CHAPTER 5

AQUIFER CHARACTERISTICS

The study of reliability of an aquifer to produce the required supply is an important aspect of groundwater investigation. The capability of the country rock of storing and transmitting water depends greatly on the type of rock, the mode of origin, and the deformation during its geologic history. Locating the aquifers is not enough to solve the hydrogeological problems of an area, rather laboratory and field observations and experiments are to be undertaken to determine their various parameters. Pumping test has proved to be the most reliable means to determine the representative values of hydraulic characteristics of aquifers.

The primary porosity and permeability of a country rock are usually low but secondary or induced porosity and permeability plays a dominant role in groundwater occurrence. An aquifer is charged with water by vertical percolation through the porous overburden and the lateral movement of groundwater is attributed to water table gradient. Majority of dugwells derive water from the weathered zone which acts as storage reservoir. This stored water is transmitted to the well through the intergranular spaces and fractures within the zone. The variation of petrological characters of an aquifer, viz., mineralogical composition, intergranular openings and fractures, is generally
uncertain in space, which make the mathematical treatment of the hard rock aquifers rather complex (Marsily et al, 1984; Cacas et al, 1989; Lachassagne et al, 1989).

The pumping test is a controlled field experiment to evaluate the hydraulic characteristics of an aquifer. The methods proposed by Dupit (1863), later modified by Theis (1935), Cooper et al (1946), Jacob (1946, 1947), Chow (1952), Boulton (1954), Hantush and Jacob (1955), Hantush (1956, 1964), and Walton (1962) to determine aquifer characteristics are all based on certain assumptions. The incompatibility between the methods applied and the actual field conditions give highly diverse results. Hence, the choice of a particular method for estimating aquifer parameters should be decided depending upon the geology and field conditions.

5.1 REVIEW OF METHODS FOR AQUIFER PARAMETER DETERMINATION

There are a large number of dugwells as compared to energised borewells in the study area. The specific capacity of a well is its discharge per unit drawdown. It depends on the permeability and thickness of the aquifer tapped, cross-sectional area of the well and frictional resistance at the entrance to the well (Bohmer et al, 1987; Ballekaya et al, 1991). A brief description of various pump-tests for large diameter dugwells and their limitations are discussed here, and also the reason for choice of a particular method is dealt with.
Slichters' formula (1906) was derived by application of Darcy Law for vertical flow of water into the well after assuming that the well is completely lined and the flow into the well is only from the bottom. The well is pumped till the steady state of drawdown $S_1$ is reached. The time $t$ in minutes, is observed till the residual drawdown $S_2$, is reached after pumping is stopped,

$$C = 2.30 \frac{A}{t} \log_{10} \frac{S_1}{S_2}$$

where,

- $C$ = specific capacity of well in cubic meters per minute for drawdown of unit meter,
- $A$ = area of cross section of well in square meter,
- $S_1$ = drawdown of water level in meters at the steady state,
- $S_2$ = residual drawdown in meters,
- $t$ = time in minutes taken by water level to reach from $S_1$ to $S_2$.

Muskat (1937) modified Slichters' equation for estimation of transmissivity by combining it with Theim (1906) solution for steady state flow. The major set back to this method is the assumption that Theim's equation is valid for confined aquifers where the lateral flow in the well is in steady state condition, while the application of Slichters' equation is valid when the flow in dugwell is from the bottom, which is contradictory to each other. Also, the method requires estimation of a distance to a point of zero drawdown ($r_d$), which demands, observation wells in the proximity of the well being pumped.
Hvoresley (1951), propounded a method based on Slichters' for estimation of permeability. In this method, shape factor \( s \) (\( s = 2.0 \Delta \text{ where, } \Delta = \text{diameter of dugwell} \)) is introduced so as to take care of storage of the well. The only serious limitation to this method is of practical applicability to large diameter wells as the method is based on experimental work on small diameter piezometers.

Papadopoulos-Cooper (1967) proposed a modification of Theis method for aquifer parameter evaluation of large diameter wells taking well storage in consideration. The method is valid for confined aquifers and requires sufficient duration of pumping for reliable curve matching data. It requires an observation well in the proximity of the pumped well. Rushton and Singh (1982) proposed a modification of Papadopoulos-Cooper method. On plotting the drawdown versus time data, the curve is magnified which helps in curve matching.

