CHAPTER - IV

HYDROGEOLOGY
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Groundwater occurs in large reservoirs, beneath the watertable. It saturates the earth material through which it is moving and in which it is stored. Groundwater in its natural state is invariably moving and movement of the groundwater is from greater to areas of lesser hydrostatic head. The prime moving force is the hydraulic gradient. Occurrence, movement and storage of the groundwater is influenced by the sequence, lithology, thickness and the structure of the rock, formation. Movement and storage capacity is chiefly controlled by the permeability and porosity of the host rocks.

Lot of developments have been taken place and scientific procedures are available for evaluation, analysis and management of groundwater resources. However, R & D programmes have to be encouraged so that the evaluation of groundwater can be carried out on a more scientific ways to fill in the gaps and appropriately developed strategies evolved for alluvial regions and adequate attention has to be given on various aspects of groundwater resource, evaluation, planning and development.

The growth in population every year will need more quantity of food and fibre by the year 2000 A.D. This demands a refined re-evaluation of our groundwater resources afresh. Taking into account the above view; detailed hydrogeological investigations have been carried out in Yamuna-Karwan sub-basin in parts of Aligarh-Mathura districts, for the delineation of the regional aquifer systems and their groundwater resource potential.
Fig. 4.1: Showing the Hydrogeological divisions of Uttar Pradesh (After Pathak, 1978).
4.1 HYDROGEOLOGICAL SETTING:

The Ganga basin forms one of the most potential groundwater provinces of India (Pathak, 1978) of which the state of Uttar Pradesh forms an important part. Out of a total area of 234,413 sq. kms. of the state, an area of 2,00,492 sq.kms. has been covered by systematic hydrogeological surveys. The greater part of the state is covered unconsolidated formations having extensive and productive aquifers with yield prospects of more than 15 m³/hour. Extensive aquifers having yield prospects of less than 150 m³/hour are located in Western Ganga-Yamuna 'Doab' covering the districts of Aligarh, Bulandshahar and parts of Agra, Etah, Mainpuri, Mathura, Meerut, Muzaffarnagar and Saharanpur districts; in the central part of the state covering parts of Barabanki, Faizabad, Lucknow, Rai Bareli, Sultanpur and Unnao districts and in eastern part covering the district of Ballia and parts of Azamgarh and Ghazipur districts. Local and discontinuous aquifers capable of yielding more than 150 m³/hour are encountered in intermontane Doon valley. Southern marginal areas covering most of the trans-Yamuna plains and the area covered by semiconsolidated formations in northern Uttar Pradesh have local and discontinuous aquifers having yield prospects of less than 150 m³/hour. In southern Uttar Pradesh fissured sedimentary and metasedimentary formations form aquifers capable of yielding more than 20 m³/hour while the crystallines have local and discontinuous aquifers having yield prospects of less than 20 m³/hour.

Based on physiography and hydrogeological conditions evaluated on the basis of systematic surveys and groundwater exploration the state can be divided into the following hydrogeological zones (Fig. 4.1).
### Table 4.1: Showing hydrogeological zones of Uttar Pradesh

<table>
<thead>
<tr>
<th>Zone</th>
<th>Sub zone</th>
<th>Approximate area (Sq.kms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Himalayan</td>
<td>Lesser and central Himalayans</td>
<td>59,257</td>
</tr>
<tr>
<td></td>
<td>Sub Himalayan or Siwalik</td>
<td>3,000</td>
</tr>
<tr>
<td>Inter-montane valley</td>
<td></td>
<td>1,020</td>
</tr>
<tr>
<td>Alluvial Tract</td>
<td>Bhabar</td>
<td>2,460</td>
</tr>
<tr>
<td></td>
<td>Tarai</td>
<td>11,200</td>
</tr>
<tr>
<td></td>
<td>Central Ganga plain</td>
<td>176,000</td>
</tr>
<tr>
<td></td>
<td>Marginal Ganga plain</td>
<td>119,728</td>
</tr>
<tr>
<td>Vindhyan Terrain</td>
<td></td>
<td>10,468</td>
</tr>
<tr>
<td>Bundelkhand</td>
<td></td>
<td>11,280</td>
</tr>
<tr>
<td>Granitic Terrain</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The boundaries of these zones are approximate and more detailed studies are required for precise demarcation. However, the areas of each zone has been calculated. Hydrogeology of the above five zones is summarised in the following paragraphs.

**Himalayan Zone:**

The Himalayan zone has been divided into two sub-zones viz. the lesser and central Himalayan sub zones. The two sub-zones are separated by the main boundary fault.

The Himalayan zone is underlain largely by sedimentary rocks of Paleozoic to Cenozoic Era, which have been greatly deformed and metamorphosed during the orogeny
of the Himalayas. The high land is dissected by deep groges and narrow valleys. The lithological units include sandstones, shales, clays and conglomerates of Neogene Siwaliks followed due north by the peletic, arenaceous and calcareous sediments and the crystalines of the central Himalayas.

Intermontane Valley:

"Doon valley" is the most prominent intermontane valley is a spindle shaped tectonic valley bordered by Lesser Himalayas in the north and Siwalik ranges in the south. The valley is underlain by unconsolidated sediments comprising boulders, cobbles, pebbles, gravels mixed with sand. Groundwater in the valley occurs under water table condition and water levels are generally deep. The static water level in the tubewells ranges from 22 meters to 76 meters below the land surface and discharge varies from 50 to 180 m$^3$/hour for drawdown varying from 0.7 to 8.4 meters. The coefficient of permeability of these aquifers ranges from 15 to 250 m/day.

Alluvial Tract:

The alluvial tract considered to be the most important part as the groundwater resources of the state are concerned, it is underlain by unconsolidated sediments dating from Pleistocene to Recent. The Ganga alluvial tract extends in a NW-SE direction and spreads over an area of 209,388 sq.kms. This low land occupies a great crustal down-buckle formed between the mobile orogenic belt of the Himalayas and the static Peninsular shield and was filled
up with the Quarternary alluvium which at places attains a thickness of more than 1000 m. This zone contains the most potential groundwater reservoir in the state. This is divided into four sub-zones viz. Bhabar, Tarai, Central Ganga Plains and Southern Marginal Plains.

i) Bhabar or Piedmont Zone

The northern boundary of the Bhabar belt is generally marked by the southern edge of Siwalik hill ranges and the southern limit is characterised by the spring lines. The general width of 'Bhabar' belt ranges from 10 to 30 kms. The Bhabar belt is composed of piedmont deposits formed by lateral coalescence of fan deposits of innumerable streams emerging out of the Himalayas. Lithologically it comprises boulder, cobbles, pebbles and gravels mixed with sand. Groundwater in these deposits is mostly unconfined and water table is generally deep being 30 meters or more below land surface. Perched bodies are of common occurrence.

