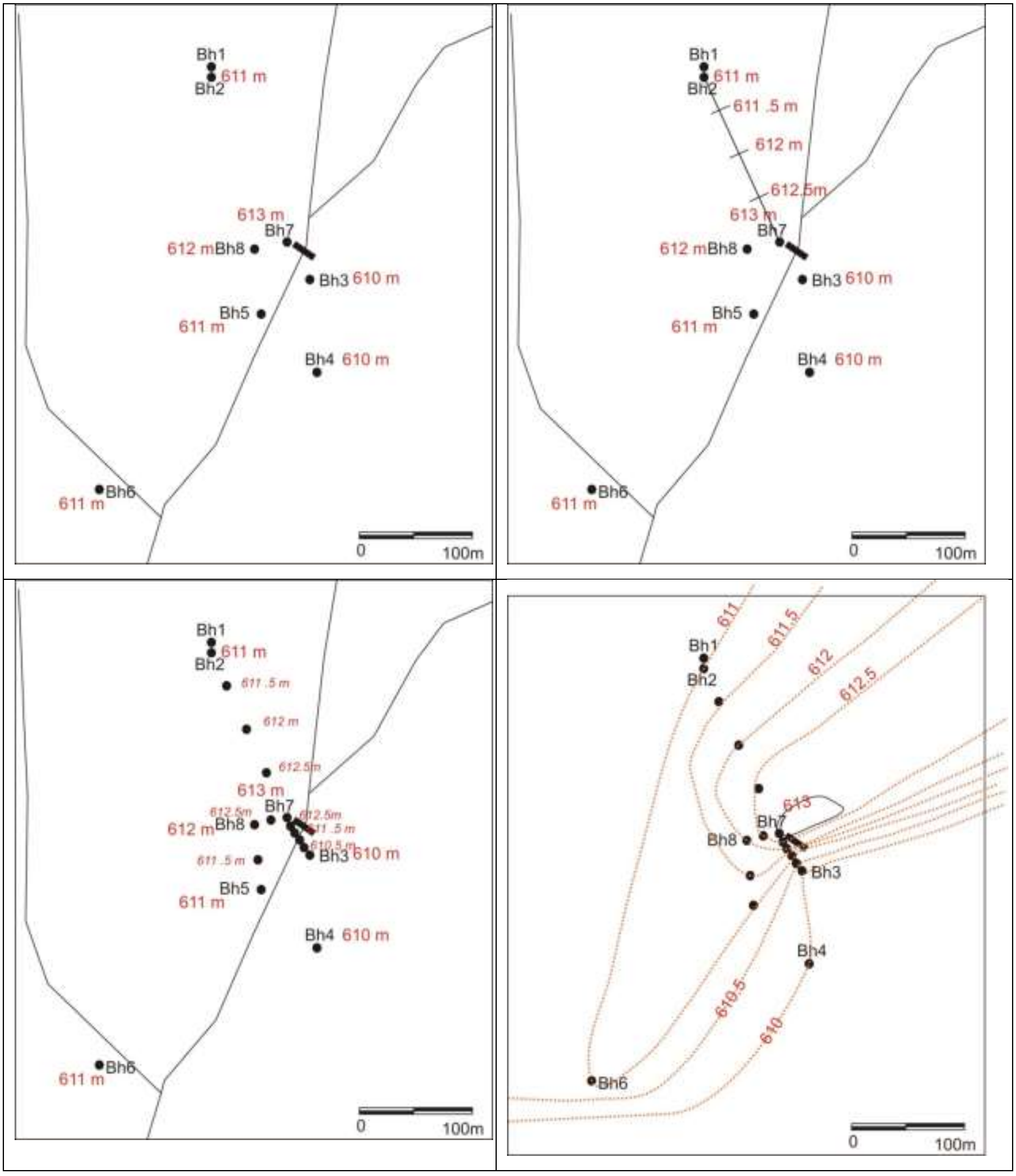
The water table contours and flow lines also indicate *recharge and discharge areas*. Converging flow directions show discharge area whereas diverging flow direction show recharge area.(as shown in the figure below.) Moreover, the groundwater mounds indicate groundwater recharge area whereas groundwater troughs represent groundwater discharge area.



The water table contour map is prepared using well locations and well water levels. The procedure for preparing a GW contour map is given below.

Procedure:

- First, calculate the reduced water level by subtracting water levels of the wells from elevation of the wells from mean sea level (msl).
- Write the reduced water level against each well point in the given sheet (Base map or well location map).
- Take one meter reduced water level interval (or desired RWL interval) between each two wells and mark the point on the well location map.
- Draw a contour line joining the same elevation points or reduced water level points with free hand and similarly draw all the contours in the same way.
- Once the contour map is complete, flow lines can be drawn at right angles from the contours.
- The flow lines are extended until the next contour line is intercepted, and are then continued at right angles to new contour line.


Bh1
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Bh7
612 m Bh8
Bh3 610 m
Bh5
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Bh4 610 m
Bh6
611 m
611 .5 m
612 m
612.5m
612.5m
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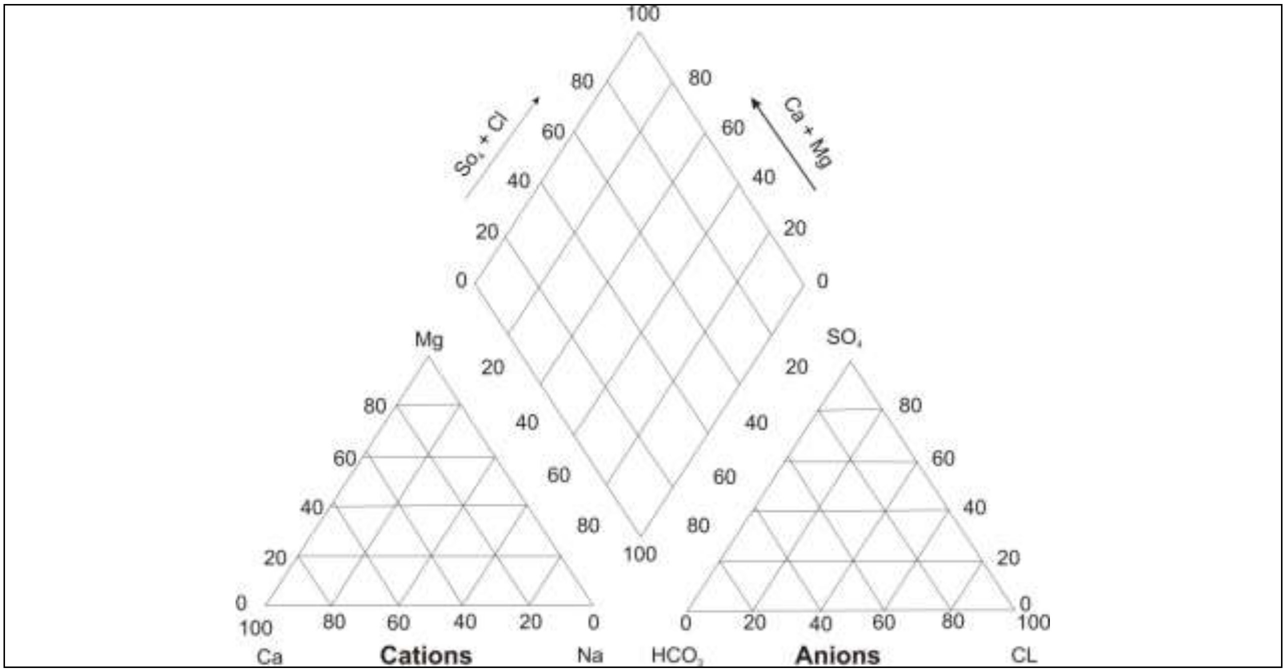
610.5m
611
611.5
612
612.5
613
610.5
610
0
100m

