EVALUATION OF AQUIFER PARAMETERS FROM DRAWDOWN AND PUMPING OUT DATA IN OPEN WELLS

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PROJECT REPORT

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TAVANUR-679 573, MALAPPURAM
KERALA, INDIA

DECLARATION

We hereby declare that this project report entitled **“EVALUATION OF AQUIFER PARAMETERS FROM DRAWDOWN AND PUMPING OUT DATA IN OPEN WELLS”** is a bonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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CERTICICATE

Certified that this project work entitled **“EVALUATION OF AQUIFER PARAMETERS FROM DRAWDOWN AND PUMPING OUT DATA IN OPEN WELLS”** is a record of project work done jointly by Haripriya P.R., Neetha Shaju, Sandeep Soman and Yuvraj Siddharth under my guidance and supervision and that and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to them.

Place - Tavanur,
Date - 20-01-2014

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

SYMBOLS AND ABBREVIATION

Symbols	**Abbreviation**
°	Degree
-	Minus
+	Plus
/	Per
:	Is to
<	Less than
>	Greater than
≤	Less than or equal to
≥	Greater than or equal to
˚C	Degree Celsius
et al	And others
Fig.	Figure(s)
Hrs	Hour(s)
Hp	Horse power
KAU	Kerala agricultural University
KCAET	Kelappaji College of Agricultural engineering And Technology
Ltd	Limited
Lps	Liters per second
m^3/d	Cubic meter per day
M	Meters
Mm	Millimeter
Mha m	Million hector meter
Min	Minutes
No.	Number
%	Percentage
Pp	Pages(s)
Pvt	Private
Viz	Namely
w. l	Water level
Avg.	Average
Inst.	Instantaneous
Dep.	Depression
Sp.	Specific
Sq.m	Square meter
Dia	Diameter
Ed	Edition
Vol.	Volume
G. L	Ground level

INTRODUCTION

CHAPTER 1

INTRODUCTION

Water is a pure natural resource and a precious natural asset. It is vital to life, which is one of the indispensable elements sustaining all life. It is a bountiful boon nature has bestowed on us. This most precious resource is sometimes scares, sometime abundant and always very unevenly distributed both in space and time. Among the different components of water resources of the nation, ground water is most widely distributed, dependable and pure water resources. Groundwater unlike surface water is available in some quantity almost in all places where men establish his living. The amount of ground water with in 800m from the ground surface is over 30 times the amount in all fresh water lakes and reservoirs and about 3000 times the amount in stream channel at any one time

The world total water resources are estimated at $1.378X10^8$Mha-m. Of the global water resources only 2.7% is available as fresh water and 97.3% as saline water out of these 2.7% about 77.2%is contributed from glaciers 22.4% from ground water and soil moisture, 0.35% from swamps and lakes, 0.04% from atmosphere and 0.01% from the streams.

At present, nearly one fifth of the total water is used in the world is obtained from ground water resources. Agriculture is one of the greatest user of water accounting to about 80% of the entire consumption. Now a days, around water resource contribute more than 90% of world fresh water supply. The main source of ground Water is rain .The rainwater gets infiltrated after meeting the soil moisture deficiency, percolates downwards and becomes ground water. The subsurface occurrence of ground water may be divided into zones of saturations and aeration. In the zone of saturation, all the interstices are filled with water under hydrostatic pressure.in the zone of aeration. The interstices are partially occupied by air and partially by water. The water occurring in the zone of saturation is generally regarded as ground water. The upper boundary of zone of saturation is called water table. In general shape of the water table tends to fallow the topography of the water surface.

Ground water occurs within the surface depending on the property of the physical formation that exists. This geological formation or strata within the saturated zone below the ground surface from which ground water can be obtained for beneficial use are called aquifers. Water bearing formations or ground water reservoirs are the other term commonly used instead of aquifer. These are the permeable geological formations that permit appreciable amount of water pass through them. The ground water may be classified as unconfined, confined, and semi confined aquifers.

An aquifer upper surface of which is defined by the water table is called an unconfined or water table or phreatic aquifer. Ground water such an aquifer is under unconfined conditions, the upper surface being in vertical contact with atmosphere either directly effluent with seepage zones or through interstitial voids in the aeration zone. The zone of saturation may be consist of permeable, impermeable and semi permeable earth materials. An aquifer found between two impermeable layers is said to confined. It is also called artesian aquifer. Because the presence of an upper confining layer, the water in pores of confined aquifer is not opened to the atmospheric pressure, but is at a greater pressure.

An aquifer performs two important functions – a storage function and a conduit function. It store water, serves as reservoir and act as a pipe line to transmit water. The opening or pore in water bearing formation similarly serves both as storage space and network of conduits. The ground water is constantly moving over an extensive distance from area of recharge to area of discharge. The assignment of ground water resources is much more difficult as it involves the evaluation of various hydrological components within the frame work of a complex geological environment.

The importance of the role of the ground water to meet water supply requirement for domestic, rural, urban, industrial and agricultural use needs no emphasis. During the last two decades, availably of credit facilities through institutional finance for ground water development for irrigation has given rise to large scale withdrawal of ground water. Even in developing country like India there are area where ground water development reached at critical stage and adverse effect are imminent. The increasing demand has simulated the investigation oriented towards quantification of the resources which is basic of formulation of plans for its exploration, management and conservation.

For tapping the ground water for irrigation and water supply, diverse geological formation require different type of wells mainly open wells, dug wells, dug cum bore wells and tube wells. Tube well is the most suitable method of tapping ground water from the deeper zones. These wells are constructed by drilling a deep bore passing through many strata. The wells go deeper and draw water from more than one strata and the arability of water is more compared to that of open wells. Open well draw water only from uppermost layer of soil profile. Advantage of tube well over open well is it have high discharge rate.

According to Central water commission the total available water resource is about 116Mha-m, out of which surface water component is 74Mha-m and ground water resource is 42Mha-m .ground water resource are all though replenish able is not inexhaustible .The per annum utilization of ground water is estimated as 18.58Mha-m.the groundwater occurs within the surface depending on the physical properties of different formations that exist .Aquifers are formations contain ground water and sufficiently permeable to transmit and yield it in usable quantities. An unconfined aquifer is one in which water table serves as the upper surface of saturation. There is no clay or other restricting materials at the top of the ground water .so the ground water levels are free to rise or fall. Confined aquifer is a layer of water bearing material that is sandwiched between two clay layers or sand stones between layers of shale solid lime stone.

A major part of Indian peninsular and a vast number of developing and underdeveloped countries depend on large diameters open dug wells for their domestic and agricultural needs. Dug wells comprises of open surfaces wells of varying dimensions dug or sunk from the ground surface into the water bearing stratum. They may be circular or rectangular in cross section .usually two types of wells are constructed. Lined wells and unlined wells in hard rock .linings may be of concrete rings or masonry.

There are numerous examples of ground water flow problem whose solution requires the hydraulic characteristics of the water bearing layer .the parameters play a key role in accurate assessment and proper management of ground water. The important aquifer parameters are hydraulic conductivity, transmissivity, specific yield and storability. The knowledge about aquifer parameters help

The specific objectives of study are;

- To study seasonal water level variation in the pumping well.
- To evaluate the aquifer parameters based on drawdown analysis.
- To developed the relationship between time and drawdown by regression analysis.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

A brief review of drawdown and recuperation pattern, their analysis in open wells for determinations of aquifer parameters are described in this chapter.

Drawdown and recuperation pattern of wells are much dependent on the aquifer parameters. Analysis of drawdown and recuperation pattern of wells is necessary for the determination of various aquifer parameters. The levels at which water stands in a well before pumping is called static water level. When a well is being pumped, the water level in the well lowers. In general case initial contribution of water from the well mostly comes from the well storage. It is only after sometime that the aquifer starts contributing to pumpage. The time gap between the onset of pumping and the beginning of an appreciable flow of water from the aquifer to the well depends mainly on the transmissivity of the aquifer. The linear relationship between drawdown and time implies that the water is pumped mostly from storage. Thus time drawdown curves were initially linear, but later with the beginning of the contribution from the aquifer; they gradually become non-linear.

When the pump is stopped, at the end of the pumping test, the water level in the well starts rising. This is referred to as recovery of the ground water level. Recovery rate is high at the beginning of the recuperation due to steep hydraulic gradient. It is gradually reduces as the static water level approaches.

Hilton *et al.* (1967) presented a solution for the change in water level in a well of finite diameter after a known volume of water is suddenly injected or withdrawn. A set of type curves computed from the solution permits a determination of the transmissivity of the aquifer.

Papadopulos and Coope (1967) analyzed the drawdown in a well of large diameter. Their purpose was to present an exact solution of the drawdown in and around the well of finite diameter taking into consideration the effect of water stored in it. Under some conditions, the solution may be useful in analyzing pumping from a pond. A set of type curves computed from the solution permits the determination of transmissivity of the aquifer by analysis of drawdown observed in the pumped well.

Neumann (1975) analyzed the pumping test data from unconfined aquifers considering delayed gravity response. He developed two methods of analysis, one based on matching of field data with theoretical type curves and the other based on semi logarithmic relationship between drawdown and time. Owing to the reversible nature of the delayed response process as represented by the analytical model, he used the recovery test data to determine the aquifer transmissivity.

Bintley (1979) determined aquifer coefficients from multiple well effects at Fernandina beach in Florida. A water level recorder was used to record the change in water level following shut down and start up. Pumping rates of the well ranged from 400,000 to 590,000 cubic feet per day. Distance from the pumped wells to the observation wells ranged from 660 to 7920 feet. Analysis of water level data was further complicated because the wells were neither turned off nor restarted simultaneously. The Copper-Jacob graphical method based on the principle of super position and using the value of specific drawdown or specific recovery (S/Q) and the weighted logarithmic mean of the distance squared divided by the time (r^2/t), was applied to determine the aquifer coefficients for the upper water bearing zone of the aquifer. A transmissivity of 30,000 feet squared per day and a storage coefficient of between 2.5×10^{-4} and 4.0×10^{-4}werecomputed.

Baker and Herbert (1982) conducted study on pumping test in a patchy aquifer and developed a evaluation describing the long time behavior of draw down so that Jacob’s method can be employed to estimate the regional transmissivity from draw down measured at any point in aquifer. These equation shows that an average storage coefficient should be calculated from draw down measured outside of the aquifer discontinuity. The result of the study support the hypothesis that the average transmissivity of the heterogeneous aquifer can be calculated from the rates of draw down observed after a long period of pumping.

Norris (1983) conducted and analyzed aquifer tests and well field performance at Scioto River valley, Ohio. Values of drawdown measured in the observation wells at the end of constant rate pumping periods, usually of 3 days duration, were used to determine line source distance and aquifer transmissivity based on 13 aquifer infiltration rate at 11 sites, aquifer transmissivity ranged from 17,000 to 40,000 square feet per day and the saturation infiltration range ranged from 0.06 to 0.19 million gallons per day per acre along a 7 mile reach of the Scioto river in south central Ohio.

Walthall and Ingram (1984) determined the aquifer parameters using the multiple piezometers. The study was being carried to evaluate the North Merseyside Permian-Triassic sand stone aquifer with particular reference to saline intrusions and water resources. The study had included a full range of hydrological investigations of which the behavior of observation boreholes has formed an important part in addition to water levels, these observation boreholes had been used to assess the regional permeability of the aquifer, variations of hydraulic properties over the aerial extent of the aquifer and for hydrological sampling. The use of multiple piezometers proved to be the only way of obtaining sensible results for field pumping tests and has given storage coefficients for both confined and unconfined sections of the aquifer.

Rushton (1985) studied the interference due to neighboring wells during pumping test. An important finding of the analysis is that the distance between the test and interfering wells has a small effect during both pumping and recovery face

Butt and McElwee (1985) conducted convolution and sensitivity analysis on variable rate pumping tests to evaluate aquifer parameters. They used the convolution and sensitivity analysis to obtain ‘best fit’ of the aquifer parameters in the least square sense from a pumping with variable pumping rate. It can also be used to analyze the residual drawdown data obtained during the recovery period. The method is used to analyse the drawdown and recovery data conjunctively. The method developed by them was straightforward, quick, inexpensive and is always objective.

