ICIWRM – 2000, Proceedings of International Conference on Integrated Water Resources
Management for Sustainable Development, 19 – 21 December, 2000, New Delhi, India

# Identification of seepage points inside the additional storage reservoir - I in the industrial complex of SPIC - a case study

**N. RAMANUJAM**
P.G. Department of Geology and Research Centre, V.O.Chidambaram College, Tuticorin - 628 008, India

## Abstract

Southern Petrochemical Industries Corporation Ltd has constructed two reservoirs to meet the demand of water for industrial purpose. In recent times one of the reservoir has reported loss of water probably due to seepage.

To identify the seepage zone inside the tank, the geological, geophysical, hydrogeological and sedimentological studies were carried out. With the above aim, piezometric wells to monitor the water heads were erected and monitoring of piezometric water heads in the wells was continued for two weeks. From the observations, it is found that increase of water head ('A' type) in certain profiles and decrease of water head (Q type) in some profiles and intermediate types are also recorded in the profiles of the study area. The increase of elevation head are called as 'A' type, decrease of elevation head as K type and intermediate types as H and Q types of piezometric surfaces. 'A' type of piezometric surface are having deeper water table than the Q, K and H types.

Identification of seepage points inside the tank by utilizing the variables like piezometric water head differences in the wells, distances of the wells from the tank, depth of soil column in each wells, water level in the tank. Analysis reveals the distances of the seepage inside the tank. Higher concentration of seepage points of found within the distances of 20-30 m from the bund of the tank. 'A' types of piezometric surface are called vertical seepage and other K, H and Q types of the piezometric profiles are called as horizontal seepage. This is because the elevation of water head for the horizontal seepage, the points are identified in close proximity to the bund of the tank, whereas for the 'A' types, of piezometric wells, the seepage points are found to be distributed in the longer distances from the bund.

The percolation of water increased the intergranular pressure in the subsurface condition. Since 'A' type of piezometric surface are found in the homogenous and permeable formation, as a result the velocity of the water flow is reduced. The reduction of velocity increased the water head from the source outwardly. In the zones of K and H and Q types, the pressure heads in the piezometric wells are decreasing. The head losses are due to the internal and external friction. Seepage points identified inside the reservoir were checked physically after dewatering of the reservoir. Wherever these points were marked in the layout, there were conical shaped depressions in the sand bed. These conical depressions were created due to the seepage of water through the polypropylene sheets. The computed seepage points and actual seepage points were corroborating with each other. Authority removed the sand bed and sealed the damaged sheets, then seepage was completely stopped.

## INTRODUCTION

Southern Petrochemical Industries Corporation Ltd in Tuticorin is one of the biggest fertilizer complex in Asian Countries. To meet the summer demand of the industrial purpose, the water is stored in the Additional Storage Reservoirs (ASR) in SPIC complex. Of the two reservoirs, ASR - I has got seepage problem in recent time (Figure -1).

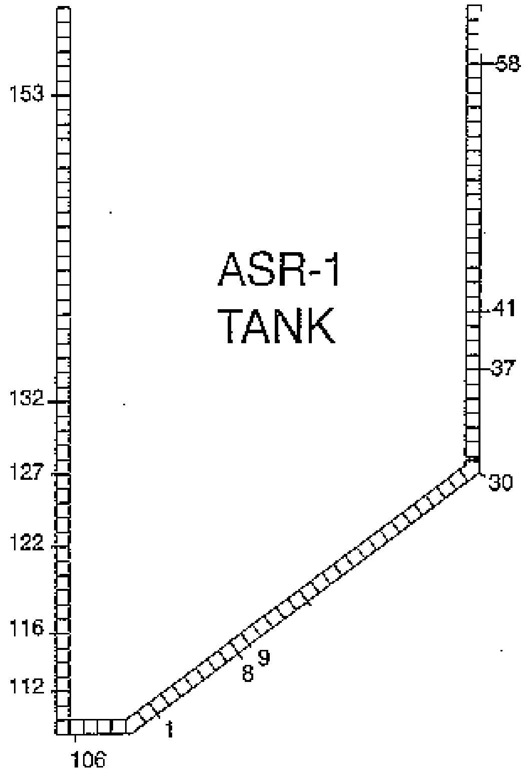



**Figure 1. ASR-1 tank.**

To locate the seepage points inside the reservoir tank, geophysical and hydraulic conductivity through piezometric surveys were carried out. The reservoir tank is located on the superficial deposits of former beach sediments of heterogeneous media of sands and pockets of clay deposits.

The length of the ASR - I is 520m. Eastern bund of the ASR - I is common to the ASR - II tank and the length is about 300m. The western bund is curved one and the length is 333m. The bottom of the reservoir is completely covered with polypropylene sheets. The average depth of the tank during the maximum water level is 3m. The width of the concrete bund is 17m. The maximum capacity of the tank is 87 MG.

## GEOPHYSICAL STUDIES AROUND THE RESERVOIR - TANK

133, Vertical Electrical Soundings (VES) were carried out, at an constant interval of 10m to study the level of water table, and subsurface lithological condition, around the ASR - I. The electrode spacing were progressively increased upto a depth of 30m, to identify the seepage zones.

The apparent resistivity values in the study area range from 418 ohm.m to 0.78 ohm. m. The fresh water zones are encountered within the depth range of 7-9m . The interphase of fresh and saline water continue upto a depth of 10m. Below that saline water zones exist.

For a comparative study, VES surveys in the salt pans and also in the adjoining reservoir ASR - II were also conducted. Preparation of iso-resistivity contour maps in the subsurface conditions around the reservoir - I, based on the apparent resistivity values helped us to delineate the various litho units, zones of fresh water saline water and diffused zones.

### Installation of piezo meters

To predict seepage pattern from the storage reservoir, sixty piezometers with average diameter of 20 cm to maximum depth of 3m below the ground level with suitable slit openings were installed, in fifteen profiles. Four piezometric wells in each profile were spaced at 2m interspacing. The water levels in the piezometers indicate the direction of ground water flow and vertical head differences.

### Leveling

With the help of the leveling instrument leveling across the embankment of the reservoir and the locations, where the piezometers installed was carried out. The leveling studies helped to compare the water level in the reservoir to the ground level and also to the water levels to the piezometric wells. Since water level in the tank maintains its horizontallity it is taken as datum line.

## POROSITY AND PERMEABILITY

To determine the porosity and permeability, the sediment samples were collected from the piezometric wells. Permeameters with various diameters were utilised to determine the permeability and porosity. (Blyth, 1965)

The porosity $$\eta = \frac{W_s - W_o \times pw}{V} \times 100$$

$V(\eta)$ = porosity
$W_s$ = Weight of saturated sand
Wo = Weight of dry sand
Pw = Density of water

and the permeability was calculated by using the formula, Q/A

$$Q = \frac{\text{Percentage of water collected}}{\text{Time taken to drop the last drop of water}}$$

A = $\pi r^2 h$
r = radius of the tube
h = height of the sand column

The sand grains collected from the piezometric wells were medium size grade. The porosity ranges from 2.25 to 44.55% and permeability values vary from 0.02 to 4.42 $cm^2$ / day (Table - 1)

