CHAPTER V

HYDROGEOLOGY

The state of Uttar Pradesh can be divided into five hydrogeological units from north to south viz. Intermontaneous valley, Bhabar, Tarai, Central Ganga Plain, and Southern marginal alluvial plain.

Among the Intermontaneous valley, Doon valley is the good example. The Bhabar belt stretches parallel to the Himalayan foothills due south upto spring line. It is originated due to coalescence of fan deposits comprising bouldery strata mixed with sand which is highly transmissive, has deep water table and acts as a recharge area for the deeper aquifers in Tarai and central Ganga plain. The spring line defines the northern limit of the Tarai, while its southern limit imperceptively merges with the Central Ganga Plain. The beds are characterised by prominent clayey sediments intercalations with the beds of sands and gravels with frequent free flowing conditions. The southern limit of the Central Ganga plain is fixed by Yamuna and after its confluence with Ganga. The Ganga forms the southern limit of the Central Ganga Plain. This sub zone covers major part of the state encompassing the Ganga - Yamuna interfluves and the area north of it.

In order to study the general ground water conditions and behaviour of water table to the variations in recharge and discharge of ground water.

Systematic inventory of 158 dug wells, 25 shallow tube wells and 30 deep tube wells has been carried out and relevant hydrological/hydrogeological data were collected.
In addition, lithologs of tube wells range in the depth from 41.0 m.b.g.l. to 123.0 m b.g.l. were studied and utilised to depict the sub-surface lithology and the disposition of aquifer systems in the area. (Appendix III).

GROUND WATER CONDITIONS

The coarser clastics in the alluvial sequence form the major repositories of the ground water in the study area. Ground water in the area occurs both under phreatic and semi confined to confined conditions, depending upon the absence or presence of aquitard (Clay with Calc-concretion) and aquiclude as confining beds. The shallow aquifers are phreatic in nature, whereas, the deeper aquifers are mostly semi confined and rarely confined in nature. The rainfall forms the major source of ground water recharge. However, recharge also occurs through irrigation return flow and seepage from the unlined Upper Ganga Canal which traverse through the Central upland of the study area.

EVALUATION OF AQUIFERS

The Ganga basin came into existence due to the sudden sagging of northern fringe of the Peninsula during the post Siwalik times. The sag was later on filled with the sediments brought by the rivers emerging from the newly risen Himalayas and Peninsula. These sediments were deposited on the eroded and upturned surface of the Delhi system, which comprised alternate deposits of sand, clay with occasional interbeds of calcareous concretions.
The Ganga river has constantly been changing its course thereby giving rise to three kind of deposits viz. the channel deposits, the flood plain deposits and the back swamp deposits.

**CHANNEL DEPOSITS**

The typical deposits of the river Ganga as observed in the area from bottom upward, comprise coarse sand mixed with gravels, through medium to fine sand to silt, and a thin clay layers at the top. This top clay and some fine sand layers are washed away during the succeeding flood period and a fresh body of sand with fining upwards sequence as above is deposited again each year, 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 ground water and hence form the 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 channel deposits.

**BACK SWAMP DEPOSITS**

The flood water further moves down the slope, to the low lying areas where it is left predominantly with the suspended materials 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 with the thick clay beds. Such bodies of sand forms the poor aquifers often with quality problem due to non flushing of the aquifers through annual recharge. These aquifers are typical representatives of back - swamp environment or Ox - Bow lake environment. Thereafter the river changes its course under tectonic control, convulsion or some other factors like earthquakes etc. Thus with the passage of time the position of the channel, flood plain and back swamp deposits also continue changing. That is why we do not get continuous body of sand or clay except under certain extra - ordinary situation in a single drill hole. The above lithological variations are attributable to their mode of deposition by the constantly shifting nature of the river Ganga.

The Ganga fluvial system which has generated various aquifers in the area precisely speaking, are as follows:

1. Channel deposits: Thick bodies of sand of infinite areal extent, hence form the most potential ground water reservoirs.

2. Flood Plain deposits: Lenticular bodies of sand, limited in thickness and areal extent form moderately potential aquifers.

3. Back - Swamp deposits: Lensoid bodies of sand, occurring as enclaves or stringers within the thick clay bed generally form the low potential aquifers, often, with quality problem due to non flushing through annual recharge.
However, it was found that in the thick Ganga alluvium, the complex of the channel, flood plain and back swamp facies reappear several times in wells drilled at several places in the study area. Thus, the terrigenous clastic depositional system of the river Ganga in the study area, is an index of its complex hydrodynamic regime which has led to the evolution of the various aquifers system in the central Ganga basin.

AQUIFER GEOMETRY

The fence diagram and the cross sections (Plate XVIII and Plates XIX to Plate XXXV) reveal the vertical and probable a lateral extensions of the lithological units. A perusal of these shows that in all, there occurs two to three tier aquifer system in the Kali - Ganga sub basin in the district of Ghaziabad.

By and large these aquifers appear to merge with each other and behave as a single bodied aquifer system. The study further shows that the granular zone comprising sand and gravel form about 35% to 45% of the total formations encountered down to a depth of 110 m.b.g.l. in the western margin of the study area along the Kali river (Section GH). Gradually the clay beds pinch out in the central part of the area and the aquifer attains relatively greater thickness there (Sections CD, KL & EF). This situation continues progressively due east along the Ganga river, where the aquifer attains the maximum thickness of 70 metres (Sections AB & MN). In the northeastern section too the granular zones predominate over the impervious beds (Section AB) whereas in the south western part of the study area the clay predominates over the granular zones (Section MN & AB), here the granular zones comprises 30% to 40% of the total strata encountered down to a
SUB-SURFACE LITHOLOGICAL BORE HOLES (ALONG C D SECTION) OF KALI GANGA SUB-BASIN
DISTRICT GHAZIABAD

Cste St 59
st 59 st75 D

10
30
50
70
90
110

SAND
CLAY WITH CALC-CONCRETION
SAND
SANDY CLAY
SUB-SURFACE LITHOLOGICAL BORE HOLES
(ALONG E F SECTION) OF KALI GANGLA SUB-BASIN
DISTRICT GHAZIABAD

CLAY
SAND
CLAY WITH CALC-CONCRETION
SAND
SANDY CLAY
SUB-SURFACE LITHOLOGICAL BORE HOLES (ALONG I J SECTION) OF KALI GANGA SUB-BASIN
DISTRICT GHAZIABAD

CLAY
SAND
CLAY WITH CALC-CONCRETION
SAND
SANDY CLAY
SUB-SURFACE LITHOLOGICAL BORE HOLES (ALONG K L SECTION) OF
KALI GANGA SUB-BASIN DISTRICT GHAZIABAD

K st66 st27 st28 st61 st25 st55 st59 st36 L

10
30
50
70
90
110
130

CLAY
SAND
CLAY WITH CALC-CONCRETION
SAND
SANDY CLAY
SUB SURFACE LITHOLOGICAL BORE HOLES (ALONG MN SECTION) OF KALI GANGA SUB-BASIN DISTRICT GHAZIABAD

Diagram showing layers of clay, sand, and clay with calc-concretion.
depth of 107 m.b.g.l. and the aquifer zones occur as lenticular bodies of sand trapped within thick clay beds.

Fine, through medium, to occasionally coarse sand with gravel generally comprises the aquifer materials in the study area. The aquifer materials have various shades of colour and generally are micaceous in nature.

On the basis of the study of geological sections, lithology of boreholes and hydrogeological properties, the aquifers can be described under two distinct categories.

1. Shallow aquifers: Occurring within the depth of 50 mtrs.
2. Deeper aquifers: Below 50 mtrs.

**SHALLOW AQUIFERS**

The shallow aquifers occurring within the depth of 50 metres from the land surface, comprise mainly fine to medium sand. At places the thickness of the shallow aquifers ranges between 8.0 to 12.0 metres. Ground water in these aquifer zones occur under water table condition. These aquifers are generally tapped by open wells, hand pumps and shallow farmer's tube wells. Due to the heavy withdrawal of water from these aquifers, they have become moderately strained. The discharge of these wells varies from 30-45 m$^3$/hour at a draw-down of 3.5 metres.

**DEEPER AQUIFERS**

The deeper aquifers are encountered generally within the depth range of 50.0 to 123.0 m.b.g.l. The fence diagram as well as the cross sections reveal that the deeper aquifers are mostly semi-confined in nature because of the presence of semi-permeable layer i.e. clay mixed with calc-concretion. However, at greater depth the confined aquifer may be encountered. Raju and Rao (1964) has also observed similar nature of aquifers in the adjacent area at
\[ K = A d_{10^2} \]

Cu

\[ 1.1 = 3.3 \]
\[ 2.2 = 3.7 \]
\[ 2.3 = 3.8 \]
\[ 2.4 = 2.20 \]

K = 0.496 cm/sec

K = 0.518 cm/sec

K = 0.588 cm/sec

K = 0.187 cm/sec
Bhurwa village in Ghaziabad. The tubewells tapping the granular zones usually in the depth range of 51.0 to 107.0 m.b.g.l., have discharged which ranges between 135 to 170 m³/hour with draw down varying from 2.6 to 10.3 metres.

