6.1 Introduction

It is a known fact that groundwater in crystalline terrain, more specifically in granitic rocks, occurs in weathered zone and in the fracture networks below it. It is common experience in such terrains that a well located at a few meters away from a high yielding well fails to yield enough water or sometimes even goes practically dry. In some cases it affects the yield of the wells nearby and often the well yields good amount of water in the beginning and subsequently the yield reduces to minimum and finally goes dry. Reason for such behaviour of wells is probably geological than simply hydrological. As Davis and De Weist (1966) have put it "few tasks in hydrogeology are more difficult than locating drilling sites for wells in igneous and metamorphic rocks; studying such phenomena and finding reasons become more difficult". One has to explore in detail the geological factors and identify the water bearing, water yielding properties of the formations and ultimately study the occurrence of groundwater in them. In the earlier sections it was possible to identify the potential zones which have to be further proved and the various phenomena are to be explained. Therefore, in this section an attempt has been made to give the hydrogeological factors that control the occurrence of groundwater in Sasive Halla Basin.
The hydrogeological investigations were carried out in two phases: i) Large number of existing wells have been inventoried and based on the geophysical, hydrogeological investigations drilling sites were suggested for the needy farmers on mutual cooperation basis. ii) 4-short duration pumping tests were conducted in borewells.

6.2 Well inventory

To assess the nature of hydrogeological conditions in the area, as a first step well inventory is carried out. It involves study of existing wells. It is difficult to keep tract of the increasing number of wells every year as the groundwater development is quite active in some part of the basin. But it was noticed that prior to the year 1984 there were hardly any borewells in this region and the irrigation was through the water supply from dugwells. But recently farmers have gone in for borewells and often existing wells have been further developed by bore holes at the bottom. Thus, when the present work was initiated in July, 1987 the open wells that have been supplying water have been inventoried. For this work a proforma for collecting general hydrogeological, geological, geomorphological and other information was prepared (Fig.6.1). About 120 open wells spread out in the area were inventoried using this proforma and about 50 borewells also have been inventoried.
Some of the typical well sections in Sasive Halla Basin is shown in Plates 12, 19 & 20. The top layer is made up of soil which is generally 0.25 - 1.5 m. thick. In areas covered by red sandy loams, it is from 0.25 - 1.00 m. where as in black soils from 0.5 - 3.00 m. However, number of wells in black soil are less as the groundwater in that region is saline.

The soil layer is followed by weathered rock whose thickness is highly variable from place to place. It generally varies from 1.5 - 15.00 m. and occasionally reaches 25.00 m. However there are some borewells where weathered zone extending upto 30.00 m. is noticed. At a few places the weathered layer appears to be persisting upto a depth of 100 m. as indicated by geoelectrical survey.

The weathered layer is followed by jointed and fractured rock, thickness of which varies from 30 - 40 m. As most of the open wells are shallow (maximum depth noticed is 20 m.), information regarding deeper horizon was obtained by borewell data which indicates that fractured rock normally extends upto 45 m. However, RVES and VES data discussed in earlier section have indicated presence of fractures at greater depth also.

Most of the openwells are lined with stone masonry or concrete rings upto the weathered zone; otherwise the wells are 'open holes' in the semiweathered and fractured rock. Sometimes the weathered layer is immediately underlain by fresh rock without a
fractured / jointed rock. This is seen quite often in black soil region where it is underlain by migmatitic gneisses.

The depth of openwells ranges from 10 - 20 m. They are either rectangular, circular or square in shape. Rectangular wells are more often in the red soil zones near Naregal. The dimensions of wells vary from place to place and depends upon the capacity of the farmer and generally the perimeter ranging from 20 - 40 m.

