CHAPTER 5

DELINEATION OF AQUIFER SYSTEMS AND THEIR GEOMETRY
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5.1 BACKGROUND INFORMATION

Hydrogeological investigations were carried out in the area under Upper Yamuna project by Central Groundwater Board. To depth levels of 450 m bgl, four distinct groups of aquifers were identified, which have been designated as I, II, III and IV, respectively (Bhatnagar et al., 1982).

First aquifer is encountered to a depth of 185 m bgl. It is an unconfined to semi confined in nature. Aquifer materials are coarser in nature.

Second aquifer lies between the depth ranges of 115 to 235 m bgl. This granular zone is less coarse than the first aquifer group and occurrences of clay and kankar lenses are relatively abundant.

The third aquifer system occurs in the depth range of 255 to 329 m bgl. Fine sand comprises the aquifer material.

The fourth aquifer occurs at varying depth of 355 to 480 mbgl. At places the third and fourth aquifers merge with each other and their individual identity is lost. The fourth groups of aquifer materials are coarser in the east and gradually become finer, eventually acquiring clayey nature in the vicinity of Yamuna river. In other words, sediments are coarser along Ganga and gradually become finer towards Yamuna in the west.

These aquifers are separated from one another by poorly permeable to impermeable horizons (Bhatnagar, 1982). Each group represents a separate sedimentological environment and hence may be identified as having its own spatial and temporal characteristics (Khan, 1992). In the present investigation the first group of aquifers (I) have been studied in details.

5.2 AQUIFER GEOMETRY

The aquifer geometry is mainly controlled by the changes in the river system, depositional history of the alluvial plain and bed rock topography (Khanna, 1992). Aquifer geometry means length, width, thickness and its vertical and lateral...
extensions (Walton, 1970). On the basis of borehole data, a fence diagram and four hydrogeological cross sections were prepared.

### 5.2.1 Fence diagram

A fence diagram based on lithological logs of the bore holes drilled by the State Tubewell Department has been prepared (Figure 5.1). The fence diagram reveals the vertical and lateral disposition of aquifers, aquicludes and aquitards in the study area to a depth of 121 m bgl.

A perusal of fence diagram shows the occurrence of a single aquifer to depth of 121 m bgl. The top clay layer is persistent throughout the area varying in thickness from 5 to 45 m bgl. The top clay bed is underlain by a single granular zone which extends downwards to different depth varying up to 121 m b.g.l. The granular zone is intercalated by local clay lenses. The granular zone is composed of medium to coarse sand and gravel and form about 60 to 75% of the total formation encountered particularly in the upper central part of the study area. This area being a down faulted area due to NE-SW Muzaffarnagar fault possibly became a dominant recipient of sand than the area north of fault. Muzaffarnagar fault is an active transverse E-W fault passing through the city of Muzaffarnagar (Bhosle et al., 2007).

### 5.2.2 Hydrogeological cross section

Four hydrogeological cross sections (Figure 2.1) based on lithological logs of bore holes drilled by State Tube Well Department were prepared. These sections reveal vertical and probable lateral extension of aquifers. The lithologs are given in Appendix (II). These sections show a single layered aquifer system up to 117 m in depth.

Section AB (Figure 5.2a) is an E-W section in the upper part of the study area showing a monostatum aquifer system. The top clay layer is persistent throughout though it varies in thickness from 29.5 m in the west to 33 m in the east. Within this thick clay layer there are four sand lenses. Out of these two sand lenses, with thickness of 3 to 6 m and pinching in east and west, respectively, tend to show
Figure- 5.1 Fence diagram showing aquifer disposition in area
potential for being reasonably good aquifers. Underlying this clay bed is a granular zone which is approximately 65 m thick. In this granular zone, a number of clay lenses were encountered at variable depth. These clay lenses pinch out laterally, and therefore, the granular zone behave as a monostratum aquifer.