Raju and Raghav Rao (1967) have put forward a method for determination of the time period of constant inflow rate to a well. The drawdown measurements are plotted against log \( t \) to be analysed by Cooper-Jacob (1946) straight line method. The method is applicable only when the data plot confirm to Theis curve.

Adyalkar and Mani (1972) applied Muskat's equation for unconfined aquifers by assuming \( r_0 \) to be 150-250 feet for basalt. They have proposed \( \mathbf{580} \) as a constant to be multiplied to specific capacity values obtained by Slichters' method to obtain
transmissivity values (Adyakshar et al., 1973). This method too, violates the basic assumption of vertical flow of Slechier by implying lateral flow to the well. The assumed value of r_o may not be the same in all cases due to inherent geological and structural conditions.

Kumarswamy (1973) observed that due to inhomogeneity of flow in the well in hard rock areas, conventional methods fail to determine accurate field values of transmissivity and storativity. The reliability of this method is doubtful as it assumes (i) lateral laminar conduit flow, and (ii) negligible effect on static water level outside the well.

Zdankus (1975) has presented a method for aquifer parameter evaluation of dugwells in hard rock terrain. The method is applicable for fully penetrating well and it requires the assumption of specific yield value. The complex nature of data requirements and its complicated method of analysis make it of little practical use.

Boulton-Streltsova (1975) have forwarded the most generalised method for an unconfined aquifer pumped at constant discharge considering anisotropic nature of aquifer, partial penetration and well storage. Due to large number of parameters, the method is complex and time consuming.

5.2 SPECIFIC CAPACITY OF DUGWELLS

After reviewing various methods, Slechier's Method was found to be most suitable for determining the specific capacity of dugwells of thin
investigation area. The method is simple and requires observation of drawdown at specific time intervals. One big advantage is, that only one well with pump is sufficient for the study and the additional observation well is not needed. Also, Slichters’ formula does not take into consideration the total length of time that a well is pumped prior to shut down of the pump. Slichters’ method is also useful to compare the recovery performance of dugwells in same aquifer (Samel, 1974).

The specific capacity values, as calculated for 44 dugwells in various formations, are given in Table 6. The discharge has been measured by horizontal jet method (Fig. 37). The comparatively higher specific capacity of wells in limestone than rhyolite is assigned to thick mantle cover either of latosol or laterite and to a minor extent due to karstification of limestone. The shearing in rhyolite has conspicuously affected the specific capacity as it lowers down the value to 231 lpm/m at Mahratola, and 58 lpm/m at Chhuikhadan. High specific capacities are observed due to: (i) limestone covered with coarse weathered material providing recharge as observed at Bhandarpur (906 lpm/m). (ii) presence of thick laterite capping over limestone for example at Dewarbhat (774 lpm/m), Kanchri (974 lpm/m), Kulibasa (806 lpm/m), Pauntara (904 lpm/m), Rengakathera (812 lpm/m), and Saloni (939 lpm/m). The specific capacity values as determined for dugwells in the regions occupied by andesite, shiplt group, and sandstone do not give any clear picture of aquifer characteristics.
Fig. 37. Measurement of yield by horizontal jet method as a part of pump-test for aquifer characteristics determination at Daniya village.
Table 6: Specific Capacity of Dugwells by Slichters' Method

<table>
<thead>
<tr>
<th>No</th>
<th>Village</th>
<th>Soil Type</th>
<th>Total Dia.</th>
<th>Area of cross section(sq m)</th>
<th>Static Water Drawdown (m)</th>
<th>Water Drawdown at 1st hr (m)</th>
<th>Pumping Specific Capacity at 1st hr (lpm/ml)</th>
<th>Specific Capacity (litre/hr)</th>
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<tbody>
<tr>
<td>1</td>
<td>Angaon</td>
<td>Rhyolite</td>
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<td>Rhyolite</td>
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<td>8.56</td>
<td>4.26</td>
<td>2.13</td>
<td>1.60</td>
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<td>Rhyolite</td>
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<td>10.79</td>
<td>3.37</td>
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<td>1.77</td>
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Hydro lithounit: Andesite

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<th>No</th>
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<th>Specific Capacity (litre/hr)</th>
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<td>Limaulila</td>
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Hydro lithounit: Basalt Group

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<th>Specific Capacity (litre/hr)</th>
</tr>
</thead>
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<td>Jhargadha</td>
<td>11.22</td>
</tr>
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<td>2</td>
<td>Sitla</td>
<td>23.72</td>
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### Static Drawdown