The tube wells down to 100 meters depth generally yield between 97 to 227 m³/hour for drawdown varying between 2.7 and 9.7 meters. The hydraulic conductivity of the aquifer is estimated to range between 15-250 m/day.

ii) Tarai or Wet Land Zone

The deep water table at the foot hills cuts the land surface and gives rise to the series of springs hence this zone is called as wet land zone or Tarai. The spring line defines the northern limit of Tarai, while its southern limit imperceptibly merges with the Central Ganga
plain. This is about 8 to 16 kms. wide and runs parallel to Bhabar zone. the belt is characterized by predominant clayey sediments with intercalated beds of sands and gravels. This belt is characterised by the localised occurrence of flowing conditions with piezometric heads above ground level. the top aquifers are generally unconfined and the water table is normally within four meters below land surface. The piezometric head in the flowing wells of this zone varies between 6.60 and 8.90 meters above the ground level while in the nonflowing wells it ranged between 1.65 and 11.20 meters below ground level.

iii) Central Ganga Plain

The northern limit of this sub zone is the southern limit of the 'Tarai'. It lies between Yamuna and Ganga rivers and extends upto their confluence at Allahabad which marks the southern limit of this sub zone. Stretching from West-north-west to east-south-east, this belt covers the major part encompassing of the Ganga-Yamuna interfluves and contain several potential aquifers down to the bed rocks. The quaternary alluvium consists of gravels and sands of various grades, silt, clay, often intercalated with calcareous concretions in varying proportions. The beds are generally lenticular and there are rapid alterations and gradations between granular and clayey horizons. The near surface groundwater is unconfined while deeper aquifers lying below 100 m are under confined to semi-confined conditions.

Depth to water level in tubewells generally ranges between 2 and 12 meters below land surface. The discharge of deep tubewells ranges between 100 and 300 m$^3$/hcur for
drawdowns of 6 to 10 meters. The pump test done in this area by various Govt. agencies reveal wide variation in permeability and transmissibility of the aquifers due to rapid change in their thickness and texture of the granular zones.

iv) Marginal Alluvial Plain

This subzone lies between Central Ganga plain and the region occupied by the Bundelkhand granite and Vindhyan rocks. The alluvium is composed of silt, clay and sand of various grades. Groundwater occurs both under water table and confined conditions.

In western Uttar Pradesh, this type of marginal alluvium occur at the western most margin of the region where Vindhyan rocks are exposed at a depth ranging between 220 to 280 meters (220 mts at Raya and 280 mts at Surirkalan in Mathura district). A prominent and persistent granular zone comprising fine to coarse sand with varying amount of gravel has been encountered between the depth of 30 and 170 meters in the northern part of this sub-zone.

The static water level in tubewells generally ranges from flowing conditions to 26 meters below ground level. The discharge of the tubewells varies between 60 and 240 m³/hour for drawdowns from 3 to 16 meters.

4.2 HYDROGEOLOGIC FRAMEWORK OF THE STUDY AREA:

The area under investigation i.e. Yamuna-Karwan sub-basin is a part of Ganga-Yamuna interfluves which forms
a part of the central Ganga plain. The thick pile of sediments comprising sands of various grades, silt and clay intercalated with 'Kankar', the various sand bodies form the prolific aquifers. Groundwater occurs in these saturated zones. Rainfall forms the principal source of groundwater recharge in the area, besides the surface recharge in form of irrigation return flow and numerous surface bodies like ponds and lakes in the area also contribute to the groundwater bodies through the vertical seepage. Seepage of Mat branch of the upper Ganga canal has its own importance in the area. The bottom width of this canal is 24.4 mts. with depth of 1.87 mts and bedslope is 0.15 m/km. The discharge of the canal is 21.63 cumec in the study area.

**Hydrogeological Surveys:**

Groundwater plays an important role in determining the water bearing and transmitting capacity of geological formations. The existing hydrogeological information, based on the work of Central Groundwater Board, Groundwater Department, U.P., was compiled and analysed. To fill in the information gap and to have a control on hydrologic system, entire study area was then covered through reconnaissance traverses.

For a proper evaluation, development and management of the groundwater resources in the study area, systematic well investigations of 93 observation wells were carried out and pertaining hydrogeological data were collected to bring out valuable informations relating to groundwater conditions and to study the changes in water levels in response to rainfall, evaporation, groundwater use and
other factors. The pre and post monsoon water levels were measured in the observation wells during 1992 and 1993.

The collected data were processed and utilized in the preparation of depth to water level maps, water level fluctuation maps, and water table contour maps, etc. which bring out the potential area for further groundwater development. Besides, the lithological logs of the boreholes were collected and studied and utilized to prepare cross-sections and fence diagram in order to depict the disposition of various aquifer systems and their lateral and vertical extensions in the area. Locations of observation wells and tubewells inventoried are shown in Fig. 4.2.

4.3 EVOLUTION OF AQUIFERS:

The evolution of aquifers in fluvial system is dependent upon the hydrodynamics of the flow regime, geology and topography of the terrain, leading to the terrigeneous clastic deposition system, which are typically represented as the channel, flood plain and back swamp deposits.

Channel Deposits:

The typical channel deposits of the river Yamuna as observed in the study area from bottom upward comprise coarse sand mixed with gravel through medium to fine sand to silt and finally capped by a thin clay layer at the top. This top clay and some fine sand layers are washed away during successive flood periods and a fresh body of sand with the fining upward sequence is deposited again each
year during the flood, forming thereby a reasonably thick terrigenous clastic deposits till the river changes its course due to some tectonic control through convulsion. These thick bodies of sand form the potential repositories of groundwater or the most potential aquifers.

Flood Plain Deposits:

During the flood season when the flood water overflows the banks, medium to fine sand bodies of moderate thickness and limited areal extent are deposited over the flood plain. These lenticular bodies of sand form the moderately potential aquifers in comparison to the highly potential aquifers of the channel deposits. The lenticular shape of the aquifers is due to the fact that flooding takes place in a limited stretch of the river bank at a time.

Back Swamp Deposits or Oxbow Lake Deposits:

The flood water from the high banks further moves down the slope towards the low lying areas where it is left predominantly with the suspended material which get settled under the influence of gravity and form a lensoid body of sand which is further overlain by the still finer clastics i.e. clay. Thus there occurs enclaves of sand bodies intercalated within the underlying and overlying clay beds. Such bodies of sand characterise the back swamp environment and form the low potential aquifers, very often associated with the quality problem. The enclosed nature of such aquifers obstruct the regular flushing or recharge rendering thereby to poor quality formation of water.

Thereafter, the river changes its course under tectonic control through convulsion or some other factor
like earth quake etc. Thus with the passage of time, the position of channel, flood plain, and back swamp deposits also continue changing. That is why that no continuous body of sand or clay except under certain extraordinary situation in a single bore hole. Thus the lithological variations are attributed to their mode of deposition by the constantly shifting nature of the river Yamuna and other streams draining the study area.