GRAIN SIZE EFFECT ON THE PERMEABILITY OF THE AQUIFER MATERIALS

The economic development and the utilization of ground water resources require an understanding of the factors that govern the hydraulic transmission of the ground water through an aquifer. One of the important quantitative measure of such transmission is permeability. The permeability which may be considered as a measure of the ease with which water flows through a given porous medium (sand), is dependent both upon the physical properties of the flowing water and the characteristics of the transmitting medium (Todd, 1980). In many natural occurrences, however, the physical properties of the flowing water i.e. viscosity and specific weight are practically constant, so that the permeability may be considered to be a function of properties of medium alone. The main objectives of the present study are as follows:

1. To determine the permeability values of field samples from the analysis of their grain size.
2. To conduct a series of permeability tests using unconsolidated medium (Ganga sand) with known grain size distribution and to relate these permeability values with grain size, depth range of samples and predicted permeability values.

Several studies have shown that the permeability of the sand can be correlated with the square of the grain size parameters.
SURVEY WORK IN PROGRESS

SAND SAMPLING IN PROGRESS
Kumbien and Monk (1942) studied this relationship by using sand samples made up of sieved tractions that had been combined in the properties required to give log normal distribution, having given values of geometric mean grain size and standard deviation. They found out that the permeability of the samples were proportional to the product of a power function of geometric mean diameter and an exponential function of standard deviation of grain size distribution. Johnson (1963) has done experimental work similar to that of Bedinger. The permeability values of Johnson, which were corrected to a 60°F temperature and which were recorded at the time of complete saturation of the samples, were in very close agreement with those of Bedinger. Kozney (1953) have studied the relationship between permeability and the pore size distribution which is governed at least partially by grain size distribution.

Preuss and Todd (1963) attempt to relate the specific yield to several physical properties of sedimentary samples including a representative grain size diameter and a uniformity coefficient. Ward (1964) described both laminar and turbulent flow in porous medium. A part of this analysis considered as determining permeability values for different medium and relating these values to geometric mean grain size.

Marsh and Denny (1966) made a broader examination of the factors that influence the permeability.
ANALYSIS AND DISCUSSION

1. SOIL PARTICLE SIZE ANALYSIS:

The grain size analysis is determined by means of its particle size analysis, known as sieve analysis. It is a screening process in which coarser fractions of soil are separated by means of a series of sieve graded mesh. The proportion by dry weight of each of these fractions relative to the total dry weight of the dry soil samples (Ganga sand) used for the analysis are established by weighing (Appendix II).

The cumulative soil particle size accumulation curves were plotted for the study area because of the wide range in diameter between the coarsest and finest soil particles and in order that the content of the fine size may become more visual. The diameter of the soil particles were plotted to a logarithmic scale to obtain a more compact curve. The cumulative weight percent finer than size shown were plotted on the arithmetic scale (Plate XXVI).

2. DETERMINATION OF UNIFORMITY COEFFICIENT:

The shape of the cumulative particle size distribution curve is an indication of the uniformity of the soil. It is defined as a ratio of the diameter of the particle which has 60% of the sample (D60) finer than the size shown to the size which has 10% by weight material finer than the size (D10) i.e. Cu = D60 / D10, Allen Hazen (1911) established a relation between the numerical values of uniformity coefficient (Cu) and soil uniformity as:
A VIEW OF PERMEAMETER

A VIEW OF PERMEAMETER
\[ \frac{\Delta H}{L} = 0.506 \]

Velocity .06

\[ V = 0.06, I = 0.506 \]

Measured Permeability, cm/s•sec.

Grain size D10 values

0.0

0.01

0.02

0.03

0.04

0.05

0.06

0.07

0.08

0.09

0.10

0.11

0.12

0.13

0.14

0.15

0.16

0.17

0.18

0.19

0.20

0.21

0.22

0.23

0.24

0.25

0.26

0.27

0.28

0.29

0.30

0.31

0.32

0.33

0.34

0.35

0.36

0.37

0.38

0.39

0.40

0.41

0.42

0.43

0.44

0.45

0.46

0.47

0.48

0.49

0.50

Plate - XXVII

Permeability plot for sample
Cu < 5.0 is very Uniform Soil
Cu = 5.0 is Medium Graded Soil
Cu > 15.0 is Well Graded Soil

A perusal of the Figures (XXVI) show that in the study area the numerical values of Cu is below 5.0, hence it indicates that the soil is very uniform.

3. **DETERMINATION OF COEFFICIENT OF PERMEABILITY THROUGH ANALYSIS (PREDICTED PERMEABILITY):**

The coefficient of permeability is based upon empirical relation between the permeability and effective grain size i.e. D10 values as \( K = CD10^2 \) where \( K = \text{Hydraulic Conductivity} \), \( C \) is a constant (\( C = 6.0 \) for Unconsolidated sand) and D10 is the diameter of the effective grain size. A perusal of the figure (XXVIII) indicates that the values of the Predicted Permeability becomes higher with coarser diameter and it decreases with lower grain diameter. This is because the permeability of the sand is controlled by size, shapes and degree of interconnections of its pores, which is found more convincing in coarser grain than in finer one.

4. **MEASUREMENT OF COEFFICIENT OF PERMEABILITY BY CONSTANT HEAD METHOD (MEASURED PERMEABILITY):**

The laboratory determination of permeability were carried out using a constant head permeameter and to ensure reproducible conditions, samples were prepared and tested according to A.S.T.M. (1955) recommendations. Permeability tests were run on each synthetically prepared sample at least three times at different gradients as shown in the (Plate XXVII) and the coefficient of
PLOT SHOWING RELATION BETWEEN PREDICTED / MEASURED PERMEABILITY WITH DEPTH.

PLOT SHOWING CORRELATION BETWEEN MEASURED PERMEABILITY / PREDICTED PERMEABILITY.
permeability determined from the slope of the average curves. Similarly for all other samples it was determined. The results are as follows:

**TABLE 7.0 SHOWING DETERMINATION OF PERMEABILITY BY CONSTANT HEAD METHOD**

<table>
<thead>
<tr>
<th>Sample Nos.</th>
<th>Discharge: Q</th>
<th>Time: Q = v/t</th>
<th>Permeability K = QL/AH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>140.2</td>
<td>90 sec</td>
<td>1.56</td>
</tr>
<tr>
<td>2.2</td>
<td>146.7</td>
<td>90 sec</td>
<td>1.63</td>
</tr>
<tr>
<td>2.3</td>
<td>162.9</td>
<td>90 sec</td>
<td>1.81</td>
</tr>
<tr>
<td>2.4</td>
<td>1.98</td>
<td>90 sec</td>
<td>2.20</td>
</tr>
</tbody>
</table>

A perusal of the table indicates that the coefficient of permeability increases from top to bottom. This is because the textural variation of the unconsolidated sand is due to the fining upward sequence.

**CORRELATION BETWEEN THE COEFFICIENTS OF PREDICTED AND MEASURED PERMEABILITIES**

The co-relation between the coefficients of predicted permeability and their corresponding measured permeability values are plotted in (Plate XXVIII). A perusal of figure indicates that the coefficients of measured permeability values were lower than the Predicted values. This is because the predicted samples and their ingredients are well sorted as a result of sieving, as compared to
A VIEW OF OVEN

A VIEW OF SIEVE SHAKER
measured samples. It is important to realize that even if both of these coefficients would have exhibited perfect co-relations, this would have not necessarily mean that the predicted coefficient is equal to those obtained from the field tests conducted on the aquifer material. Since there is a certain degree of cementation and consolidation present in nature, aquifer's field permeability tests performed on these aquifers would yield lower permeability values than those obtained from the laboratory.

Since, in the grain size analysis, the coefficient of permeability has got an emperical relation with grain size, hence the accuracy of the methodology employed in the study is also limited by the inability to reconstitute the natural grains arrangement in permeameter. The incomplete stratification in the theoretical model based on the mechanical analysis of the grain size. Also the model does not include the directional aspect of the permeability. The other reason of inaccuracy of this methodology may be that the samples taken from an aquifer may not be completely representative of the grain size characteristics of the entire horizon.

CONCLUSION:

The study indicates that the grain size distribution does have an effect on the permeability of the unconsolidated Ganga sand of Ghaziabad district. The study further shows that the values of coefficient of permeability, either predicted or measured, increased with increase in the grain size. It is also found that the measured permeability values are less than the predicted one. It indicates that the Ganga sand are not well sorted in the study area and due to poor and moderate sorting of the material the
DEPTH TO WATER LEVEL MAP IN KALI-GANGA SUB-BASIN DISTRICT GHAZIABAD, U.P. (MAY 1989)
the measured permeability values decrease.

On the basis of the above data it can be predicted that the permeability under in-situ conditions will further decrease because of the mixing of more percentage of silt and clay as a result of geomorphic variation in the study area.

**DEPTH TO WATER LEVEL**

Water table defined by the levels at which the water stands in the wells that penetrate the aquifer, just enough to hold the standing water. However, in general the water level standing in dug wells are considered accurate enough to represent water table of an area. The water table is the upper surface of zone of saturation in an unconfined water body over which the atmospheric pressure occurs.