Boonstra (1989) developed a computer program names SATEM for the determination of aquifer parameters in consolidated aquifers. In order to run the program some limiting conditions are there to be satisfied:

- Discharge should not be less than 100m^3/day
- Minimum pumping hour should be 8 hours

This program is only applicable to tube wells.

Ballukraya and Sharma (1991) suggested a method for estimating storativity using residual drawdown measurement from an observation well in confined aquifer. An equation derived from Cooper Jacob is suggested for estimating storativity using residual drawdown measurement from an observation well. It may be pointed out that in cases where Cooper Jacob straight line method can be applied, the proposed method can be safely employed.

Avci (1992) developed a procedure that analysis step drawdown test with pumping stage of unequal time duration was formulated and developed in the computer program.

This method is applicable the confined aquifer where the water level drawdown is governed by Theis' well function. A least square fit error analysis is used in the determination of aquifer properties and the well loss component of the drawdown. The method considers the time dependency of the aquifer loss coefficient during the collection of step drawdown data without requiring equal pumping stage duration.

Chapuis (1992) studies proposed a graphical representation for visualizing and quantifying difference between Cooper – Jacob's solution and Theis solution. The graph of drawdown versus log time may be divided into three zones, the early one being influenced by storativity, pumping well pipe capacity and skin effects and the intermediate one by the transmissivity and storativity of the aquifer. The solution can be used when Cooper – Jacob's approximation and values does not require curve matching. Early data can be used, however to obtain a better estimate of storativity and transmissivity from drawdown data of observation wells.

Szekely (1993) conducted studies for estimation of unsteady vertically heterogeneous aquifers exhibit three dimensional flow patterns around pumping wells that partially penetrate the formations. A quasi, a mixed and a weighted three dimensional model are applied to approximate the three dimensional, unsteady drawdown in vertical pumping and observation wells. Case of confined, semi confined and unconfined flow conditions are considered and numerical examples are used to quantify the numerical error of the methods, introduced by the vertical homogeneity of the aquifer.

Helweg (1994) proposed General Well Function (GWF) to replace Jacob’s step drawdown equation. Jacob’s equation requires preselected discharge duration and does not incorporate time as an independent variable. The General Well Function not only corrects for this weakness but appears to better predict drawdown that extent beyond the test data. The GWF assumes that both formation and well losses increases over time.

Kawecki (1995) conducted step drawdown test to evaluate the well performance. This method is restricted to confined aquifer and determines the total well losses as a function of discharge with linear and nonlinear components. This method is valid for any stepped pumping pattern and any observed fluctuation in discharge during a step are simply accommodated as additional steps.

Chung and Quazar (1995) made a study on Theis solution under aquifer parameters uncertainty. This study showed that drawdown is almost inversely proportional to transmissivity and also find that there is no correlation between transmissivity and storativity.

Bhadouria and Seth (1996) conducted a study on time drawdown and recovery trends of open wells and they found that flow of water to well is dependent on rate of pumping. They also found specific gravity of well at different well depth and uneven variation in specific capacity shows the heterogeneous formation within the well depth. The recovery trends are dissimilar because the wells are located in different well logs in the case this case study the rate of pumping 5 liters per second had exceeded the rate of inflow. Hence determination of specific capacity at this rate was not feasible.

Xunhong and Jerry (1997) used Hantush solution for simultaneous determination properties using Taylor series and non-linear least square method. The main limitation of this case is that the construction characteristics of the well should be known and also will should be located within a radial distance 1.5 times the thickness of aquifer. The error between determined and true parameter values was less than 0.1% depending on the quality of the field data.

Moench (1999) proved that on the basis of a pumping test in an unconfined aquifer, it is possible to derive values of horizontal and vertical hydraulic conductivities, specific storage, and specific yield using analytical methods. However, because it is a time consuming process and the difficulty to obtain accurate fits of theoretical curves to observed drawdown data, numerical modeling makes it possible to eliminate some of the simplifications and assumptions on which the analytical solutions are based (Lebbe et.al., 1992). Moench recommended the composite analysis of pumping test data and grouping of corresponding time drawdown data for parameterization as opposed to the analyses of individual drawdown curves.

Hvilshoj et al. (2000) demonstrated that it is possible to determine horizontal and vertical hydraulic conductivities, specific yield, and specific storage based on a pumping test of a partially penetrating well. Also, from the analyses of the Vejen unconfined aquifer in found to be in accordance with the horizontal hydraulic conductivity determined by the pumping tests of partially penetrating wells. However, pumping tests of fully penetrating wells are the most common, and analyses of such tests yield values of transmissivity, storage coefficient, and leakage factor

Chen et al. (2003) showed from the contours of relative errors (REs) for, Kz, S, and Sy that the areas immediately above and below the pumping well screen are poor locations for an observation well. Shallow locations with distances of 15 m or closer to the pumping well seem to be poor choices for obtaining reliable Kz and S values. Favorable locations for Sy are often in the shallow part of the aquifer and a certain distance from the pumping well. At least two observation wells are needed for locations good for Sy if the flexibility of Kh is considered; otherwise, three wells are preferred over a vertical profile. Although REs for Kh are small over the entire vertical profile, a deep observation well generates a slightly larger error. Therefore, constructing observation wells in the depth interval opposite the pumping well screen is likely to generate good quality data because the REs for Kr, Kz, and S are usually small.

Raman, (2006) had been achieved from the analysis of pumping system, by the use of Aquifer Test and comparing the results with those obtained by linking MODFLOW with WinPest. To authenticate his results, we made use of the Neuman (1975) method set in Aquifer Test to calculate dimensional drawdown for each observation well, for which dimensional drawdown computed by WTAQ are compared to affirm the values obtained for the *T, S,* Kh, Kv, and *Sy* of the aquifer. Under consistent assumptions, analytical drawdown curves derived by WTAQ (by using values for all hydraulic parameters that were calculated by Aquifer Test), should be super imposable on those obtained using Aquifer Test

2.1 Aquifer parameter evaluation

Evaluation of hydraulic properties of aquifer and those of adjoining formation layers is an important aspect of any scheme of ground water resources assessment. Knowledge of aquifer parameters gives an idea of regarding an aquifer’s water transmitting and storage capacity. Hydraulic properties of aquifer and associated layers can be determined by a pumping test. It involves abstraction of water from a well at controlled rate and observing the changes in the water level in pumped well or in one or more observation well. Pumping test can also be conducted to obtain information of yield and drawdown of wells for proper selection and positioning of pumps.

Sayed (1982) developed two programs for pumping test analysis by least square method using Jacob’s modification of Theis equation. Two programs are given for the direct computation of transmissivity and storativity from time drawdown and distance drawdown data. The programs also calculate drawdown at various times and distance using the computed transmissivity and storativity.

Norris (1983) conducted aquifer test at 11 sites to determine the hydraulic properties. The values of drawdown are measured from the observation wells at the end of constant rate pumping periods, usually of three days duration were used to determine line- source distance and aquifer transmissivity. Results of the best assess the characteristics of aquifer system. Another purpose is to compare the performance of production well with prediction of yield and drawdown based on aquifer and stream infiltration characteristics determined from the test.

Franke (1987) developed a procedure for the analysis of aquifer test using the Theis non equilibrium solution. A classical dimensional analysis of the Theis non equilibrium radial flow problem in a confined aquifer requires three dimensionless parameters for representation. A type curve based on three dimensional parameters is developed that can be employed to analyze the aquifer test data by curve matching procedure. The shape of the proposed curve gives the approximate estimate for field parameters T and S.

Johns *et al* (1992) conducted studies to estimate aquifer properties by nonlinear least square analysis of pump test data developed for different aquifer models viz. Theis model, Equipotential model, Boundary model, Confined leaky model and Water table aquitard model. More than one aquifer model was found to match the pump test response with the same residual least square error and the well site hydrogeological information. The fitting routine employed in the pump test analysis were found to be enhance the interpretation by conventional method allowing parameter estimates to be defined for tests which may only weakly exhibit the long term aquifer behavior. This study illustrate that least square routine cannot replace the judgments of hydro geologist in interpreting pump test data particularly in assessing the validity of alternative aquifer model.

Mishra and Guyonet (1992) developed a simple method for computing transmissivity and storativity of the analysis from observation well response during constant head aquifer test. Objectives of this is to develop and demonstrate a procedure for interpreting the observation well data when the head at the test well is kept constant and considered as a fully penetrating well in confined, homogeneous and isotropic aquifer which is of infinite lateral extent, both the test well and observation wells are assumed to have negligible bore hole storage or skin effect. The proposed methodology is based on the approximate solution developed using the Boltzmann transformation technique.

Sen (1992) developed a simplified conceptual model for ground water flow pattern around an extended well leading to an analytic solution with type curve which can be used in determining the aquifer parameters from the field measurement of time drawdown data. It is observed that extended well type curve merge with Theis curve and consequently Jacob straight line method becomes applicable. The application of methodology to actual field data did not show any complication. Parameters estimation becomes reliable if length of the extended well is known.

Srivasthava and Guzmen (1994) proposed slope matching techniques which obtain the parameter values without using any tables or iterative procedure. It is shown that the slope of the drawdown with respect to the logarithm of time result in the most accurate prediction of aquifer parameters. The methods are then applied to some field data and the results are compared with published data and are found to work reasonably well for field application.

Jio and Zheng (1995) conducted studies for different characteristics of aquifer parameters using the concepts of two ways coordinate and one way coordinate. An upstream observation well can produced information on storativity and both upstream and downstream, but it can produce little information on transmissivity downstream. These characteristics of aquifer parameters have important implication on pumping test designs and interpretations.

Li and Derek (1995) proposed a modified method for the aquifer parameter estimation procedure. In this the parameters are evaluated by a modified Gauss-Newton method, which is applied to transient ground water flow. Three different approaches of evaluating the sensitivity coefficient matrix are examined including influence coefficient, sensitivity equations and variational approaches. The performance of each of the techniques is evaluated by applying a common synthetic data set.

Banton and Bangoy (1996) developed a new method to determine the transmissivity and storage coefficient from recovery data. The method requires from observation from a minimum of two points. The results obtained are close to those using the Theis' or Jacob's methods applied to drawdown data during the pumping period.

Bergelson*et al*. (1998) conducted studies to determine hydraulic parameters of the aquifer around the Sea of Galilee. Water level fluctuations were used to calculate specific storage values which duffers in the lower and upper aquifer. Depletion curves were used to calculate transmissivity in the lower and upper aquifers respectively. Age indicators were used to calculate the hydraulic conductivity, those obtained by radio carbon data. The pumping test provides values which are too high because of leakage from adjacent formation during the test. This technique is more adaptable than that of conventional pumping test.

Heidari and Ranjithan (1998) developed a method Genetic Algorithm is combined with Truncated Newton research technique to estimate ground water parameters for a confined steady state groundwater model. Use of prior information about the parameter is shown to be important in estimating correct or near correct values on the regional scale. Results from estimated parameters depend on the level of noise in the hydraulic head data and the initial values in the Truncated Newton research technique.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The details of methodology of experimentation. Data collection and analysis are preceded in this chapter.

3.1 GENERAL

3.1.1 LOCATION

Theoretically any site is easily accessible for man power and equipment are suitable for an aquifer test. The factor to be kept in mind when selecting an appropriate site is:

- The hydrological conditions should be representative of the area
- Water table gradient should be small
- The aquifer should extent in all directions over a relative large distance

The study site is situated in KCAET campus, Tavanur in Malappuram district of Kerala situated at 10º 53´and 30´´ north latitude and 76´east longitude. Bharatapuzha River forms northern boundary of study area.

3.1.2 Geology

The climate profile at the study site is composed of laterite, clay and alluvial formations.

3.1.3 Climate

Kerala has a humid tropical climate with a temperature averaging between 20 and 30ºC throughout the year. The mean annual precipitation averaging 300 cm is distributed over 125 rainy days. Kerala is situated in monsoon zone and expressed to seasonal contrasts. One can differentiate between a ‘hot weather periods’ from March to May, a south west monsoon period’ from June to September, ‘a north east monsoon period’ in November to December. The south west monsoon is dominant in rainy seasons.