The various aquifer systems, thus generated by the river Yamuna and Karwan are as under:

a) The channel deposits are thick bodied aquifers of infinite areal extent forming most potential ground-water reservoir.

b) Flood plain deposits giving rise to the lenticular type of aquifers of limited thickness and areal extent and are only moderately potential.

c) Lensoid bodies of sand occurring as enclaves or stringers within the thick clay beds, generally form the low potential aquifers often with quality problems.

In a thick Yamuna alluvium, the complexes of the channel, flood plain, and back swamp facies reappear several times in a well drilled at places in the area. Thus the terrigenous clastic depositional system of the river Yamuna in the study area is an index of its complex hydrodynamic regime which generated various aquifers in the sub-basin.

4.3.1 Delineation and System of Aquifers:

In order to ascertain the sub-surface geological framework and aquifer disposition in the study area, the
Fig. 4.2: Map showing the area surveyed Dug-wells and tubewells inventoried in Yamuna-Karwan Sub-basin.
lithological logs of the boreholes of the existing tubewells drilled by the state Tubewell Department in the area (Appendix II) were utilized to prepare the fence diagram (Fig. 4.3) and hydrogeological cross-sections along the lines AA', BB', CC', DD' and EE' (Fig. 4.4a to 4.4e). The location of these lines are shown in Fig. 4.2.

The fence diagram reveals the vertical and lateral disposition of aquifers, aquicludes and aquitards in the study area down the depth of 92.0 metre b.g.l. A perusal of fence diagram shows that in all there occurs two to three tier aquifer system down to the depth of 92.0 m.b.g.l.

In northeast portion adjacent to the Karwan river the aquifers appear to merge with each other and behave as a single bodied aquifer system with the maximum thickness of 37.78 meters. Comprising fine through medium to coarse sand occasionally mixed with Kankar. It appears to be the channel deposits of the hydrodynamics of river Yamuna. It is also confirmed by the section A-A' and B-B', which shows that the clay beds occur simply as a lensoid body. The depth of shallow aquifers ranges between 4.0 m.b.g.l. to 35.66 m.b.g.l. The minimum depth of shallow aquifer is 4-15.25 m.b.g.l. found in eastern portion of Khair block, while the maximum depth of shallow aquifer is 35.66 m.b.g.l. in the central portion of the study area in Tappal block and the maximum depth of shallow aquifer in Nojhil block is 25.50 m.b.g.l. The shallow aquifers are under the water table condition while the deeper aquifers have been identified as leaky confined in character. The deeper aquifers behave as a single bodied aquifer. The shallow and deeper aquifers are separated with clay bed intermixed with silt and Kankar which serves as an aquitard.
Fig. 4.3: Fence diagram of the area showing aquifer disposition.
Fig. 4.4b: Hydrogeological cross-section along line B-B'.
Fig. 4.4c: Hydrogeological cross-section along line C-C'.
Fig. 4.4d: Hydrogeological cross-section along line D-D'.
From east to west direction the clay beds gradually start attaining thickness and occur in repeated alternation with the granular zones. The percentage of granular zone is around 40 to 50% and it appears to be the flood plain deposit. It is also revealed by the hydrogeological sections which shows alternate sand and clay beds where the clayey horizons gradually pinch out. Similar position is observed in the central part of the area too. The most peculiar subsurface hydrogeological set up is found in the SE and SW parts of Nojhil and Khair blocks, where the clay predominates over the sand. The granular zone here comprises 30 to 40% of total lithounits. These appear most probably as back swamp deposits which also possess the quality problem.

4.4 DEPTH TO WATER LEVEL:

In an unconfined aquifer, the water level is the upper surface of the zone of saturation where the pressure is atmospheric. It is defined by the level at which water stands in wells penetrating the aquifer, just enough to hold standing water. However, in general the water level standing in dugwells are considered accurate enough to represent water level of an area. The depth to water level map depicts the regional variations of the water level with respect to land surface all over the area.

Based on the data collected from the field observations of static water levels in the shallow well during June and November, 1992 (Appendix III) and June and November, 1993 (Appendix IV) depth to water level maps of pre-monsoon and post-monsoon periods have been prepared (Fig. 4.5, 4.6, 4.7 and 4.8).
Fig. 4.5: Pre-monsoon depth to water map, June 1992.
Fig. 4.7: Pre-monsoon depth to water map, June, 1993.
4.4.1 Depth to water level (pre-monsoon, 1992, 1993):

In pre-monsoon (1992, June) the depth to water ranges between 1.20 to 18.52 meters below ground level, while in June 1993 it ranges between 1.15 to 18.70 meters below ground level (b.g.l.). The area has been divided into 10 depth to water level zones varying from (1) upto 2 (2) 2-4 (3) 4-6, 94) 6-8, (5) 8-10, (6) 10-12, (7) 12-14, (8) 14-16, (9) 16-18 and (10) more than 18 meters below the ground level (Figs. 4.5 and 4.7).

The deeper levels viz. 19.0 and 19.72 m.b.g.l. were recorded at Ghagauli village in June 1992 and 1993, respectively while shallowest water levels viz. 1.20 and 1.15 m.b.g.l. were recorded at village Mayaramgarhi adjacent to the Mat canal in the 1992 and 1993, respectively.

A perusal of maps shows that depth to water level is increasing towards eastern upland along the Karwan river where it ranges between 8 to m.b.g.l. and in western parts of the study lying between Yamuna river and Patwah drain the depth to water level ranges between 8-19 m.b.g.l.

In the vicinity of Mat canal, the depth to water level is generally shallow which ranges from less than 2 to 6 m.b.g.l. Two patches have been demarcated water logged area around Nagla, Mayaramgarhi, Pachara, Bhureka and Moinuddinpur where the water level ranges between 1.15 to 2.0 m.b.g.l. which is the resultant effect of the quantum of seepage that has been taking place ever since the commissioning of the Mat canal. The excessive seepage is taking place through the unlined canal beds and consequently
Table 4.2a: Depth to water level (June 1992, 1993)

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of well</th>
<th>Depth to water range (m.b.g.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>0-2</td>
</tr>
<tr>
<td>1992</td>
<td>93</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.37%</td>
</tr>
<tr>
<td>1993</td>
<td>93</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8.60%</td>
</tr>
<tr>
<td>Average %</td>
<td></td>
<td>6.98</td>
</tr>
</tbody>
</table>

Table 4.2b: Depth to water level (November 1992, 1993)

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of well</th>
<th>Depth to water range (m.b.g.l.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>0-2</td>
</tr>
<tr>
<td>1992</td>
<td>93</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.15%</td>
</tr>
<tr>
<td>1993</td>
<td>93</td>
<td>nil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.4%</td>
</tr>
<tr>
<td>Average %</td>
<td></td>
<td>2.15</td>
</tr>
</tbody>
</table>
the general water level in the area proximal to the canal has progressively been rising.