**Table 1. Porocity and permeability values of sample collected.**

| WET SAND Kg | DRY SAND Kg | VOLUME ml | POROS-ITY % | WATER % | TIME hrs | sec | RADIUS cm | HEIGHT cm | AREA $cm^2$ | Q 1/day | PERMEABI $1/cm^2$*day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.415 | 1.200 | 110 | 19.51 | 36.67 | 5.59 | 20124 | 1.750 | 86.5 | 950.64 | 157.44 | 0.17 |
| 1.425 | 1.125 | 110 | 26.50 | 37.67 | 5.20 | 18720 | 1.875 | 82.0 | 965.55 | 173.86 | 0.48 |
| 1.515 | 1.200 | 111 | 28.32 | 37.00 | 4.35 | 15660 | 1.875 | 82.0 | 965.55 | 204.14 | 0.21 |
| 1.375 | 1.150 | 107 | 20.99 | 35.67 | 5.02 | 18072 | 1.875 | 78.0 | 918.45 | 170.53 | 0.19 |
| 1.315 | 1.100 | 150 | 14.30 | 42.86 | 2.28 | 8208 | 1.750 | 86.5 | 950.64 | 451.16 | 0.47 |
| 2.000 | 1.375 | 148 | 42.15 | 42.29 | 2.46 | 8856 | 1.875 | 82.0 | 965.55 | 412.59 | 0.43 |
| 1.640 | 1.150 | 110 | 44.46 | 31.43 | 2.19 | 7884 | 1.875 | 82.0 | 965.55 | 344.44 | 0.36 |
| 2.025 | 1.400 | 140 | 44.55 | 40.00 | 2.33 | 8388 | 1.875 | 78.0 | 918.45 | 412.02 | 0.45 |
| 1.365 | 1.200 | 195 | 8.44 | 55.71 | 1.42 | 5112 | 1.750 | 86.5 | 950.64 | 941.58 | 0.99 |
| 1.575 | 1.350 | 130 | 17.27 | 37.14 | 3.41 | 12276 | 1.875 | 82.0 | 965.55 | 261.40 | 0.27 |
| 1.400 | 1.300 | 148 | 12.81 | 42.29 | 3.44 | 12384 | 1.875 | 82.0 | 965.55 | 295.05 | 0.31 |
| 1.275 | 1.100 | 158 | 11.05 | 45.14 | 2.42 | 8712 | 1.875 | 78.0 | 918.45 | 447.67 | 0.49 |
| 1.340 | 1.200 | 164 | 8.52 | 54.64 | 5.57 | 20052 | 1.750 | 86.5 | 950.64 | 235.43 | 0.25 |
| 1.500 | 1.250 | 78 | 31.00 | 26.00 | 5.08 | 18288 | 1.875 | 82.0 | 965.55 | 122.83 | 0.13 |
| 1.615 | 1.300 | 170 | 18.40 | 5.67 | 2.58 | 9288 | 1.875 | 82.0 | 965.55 | 52.74 | 0.05 |
| 1.525 | 1.250 | 36 | 26.24 | 12.00 | 3.19 | 11484 | 1.875 | 78.0 | 918.45 | 90.28 | 0.10 |
| 1.315 | 1.125 | 170 | 11.15 | 48.57 | 6.29 | 22644 | 1.750 | 86.5 | 950.64 | 185.32 | 0.19 |
| 1.575 | 1.250 | 145 | 22.37 | 41.43 | 6.34 | 22824 | 1.875 | 82.0 | 965.55 | 156.83 | 0.16 |
| 1.440 | 1.275 | 210 | 7.84 | 60.00 | 6.38 | 22968 | 1.875 | 82.0 | 965.55 | 225.71 | 0.23 |
| 1.425 | 1.225 | 175 | 11.41 | 50.00 | 6.30 | 22680 | 1.875 | 78.0 | 918.45 | 190.48 | 0.21 |
| 1.225 | 1.050 | 160 | 10.92 | 45.71 | 5.41 | 19476 | 1.750 | 80.0 | 879.20 | 202.78 | 0.23 |
| 0.400 | 0.325 | 110 | 6.80 | 62.86 | 5.25 | 18900 | 0.900 | 80.0 | 452.16 | 287.36 | 0.64 |
| 0.125 | 0.125 | 46 | 10.00 | 52.57 | 2.06 | 7416 | 0.600 | 80.0 | 301.44 | 612.47 | 2.03 |
| 1.075 | 0.925 | 166 | 9.02 | 55.33 | 5.02 | 18072 | 1.750 | 80.0 | 879.20 | 264.53 | 0.30 |
| 1.365 | 1.175 | 151 | 12.56 | 43.14 | 5.39 | 19404 | 1.750 | 86.5 | 950.64 | 192.09 | 0.20 |
| 1.475 | 1.200 | 143 | 19.19 | 40.86 | 5.25 | 18900 | 1.875 | 82.0 | 965.55 | 186.79 | 0.19 |
| 1.590 | 1.375 | 120 | 17.88 | 34.29 | 5.12 | 18432 | 1.875 | 82.0 | 965.55 | 160.73 | 0.17 |
| 1.350 | 1.175 | 138 | 12.66 | 39.43 | 5.35 | 19260 | 1.875 | 78.0 | 918.45 | 176.88 | 0.19 |
| 0.410 | 0.350 | 108 | 5.54 | 72.00 | 5.30 | 19080 | 0.900 | 80.0 | 452.16 | 326.04 | 0.72 |
| 0.150 | 0.125 | 48 | 5.80 | 57.33 | 4.55 | 16380 | 0.600 | 80.0 | 301.44 | 302.40 | 1.00 |
| 0.375 | 0.325 | 93 | 5.37 | 62.00 | 5.05 | 18180 | 0.900 | 80.0 | 452.16 | 294.65 | 0.65 |
| 1.350 | 1.175 | 95 | 18.38 | 31.67 | 4.51 | 16236 | 1.750 | 80.0 | 879.20 | 168.53 | 0.19 |
| 1.290 | 1.100 | 156 | 12.16 | 52.00 | 5.36 | 19296 | 1.750 | 86.5 | 950.64 | 232.84 | 0.24 |
| 1.375 | 1.325 | 113 | 4.42 | 37.67 | 5.37 | 19332 | 1.875 | 82.0 | 965.55 | 168.36 | 0.17 |
| 1.565 | 1.425 | 153 | 9.13 | 51.00 | 5.34 | 19224 | 1.875 | 82.0 | 965.55 | 229.21 | 0.24 |
| 1.275 | 1.075 | 164 | 12.17 | 54.67 | 5.30 | 19080 | 1.875 | 78.0 | 918.45 | 247.56 | 0.27 |
| 0.175 | 0.125 | 53 | 2.42 | 70.67 | 4.23 | 15228 | 0.600 | 80.0 | 301.44 | 400.96 | 1.33 |
| 0.150 | 0.125 | 55 | 4.54 | 73.33 | 3.02 | 10872 | 0.600 | 80.0 | 301.44 | 582.75 | 1.98 |
| 0.400 | 0.375 | 90 | 2.77 | 60.00 | 3.49 | 12564 | 0.900 | 80.0 | 452.16 | 412.61 | 0.91 |
| 0.150 | 0.125 | 46 | 5.42 | 61.33 | 3.13 | 11268 | 0.600 | 80.0 | 301.44 | 470.26 | 1.56 |
| 1.315 | 1.200 | 187 | 6.14 | 762.33 | 4.35 | 15660 | 1.750 | 86.5 | 950.64 | 4205.96 | 4.42 |
| 1.425 | 1.175 | 148 | 16.86 | 49.33 | 4.30 | 15480 | 1.875 | 82.0 | 965.55 | 275.33 | 0.29 |
| 1.565 | 1.425 | 131 | 10.67 | 43.67 | 4.10 | 14760 | 1.875 | 82.0 | 965.55 | 255.63 | 0.26 |
| 1.550 | 1.325 | 125 | 17.82 | 42.00 | 44.45 | 16002 | 1.875 | 78.0 | 918.45 | 22.68 | 0.02 |
| 1.165 | 1.025 | 187 | 7.47 | 62.33 | 5.55 | 19980 | 1.750 | 86.5 | 950.64 | 269.54 | 0.28 |
| 1.675 | 1.525 | 159 | 9.42 | 53.00 | 5.27 | 18972 | 1.875 | 82.0 | 965.55 | 241.37 | 0.25 |
| 1.620 | 1.575 | 200 | 2.25 | 66.67 | 3.35 | 12060 | 1.875 | 82.0 | 965.55 | 477.64 | 0.49 |
| 1.450 | 1.325 | 214 | 5.83 | 73.33 | 3.47 | 12492 | 1.875 | 787.0 | 9266.93 | 493.35 | 0.05 |
| 0.375 | 0.350 | 100 | 2.50 | 66.67 | 4.12 | 14832 | 0.900 | 80.0 | 452.16 | 388.37 | 0.86 |
| 1.575 | 1.400 | 149 | 11.72 | 49.67 | 4.50 | 16200 | 1.875 | 82.0 | 965.55 | 264.91 | 0.27 |
| 1.515 | 1.325 | 179 | 10.59 | 59.67 | 6.18 | 22248 | 1.875 | 82.0 | 965.55 | 231.73 | 0.24 |
| 1.300 | 1.175 | 236 | 5.29 | 78.67 | 5.16 | 18576 | 1.875 | 78.0 | 918.45 | 365.91 | 0.40 |
| 1.340 | 1.225 | 205 | 5.60 | 68.33 | 6.26 | 22536 | 1.750 | 86.5 | 950.64 | 261.97 | 0.28 |
| 0.150 | 0.125 | 50 | 4.99 | 66.67 | 4.33 | 15588 | 0.600 | 80.0 | 301.44 | 368.53 | 1.28 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.150 | 0.110 | 32 | 12.48 | 42.67 | 2.35 | 8460 | 0.600 | 80.0 | 301.44 | 435.78 | 1.45 |
| 0.150 | 0.125 | 53 | 4.71 | 70.67 | 3.55 | 12780 | 0.600 | 80.0 | 301.44 | 477.77 | 1.58 |
| 1.440 | 1.175 | 120 | 22.04 | 40.00 | 5.56 | 20016 | 1.750 | 86.5 | 950.64 | 172.66 | 0.18 |
| 1.650 | 1.425 | 131 | 17.14 | 43.67 | 5.33 | 19188 | 1.875 | 82.0 | 965.55 | 196.64 | 0.20 |
| 1.440 | 1.325 | 200 | 5.74 | 66.67 | 6.00 | 22320 | 1.875 | 82.0 | 965.55 | 258.08 | 0.27 |
| 1.625 | 1.375 | 103 | 24.22 | 34.33 | 5.00 | 18000 | 1.875 | 78.0 | 918.45 | 164.78 | 0.18 |
| | | | | | | | | | | max | 4.42 |
| | | | | | | | | | | min | 0.02 |

## MONITORING OF PIEZOMETRIC LEVELS IN THE PIEZOMETRIC WELLS

Monitoring of water levels in the piezometric wells, two times a day was started from 08-03-98 to 24-03-98 and to average water levels were recorded. The reduced water levels in relation to water levels in the reservoir and also to the piezometric wells were also tabulated.

The depth of the soil column in each well above the water levels were also measured and tabulated. Construction of the piezometric surfaces connecting the piezometric wells of I, II, III and IV exhibit various types of shape, elevation and configuration. Based on the above observations, the following major types of the potentiometric surfaces were recognised, as follows. (Figure- 2a and 2b).

| | | | | |
|---|---|---|---|---|
| High | - | low | - high | H Type ⟶ |
| Low | - | low | - high | A Type ⟶ |
| Low | - | high | - low | K Type ⟶ |
| High | - | low | - low | Q Type ⟶ |

**Table 2. Details of Potentiometric surface and piezometric head differences.**

| Profile No. | (Piezometric) Potentiometric surface | Piezometric Head differences | |
|---|---|---|---|
| 153 | K and Q types | 0.20 m 0.00m | (-)0.20m |
| 132 | H and Q types | 0.67 m 0.57 m | (-)0.10m |
| 127 | A types | 0.86 m 0.66m | (+)0.20m |
| 122 | A, H and K types | 0.97m 0.80m | (+)0.17m |
| 116 | K and Q types | 0.53m 0.26m | (-)0.27m |
| 112 | K and Q types | 0.53m 0.33m | (-)0.20m |
| 106 | K and Q types | 0.35m 0.12m | (-).23m |
| 1 | A type | 1.20m 1.00m | (+)0.20m |
| 8 | A type | 1.20m 0.92m | (+)0.28m |
| 9 | A type | 1.18m 0.95m | (+)0.23m |
| 14 | A type | 1.17m 0.90m | (+)0.27m |
| 30 | K and Q types | 0.50m 0.42m | (-)0.08m |
| 37 | K and Q types | 0.68m 0.60m | (-)0.08m |
| 41 | A type | 0.85m 0.70m | (+)0.15m |
| 58 | A and K types | 0.65m 0.50m | (+)0.15m |

The potentiometric surfaces such as H, A, K and Q types were constructed on the coordinates of the extreme points of the elevation of water levels in the piezometric wells of I, II, and III at a time. For this study the coordination from the four wells were considered (Table 2). For the potentiometric difference, piezometric well - II is considered as reference point. The increase or decrease of water levels in the piezometric wells with reference to the well - I will be given (+) or (-) sign to the piezometric head differences. The overall shape of these curves are analogy with the resistivity curves of multilayed profiles. Ragunath (1987) and Karanth(1987).