<table>
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<th>S.No</th>
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<th>Depth (m)</th>
<th>Area (sq m)</th>
<th>Static Drawdown (m)</th>
<th>Residual Drawdown (m)</th>
<th>Pumping Capacity (lpm)</th>
<th>Unit area Capacity (lpm)</th>
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<tbody>
<tr>
<td>1</td>
<td>Pipariya</td>
<td>2.42</td>
<td>4.60</td>
<td>2.13</td>
<td>2.33</td>
<td>4.50</td>
<td>373</td>
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</tbody>
</table>

### Hydrological Studies

#### Pumping

1. **Pipariya**
   - Depth: 2.42 m
   - Area: 4.60 sq m
   - Static Drawdown: 2.13 m
   - Residual Drawdown: 2.33 m
   - Pumping Capacity: 4.50 lpm
   - Unit area Capacity: 373 lpm
   - Hydrological Unit: Pumping
   - Specific Capacity: 68.04 lpm

2. **Other Villages**
   - List includes additional villages with similar data.

#### Residual Levels

1. **Pipariya**
   - Hydrological Unit: Residual
   - Residual Levels: 2.43 m
   - Specific Capacity: 373 lpm

2. **Other Villages**
   - Residual Levels vary across different villages.

#### Specific Capacities

- Specific Capacities range from 68.04 lpm to 141.72 lpm.

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**Note:**
- The data represents Hydrological Studies of specific villages with detailed measurements.
- The specific capacities and other parameters are crucial for understanding groundwater dynamics.
3.2.1 Relation between specific capacity and area of crosssection

In Slichters' formula, the specific capacity is directly proportional to area of cross section (A) of the dugwell being considered (Kupandhi et al., 1973). The data plot of specific capacity values against the respective area of cross-section for dugwells in limestone region fall under two distinct zones (Fig 38). In Zone 1, for the area of cross-section ranging from 2.43 sq m to 7.36 sq m the variation in specific capacity is from 27 lpm/m to 41 lpm/m. On critically analysing the local geology of the well sites, it was observed that shale occurs as a patch beneath the laterite at Ataria, Buranbhat, Khonga and Tolagaon, due to which there is no significant increase in specific capacity of wells. Whereas for comparable cross-sections of wells at Bafrah, Dewarbhat, Garaghat, Karamtara, Kumhi and Rahud, the specific capacity progressively increases depending upon the absence of shale patches, extent of weathering and the topography.

The data plots falling in Zone 2 indicate that as the area of cross-section increases, there occurs corresponding increase in the specific capacity of wells, e.g. Bhandarpur, Chikhaladah, Kanchri, Kulikasa, and Saloni. However, for a comparable cross-sections as at Madrakuhi and Bhandarpur, a wide variation in specific capacity values is observed. On observing the well-section at Madrakuhi, it is found that beneath thick laterite capping, there occurs shale which reduces permeability and hence the contribution to the well, while at Bhandarpur the
FIG. 39. PLOT OF SPECIFIC CAPACITY VS AREA OF CROSS-SECTION (RHYOLITE)

FIG. 38. PLOT OF SPECIFIC CAPACITY VS AREA OF CROSS-SECTION (LIMESTONE)
soil is seen to contain weathered limestone as nodules (kankar) which has attained a comparable thickness. The presence of these nodules in soil helps to increase its permeability and hence the specific capacity.

The inherent geological conditions of the wells at Madrakuhi and Aweli on the one hand and Kulikasa and Rangakathera on the other, have clearly indicated that even after increasing the area of cross section of wells the specific capacity remains the same. The lithological variation is the main factor at Madrakuhi and Aweli, whereas the topography has played a dominant role in Kulikasa and Rangakathera.