It is observed that the eastern upland is facing water logging situation due to excessive seepage while, the western part shows the declining trend of water level due to heavy withdrawal of groundwater through shallow and deep tubewells. The table 4.2a shows number and percentage of wells falling in different depth to water zones.

It may be observed from the tables 4.2a & b that during pre-monsoon period, 50.51% of wells show depth to water level ranging between 6 to 16 m.b.g.l., 2.15% of wells ranges between 16 to 20, m.b.g.l., 36.55% of well 2-6 and 5.37% of the wells showing less than 2 m.b.g.l. Similarly during post-monsoon period, 49.44% of well are showing the depth to water level ranging between 6-16 m.b.g.l., 3.22%, 16-20, 32.25% wells, 2-6 and 6.45% of the wells showing less than 2 m.b.g.l.

A comparison of the tables 4.2a & 4.2b shows that the percentage of wells recording depth to water less than 2 meters is increasing by 4.30% during the post- monsoon in the year 1992 but during 1993 it decreases by 0.35%, and there is decrease by 5.37% in the value of wells recording the depth to water more than 12 m.b.g.l. during the year 1992 but no significant change have been observed during 1993. The change during 1992 can be attributed to the recharge of aquifers through rainfall but due to less rainfall during 1993.

4.4.2 Post Monsoon depth to water level:

Figures 4.6 and 4.8 show the depth to water level of post monsoon (November, 1992 and 1993).
Fig. 4.6: Post-monsoon depth to water map, November, 1992.
Fig. 4.8: Post-monsoon depth to water map, November, 1993.
A perusal of figures shows that during November 1992 and 1993, the shallowest water level is recorded at Pachara i.e. 0.78 and 0.74 m.b.g.l. while the deepest level i.e. 18.30 and 19.04 m.b.g.l. were observed at Ghaguali village in the western upland.

Shallow water level leading to swampy conditions during and after monsoon season is characteristic features of the low land, and Mat canal command areas. The shallow water zones lie along the Mat canal with the depth ranging between less than 2 to 6 m.b.g.l. The another depth to water level zone was observed on eastern upland along the Karwan river, where the depth to water ranges between 8 to 15 m.b.g.l. The post-monsoon depth to water level map of 1993 does not show any significant difference. This is caused due to the deficient rainfall during 1993.

In general depth to water zones described are found in conformity with the general physiographic units of the area.

4.5 WATER LEVEL FLUCTUATION:

The groundwater level fluctuation is a function of time and space in response to precipitation. The change in water levels are due to the change in storage of groundwater in an area. It can also be caused due to excessive withdrawal of water from the aquifer than the quantum of the average annual recharge.

The water level fluctuation maps (Fig. 4.9 and 4.10) have been prepared for the period of 1992 and 1993 by way of
Fig. 4.9: Water level fluctuation map of the study area, during the year 1992.
Fig. 4.10: Water level fluctuation map of the study area during the year 1993.
contours of water level difference in pre-monsoon and post-monsoon water levels. This difference in groundwater level show a seasonal pattern of fluctuations. This results from influence such as rainfall and irrigation pumping that follow well defined seasonal cycles (Todd, 1980). A perusal of fluctuation maps (Fig. 4.9 & 4.10) shows that with an interval of 0.50 m, the area is divisible into 0-0.5 (2) 0.5-1.0, (3) 1-1.5, (4) 1.5-2.0 and (5) 2-2.5 meters water level fluctuation zones. Table 4.3 gives the number of wells falling in different fluctuation zones.

Table 4.3: Showing range of fluctuation in percent

<table>
<thead>
<tr>
<th>Year</th>
<th>No. of wells</th>
<th>Fluctuation range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0-0.5</td>
</tr>
<tr>
<td>1992</td>
<td>88</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>14.77%</td>
</tr>
<tr>
<td>1993</td>
<td>85</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30.58%</td>
</tr>
</tbody>
</table>

The table 4.3 shows that in the major part of the area the fluctuation ranges between 0.5 to 1.0 meter and is followed by the zone showing fluctuation in the range of 1 to 1.5 m in 1992 and 0 to 0.5 in 1993. While the fluctuation of 0.5 m was recorded only 14.77% during 1992. The difference in fluctuation of 1992 and 1993 shows that the recharge of the groundwater was less in 1993. The variation in fluctuation in the low lying areas close to the feeder canal (Mat branch) is probably due to the constant recharge of the top aquifers through vertical seepage leading to the rise of water table above the ground level.
It is very interesting to note that this water above the ground surface be really called surface water or groundwater above the ground level. The literature is full with the defined difference between the two as the water above the zone of aeration is surface water and that below it is the groundwater. So far my knowledge goes nobody has ventured to define this groundwater which rises under the impact of rampant seepage of surface water into the aquifer below the canal beds.

High fluctuation areas (upland areas) are recharge areas and the less fluctuation areas (low land) are the discharge areas as the same is apparent from the above discussion. The fluctuation map of 1993 (Fig. 4.10) does not show any significant change in water level. this is caused due to scanty rainfall during the year 1993.

4.6 GROUNDWATER MOVEMENT:

Groundwater is invariably moving. This movement is governed by established hydraulic principles (Todd, 1959). Groundwater moves in the direction of slope of water table and the slope of water table in turn depends upon many factors such as permeability and thickness of water bearing zone, the topography, lithology and local variations in the quantity of recharge and discharge (Hubbert and Toth, 1962).

4.6.1 Water Table Contour Maps:

Water level data of wells collected during pre-monsoon and post-monsoon (1992, 1993) have been analysed and altitudes of water level with reference to the mean sea level were worked out. For this purpose, all the
observation wells were connected with survey of India Bench Marks, wherever available. The reduced levels of water table with reference to mean sea level were plotted on a map and water table contour maps were prepared with contour interval of two meters (Fig. 4.11, 4.12, 4.13 and 4.14).

The water table contour maps are very useful in deciphering the groundwater flow direction, hydraulic gradient and area of recharge and discharge. Convex contours indicate area of groundwater recharge, while concave contours show tract of groundwater discharge (Todd, 1980). Further, the divergence of flow lines indicates a recharge area whereas convergence of flow lines depicts the discharge area (Fetter, 1980).

4.6.2 Form and slope of water table:

A perusal of pre-monsoon water table contour maps (1992, 1993 (Fig. 4.11 and 4.13) shows the elevation of water table ranges between 190 meters in north-west parts to 162 meters in the south-east above the mean sea level. The general groundwater flow in consonance with the regional groundwater flow direction in the central Ganga basin is from NE-SE direction. However, at places there are some variations which are caused due to local factors.