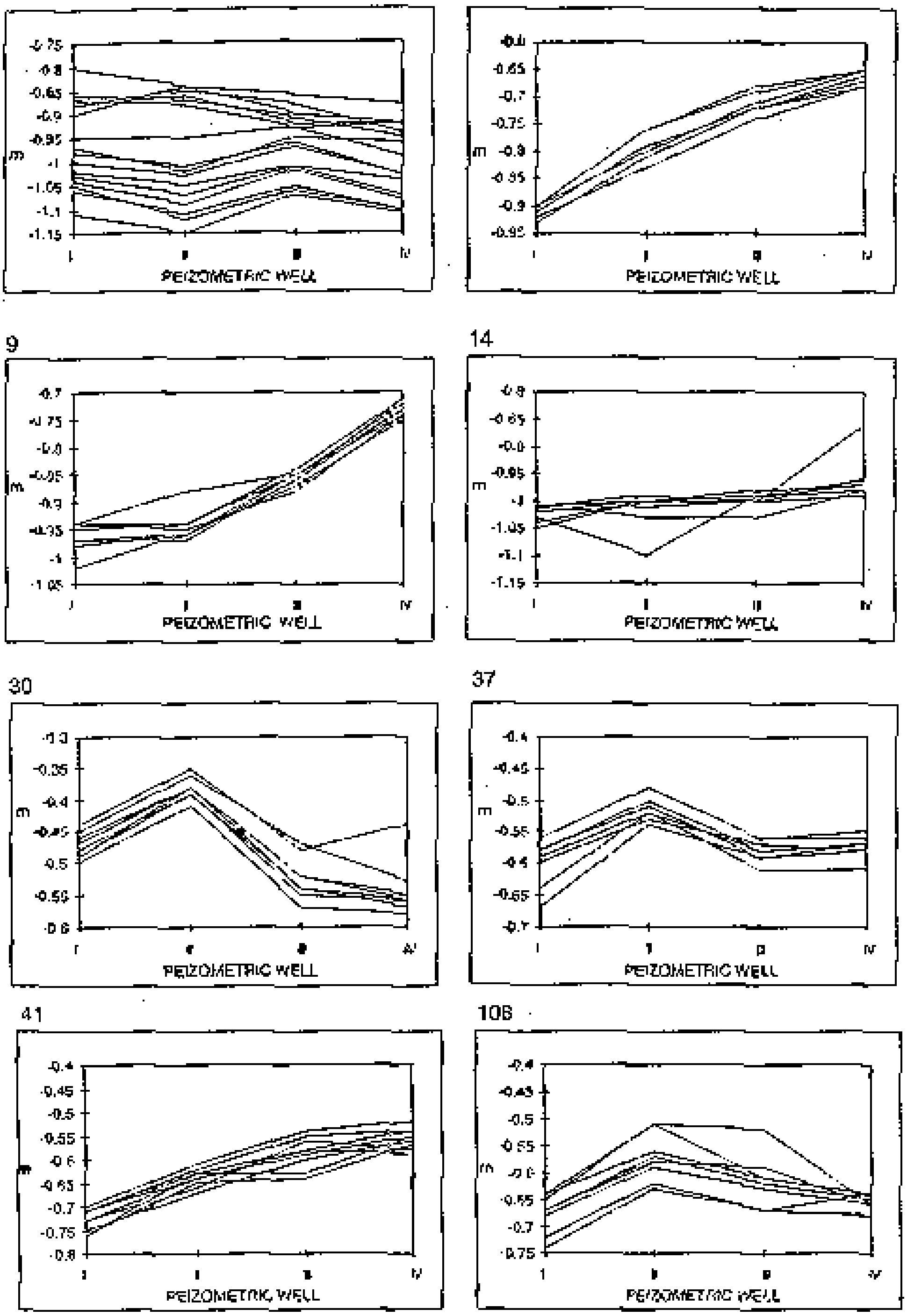



**Figure 2a. Peizometric profile at various locations around the bund of ASR-1 tank.**

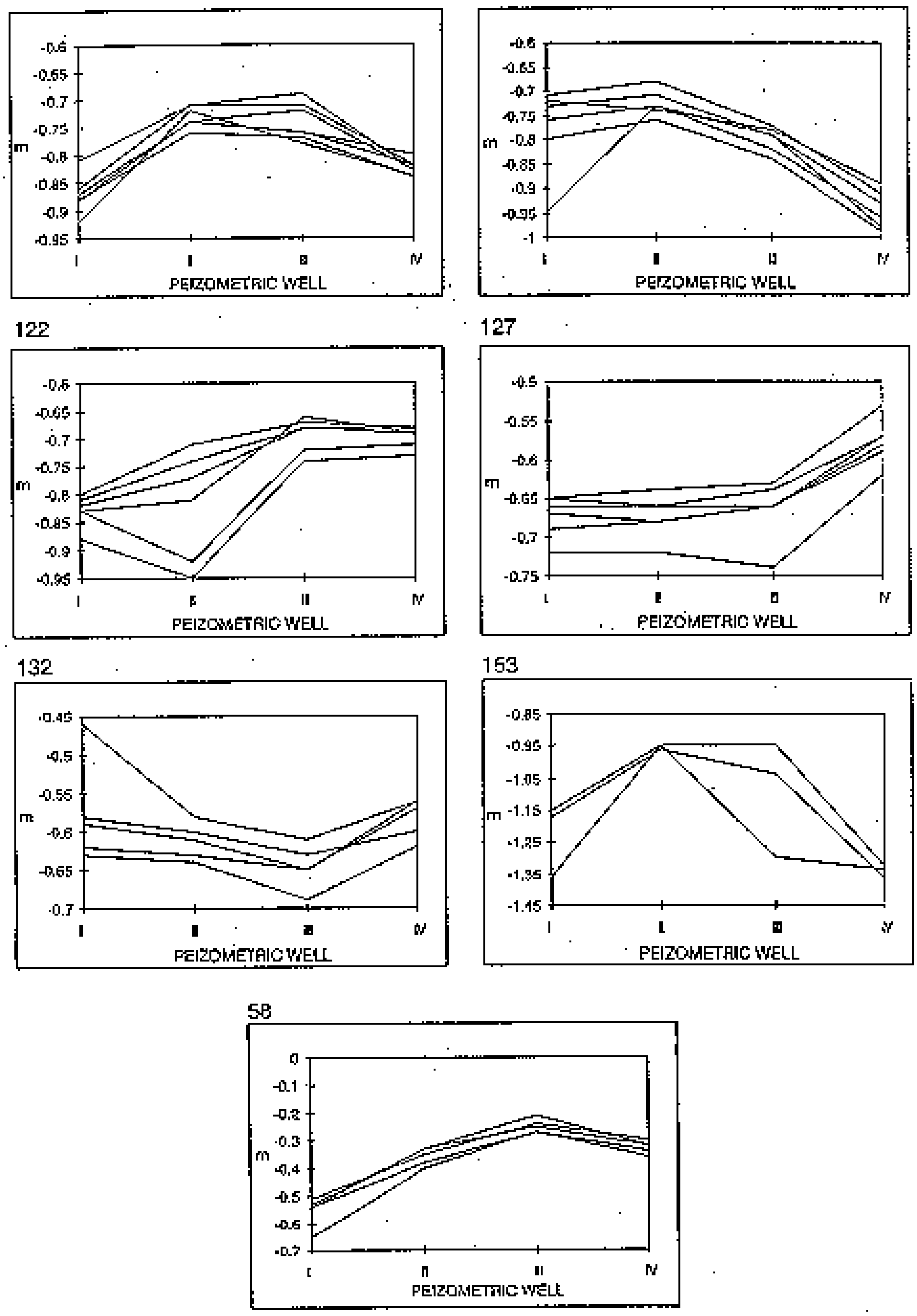



**Figure 2b. Peizometric profile at various locations around the bund of ASR-1 tank.**

The potentiometric surfaces of 'A' type exhibit depth range as the maximum of 1.20m and minimum as 0.66m. These (A types) profiles constitute about 40% of the piezometric profiles. The depth range of K and Q combinations vary from 0.60m as maximum and 0.00m as minimum. These combinations also share the major percentage as 40%. The remaining 20% of the profiles are shared by the combination of A with K; A with H and K; and H with Q are sharing the equal percentage of 6.66%. The depth ranges of these profiles are 0.65m - 0.50m; 0.97m - 0.80m; 0.20m - 0.00m respectively.

## IDENTIFICATION OF SEEPAGE POINTS INSIDE THE RESERVOIR TANK

To identify the seepage points inside the reservoir tank, the following variables were taken into consideration.

Piezometric levels in the piezometric wells ( I, II, III and IV)
The distances, width of the bund and the distances between the wells.

The depth of the soil column in each piezometric wells ( I, II, III and IV)
Average water level in the reservoir

Data are coded as A, B, C, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R, S, T. and tabulated in the form as shown,

| | | |
|---|---|---|
| Loc | - | Location |
| Depth of the soil | - | Depth |
| Distance | - | Dis |
| Ht | - | Height of water column |
| Lev | - | Level of water in the reservoir |
| YI | - | Distance of the seepage points for well I |
| YII | - | Distance of the seepage points for well II |
| YIII | - | Distance of the seepage points for well III |
| YIV | - | Distance of the seepage points for well IV |
| Aw | - | Computed water levels for wells. |

These notations are coded as follows.

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| Date | Loc | DepI | DepII | DepIII | DepIV | DisI |
| H | I | J | K | L | M | N |
| DisII | DisIII | DisIV | HtI | HtII | HtIII | HtIV |
| O | P | Q | R | S | T | |
| Lev | YI | YII | YII | YIV | AW | (Figure -3) |

To calculate the distance of the seepage points inside the reservoir tank for the wells I, II, III and IV.

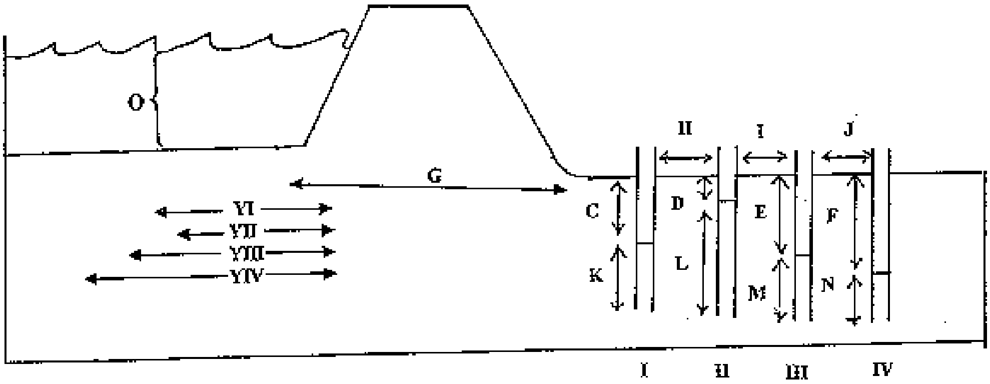



**Figure 3. Cross section showing the peizometric wells positioning and the values recorded.**

The following equation modified after Driscoll (1986)