3.1.4 Descriptions of Wells

The wells selected were numbered as follows,

Table. 3.1 Location of wells

Well number	**Location**
1	Farm house
2	Dairy farm
3	Near the temple
4	Bharatapuzha river
5	Kellapaji home
6	Near KSEB substation
7	Near pump house
8	School ground
9	KCAET entrance

3.2 Physical properties of aquifer

3.2.1 Hydraulic conductivity (K)

The hydraulic conductivity is the constant of proportionality in Darcy' law and defined as the volume of water that will move from a porous medium in unit time under unit hydraulic gradient through a unit area measured at right angle to the direction of the flow. It is expressed as mm/day.

The hydraulic conductivity can be determined from pumping test by using the relation

$$K = T/H$$

where

T = Transmissivity of the formation in m^2/day

H = Thickness of the formation in meters

3.2.2 Saturated thickness (H)

For unconfined aquifers, the saturated thickness is equal to the difference between free water table and aquiclude. The saturated thickness of an unconfined aquifer is not constant, because the water table changes its proportion with time.

3.2.3 Transmissivity (T)

The transmissivity is the product of the average hydraulic conductivity and saturated thickness of the aquifer expressed in m^2/day. Consequently, transmissivity is the rate of flow under hydraulic gradient equal to unit cross section of unit width over the whole saturated thickness of water bearing layer.

3.2.4 Specific storage (S)

The specific storage of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from the storage under a unit decline head.

3.2.5 Specific yield (S_y)

Specific yield is the volume of water that an aquifer releases from storage per unit surface area of aquifer per unit decline of water table.

3.2.6 Specific gravity (G)

Specific gravity is defined as the ratio of the mass of given volume solids to the mass of an equal volume of water at 4˚C. The specific gravity of solids falls in the range of 2.65 to 2.80.

3.3 Performing Aquifer tests

An aquifer test depends heavily three sets of measurements: time, head and discharge.

3.3.1 Time

The time measurement started at the beginning of the test. Water level is dropping fast during initial period. Water table is measured at every one minute during the first 10 minute, two minute interval for next 20 minutes.

3.3.2 Head

Before pumping starts, the water levels in the entire well should be measured from the ground level. Water levels are measured by means of a tape provided with a sensor. In order to get drawdown data, the initial depth of water level prior to pumping must be subtracted from the depth to water level during the test.

3.3.3 Discharge

The required discharge rate of pump depends on many factors like depth, diameter, screen length, aquifer properties etc. During the test, discharge is made constant by means of gate valve and pressure gauge. Constant discharge should be maintained during the test. Also the water discharged from the well should be disposed off sufficiently far away from the site to avoid recirculation by percolation.

3.3.4 Duration of the test

Duration of test depends on the type of aquifer being tested. The test has to be continued until complete water is pumped out.

3.3.4.1 Pumping Tests of Wells

Pumping tests are conducted to obtain information on the characteristics of the water-bearing formations of the well. Such tests provide information on the hydro-geological properties of the well site such as the type of aquifer and its areal extent and thickness, water table gradients and recharge boundaries. The hydraulic properties of the aquifer such as hydraulic conductivity, transmissibility, storage coefficient, specific yield, leakage factor and hydraulic resistance could be obtained from pumping test data. A pumping test will also provide information about the drawdown and yield capacity of the well. This will help in selecting the pump, the characteristics of which will match best with those of the well.

Pumping test procedure

The step-by-step procedure commonly adopted in conducting pumping tests is enumerated below.

(1) **Selection of the test site :** In selecting the site of the pumping test the following points are kept in mind

- ➢ The hydro-geological conditions of the test site should not change over short distance and should be representative of the area or a large part of the area under consideration.
- ➢ The site should not be close to railway lines or highways with heavy traffic. Such sites may produce measurable fluctuations of the piezometric surface in case of confined aquifers.
- ➢ The pumped water does not return back to the aquifer.
- ➢ The gradient of water table or piezometric surface should not be low.
- ➢ Man power, instruments and equipment’s to be able reach the site easily.
- ➢ Measure ground water levels in both the pumping test well and nearby wells before 24 hours of start pumping.

(2) **Observation wells:** Water level measurements during pumping test are made in observation wells are installed close to the wells or at some distance away from it. The installation and design of the observation well requires the following points to be considered.

- **Number of observation wells:** The number of observation wells depends on the amount of information desired and the degree of precision expected. A single observation well permits the determination of hydraulic properties, more precise values of these properties can be installed by installing two or more observation wells at varying distances from the center of the well. A large number of observation wells also provide information on distance-drawdown relationship which can be utilized for designing the spacing of the wells.
- **Spacing of observation wells**: In general, observation wells should be placed neither too far from the pumped well nor too close to it.

(a) **Type of aquifer***:* In confined and semi-confined aquifers a loss of head caused by pumping propagates faster than in an unconfined aquifer because the release of water from storage is due to the compressibility of the aquifer material and that of water. Hence, the nearest observation well should be placed a little farther in confined and semi-confined aquifers than in an unconfined aquifer for the same discharge rate of the test well,. For the same discharge rate, the radius of influence is more in confined and semi- confined aquifers than in an unconfined aquifer. The farthest observation well should be placed at a greater distance in these aquifers than by an unconfined aquifer to evaluate the boundary of the extent of the aquifer.

(b) **Hydraulic conductivity:** When the hydraulic conductivity of the aquifer material is high, the cone of depression produced by pumping will be wide and flat, which results in a large radius of influence as well as a greater amount of turbulence. Therefore, observation wells should be placed farther in an aquifer with a high value of hydraulic conductivity as compared to an aquifer of lower conductivity.

(c) **Length of well screen:** The distance of the observation well adjacent to the test well is influenced by the length and depth of penetration of the well screen of the test well. The minimum distance of the observation well from the test well in partially penetrating confined and semi-confined aquifers should be greater than 0.5 to 2 times the thickness of the aquifer (Krussenman and De- Ridder, 1970). In case of an unconfined aquifer a lesser distance can be used.

- **Depth of the observation well***:* In fully penetrating confined and semi-confined aquifers, the depth of the observation well should be up to the center of the well screen. For a partially penetrating well, the depth of the observation well should be the same as that of the test well.

- **Diameter of the observation well:** Precise measurements of the drawdown can be made in a small diameter observation well.

- **Length of the perforated portion of the observation well:** The portion of the observation well casing in the aquifer should be generally perforated. However, a shallow observation well which is installed above or below a semi-confined aquifer may be perforated only about 1 to 2 m at the bottom.

- **Size of perforations of the observation well***:* The size of the perforations should be designed on the basis of the particle size distribution of the strata in which it is installed and the size of the drilling tool available.

- **Installation of observation wells***:* The observation well is placed in the hole made by a soil augers or core drilling machine

Duration of the pumping test: The duration of the pumping test depends on the type of aquifer and its hydraulic properties and the method to be used for analysing the pumping test data.

Table. 3.2 Duration of Pumping Out Test

Time since start of pumping (min)	**Time interval (min)**
0 – 10	1
10 – 20	2
20 – 50	5
50 – 100	10
100 -180	20

Water level measurement*:* An important part of a pumping test is precise measurement of the depth of water in the observation well and, if possible, in the pumped well. These measurements must be taken many times during the pumping test.

3.4 Analysis of data

Data collected as described earlier are analyzed using the procedure given below.

3.4.1 Textural Analysis

Four soil specimens were selected from the instructional places of KCAET campus. These samples having varying soil parameters were selected. All the samples were subjected to textural analysis.

Textural analysis was done for each soil sample. 1kg of each soil sample was taken &placed in the mechanical sieve shaker after drying in the oven for 24hrs. The sieves were placed in decreasing order of sieve size from top to bottom. The sieves used for the analysis have the dimension of 4.75mm, 2mm, 1mm, 600, 425,300, 212, 150, 75µm. Sieving was done for 10minute. From the results obtained, the particle size distribution curve was drawn. For each specimen the soil texture was determined.

3.4.2 Regression analysis

Regression analysis is one of the most of common method to correlate two or more variables. Plotting drawdown values against time and drawing best fit line can be adopted for rough estimate. A better method to fit a linear regression line between drawdown and time is adopted if the correlation coefficient is nearly unity. The equation for straight line regression between drawdown and time is

$$D = at + b$$

The value of coefficient ‘a’ and ‘b’ are given by

$$a = \frac{N(\sum Dt)-(\sum D)(\sum t)}{N(\sum t2)-(\sum t)2}$$

$$b = \frac{\sum D - a\sum t}{N}$$

Coefficient of correlation, r

$$\sum(t)(\sum D)$$

¿

$$\sum(t2)-(\sum t)2[N(\sum D2)-(\sum D)2]\}1/2$$

N¿

{¿

$N\sum(Dt)-$¿

¿¿

where

D = Drawdown in meters

t = Time in minute

N= Number of observations

r = Coefficient of correlation

3.4.2.1 Draw down pattern

Time drawdown curve was obtained by plotting time along X axis and draw down along Y axis for each of the wells. Relationship between time and drawdown were developed by regression analysis.

3.4.2.2 Recuperation pattern

Time recovery curves were obtained by plotting time along X axis and recovery along Y axis time regression relationship were developed by regression analysis.

3.4.3 Time drawdown analysis

All the water discharged from a well in a confined aquifer must be derived from its storage by compression of the aquifer skeleton and expansion of water from reduction of hydrostatic pressure. Attainment of steady state flow is not possible as the release of water from the aquifer is solely related to the decline in head.

Theis (1935) developed an equation for unsteady state of flow for a well, based on the assumption that the flow of groundwater is analogues to the flow of heat and that the mathematical theory of heat conduction is largely applicable to hydraulic theory the formula derived was taking into an account the time factor and also the removal of water from storage in the development of the cone of depression.

For unconfined aquifer, the Theis equation, which was derived from the analogy between the flow of ground water and the conduction of heat, is written as,

$$S=\frac{Q}{4\pi KH}\int_0^\infty \frac{1}{y}e^{-y}dy=\frac{Q}{4\pi KH}W(u)$$

and

$$U = \frac{r^2\mu}{4KHt}$$

where

S = Drawdown measured in a well (m)

Q = Constant well discharge (m^3/day)

KH = Transmissivity of the aquifer (m^2/day)

r = Radius of the well (m)

µ = Specific yield of the aquifer

U = Help parameter

t = Time since pumping is started

W (u) = Theis well function

In the above equations, the exponential integral expression is symbolically expressed as W (u) for ‘well function u’.

$$W(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \dots$$

For the analysis of aquifer tests the following assumptions are to be considered.

- The aquifer has seemingly infinite areal extent.
- The aquifer is homogeneous, isotropic and is of uniform thickness.
- Prior to pumping, the hydraulic head is horizontal over the area influenced by the test.
- The aquifer is pumped at constant discharge rate.
- The flow to the well is in unsteady state.
- The water removed from storage is discharged instantaneously with decline of head.
- The diameter of the pumped well is small.

Other limiting conditions implied in the assumptions are – aquifer is horizontal and confined; has a constant coefficient of storage, is not recharged; the pumped well is fully penetrating and screened in the entire aquifer; the piezometric surface is horizontal and storage in the well can be neglected.

3.4.3.1 Theis Method

Theis (Wenzel, 1942) devised a convenient graphical method of superposition which makes if possible to obtain solutions for the aquifer constants. The non-equilibrium formula cannot be solved directly for *T* and *S*. the graphical method employs a type cure of *u* versus W (*u*). On log paper to analyse the drawdown distribution. The values of W(*u*) for the values of *u* are given by Wenzel.

$$\log s = \log\left(\frac{Q}{4\pi T}\right) + \log W(u)$$

$$\log \frac{r^2}{t} = \log\left(\frac{4T}{S}\right) + \log u$$

From the above, it is seen that if the discharge *Q* is held constant, the bracketed part of the equation are constant for a given pumping test and W(*u*) is related to *u* in the manner that s is related to $\frac{r^2}{t}$. If a well is pumped at a constant discharge Q and if drawdown s is measured for one value of r (i.e. at a single observation well.) and several values of t and several values of r (i.e. several observation wells), then S and T can be determined.