In eastern flank the groundwater flows towards Karwan rivers, which shows the effluent nature of this river. Similarly, the Patwah drain is also receiving the groundwater in the central part of the study area. The river Yamuna receives groundwater runoff all along half of its northern stretch and along its southern most stretch and thereby behaves as an effluent stream. However, the river
Fig. 4.11: Pre-monsoon water table contour map, June, 1992.
Fig. 4.13: Pre-monsoon water table contour map, June, 1993.
Yamuna recharges aquifers at some places and behaves as an influent stream as is evident from the troughs which are formed around Nurpur, Mangarhi and Nojhil along the Yamuna river. These troughs are the resultant effect of over development or heavy withdrawal of groundwater through the huge number of shallow formers tubewells as there are no canal in these areas except Jarara distributary of Mat feeder canal at Nurpur (transperancy showing canal network can be superimposed over the map), which is not recharging the aquifer commensurate to the water withdrawal.

Three groundwater mounds appear to have formed around Amangarhi, Ahrola, Khera, Edalpur and Bhureka along the Mat feeder canal. Which is caused due to the rampant seepage of water into shallow aquifers through unlined canal beds. Similarly, a mound has also developed at Naglakura and Udaipur villages along Jewar distributary.

The hydraulic gradient in the study area varies from 0.50 m/km in general to 2.5 m/km all along the Mat feeder canal and at few places in the north western end of the area. The steep hydraulic gradient is indicative of low permeability horizons (Todd, 1980).

4.6.3 Post-Monsoon Water Table Contours:

Maps (Figs. 4.12 and 4.14) show the post-monsoon water table contours for the period November, 1992 and 1993. The post-monsoon water table contour values remain essentially the same because of low fluctuation in water table.
Fig. 4.12: Post-monsoon water table contour map, Nov., 1992.
Fig. 4.14: Post-monsoon water table contour map, November, 1993.
Fig. 4.15a: Hydrograph of Khair observation well.
Fig. 4.15b: Hydrograph of Tappal observation well.
Fig. 4.15c: Hydrograph of Pisawan observation well.
Fig. 4.15d: Hydrograph of Nojhil observation well.
Fig. 4.15e: Hydrograph of Chinpari observation well.
Fig. 4.15f: Hydrograph of Bajna observation well.
4.7 HYDROGRAPHS:

In order to study the groundwater behaviour with respect to time and space, and their dependence on natural phenomenon, the water levels of key observation wells were used to prepare the hydrographs of the well with respect to rainfall for the period of 1983 to 1993 (Fig. 4.15a to 4.15f). A perusal of the hydrographs indicates that water level variation is cyclic and sinuosoidal as a function of time and space. It is observed that water level starts rising by the last week of June and attains shallowest level in November. From November & December there is slow decline in water level but from January onwards the decline is very sharp.

In the view of above discussion, it is inferred that the rising and declining trends of the water level with respect to time and space are attributed to input of groundwater namely rainfall and the seepage from canal.

Further, a critical study of the long range trend of water levels with respect to rainfall indicates the response of water levels to rainfall and drought is reasonably quick and prominent. The ascent of level is also greatly affected by the intensity and distribution of rainfall.

4.8 GRAIN SIZE ANALYSIS OF THE AQUIFER MATERIALS:

The economic development and the utilisation of groundwater resources require an understanding the factors that govern the hydraulic transmission of the groundwater through an aquifer. One of the important quantitative measures of such transmission is the permeability, which
depends both upon the physical properties of flowing water and the characteristics of the transmitting medium. In many natural occurrences the physical properties of flowing water, i.e. viscosity and specific weight are practically constant so the permeability may be considered to be a function of the properties of medium alone (Masch, 1966). Such medium properties include the particle size, shape, structure, degree of compaction and grain size distribution.

The most common method of measuring particle size is sieving. The process of analysing sediments for the range sizes is called mechanical analysis. The purpose of mechanical analysis is to obtain graphic or numerical data about particle size in a sediment. Size analysis has been used in determining if a sand will contain water.

Many earlier workers attempted to relate properties of aquifer materials to the transmitting capabilities of an aquifer. Krumbien and Monk (1952) studied the effect of both particle size and sorting in artificially mixed sand and expressed their results in following semiempirical equation.

\[ K = 760 \, d^2 \, e^{-1.36} \]

where \( K \) is permeability in darcys
\[ d = \text{geometric mean diameter} \]
\[ e = \text{dimensionless constant} \, 2.0718 \]
\[ \sigma = \text{the log standard deviation of size distribution which is dimensionless and 760 is a constant for the conversion of permeability units to Darcy.} \]

A correlation between the laboratory permeability values and median grain size was developed by Bedinger (1961). He found that straight line relation existed between
the logarithm of the permeability and the median grain size diameter. The results of this work revealed that the permeability expressed in gal/ft$^2$/day ranged from 9000 for very coarse sands to about 10 for very fine sands. Johnson (1963) has done experimental work similar to Bedinger, his results also were found in very close with those of Bedinger (1961). Kozney (1953) has studied the relationship between permeability and the pore size distribution which is governed at least partially by the grain size distribution. Preuss and Todd (1963) attempted to relate the specific yield to several physical properties of sedimentary samples including representative grain size diameter and a uniformity coefficient they found that $d_{50}$ or median size was best studied as a measure of representative grain diameter. The uniformity coefficient used to describe the sample was defined as follows.

$$ U = \frac{d_{60}}{d_{10}} $$

The results indicate maximum value of specific yield occurred for $d_{50}$ between 0.4 to 0.5 mm and the specific yield decreased for the values of $d_{50}$ outside this range. They also concluded that in general specific yield decreases as the magnitude of uniformity coefficient increases. Cohen (1963) found the same results as those of Preuss and Todd. Masch, (1966) concluded that the permeability value increases with increasing value of the M.$d_{50}$ diameter.

Uma et al., (1989) has given a new statistical grain size method for evaluating the hydraulic conductivity of sandy aquifers as follows.

$$ K = A d_{10}^2 $$
Fig. 4.16: Grading curves of Aquifer sample.
Fig. 4.16: Grading curves of Aquifer sample.
Fig. 4.16b: Grading curve of aquifer sample.
Fig. 4.17a: Grading curves of sand sample of Yamuna river.
Fig. 4.17b: Grading curves of sand sample of Karwan river.
Where,

\[ \begin{align*}
K &= \text{Hydraulic conductivity} \\
A &= \text{Constant} \\
d_{10} &= \text{Effective grain size}
\end{align*} \]

where the value of A is established as 6 for sandy aquifer.

In the present investigation, aquifer materials were collected from the available drilling sites and sand samples have also been collected from the Yamuna and Karwan river beds through trenching and two samples were collected at the 30 cm and 100 cm depth trench. These samples were mechanically analysed.

The equipment required for sieve analysis includes a small hot plate for drying the samples, a set of standard testing sieves and accurate physical balance for weighing the aquifer materials. A representative sample 150-400 gms was taken in laboratory by coning and quatering. Oven dried and exact weight poured into the top sieve and covered with lid. The whole nest was shaken through shaker for about 15 minutes and material retained in each sieve was accurately weighed and data obtained were statistically analysed (Appendices - V, VI-A & VI-B). Percentage of material passing through each sieve gave a point on grading curve. The grading curve (Fig. 4.16a & 4.17a&b) was plotted on a semi-log paper to determine the following parameters.

