CHAPTER 5

HYDROGEOLOGY

5.1 INTRODUCTION

Ground water resource evaluation of any type requires a study of their occurrence, availability and distribution and also their behaviour and evaluation of the aquifer parameters. Parameters such as these help the hydro-geologist in quantifying the groundwater potential of an area and modelling the groundwater system. In this chapter the behaviour of the groundwater system of Madras has been analysed.

5.2 TYPES OF AQUIFERS AND TYPES OF FLOW

The ability to store, transmit and yield groundwater shows the potential of an aquifer. Most of the aquifers are of large areal extent and may be called as underground storage reservoirs. Water enters into these reservoirs either from artificial or natural recharge, it flows under the action of gravity or is pumped out from extraction structures like wells and bore holes.

5.2.1 Bounded aquifers

Many aquifers are laterally limited by boundaries in one or more directions, rendering invalid the assumption that the aquifer is of infinite areal extent. The boundaries may have either a recharging effect on the aquifer, as in
the case of a stream, or a discharging effect, as in the case of an impermeable barrier. Once the cone of depression intercepts such a boundary, it gets modified for which due consideration has to be given during analysis. The well known 'Method of images', which assumes that the boundary is effectively equal to an image of the pumped well is a simple tool for interpreting boundary conditions.

Analysis have also been carried out for types of aquifer configurations. For example, Hantush studied the conditions of flow in a wedged - shaped aquifer whose thickness varied exponentially in one direction, while remaining constant in the direction perpendicular to it.

5.2.2 Leaky aquifers

Most artesian aquifers are confined by aquicludes or aquitards which are not strictly impermeable. They may contribute significant quantities of water during a pumping test by way of vertical leakage. Analysis of leaky aquifers have been carried out by Jacob, Hantush and others. A relatively simple type - curves of the function, \( W(u,r/B) \) vs \( u \). This method not only enables the determination of 'T' and S, but also of the 'Leakage Factor' which is a function of the vertical permeability and thickness of the aquicludes. As an alternative, on inflection point method by Hantush could also be used, utilising the semilog plot of the time - draw down relationship.

In the case of a leaky aquifer, it is easy to visualise that after pumping progresses for sufficient time, their entire well discharge would be sustained by leakage from the aquicludes. This would establish a steady-state flow condition around the pumped well. Once this state is reached and more than one
observation well are available, the aquifer parameters could be computed with
the help of a type-curve method devised by Jacob. This method involves the
matching of the distance drawdown data against the type-curve of the function,
\( K_0(x) \) vs \( x \), plotted on a log-log paper. In place of this method, a semilog plot,
based on the same principle as Jacob's straight line method for ideal aquifers,
could be employed.

The theory of leaky aquifers assumes among other things, that the
quantity of water derived from storage in the semipervious layers is negligible.
In some cases this assumption may not be valid, and significant quantities of
water of solution involving the function \( H(u, B) \).

5.2.3 Water table aquifers

An important assumption made in the derivation of the Theis equation is
that water is instantaneously released for development from storage. This
assumption is practically valid in the case of confined aquifers, which yield
water through a process of elastic release. However, in the case of water table
aquifers, water is derived through a drainage of the pore spaces in the region
through which the con of depression moves. This drainage is not instantaneous
and due consideration would therefore have.

This drainage is not instantaneous and due consideration would
therefore have to be bestowed during analysis for delayed drainage. The water
table aquifer reacts to pumping in three different phases, viz., an initial short-
lived behaviour like that of an artesian aquifer an intermediate, rather
prolonged phase during which slow drainage occurs and the third phase during
which the behaviour is like that of an artesian aquifer. If at all it could be
applied only to data falling in the first and the third phases.

Detailed analysis of flow of water in a water table aquifer, giving due consideration to delayed drainage, was made based on Boulton's analysis, Prickett suggested a type-curve solution, which enables the computation of $T$, $S$ and the 'Delay Index' of the aquifer, using the function, $W(u,B)$.