The procedure involved in the analysis is:

- Plot the type curve for the values of 1/u against W(u) as tabulated by Wenzel.
- Plot s against t of observation well on logarithmic tracing paper, to the same scale as that of the type curve. The curve so obtained will be similar in form and to match with some part of type curve, provided the assumptions on which the formula as derived are satisfied.
- The data curves superposed on the type curve, the coordinates axes of the two curves being held parallel and moved to a position of best fit with the type curve.
- At the match position, a point is selected and the coordinates of s,t, and W(u), 1/u) of which on both sheets are recorded. These coordinate values are then used in the simplified equations given below to solve for T and S.

$$T = \frac{Q}{4\pi s} \quad \mathrm{W(u)}$$

$$s = \frac{4uTt}{r^2}$$

3.4.3.2 Jacob's method

Cooper and Jacob (1942) showed that for values of u less than about 0.001 ($\frac{1}{u}$ greater than 100) the expression for W(u) in Theis equation can be replaced by the first two terms of the convergent series in as much as the as sum of the beyond $\log_e$u in the series can be neglected. Hence for large values of t and small values of r corresponding to values of u<0.001,

$$s=\frac{q}{4\pi s}(-0.5772-\log\frac{r^2}{4Tt})$$

$$s= \frac{2.303}{4\pi T}\ \mathbf{\log_{10}}\ \frac{2.25Tt}{r^{2s}}$$

From the above, it is apparent that the relationship of s is linear to the log terms of t and $\frac{t}{r^2}$ in the same manner as plot of u versus W(u) is a straight line for values of u<0.001, in a semi logarithmic graph.

The steps involved in Jacob's method are

- Plotting values of s on arithmetic scale and the corresponding values of t on the logarithmic scale. For one of the observation wells, plot values of drawdown s against time t, r being constant. For convenience the drawdown is taken as zero at the top so that it increases downwards. Straight lines are drawn passing through the plotted points. If the drawdown is determined for one log cycle of log term ,the equation for T is taken as

$$T=\frac{2.303Q}{4\pi\Delta s}$$

where

T $¿Transimissivity\in\frac{m^2}{day}$

Q ¿ Constant discharge in $\frac{m^3}{day}$

$\Delta s=¿$ Drawdown for one log cycle of t

t ¿ Time in days since pumping started

r ¿ Radial distance from discharge well to the point of observation in m

- The solution for S involves extrapolation of a straight line to intercept zero drawdown axis. At zero drawdown, the equation for S is,

$$S=\frac{2.25\,T\,t_0}{r^2}$$

where

t_0 ¿ Intercept of t of zero drawdown axis
r ¿ Radial distance from discharge well to the point observation in m.

3.4.3.3 Chow's method

Based on Theis non equilibrium equation, Chow (1952) developed a method that dispenses with the curve matching procedure in Theis' method and has an advantage over Jacob's method is that it can be applied even when u is greater than 0.01. However Theis' method has a wide range of application in solving boundary problems. Chow method is used for analyzing short duration tests. Chow gave table showing the relation between W(u), u and a function F(u). The function F(u)is given by,

$$F(u)=\frac{W(u)\,e^{u}}{2.30}$$

The procedure involves the analysis of time drawdown data of observation wells as follows:

- Plot one observation well the drawdown s versus time ton semi logarithmic graph paper with t on logarithmic scale and s on arithmetic scale.
- Select an arbitrary point Aon the curve of the plotted points. Draw a tangent to curve, through the point A.
- Read the coordinate values for the point A, drawdown s_A on the y axis and t_A on the x axis, also Δs per log cycle of time t.

- Calculate the value of F(u) for the point A, from

$$F(u)=\frac{s_A}{\Delta s_A}$$

- Read the values of W(u) and u for the values of F(u)from the table and substitute them along with the values of t_A and s_A in Theis' equation to solve the values for T and S.

$$u\text{¿}_A$$

$$T=\frac{Q}{4\pi s_A}W\text{¿}$$

$$S=\frac{4u_A T t_A}{r^2}$$

3.4.4 Jacob's modification of the Theis method

Theis well function W(u) is plotted versus 1/u on log graph paper. Then the Cooper and Jacob (1946) showed a straight line segment. The equation could be written as

$$S=\frac{2.3Q}{4\pi KH}\log\frac{2.25KHt}{r^2\mu}$$

If pumping time is long enough, the graph is plotted as drawdown vs. logarithm of time (t). Then

$$\text{KH} = \frac{2.3Q}{4\pi\Delta s}$$

If straight line is extended until it intercepts the time axis where s = 0, then the interception point has coordinates s = 0 and t = t_o. Substituting the values in above equation

$$S = \frac{2.25\, KHt_o}{r^2}$$

Jacob (1950) showed that if the drawdown in an unconfined aquifer is small compared with the initial saturated thickness of the aquifer, the condition of horizontal flow towards the well is approximately satisfied so that the Theis' equation which was originally developed for confined aquifers can be applied to aquifers as well.

3.4.5 Determination of specific capacity

There may be different sections contributing water to the open well. For each section specific capacity was determined using the following two methods,

<u>Average head method</u>

$$\frac{K}{A} = \frac{Ah}{h' ATr} \quad = \quad \frac{h}{h' Tr}$$

where

K/A= Specific capacity (cum/hr/ $m^2 depression\, head$)

A= Area of the well (m^2¿

h = Instantaneous rise in the depth of water (m) in time

$h' = Average\, depression\, head\,(m)$

__Slither's method__

$$\frac{K}{A} = \frac{A}{Tr} = \frac{H1}{H2}$$

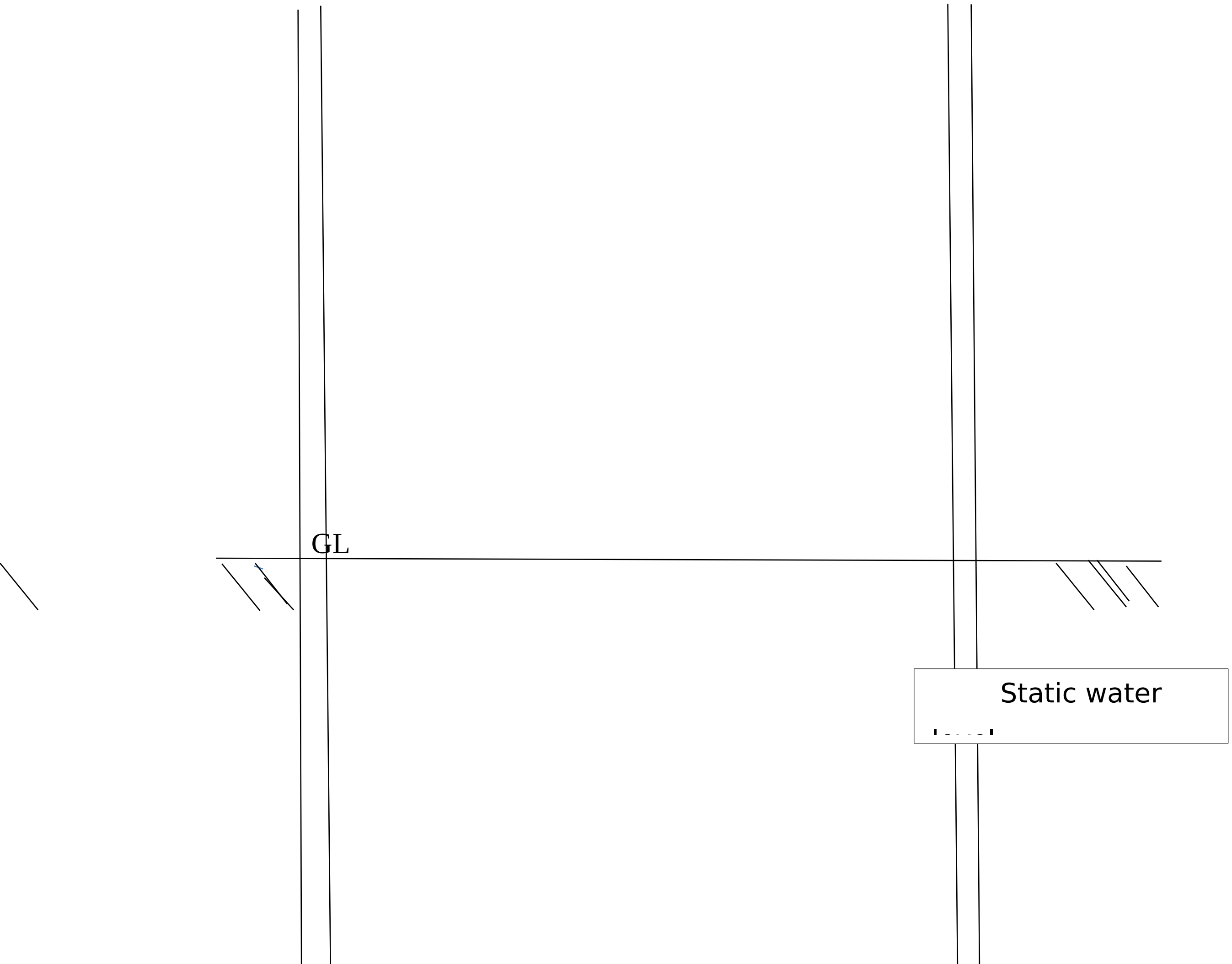
where

$H_2 = h' + h/2$

$H_1 = h' - h/2$

Tr= Transmissivity

h' and h are the same as above.



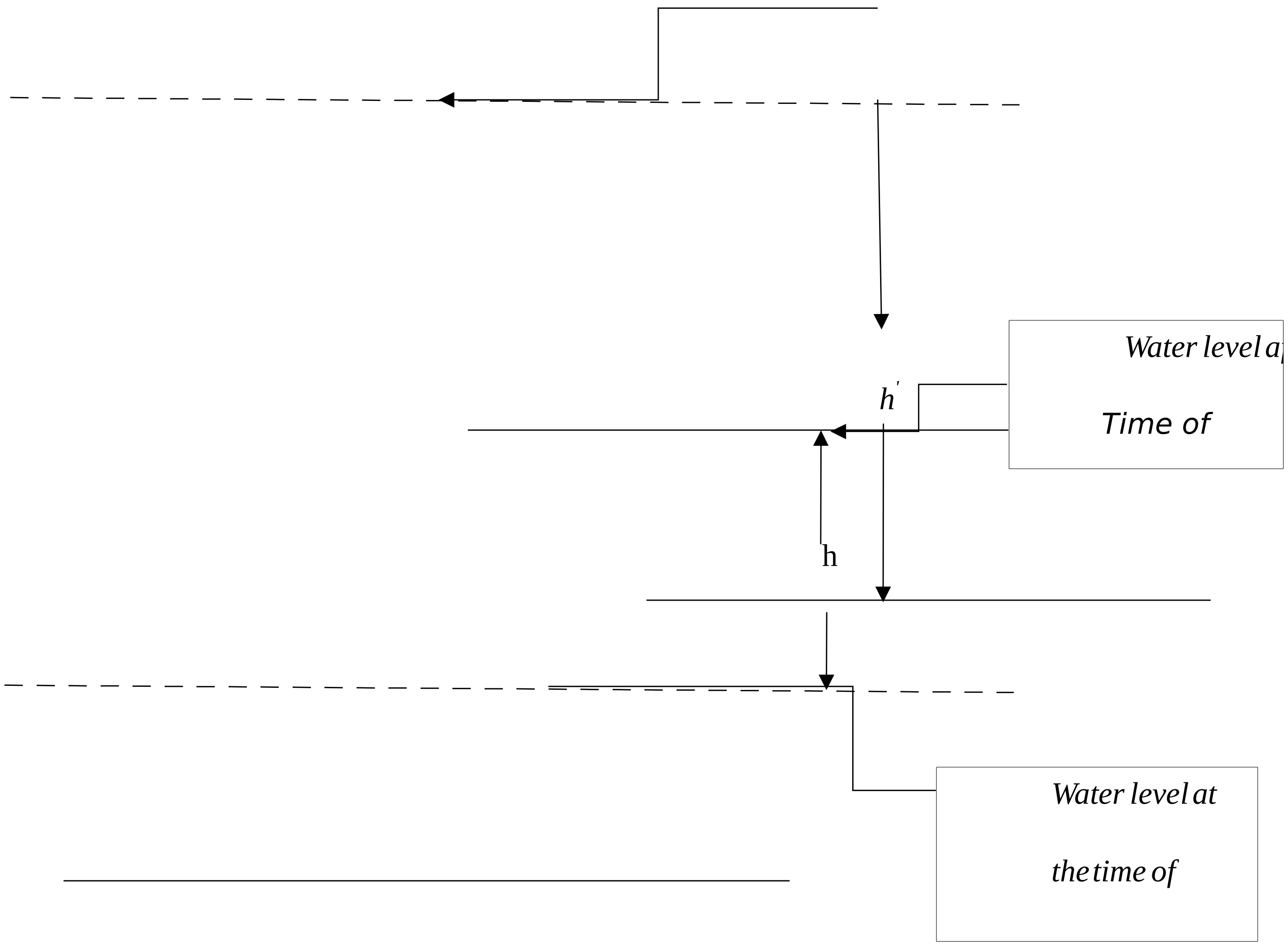


Fig.3.1 Definition sketch of the theory

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

Estimation of aquifer parameters is helpful to predict the future water table. The aquifer parameters obtained for three different formations and mathematical relationship developed between time versus drawdown and time versus recovery period are given. Also specific capacity of the well formations at different depth is calculated from the recuperation data. Particle size distribution of four soil near to wells are also included in this chapter.