4.8.1 Effective size:

The term effective size was developed by Allen Hazen (1892) in his studies of filter sands. He defined it as a
particle size where 10% of sand is finer and 90% coarser. It is believed that \( d_{10} \) is the most important parameter among those governing the permeability properties of a medium (Marsily, 1986).

4.8.2 Uniformity coefficient (Cu):

Cu is average slope of the grading curve between 10% and 60% size and is given by

\[
Cu = \frac{D_{60}}{D_{10}}
\]

It gives an idea of grading of particle size distribution in material. Lower values (\( Cu < 2 \)) indicate more uniform material or poor grading and higher values indicate well graded material (Raghunath, 1987).

4.8.3 Hydraulic Conductivity (K):

Hydraulic conductivity was determined by using formula given by Uma et al. (1989).

\[
K = A d_{10}^2
\]

where \( A = 6 \)

\( d_{10} = \) effective grainsize

The results of grain size analyses show that the effective grain size of aquifer material ranges between 0.07 to 0.160 mm which shows that the sand size ranges between medium to fine. The effective grain size of the Yamuna sediment ranges between 0.092 to 0.128 mm, while the effective size of Karwan sediments ranges between 0.078 to 0.106 mm, which reveals that the Karwan sediments are finer than the Yamuna sand.
Uniformity coefficient of the aquifer material is given in (Table 4.4).

**Table 4.4:** Shows the values of effective size, uniformity coefficient and hydraulic conductivity (K) (Statistical grain size method)

<table>
<thead>
<tr>
<th>Location</th>
<th>Effective grain size ( (d_{10}) )</th>
<th>Uniformity coefficient ( (C_u) )</th>
<th>Hydraulic conductivity ( (K) )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cms(^{-1})            m/day</td>
</tr>
<tr>
<td>Tappal</td>
<td>0.070</td>
<td>1.94</td>
<td>0.029</td>
</tr>
<tr>
<td>Palsera</td>
<td>0.072</td>
<td>1.85</td>
<td>0.031</td>
</tr>
<tr>
<td>Musmana</td>
<td>0.120</td>
<td>1.70</td>
<td>0.086</td>
</tr>
<tr>
<td>Nojhil</td>
<td>0.179</td>
<td>4.46</td>
<td>0.153</td>
</tr>
<tr>
<td>Jamunka</td>
<td>0.13</td>
<td>1.57</td>
<td>0.101</td>
</tr>
</tbody>
</table>

A perusal of the above table shows that uniformity coefficient ranges between 1.57 to 4.46, which reveals the value of \( C_u < 2 \) except at Nojhil, where the value is 4.46, hence the porosity of the samples is high and they are uniform but at Nojhil, the sand is well graded and non-uniform. The uniformity coefficient of the Yamuna sediment (Table 4) ranged between 1.32 to 1.57. It also shows lower values for \( C_u \) i.e. < 2, which indicates that the Yamuna sediment is poorly graded and their porosity is high. The samples from Karwan river show higher values of \( C_u \) than the Yamuna sediments which ranges between 1.49 to 2.31 and indicates that the porosity of Karwan sediments is lower than the Yamuna sediments. The hydraulic conductivity in general ranges between 25.40 to 132.71 m/day of aquifer material. The hydraulic conductivity of the Yamuna sediments
ranges between 43.87 to 84.93 m/day and that of the Karwan sediments varies between 25.40 to 58.24 m/day.

Table 4.5: Shows values of effective size, uniformity coefficient and hydraulic conductivity of the Yamuna and Karwan river sediments.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (cm)</th>
<th>Effective grain size ($d_{10}$)</th>
<th>Uniformity coefficient (Cu)</th>
<th>Hydraulic conductivity (K)</th>
<th>CmS$^{-1}$</th>
<th>m/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yamuna River-1</td>
<td>30</td>
<td>0.11</td>
<td>1.38</td>
<td>0.072</td>
<td>62.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.098</td>
<td>1.47</td>
<td>0.057</td>
<td>49.24</td>
<td></td>
</tr>
<tr>
<td>Yamuna River-2</td>
<td>30</td>
<td>0.128</td>
<td>1.32</td>
<td>0.098</td>
<td>84.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.092</td>
<td>1.57</td>
<td>0.50</td>
<td>43.87</td>
<td></td>
</tr>
<tr>
<td>Karwan River-1</td>
<td>30</td>
<td>0.090</td>
<td>1.50</td>
<td>0.048</td>
<td>41.99</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.106</td>
<td>1.49</td>
<td>0.067</td>
<td>58.24</td>
<td></td>
</tr>
<tr>
<td>Karwan River-2</td>
<td>30</td>
<td>0.078</td>
<td>1.78</td>
<td>0.360</td>
<td>31.53</td>
<td></td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.070</td>
<td>2.31</td>
<td>0.029</td>
<td>25.40</td>
<td></td>
</tr>
</tbody>
</table>

4.9 ISO-PERMEABILITY MAP:

Logan (1964) opined that if a well is pumped for such a long time that the flow is in steady state, then an approximate estimation of the order of magnitude of the transmissivity can be made using the Theims formula for a confined aquifer which can be written as:

$$T = \frac{2.3 Q \log (r_{\text{max}}/r_w)}{2K S_{\text{mw}}} \quad ... \ (1)$$

where,

- $r_w$ = radius of pumped well in meters
- $r_{\text{max}}$ = radius of influence in meters
- $S_{\text{mw}}$ = maximum drawdown in pumped well in meters
Fig. 4.18: Isopermeability map of the study area.
Logan, further stated that the accuracy of the calculation depends only on the accuracy of measurement of $S_{mw}$ (on which well losses may have substantial influence) and on the accuracy of the ratio $r_{max}/r_w$. As $r_{max}/r_w$ cannot be accurately determined generally. Logan reasoned that although the variation in $r_{max}$ and $r_w$ may be substantial, the variation in the logarithm of their ratio is much smaller. Hence, assuming average conditions of ratio, he gave a value of 3.33 for log ratio which may be taken as rough approximation. Substituting the value in equation (1), the Logan's formula can be written as:

$$T = \frac{1.220}{S_{mw}}$$

where, $S_{mw}$ is the maximum drawdown in a pumped well. According to Krusemann and deRider (1970) Logan's formula in above form gives erroneous results of the order of 50% or more.

However, based on Logan's formula, an isopermeability map of the area was prepared (Fig. 4.18). For the purpose, specific capacity and drawdown data of various tubewells were collected and utilised for the determination of transmissivity and permeability by Logan's formula (Appendix VII).