Section CD, (Figure 5.2b) also an E-W section south of section AB, also shows a single tier aquifer. The top clay layer is 52 m thick in the west and 55 m in the east. Here three sand bodies occur as enclaves within the clay bed. One of these sand lenses is particularly prominent and it extends from well 45 to 70. Underlying the clay layer is a potential aquifer which is approximately 50 m thick. Small clay and calc concretion lenses occur as small and impersistent enclaves within this potential aquifer.

Section EF, (Figure 5.2c) further south, represents the central part of the study area. It also shows occurrence of a single aquifer. The top clay layer is prominent throughout the area and is 42 m in thickness in the west and 35 m in the east. Small sand bodies occur in the top portion of the clay layer. Underlying this clay bed is the single bodied aquifer system down to a depth of 49 m. This aquifer is traversed by two clay horizons occurring at variable depth which give evidence of pinching out laterally. The base of the granular zone is marked by the presence of a relatively persistent clay layer having a thickness of about 5 to 10 m.

Section GH, (Figure 5.2d) the southern most section in the area of study, shows the presence of many lensoidal bodies of sand within the thick clay layer occurring on the top of the section. These lensoidal bodies, evidently, have potential for being aquifers. The thickness of clay layer varies from 25 m in the west to 56.5 m in the east. As deciphered from the section (Figure 5.2d), this clay layer shows an irregular and some what zig-zag contact with the underlying granular zone showing the effects of palaeo-topography/differential weathering. Underlying this clay bed is a single potential granular zone which extends to a depth of 54 m in the west and 38 m in the east. Minor clay lenses are present within the granular zone. There is small clay layer below the granular zone and which is thicker towards east.

From all the sections it can be inferred that the top clay layer is persistent throughout the area. These sections show that granular zone comprising fine to coarse sand, and subordinate gravel, forms about 50% by volume of the total solid phase down to 117 m bgl.
Figure- 5.2a Hydrogeological cross section along line AB
Figure- 5.2b Hydrogeological cross section along line CD
Figure- 5.2c Hydrogeological cross section along line EF
5.3 GRAIN SIZE ANALYSIS

The most common method of measuring particle size is sieving. The process of analyzing sediments for the range sizes present is called mechanical analysis. The purpose of mechanical analysis is to obtain graphic or numerical data about particle size of sediments.

The aquifer materials (sand sample) were collected from available drilling sites for grain size analysis (Table 5.1) with sampling depths ranging between 33 and 66 m bgl. Two parameters, that is, effective grain size and uniformity coefficient were evaluated.

5.3.1 Effective Grain Size (d\(_{10}\))

The term “effective grain size” was coined by Allen Hazen (1893) in his studies of filter sands. It is a particle size where 10% of sand is finer and 90% coarser. It is accepted that \(d_{10}\) is the most important parameter among those governing the permeability properties of a medium (Marsily, 1986).

The result of size analysis shows that the effective grain size of samples ranges from 0.08 to 0.17 mm indicating that the sand is fine to very fine in size (Table 5.1).

5.3.2 Uniformity Coefficient (Cu)

Pruess and Todd (1963) tried to relate the specific yield to several physical properties of the sediment samples including representative grain size diameter and a uniformity coefficient (Cu) used to describe the grading or the particle size distribution in the aquifer material. Uniformity coefficient (Cu) is average slope of grading curve between 10% and 60% size and is given by

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

Where, \(d_{60}\) is grain size of 60\% finer by weight and \(d_{10}\) is effective grain size or the grain size of 10\% finer and 90\% coarser by weight.

The values of \(d_{10}\) and \(d_{60}\) are obtained by plotting grain size against cumulative percent finer by weight on semi-log graphs in Microsoft Excel (Figures 5.3a, b, c, d, e and f). It gives an idea of grading of particle size distribution in the material. Lower value of Cu<2 indicates more uniform material or poor grading, higher values indicate well graded material and are indicative of lower porosity (Raghunath, 1987).
Figure- 5.2d Hydrogeological cross section along line GH
The result of uniformity coefficient calculation (Table 5.1) reveals a value of ≪2 at two location indicating their high porosity, while remaining samples show values of >2 indicating lower porosity.