Also in the case of water table aquifers if the drawdown caused is considerable the saturated thickness of the aquifer is decreased, resulting in a reduction in the magnitude of $T$. This in turn, results in an increase in drawdown and a consequent distortion in the cone of depression. Jacob analyses this problem and devised a solution by which suitable corrections could be applied to the observed drawdown and the aquifer parameters determined.

The more complex problem of a sloping water table aquifer was studied by Hantush, who devised a type-curve and on inflection point method of analysis.

5.2.4 Anisotropic aquifers

By and large, aquifers are made up of water-laid sediments and therefore as a whole, are Anisotropic. The analysis of flow in definite, homogenous, Anisotropic aquifers has been carried out by Hantush and by Papadopulos. In order to determine the parameters of such an aquifer it is necessary to have atleast three observation wells at different distances and in different directions from the pumped well. Or if the primary direction of anisotropy are known, atleast two such wells would be necessary. The drawdown data for each observation well is analyses using the type curve or the straight line method of
ideal aquifers and solved again in the form of simultaneous equation to determine the aquifer parameters as well as the primary directional of anisotropy. A similar analysis could also be carried out with the help of recovery data.

5.2.5 Coastal aquifers

Coastal aquifers are an important source of groundwater resource for an urban development in areas adjoining the sea. Coastal hydrological condition can be unconfined or confined aquifers. If the water table is lowered in unconfined aquifers or the potentiometric surface in confined aquifers by over draft results in the reduction or reversal of natural hydraulic gradient sloping towards the ocean leading to the salt water intrusion, if the aquifer is improperly mined, then the whole aquifer media gets contaminated due to salinity. The reclamation is expensive once the freshwater horizons are affected by salinity.

The value of an aquifer as a source of water greatly depends upon two characters viz.

1. its ability to store and 2. its ability to transmit.

5.2.5.1 Basic Principles

Salt water is overlain by fresh water usually in coastal areas. This is due to the difference in unit weight of freshwater (1.00 gm/cc) from saltwater (1.025 gm/cc). The boundary between the saltwater and freshwater zone is termed as freshwater interface. Due to indiscriminate extraction of freshwater, the equilibrium is disturbed and saltwater moves inland until a new equilibrium
is established which may be due to heavy rains.

Transition of fresh water into salt water may not be a sharp one but may be a diffused one due to the effects of mechanical dispersion. Cooper (1959) and Kohout (1964) have shown that in the zone of mixing the diluted sea water is less dense than the actual seawater causing it to rise and move seaward along this interface. The flow of salt water from the sea through the ocean floor, to the zone of mixing and back to the sea take place in the form of a cyclic flow.

The flow within the freshwater region is modified by inland changes such as recharge and discharges which causes the shift of the interface.

5.3 BEHAVIOUR OF THE GROUNDWATER SYSTEM

The most important parameter to be considered in the study of groundwater problems is the water table as it gives very important information about the extent of zone of saturation, the gradient and the direction in which the groundwater moves and it also gives the nature of inflow and outflow of the system.

Water level reading of a place are easily studied with the help of maps and graphs that are prepared from the readings. Among the most frequently used are the water table contour maps, water level fluctuation, depth to water level maps, water level profiles, and well hydrographs. If the available details of well construction and aquifer geometry are precise, water level contour maps can be classified more precisely as piezometric maps, water table maps or potentiometric maps. (Davis and De Wiest, 1966). Long term water level measurements made in the wells of the area have been utilized for this study.
5.3.1 Depth to water levels

The depth to water level has a close relation to the topography, surface water bodies and rainfall. An analysis of long-term water level observations can help in deciphering the flow patterns and modifications. The 10 year water level data measured from 17 observation wells have been considered here and their location is given in figure 5.1. As the months before October and the months after November are considered to be the periods of premonsoon and post-monsoon respectively, the depth to water levels before October and after November have been taken into account for the preparation of water table contour maps and shown as Figures 5.2 and 5.3. The maps hence prepared give an indication of the relationship between recharge and discharge patterns. Using the long term water level records, of observation wells, an average value for each well has been computed. An average to all these well averages has been worked out. This is referred as the area average. The deviations in the long term average water levels of each well from this area average has been calculated. All areas coming under recharge horizon will have positive deviations. All areas coming under the discharge zone will have negative deviations. The grid-deviation water table map can be prepared using the deviation values. Figure 5.4 shows the grid deviation contours.