A perusal of the isopermeability map of the area shows that there are four isopermeability zones viz. (1) less than 25 (2) 25-30 (3) 30-45 and (4) more than 35 m/day.

The permeability ranges between 25 to 30 m/day in the area lying close to the Yamuna river, Patwahnala and at some portion of Karwan river it gradually increases towards
the Mat branch canal where it ranges between 30-35 m/day with some local variations at places. In between the Karwan river and Mat canal the permeability ranges between 25 to 30 and 30 to 35 m/day in most of the area. But along the Mat canal and Patwah nala the permeability values recorded are more than 35 m/day and towards SE direction it ranges less than 25 m/day. The low values of permeability may possibly be due to the subtle variation in the grain size; sorting characteristics, and grain packing presenting microscopic inhomogeneties that control porosity and permeability, and thus fluid flow characteristics.

Because of paucity of pumping test data analysis the values of T and K determined by Logan's formula could not be compared with the pumping test data except for two places only.

In Nojhil, the value of K obtained by Logan's formula is in close agreement with the values of K determined through pumping test data analysis. But at Sopha the difference in the value is about 50%. Thus the values obtained by Logan's method give only approximate picture.

4.10 SPECIFIC CAPACITY INDEX MAP:

The specific capacity, being an index of well productivity, serves also as a parameter of yielding and transmissive capacity of an aquifer (Karanth, 1987). the yielding capacity is denoted by an yield factor (or specific capacity of the well for the unit thickness of the aquifer tapped.

\[
\text{Specific capacity Index} = \frac{\text{Specific capacity}}{\text{Thickness of the aquifer}} = \frac{\text{Yield factor}}{
\]
Fig. 4.19: Specific capacity index map of the area.
Based on the above formula the specific capacity index was determined from the available data of tubewells of the area, and the specific capacity index map was prepared (Appendix VII & Fig. 4.19).

A perusal of the map shows that there are following yield factor zones. (1) <20 (2) 20-25 (3) 25-30 (4) 30 m/day. The yield factor ranges between 20 to 25 m/day towards Yamuna river. The area surrounding the Khair town shows high value of specific capacity index or yield factor which ranges between 25-30 and more than 30 m/day. In the south-east portion near Mat canal the value of specific capacity index is 20 m/day. However, the average value of the specific capacity for the entire sub-basin is recorded as 24 m/day.

4.11 PUMPING TEST DATA ANALYSIS AND EVALUATION OF AQUIFER PROPERTIES

Groundwater resource development and management concern with the sustained yields of wells and aquifers, the interference between wells and well field, the interrelation between surface and groundwater and its quality. As the use of groundwater resources requires that pumping be related to water level changes with reference to time and space. The hydrogeologic properties and dimensions of aquifers, aquitards and the boundaries of aquifers are important in relating cause and effect. Hydraulic properties of aquifers and associated layers can be determined by a pumping test and data analysis. One of the fundamental aspect of groundwater resources investigation is the determination of the aquifer characteristics of permeability (K), transmissivity (T) and storage coefficient (S). These characteristics are
important in determining the natural flow of water through an aquifer and its response to withdrawls. Generally, these aquifer parameters are determined on the basis of data obtained from pumping test of wells. For the proper evaluation and utilization of groundwater resources it is an essential method for reliable assessment of these parameters. Furthermore such data are also required for proper well spacing and scientific development of this valuable resource.

4.11.1 Method of Analysis:

Analysis of results of systematic observations of water level changes and other field test data yield values of aquifer characteristics. The extent and reliability of these analyses are dependent on features of the test including duration of test, number of observation wells, and method of analysis.

Various methods are available for analysis of pumping tests data of different aquifer types under different flow conditions. Each method is based on certain physical assumptions. The two types of methods are grouped as: Pumping tests under simple conditions and pumping tests under special conditions. Pumping tests under simple conditions deal with aquifers which are homogeneous, isotropic, infinite in areal extent and under fully penetrating constant discharge conditions, whereas, pumping tests under special conditions are performed on non-uniform aquifers of restricted extent under partial penetration and variable discharge conditions.

The available pumping test data of the study area are analysed by methods which were considered most
appropriate to the field conditions. The method of analysis of drawdown/recovery data in different types of aquifers are outlined below.

4.11.2 Confined Aquifers:

The only solution available for radial flow problems prior to 1935 were steady-state formulae such as that of Dupuit-Theim, which frequently required a lengthy duration of pumping to satisfy the conditions governing the equation.

Theis (1935) developed the first non-steady state solution which took into account the related parameters of time factor and the removal of water from storage in the development of the cone of depression. The equation which he derived for non-steady flow in confined aquifer is expressed as:

\[ S = \frac{Q}{4\pi T} \int_{u}^{\infty} e^{-u} du \]

or
\[ S = \frac{Q}{4\pi T} W(u) \] ... (1)

or
\[ T = \frac{Q}{4\pi S} W(u) \] ... (2)

where
\[ U = \frac{r^2 S}{4 Tt} \]

or
\[ S = \frac{4 Tt \times U}{r^2} \] ... (3)

where,
\[ r = \text{Distance in meters of an observation well from the pumped well in meters.} \]
\[
\begin{align*}
S &= \text{The storativity (dimensionless)} \\
T &= \text{Transmissivity in m}^2/\text{day} \\
t &= \text{The time in days since pumping started} \\
W(u) &= \text{Well function of U} \\
&= -0.5772 - \ln u + U - \frac{u^2}{2.21} + \frac{u^3}{3.31} - \frac{u^4}{4.41} + \ldots
\end{align*}
\]

For the use of Theis's method following assumptions and limiting conditions should be satisfied.

1. The aquifer is homogeneous, isotropic and of uniform thickness and infinite areal extent.
2. Before pumping the piezometric surface is horizontal.
3. The well is pumped at constant discharge rate.
4. The pumped well penetrates the entire thickness of aquifer, and flow is everywhere horizontal within the aquifer to the pumped well.
5. The well diameter is infinitesimal so that the storage within the well can be neglected.
6. The water removed from storage is discharged instantaneously with decline of head.
7. The aquifer is confined and flow to the well is in unsteady-state.

For calculation of aquifer parameters, Standard technique of matching field data curves \( \left( \frac{r^2}{t} \right) \text{ vs } s \) with Theis's type curves \( W(u) \text{ vs } 1/u \) choosing match point and substituting their coordinate values in the equations mentioned, are used. The values are plotted on a double logarithmic paper.
4.11.3 Jacob's Method:

Copper and Jacob (1946) suggested a simplification of Theis equation (1) which dispenses with the need for type curves by utilizing a semilogarithmic plot for those field data where \( u < 0.01 \), which beyond the first log cycle of time usually gives a straight line relationship.