Table 5.1: Values of effective grain size and uniformity coefficient

<table>
<thead>
<tr>
<th>Sand sample No.</th>
<th>Location</th>
<th>Depth (m)</th>
<th>Effective grain size (d10)</th>
<th>Uniformity coefficient (Cu)</th>
<th>Typical sand type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fatehpur</td>
<td>43</td>
<td>0.12</td>
<td>2.08</td>
<td>Fine sand</td>
</tr>
<tr>
<td>2</td>
<td>Fatehpur</td>
<td>60</td>
<td>0.08</td>
<td>2.6</td>
<td>Very Fine sand</td>
</tr>
<tr>
<td>3</td>
<td>Sarai</td>
<td>50</td>
<td>0.16</td>
<td>1.9</td>
<td>Fine sand</td>
</tr>
<tr>
<td>4</td>
<td>Bhaju</td>
<td>66</td>
<td>0.08</td>
<td>3.25</td>
<td>Very Fine sand</td>
</tr>
<tr>
<td>5</td>
<td>Jaula</td>
<td>33</td>
<td>0.1</td>
<td>2.7</td>
<td>Fine sand</td>
</tr>
<tr>
<td>6</td>
<td>Jaula</td>
<td>66</td>
<td>0.17</td>
<td>1.76</td>
<td>Fine sand</td>
</tr>
</tbody>
</table>

Figure- 5.3a Grading curve of the aquifer samples at Fatehpur
Figure- 5.3b Grading curve of the aquifer samples at Fatehpur

Figure- 5.3c Grading curve of the aquifer samples at Sarai

Figure- 5.3d Grading curve of the aquifer samples at Bhaju
5.4 SAND PERCENT MAP

For the sand percent map, the granular zones encountered down to 90 m have been utilized (Figure 5.4). Sand percent map has been prepared on the basis of cumulative thickness of granular zones encountered in boreholes. The area has been divided into seven sand percent zone viz. (1) <45 (2) 45- 50 (3) 50- 55 (4) 55- 60 (5) 60- 65 (6) 65- 70, and (7) >70.

The sand percent map reveals that the granular zone that attains a maximum thickness is 74% in the village Gangnauli near the left bank of river Krishni in the western part of the area. The granular material gradually increases towards both the river banks, and decreases due south towards central tract at Bhaju, Kharar, Jaula and
Figure- 5.4 Sand percent map
Palra. These findings are consistent with the inferences from the fence diagram. It can also be inferred that variations in sand percent map is more along the course of Krishni as compared to Hindon. This may be explained by the dominance of clay horizons along the river Krishni, which is also reflected by its highly meandering character. The minimum value of sand percent is 34% at Bhaju and the average value of sand percent is 55%. Fine through medium to coarse sand generally comprise the aquifer material in the area.

5.5 INFERENCE

Four tier aquifer systems are reported to occur to depth of 450 m bgl. The first group of aquifer which extends to 185 m bgl is taken for detailed study.

The fence diagram shows occurrence of single aquifer down to depth of 121 m bgl. The top clay layer is persistent throughout the area varying in thickness from 5 to 45 m bgl. The top clay bed is underlain by a single granular zone which extends downwards to different depth varying up to 121 m bgl. The granular zone is intercalated by local clay lenses. The granular zone is composed of medium to coarse sand and form about 60 to 75% of the total formation encountered particularly in the upper central part of the study area.

The sand percent map of the area ranges from 34 to 74%. The map reveals that the granular zone attains a maximum thickness near left bank of river Krishni of the lower western part of the area. It gradually increases towards both the river banks, and decreases due south towards central tract.

Fence diagram and sand percent map are mutually consistent.