The depth to the water level in wells varies from 1.2 to 4.8 in post-monsoon and 3.1 to 7.92m during pre-monsoon periods.

The depth to water level varies widely in the area of study exists. The shallowest water level is encountered in Nungambakkam and the deepest one is noticed at Tondiarpet. The deep water level may be due to the excessive tapping
Figure 5.2
Figure 5.3
GRID DEVIATION CONTOURS OF GROUNDWATER TABLE

Figure 5.4
of groundwater.

5.3.2 Water level fluctuations

Water level fluctuation has been classified into four basic types by Davis and De Wiest (1966) as follows:

1. Fluctuations owing to groundwater storage (recharge or abstraction)
2. Fluctuations brought about by atmospheric pressure in contact with the water surface in wells.
3. Fluctuations resulting due to deformation of aquifers and
4. Fluctuations owing to disturbance within the well, minor fluctuations are attributed to chemical or thermal change in and around the wells.

The water level fluctuation in the wells may be due to several reasons, but the long term and seasonal fluctuations are attributed to the change in the ground water storage. When the recharge exceeds discharge a rise in the water table is noticed whereas a fall may indicate the dominance of discharge over recharge due to over exploitation and base flow. The rate and magnitude of fluctuation during any period portrays the net effect of the recharge or discharge during that period in relation to the inherent characteristics of the aquifer media.

5.4 AQUIFER GEOMETRY AND BOUNDARY CONDITIONS

Based on the subsurface lithology data and on the water table contour maps, the following points have been deciphered in relation to the geometry of the aquifer.
1. The depth to the basement rock is shallow along the western boundary. It is deeper along the coastline.

2. The topographic gradient of the basement rock is very steep towards the coastline. This denotes that the sedimentary beds are more nearer at the coast forming a very good groundwater reservoir.

3. The presence of charnockite layers in a few parts of the area above the coastal sediments, denotes a confined aquifer environment, in those regions.

4. The aquifer horizon is continuous and heterogeneous having a layered sequence at a few places.

5. Hydraulic gradient is flat to very gentle in the northern part of the area. Any development in extraction will reduce the hydraulic gradient further inviting the sea water.

6. The hydraulic gradient seems to be reversed at the southern part of the study area upto a distance of about 3 to 4 kms landward from the coast. This condition does not change even after the onset of monsoon. This may be due to a topographic or hydraulic trough, intensive exploitation, or a change in the aquifer hydrologic properties.

7. The aquifer thickness is more near the coastline.

8. This coastal area has a recharge zone all along the western margin.

9. The fresh groundwater flows generally from the west to the east with slight changes in flow directions near the southern and northern boundaries.

10. Flow of sea water towards the land may be anticipated along two different directions, one in the area north of Cooum river and the other in the area bordering Adayar river.
5.5 AQUIFER PARAMETERS

5.5.1 Pumping test

Pumping tests were conducted at 13 different locations around Madras City. The exploitation of groundwater in any aquifer leads to water level decline that serve to limit yields. One of the primary goals of groundwater resource evaluation must therefore be the prediction of hydraulic head (draw downs) in aquifer under proposed pumping schemes. Pumping test is one of the most useful means of not only determining the aquifer hydraulic characteristics but also in the determination of yield and draw down, specific capacity of well and in the design of extraction structures.

5.5.1.1 Extraction structures

Wells with both circular and rectangular cross sections are common in this state and most of them are of large diameter in size. These wells have the property that during the abstraction phase, most of the water is taken from storage but when the pump is switched off, water continues to flow from the aquifer to refill the well. In many cases more water is drawn from the aquifer during the recovery phase, than during pumping phase.