Water level data of 156 wells evenly spaced at a distance of one km were utilized to prepared the depth to water maps of the study area (Plates XXIX and XXX). The maps show the depth to water level, for pre-monsoon (June, 1989) and post-monsoon (Nov. 1989) periods. It is found that the contrast in the water levels are attributed to the difference in the permeability and storage characteristics of the aquifers.

In the pre-monsoon period the depth to water ranges from 2.8 m.b.g.l. (Ratupura village) to 13.8 m.b.g.l. (Sikanderpur village) and in the post-monsoon, the depth to water ranges from 2.4m. (Ratupura village to 13.0 m.b.g.l. (Sikanderpur village). The area has been divided into six depth to water zones varying from (1) Less than 4.0 m.b.g.l. (2) 4.0 - 6.0, (3) 6.0 - 8.0,
They can be described as follows.

**TABLE 8.0 DEPTH TO WATER (1989)**

<table>
<thead>
<tr>
<th>Period</th>
<th>No. of Wells</th>
<th>Depth to water Range (m)</th>
<th>4.0</th>
<th>4.0-6.0</th>
<th>6.0-8.0</th>
<th>8.0-10.0</th>
<th>10.0-12.0</th>
<th>12.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Monsoon</td>
<td>158</td>
<td></td>
<td>16</td>
<td>61</td>
<td>27</td>
<td>19</td>
<td>23</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10.13%</td>
<td>38.6%</td>
<td>17.1%</td>
<td>12.03%</td>
<td>14.56%</td>
<td>7.6%</td>
</tr>
<tr>
<td>Post-monsoon</td>
<td>158</td>
<td></td>
<td>20</td>
<td>66</td>
<td>30</td>
<td>21</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12.7%</td>
<td>41.78%</td>
<td>18.9%</td>
<td>13.3%</td>
<td>9.5%</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

It may be seen that during the pre-monsoon season (June 1989) 10.33% of wells recorded in the depth to water range of less than 4.0 m, 38.6% of wells in the depth to water range of 4.0 - 6.0 m, 17.1% of wells in the depth to water range of 6.0 - 8.0 m, 14.56 of wells in the depth to water range of 10.0 - 12.0 m and 7.6% of wells were recorded in the depth to water range of more than 12.0 m.b.g.l.

However, in the Post-monsoon season (November 1989) 12.7% of wells recorded in the depth to water range of less than 4.0 m, 41.78% of wells in the depth to water range of 4.0 - 6.0 m, 18.9% of wells in the depth to water range of 8.0 - 10.0 m, 9.5% of wells in the depth to water range of 10.0 - 12.0 m and only 3.8% of wells were recorded in depth to water range of more than 12.0 m.b.g.l.

A comparison between pre and post monsoon indicates that during the post monsoon period the number of wells and their percentage increased upto 8.0 - 10.0 m depth to water level range and is decreased in the case of 10.0 - 12.0 and more than 12.0 m.b.g.l.
hence it may be visualised that the quantum of recharge to ground water through rainfall of 1989, has been imprinting effect in the post monsoon depth to water level.

An important observation is that certain wells (About 10%) in the study area show shallow water in the canal command areas. A perusal of the depth to water level maps of pre and post monsoon show that in north eastern margin of the study area the water level ranges between 8.0 - 10.0 m whereas a major portion of the study area is covered by 4.0 - 6.0 m.b.g.l. depth to water level, with the exception of the tract along the bank of the Upper Ganga Canal where the depth to water ranges from 2.4 - 4.0 m.b.g.l. However, the shallowest water levels were recorded at Ratupura village and the deepest at Sikanderpur. This variation is due to the quantum of seepage that has been taking place ever since the commissioning of the Upper Ganga Canal, through the unlined canal bed and consequently the general water table proximal to the canal has progressively been rising.

The study further shows that a considerable portion of the area, adjacent to the Ganga river (i.e. Moinuddinpur village in north and Badsauna in south) has the depth to water level which ranges between 10.0 - 12.0 m.b.g.l. However, the small narrow patches parallel to the Ganga bank which is known as the low valley of Ganga or Khadir, there the pre-monsoon water level ranges between 3.1 - 3.8 m and the post monsoon between 2.9 to 3.6 m.b.g.l. respectively. In general the depth to water zones described, are found in the conformity with the general physiographic units of the study area.
MOVEMENT OF GROUNDWATER

Water level data of the wells collected during post and premonsoon period were analysed and altitude of water level with reference to the mean sea level were worked out. The reduced water level with reference to the mean sea level were plotted and water table contour maps were prepared, at the contour interval of one metre. The water table contour maps are very useful in deciphering the ground water flow direction, hydraulic gradients and area of recharge and discharge. The convex contours indicate an area of groundwater recharge while the concave contours indicate the area of ground water discharge (Todd, 1980).

A perusal of the water table maps, (Plate XXXI and XXXII) show that the general direction of the ground water flow is from northwest to southeast with little variations caused by the local factors. The study further shows that in the western end of the study area the groundwater flow from northeast to southwest towards Kali river while in the eastern part of the area, the groundwater flows from west to east i.e. from the eastern slope of the central upland(occupied by the Upper Ganga canal Network ) (Seepage Water) towards the Ganga river. However, in the central part of the area the ground water flows from northwest to southeast direction.

In the study area the gradient varies from 2.0 m/km to 0.8m/km in the western part of the area, but the gradient varies from 2.0 m/km to 0.5 m/km in the eastern margin of the area proximal to the Ganga bank. However, in central part of the area gradient is
about 0.4 m/km. In general the gradient varies from 0.7 m/km to 2.0 m/km. The study further shows that the areas with wide contour spacing seems to possess the high hydraulic conductivity than those with the narrow spacing i.e. steep gradient. In the northwestern part of the area close to river Ganga the gradient of the ground water is very steep about 2.0 m/km. This steep gradient is the indication of the two factors viz.

1. Due to heavy withdrawal of the ground water from the said area. or
2. Due to low permeability of the horizon.

It has been observed from the field survey that the concentration of wells are relatively low in the above mentioned area by which it could be emphasized that the steep gradient in this tract is low due to low hydraulic conductivity of the litho units. The low hydraulic conductivity may be the back - swamp deposit of river Ganga in the area. Similar to the Ganga bank the area close to the Kali river too, shows varied hydraulic gradient viz. it is deeper where the calcareous nodules are missing and less steeper where the calcareous nodules are found intercalated within the clay beds. It is because of the clay mixed with the calcareous concretions acting like a semi pervious body and hence increases the hydraulic conductivity.

The slopes of the water table is towards the river Ganga which depicts that the river Ganga is effluent in nature, similarly the slope of the water table in the western margin of the area, is towards the river Kali which indicates that the Kali river is also effluent in nature. Water table contour maps of the pre and post
monsoon show that the groundwater mounds have been formed in either side of the Upper Ganga Canal system due to excessive seepage of surface water into the shallow aquifers through unlined canal beds of the existing canals. These mounds are shedding water from their eastern flanks to river Ganga and from western flanks to river Kali. The shallow aquifer system in this part is very much receptive of massive seepage leading to the formation of mounds. However, the ground flow direction is departing from the area of Alipur and Neknampur villages, where ground water trough has been developed due to the concentration of shallow and deep tubewells without any proper well spacing. Since the decline in water levels has already started due to the excessive withdrawal of groundwater, the situation may aggrevate in future with the increasing withdrawal of ground water. Hence further study is required to estimate the rate of annual decline of general water table in the area. The river Kali appears to be influent in nature in southwestern end of the area as it is feeding the groundwater bodies.

The piezometric surface map from the piezometric levels recorded in the existing tubewells in the area were prepared for seasons of pre-monsoon (June-1989) and the flow pattern has been indicated (Plate XXXIII).

The piezometric map of the area for the summer 1989 indicates that generally confined groundwater is flowing, in the eastern margin towards river Ganga and from the Kali river towards eastern margin, in the study area.
The average hydraulic gradient is about 0.6 m/km in the eastern part and is about 0.8 m/km in the western part of the study area.

The average hydraulic gradient of the piezometric surface is about 0.4 m/km in the eastern part of the area whereas it becomes 0.5 m/km in the western part of the area. In general a shift in the piezometric surface contours has taken place which clearly shows the recharge in the rainy season.

A comparison of the water levels and the piezometric contour map of the area indicate that the flow of the ground water in both the cases is almost in the same direction. At places the hydraulic gradient of piezometric surface is slightly steeper than the hydraulic gradient of the water table, this may be due to the continuous withdrawal of groundwater mainly from the main aquifer, the piezometric levels of which were considered during the study.

On the whole it can be seen that there is no significant difference between the levels of water table and piezometric surface in the area. This may be because of the semi-permeable nature of the clay-calC-concretion beds separating both the aquifer through which hydraulic connection is established. As such both the aquifers maintain hydraulic equilibrium under non-pumping conditions, and maintain almost the same level.

**GROUND WATER BEHAVIOUR**

**HYDROGRAPH:**

The water levels of the key observation wells in the study area have been utilized for preparing continuous hydrographs of
the wells with a view to study their behaviour with respect to time and space and their dependence to natural phenomena. A perusal of these hydrographs indicate that the water level variation is cyclic and sinusoidal as a function of time and space. The water levels are deepest during the month of June and shallowest during the month of November. From mid November onwards there is a sharp decline in water level till January and from January onwards the recession in water level is slow indicating natural ground water discharge through steady sub-surface outflow, in harmony with regional groundwater movement.