$$P = \frac{J \times K - O \times (G+2)}{O - K}$$

$$T = \frac{O \times (G + 2 + P)}{J + P}$$

## Table 3. Values of variables considered in the analysis.

| DATE | LOC | DEP_A | DEP_B | DEP_C | DEP_D | DIST_A | DIST_B | DIST_C | DIST_D | HT_A | HT_B | HT_C | HT_D | LEV | YA | YB | YC | YD | (A) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08-Mar-98 | 1 | 0.95 | 0.96 | 0.99 | 1.01 | 17.50 | 19.50 | 21.50 | 23.50 | 0.90 | 0.84 | 0.86 | 0.88 | 0.7000 | -37.50 | -33.50 | -23.50 | -15.72 | 0.9 |
| 09-Mar-98 | 1 | 1.02 | 0.99 | 1.04 | 1.09 | 17.50 | 19.50 | 21.50 | 23.50 | 0.88 | 0.85 | 0.88 | 0.94 | 0.7380 | -44.29 | -36.68 | -23.50 | -16.79 | 0.88 |
| 10-Mar-98 | 1 | 1.05 | 1.02 | 1.05 | 1.11 | 17.50 | 19.50 | 21.50 | 23.50 | 0.86 | 0.87 | 0.91 | 0.95 | 0.6980 | -40.73 | -31.62 | -23.50 | -17.96 | 0.86 |
| 11-Mar-98 | 1 | 1.05 | 1.05 | 1.11 | 1.14 | 17.50 | 19.50 | 21.50 | 23.50 | 0.87 | 0.88 | 0.93 | 0.92 | 0.6820 | -38.01 | -30.39 | -23.50 | -17.77 | 0.87 |
| 12-Mar-98 | 1 | 1.01 | 1.01 | 0.99 | 1.2 | 17.50 | 19.50 | 21.50 | 23.50 | 0.80 | 0.84 | 0.9 | 0.92 | 0.6690 | -43.93 | -31.32 | -23.50 | -18.17 | 0.8 |
| 13-Mar-98 | 1 | 1.03 | 1.03 | 1.13 | 1.09 | 17.50 | 19.50 | 21.50 | 23.50 | 0.88 | 0.86 | 0.92 | 0.92 | 0.6650 | -35.87 | -30.32 | -23.50 | -18.28 | 0.88 |
| 14-Mar-98 | 1 | 1.16 | 1.15 | 1.16 | 1.21 | 17.50 | 19.50 | 21.50 | 23.50 | 0.95 | 0.95 | 0.93 | 0.99 | 0.6400 | -31.76 | -27.63 | -23.50 | -19.84 | 0.95 |
| 15-Mar-98 | 1 | 1.22 | 1.26 | 1.21 | 1.24 | 17.50 | 19.50 | 21.50 | 23.50 | 0.97 | 1.02 | 0.95 | 0.96 | 0.5440 | -28.61 | -25.79 | -23.50 | -20.88 | 0.97 |
| 16-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 0.98 | 1.01 | 0.964 | 1.03 | 0.5440 | -28.41 | -25.80 | -23.50 | -21.30 | 0.98 |
| 17-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 1.00 | 1.03 | 0.976 | 1.03 | 0.467 | -27.00 | -25.16 | -23.50 | -21.84 | 1 |
| 18-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 1.02 | 1.05 | 1 | 1.04 | 0.408 | -26.17 | -24.77 | -23.50 | -22.21 | 1.02 |
| 19-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 1.03 | 1.07 | 1.013 | 1.073 | 0.336 | -25.44 | -24.42 | -23.50 | -22.59 | 1.03 |
| 20-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 1.04 | 1.09 | 1.019 | 1.081 | 0.23 | -24.64 | -24.03 | -23.50 | -22.96 | 1.04 |
| 21-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 1.06 | 1.06 | 1.053 | 1.103 | 0.124 | -24.03 | -23.75 | -23.50 | -23.25 | 1.06 |
| 22-Mar-98 | 1 |  |  |  |  | 17.50 | 19.50 | 21.50 | 23.50 | 1.05 | 1.05 | 1.06 | 1.105 | 0.045 | -23.68 | -23.58 | -23.50 | -23.42 | 1.05 |
| 23-Mar-98 | 1 | 0.00 | 0.00 | 0.00 | 0.00 | 17.50 | 19.50 | 21.50 | 23.50 | 1.11 | 1.11 | 1.07 | 1.11 | 0.045 | -23.67 | -23.58 | -23.50 | -23.42 | 1.11 |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 08-Mar-98 | 8 | 0.95 | 0.80 | 0.73 | 0.71 | 16.60 | 18.60 | 20.60 | 22.62 | 0.90 | 0.76 | 0.69 | 0.65 | 0.7000 | -36.49 | -46.19 | -21.22 | -50.62 | 0.9 |
| 09-Mar-98 | 8 | 1.01 | 0.86 | 0.74 | 0.74 | 16.60 | 18.60 | 20.60 | 22.62 | 0.90 | 0.76 | 0.68 | 0.65 | 0.7380 | -40.93 | -90.38 | -22.37 | -39.39 |  |
| 10-Mar-98 | 8 | 1.04 | 0.88 | 0.81 | 0.77 | 16.60 | 18.60 | 20.60 | 22.62 | 0.91 | 0.79 | 0.72 | 0.66 | 0.6980 | -35.86 | -37.95 | -23.25 | -59.36 |  |
| 11-Mar-98 | 8 | 1.95 | 0.8 | 0.71 | 0.65 | 16.60 | 18.60 | 20.60 | 22.62 | 0.91 | 0.79 | 0.72 | 0.66 | 0.6820 | -34.64 | -35.98 | -22.98 | -84.62 |  |
| 12-Mar-98 | 8 | 1.01 | 0.91 | 0.81 | 0.77 | 16.60 | 18.60 | 20.60 | 22.62 | 0.90 | 0.80 | 0.71 | 0.65 | 0.6690 | -34.26 | -32.94 | -22.95 | -93.04 |  |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13-Mar-98 | 8 | 1.05 | 0.99 | 0.85 | 0.79 | 16.60 | 18.60 | 20.60 | 22.62 | 0.93 | 0.81 | 0.72 | 0.67 | 0.6650 | -32.71 | -31.88 | -22.86 | 243.38 | |
| 14-Mar-98 | 8 | 1.06 | 0.96 | 0.88 | 0.82 | 16.60 | 18.60 | 20.60 | 22.62 | 0.93 | 0.81 | 0.72 | 0.68 | 0.6400 | -31.49 | -30.22 | -22.78 | 9.38 | |
| 15-Mar-98 | 8 | 1.12 | 1.00 | 0.90 | 0.89 | 16.60 | 18.60 | 20.60 | 22.62 | 0.92 | 0.83 | 0.74 | 0.68 | 0.5440 | -28.44 | -26.46 | -22.68 | -14.62 | |
| 16-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 0.95 | | | | 0.5440 | | | | | |
| 17-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 0.94 | | | | 0.467 | | | | | |
| 18-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 0.98 | | | | 0.408 | | | | | |
| 19-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 1.01 | | | | 0.336 | | | | | |
| 20-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 1.03 | | | | 0.23 | | | | | |
| 21-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 1.06 | | | | 0.124 | | | | | |
| 22-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 1.08 | | | | 0.045 | | | | | |
| 23-Mar-98 | 8 | | | | | 16.60 | 18.60 | 20.60 | 22.62 | 1.11 | | | | 0.045 | | | | | |
| | | | | | | | | | | | | | | | | | | | |
| 08-Mar-98 | 9 | 1.03 | 0.92 | 0.93 | 0.83 | 17.60 | 19.60 | 21.60 | 23.60 | 0.94 | 0.88 | 0.85 | 0.72 | 0.7000 | -35.27 | -31.38 | -23.60 | 46.40 | |
| 09-Mar-98 | 9 | 1.06 | 1.05 | 0.94 | 0.81 | 17.60 | 19.60 | 21.60 | 23.60 | 0.95 | 0.94 | 0.84 | 0.71 | 0.7380 | -37.52 | -30.91 | -23.60 | -76.31 | |
| 10-Mar-98 | 9 | 1.10 | 1.08 | 0.98 | 0.88 | 17.60 | 19.60 | 21.60 | 23.60 | 0.98 | 0.96 | 0.85 | 0.74 | 0.6980 | -33.5 | -28.93 | -23.60 | 9.64 | |
| 11-Mar-98 | 9 | 1.13 | 1.11 | 1.01 | 0.86 | 17.60 | 19.60 | 21.60 | 23.60 | 0.97 | 0.97 | 0.86 | 0.71 | 0.6820 | -33.07 | -28.34 | -23.60 | 25.11 | |
| 12-Mar-98 | 9 | 1.10 | 1.06 | 1.00 | 0.88 | 17.60 | 19.60 | 21.60 | 23.60 | 0.94 | 0.94 | 0.85 | 0.73 | 0.6690 | -33.47 | -28.54 | -23.60 | -1.67 | |
| 13-Mar-98 | 9 | 1.15 | 1.14 | 1.01 | 0.91 | 17.60 | 19.60 | 21.60 | 23.60 | 0.97 | 0.96 | 0.86 | 0.73 | 0.6650 | -32.32 | -28.11 | -23.60 | -3.14 | |
| 14-Mar-98 | 9 | 1.13 | 1.15 | 1.08 | 0.94 | 17.60 | 19.60 | 21.60 | 23.60 | 0.94 | 0.95 | 0.88 | 0.74 | 0.6400 | -32.13 | -27.73 | -23.60 | -10.80 | |
| 15-Mar-98 | 9 | 1.22 | 1.23 | 1.13 | 1.01 | 17.60 | 19.60 | 21.60 | 23.60 | 1.02 | 0.96 | 0.87 | 0.75 | 0.5440 | -28.17 | -26.22 | -23.60 | -18.32 | |
| 16-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.5440 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 17-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.467 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 18-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.408 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 19-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.336 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 20-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.23 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 21-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.124 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 22-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.045 | -19.60 | -21.60 | -23.60 | -25.60 | |
| 23-Mar-98 | 9 | | | | | 17.60 | 19.60 | 21.60 | 23.60 | | | | | 0.045 | -19.60 | -21.60 | -23.60 | -25.60 | |