VI. Water quality interpretation using Piper diagram

A **piper diagram** is a graphical representation of the chemistry of a water samples.

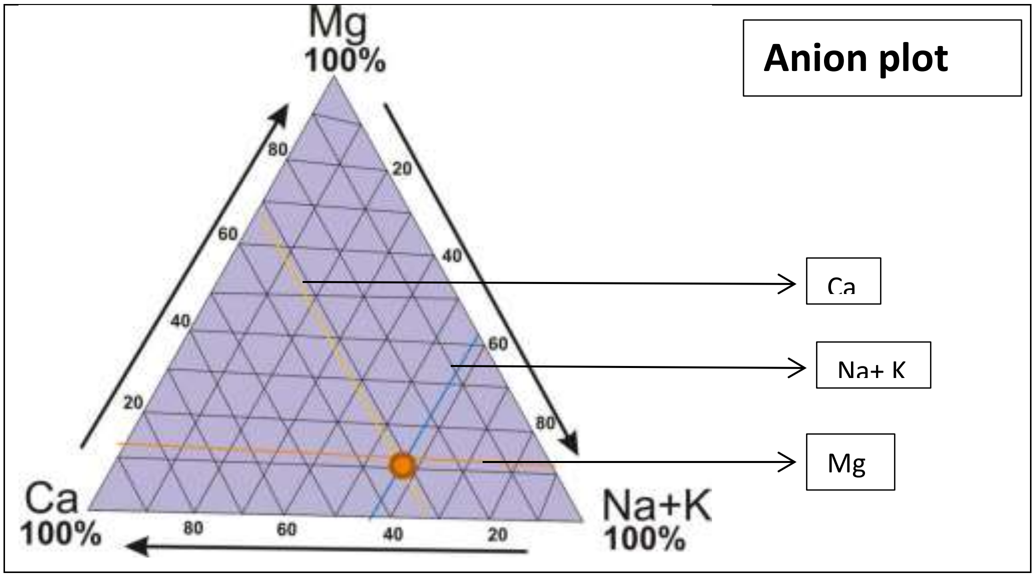
The cations and anions are shown by separate ternary plots. The apexes of the cation plot are calcium, magnesium and sodium plus potassium cations. The apexes of the anion plot are sulfate, chloride and carbonate plus bicarbonate anions. The two ternary plots are then projected onto a diamond. The diamond is a matrix transformation of a graph of the anions (sulfate + chloride/ total anions) and cations (sodium + potassium/total cations)



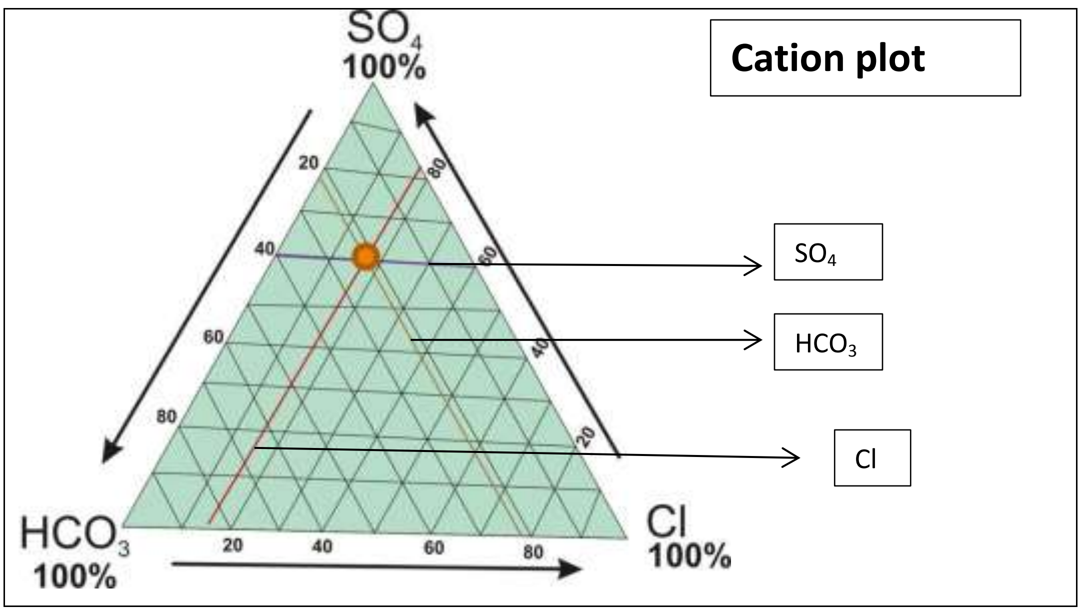
Piper plot

In Piper the data is plotted in meq/l. The procedure for calculating meq/l from mg/l is given in the annexure. The data is obtained as a percentage of Ca, Mg, Na+K, HCO_3, Cl and SO_4. This data is plotted in the respective ternary plot or triangle. The anions are plotted in anion plot while cations are plotted in cation plot. This is how we plot.