From the above discussion it will be seen that the water level has a rising and declining trend with respect to time and factor which causes such rise in water levels i.e. input source of ground water in the form of rainfall.

WATER LEVEL FLUCTUATION

The water level fluctuations are represented by way of countours of water level difference of pre and post monsoon water levels for the period of June and November, 1989.

A perusal of the water level fluctuation map (Plate XXXIV) shows that the study area is demarcated by four water level fluctuation zones with the interval of 0.2 m. The study further shows that in general the fluctuation varies from 0.6 m to 0.8 m in the western margin of the area i.e. near Kali river whereas the general water level fluctuation of 0.4 m to 0.6 m in the eastern margin of the area i.e. near Ganga river. However, the maximum water level fluctuation was recorded from the Nurpur village and
the minimum fluctuation was recorded from the Ganga Khadir area. The area covered by these fluctuation zones are as follows:

TABLE 9.0 PRE MONSOON AND POST MONSOON, FLUCTUATION (1989)

<table>
<thead>
<tr>
<th>Formation</th>
<th>No. of wells</th>
<th>0.4</th>
<th>0.4-0.6</th>
<th>0.6-0.8</th>
<th>0.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allavium</td>
<td>158</td>
<td>29</td>
<td>66</td>
<td>45</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18.35%</td>
<td>41.78%</td>
<td>28.48%</td>
<td>11.39%</td>
</tr>
</tbody>
</table>

A perusal of the table indicates that the number of wells falling in different water level fluctuation range (June 89) to (Nov. 1989). It may be seen that 18.5% of wells recorded in the water level fluctuation range of less than 0.4 m, 41.78% of wells in water level fluctuation of 0.4 m to 0.6 m, 28.48% of wells in the water level fluctuation range of 0.6 to 0.8 m and 11.3% of wells recorded in the water level fluctuation range of more than 0.8 m.

The little change in the fluctuation is attributed to the scanty and sporadic rainfall during 1989 monsoon season. The study further shows that the upland areas shows greater water level fluctuation than low land areas.

From the above discussion it would be apparent that these high fluctuation areas are also the areas of high relief with minor local variation at places. As revealed from the Groundwater movement that these upland tracts are the groundwater recharge area from where the groundwater moves towards Ganga and Kali rivers or down the regional gradient in its respective directions.
VARIATION IN AVERAGE WATER TABLE AND MONTHLY RAINFALL

AT HAPUR, KALI-GANGA SUB-BASIN

DISTRICT GHAZIABAD, U.P.
VARIATION IN AVERAGE WATER TABLE AND MONTHLY RAINFALL
AT GARIH MUKTESHWAR KALI-GANGA SUB-BASIN
DISTRICT GHAZIABAD, U.P.
PLATE - XXXVII

VARIATION IN AVERAGE WATER TABLE AND MONTHLY RAINFALL AT UPEHARA AND RATUPURA VILLAGES KALI-GANGA SUB-BASIN DISTRICT GHAZIABAD, U.P.

AT UPEHARA

AT RATUPURA

Rainfall in m.

Water Table Elevation in Metres

JFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASONDJFMAMJASOND

CORRELATION WITH RAINFALL

In order to study the long range trend of water levels as a function of rainfall, the hydrographs of permanent network stations situated at Hapur (Plate XXXV) and Garh-Mukteshwar (Plate XXXVI) as well as Upehara at Ratupura villages (Plate XXXVII) were selected, so as to have an overall picture of groundwater behaviour in the study area. The correlation of groundwater levels with rainfall were made from the data available since 1980 through 1989. The hydrographs of Hapur and Ratupura villages represent the upland area whereas the hydrographs of the Garh-Mukteshwar and Upehara villages represent the upland margin area.

The critical study of the hydrographs indicate that the response of water level to the rainfall and drought is quick. The ascent of the water level is also affected by the intensity and distribution of rainfall.

A perusal of the hydrographs reveal that at Hapur and at Garh-Mukteshwar there is prominent response of rainfall on the water levels. This is because in the upland area the rainfall is the only source of ground water recharge and there is continuous discharge of water. The maximum decline in water level was recorded during the month of June. A similar but considerably less response of water level was also recorded at Upehara well hydrograph station because of the addition in recharge from the high land margin to the low land area alongwith rainfall. However, the Ratupura hydrograph shows that though the rainfall effect the water level but it is not very prominent. This is because the hydrograph
well at Ratupura is situated at the upland area between the Upper Ganga canal and the Ganga river. The shallow aquifers below the canal beds are constantly being recharged through seepage from the upper Ganga canal and moreover the movement of groundwater is towards the river Ganga. Hence the effect of scanty and sporadic rainfall or drought is compensated by the excessive recharge and the seasonal fluctuation is not that well marked as it is observed at other hydrograph stations.

**PUMPING TEST ANALYSIS**

1. **Introduction**

One of the fundamental aspects of groundwater resources investigations is the determination of aquifer characteristics of permeability \( K \) and storage \( S \). The characteristics are important in determining the natural flow of water through an aquifer and its response to obstruction. Normally the determination of permeability and storage are made on the basis of data obtained from test pumping wells. Although such tests are not run exclusively for the determination of aquifer characteristics, it is essential that test programmes are designed so that they can be clearly and reliably assessed.

**INTERPRETATION AND EVALUATION OF AQUIFER CONSTANTS**

The non-equilibrium formula introduced by thesis \((1935)\), is widely used for analysing the pumping test data and for determining the hydraulic properties of an aquifer. The non-equilibrium formula is:
\[ s = \frac{Q}{4\pi T} \wedge (u) \ldots \ldots (1) \]

\[ s = \left[ -0.5772 - \log u + u - \frac{u^2}{2.21} + \frac{u^2}{3.31} - \frac{u^4}{4.41} \right] \]

Where \[ U = \frac{r^2 S}{4 T t} \ldots \ldots \ldots (2) \]

\( s \) = drawdown in metres in the observation well

\( r \) = distance of the observation well from pumping well in metres.

\( Q \) = rate of discharge of the well in m\(^3\)/day

\( t \) = time of pumping in days.

\( T \) = co-efficient of Transmissibility

\( S \) = Storage co-efficient of the aquifer.

The co-efficient of Transmissibility and storage can not be determined directly from eq (1) because it involves an exponential integral and two unknown coefficients, one of which occurs both in the argument of the integral and as a division of the function. Solution can be obtained by the use of a graphical method of superposition (Type curve method) devised by Theis and described by Jacob (1940).

Copper and Jacob (1946) devised a less complicated method (straight line method) for solving the non-equilibrium formula. The straight line method is popular largely because of its simplicity of application and interpretation. This method is designed especially for artesian conditions, but it may be applied
HYDROGRAPH OF DUGWELL No.1
DURING THE PUMPING OF TUBEWELL No. 27

PLATE - XXXIX

TIME

0 Hrs.  24 Hrs.  48 Hrs.  72 Hrs.  96 Hrs.

METERS

RESIDUAL DRAWDOWN IN METER

0.0

Pump Stopped

0.5

1.0
TIME DRAWDOWN PLOT OF THE OBSERVATION WELL No.1

\[ T = 1435 \text{ m}^2/\text{day} \]
\[ S = 0.000536 \]

DRAWDOWN IN METERS

\[ ds = 0.512 \text{ m} \]
TIME DRAWDOWN PLOT OF THE OBSERVATION WELL No. 3

\[ T = 1231 \text{ m}^2/\text{day} \]
\[ S = 0.0004239 \]
\[ \Delta h = 0.597 \text{ m} \]

DRAWDOWN IN METERS
successfully to tests of non-artesian aquifers under favourable circumstances. As subsurface lithology indicated that the main aquifer in the area is in semi confined conditions, first this method was attempted.