| DATE | LO-CA | DEP_A | DEP_B | DEP_C | DEP_D | DIST_A | DIST_B | DIST_C | DIST_D | HT_A | HT_B | HT_C | HT_D | LEV | YA | YB | YC | YD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 08-Mar-98 | 14 | 1.05 | 1.05 | 1.03 | 1.02 | 17.55 | 19.55 | 21.55 | 23.55 | 1.01 | 1.00 | 0.99 | 0.97 | 0.7000 | -32.58 | -28.22 | -23.55 | -18.36 |
| 09-Mar-98 | 14 | 1.06 | 1.06 | 1.05 | 1.05 | 17.55 | 19.55 | 21.55 | 23.55 | 1.02 | 1.01 | 1.00 | 0.99 | 0.7380 | -34.02 | -28.98 | -23.55 | -17.69 |
| 10-Mar-98 | 14 | 1.08 | 1.08 | 1.08 | 0.95 | 17.55 | 19.55 | 21.55 | 23.55 | 1.04 | 1.00 | 1.00 | 0.86 | 0.6980 | -31.71 | -28.17 | -23.55 | -14.93 |
| 11-Mar-98 | 14 | 1.09 | 1.11 | 1.1 | 1.07 | 17.55 | 19.55 | 21.55 | 23.55 | 1.01 | 1.03 | 1.03 | 0.98 | 0.6820 | -31.87 | -27.47 | -23.55 | -18.97 |
| 12-Mar-98 | 14 | 1.13 | 1.09 | 1.09 | 1.1 | 17.55 | 19.55 | 21.55 | 23.55 | 1.03 | 1.10 | 0.99 | 0.96 | 0.6690 | -30.96 | -26.65 | -23.55 | -18.95 |
| 13-Mar-98 | 14 | 1.15 | 1.13 | 1.14 | 1.07 | 17.55 | 19.55 | 21.55 | 23.55 | 1.01 | 0.99 | 1.00 | 0.96 | 0.6650 | -31.26 | -27.64 | -23.55 | -19.04 |
| 14-Mar-98 | 14 | 1.21 | 11.15 | 1.11 | 1.13 | 17.55 | 19.55 | 21.55 | 23.55 | 1.02 | 1.00 | 0.99 | 0.98 | 0.6400 | -30.29 | -27.11 | -23.55 | -19.79 |
| 15-Mar-98 | 14 | 1.25 | 1.21 | 1.19 | 1.16 | 17.55 | 19.55 | 21.55 | 23.55 | 1.05 | 1.00 | 0.98 | 0.97 | 0.5440 | -27.85 | -25.94 | -23.55 | -21.00 |
| | | | | | | | | | | | | | | | | | | |
| 14-Mar-98 | 30 | 0.32 | 0.24 | 0.35 | 0.39 | 19.45 | 21.45 | 23.45 | 25.45 | 0.44 | 0.35 | 0.48 | 0.44 | 0.6400 | -12.65 | -21.04 | -25.45 | -31.85 |
| 15-Mar-98 | 30 | 0.39 | 0.31 | 0.50 | 0.44 | 19.45 | 21.45 | 23.45 | 25.45 | 0.45 | 0.36 | 0.47 | 0.53 | 0.5440 | -2.30 | -19.54 | -25.45 | -103.16 |
| 16-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.47 | 0.38 | 0.52 | 0.55 | 0.5440 | | -18.70 | -25.45 | |
| 17-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.46 | 0.38 | 0.52 | 0.56 | 0.467 | | -14.71 | -25.45 | -15.41 |
| 18-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.48 | 0.39 | 0.54 | 0.56 | 0.408 | -48.12 | | -25.45 | -20.08 |
| 19-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.49 | 0.39 | 0.54 | 0.57 | 0.336 | -34.18 | -37.89 | -25.45 | -22.58 |
| 20-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.49 | 0.38 | 0.54 | 0.57 | 0.23 | -28.99 | -28.52 | -25.45 | -24.10 |
| 21-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.49 | 0.39 | 0.55 | 0.56 | 0.124 | -26.81 | -26.38 | -25.45 | -24.88 |
| 23-Mar-98 | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 19.45 | 21.45 | 23.45 | 25.45 | 0.50 | 0.41 | 0.57 | 0.58 | 0.045 | -25.85 | -25.70 | -25.45 | -25.28 |
| | | | | | | | | | | | | | | | | | | |
| 08-Mar-98 | 37 | 0.44 | 0.34 | 0.43 | 0.41 | 19.10 | 21.10 | 23.10 | 25.10 | 0.56 | 0.48 | 0.56 | 0.55 | 0.7000 | -5.10 | -18.74 | -25.10 | -34.43 |
| 09-Mar-98 | 37 | 0.43 | 0.37 | 0.44 | 0.44 | 19.10 | 21.10 | 23.10 | 25.10 | 0.56 | 0.48 | 0.56 | 0.56 | 0.7380 | -8.52 | -19.38 | -25.10 | -33.39 |
| 10-Mar-98 | 37 | 0.50 | 0.40 | 0.47 | 0.48 | 19.10 | 21.10 | 23.10 | 25.10 | 0.58 | 0.50 | 0.58 | 0.57 | 0.6980 | -1.44 | -18.05 | -25.10 | -36.01 |
| 11-Mar-98 | 37 | 0.54 | 0.48 | 0.49 | 0.51 | 19.10 | 21.10 | 23.10 | 25.10 | 0.61 | 0.54 | 0.59 | 0.58 | 0.6820 | 12.79 | -15.49 | -25.10 | -38.47 |
| 12-Mar-98 | 37 | 0.53 | 0.44 | 0.52 | 0.50 | 19.10 | 21.10 | 23.10 | 25.10 | 0.58 | 0.51 | 0.59 | 0.57 | 0.6690 | 4.97 | -16.68 | -25.10 | -38.62 |
| 13-Mar-98 | 37 | 0.58 | 0.47 | 0.54 | 0.52 | 19.10 | 21.10 | 23.10 | 25.10 | 0.59 | 0.52 | 0.58 | 0.57 | 0.6650 | 10.37 | -15.93 | -25.10 | -39.10 |
| 14-Mar-98 | 37 | 0.59 | 0.55 | 0.54 | 0.54 | 19.10 | 21.10 | 23.10 | 25.10 | 0.60 | 0.53 | 0.57 | 0.58 | 0.6400 | 39.90 | -13.46 | -25.10 | -46.43 |
| 15-Mar-98 | 37 | 0.69 | 0.64 | 0.64 | 0.63 | 19.10 | 21.10 | 23.10 | 25.10 | 0.52 | 0.52 | 0.61 | 0.61 | 0.5440 | -47.77 | 20.33 | -25.10 | -8.62 |
| | | | | | | | | | | | | | | | | | | |
| 08-Mar-98 | 41 | 0.63 | 0.51 | 0.44 | 0.40 | 18.00 | 20.00 | 22.00 | 24.00 | 0.70 | 0.61 | 0.54 | 0.52 | 0.7000 | ERR | -8.44 | -24.00 | -31.78 |
| 09-Mar-98 | 41 | 0.66 | 0.54 | 0.45 | 0.43 | 18.00 | 20.00 | 22.00 | 24.00 | 0.71 | 0.62 | 0.55 | 0.54 | 0.7380 | 81.43 | -11.49 | -24.00 | -31.45 |
| 10-Mar-98 | 41 | 0.68 | 0.57 | 0.52 | 0.47 | 18.00 | 20.00 | 22.00 | 24.00 | 0.71 | 0.63 | 0.58 | 0.54 | 0.6980 | ****** | -3.47 | -24.00 | -32.84 |
| 11-Mar-98 | 41 | 0.70 | 0.60 | 0.53 | 0.48 | 18.00 | 20.00 | 22.00 | 24.00 | 0.73 | 0.64 | 0.59 | 0.55 | 0.6820 | -80.83 | 8.48 | -24.00 | -34.33 |
| 12-Mar-98 | 41 | 0.72 | 0.61 | 0.55 | 0.53 | 18.00 | 20.00 | 22.00 | 24.00 | 0.71 | 0.64 | 0.58 | 0.59 | 0.6690 | -89.27 | 22.14 | -24.00 | -40.94 |
| 13-Mar-98 | 41 | 0.74 | 0.64 | 0.57 | 0.55 | 18.00 | 20.00 | 22.00 | 24.00 | 0.73 | 0.66 | 0.56 | 0.58 | 0.6050 | -43.36 | -46.00 | -24.00 | -72.40 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14-Mar-98 | 41 | 0.77 | 0.68 | 0.61 | 0.56 | 18.00 | 20.00 | 22.00 | 24.00 | 0.75 | 0.67 | 0.60 | 0.56 | 0.6400 | -47.27 | -66.67 | -24.00 | -40.00 |
| 15-Mar-98 | 41 | 0.86 | 0.72 | 0.70 | 0.61 | 18.00 | 20.00 | 22.00 | 24.00 | 0.76 | 0.63 | 0.63 | 0.55 | 0.5440 | -34.07 | -36.65 | -24.00 | 157.33 |
| 16-Mar-98 | 41 | 0.89 | 0.75 | 0.71 | 0.64 | 18.00 | 20.00 | 22.00 | 24.00 | 0.76 | 0.65 | 0.64 | 0.57 | 0.5440 | -33.82 | -33.82 | -24.00 | 12.00 |
| | | | | | | | | | | | | | | | | | | |
| 09-Mar-98 | 106 | 0.61 | 0.43 | 0.42 | 0.59 | 18.50 | 20.50 | 22.50 | 24.50 | 0.64 | 0.51 | 0.52 | 0.66 | 0.7380 | -19.56 | -22.47 | -24.50 | -27.05 |
| 10-Mar-98 | 106 | 0.61 | 0.46 | 0.54 | 0.58 | 18.50 | 20.50 | 22.50 | 24.50 | 0.65 | 0.51 | 0.61 | 0.64 | 0.6980 | -19.41 | -22.47 | -24.50 | -27.00 |
| 11-Mar-98 | 106 | 0.65 | 0.52 | 0.55 | 0.60 | 18.50 | 20.50 | 22.50 | 24.50 | 0.64 | 0.56 | 0.61 | 0.64 | 0.6820 | -19.47 | -22.31 | -24.50 | -27.02 |
| 12-Mar-98 | 106 | 0.68 | 0.54 | 0.57 | 0.63 | 18.50 | 20.50 | 22.50 | 24.50 | 0.67 | 0.57 | 0.62 | 0.65 | 0.6690 | -19.14 | -22.27 | -24.50 | -27.08 |
| 13-Mar-98 | 106 | 0.69 | 0.56 | 0.59 | 0.65 | 18.50 | 20.50 | 22.50 | 24.50 | 0.67 | 0.58 | 0.59 | 0.66 | 0.6050 | -18.94 | -22.20 | -24.50 | -27.22 |
| 14-Mar-98 | 106 | 0.72 | 0.58 | 0.62 | 0.65 | 18.50 | 20.50 | 22.50 | 24.50 | 0.68 | 0.59 | 0.63 | 0.66 | 0.6400 | -18.93 | -22.17 | -24.50 | -27.17 |
| 15-Mar-98 | 106 | 0.83 | 0.69 | 0.70 | 0.72 | 18.50 | 20.50 | 22.50 | 24.50 | 0.72 | 0.62 | 0.67 | 0.64 | 0.5440 | -17.78 | -21.93 | -24.50 | -27.19 |
| 16-Mar-98 | 106 | 0.85 | 0.72 | 0.72 | 0.78 | 18.50 | 20.50 | 22.50 | 24.50 | 0.74 | 0.63 | 0.67 | 0.68 | 0.5400 | -17.30 | -21.87 | -24.50 | -27.50 |
| | | | | | | | | | | | | | | | | | | |
| 09-Mar-98 | 112 | 0.86 | 0.66 | 0.65 | 0.76 | 19.50 | 21.50 | 23.50 | 25.50 | 0.81 | 0.71 | 0.69 | 0.83 | 0.7380 | -18.60 | -22.70 | -25.50 | -29.12 |
| 10-Mar-98 | 112 | 0.84 | 0.68 | 0.69 | 0.78 | 19.50 | 21.50 | 23.50 | 25.50 | 0.86 | 0.71 | 0.71 | 0.82 | 0.6980 | -17.24 | -22.64 | -25.50 | -29.19 |
| 11-Mar-98 | 112 | 0.86 | 0.72 | 0.73 | 0.79 | 19.50 | 21.50 | 23.50 | 25.50 | 0.87 | 0.74 | 0.72 | 0.83 | 0.6820 | -16.76 | -22.41 | -25.50 | -29.38 |
| 12-Mar-98 | 112 | 0.87 | 0.74 | 0.78 | 0.84 | 19.50 | 21.50 | 23.50 | 25.50 | 0.88 | 0.74 | 0.76 | 0.80 | 0.6690 | -16.24 | -22.38 | -25.50 | -29.13 |
| 13-Mar-98 | 112 | 0.91 | 0.73 | 0.80 | 0.85 | 19.50 | 21.50 | 23.50 | 25.50 | 0.88 | 0.74 | 0.76 | 0.82 | 0.6050 | -14.74 | -22.18 | -25.50 | -29.75 |
| 14-Mar-98 | 112 | 0.94 | 0.81 | 0.82 | 0.86 | 19.50 | 21.50 | 23.50 | 25.50 | 0.88 | 0.76 | 0.77 | 0.84 | 0.6400 | -15.65 | -22.13 | -25.50 | -29.77 |
| 15-Mar-98 | 112 | 1.02 | 0.84 | 0.91 | 0.91 | 19.50 | 21.50 | 23.50 | 25.50 | 0.92 | 0.72 | 0.78 | 0.84 | 0.5440 | -7.95 | -22.14 | -25.50 | -30.83 |
| | | | | | | | | | | | | | | | | | | |
| 10-Mar-98 | 116 | 0.72 | 0.67 | 0.76 | 0.90 | 17.00 | 19.00 | 21.00 | 23.00 | 0.71 | 0.68 | 0.77 | 0.91 | 0.6980 | -17.28 | -20.31 | -23.00 | -27.85 |
| 11-Mar-98 | 116 | 0.74 | 0.74 | 0.74 | 0.92 | 17.00 | 19.00 | 21.00 | 23.00 | 0.72 | 0.74 | 0.78 | 0.89 | 0.6820 | -17.10 | -19.91 | -23.00 | -27.67 |
| 12-Mar-98 | 116 | 0.76 | 0.75 | 0.79 | 0.96 | 17.00 | 19.00 | 21.00 | 23.00 | 0.73 | 0.71 | 0.79 | 0.93 | 0.6690 | -16.90 | -20.08 | -23.00 | -28.60 |
| 13-Mar-98 | 116 | 0.82 | 0.76 | 0.80 | 0.97 | 17.00 | 19.00 | 21.00 | 23.00 | 0.76 | 0.73 | 0.82 | 0.96 | 0.6050 | -15.99 | -19.77 | -23.00 | -31.34 |
| 14-Mar-98 | 116 | 0.84 | 0.79 | 0.89 | 1.04 | 17.00 | 19.00 | 21.00 | 23.00 | 0.95 | 0.73 | 0.82 | 0.96 | 0.6400 | -9.53 | -19.88 | -23.00 | -30.11 |
| 15-Mar-98 | 116 | 0.90 | 0.85 | 0.91 | 1.10 | 17.00 | 19.00 | 21.00 | 23.00 | 0.76 | 0.73 | 0.79 | 0.98 | 0.5440 | -15.34 | -19.54 | -23.00 | -40.00 |
| 16-Mar-98 | 116 | 0.97 | 0.90 | 0.99 | 1.16 | 17.00 | 19.00 | 21.00 | 23.00 | 0.80 | 0.76 | 0.84 | 0.99 | 0.5440 | -14.00 | -19.14 | -23.00 | -44.60 |
| | | | | | | | | | | | | | | | | | | |
| 11-Mar-98 | 122 | 0.86 | 0.76 | 0.74 | 0.71 | 17.50 | 19.50 | 21.50 | 23.50 | 0.80 | 0.71 | 0.67 | 0.68 | 0.6820 | -46.62 | -72.21 | -23.50 | -705.50 |
| 12-Mar-98 | 122 | 0.89 | 0.81 | 0.76 | 0.74 | 17.50 | 19.50 | 21.50 | 23.50 | 0.81 | 0.74 | 0.68 | 0.68 | 0.6690 | -42.48 | -42.35 | -23.50 | 98.14 |
| 13-Mar-98 | 122 | 0.94 | 0.84 | 0.78 | 0.76 | 17.50 | 19.50 | 21.50 | 23.50 | 0.82 | 0.77 | 0.68 | 0.69 | 0.6050 | -34.76 | -30.83 | -23.50 | -9.26 |
| 14-Mar-98 | 122 | 1.03 | 0.89 | 0.81 | 0.78 | 17.50 | 19.50 | 21.50 | 23.50 | 0.83 | 0.81 | 0.66 | 0.69 | 0.6400 | -36.97 | -31.03 | -23.50 | 2.10 |
| 15-Mar-98 | 122 | 1.01 | 0.96 | 0.93 | 0.89 | 17.50 | 19.50 | 21.50 | 23.50 | 0.83 | 0.92 | 0.72 | 0.71 | 0.5440 | -31.11 | -26.39 | -23.50 | -16.95 |
| 16-Mar-98 | 122 | 1.12 | 1.01 | 0.96 | 0.94 | 17.50 | 19.50 | 21.50 | 23.50 | 0.88 | 0.95 | 0.74 | 0.73 | 0.5440 | -29.85 | -26.13 | -23.50 | -17.82 |
| | | | | | | | | | | | | | | | | | | |
| 11-Mar-98 | 127 | 0.74 | 0.63 | 0.62 | 0.57 | 17.60 | 19.60 | 21.60 | 23.60 | 0.65 | 0.64 | 0.63 | 0.53 | 0.6820 | 61.65 | 8.88 | -23.60 | -32.57 |
| 12-Mar-98 | 127 | 0.76 | 0.74 | 0.69 | 0.64 | 17.60 | 19.60 | 21.60 | 23.60 | 0.65 | 0.66 | 0.64 | 0.57 | 0.6690 | 117.24 | 125.07 | -23.60 | -37.12 |
| 13-Mar-98 | 127 | 0.79 | 0.75 | 0.74 | 0.65 | 17.60 | 19.60 | 21.60 | 23.60 | 0.66 | 0.66 | 0.66 | 0.57 | 0.6050 | -67.60 | -45.60 | -23.60 | -58.17 |
| 14-Mar-98 | 127 | 0.82 | 0.79 | 0.76 | 0.69 | 17.60 | 19.60 | 21.60 | 23.60 | 0.67 | 0.68 | 0.66 | 0.58 | 0.6400 | ***** | 55.60 | -23.60 | -44.93 |
| 15-Mar-98 | 127 | 0.91 | 0.82 | 0.84 | 0.86 | 17.60 | 19.60 | 21.60 | 23.60 | 0.69 | 0.68 | 0.66 | 0.59 | 0.5440 | -38.50 | -31.60 | -23.60 | 0.05 |
| 16-Mar-98 | 127 | 0.95 | 0.92 | 0.95 | 0.81 | 17.60 | 19.60 | 21.60 | 23.60 | 0.72 | 0.72 | 0.74 | 0.62 | 0.5440 | -35.60 | -29.60 | -23.60 | -10.10 |
| | | | | | | | | | | | | | | | | | | |
| 12-Mar-98 | 132 | 0.49 | 0.60 | 0.64 | 0.58 | 18.50 | 20.50 | 22.50 | 24.50 | 0.46 | 0.58 | 0.61 | 0.56 | 0.6690 | -11.70 | -9.47 | -24.50 | -36.78 |
| 13-Mar-98 | 132 | 0.63 | 0.64 | 0.63 | 0.64 | 18.50 | 20.50 | 22.50 | 24.50 | 0.58 | 0.60 | 0.63 | 0.60 | 0.6050 | 72.30 | 217.50 | -24.50 | -266.50 |
| 14-Mar-98 | 132 | 0.65 | 0.67 | 0.72 | 0.62 | 18.50 | 20.50 | 22.50 | 24.50 | 0.59 | 0.61 | 0.65 | 0.57 | 0.6400 | 26.70 | 18.17 | -24.50 | -42.79 |
| 15-Mar-98 | 132 | 0.71 | 0.76 | 0.80 | 0.70 | 18.50 | 20.50 | 22.50 | 24.50 | 0.62 | 0.63 | 0.65 | 0.56 | 0.5440 | -53.13 | -37.15 | -24.50 | 43.50 |
| 16-Mar-98 | 132 | 0.78 | 0.78 | 0.83 | 0.81 | 18.50 | 20.50 | 22.50 | 24.50 | 0.63 | 0.64 | 0.69 | 0.62 | 0.5440 | -48.50 | -35.30 | -24.50 | -11.00 |
| | | | | | | | | | | | | | | | | | | |
| 13-Mar-98 | 153 | 0.41 | 0.25 | 0.31 | 0.63 | 19.00 | 21.00 | 23.00 | 25.00 | 0.39 | 0.27 | 0.33 | 0.65 | 0.6050 | -21.62 | 23.55 | -25.00 | -27.66 |
| 14-Mar-98 | 153 | 0.19 | 0.94 | 1.02 | 1.34 | 19.00 | 21.00 | 23.00 | 25.00 | 1.15 | 0.95 | 1.34 | 1.34 | 0.6400 | **** | 18.26 | -25.00 | -18.60 |
| 15-Mar-98 | 153 | 0.24 | 0.97 | 1.14 | 1.39 | 19.00 | 21.00 | 23.00 | 25.00 | 1.36 | 0.95 | 0.95 | 1.33 | 0.5440 | -31.89 | -13.43 | -25.00 | -21.20 |
| 16-Mar-98 | 153 | 0.46 | 1.01 | 1.33 | 1.41 | 19.00 | 21.00 | 23.00 | 25.00 | 1.17 | 0.96 | 1.04 | 1.37 | 0.5440 | -41.62 | -11.50 | -25.00 | -21.73 |
| | | | | | | | | | | | | | | | | | | |
| 18-Mar-98 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 19.25 | 21.25 | 23.25 | 25.25 | 0.51 | 0.35 | 0.24 | 0.30 | 0.408 | -21.15 | -23.79 | -25.25 | -26.59 |
| 19-Mar-98 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 19.25 | 21.25 | 23.25 | 25.25 | 0.53 | 0.33 | 0.25 | 0.32 | 0.336 | -20.86 | -23.92 | -25.25 | -26.55 |
| 20-Mar-98 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 19.25 | 21.25 | 23.25 | 25.25 | 0.54 | 0.33 | 0.21 | 0.32 | 0.23 | -20.41 | -24.10 | -25.25 | -26.37 |
| 21-Mar-98 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 19.25 | 21.25 | 23.25 | 25.25 | 0.54 | 0.38 | 0.27 | 0.34 | 0.124 | -19.35 | -24.23 | -25.25 | -26.12 |
| 23-Mar-98 | 58 | 0.00 | 0.00 | 0.00 | 0.00 | 19.25 | 21.25 | 23.25 | 25.25 | 0.65 | 0.40 | 0.27 | 0.36 | 0.045 | -26.96 | -24.63 | -25.25 | -25.74 |