The data plot of specific capacity values against area of cross section for dug wells in rhyolite (Fig. 39) clearly indicates that there exists a direct relationship between the above parameters as with the increase in area of cross section, the corresponding specific capacity also increases. This fact might be attributed to the development of a uniform thick weathered zone in rhyolite. However, for a comparable cross sections, there occurs a wide variation in specific capacity of wells. The significant decrease in specific capacity of wells at Mahratola, Mohdabri, and Salewara as compared to Nawagaon, Gatapar, and Kohkabor, Deori respectively is mainly due to the fact that clay patches have developed along the shear planes of rhyolite at former places reducing the permeability of the rock.
5.4.2 Relation between specific capacity and water level

The plot of values between unit area specific capacity of the wells of the studied basin and the static water level below the ground level are shown in Fig. 40 and 41. It is observed that there is a positive correlation among the plots for wells in rhyolitic formation as well as wells in the limestone formation. The reason for this may be attributed to the fact that in areas of shallow water table the top saturated portion is more permeable due to weathering. Thus, it can be said that wells with shallow water table have higher specific capacities. Another interesting fact observed is that for rhyolite the plots tend to cluster in the left middle part (Fig. 40), whereas for limestone they are spread out more evenly (Fig. 41). The behavior of these plots is an indirect evidence of the effect of weathering on permeability of rocks. Rhyolite being igneous rock is resistant to weathering and its primary porosity depends upon the cooling history. Whereas, the secondary porosity in limestone is due to joints and karstification which affects its permeability. The clustering of points for rhyolite may be ascribed to the development of a uniform weathered zone in rhyolite area. Also the unit specific capacity values fall sharply for same static water level, which may be due to the presence of clayey patches in the weathered zone. The spreading of points for limestone gives an indirect evidence of karstification which facilitates in groundwater movement.
FIG. 40. PLOT OF SWL vs UNIT AREA SPECIFIC CAPACITY (in Rhyolite)

UNIT AREA SPECIFIC CAPACITY
in lpm/m/m

FIG. 41. PLOT OF SWL vs UNIT AREA SPECIFIC CAPACITY (in Limestone)
5.3 EVALUATION OF TRANSMISSIVITY BY PUMP TEST OF BOREWELLS

Aquifer characteristics were also determined by aquifer performance test on borewells. The mathematical difficulties encountered due to varying flow conditions like, steady/unsteady radial flow, and the nature of aquifer either confined or unconfined, have led to several investigators to develop approximate solutions which may be applied according to prevailing conditions. These methods are: Theis graphical method, Jacob method, Chow method, and Double slope method. All these methods follow Dupuits' assumption for steady-flow condition, which are,

(i) the water removed from storage is discharged instantaneously with reduction in head,

(ii) the diameter of the pumped well is small, i.e. the storage in the well can be neglected.

On comparing the various methods, Jacob (1960) time drawdown method is found more suitable for the data collected, because this method gives a solution to the Theis nonequilibrium equation using a straight line graphical approach. The method is simple and advantageous over the type curve method. Drawdown in wells since the inception of pumping is plotted against time on log scale. The straight line portion of the plot is projected to intercept one or more log cycles and the zero drawdown axis. The value of transmissivity is computed using the following equation:
2.30 $Q$

\[ T = \frac{2.30 \, G}{A} \]

where,

$\Delta S = \text{drawdown difference per log cycle,}$

$Q = \text{discharge.}$

In the study area, the energised borewells are limited in number. Out of nine energised borewells in sedimentary pediplain only five were in working condition, whereas the igneous pediplain is devoid of energised borewells. The calculation of transmissivity is limited to five borewells tapping limestone (Table 7). The observed values of time and drawdown are plotted on semi-log paper to obtain drawdown curves (Fig 42) from which the transmissivity values were calculated.

At Khairagarh, pump test was carried out at two locations. These tubewells supply water to Khairagarh town. The remaining three locations are Mangikata, Chingli and Daniya villages. The calculated values of transmissivity are 31.19 lpm/m and 35.89 lpm/m at Khairagarh, 34.14 lpm/m at Mangikata, 52.58 lpm/m at Chingli, and 59.04 lpm/m at Daniya.

The calculated values show a wide variation in transmissivity highlighting the anisotropic nature of the aquifer. The anisotropy is introduced here due to karstification of limestone. The limestone at Khairagarh and Mangikata is more shaly, whereas in Chingli and Daniya it is more calcareous, due to which the intensity of karstification is more in later and hence causes variation in transmissivity values.
Table 7: Pump Test Data to determine Transmissivity Values

<table>
<thead>
<tr>
<th>Time</th>
<th>Location</th>
<th>Drawdown (m)</th>
</tr>
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<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.10</td>
<td>0.04</td>
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<td>0.70</td>
<td>0.09</td>
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<td>0.14</td>
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<td>0.70</td>
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<td>4.02</td>
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</table>
Pump Test Data Plot to Evaluate Transmissivity

\[ \frac{Q \cdot L}{H} = \frac{Q}{H} \cdot \frac{L}{H} = \frac{Q \cdot L}{H^2} \]