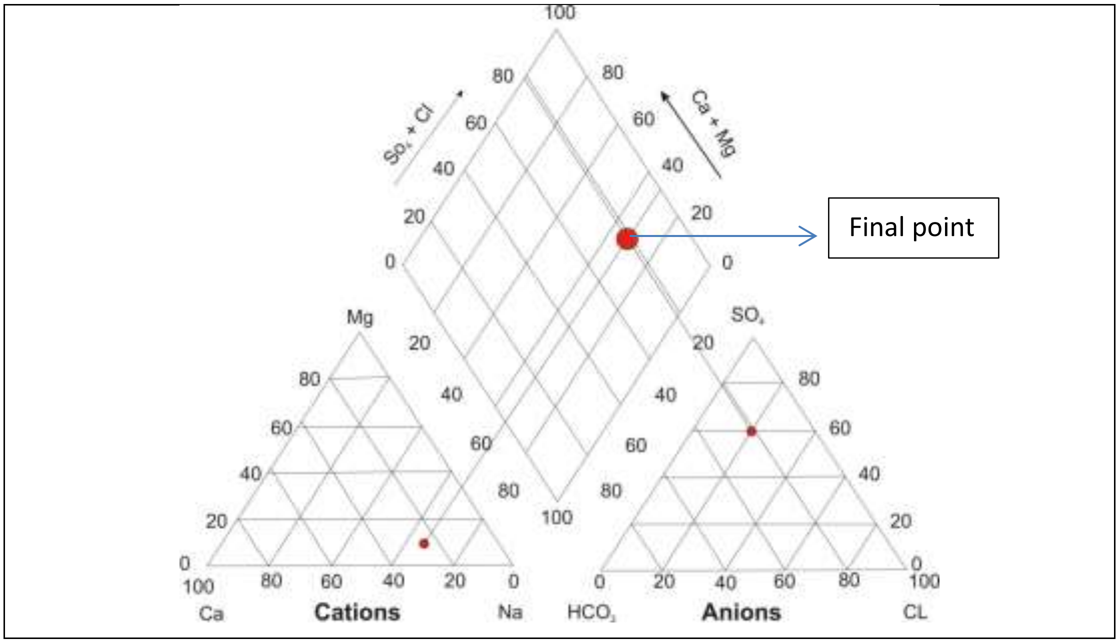
IF the Na+K =58%, Ca= 31% and Mg= 11% then the point can be drawn where the three lines meet.



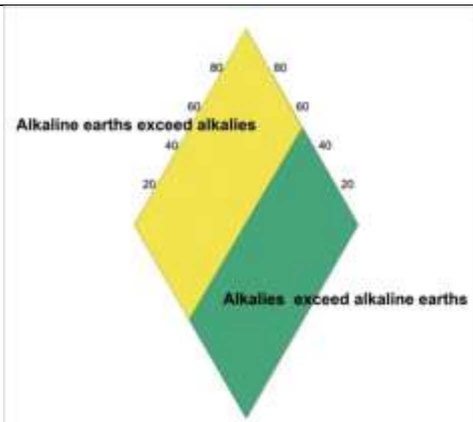
Similarly, if the Cl = 18%, HCO3 = 22% and SO4 = 60%, then the plot will as follows.

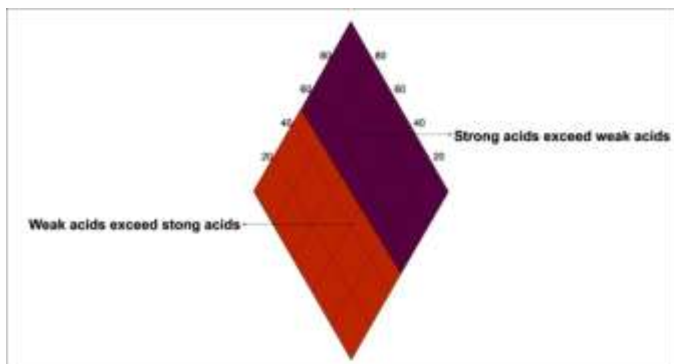


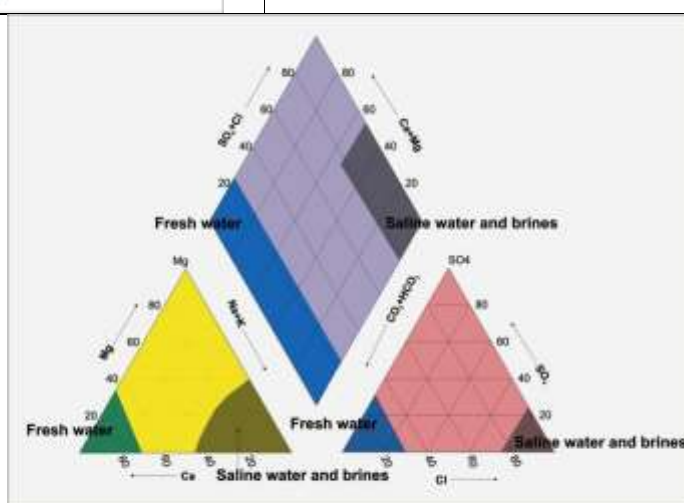
Once these two ternary plots are ready, the two points are projected onto the diamond.