The calculated value (T) of the water levels in each wells are corroborating with the values of the piezometric levels in the wells ( HtI, HtII, HtIII, HtIV).

The computed values of YI, YII, YII and YIV are the distances inside the reservoir from the embankment. For plotting of the computed values inside the tank, the inner boundary of the embankment of the tank is considered as "0" line. From this boundary line, the values of the seepage points are plotted. The values -10, -20 are closer to the bund of the reservoir and -50, -60 are away, towards the centre of the tank (Figure-4)

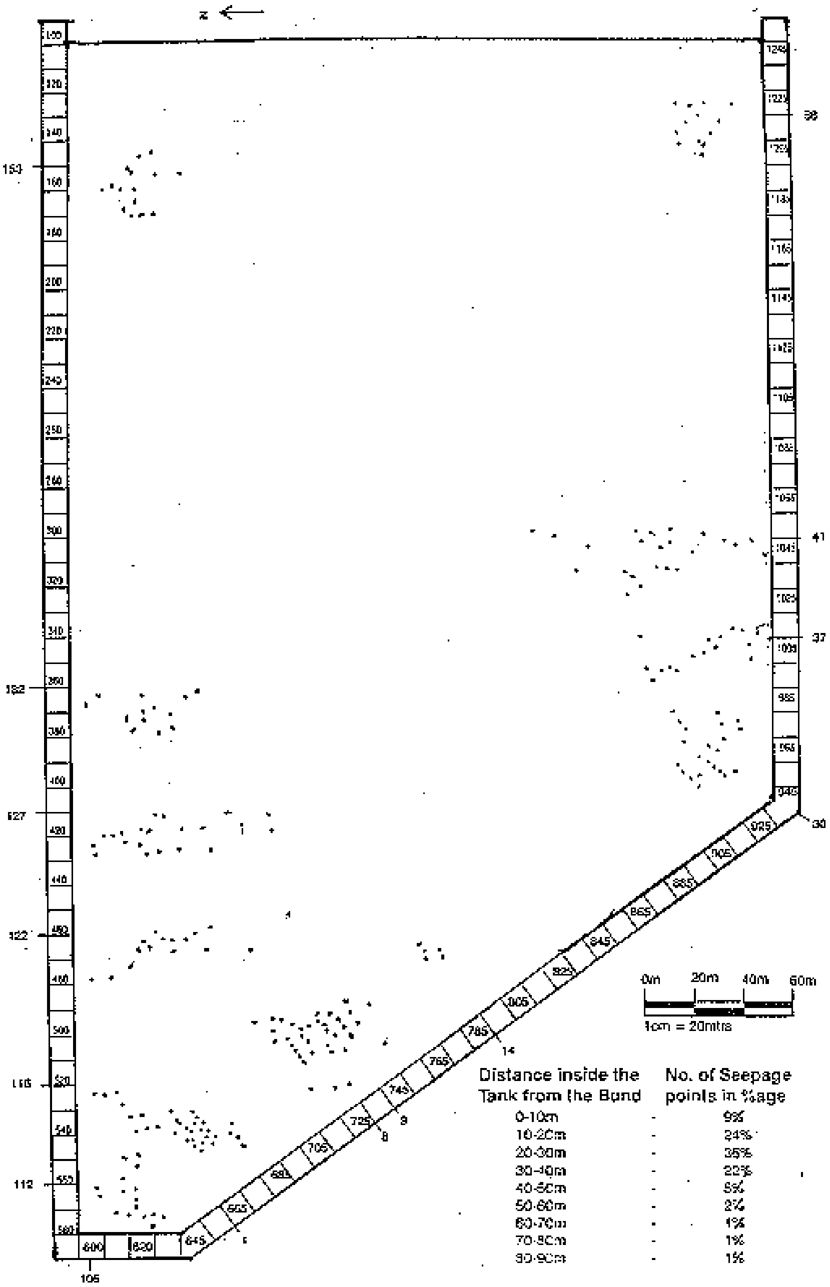



**Figure 4. Seepage points inside the ASR-1 tank.**

The distribution pattern of the plots of the seepage points inside the reservoir tank reveals that the major concentration (36%) of the seepage points are found within the distance of 20-30m from the bund of the reservoir.