6.3 Groundwater Occurrence

Study of existing wells revealed, that groundwater occurs under water table conditions in weathered zone. Depth to water table varies from place to place and generally ranges from 3.5 - 12.00 m. below ground level. The borewells that have entered the hard rock below the weathered zone have yielded copious water indicating that the groundwater occurs in deeper fractured zone also. Whenever groundwater occurs in jointed and fractured rock below the weathered zone, it is under semi confined to confined conditions. This could be observed from the over flow of the revitilised dug wells where the bore holes have penetrated the fractured rock. It was confirmed by test drilling that separate fracture systems occur at different depths separated by plinths of massive hard rock which is also indicated by the resistivity soundings. Thus it is confirmed that the difference in the depth of different fracture horizons causes plastic conditions in the fractured zones.
There are instances (e.g., near Itgi, Hosahalli etc.) where neither openwells nor borewells yielded water. This indicates that there is no continuous aquifer system and water is confined often to small, separate zones of decomposed rock. This is clearly depicted in the bedrock topography map prepared by the resistivity sounding data. The subsurface is characterised by highly undulating topography with many fresh, fractureless hard rock horizons.

The weathered zone generally extends up to a depth of 20 m below the surface. The weathered rock is more pervious than the jointed/fractured rock, but permeability in weathered zones is sometimes very less due to the formation of clay minerals and secondary deposition of salts. The fractured rock is relatively fresh where permeability is moderately high. Hence, the wells which have penetrated the saturated fractured rock generally yield more water.

6.4 Test drilling

The RVES discussed in the earlier section have shown that the fractures persist at places even up to a depth of 70 m. The VES carried out in the identified fracture zones have also indicated considerably deep weathered zone. Hence it was decided to go for test drilling in order to confirm the significance of different fractures in the area and compare the groundwater potential of fracture zones with those of fractureless fresh rock zones. As it
was difficult to manage independently such task, the author has suggested the drilling sites for the needy farmers based on detailed investigations.

About 55 borewells were drilled in the area based on the recommendation of the author. However, the Government agencies like Public Health Engineering Department has been drilling borewells for the village water supply and many farmers have also drilled wells based on the recommendation of either Government agencies like the Mines & Geology Department or the Central Groundwater Board, private consultants, voluntary organisations and water diviners. The information from such borewells have also been collected. Out of the 55 borewells drilled by the farmers on the recommendation of the author, one was abandoned near Rajur because of the collapsible clay zone at a depth of 20 m. and absence of saturated fractures below 30 m. The details of the yield of the borewells of this drilling programme are given in the following table.

<table>
<thead>
<tr>
<th>No. of wells</th>
<th>Yield range in m$^3$/h</th>
</tr>
</thead>
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<tr>
<td>13</td>
<td>$&lt; 4.5$</td>
</tr>
<tr>
<td>08</td>
<td>4.5 - 9.00</td>
</tr>
<tr>
<td>18</td>
<td>9.0 - 13.50</td>
</tr>
<tr>
<td>15</td>
<td>$&gt; 13.50$</td>
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</table>

Maximum depth drilled during this programme was 60 m. In addition to this, yield of the borewells drilled by PHE and other farmers was also studied. The depth and yield relation of these wells is
shown in the Fig. 6.2. It is clear from the graph that the yield of borewell is not related to depth. This gives clear indications that the yield is fracture controlled and fractures are not uniform and present everywhere. Further it was observed that the wells located within the tensile fracture zones have generally higher yield as compared to those near shear fractures. However, at a few places the wells located near the shear fractures also have yielded significantly large quantity of water indicating that these fractures have been probably opened up and are intersected by other fracture systems of later deformation. The wells located away from the fractures have in general low yields. A borewell drilled at Lakkalakatti village has caused considerable decrease in discharge of another borewell existing nearby. This indicated that the subsurface fractures are interconnected and both the wells have intersected the same fracture zone. The higher capacity and rate of pumping in the former has resulted in the decrease of the discharge of the latter.

6.5 Aquifer Characteristics

The determination of hydraulic properties of aquifer or water bearing layer (horizon) is a prerequisite for the planning and development of groundwater resources of any region. Important aquifer characteristics are permeability, transmissivity, specific yield and specific capacity of a well etc. One of the most dependable method of determining these parameters in the field is by conducting pumping tests in the wells.
The properties of an aquifer can be divided into two categories; i) properties related to the capacity of aquifers to store fluids (eg. specific capacity, porosity) and ii) properties related to the capability to transmit fluids (permeability, transmissivity). Once the properties of an aquifer are known, the equations of flow can be solved to quantify them. The important condition to be fulfilled in such calculations is that the type of flow must be identified. The porous media flow systems have well defined equations, but it is not easy to ascertain the flow characteristics in fractured rock by using conventional approaches.