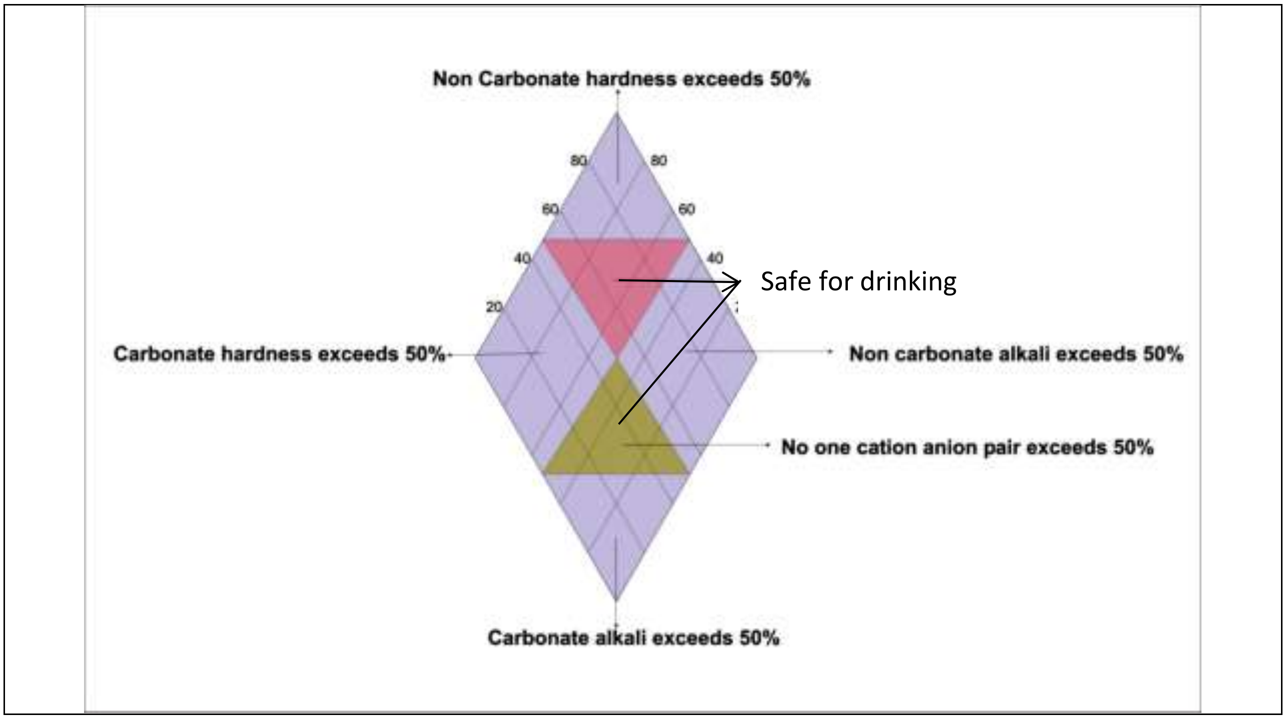


Interpretation of piper plot









Piper diagram can be used to understand the groundwater chemistry. This diagram can be used for spatial as well as temporal analysis of water samples. This diagram can be used to analyse a number of samples at a time.

VII. Spring hydrogeology

Springs are points on the surface of the earth through which groundwater emerges and flows. This water is then used as a main source of drinking and domestic purposes in many areas. It also forms a main source of irrigation water in many parts of the country. Springs are characteristic to the mountainous terrains and remain the only sustainable fresh water source.

The Himalayas are 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 and quantity of water is threatened from anthropogenic activities and the changing climate. 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.

Springs are classified into different types based on their hydrogeology and the rock structure which leads to the formation of the spring. The different types of springs are depression, contact, fracture, karst and fault springs. Spring discharge data and water quality data also support the classification of springs in the different types. Such a classification is critical in the study of springs as the recharge areas and the discharge mechanism are highly dependent on the type of the spring.

The discharge of springs is directly dependent 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.

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

1. Weather (primarily rainfall)

2. Spring Discharge

3. Water Quality

Measurement of rainfall is of utmost importance, as the behaviour of a spring is directly influenced by precipitation.

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**.

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) litre 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.

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.

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 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

Box no.3: Format for Recording Water Quality Data

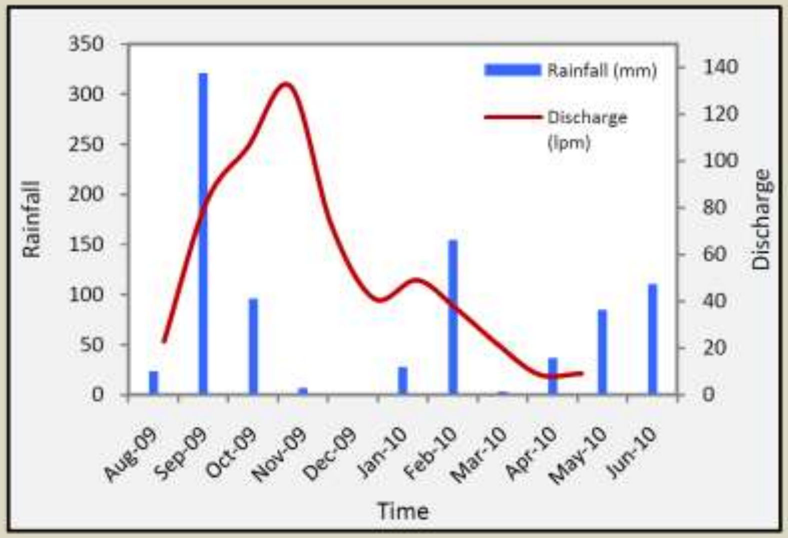
Spring Name/Code	Spring Location	Spring Type	Geology	Latitude	Longitude
Write the name and code	Write the name of the area	Contact, fracture etc.	Sandstone, phyllite etc.	N deg° min' sec"	E deg° min' sec"

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

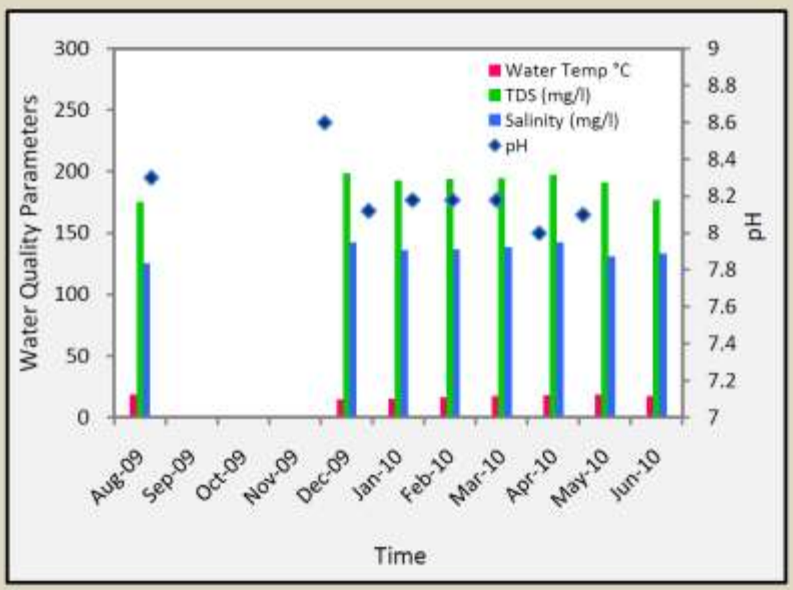
An additional column of rainfall can be added for the purpose of analysis.

Plotting of spring related 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

VIII. Practical session on Socio-hydrology

This practical is the part of the three days exercise of understanding practical aspects of socio-hydrology and using it in watershed development and other water related interventions at the field level. This process is divided into three aspects: classroom practical, field work by participants and presentations of their findings. Each process is linked to the following and feeding into it. On first day participants first prepare for the field work during the classroom practical session, conduct fieldwork on the second day and present their findings and understanding on the third day.