Large diameter wells are generally used to supply water for irrigation throughout the growing seasons of a crop. Water is pumped each day for several hours and the wells are then allowed to recover until the next day for pumping again. Depending upon the nature of subsurface formation the wells are constructed with either concrete walls or rings, almost upto the bottom of the wells from the surface. In such cases effects like seepage phase will not be seen.
As the aquifer zone is expected to be productive all along the coastal belt, the gravity drainage is faster ruling out possibility of delayed yield. Many attempts have been made to estimate the aquifer transmissivity in large diameter wells.

5.5.1.2 Field measurements

The measurements to be taken during an actual pumping test fall into two groups:

i) Pumping rate or recovery rate and

ii) Drawdown response in water level during pumping or recuperation.

Before conducting a test at least for one or two days the water level should be monitored in a well. If the trend is not expected change suddenly during this period then, pumping test can be conducted. After the completion of the recovery test also the water level could be monitored depending upon the purpose of study.

The primary features of well to be observed before conducting test are its radius, total depth, length, breadth, static water level, depth of cement lining in the well, capacity of the pump, rate of discharge and aquifer lithology.

5.5.1.3 Measurements of water levels

The water level during test is normally measured by metal lined water proof cloth tape. The following measurements have been made during the study.
i) measurements of water level before pumping.

ii) Measuring the water level at regular intervals after pumping and computing the drawdown till the end of pumping.

5.5.1.4 Time interval of water level measurements

Since water levels are expected to fall or raise faster during either the first one or two hours of the pumping phase, water level readings should be taken at brief intervals initially. The time duration between measurements has been gradually increased as the pumping period increased.

Kruseman and De Ridder (1970) proposed a range of time intervals for measurements in the pumped wells of small diameter.

<table>
<thead>
<tr>
<th>Time since pumping started (minutes)</th>
<th>Time intervals between measurements (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 50</td>
<td>5 - 10</td>
</tr>
<tr>
<td>50 - 120</td>
<td>10 - 15</td>
</tr>
<tr>
<td>120 - till shutdown of the pump</td>
<td>15 - 30</td>
</tr>
</tbody>
</table>

5.5.1.5 Discharge measurements

Amongst the arrangements to be made for an aquifer test is the control of discharge rate. It should be preferably kept constant throughout the test. Pumping tests have been conducted at 13 locations in the Madras City.
5.5.2 Computations

Walton (1987) has given 35 micro computer programs and a series of analytical and simple numerical programs to analyse flow, transport of solutes, heat in confined or leaky or water table aquifer, transmissivity and storativity with simple geometry. For the analysis of the pumping test data the program given by Walton (1987) has been used.

5.6 RESULTS

The transmissivity (T) of the aquifer media has been spatially interpolated to prepare the figure 5.6. It could be seen that

1. the aquifer transmissivity is high nearer the coastline.
2. the zone north of Cooum river shows a potential horizon for groundwater occurrence.
3. in the southern part of the study area, the aquifer transmissivity T is very low and
4. there seems to be a structural control over the groundwater conditions in the northern part of the study area.
5. The aquifer storativity is normally determined for confined aquifers and is referred as specific yield in unconfined aquifers. The aquifer storability obtained from the pumping test data interpretations has been used to prepare a spatial variation map (figure 5.7), though it is not customary in hydrological analysis. The values are mostly ranging from .01 to 0.3. This is suggestive of the range values of the unconfined aquifer environments given by Walton (1987).
Pumping Test Location Points

Figure 5.5
Figure 5.6.
5.6.1 Well coordinates

For the reproductive well coordinates different pumping rates were assigned and the drawdown were predicted. Table 5.1 shows the predicted drawdown of the aquifers.

It could be seen that the northern part of Madras Coast will be having more impact due to any amount of extraction than the southern coast. This is due to the geometry of aquifer and the aquifer parameters.
Table 5.1  Predicted drawdown

<table>
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<tr>
<th>Sl No.</th>
<th>Drawdown at 80 GPM - D</th>
<th>Drawdown at 120 GPM - D</th>
<th>Drawdown at 180GPM - D</th>
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