4.1 DETERMINATION OF PARTICLE SIZE DISTRIBUTION OF THE SOIL

(Textural analysis)

The soil samples were collected from different representative locations. They were analyzed for grain size distribution. The results of the analysis for the each selected soil sample are shown in Appendix. 1. The particle size distribution curves drawn for these soil samples are shown below.

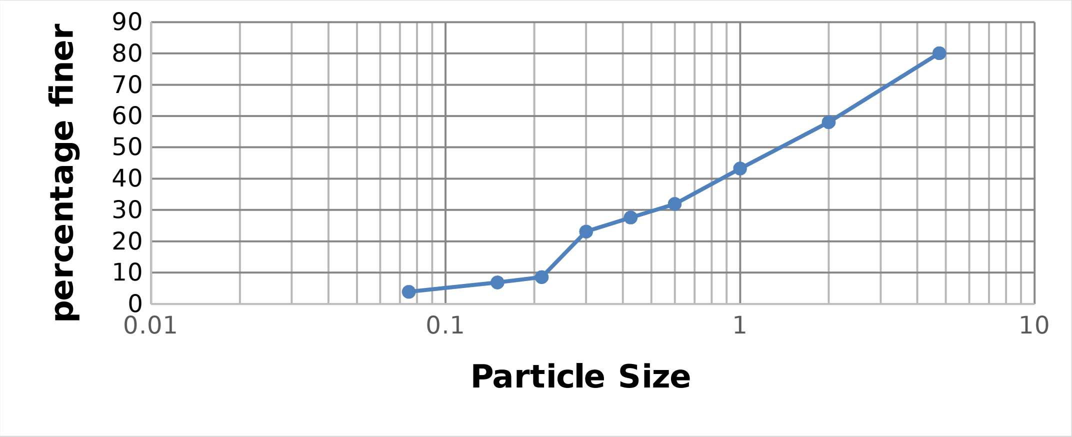
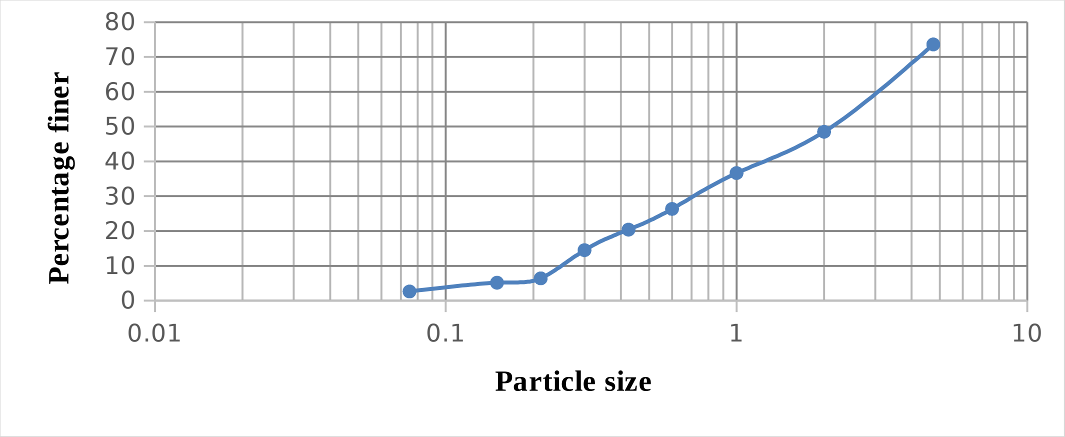


Fig. 4.1 Particle size distribution of soil near Well No. 1



The particle size distribution of farm soil lies in the range of 75µm to 4.75mm. The curve obtained is not an exact S curve and it is aligned towards the extreme right side of the graph which shows the soil contains negligible amount of clay.

Fig. 4.2 Particle size distribution of soil near Well. No. 6

The particle size distribution of soil collected from KSEB substation is having the range of 75µm to 4.75mm. From the data obtained, it is seen that the soil have some lateritic properties.

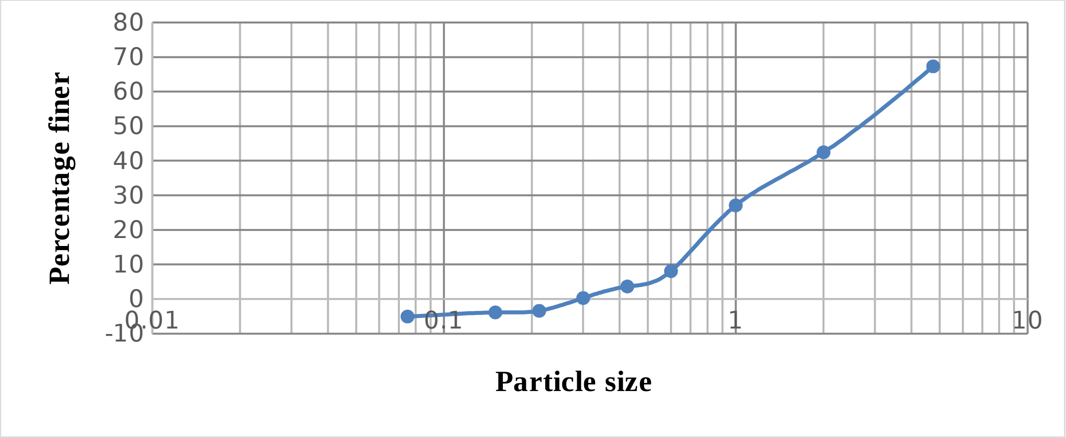


Fig. 4.3 Particle size distribution of soil near to Well No. 7

The particle size distribution of soil collected from near the pump house and is having the range of 75µm to 4.75mm

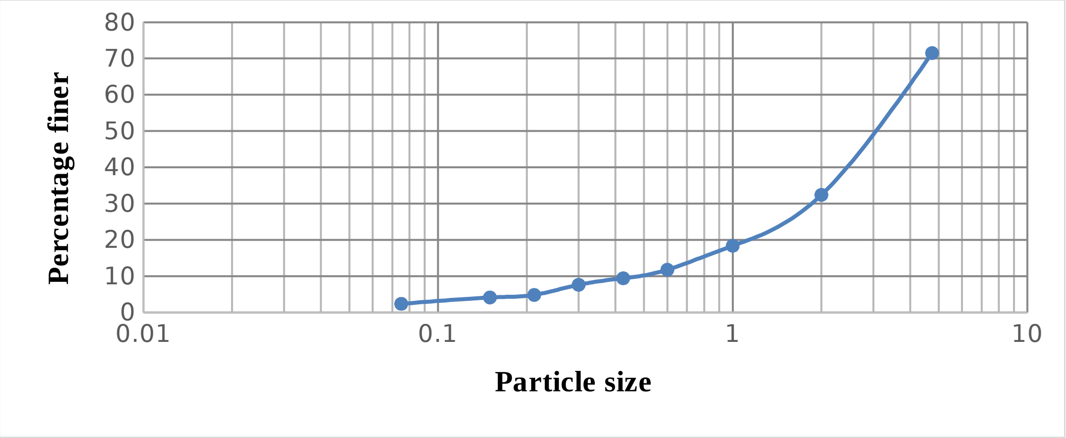


Fig. 4.4 Particle size distribution of soil near Well No. 8

The particle size distribution of soil collected from entrance of KCAET is having the range of 75µm to 4.75mm

4.2 Evaluation of aquifer parameters

The aquifer parameters of the well are calculated as described in Materials and Methods. Three methods are used for the evaluation of the aquifer constants. The methods adopted for the study are Theis' method, Chow method and Jacob's method.

For the analysis of the parameters by Jacob's method, the drawdown vs time (in log scale) is plotted and is given in Fig. 4.5. The plot is performed from the data obtained from pumping out test and is given in Table 4.2. Fig. 4.5 gives drawdown on arithmetic scale and the corresponding values of t on logarithmic scale. The method of analysis has the advantage that the relationship of s is linear to the log terms of t. The aquifer constants are evaluated by the methods illustrated as earlier and are given in Table. 4.2.

The aquifer constants are evaluated by Chow's method. This method is especially suited for analyzing short duration test. Graph is plotted by using time vs drawdown values given in Table 4.2. It is plotted by taking s on arithmetic scale and t on logarithmic scale and is given by Fig. 4.5. The aquifer constants so obtained is given in Table 4.2.

In the time drawdown plot the early drawdown are higher than those according to the theoretical curve based on Thies' equation. This may be due to time lag between the early elastic response of the aquifer and the subsequent downward movement of the water table due to gravity drainage, which is the delayed yield effect. From the time vs drawdown graph it was seen that in time drawdown plot the early drawdown are higher than those according to the theoretical curve based on Theis equation. In this case the early time drawdown should not be taken into consideration when judging the goodness of fit between the field data and the theoretical data. Due to the effect of delayed yield, clay formation starts contributing water from storage after 120min, but for laterite and alluvial formations the time is obtained as 30min and 20min respectively. This is due to the reason that the clay has high water holding capacity.

Table.4.1 Drawdown Response of Well No. 1

Time (min)	**Drawdown (m)**
1	0.02
2	0.03
3	0.04
4	0.05
5	0.06
6	0.08
7	0.09
8	0.1
9	0.11
10	0.12
12	0.14
14	0.16
16	0.175
18	0.19
20	0.2
24	0.23
30	0.27
35	0.3

40	0.33
45	0.36
50	0.38
60	0.43
70	0.48
80	0.53
90	0.59
100	0.625
120	0.67
140	0.76
160	0.84
180	0.92

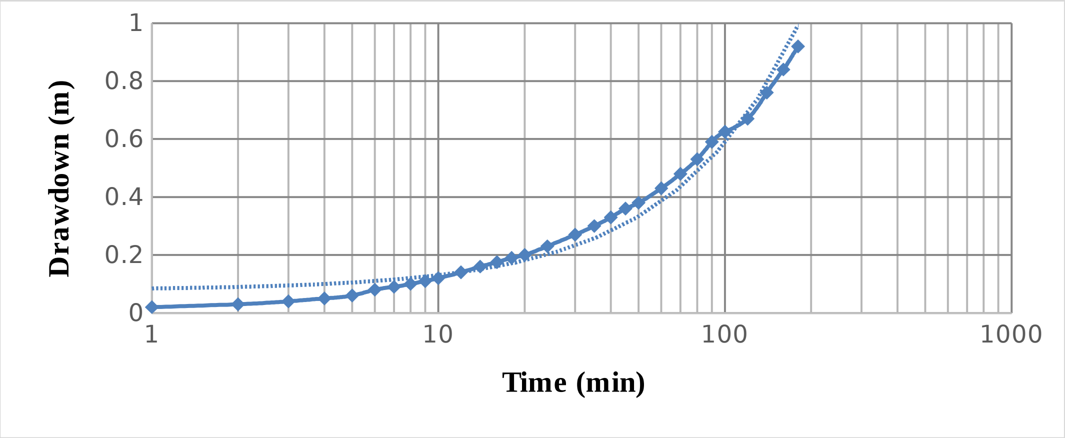


Fig. 4.5 Time-drawdown plot of Well No. 1

4.2.1 Hydraulic Conductivity

Hydraulic conductivity of the three different well formations is calculated and presented in Table 4.1. The alluvial formation can transmit water easily due to the porous nature. Hydraulic conductivity of laterite is found to be very near to that of clay, this may be due to the loose nature of laterite. Clay formations have low hydraulic conductivity.