Classroom session:

Participants are divided into 3-4 groups comprising 6-8 members in each group and each group is provided charts and sketch pens. They are asked to prepare a questionnaire to conduct a socio-hydrological survey in the fieldwork. This questionnaire will be used as a tool to understand the groundwater situation, and related issues in the village and come up with a management plan for that village. Following are the guidelines for questionnaire preparation:

- It should only focus only on water related issues and no unnecessary information (which is not directly liked to water management) should be collected through this.
- It should not be too long- only 20-25 questions.
- Should try to capture information about Demand, Supply and Availability of groundwater in specific and water in general.
- It should include such questions that help the participants in preparing a management plan for that village.

Groups will be given 45 to 60 minutes to discuss and prepare questionnaire for their group. Each group will present their questionnaire in front of participants and ACWDAM team. Participants and ACWADAM team will review each questionnaire, give suggestion and comments and come up with a common questionnaire which will be used in the fieldwork to conduct socio-hydrological survey.

Field work:

Fieldwork will include two aspects; social survey and technical data collection. Each group will divide into two sub groups. One subgroup will conduct social survey in sample households and second sub group will conduct hydrogeological mapping, collect well and spring data etc. Village will be divided into 3-4 clusters (according to the number of groups) and one group will conduct both social and technical surveys in that cluster.

Presentation:

Groups will be given 1 hour to compile the information collected during fieldwork. Each group will compile social and technical and come up with a groundwater/water management plan for that village and present it in front of all participants and ACWADAM team.

Presentation will include following aspects:

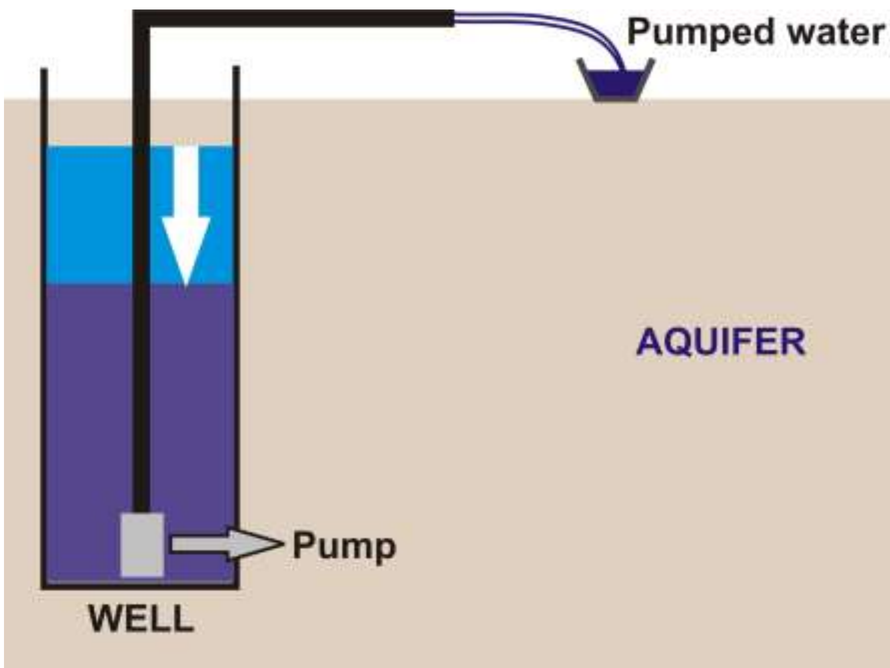
- Situation of water Demand, Supply and availability in the village.
- Problems related to water.
- Proposed interventions (physical and social both)
- Hydrogeological map and section of that village.

IX. Pumping Tests

In hydrogeology, once the aquifers have been delineated it is necessary to find out how an aquifer will respond to pumping out the water from aquifer storage. Different users of groundwater will require answers to questions such as :

- How much water can a well supply?
- What should be the capacity of the pump to be fitted on a well?
- What is the range of Transmissivity and Storativity of the aquifer?

Such questions can be answered by conducting certain tests on wells and these are known as 'pumping tests'. Pumping tests involve the pumping out of water from a well so that the water table or potentiometric surface declines as water is pumped out from the aquifer storage. This is measured along with how much water is pumped out.



The basic procedure of a pumping test involves:

- Water being pumped from a well (pumping well)
- Its impact on the pumping well as well as on the aquifer it taps is ascertained by
  - observing the change in water levels in wells tapping the aquifer and
  - measuring how the rate at which the water is pumped out from the well

There are 2 types of pumping tests;

- Well tests
  In this type, the well is tested by measuring the effects of pumping only in the pumping well. The aim of such a test is to measure the yield of the well.

- Aquifer tests
  In this type of tests, an attempt is made to quantify the aquifer properties. Measurements are carried out in the pumping well as well as in observation wells surrounding the pumping well. Aquifer tests help to estimate the performance of the aquifer as well as to estimate aquifer properties like Transmissivity and Storativity

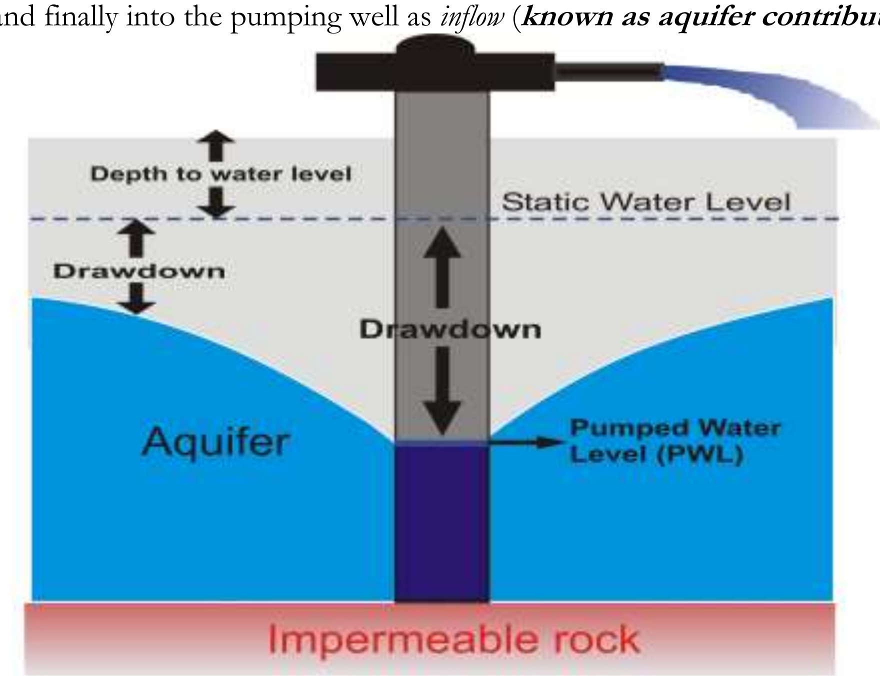
Pumping tests require a specific set of equipment such as a pump, measuring tapes, stop watch, and a container of known volume for measuring discharge rates of the pump.