Next higher percentages of 25% and 22% are distributed in two zones at a distances of 10-20m and 30- 40m respectively from the bund of the tank.

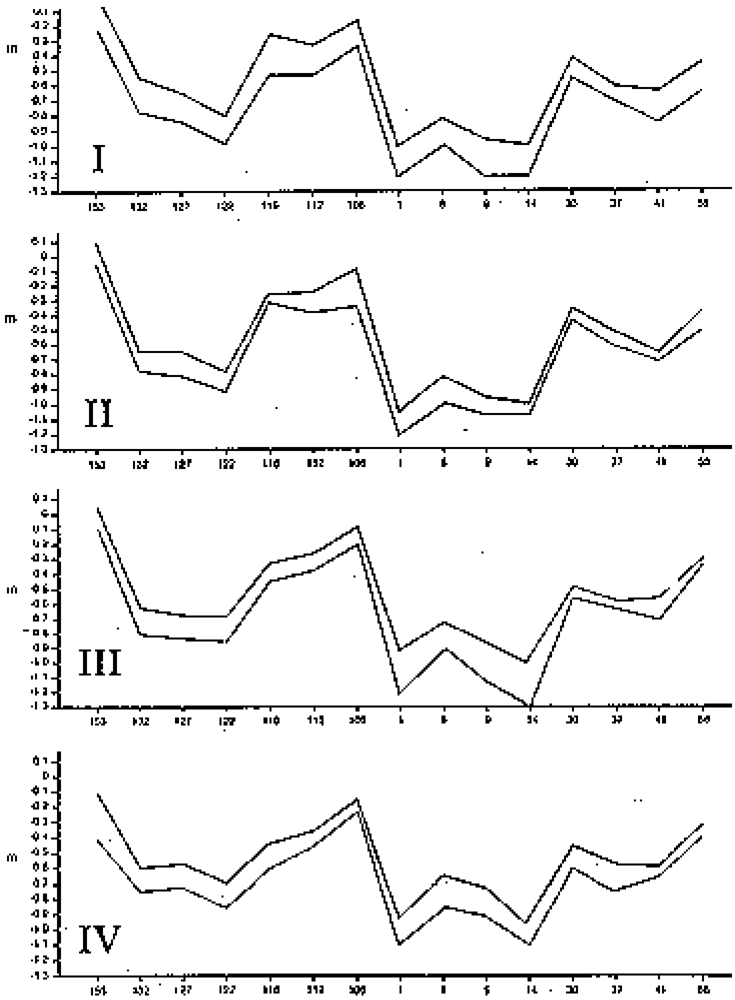



**Figure 5a. Maximum and minimum peizometric levels in the different wells along the locations around the tank at ASR-1 tank.**

In the Figure.5a the maximum and minimum potentiometer levels in the wells (I, II, III and IV) along the locations around the reservoir tank are shown. The four wells in all the locations exhibit more or less same trend.

The piezometric wells ( 127, 1, 8, 9, 14, 41) exhibit potentiometric water surfaces at greater depths when compared with the potentiometric surfaces of the wells such as 153, 132, 116, 112, 106, 30, 37 and 58.

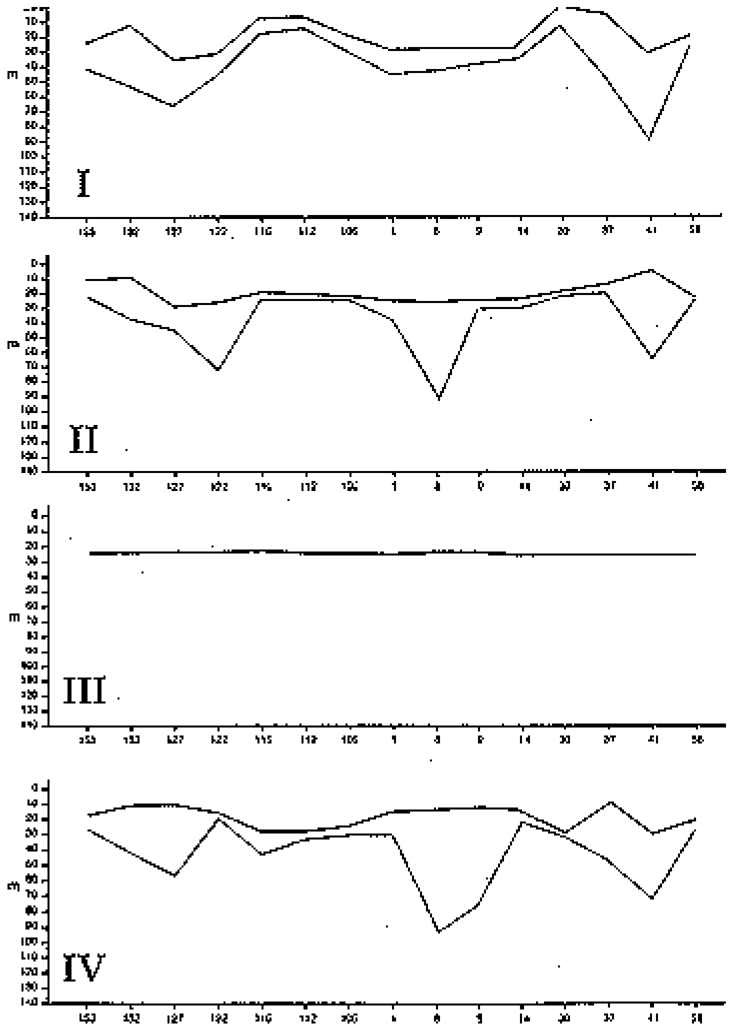



**Figure 5b. Calculated maximum and minimum seepage point distances from the bund towards the centre of the tank at different locations.**

In Figure 5b exhibit the distribution pattern of computed seepage points inside the reservoir tank. The distribution pattern of the seepage points, which influence potentiometric surfaces of the wells, I, II, III and IV show more or less same trend except for the seepage points for the wells III.

The piezometric profiles of 127, 189, 14 and 41 are having the distribution points of seepage at greater distances than the other seepage points.

Closer observation of these two figures reveals that those piezometric wells, which are having the potentiometric surfaces at greater depths, are found their seepage points at greater distances from the bund of the reservoir tank. Similarly the shallow potentiometric surfaces for the wells are having their seepage points at closer distances from the bund of the reservoir.

Another striking features found in the piezometric profiles ( 127, 1, 8, 9, 14 and 41) which are having deeper, potentiometric surfaces and are also classified as " 'A' Type". The other shallower potentiometric surface wells are classified as K and Q types and A and K types. (Ref Table -2)

In the ' A type ' piezometric wells, the ground water moves vertically downwards more distances than the other types of piezometric surfaces such as K, Q and H type. So, the potentiometric surfaces found in the 'A' types are classified ' vertical seepage' and others are classified as ' horizontal seepage' and other combination of vertical and horizontal seepage are also observed. (Fetter 1990).

| Profile Nos. | | Types of seepage |
|---|---|---|
| 127, 1, 8, 9, 14, 41, 58 | - | Vertical |
| 132,122, 58 | - | Vertical, Horizontal |
| 153, 116, 112, 106, 30, 37 | - | Horizontal |

Figure 5a and 5b-show vertical and horizontal piezometric level around the reservoir and their correspondence with the maximum and minimum seepage point distance in the reservoir.

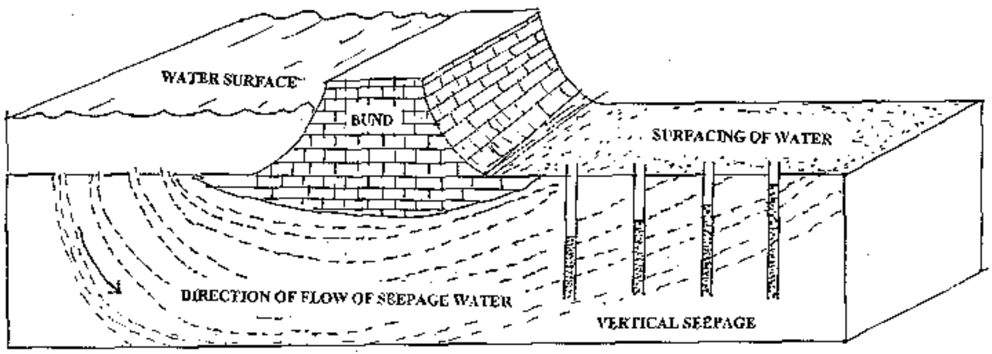



**Figure 6. Three-dimensional diagram showing vertical seepage.**

Three-dimensional diagram (Figure-6) depicts the flow pattern of vertical and horizontal seepage of water. In the vertical movement, water has to travel more downward distances, and so the water level observed in the I piezometric wells is at greater depth than IV potentiometric well in the same alignment. Whereas the horizontal movement exerts no such differences in the water levels in the wells.

## PIEZOMETRIC HEAD DISTRIBUTIONS IN THE STUDY AREA

Ground water is in constant motions from the point of recharge to a point of discharge with laws governing flows of fluids in media. Ground water moves in the direction of decreasing head of potentials. The head at a point is taken as the elevation above an arbitrary datum of the static column of water. The hydraulic gradient is more in the direction of flow.

In the Study area various types of piezometric surfaces such as A, K with Q and A and K types are distributed. In the K and Q types of piezometric surfaces, the elevation of water head is slope downward from the I well to IV well, whereas in the 'A' type of piezometric surfaces the potentiometric surface increases from the I well to IV well. This type of elevation head is called as pressure head.

The development of the pressure head in the study area is due to the downward seepage of water into the underlying litho-media. The seepage of water through the intergranular median initiated or increased the friction between the moving water and the stationary grains. This action causes a drag, which exerts a force on a granular material in the direction of flow. This type of force is called as seepage force or seepage pressure. The increase of intergranular forces increases the flow of water either downward or horizontal. When the intergranular pressure decreases, the flow of water turns upward. This ideal condition exists in the study area. The upward hydraulic gradient found in the profiles of 1, 8, 9, 14, 41, 58, 127 and 122 where 'A' types of piezometric surfaces are present. In the above said area, the infiltration of water was evidenced from the deeper potentiometric surfaces in the I and II piezometric wells than the III and IV wells.

As the intergranular pressure decreases the flow of water moves upward. The constant upward seepage force that is responsible for producing 'quick' conditions in the soil landward especially in the 'A' type piezometric profiles. Terzaghi (1922) was the first engineer to examine this problem and his analysis is still valid today.

The velocity of the fluids depends upon thickness and properties of the sediments. In the K and Q types of piezometric surfaces, the flow of water vary with different velocity. The piezometric level in the well is high and low in the well II than the well III. The water level variation in the wells in the same profile can be explained, as velocity increases in the narrow zone and ultimately it levels to the reduction of water head in the wells II and increase of water head in the broader permeable zone, where the wells III exist, so that the water level in the wells increased.

Majority of the 'Q' and associated piezometric surfaces have linear gradient is the potentiometric surfaces, because of the steady movement of ground water in a confined aquifer.

The Bernoulli's principle is explained in Figure.7. When the water moves in the bend area, both hydrostatic and hydrodynamic heads are registered. Bernoulli (1700 - 1782) shared those two arbitrary cross sections, which exhibit the flow of an ideal liquid.

$$\frac{P_S\,(A)}{W} + \frac{V^2A}{2g} = \frac{P_S(B)}{W} + \frac{V^2B}{2g} = H = \text{Constant}$$

The Bernoulli's equation clearly shows that if velocity of water flows is increased its hydrostatic head is proportionally decreased and viceversa.