4.2.2 Transmissivity

Transmissivity of the aquifer is dependent on the aquifer thickness and hydraulic conductivity. It is seen that transmissivity of the alluvial formation is larger than clay and laterite formation.

4.2.3 Specific Yield

The specific yield is the volume of water an unconfined aquifer releases from storage per unit surface area of the aquifer per decline of water table. Table 4.1 shows that the specific yield of clay is more than laterite and alluvial formations.

4.2.4 Specific capacity

Specific capacity of Well No.1 is computed at different depths from recuperation data as described in Table 4.2. Usually specific capacity of the wells decreases as pumping time increases. From the table it can also be seen that the specific capacity obtained by average head method matches with the computed value by Slitchers' method with minimum deviation at different depth in three wells. Regarding this study, the uneven variation in specific capacities of different recovery depths shows that wells are situated in heterogeneous formations and receive water from isolated zones. From the tables it can be seen that the average values of specific capacity in alluvial formation is comparatively greater than that of clay and laterite formation.

Table 4.2 Aquifer parameters

Types of well formations	Hydraulic conductivity (m/sec)	Transmissivity (m^2/sec)	Specific yield
Laterite	3.68×10^{-5}	1.25×10^{-4}	0.00135
Clay	3.12×10^{-5}	1.18×10^{-4}	0.0307

Alluvial	4.65 x 10^{-4}	1.30 x 10^{-3}	0.00249

Table 4.3 Specific capacity from recuperation data Well No. 1

Time (min)	Depth of water recovered (m)	Inst. Rise in depth of water h (m)	-Avg. dep. rise in water h/2 (m)	Avg. dep. head h' (m)	Avg. head method	Slitcher's method
1	0.01	0.01	0.005	5.38	0.0409	0.0408
2	0.02	0.01	0.015	5.37	0.0204	0.0204
3	0.03	0.01	0.025	5.36	0.0137	0.0316
4	0.04	0.01	0.035	5.35	0.0103	0.0103
5	0.05	0.01	0.045	5.34	0.00824	0.00824
6	0.06	0.01	0.055	5.33	0.0069	0.0069
7	0.07	0.01	0.065	5.32	0.00591	0.00591
8	0.08	0.01	0.075	5.31	0.00517	0.00518
9	0.09	0.01	0.085	5.3	0.00416	0.00415
10	0.1	0.01	0.095	5.29	0.00416	0.00416
12	0.12	0.02	0.11	5.275	0.00695	0.00695
14	0.135	0.015	0.1275	5.2575	0.00447	0.00447
16	0.155	0.02	0.145	5.24	0.00525	0.00525
18	0.165	0.01	0.16	5.225	0.0023	0.0024
20	0.185	0.02	0.175	5.21	0.00422	0.0042
25	0.22	0.035	0.2025	5.1825	0.00594	0.00594
30	0.25	0.03	0.235	5.15	0.00427	0.00427
35	0.285	0.035	0.2675	5.1175	0.1504	0.1504
40	0.315	0.03	0.3	5.085	0.00324	0.0032
45	0.34	0.025	0.3275	5.0575	0.00241	0.00241
50	0.36	0.02	0.35	5.035	0.00358	0.0036
60	0.41	0.05	0.385	5.0	0.00367	0.0036
70	0.445	0.035	0.4275	4.9575	0.00219	0.00219
80	0.48	0.035	0.4695	4.9225	0.00195	0.00194
90	0.51	0.03	0.495	4.89	0.0015	0.0016
100	0.53	0.02	0.52	4.865	0.0009	0.0009
120	0.58	0.05	0.555	4.83	0.00189	0.00189
140	0.62	0.04	0.6	4.785	0.0013	0.0013
160	0.67	0.05	0.645	4.74	0.00145	0.00145
180	0.69	0.02	0.68	4.68	0.00052	0.00052

4.2.5 Seasonal Water table variation of Wells

Seasonal water table variation of different wells located near KACET campus were analysed and were plotted. The seasonal water table variation of Well No. 1 is given in Table 4.3 and that of other wells are given in Appendix.

Table 4.4 Seasonal water table variation of Well No. 1

Date	Static water table (m)
30/08/2013	6
2/09/2013	6.15
5/09/2013	5
6/09/2013	5
7/09/2013	4.6
8/09/2013	5
9/09/2013	5.3
10/09/2013	5.3
11/09/2013	4.6
12/09/2013	5.31
13/09/2013	5.09
14/09/2013	4.33
15/09/2013	4.05
16/09/2013	3.95
17/09/2013	3.75
18/09/2013	3.34
19/09/2013	3.21
20/09/2013	3.37
21/09/2013	3.54
22/09/2013	3.61
23/09/2013	3.85
24/09/2013	4.02
24/09/2013	4.34
25/09/2013	4.36
26/09/2013	4.41
27/09/2013	4.2
28/09/2013	4.17
29/09/2013	4.13
30/09/2013	4.1
1/10/2013	4.26
2/10/2013	4.46
3/10/2013	4.5
4/10/2013	4.53
5/10/2013	5.3
6/10/2013	5.47
7/10/2013	5.33
8/10/2013	5.36