Well Hydraulics or ***Mechanics of pumping*** are terms used to describe the effects of pumping on the well as well as the surrounding aquifer. Before pumping begins, the water level in the aquifer including pumping well is referred to as the "static water level" (SWL). It represents the level above which water in a well does not rise at any particular time as there is no recharge into or discharge from the aquifer storage.

When pumping begins, water levels in the pumping well and in wells nearby (observation wells) declines. Any level measured during the process of pumping is called **pumping water level.** The pumping water level in the pumping well stands at a lower elevation (deeper) as compared with the water levels in the surrounding aquifer and such water level can be referred to as ***"Head".***

Hydraulic Gradient

A head difference exists between the pumping well and the surrounding aquifer and therefore, a hydraulic gradient is created from the surrounding aquifer towards the pumping well (according to Darcy's law - from **higher head** to **lower head**). Under the influence of this artificial hydraulic gradient the water stored in the aquifer surrounding the pumping well starts moving towards the pumping well and finally into the pumping well as *inflow* (***known as aquifer contribution "q").***

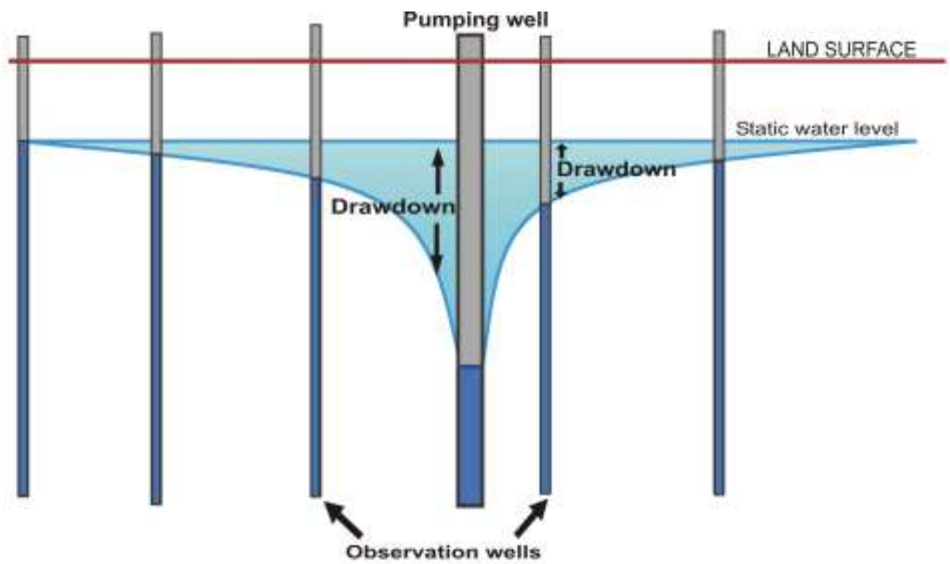


TERMS RELATING TO WELL PERFORMANCE

As pumping continues, *inflow water* from the aquifer is also pumped out along with water stored in the pumping well and more and more water is now derived from the aquifer dewatering the volume of the aquifer surrounding the pumping well. Dewatering of aquifer volume (due to discharge from aquifer storage) results in lowering the water level (i.e. Head) in pumping well as well as over aquifer surface area where dewatering of openings under the hydraulic gradient has taken place. The decline of water level will be reflected in these observation wells. The difference between the static water level and the pumping water levels in different wells is known as "**drawdown**".

Cone of Depression

A shape of an inversed cone results on joining the drawdown in the pumping and observation wells. This inverted cone is called as ***Cone of Depression*** and it continues expanding with continued pumping.



TRACE OF THE CONE OF DEPRESSION SHOWING VARIATION IN DRAWDOWN WITH DISTANCE FROM PUMPED WELL

The expansion of cone of depression depends upon:

- The rate of pumping- Q
- The aquifer contribution- q from the aquifer to the well (as inflows into the well)