6.5.1 Flow through fractured media

The investigation of groundwater flow in porous media has been dominated by the theories of Dupuit, Theim and Theis. Each of these theories assumes that the horizontal components of flow are dominant and the vertical components are small enough to be neglected (Rushton, 1988). This does not hold good in a fractured media which consists of an interconnected network of fractures surrounding the blocks of hard rocks. The permeability and storativity of these fractures depend on width of the fracture, frequency of fractures with respect to the whole system, orientation of fractures and nature of the material filling the fracture. In granitic terrains, the permeability of aquifers is mostly due to the sheet fractures which are often hydraulically connected with each other and to the surface by vertical or
inclined fractures / joints. Thus, there appears to be two kinds
situation in hard rocks where the blocks may be:

i. practically impervious and the properties of the fractured medium are depending upon the properties of the network of fractures: one permeability - storativity system.

ii. pervious due to a secondary system of fractures where the medium is characterised by both fractures and blocks: double permeability - storativity system.

There are two basic approaches to the mathematical treatment of the fractured media

i. The discrete approach - where equation of flow are written separately for each fissure and the system equation is solved with the basic condition of continuity of fluxes and pressures at the point of intersection and for the appropriate boundary and initial conditions. This requires the exact knowledge of geometry and hydraulic property of individual fracture within the system.

ii. The continuum approach - which is similar to ordinary porous media model. For one
conductivity, storativity system the impervious blocks play the role of impervious grains and void spaces of fracture system is similar to voids in normal porous media. This approach is applied in the analysis of fractured rock aquifer.

Generally aquifer properties are determined by laboratory experiments and field tests. The conventional laboratory experiments on small cores for determination of porosity and permeability cannot be applied in the case of fractured rock. Hence, the most dependable method of determining of these parameters is the field method by conducting a pumping test and recovery test.

Lots of investigations have been made to understand and quantify the groundwater flow through fractured media. These include the works of Rushton (1989), Cacas et al. (1989), Rushton and Srivastava (1988), Rushton and Sakthivadivel (1988), Mishra and Chachadi (1985), Das and Mallik (1989), Kiraly (1971), Barenblatt et al. (1960), Boulton and Streltsova (1978, 1979a), Streltsova (1976) and others. These studies have shown that two types of flow phenomena can be observed in hard rocks:

i. at the initial stage of pumping, water is released from the fractures of high permeability i.e., from the storage in the weathered zone.
ii. as pressure decreases water is released from the blocks of the main system of fractures.

6.5.2 Analysis of pump test data

Since the fractured rocks are characterised by high degree of heterogeneity, the drawdown/recovery data of pumping test conducted in these rocks are commonly not subjected to interpretations by general methods applicable for homogeneous porous media. Jointing/fracturing may result in development of porosity - permeability features such as infinite permeability in one direction to absence of permeability in other direction which would lead to a large distortion of cone of water table depression around the pumped well (Kohut et.al, 1983). Thus various combinations of fracture location, fracture width, amount of groundwater for storage in the vicinity of the well can result in any type of 'time-drawdown' curve, not amenable to analysis by standard pumping test methods. Further an observation well may tap an entirely different fracture system to the one encountered in the pumped well rendering the observation well data of little relevance. However, at times, pumping tests carried out in hard rocks where jointing or weathering has resulted in uniform development of secondary porosity - permeability system, could be analysed in the usual manner. Pumping test carried out so far in hard rocks brought out the prevalence of aquifer conditions such as confined aquifer, leaky confined aquifer, unconfined aquifer showing delayed yield and aquifers of limited areal extent.
Analysis of pump test data to estimate the aquifer parameters in hard rocks have been made by different scientists using different methods. All these have been site specific and cannot be generalised. The investigators who have contributed in this regard are Gowdreddy (1979), Muralidharan et al. (1987), Sudarsan Raju and Anantha Reddy (1985), Sudarsan Raju and Muralidhar (1989), Barker and Black (1983), Srinivas (1989) and others. Mathematical models, simulation models, stochastic models and numerical methods have also been used to estimate these parameters by the researchers like Sridharan (1989), Rai and Hoffman (1989), Balasubramanian and Sastri (1989), Thangarajan and Shakeel Ahmed (1989) and so on. Scientists like Mishra et al. (1989), Deepak Kashyap et al. (1989), Ballukraya et al. (1989), Rushton and Sing (1987), Jenkins and Prentice (1982) have critically reviewed the analysis of pump test data in hard rock aquifers.