Jacob has shown that for small value of \( u \) \((u < 0.01)\), i.e. when \( r \) is small and \( t \) is large, the Eq. \( s = Q/4\pi T W(u) \) can be simplified and expressed as:

\[
s = \frac{2.30 Q \log 2.25 Tt}{4\pi T r^2 s} \quad \ldots (4)
\]

Thus a plot of drawdown \( s \) versus the logarithm of time \( t \) or distance \( r \) from the pumped well describes a straight line. Equation (4) can further be solved to give:

\[
T = \frac{2.30 Q}{4\pi \Delta s} \quad \ldots (5)
\]

\[
S = \frac{2.25 Tt_o}{r^2} \quad \ldots (6)
\]

where,

\( t_o \) = the time intercept in days corresponding to interception of straight line with zero drawdown axis, \( s = 0 \)

\( \Delta s \) = slope of the straight line in meters.

By plotting time versus drawdown on a semilogarithmic paper (time on log scale) a straight is fitted by discretion. The slope of straight line \( \Delta s \), the drawdown
difference over one log cycle of line are determined and by
substituting the values of Q and ∆s in equation (5) for
determination of T. By substituting the values of computed
T, to and r into Eq. 6 the value of S is determined.

For use of Jacob's method, the same assumptions as
for the Theis's method are followed and the value of 'u'
should be small (u < 0.01) i.e. 'r' is small and 't' is large.

4.14.4 Aquifer Performance Test:

Prior to present investigation various agencies had
undertaken hydrogeological investigations of the study area
for different purposes. As part of present investigation
efforts were made to collect aquifer parameter data for the
analysis.

The Central Groundwater Board and State Groundwater
Department have carried out exploratory drilling in various
parts of Aligarh-Mathura districts. During investigation,
short duration pump tests were conducted with or without
observation wells by the hydrogeologists at the different
sites. But, in the present investigated area the pump tests
were conducted only at two places i.e. village Makhdumpur
(Nojhil Block) and Sopha (Khair block). The details of pump
test results at village Makhdumpur are summarised as below:

<table>
<thead>
<tr>
<th>Method used</th>
<th>Flow condition</th>
<th>( T(m^2/day) )</th>
<th>S</th>
<th>K(m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theis</td>
<td>Unsteady state</td>
<td>411.0356</td>
<td>6.77842x10^{-2}</td>
<td>21.6334</td>
</tr>
<tr>
<td>Theis Recovery</td>
<td>Unsteady state</td>
<td>759.681</td>
<td>-</td>
<td>39.9832</td>
</tr>
<tr>
<td>Cooper Jacob</td>
<td>Unsteady state</td>
<td>580.120</td>
<td>5.178x10^{-2}</td>
<td>30.5320</td>
</tr>
<tr>
<td>Chow's</td>
<td>Unsteady state</td>
<td>398.4569</td>
<td>8.073x10^{-2}</td>
<td>20.9714</td>
</tr>
</tbody>
</table>
The pump test data of aquifer performance test conducted at village Sopha in Khair block by C.G.W.B. was collected and analysed to determine the various aquifer parameters, are computed and given as under:

**Summary of Observation**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Name of site</td>
<td>: Village Sopha</td>
<td></td>
</tr>
<tr>
<td>Block &amp; Sub-division</td>
<td>: Khair</td>
<td></td>
</tr>
<tr>
<td>District</td>
<td>: Aligarh</td>
<td></td>
</tr>
<tr>
<td>2. Longitude &amp; latitude</td>
<td>: 77°45'20&quot;, 27°58'40&quot;</td>
<td></td>
</tr>
<tr>
<td>3. R.L. of ground level</td>
<td>: 194.73 mts.</td>
<td></td>
</tr>
<tr>
<td>4. Date of test</td>
<td>: 29.8.82 &amp; 30.8.82</td>
<td></td>
</tr>
<tr>
<td>5. Pump started on</td>
<td>: 29.8.82 at 1200 hrs.</td>
<td></td>
</tr>
<tr>
<td>6. Pump stopped on</td>
<td>: 30.8.82 at 1225 hrs</td>
<td></td>
</tr>
<tr>
<td>7. Duration of pumping</td>
<td>: 1465 mts.</td>
<td></td>
</tr>
<tr>
<td>8. Thickness of aquifer tapped</td>
<td>: 27 mts.</td>
<td></td>
</tr>
<tr>
<td>Static water level in observation well</td>
<td>: 6.87 mts</td>
<td></td>
</tr>
<tr>
<td>10. Distance between main well and observation well</td>
<td>: 15.75 mts.</td>
<td></td>
</tr>
<tr>
<td>11. Maximum drawdown:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main well</td>
<td>: 6.30 mts.</td>
<td></td>
</tr>
<tr>
<td>Obs. well</td>
<td>: 4.65 mts.</td>
<td></td>
</tr>
<tr>
<td>12. Discharge at which test conducted</td>
<td>: 0.368 m³/sec or 36.83 LPS</td>
<td></td>
</tr>
</tbody>
</table>

**4.11.5 Analysis of Data:**

The pumping data and recovery data recorded during test are given in appendices VIII A & VIII B.
Fig. 4.21: Plot of time Vs drawdown (Jacob's Method) - observation well - village Sopha.
Fig. 4.22a: Plot of Residual Drawdown vs t/t', (Recovery method), site Sophia (Main well).
Fig. 4.22b: Plot of residual drawdown Vs t/t' (Recovery method) observation well - village Sopha.(Observation well).
Time-drawdown field data curves of observation wells resemble the typical 'time-drawdown curve' for a confined aquifer, and suggest an unsteady state flow conditions, Thies's, Jacob's and recovery methods to calculate aquifer parameters have been selectively used (Fig. 4.20, 4.21, 4.22a & 4.22b).

4.11.6 Evaluation of Results:

Aquifer-parameters evaluated by pumping test data analysis are tabulated as below:

<table>
<thead>
<tr>
<th>Methods</th>
<th>Well data</th>
<th>Transmissivity (T)</th>
<th>Storativity (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theis method</td>
<td>Observation well</td>
<td>506.29</td>
<td>1.19x10^{-4}</td>
</tr>
<tr>
<td>Jacob's method</td>
<td>Observation well</td>
<td>520.92</td>
<td>1.50x10^{-4}</td>
</tr>
<tr>
<td>Recovery method</td>
<td>Main well</td>
<td>498.66</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Observation well</td>
<td>486.20</td>
<td>-</td>
</tr>
</tbody>
</table>

Since the results obtained by analysing the data through various methods are almost comparable, but the field curve of observation well match well with Theis type curve, hydraulic properties of the aquifer determined by this method can be taken as best approximation of aquifer parameters.

It may be concluded that tested aquifer of thickness tapped as 27 meters is confined in nature and has the following hydraulic properties:
(i) Transmissivity (T) = 503 m²/day
(ii) Storativity (S) = 1.34 \times 10^{-4}
(iii) Hydraulic conductivity (K) = 18.64 m/day

The quality of the groundwater below 85 meters depth was found doubtful and in depth from 114 to 120 meters b.g.l., the quality is very poor.