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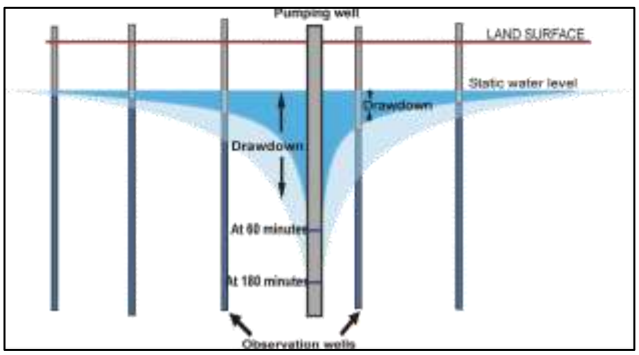
<td>
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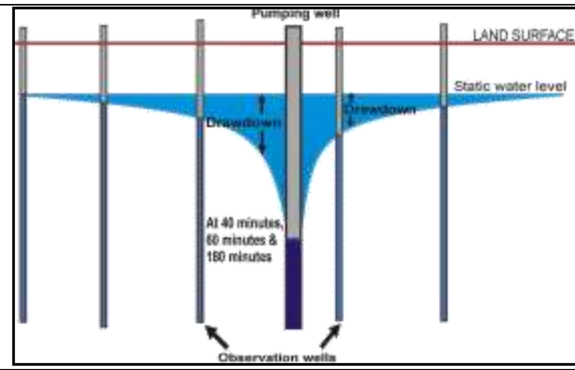
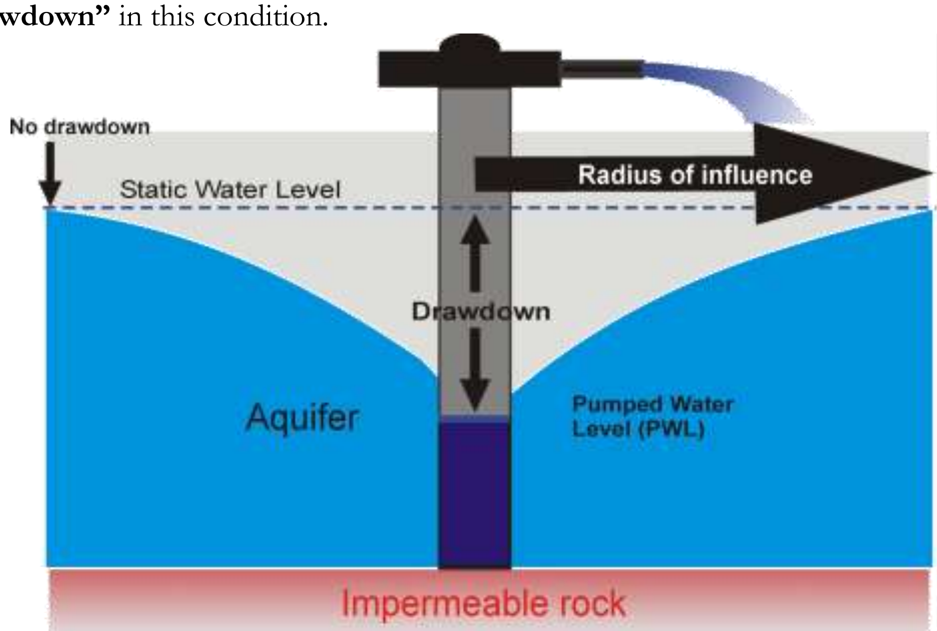
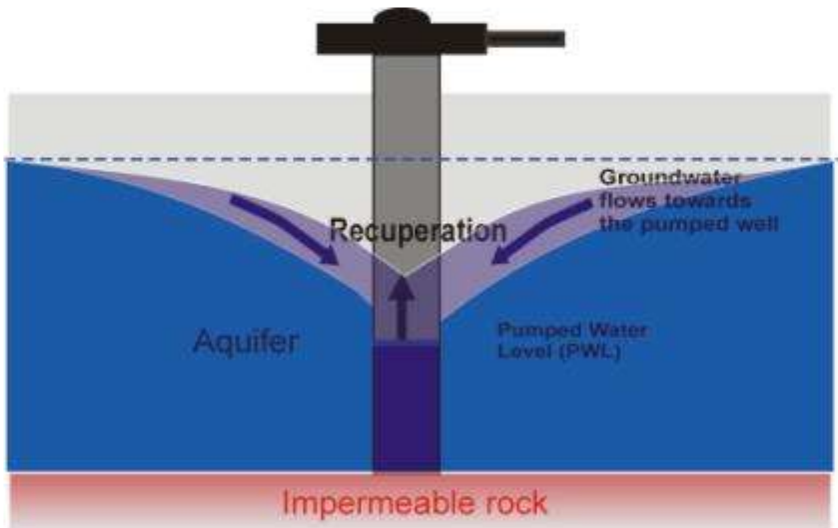
<td>
</td>
</tr>
<tr>
<td>Q > q
INEQUILIBRIUM or UNSTEADY STATE CONDITION</td>
<td>Q = OR < q
EQUILIBRIUM or STEADY STATE CONDITION</td>
</tr>
</table>

The distance from centre of pumping well to the periphery of the cone of depression is *known as the* ***"radius of influence"***. After the pumping is stopped, the level of water in pumped well is known as **"*pumped water leve*l"**. The difference in static water level and pumped water level is known as **"Total Drawdown"** in this condition.



Recovery or Recuperation



After the pumping has stopped, water from the surrounding aquifer continues to flow towards the pumping well under the influence of the (artificial) hydraulic gradient towards the pumping well. Due to continued aquifer contribution **q**, water level in the pumping well as well as in the aquifer surrounding the pumping well rises. This is because the portion of the aquifer which was earlier dewatered during pumping starts resaturating due to the water inflowing towards the pumping well (indicated by rise in water level in pumping and observation wells)
This process is known as ***"recovery or recuperation".***

During the process of recuperation or recovery, more and more desaturated portion of the aquifer gets resaturated. This is indicated by a rise in water in areas away from pumping well also. Due to rise in water level the hydraulic gradient towards pumping well becomes gentler with time, thereby reducing the rate of the aquifer contribution q. Subsequently, the water required for this resaturation process is derived by dewatering the peripheral areas of cone of depression i.e. cone of depression continues to expand in peripheral areas even after the pump is switched off. Slowly, with time, the water level rises in the aquifer and finally gets stabilized at a new static water level (which may be fractionally lower as compared to the original S.W.L.).

Some practical aspects for conducting pumping tests

- The wells in the vicinity of chosen pumping wells should not be pumped at least 48 hours prior to a pumping test. This ensures that water levels in the aquifer surrounding the pumping wells are as close to the static water level as possible and that there are no artificial hydraulic gradients
- The dimensions (depth and diameter / length & breadth) of the pumping well are measured
- Nature of the aquifer to be tested is ascertained on the basis of well inventory data:
    - rock type
    - unconfined / confined / leaky
    - thickness of the aquifer
- A measuring point (MP) is selected and marked on the pumping well head and observation well head with respect to which all water levels are measured

Pumping test data collection

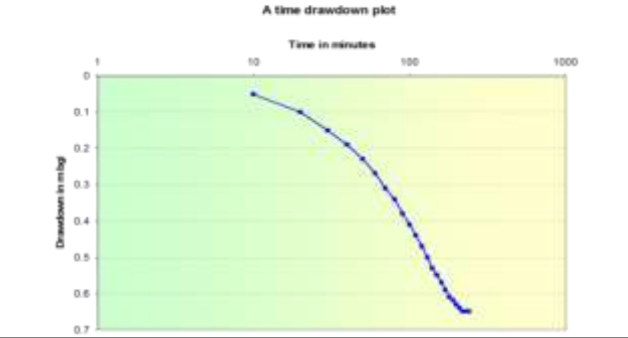
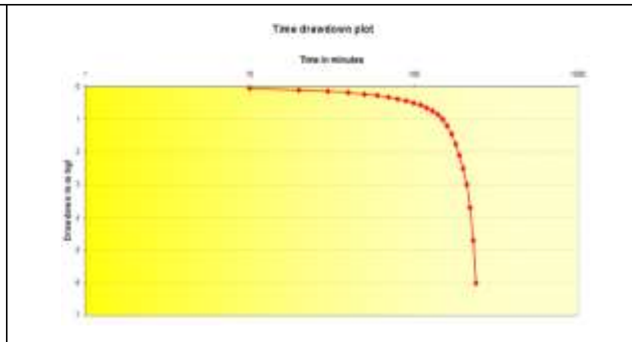
- During pumping (drawdown part) the water levels are measured with respect to the MP at regular time intervals. The time interval could be
  - 1 min or 2min or 5min or 20 minutes and so on
  - The time interval is subjective and mostly dictated by hydrogeological field conditions
- In a well test, the drawdown is recorded in the pumping well only and in aquifer performance test drawdown is recorded in pumping well as well as in observation wells
- During the drawdown measurements the discharge of the pump (Q) is also measured (preferably with a simple drum/bucket of known volume using the stopwatch method)
- Pump discharge should be measured frequently as it tends to vary depending upon the efficiency of the pump, drawdown and voltage fluctuations
- Once the pumping from pumping well is stopped, the recovery or recuperation measurements are also made in pumping well as well as in observation wells at fixed intervals
- During the pumping test the water level in pumping well (if it is dug well) goes down exposing the walls of the well below water table for observation, regarding how and at what depth water is flowing into the well from the aquifer (i.e. information on the *inflow zones*)