6.6 Test in Sasive Halla Basin

Groundwater development through borewells in Sasive Halla Basin is a recent phenomena. Prior to 1984, there were only dug wells distributed sparsely tapping the water only from the weathered zone. Later, in most cases, dug wells have been further developed by bore holes and the yield has considerably increased. Now, both dug-cum-bore wells and bore wells are tapping the groundwater resources from weathered and fractured zones. Thorough observation during hydrogeological investigations and inventory
has revealed that water levels in the open wells are decreasing (in fact most of the dug wells have gone dry) in general and at certain localities, it was clear that water levels in the open wells, dug-cum-bore wells in the vicinity of borewells have gone deeper.

In a field well near Itgi, normal centrifugal pump is being used to lift the water from a bore well. It is interesting that for a considerably longer period of pumping the drawdown in the well has not been much and it is within the range of capacity of the pump i.e., 25 ft. Thus, an attempt has been made to determine the aquifer parameters by conducting pump tests in the study area.

6.6.1 Procedure adopted

A proper pumping test needs elaborate arrangements. Generally, in addition to the observation of water levels in the pumping well, measurement of the fluctuation in the observation well are also needed. The change in the water level in the pumping/observation wells are to be accurately recorded at short intervals. Also, the discharge from the pumping well has to be measured at regular intervals. Thus, it requires more number of trained personnel. And pumping test has to be of longer duration for which constant power supply is a necessity. All these factors cause increased expenditure to conduct a proper pumping test and hence, hydrogeological investigations particularly the pumping tests in hard rocks often have to be based on single boreholes.
In the present investigation, because of such limitations only four short duration pumping tests were conducted in borewells near Krishnapur, Hosahalli, Itgi and Rajur villages, in order to study the well performances.

As the continued supply of power for long period was the main obstacle the tests were run only for 300 minutes duration in two wells and for 180, 240 minutes respectively in the other two. Wells have been pumped continuously with a constant discharge with the help of already installed deep well submersible pumps. Water levels during the test were recorded with the help of electronic water level indicator. The discharge was measured both by the volumetric and 90° 'V' notch method. Water levels could not be recorded for all these wells after stopping the pump. However, wherever possible, recovery up to one hour was noted. The draw down / recovery data are shown in the Table.6.1.

6.6.2 Results

The details of the pumped well and time - draw down plots for the pumped well are shown in Fig.6.3.

All the wells have behaved as semiconfined aquifers characterised by boundary conditions. The time - draw down plots indicate that at Krishnapur a barrier boundary becomes effective after seven minutes of pumping and recharging boundary seems to be effective after 12 minutes, while a recharge boundary becomes effective after 10 minutes at Hosahalli. The well at Itgi shows
recharging boundary conditions after 40 minutes of pumping. The
time - draw down curve for the pumped well at Rajur indicates a
recharging condition after 10 minutes.

Maximum drawdown of 19.98 m. was observed for a period of 300
minutes of pumping in Hosahalli and the maximum recovery
observed in 60 minutes was 19.65 m. The well near Rajur recorded
a drawdown of 16.8 m. for 240 minutes. 4.31 m. was the maximum
drawdown observed for 300 minutes of pumping in Krishnapur and
the well showed a recovery of 4.21 m. in 60 minutes. The well
near Itgi showed a drawdown of 2.14 m. for 180 minutes of pumping
and the original water level was recovered within 60 minutes.