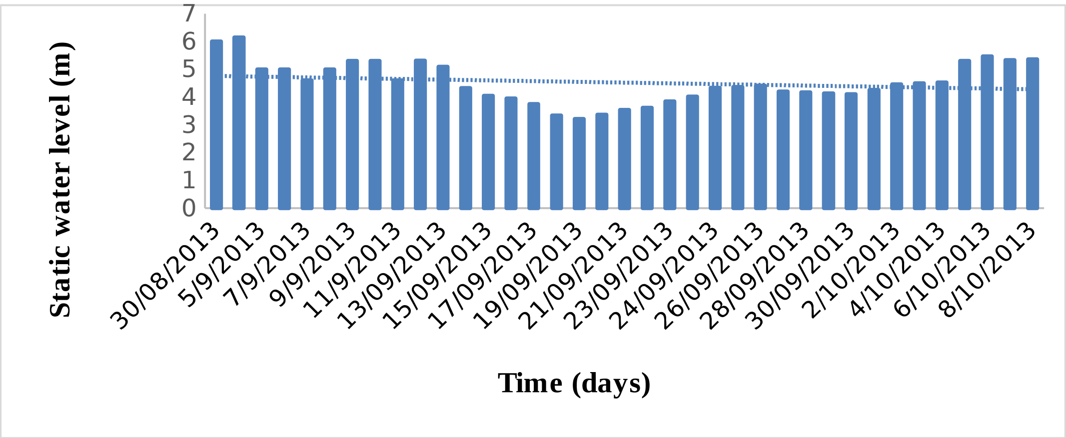


Fig. 4.6 Seasonal water table variation of Well No. 1

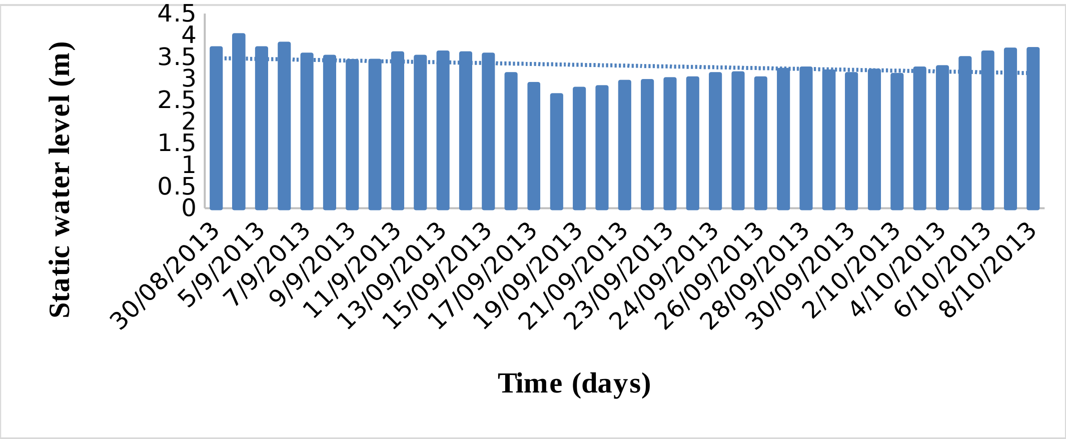


Fig. 4.7 Static water table variation of Well No. 2

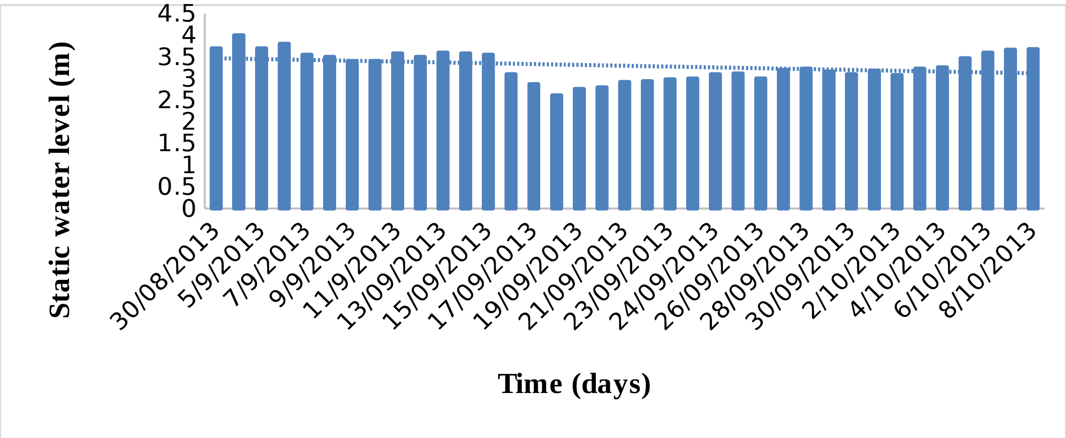


Fig 4.8 Seasonal water table variation Well No. 3

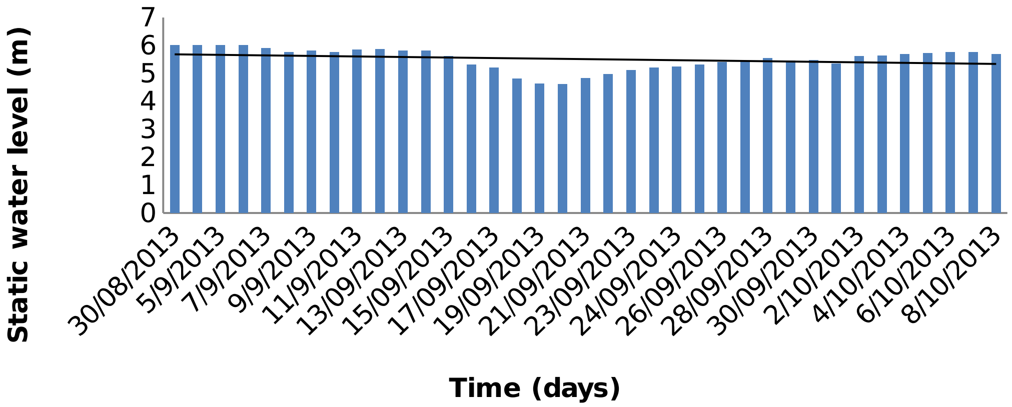


Fig. 4. 9 Seasonal water table variation of Well No. 4

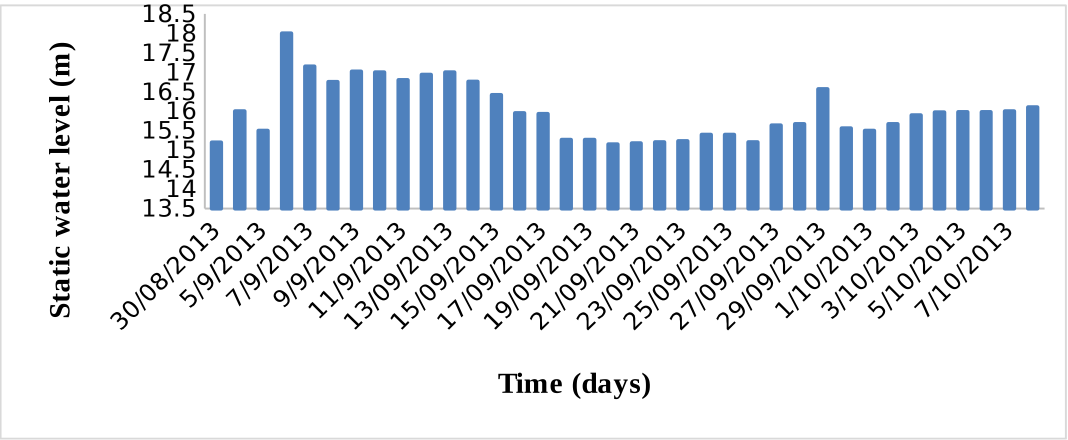


Fig. 4.10 Seasonal water table variation of Well No. 5

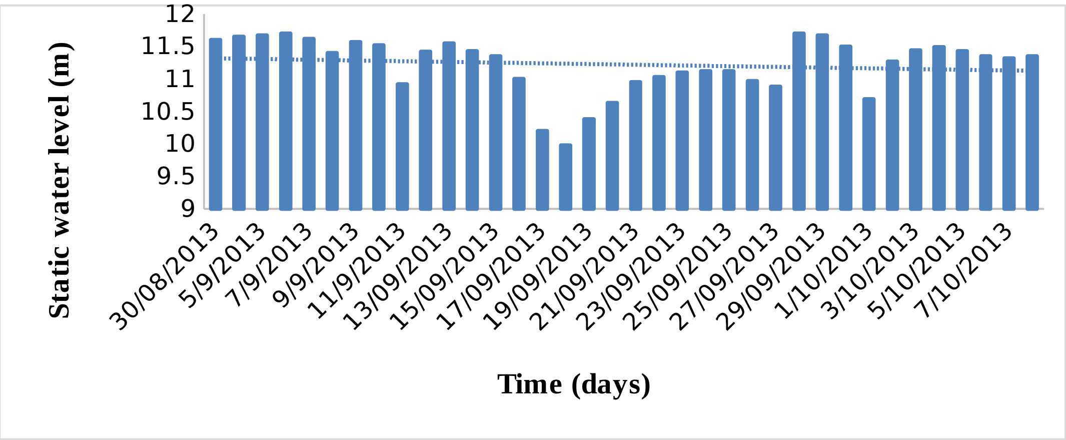


Fig. 4.11 Seasonal water table variation of Well No. 6

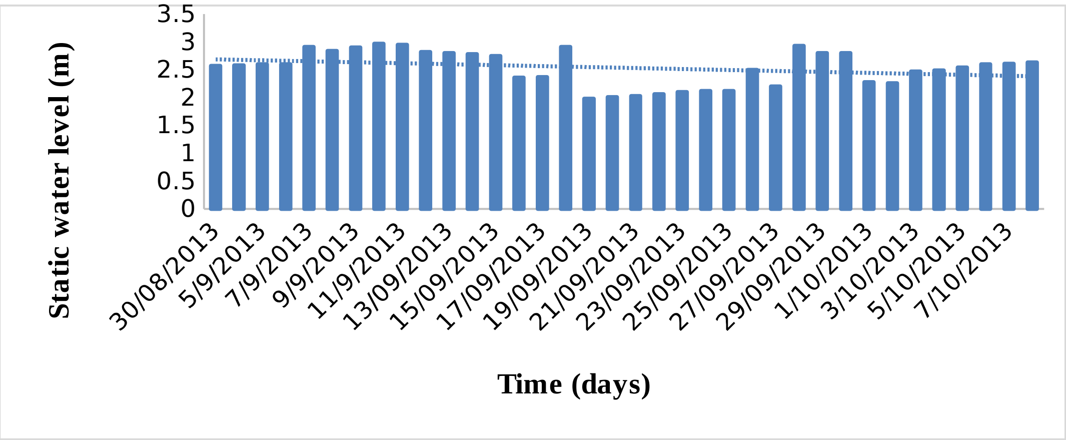


Fig. 4.12 Seasonal water table variation of Well No.7

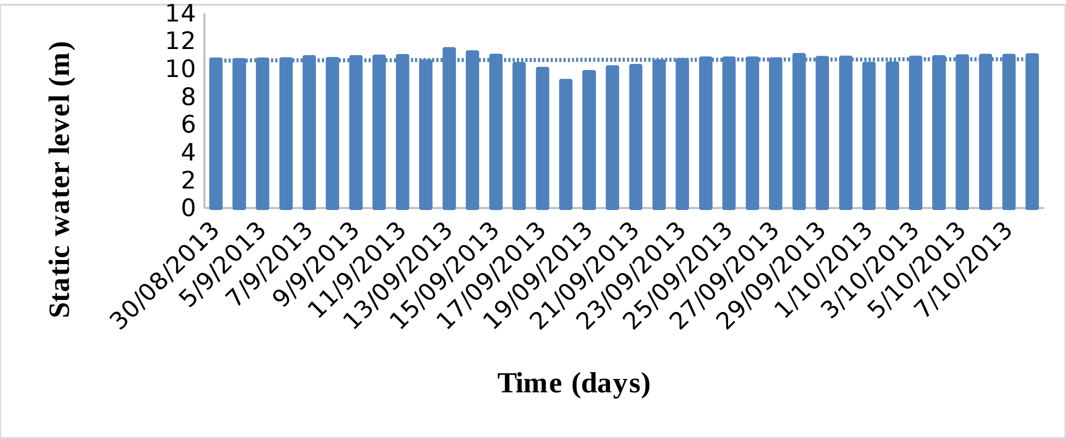


Fig. 4.13 Seasonal water table variation of Well No. 8

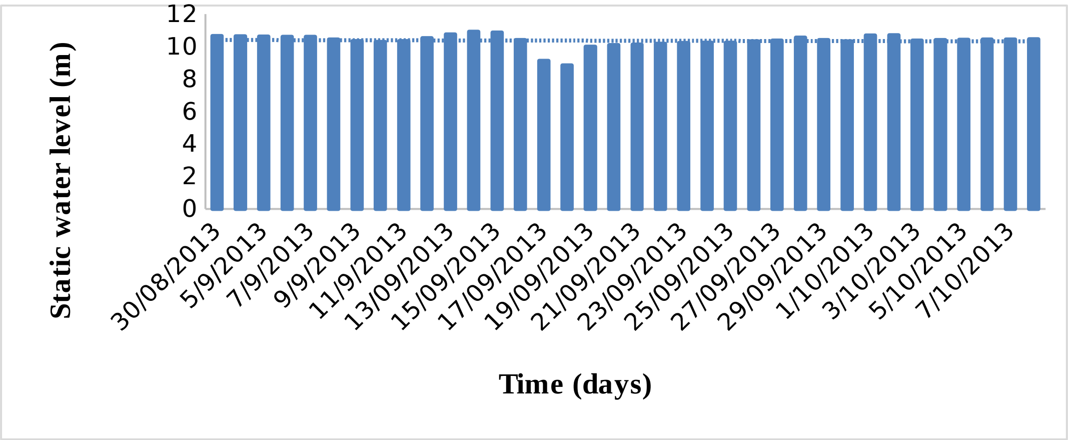


Fig. 4.14 Seasonal water table variation of Well No.9

4.2.6 Draw down and recovery response

The water level measurements are taken during drawdown and recovery stages, for the open well. Comparing recuperation pattern for well the recovery rate is maximum for alluvial formation. This is because the inflow of water takes place from all sides of the well. For well in the initial stages of recuperation, the later shows higher recuperation rate while towards the end of recuperation it is almost the same.

This is due to clay formation. In clay some permeable formations are present which stores water and supplies to the wells when hydraulic gradient becomes steeps.

4.2.7 Drawdown

The drawdown observations were used to plot the time drawdown curves for Well No.1 as shown in Fig 4.13. During the initial stages, time vs drawdown shows a linear relationship and gradually it becomes nonlinear. This is because the delayed yield effect and after that aquifer starts contribution to pumpage.

4.2.8 Time-Drawdown Relationship

Relation between time and drawdown for Well No. 1 is represented by the regression equation.

Well No.1

$s=0.00133t + 0.097253$

Coefficient of correlation = 0.097253

4.2.9 Recovery Curves

The time vs recovery curves for well No.1 is given by Table 4.5. The rate of recovery is seen to be fast in the initial phase and gradually decreases as the static water level is approached. The initial fast recovery rate is due to the steep hydraulic gradient .Ground water moves in the direction of decreasing head or potential.

Well No.1

$R = 0.00133t + 0.097253$

Coefficient of correlation = 0.097253

Table. 4.5 Recovery Response of Well No. 1

Time (min)	Recovery (m)
1	0.01
2	0.02
3	0.03
4	0.04
5	0.05
6	0.06
7	0.07
8	0.08
9	0.09
10	0.1
12	0.12
14	0.135
16	0.155
18	0.165
20	0.185
25	0.22
30	0.25
35	0.285
40	0.315
45	0.34
50	0.36
60	0.41
70	0.445
80	0.48
90	0.51
100	0.52
120	0.58
140	0.62
160	0.67
180	0.69

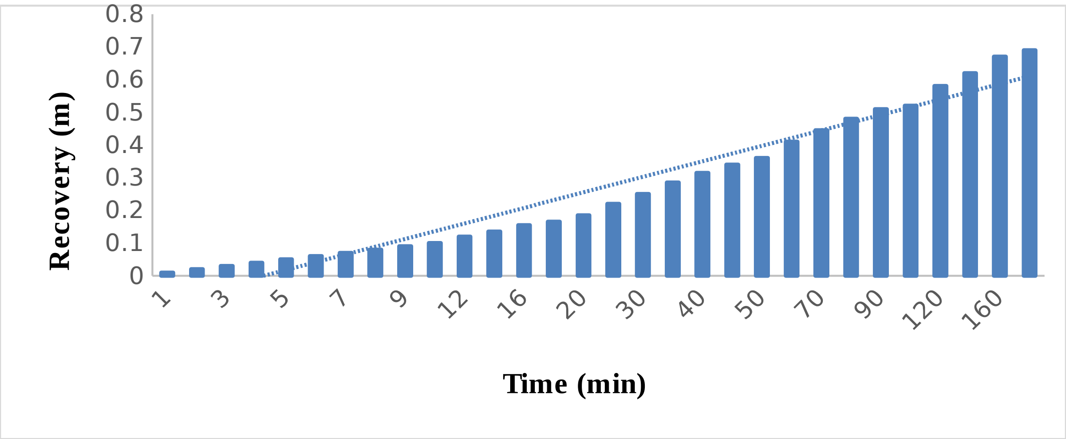


Fig. 4.15 Recovery curve of Well No. 1

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

Evaluation of hydraulic properties of aquifer and those of adjoining formation is an important aspect of any scheme of ground water resource assessment and for predicting future water table. Hence a field study is conducted to determine aquifer parameters for three different formation (laterite, clay and alluvial) of existing open wells and are evaluated by different methods viz. Theis method, Jacob method and Chow method for the drawdown data of pumping out test. Seasonal water level fluctuations in 9 open wells of different formations were collected.