The straight line method is based on the fact that when 'u' becomes small, a plot of drawdown against the logarithm of the time after pumping started or distance from the pumped well describes a straight line. The coefficient of transmissibility is computed from the slope of the straight line over one log cycle (ds) using the formula.

\[ T = \frac{2.3 Q}{4 \pi ds} \] .......(3)

The value of the intersection of straight line on the zero drawdown axis is used to determine the coefficient of storage by the application of the formula.

\[ S = \frac{2.5 T \text{ to } r^2}{r^2} \]

The time drawdown plots for each observation well were prepared by plotting drawdowns against the logarithm of time after pumping started. (Plate Nos. XL to XLIV). Time drawdown plots of all the observation wells (except observation well No.5) indicate that after about 50 to 90 minutes of pumping the data is deviating from the straight line, and a decrease in the time - rate of drawdown is observed, indicating that later drawdown data are
influenced by geohydrological boundaries. As such the early time drawdown data was given special consideration and the hydraulic properties of the aquifer were determined from drawdown measurements made during the initial period of 40 to 90 minutes of pumping. The results are summarised in the Table 10.0 given below:

**TABLE 10.0**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Observation Well Nos. in metre</th>
<th>Distance from pumping well in metre</th>
<th>Transmissibility in m²/day (T)</th>
<th>Storage coefficient (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Well No. 1</td>
<td>91.44</td>
<td>1435</td>
<td>0.000536</td>
</tr>
<tr>
<td>2</td>
<td>Well No. 2</td>
<td>45.72</td>
<td>1339</td>
<td>0.000466</td>
</tr>
<tr>
<td>3</td>
<td>Well No. 3</td>
<td>61.0</td>
<td>1231</td>
<td>0.000424</td>
</tr>
<tr>
<td>4</td>
<td>Well No. 4</td>
<td>147.16</td>
<td>1587</td>
<td>0.000698</td>
</tr>
<tr>
<td>5</td>
<td>Well No. 5</td>
<td>332.8</td>
<td>10270</td>
<td>0.00217</td>
</tr>
</tbody>
</table>

Average excluding Well No.5

<table>
<thead>
<tr>
<th>Distance from pumping well in metre</th>
<th>Transmissibility in m²/day (T)</th>
<th>Storage coefficient (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1398</td>
<td>0.000531</td>
</tr>
</tbody>
</table>

The values of 'T' and 'S' obtained in case of observation wells 1 to 4 are quite consistent and slight variation may be due to the local variations in the thickness and texture of the aquifer. The values of 'T' and 'S' obtained at observation well No.5 are extraordinarily high and the value of storage coefficient almost falls in the range of the water table aquifer.
Theis (1930) introduced a formula for determining transmissibility from the recovery of the water level in a well after its discharge has stopped. It is based on the assumption that if a well is pumped or allowed to flow for a known period, the residual drawdown at any instant after the discharge of the well has stopped will be the same as if the discharge of the well had continued but a recharge well with the same flow had been introduced at the same point of in the flow system at the instant the discharge stopped. Hydrological and geohydrological assumptions are the same as for the non-equilibrium, formula. The formula may be rewritten as:

\[ T = \frac{2.3Q}{4\pi ds} \log_{10} \left( \frac{t}{t'} \right) \]  \hspace{1cm} (5)

Where \( 'd_1' \) = is the residual drawdown in metres.

\( t = \) is time in minutes since pumping started.

\( t' = \) is time in minutes since pumping stopped.

The value of \( \log_{10} \left( \frac{t}{t'} \right) \) can be determined graphically from the straight line by plotting values of \( s' \) against the logarithm of \( t/t' \) values. If \( ds' \) is determined over one log cycle then \( \log_{10} \left( \frac{t}{t'} \right) \) will become unity and the formula can be simply written as

\[ T = \frac{2.3Q}{4\pi ds} \]  \hspace{1cm} (6)

Where \( ds' \) is the residual drawdown over one log cycle. Residual drawdown Vs \( t/t' \) plots were prepared from the pump test data for all the observation wells as well as for the pumping
well by plotting the values of residual drawdowns against the logarithms of the respective \( t/t' \) values (Plate XLV to L).

These plots indicate that the data after the initial period of recovery was influenced by geohydrological boundaries. As such only earlier part of recovery data was considered for determining the transmissibility of the aquifer and the results are tabulated in Table 11.0 given below:

**TABLE 11.0**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Observation Well Nos.</th>
<th>Distance from the pumping well in m</th>
<th>Transmissibility in m²/day</th>
<th>Slope Intercept/( t' )</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Well No.1</td>
<td>91.44</td>
<td>1438.0</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>2.</td>
<td>Well No.2</td>
<td>45.72</td>
<td>1849.0</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>3.</td>
<td>Well No.3</td>
<td>61.0</td>
<td>1215.0</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>4.</td>
<td>Well No.4</td>
<td>137.16</td>
<td>1649.0</td>
<td>12</td>
<td>-</td>
</tr>
<tr>
<td>5.</td>
<td>Well No.5</td>
<td>332.8</td>
<td>-</td>
<td>-</td>
<td>Value could not be determined due to pumping of tube well in vicinity</td>
</tr>
<tr>
<td>6.</td>
<td>T.W. 27 (Pumping well)</td>
<td>-</td>
<td>984.5</td>
<td>25</td>
<td>-</td>
</tr>
</tbody>
</table>

Average '\( T' \) = 1427.1

The value of Transmissibility appears to be increasing with the distance from the pumping well and the values obtained by this method are tallying within the limits with the values obtained by
PLOT OF RESIDUAL DRAWDOWN VS \( \frac{t}{t'} \) OF OBSERVATION WELL No.1

\[ T = 1438 \text{ m}^2/\text{day} \]

\[ ds = 0.509 \text{ m} \]
PLOT OF RESIDUAL DRAWDOWN Vs \( t/t' \) OF OBSERVATION WELL No. 2

\[ T = 1149 \text{ m}^2/\text{day} \]

\[ ds = 0.640 \text{ m} \]
PLOT OF RESIDUAL DRAWDOWN vs. $t/t'$ OF OBSERVATION WELL No. 3

$T = 1215 \text{ m}^2/\text{day}$

$ds = 0.658 \text{ m}$
PLOT OF RESIDUAL DRAWDOWN VS. t'/t" OF OBSERVATION WELL No. 4

T = 1649 m²/day

Δs = 0.445 m
Time-drawdown plots. The large values of the slope intercept on $t/t'$ axis indicates that recharge has taken place on large scale.

Values

Based on the average of 'T' (1427.1 m³/day) and 'S' (0.0006) by the above methods, the theoretical drawdown for 3 days of pumping were calculated (Table No.12.0) using Theis non-equilibrium formula:

$$s = \frac{Q}{4\pi T} w(u) \quad \ldots \ldots \quad (6)$$

$$u = \frac{r^2 S}{4 T t}$$

$w(u)$ is the 'well function'.

<table>
<thead>
<tr>
<th>Observation</th>
<th>Distance from pumping well (in mtrs.)</th>
<th>Estimated drawdown (in mtrs)</th>
<th>Observed drawdown (in mtrs)</th>
<th>Difference (in metres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well No.1</td>
<td>91.44</td>
<td>1.68</td>
<td>1.15</td>
<td>0.53</td>
</tr>
<tr>
<td>Well No.2</td>
<td>45.72</td>
<td>1.98</td>
<td>1.63</td>
<td>0.35</td>
</tr>
<tr>
<td>Well No.3</td>
<td>61.0</td>
<td>1.86</td>
<td>1.47</td>
<td>0.39</td>
</tr>
<tr>
<td>Well No.4</td>
<td>137.16</td>
<td>1.50</td>
<td>0.80</td>
<td>0.70</td>
</tr>
<tr>
<td>Well No.5</td>
<td>332.8</td>
<td>1.13</td>
<td>0.25</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Earlier it was stated that after the initial period of pumping the time rate of drawdown is decreasing indicating the influence of some geohydrological boundary. Table (12.0) shows that the theoretically estimated drawdowns based on the average value of 'T' and 'S' of the aquifer from Theis Non-equilibrium formula are differing from the observed drawdowns indicating the
effect of a geohydrological boundary on the drawdown data, after the initial period of pumping for about 40-90 minutes. It can also be observed, that the percentage difference of drawdown affected by the geohydrological boundary is felt at all stations, but, increases with the distance of the observation well from the pumping well. This observation leads to the idea that some uniform change has taken place after the introduction of pumping in the entire area influenced by the discharging well.

Decrease in the time-rate of drawdown after the initial period of pumping may be attributed to:-

i) Partial penetration of the well.

ii) Due to the delayed gravity drainage under water table conditions.

iii) The cone of depression encountering a continuous infinite recharge boundary like a surface water body or a very highly permeable old river channel etc.

or v) The effects of leakage through semi-confining bed.

The first factor of partial penetration can be eliminated in this case, as in the tubewell No.27 (Pumping well) the full thickness of the aquifer was screened.

Under-water table conditions, water is derived from storage by the gravity drainage of the interstices above the cone of depression, and by compaction of the aquifer, and by the expansion of the water itself, as pressure on the groundwater is reduced.

Gravity drainage of water through stratified sediments is not immediate, and unsteady flow of water towards a well in an
unconfined aquifer is characterized by slow drainage of interstices. As such a decrease in the time-rate of drawdown occurs after an initial period of pumping when water is released instantaneously from storage. The pressure of interstratified beds of silt or clay accentuates the delay in the release of water from storage and also increases the variability of 'S'. Under such conditions storage increases at a diminishing rate with the time of pumping and decreases with distance. Contrary to this observation in case of time drawdown curves of the observation wells in this case, the value of 'S' has decreased with time and increased with distance, as at observation well 5 which is the farthest one, the value of 'S' was the highest.

Secondly, under the above conditions the value of 'S' calculated from the first segment of the time-drawdown curves should fall in artesian range and the value of 'S' calculated from the last segment should fall in water table conditions. But, in case of the time drawdown curves of the observation wells in this cases, the value of 'S' calculated from both the segments falls in artesian range.

The above observations rule out the possibility of the decrease in time rate of drawdown after the initial period of pumping due to delayed gravity drainage.