1. \( Q = 44.1 \text{ lpm/m} \)
2. \( Q = 49.4 \text{ lpm/m} \)
3. \( Q = 33.0 \text{ lpm/m} \)
4. \( Q = 58.0 \text{ lpm/m} \)
5. \( Q = 30.5 \text{ lpm/m} \)

Transmissivity

\[ T = \frac{Q}{H} \]
It is evident that there is a sharp increase in transmissivity values (T > 50 lpm/m) of the borewells (Chingli and Daniya) situated in the eastern portion of the sedimentary pediplain as compared to the borewells of Khairagarh and Mangikata (T < 35 lpm/m) situated in the western part of the sedimentary pediplain, which might be attributed to anisotropic nature of the aquifer. The eastern portion consists of more calcareous limestone supporting intensive karstification whereas the limestone of the western portion, in general, is shaly in nature due to which the karstification is not well developed. This difference in the intensity of karstification might have introduced the anisotropism in the nature of aquifer.

5.4 YIELD OF BOREWELLS

A large number of borewells have been drilled by the Public Health Engineering Department and other agencies (Appendix 3). The yield of borewells give an indication of the performance of the aquifer. The data available of 355 tubewells in the area do not show any particular relation between yield and lithology. It is observed that yield ranges for sedimentary pediplain are more when compared to the igneous pediplain. The sedimentary pediplain consists of limestone, whereas, the igneous pediplain is composed of rhyolite and andesite. From the Table 8 it is revealed that 82.8% borewells have poor yield (i.e. less than 2000 lpm) in sedimentary pediplain and 55.17% have poor yield in igneous pediplain.
Table 8: Data of Total depth and Yield of Tubewells

<table>
<thead>
<tr>
<th>Yield (Lph)</th>
<th>0-2000</th>
<th>2000-4000</th>
<th>4000-6000</th>
<th>6000-8000</th>
<th>8000-10000</th>
<th>10000-12000</th>
<th>12000-14000</th>
<th>14000-16000</th>
<th>16000-18000</th>
<th>18000-20000</th>
<th>20000-22000</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2000</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td>22</td>
</tr>
<tr>
<td>2000-4000</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>4000-6000</td>
<td>76</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>76</td>
</tr>
<tr>
<td>6000-8000</td>
<td>145</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>145</td>
</tr>
</tbody>
</table>

Depth (ft):

A. Pediserial Plain

| 0-30 | 3 | 1 | 1 | - | - | - | - | - | - | 22 |
| 31-45 | 16 | 3 | 3 | - | 1 | 1 | - | - | - | 25 |
| 46-60 | 52 | 8 | 3 | 3 | 1 | 3 | - | 1 | - | 76 |
| 60-80 | 132 | 6 | 1 | - | 1 | - | - | - | - | 145 |

B. Laxad Plain

| 0-30 | 4 | 2 | 1 | 1 | - | - | - | - | - | 8 |
| 31-45 | 9 | 5 | 2 | 1 | - | 1 | 1 | - | - | 20 |
| 46-60 | 47 | 5 | 4 | 4 | 1 | - | 1 | 1 | - | 35 |
| 60-80 | 14 | 2 | 1 | 3 | - | 1 | 1 | - | - | 24 |
Fig. 43. HISTOGRAM OF TUBEWELL YIELD AND DEPTH RANGE
An attempt has been made to correlate borewell yield with depth. The histogram (Fig. 43) reveals that the percentage of yield range above 2000 lph is more in the depth range of 46-60 m in limestone pediplain, whereas in igneous pediplain two such depth ranges are observed at 31-45 and 46-60 m. The cause of failure of yield at a depth greater than 60m is due to cessation of karstification in limestone which clearly points out that there is no use in drilling beyond 60m. Whereas, in the igneous pediplain the depth range of borewells giving good yield varies from 31-60m, which may be due to the greater thickness of the aquifer. Here too, the yield decreases with depth greater than 60m which might be attributed to the fact that joints and fractures become too tight and closed beyond certain depths to hold any appreciable quantities of water. The best method to find out the desirability of drilling deeper is, however, to test the individual borewell for yield at different depths.