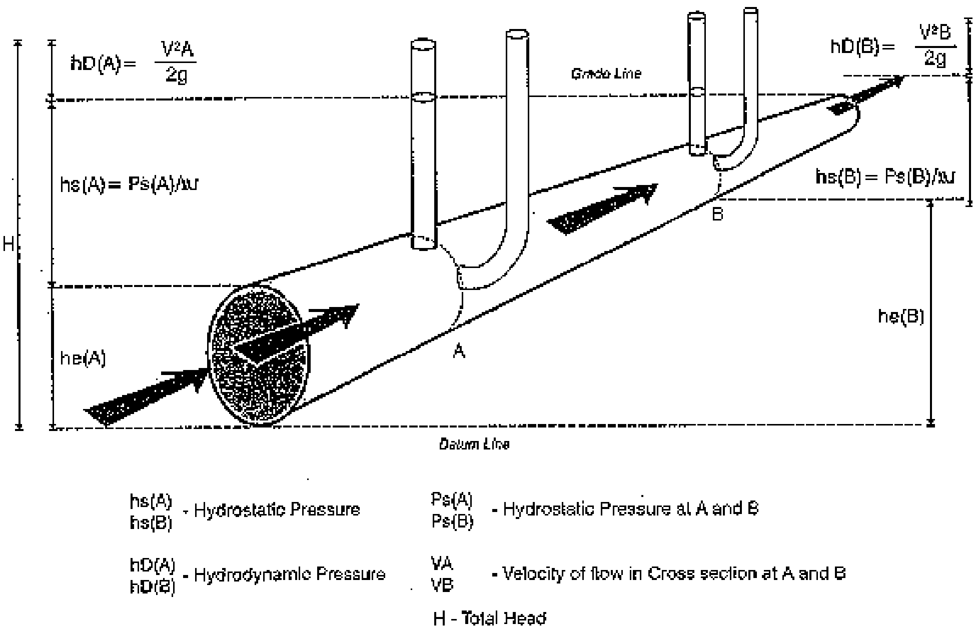



**Figure 7. Diagram to describe Bernoulli’s equation.**

Since, water under a hydro static pressure gradient flow uphill, part of its uphill fill flow in stream tube he (A) and he (B) elevation heads in cross sections 'a' and 'b' are to the elevation heads observed in the 'A' types of the piezometric surfaces in the study area. Dynamic energy is converted into potential and gravitational energies that is quantitatively represented by elevation heads (he)

$$\frac{P_S\,(A)}{W} + \frac{V^2A}{2g} + he(A) = \frac{P_S(B)}{W} + \frac{V^2B}{2g} + he(B) = H = \text{Constant}$$

It can be simplified

$$\frac{P_S}{W} + \frac{V^2}{2g} + he = H = \text{Constant}$$

(Poly voy 1996)

This equation can be also written in another form after multiplication by the weight (density) of the liquid.

$$\frac{P_S + WV^2}{2g} + Whe = WH = \text{constant}$$

Where $P_S$ and $WV^2/2g$ are hydrostatic and hydrodynamic pressure of flowing liquid respectively. ' Whe' is the gravitational pressure of the liquid and 'WH' is the total flow potential of the liquid.

Bernoulli's principle describes the conservation of energy and conversion of one form of energy to another and so the total flow energy potential ( H) or the sum of kinetic, potential and gravitational energy is constant.

In the K and Q and H types of piezometric profiles, the head losses occur, because of steady flow of water through the sediment of uniform thickness and experience friction due to viscosity and roughness.

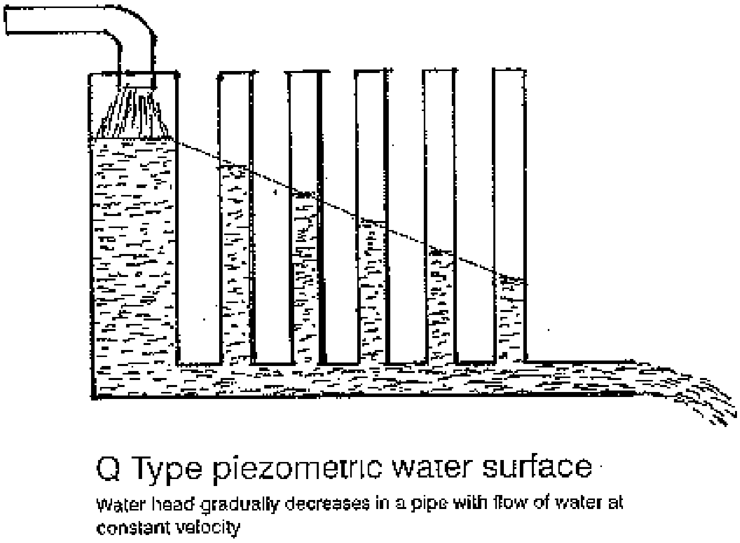
$$\frac{P_S\,(A)}{w} + \frac{V^2A}{2g} + he\,(A) = \frac{P_S(B)}{w} + \frac{V^2B}{2g} + he(B) + hL = H = \text{Constant}$$

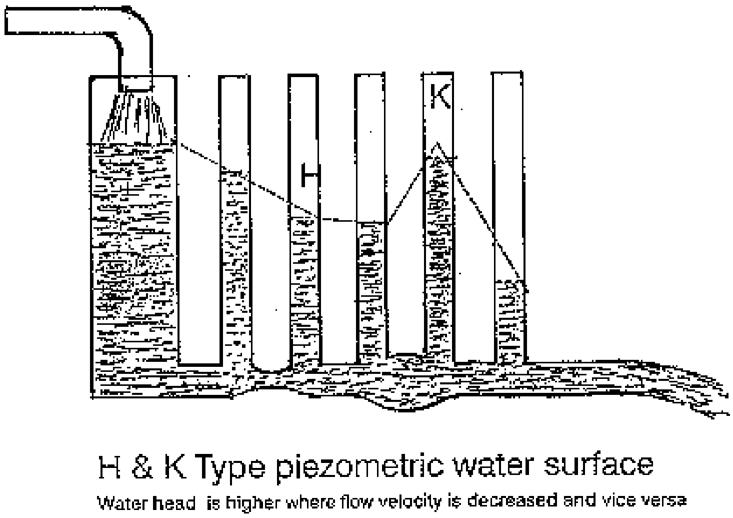
The member ' hL' represents losses of head. The head losses due to internal and external frictions, where the water passes through the permeable zones. This ideal condition is experienced in the piezometric profiles of K with Q types, and H with Q types. The head losses (hL) is expressed as a hydraulic gradient of flow I and the distance L between the two cross sections h = IL

## RESULT AND DISCUSSION

Apparent resistivity values ranges from 418 - 0.78 ohm m in the selected profiles. Dry sand formation exhibit to resistivity values from 418 - 130 ohm m in the study area upto a depth of 3 -5m. The fresh water occurrences are within range of values 130-20 ohm m within the depth of 9m. The interphase of fresh and saline water exists in the zonation of resistivity values of 20 -15 ohm m below 10m in all the locations in the study area show the persistence of saline water.

To ascertain the seepage influence around the reservoir - I a similar resistivity study upto a depth of 6m around ASR - II reveals 589-167 ohm m as maximum and minimum values. For the same depth for ASR - I the resistivity values vary to 280-15. The high range of values for ASR - II clearly show that the area is not affected by the seepage, whereas the resistivity ranges (280-15) around ASR - I exhibit the influence of moisture condition due to the seepage of water from the reservoir tank. Continuous monitoring of potentiometric surfaces in 60 piezometric wells in the 15 profiles led to the classification of potentiometric surface as 'A', K, Q and H types. 'A' types of potentiometric surface are having deep piezometric levels with the depth range of 1.20m to 066m as maximum and minimum depth. So this type (A) is classified as vertical seepage, found in the profiles nos 127, 1, 8, 9, 14, and 41. Other profiles with shallow depth range of 0.68 m to 0.00 m as maximum and minimum are classified as horizontal seepage in the profiles of 153, 116, 112, 106, 30, and 37. Combinations of the vertical and horizontal seepage points are observed in the profiles 132, 122 and 58.




**Figures 8a&b. The variation of piezometric water surfaces due to the horizontal seepage.**

'A' types of potentiometric surfaces are having the realms of maximum distances of 30-90m for the distribution of seepage points from the bund of the reservoir. For the other types of potentiometric surfaces, seepage points are found in the closer distances of 10-30m from the bund of the reservoir.

Since the potentiometric surfaces for 'A' type are found so deep when compared to K, Q and H types, the water from the reservoir has to percolate downward vertically to make such configuration found in the 'A' type profiles. Other profiles such as H, Q and K are having the seepage points in the proximity to bund of the tank and so they make shallow potentiometric surfaces. These observations reveal that the seepage water for those wells might have seepage horizontally, so this type of seepage is called as horizontal seepage. When the subsurface soil is uniform in grain size or thickness, the gradient or slope to potentiometric surfaces. And if the subsurface condition show variation in thickness or variation in permeability etc. would be reflected in the potentiometric surface, there in. The variation of piezometric water surfaces due to the horizontal seepage is explained in Figure – 8a and 8b. The first type piezometric surface is found, where the subsurface condition is uniform thickness. When the subsurface condition show the variation in thickness or porosity or permeability the piezometric surfaces also changed.

Seepage points identified inside the reservoir were checked physically after dewatering of the reservoir. Wherever these points were marked in the layout, there were conical shaped depressions in the sand bed. These conical depressions were created due to the seepage of water through the polypropylene sheets. The computed seepage points and actual seepage points were corroborating with each other. Authority removed the sand bed and sealed the damaged sheets, then seepage was completely stopped.

## Acknowledgement

The author is indebted to Mr. V. Jeyaraman, Executive Director, Mr. R. Muthu Manoharan, Chief Manager (Operation), Mr.S. Muruganandam, Senior Manager (Operation), Mr. V. Srinivasan, Manager, Mr. Venkatraman, Senior Joint Manager (Operation) and Mr. S. Venkataramani, Joint Manager ( Operation), SPIC, who have assigned, inspired and directed me to do this research and writing this assignment.

The author wish to thank Mr. V. Radhakrishnan, Mr. R. Thirugana Sambandam, Senior Lecturer, Dr.M.V. Mukesh, Research Scholar, Mr. V. Suresh, Kaliraj, Mr. Karthikeyan, Mr. Rejeshdurai, Mr.Thirumalai Raja, Mr. Somasundaram and Mr. Mathan Kumar, who have helped a great and put in volumnous efforts in the completion of this work.

The author expressed his sincere thanks to Principal Mr. R.Sooriya Narayanan and Mr. A.P.C.V. Chockalingam, Hon. Secretary of V.O. Chidambaram College, Tuticorin for their constant encouragement.

## References

Blyth, F.G.H (1965) A Geology for Engineers, The English Language Book Society, London.

Driscoll F.G (1986) Groundwater and Wells, Johnson Filtration Systems Inc., St. Paul Minnesota.

Fetter, C.W (1990) Applied Hydrogeoloty, CBS Publishers and Distributors, Delhi.

Karanth, K.R (1987) Groundwater Assessment Development and Management, Tata McGraw - Hill Publishing Company Limited, New Delhi.

Polyvoy, S.L (1996) Water Science and Engineering, Blackie Academic and Professional, London.

Ragunath, H.M (1987) Groundwater, Wiley Estern Limited, New Delhi.

Terzaghi, K.von (1922) Der Grundbruch and Stauwerken and Seine Verhutung. Die Wasser Koraft.