During the trial analysis of the pump test data, the possibility of the cone of depression encountering an infinite recharge boundary, like a marine water body or a highly permeable
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF

Analysis By Modified Non-Equilibrium Type Curve Method

For Two Well System

(STALLMAN R. W.

\[ T = 1165 \text{ m}^2/\text{day} \]
\[ S = 0.000776 \]
\[ TP = 41.44 \text{ meters} \]
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF
OBSERVATION WELL No. 3
Analysis By Modified Non-Equilibrium Type Curve Method
For Two Well System (STALLMAN R.W.)

\[ T = 1132 \text{ m}^2/\text{day} \]
\[ S = 0.000485 \]
\[ r_p = 609.6 \text{ m} \]
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF

OBSERVATION WELL No. 4

Analysis of Modified Non Equilibrium Type Curve Method
For Two Well System (STALLMAN R.W.)

\[ T = 1132.0 \, \text{m}^2/\text{day} \]
\[ S = 0.000963 \]
\[ r_p = 480 \, \text{m} \]
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF
OBSERVATION WELL No. 5
Analysis By Modified Non-Equilibrium Type Curve Method
For Two well System

\[ T = 5685 \text{ m}^2/\text{day} \]
\[ S = 0.003242 \]
\[ r_p = 1164.94 \text{ m} \]
old river channel, after the initial period of pumping was verified. Time drawdown curves of all the observation wells were matched with Stallman's (1952) Modified Non-equilibrium type curves for two well systems (Plate No.LI - LV) and the values of 'T' 'S' and (distance to the image well) were calculated from the formulae:

\[
T = \frac{Q}{4 \pi ds} \quad w(u) \quad \ldots (7)
\]

\[
S = \frac{4 \pi t U_p}{r_p^2}
\]

Where \( r_p \) = is the distance of the observation well from pumping well

\( U_p \) = is the value of \( u \) at the chosen point on the matching modified type curve.

\[
r_i = K r_p \quad \ldots (9)
\]

Where \( r_i \) = is the distance from the image well

\( K \) = is the ratio of the \( r_i \) and \( r_p \) for which the matching modified type curve was prepared.

The values of 'T' and 'S' and 'r_i' obtained from the above analysis are tabulated in Table No. 13.0.
TABLE 13.0

<table>
<thead>
<tr>
<th>Observation Well No.</th>
<th>Distance from the pumping well in Metres</th>
<th>Transmissibility in m²/day</th>
<th>Storage coefficient</th>
<th>Distance from the image Well in Metres</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>W. 1</td>
<td>91.44</td>
<td>1165.0</td>
<td>0.000776</td>
<td>640.0</td>
<td>-</td>
</tr>
<tr>
<td>W. 2</td>
<td>45.72</td>
<td>1093.0</td>
<td>0.000596</td>
<td>548.64</td>
<td>-</td>
</tr>
<tr>
<td>W. 3</td>
<td>61.0</td>
<td>1132.0</td>
<td>0.000485</td>
<td>609.90</td>
<td>-</td>
</tr>
<tr>
<td>W. 4</td>
<td>137.16</td>
<td>1132.0</td>
<td>0.000963</td>
<td>480.0</td>
<td>-</td>
</tr>
<tr>
<td>W. 5</td>
<td>332.8</td>
<td>5685.0</td>
<td>0.003241</td>
<td>-</td>
<td>May be acting as a boundary</td>
</tr>
</tbody>
</table>

Average excluding Observation well No.5

1130.5 0.0007015

Because of the high 'T' and 'S' value obtained at observation well No.5 it is assumed that this itself is acting as a recharge boundary. But the values of 'r1' calculated should have been higher for the wells away from this.

The value of 'r1' for observation well 5 (1170.43 m) is too high and actually this value must have been the minimum one, if a boundary is assumed close to this.

However, assuming the possibility of a recharge boundary near observation well 5, theoretical drawdowns were estimated by the short out graphical method devised by C.V. Theis (1960) taking the average values of T (1339 m²/day and S 0.000068) by all the three methods and the results are given in the table 14.0.
TABLE 14.0

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Observation Well No.</th>
<th>Distance from the pumping well in Mtrs.</th>
<th>Estimated drawdown in Mtrs.</th>
<th>Observed drawdown in Mtrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Well No. 2</td>
<td>45.72</td>
<td>1.176</td>
<td>1.636</td>
</tr>
<tr>
<td>2.</td>
<td>Well No. 4</td>
<td>137.16</td>
<td>0.572</td>
<td>0.8</td>
</tr>
<tr>
<td>3.</td>
<td>Well No. 5</td>
<td>332.84 (Assumed as Boundary)</td>
<td></td>
<td>0.266</td>
</tr>
</tbody>
</table>

The above table indicates that the estimated drawdowns assuming a recharge boundary at observation well 5 are far different from the observed drawdowns.

Earlier it was shown that (Table No. 14.0) the difference in the estimated drawdown by Theis Non-equilibrium formula and that of the observed drawdown was increasing uniformly with distance from the pumping well. Had it been the effect of a line source recharge boundary as assumed, the cone of depression due to the recharge boundary should have been affected and the magnitude of such an effect should have decreased with increasing distance from the boundary. But the observations made are contrary to this.

The above discussion eliminates the possibility of an infinite line source recharge boundary near the observation well 5. The other possible line source recharge boundary is due to the encountering of the cone of depression by any surface water body.
This possibility was ruled out as the two major surface water bodies i.e. river Kali and Ganga canal are relatively quite far away (4.13 km) from the pumping well. The cone of depression intercepting these boundary sources for the period of pumping introduced, rules out the scope of taking into consideration such a boundary sources for the period of pumping introduced, rules out the scope of taking into consideration such a boundary effect. This is all the more so, based on the average value obtained for 'T' being not of a very high magnitude.

The value of 'T' and 'S' estimated from the modified non-equilibrium type curves are similar to the values obtained by the other methods. This may be as apparent coincidence as there is a definite effect of recharge to the cone of depression as revealed by the time drawdown curves.

As the first three factors assumed, as the reasons for the decrease in the time-rate of drawdown after the initial period of pumping are ruled out, (as revealed by the above discussion) the pumping test data was analysed for leaky aquifer conditions in the area is inferred through the lithology and sub-surface correlation of the aquifers.

Leaky artesian conditions are usually encountered when a artesian aquifer is overlain and/or underlain by deposits (confining beds) which impede or retard the vertical movement of groundwater when the pressure head of piezometric surface is lowered by pumping, the aquifer is not dewatered but is still completely full. The water discharged from the well is derived by
the compaction of the aquifer and the associated beds and expansion of the water itself. In such cases vertical leakage through the confining bed into the aquifer is feasible depending on the favourable but created or altered pressure heads/or piezometric surface.

If the confined sand is much more permeable than the confining clay-kankar/layer above, as in the present case the leakage can be considered as vertical and proportional to drawdown. Thus in addition to the storage and Transmissibility coefficient, a third formation constant comes into effect the analysis of such problems, called by Jacob and Hantush named the constant as leakage coefficient symbolised as $P^1/m^1$ where $P^1$ is the vertical permeability of the confining layer and $m^1$ is the thickness of the confining layer, through which leakage occurs.

Hantush and Jacob (1955) derived an equation describing the non-steady state drawdown distribution in an infinite leaky aquifer which can be expressed by the relation given below:

\[ s = \frac{Q}{4\pi T} \int_0^\infty \frac{1}{y} \exp\left(-\frac{y^2}{4B^2y}\right)dy \ldots \ldots (10) \]

\[ s = \frac{Q}{4\pi T} \int_0^\infty \frac{1}{u} \exp\left(-\frac{y^2}{4B^2y}\right)dy \ldots \ldots (10) \]

The integral $\int_0^\infty \frac{1}{y} \exp\left(-\frac{y^2}{4B^2y}\right)dy$ was written by Hantush (1956) symbolically as $w(u, r/B)$ and termed the well function for leaky artesian aquifers".
NON STEADY-STATE LEAKY ARTISIAN TYPE CURVE (WALTON, 1960)

NONEQUILIBRIUM TYPE CURVE
Eq. 10 can be rewritten

\[ s = \frac{Q}{4\pi T} w(U, r/B) \ldots (11) \]

\[ u = \frac{r^2 S}{4 T t} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (12) \]

\[ \frac{r}{B} = \sqrt{\frac{r}{T/ (P^1/m^1)}} \ldots \ldots \ldots \ldots (13) \]

**s** = Drawdown in observation well, in metres

**r** = distance from pumped well to the observation well in metres

**Q** = discharge in m³/day

**t** = time after pumping started, in minutes.

**r** = coefficient of Transmissibility.

**S** = coefficient of storage of aquifers

**P^1** = Vertical permeability of confining bed,

**m^1** = Thickness of confining bed through which leakage occurs in metres

**B** = a constant known as leakage factor equal to

\[ \sqrt{\frac{T}{P^1/m^1}} \]

**Non-Steady State Time-Drawdown Type Curve Methods.**

Heintush (1955) gave values of \( w(u, r/B) \) in terms of the practical range of \( u \) and \( r/B \) values of \( w(u, r/B) \) were plotted against values of \( 1/u \) on logarithmic paper and a family of leaky artesian type curves were constructed by W.C. Walton (1962)
LOGARITHMIC TIME DRAWDOWN DATA FLOT OF OBSERVATION WELL No. 1
ANALYSIS BY NON STEADY STATE LEAKY ARTESIAN TYPE CURVE METHODE (WALTON, 1960)

\[ T = 935.0 \text{ m}^2/\text{day} \]
\[ S = 0.00066 \]
\[ \frac{P}{P_0} = 10.001 \text{ LPD/m}^3 \]