Interpretation of pumping test data

The analysis and interpretation of pumping test data is carried out for estimating aquifer properties like Transmissivity and Storativity and well characteristics; especially the well yield or specific capacity. There are many methods of interpreting pumping test data. These are given in various text books on groundwater.

An example of interpreting aquifer test data - Cooper and Jacob's (1964) graphical method to estimate T and S

- The water level in pumping well / observation wells (below MP) is plotted against time since pumping started **t** on semi logarithmic graph paper
- Water level (as drawdown s) on arithmetic scale and time on log scale.
  - The first few points reflect the effect of well storage (segment 1)
  - Segment 2 indicates the effect of contribution from aquifer in the form of inflow (in pumping well during pumping)
  - In case of observation well data, points on a straight line indicate the effect of dewatering of the aquifer in the form of drawdown
  - The third segment which also falls on a straight line, may indicate:
    - A gentler slope as compared with segment 2 indicating an increase in aquifer contribution (q) as compared to the pump discharge Q. This indicates that the aquifer is receiving recharge from some external source during pumping (may be river, lake, canal etc.), often leading to a steady state condition
    - Sometimes the slope of the segment 3 steepens as compared with segment 2. This indicates the limited extent of the aquifer, showing sudden increase in the rate of drawdown (i.e. aquifer contribution q is much smaller than the pump discharge Q)

	
STEADY STATE	DEWATERED WELL

Transmissibility from the Cooper Jacob formula

- The Transmissivity can be obtained using the semilog graph (as given in the above examples) and the following procedure:
  - The value of Δs which is the drawdown over ONE LOG CYCLE of time "t' is calculated
  - Segment 2 is generally used to obtain the Δs value used in following equation
- T= (2.303 x Q)/ 4∏Δs is the original equation where the final equation is
- T= (264 x Q) / Δs
  - Here, T is directly obtained in m^2/day directly
  - Q= Pump discharge in m^3 per min
- Δs= slope of segment 2 over one log cycle of time t expressed in metres

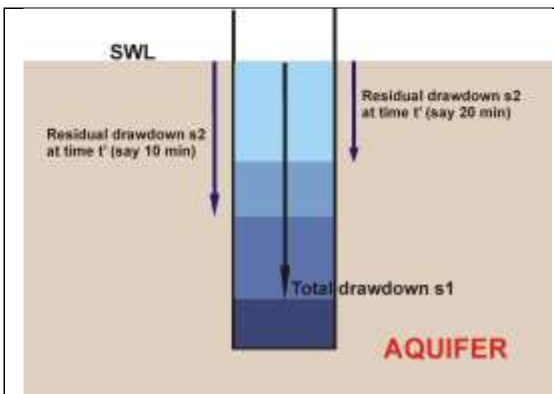
Storativity from the Cooper Jacob formula

- For Storativity S the data of drawdown in OBs well at distance "r" from the pumping well is necessary
- Storativity S is given by the equation
  - $S=2.25\ Tt_0 / r^2$ where,
    - T= Transmissivity in m^2 / min
    - t0= intercept of straight line on the time axis
    - r = distance of observation well from pumping well
- S is given in fraction

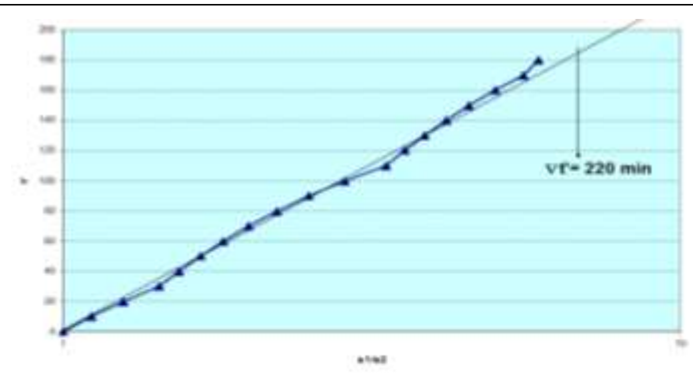
An example of interpreting well test data - Slichter's method of estimating the specific capacity (yield) of a dug well

In order to estimate the specific capacity of a dug well, the (recuperation) recovery data is used for analysis. Recovery data does not involve the effect of well storage on pump discharge (as the pump is shut off) and contains the effect of the contribution of water from the aquifer only. This effect is in the form of rise in water level in pumping well. In order to calculate specific capacity using Slichters method, the following steps are required:

- Measure the total drawdown in the well (s1) at the end of pumping
- Similar to a drawdown test, measure the water level rise in the well and estimate the residual drawdown s2 at different times (t')
- Residual drawdown (s1) can be estimated by subtracting the rise in water level over a fixed time from the total drawdown (s1)
- The ratio s1/s2 is calculated for each value of time t' for which values of s2 are measured
- A graph of t' values (Y-axis) is plotted against the ratio s1 / s2 (X-axis) on a semilog paper
- A straight line is plotted through these points and the slope of the line (change in the value of t over one log-cycle of the ratio (s1/s2) is estimated



Calculating s1 and s2



Slichter's plot for Specific Capacity

The specific capacity is calculated using Slichter's Recovery Formula:

- C = (2.303(A / t')) ($\log_{10}$ (s1/ s2)) where
  - C= Specific capacity of dug well in m^3/min per metre of drawdown or lpm/m of drawdown
  - A= cross sectional area ∏r^2 (in m^2)
  - t'= time since pumping stopped in minutes
  - s1= total drawdown in meters
  - s2= residual drawdown values in meters at respective time values since pumping stopped (t')