In all the above cases the initial trends of the time - draw down
curves have been analysed by Jacob's Method (CGWB, 1982) wherein
only the values for T (transmissivity) are obtained by using the
formula

\[
T = \frac{2.3 Q}{4 \pi \Delta s}
\]

Where Q - discharge
\(\Delta s\) - maximum drawdown for a log cycle

The transmissivity values obtained for the wells near Rajur,
Itgi, Hosahalli and Krishnapur are 35.95 m²/day, 379.47 m²/day,
16.13 m²/day and 31.65 m²/day respectively. The wells near Rajur
and Krishnapur located within the shear fracture zone have almost

89
same T values. While the other two, though located within the
tensile fracture zone, have lot of variation in T values. This
could be due to the thick clayey horizons in the weathered/
fractured rock near Hosahalli which is absent in the well near
Itgi. Thus, it can be stated, that not only the subsurface
fractures but the nature of the weathered rock also affects the
aquifer characteristics.
Table 6.1. Time - drawdown data of pumped wells.

<table>
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<tr>
<th>Time after pumping started &quot;t&quot; in minutes</th>
<th>Drawdown in meters</th>
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<th>Rajur</th>
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</tbody>
</table>
FIGURE 6.1 WELL INVENTORY PROFORMA

Basin: Well No: Recorder:

Location: Lat: Date:

Long: Source:

Village: Owner:

Type, shape of the well: Depth

: Diameter/Dimension:

: Perimeter: Lining:

Hydrogeomorphology:

Altitude of the well site:

Water bearing formation:

Depth to static water level:

Depth of water column:

Pumping pallun:

Usage of water:

Area irrigated:

Water sample No.

Well Section

Pumping level:

Pumping equipment:

Yield:

Type of crop:

Quality of water:

Remarks.
Fig. 6.2 Depth and yield relation of the borewells in Sasive Halla Basin.
Well site: Krishnapur
Hydrogeomorphology: Pediplain
Lithology: Migmatitic gneiss
Depth: 60 mts

Casing: 13.81 mts
Water struck level: 15.6 mts
Static water level: 13.32 mts
Discharge: 120.96 m³/day

Test duration: 300 minutes
Maximum drawdown: 4.31 mts
Recovery in 60 min: 4.21 mts

T computed by Jacob's method

\[
T = \frac{2.3 \times Q}{4 \pi \times \Delta s} \\
\Delta s = 0.7 \text{ mts} \\
T = \frac{2.3 \times 120.96}{4 \pi \times 0.7} \\
= 31.65 \text{ m}²/\text{day}
\]
Well site: Hosahalli
Hydrogeology: Pediplain
Lithology: Migmatitic gneiss
Depth: 36 mts
Casing: 18 mts (Perforated)

Water struck level: 3 mts
Static Water Level: 2.85 mts
Discharge: 432 m³/day
Test duration: 300 minutes

Maximum drawdown: 19.98 mts
Recovery in 60 min: 19.65 mts

T computed by Jacob’s method

\[ \Delta t = 4.9 \text{m} \]

\[ T = \frac{2.3 \times Q}{\pi \Delta s} = \frac{2.3 \times 432}{4 \pi \times 4.9} = 16.13 \text{ m}^3/\text{day} \]
Fig. 6.3c

Well site: Itgi
Hydrogeomorphology: Pediplain
Lithology: Migmatitic gneiss
Depth: 42.5 mts

Casing: 19.51 mts
Water struck level: 3 mts
Static water level: 4.62 mts
Discharge: 518.4 m³/day

Test duration: 180 minutes
Maximum drawdown: 2.14 mts
Recovery in 60 min: 2.14 mts

Δs = 0.25 mts

\[ T = \frac{2.3 \times Q}{4 \pi \times \Delta s} = \frac{2.3 \times 518.4}{4 \pi \times 0.25} = 379.47 \text{ m}^3/\text{day} \]

Aquifer lithology:

- Black soil
- Weathered gneiss
- Fractured rock
- Hard rock

Depth in mts
Fig. 6.3d

Well site: Rajur
Hydrogeomorphology: Buried pediment
Lithology: Granite
Depth: 48 mts

Casing: 15.31 mts
Water struck level: 13.5 mts
Static water level: 5.5 mts
Discharge: 648.0 m³/day

Test duration: 240 minutes
Maximum drawdown: 16.8 mts

T computed by Jacob's method

\[ T = \frac{2.3 - Q}{4 \pi \Delta h} \]

\[ = \frac{2.3 \times 648}{4 \pi \times 3.3} \]

\[ = 35.93 \text{ m}^2/\text{day} \]

Aquifer lithology:

- Black soil
- Weathered rock
- Fractured rock
- Hard rock