DRAWDOWN IN METERS

MATCHING TYPE CURVE

TIME IN MINUTES (t)
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF OBSERVATION WELL NO. 2
ANALYSIS BY NON STEADY STATE LEAKY ARTESIAN TYPE CURVE METHOD (WALTON, 1960)

\[ T = 952.6 \, \text{m}^2/\text{day} \]
\[ S = 0.000681 \]
\[ \frac{p}{m^1} = 9.61 \, \text{LPD/m}^3 \]

DRAWDOWN IN METERS

TIME IN MINUTES (t)

MACHING TYPE CURVE

0.15(t/\beta)
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF OBSERVATION WELL No. 4

( WALTON, 1960 )

\[ T = 1084 \text{ m}^2/\text{day} \]
\[ S = 0.000615 \]
\[ \frac{p_1}{m^1} = 8.8 \text{ LPD/m}^3 \]

DRAWDOWN IN METERS

TIME IN MINUTES

Matching Type Curve

0.04 \( r/b \)
LOGARITHMIC TIME DRADOWN DATA PLOT OF OBSERVATION WELL No. 3
ANALYSIS BY NON STEADY STATE LEAKY ARTESIAN TYPE CURVE METHOD

\[
T = 916.2 \, \text{m}^2/\text{day} \\
S = 0.000687 \\
P_1 = 9.87 \, \text{PD/m}^3 \\
\frac{1}{m} \\
0.2 \, (r/8)
\]

Matching
Type Curve
LOGARITHMIC TIME DRAWDOWN DATA PLOT OF OBSERVATION WELL No. 5

(Walton, 1960)

\[ T = 7345 \text{ m}^2/\text{day} \]
\[ S = 0.0026 \]
The time drawdown field data curve of each observation well, plotted on logarithmic paper of the same scale as the type curves (Plate Nos. LVII to LXI) superposed on the family of leaky artesian type curves, keeping the W (w,r/B) axis parallel with the 's' axis and the 1/u axis parallel with 't' axis. A point at the inter-section of the major axis of the leaky artesian type curve to be selected and marked on the time drawdown field data curve (The point may also be selected anywhere on the type curve). The co-ordinates of this common point (match point), s, 1/uW (u,r/B) and t are substituted in the equations 11 and 12 to determine the coefficients of Transmissibility and Storage. The value of $P^1$ is determined by noting the value of r/B used to construct the particular leaky artesian type curve found to be analogous to the time drawdown field data curve. The value of r/B of the selected type curve is substituted in eq. 13 and $P^1$ is computed.

Steady State Distance-Drawdown Type Curve Method:

Hantush (1956) pointed out that the steady state distribution of drawdown caused by pumping a well at a constant rate from leaky artesian aquifer is obtained from eq. 10 by letting (t) approaches infinity.

The steady state equation is as follows:

$$s = \frac{Q}{2\pi T} Ko (r/B) \quad \ldots \ldots \ldots (14)$$

$$\frac{r}{B} = \frac{r}{\sqrt{T/(P^1/W^1)}} \quad \ldots \ldots \ldots (15)$$

Where $Ko (r/B) =$ modified Bessel function of the second kind and zero order.
LEAKY STATE ARTESIAN TYPE CURVE (WALTON, 1960)

\[ S = \frac{229 Q K_0 (r/B)}{r^2} \]

\[ p^1 = \frac{Tm^1 (r/B)^2}{r^2} \]
DISTANCE DRAWDOWN GRAPH FOR THE LONG DURATION PUMP TEST
ON TUBEWELL No. 27 (WALTON, 1960)

\[ T = 761.4 \text{ m}^2/\text{day} \]
\[ P = 115.2 \text{ LPD/m}^2 \]
\[ \frac{p}{m^3} = 8.4 \text{ LPD/m}^3 \]

STEADY STATE LEAKY ARTESIAN TYPE CURVE
A steady state leaky artesian type curve is prepared by plotting values of \( K_0 (r/B) \) against values of \( r/B \) on logarithmic paper (Plate No. LVII to LXI) by W.C. Walton (1960). The drawdowns of the observation wells after 3 days of pumping were plotted against the respective values of \( r' \) (plate No.LXIV) on a logarithmic paper of the same scale as the type curve, with \( r' \) as abscissa and \( s \), as the ordinate to describe a distance drawdown field data curve. A match of the two curves is obtained by superposing, the steady state leaky artesian type curve over the distance-drawdown field data curve, keeping the axis of the two graphs parallel. Match point coordinates \( K_0 (r/B) r/B, s \) and \( r \) are substituted into equations 14 and 15 to determine \( T \) and \( P' \). The coefficient of storage cannot be computed by use of this steady state leaky artesian type curve because under such conditions of flow, the entire yield of the well is assumed to have been derived from leakage source only.

The values of \( T, S \) and \( P' \) obtained by both the methods for all the observation wells are summarised in Table I5-0.

In order to check the reliability of the above values, the theoretical drawdowns for 3 days of pumping at different distances are calculated from the average values of \( T, S \) and \( B \), obtained from the above analysis.
BASE PRESSURE CURVE
AFTER 3 DAYS OF PUMPING OF LSGED TUBE WELL No. 27

DISTANCE FROM THE AXIS OF THE WELL

DRAWDOWN IN METRES

0 2 4 6 8

152.2 804.8 487.2 609.6 762.0 914.4 1066.8 1219.2

METER

STATIC PIEZOMETRIC SURFACE
<table>
<thead>
<tr>
<th>Observation Well Nos.</th>
<th>Distance of the observation well from pumping well (in m.)</th>
<th>Transmissibility in m²/day</th>
<th>Storage coefficient</th>
<th>Thickness of confining bed</th>
<th>P' vertical permeability in m/day</th>
<th>p'/m' Leakage coefficient</th>
<th>Remarks</th>
<th>Leakage factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>W 1</td>
<td>91.44</td>
<td>935.00</td>
<td>0.00066</td>
<td>9.14</td>
<td>91.94</td>
<td>10.01</td>
<td>1000</td>
<td>Non-steady State</td>
</tr>
<tr>
<td>W 2</td>
<td>45.72</td>
<td>952.6</td>
<td>0.00068</td>
<td>15.24</td>
<td>145.6</td>
<td>9.61</td>
<td>1000</td>
<td>-do-</td>
</tr>
<tr>
<td>W 3</td>
<td>60.69</td>
<td>916.2</td>
<td>0.00069</td>
<td>15.24</td>
<td>150.5</td>
<td>9.87</td>
<td>1000</td>
<td>-do-</td>
</tr>
<tr>
<td>W 4</td>
<td>137.16</td>
<td>1048.0</td>
<td>0.00081</td>
<td>10.66</td>
<td>94.79</td>
<td>8.80</td>
<td>1125</td>
<td>-do-</td>
</tr>
<tr>
<td>W 5</td>
<td>332.8</td>
<td>7345.0</td>
<td>0.0026</td>
<td>15.24</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Average (excluding Well No. 5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The estimated drawdown values at different distances are summarised in Table given below.

Table 16.0

<table>
<thead>
<tr>
<th>Observation Well No.</th>
<th>Distance of observation well from pumping well in Mtrs.</th>
<th>( \frac{u}{r^2 s} )</th>
<th>( \frac{r}{B} )</th>
<th>( W(\xi, \frac{r}{B}) )</th>
<th>Estimated drawdown in Mtrs.</th>
<th>Observed drawdown in Mtrs.</th>
<th>% Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>W 1</td>
<td>91.44</td>
<td>5.6 \times 10^{-4}</td>
<td>0.296</td>
<td>2.75</td>
<td>1.09</td>
<td>1.14</td>
<td>+5%</td>
</tr>
<tr>
<td>W 2</td>
<td>45.72</td>
<td>1.39 \times 10^{-4}</td>
<td>0.148</td>
<td>4.06</td>
<td>1.62</td>
<td>1.63</td>
<td>+1%</td>
</tr>
<tr>
<td>W 3</td>
<td>60.69</td>
<td>2.49 \times 10^{-4}</td>
<td>0.197</td>
<td>3.51</td>
<td>1.40</td>
<td>1.47</td>
<td>-5%</td>
</tr>
<tr>
<td>W 4</td>
<td>137.16</td>
<td>1.26 \times 10^{-3}</td>
<td>0.443</td>
<td>2.03</td>
<td>0.81</td>
<td>0.80</td>
<td>-1%</td>
</tr>
<tr>
<td>W 5</td>
<td>332.8</td>
<td>7.532 \times 10^{-3}</td>
<td>1.084</td>
<td>0.76</td>
<td>0.30</td>
<td>0.25</td>
<td>-18%</td>
</tr>
</tbody>
</table>

From the above Table No.16.0 it is clear that the estimated drawdowns (except for observation well 5) by leakage method correspond fairly well with the observed drawdown within the limits of 5% error. The observed drawdown at observation well 5 is about 18 percent lesser than the estimated drawdown. Here it may be noted that the value of "T" calculated from observation well 5
by all methods has given a very high value when compared to those of other wells. Secondly, the value of 'S' (0.0026) is close to the range of water table aquifer, whereas the values of all other wells fall in the range of artesian aquifer. This leads to the inference that at observation well 5, the cone of depression merges or enters towards the water table conditions and due to which the same was affected resulting in slowing down the rate of drawdown. This situation stimulates a recharge boundary in the analysis of the data. It is not impossible in view of the sedimentological framework of Gangetic Alluvium that such aquifers come up to the surface at short distances.

From the analysis of the data it is evident that leaky artesian conditions exist in the area and at observation well 5, the leaky artesian aquifer merges towards water table conditions and due to which the computed values of 'T', 'S' and 'P' of the aquifers evaluated leaky confined conditions are considered representative for the area and can further be utilised for studying the groundwater potentialities and functional conditions of the reservoir.

GROUNDWATER POTENTIALITIES AND REQUIREMENTS

As leaky artesian conditions are prevailing in the area, quantitative assessment of the groundwater potentialities should account for the amount of leakage into the aquifer under pumping conditions.

In order to determine the quantity of leakage, under the conditions of pumping created during the pump test the base pressure curve was plotted with the same data, keeping the time as constant i.e. 3 days of pumping and the distance as variable. The equations used are same as previously. The calculations are summarised in the Table given below:
TABLE 17.0  BASE PRESSURE CURVE DATA

<table>
<thead>
<tr>
<th>Distance r in mtr.</th>
<th>U</th>
<th>r/B</th>
<th>W(u,r/B)</th>
<th>Drawdown 'S' in mtr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.24</td>
<td>1.556x10^-5</td>
<td>0.49</td>
<td>6.27</td>
<td>2.50</td>
</tr>
<tr>
<td>30.48</td>
<td>6.220x10^-5</td>
<td>0.099</td>
<td>4.85</td>
<td>1.93</td>
</tr>
<tr>
<td>60.96</td>
<td>2.490x10^-4</td>
<td>0.197</td>
<td>3.51</td>
<td>1.40</td>
</tr>
<tr>
<td>91.44</td>
<td>5.600x10^-4</td>
<td>0.286</td>
<td>2.75</td>
<td>1.09</td>
</tr>
<tr>
<td>152.40</td>
<td>1.555x10^-3</td>
<td>0.493</td>
<td>1.85</td>
<td>0.73</td>
</tr>
<tr>
<td>228.60</td>
<td>3.500x10^-3</td>
<td>0.739</td>
<td>1.84</td>
<td>0.49</td>
</tr>
<tr>
<td>304.80</td>
<td>6.220x10^-3</td>
<td>0.985</td>
<td>0.86</td>
<td>0.34</td>
</tr>
<tr>
<td>381.0</td>
<td>9.720x10^-3</td>
<td>1.230</td>
<td>0.63</td>
<td>0.24</td>
</tr>
<tr>
<td>458.20</td>
<td>1.396x10^-2</td>
<td>1.480</td>
<td>0.43</td>
<td>0.17</td>
</tr>
<tr>
<td>1533.40</td>
<td>1.905x10^-2</td>
<td>1.723</td>
<td>0.33</td>
<td>0.13</td>
</tr>
<tr>
<td>609.60</td>
<td>2.490x10^-2</td>
<td>1.970</td>
<td>0.23</td>
<td>0.09</td>
</tr>
<tr>
<td>62.0</td>
<td>3.890x10^-2</td>
<td>2.463</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>914.40</td>
<td>5.600x10^-2</td>
<td>2.960</td>
<td>0.07</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Base pressure curve was plotted with each of the above calculated drawdowns at different distances (Plate LXIV). This denotes the pressure curve which should exist theoretically after 3 days of continuous pumping at a steady rate of 4028 m³/day, with the help of this base pressure curve, the quantity of leakage was estimated.
Quantity of leakage through a confining bed into an aquifer can be computed, from Darcy's equation:

\[ Q_c = \frac{P'}{m'} \frac{\Delta h}{A_c} \quad \ldots \ldots (16) \]

Where  
- \( Q_c \) = leakage through confining bed
- \( P' \) = Vertical permeability of confining bed
- \( m' \) = thickness of the confining bed through which leakage occurs.
- \( A_c \) = Area of confining bed through which leakage occurs
- \( \Delta h \) = The head available in metres for leakage.

The average value of \( \frac{P'}{m'} \) evaluated for the area from the pump test data is 0.089/day. The results of the calculation of leakage from the above data are summarised in Table:

<table>
<thead>
<tr>
<th>Range in mtrs.</th>
<th>Area in sq. mtrs.</th>
<th>Average Drawdown in mtrs.</th>
<th>Amount of leakage in (LFD) Cal. 2XCol. 3X leakage coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15.24</td>
<td>729.29</td>
<td>5.19</td>
<td>36670</td>
</tr>
<tr>
<td>15.24-30.48</td>
<td>2171.0</td>
<td>2.21</td>
<td>44980</td>
</tr>
<tr>
<td>30.49-60.96</td>
<td>8757.98</td>
<td>1.66</td>
<td>138400</td>
</tr>
<tr>
<td>60.96-91.44</td>
<td>14567.2</td>
<td>1/26</td>
<td>172400</td>
</tr>
<tr>
<td>91.44-152.40</td>
<td>45748.7</td>
<td>0.91</td>
<td>406800</td>
</tr>
<tr>
<td>152.40-228.60</td>
<td>9128.87</td>
<td>0.61</td>
<td>629900</td>
</tr>
<tr>
<td>228.60-304.80</td>
<td>127741.52</td>
<td>0.41</td>
<td>505800</td>
</tr>
<tr>
<td>304.80-381.0</td>
<td>164159.32</td>
<td>0.20</td>
<td>459900</td>
</tr>
<tr>
<td>381.0-457.20</td>
<td>200671.0</td>
<td>0.21</td>
<td>399900</td>
</tr>
<tr>
<td>457.20-532.40</td>
<td>200671.0</td>
<td>0.21</td>
<td>399900</td>
</tr>
<tr>
<td>533.40-606.60</td>
<td>273785.32</td>
<td>0.10</td>
<td>284600</td>
</tr>
<tr>
<td>606.60-762.0</td>
<td>655000.00</td>
<td>0.08</td>
<td>435800</td>
</tr>
<tr>
<td>762.0-914.40</td>
<td>800820.00</td>
<td>0.03</td>
<td>47620</td>
</tr>
</tbody>
</table>
Total: 4051.7 x 10^3/day
= 4051.7 m^3/day

Hence the total amount of leakage that is taking place from the top layer to the aquifer after 3 days of steady pumping is 4051.7 m^3/day is almost equal to the amount being withdrawn from the well 4028 m^3/day. This clearly indicates that the entire amount of water being withdrawn from the well is due to the leakage only from the top aquifer through the semi-confining clay-Calc-concretion to the confined aquifer screened in the walls simulating the steady state conditions of leakage.

The above observations show that relatively the confining clay-kankar (Calc concretion) bed is (when compared with other confining beds) highly permeable and is acting like a sponge. As soon as the pumping conditions are introduced in the system (screened confined aquifer), leakage starts taking place and the same is of considerable magnitude after 20 to 40 minutes of the initial period of pumping, the entire amount of water being withdrawn from the well is supplied by the leakage source and as such slows down the time-rate of drawdown in the pumping well, as well as wells, in its vicinity.

Earlier, it was stated that during the pump test, observations were also taken of the water levels in the two open shallow wells in the top aquifer (Appendix IV). A study of the data reveals that these two dug wells have almost behaved in the same way as the other observation wells tapping exclusively the main aquifer, but for the initial sag in the reaction. This confirms
the earlier expressed view that immediately after starting the pumping, the leakage starts taking place and after a few minutes it is getting stabilized, being equal to the rate of withdrawal and the confining clay kankar (calc-concretion) bed being permeable helps in bringing the two aquifers in hydraulic connection with each other.

**SPACING OF TUBE WELLS**

Under the conditions of pumping during the testing period of tubewell No.27, it was shown that the drawdown beyond 914.4 metres distance from the pumping well is negligible, so if this value is taken \( r_o \) i.e. distance where drawdown is zero or negligible. The wells have to be spaced at an interval of about 1828.8 metres apart so that no mutual interference will take place between the wells. But with this spacing of only 300m (three hundreds) tubewells are feasible.

If the tubewells are spaced closely the mutual interference effect will be very high especially in the drought periods when the tubewells have to be run continuously for months, it becomes a problem.

Analysis of the data of detailed pump test conducted on Tubewell No.27 with a number of observation wells, indicated that the leaky aquifer conditions exist in the area. It also shows further that the withdrawal from the confined (Deeper) aquifer is being compensated by leakage from the top water table aquifer. The
availability of the groundwater in the top aquifer is a limited one and during the period of heavy withdrawal i.e. during summer months water has to be taken from the confined aquifer itself. So when the leakage from the top aquifer is negligible, the aquifer below around 40.0 metres depth would behave more like a confined aquifer.