The relevant features of experiment study are as follows:

- One well is allowed to pump and recuperate to the maximum water table. Then level measurements were taken during the recovery and drawdown period.
- The drawdown and time recovery curves were plotted for well using drawdown and recuperation data.
- Time drawdown and time recovery mathematical relationship were formulated by using regression analysis.
- Specific capacity of well at different depths was calculated by using average head method Slitcher’s method.
- Aquifer parameters are evaluated by Jacob’s method. For this time – drawdown graph is plotted on logarithmic scale.
- The drawdown curve shows a linear relationship during the initial phase of pumping because of pump storage.
- The recovery curve was found to be similar with initial fast rate recovery that is attributed to the steep hydraulic gradient in the beginning
- The aquifer parameters are determined using Jacob’s straight line method and are shown in the Results and Discussion.
- The specific capacity of the wells shows an uneven variation due to the heterogeneous formations present in the well. Specific capacity obtained by average head method shows minimum deviation as compared to Sticher’s method

- The calculated value of hydraulic conductivity ranges from 3.12 $*10^{-4}$ to 4.65* 10^{-4} m/sec for different formations. The hydraulic conductivity is maximum for alluvial and minimum for clay.
- The calculated value of transmissivity ranges from 1.25$*10^{-4}$ to 1.3$*10^{-3}$ m^2/sec.
- The calculated value for specific yield ranges from 0.00135 to 0.0307, maximum for clay and minimum for alluvial.

From this study it is clear that the knowledge of aquifer parameters is helpful in deciding proper utilization of groundwater for proper irrigation and other purposes.

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APPENDICES

Appendix. 1: Seasonal Water table Variation of Wells

1.1 Seasonal water table variation of Well No.2

Date	Static water table (m)
30/08/2013	4
2/09/2013	4.20
5/09/2013	4.30
6/09/2013	4.3
7/09/2013	4
8/09/2013	4
9/09/2013	4.1
10/09/2013	4.8
11/09/2013	4.15
12/09/2013	3.95
13/09/2013	4.23
14/09/2013	3.78
15/09/2013	3.16
16/09/2013	2.43
17/09/2013	2.18
18/09/2013	2.4
19/09/2013	2.57
20/09/2013	2.67
21/09/2013	2.76
22/09/2013	2.8
23/09/2013	2.84
24/09/2013	2.84
24/09/2013	2.67
25/09/2013	2.45
26/09/2013	3.1
27/09/2013	3.34
28/09/2013	3.24
29/09/2013	3.33
30/09/2013	3.23
1/10/2013	3.16
2/10/2013	3.59
3/10/2013	3.64
4/10/2013	3.73
5/10/2013	3.85
6/10/2013	3.26
7/10/2013	2.86
8/10/2013	2.62

1.2 Seasonal water table variation Well No. 3

Date	Static water level (m)

30/08/2013	3.7
2/09/2013	4
5/09/2013	3.7
6/09/2013	3.8
7/09/2013	3.55
8/09/2013	3.5
9/09/2013	3.4
10/09/2013	3.41
11/09/2013	3.58
12/09/2013	3.5
13/09/2013	3.6
14/09/2013	3.58
15/09/2013	3.55
16/09/2013	3.1
17/09/2013	2.87
18/09/2013	2.61
19/09/2013	2.76
20/09/2013	2.8
21/09/2013	2.92
22/09/2013	2.94
23/09/2013	2.98
24/09/2013	3
24/09/2013	3.1
25/09/2013	3.12
26/09/2013	3
27/09/2013	3.2
28/09/2013	3.23
29/09/2013	3.16
30/09/2013	3.1
1/10/2013	3.18
2/10/2013	3.08
3/10/2013	3.23
4/10/2013	3.26
5/10/2013	3.47
6/10/2013	3.6
7/10/2013	3.67
8/10/2013	3.68

1.3 Seasonal water table variation of Well No. 4

Date	Static water table (m)
30/08/2013	6
2/09/2013	6
5/09/2013	6
6/09/2013	6
7/09/2013	5.90
8/09/2013	5.75

9/09/2013	5.8
10/09/2013	5.75
11/09/2013	5.85
12/09/2013	5.87
13/09/2013	5.8
14/09/2013	5.8
15/09/2013	5.6
16/09/2013	5.3
17/09/2013	5.2
18/09/2013	4.8
19/09/2013	4.62
20/09/2013	4.6
21/09/2013	4.83
22/09/2013	4.97
23/09/2013	5.11
24/09/2013	5.2
25/09/2013	5.24
26/09/2013	5.3
27/09/2013	5.4
28/09/2013	5.45
29/09/2013	5.54
30/09/2013	5.45
1/10/2013	5.46
2/10/2013	5.33
3/10/2013	5.6
4/10/2013	5.63
5/10/2013	5.69
6/10/2013	5.73
7/10/2013	5.75
8/10/2013	5.74

1.4 Seasonal water table variation of Well No. 5

Date	Static water table (m)
30/08/2013	15.2
2/09/2013	16
5/09/2013	15.5
6/09/2013	18
7/09/2013	17.15
8/09/2013	16.75
9/09/2013	17.02
10/09/2013	17
11/09/2013	16.8
12/09/2013	16.94
13/09/2013	17
14/09/2013	16.76
15/09/2013	16.42

16/09/2013	15.95
17/09/2013	15.93
18/09/2013	15.27
19/09/2013	15.27
20/09/2013	15.15
21/09/2013	15.18
22/09/2013	15.21
23/09/2013	15.23
24/09/2013	15.4
25/09/2013	15.4
26/09/2013	15.21
27/09/2013	15.64
28/09/2013	15.67
29/09/2013	16.57
30/09/2013	15.56
1/10/2013	15.5
2/10/2013	15.67
3/10/2013	15.9
4/10/2013	15.97
5/10/2013	15.98
6/10/2013	15.98
7/10/2013	16
8/10/2013	16.1

1.5 Seasonal water table variation of Well No.6

Date	**Static water table (m)**
30/08/2013	11.6
2/09/2013	11.65
5/09/2013	11.67
6/09/2013	11.7
7/09/2013	11.62
8/09/2013	11.4
9/09/2013	11.57
10/09/2013	11.52
11/09/2013	10.92
12/09/2013	11.42
13/09/2013	11.55
14/09/2013	11.43
15/09/2013	11.35
16/09/2013	11
17/09/2013	10.2
18/09/2013	9.98
19/09/2013	10.38
20/09/2013	10.63
21/09/2013	10.95
22/09/2013	11.03

23/09/2013	11.1
24/09/2013	11.12
25/09/2013	11.12
26/09/2013	10.97
27/09/2013	10.88
28/09/2013	11.7
29/09/2013	11.67
30/09/2013	11.5
1/10/2013	10.69
2/10/2013	11.27
3/10/2013	11.44
4/10/2013	11.49
5/10/2013	11.43
6/10/2013	11.35
7/10/2013	11.32
8/10/2013	11.35

1.6 Seasonal water table variation of Well No. 7

Date	**Static water table (m)**
30/08/2013	2.57
2/09/2013	2.58
5/09/2013	2.6
6/09/2013	2.6
7/09/2013	2.91
8/09/2013	2.84
9/09/2013	2.9
10/09/2013	2.97
11/09/2013	2.95
12/09/2013	2.82
13/09/2013	2.8
14/09/2013	2.78
15/09/2013	2.75
16/09/2013	2.36
17/09/2013	2.37
18/09/2013	2.91
19/09/2013	1.98
20/09/2013	2.01
21/09/2013	2.03
22/09/2013	2.06
23/09/2013	2.1
24/09/2013	2.12
25/09/2013	2.12
26/09/2013	2.5
27/09/2013	2.2
28/09/2013	2.93
29/09/2013	2.8

30/09/2013	2.8
1/10/2013	2.28
2/10/2013	2.26
3/10/2013	2.47
4/10/2013	2.49
5/10/2013	2.54
6/10/2013	2.6
7/10/2013	2.61
8/10/2013	2.63

1.7 Seasonal water table variation of Well No. 8

Date	**Static water table (m)**
30/08/2013	10.68
2/09/2013	10.65
5/09/2013	10.69
6/09/2013	10.7
7/09/2013	10.86
8/09/2013	10.73
9/09/2013	10.85
10/09/2013	10.89
11/09/2013	10.93
12/09/2013	10.55
13/09/2013	11.43
14/09/2013	11.2
15/09/2013	10.95
16/09/2013	10.35
17/09/2013	10.02
18/09/2013	9.15
19/09/2013	9.79
20/09/2013	10.12
21/09/2013	10.23
22/09/2013	10.55
23/09/2013	10.64
24/09/2013	10.76
25/09/2013	10.76
26/09/2013	10.77
27/09/2013	10.7
28/09/2013	11.01
29/09/2013	10.8

30/09/2013	10.82
1/10/2013	10.37
2/10/2013	10.4
3/10/2013	10.81
4/10/2013	10.86
5/10/2013	10.91
6/10/2013	10.95
7/10/2013	10.96
8/10/2013	10.98

1.8 Seasonal water table variation Well No. 9

Date	**Static water table (m)**
30/08/2013	10.65
2/09/2013	10.63
5/09/2013	10.62
6/09/2013	10.6
7/09/2013	10.6
8/09/2013	10.44
9/09/2013	10.34
10/09/2013	10.3
11/09/2013	10.34
12/09/2013	10.53
13/09/2013	10.75
14/09/2013	10.92
15/09/2013	10.87
16/09/2013	10.41
17/09/2013	9.13
18/09/2013	8.85
19/09/2013	10
20/09/2013	10.1
21/09/2013	10.12
22/09/2013	10.18
23/09/2013	10.23
24/09/2013	10.25
25/09/2013	10.25
26/09/2013	10.32

27/09/2013	10.37
28/09/2013	10.56
29/09/2013	10.41
30/09/2013	10.33
1/10/2013	10.68
2/10/2013	10.7
3/10/2013	10.37
4/10/2013	10.4
5/10/2013	10.42
6/10/2013	10.44
7/10/2013	10.43
8/10/2013	10.45

Appendix2: Particle Size Distribution of Soil Samples in Different Wells

2.1 Particle size distribution of soil near to Well No. 1

Mass of dry soil sample = 1640g

IS Sieve	**Particle size(mm)**	**Mass retained(g)**	**% retained**	**cumulative % retained**	**cumulative % finer**
4.75mm	4.75	327.049	19.942	19.942	80.058
2mm	2	361.475	22.041	41.983	58.017
1mm	1	242.622	14.794	56.777	43.223
600	0.6	185.245	11.295	68.073	31.927
425	0.425	71.311	4.348	72.421	27.579
300	0.3	73.770	4.498	76.919	23.081
212	0.212	238.524	14.544	91.463	8.536
150	0.15	27.868	1.699	93.163	6.837
75	0.075	49.180	2.998	96.162	3.838
Tray		50			

2.2 Particle size distribution of soil near to Well No.6

Mass of dry soil sample = 1000g

IS Sieve	Particle size(mm)	Mass retained(g)	% retained	cumulative % retained	cumulative % finer
4.75mm	4.75	264	26.4	26.4	73.6
2mm	2	251	25.1	51.5	48.5
1mm	1	118.5	11.85	63.35	36.65
600	0.6	103	10.3	73.65	26.35
425	0.425	59.5	5.95	79.6	20.4
300	0.3	59	5.9	85.5	14.5
212	0.212	81	8.1	93.6	6.4
150	0.15	12.5	1.25	94.85	5.15
75	0.075	25	2.5	97.35	2.65
Tray		21			

2.3 Particle size distribution of soil near to Well No. 7

Mass of dry soil sample = 1000g

IS Sieve	Particle size(mm)	Mass retained(g)	% retained	cumulative % retained	cumulative % finer
4.75mm	4.75	327	32.7	32.7	67.3
2mm	2	248.5	24.85	57.55	42.45
1mm	1	153.6	15.36	72.91	27.09
600	0.6	190	19	91.91	8.09
425	0.425	44.5	4.45	96.36	3.64
300	0.3	33.5	3.35	99.71	0.29
212	0.212	37	3.7	103.41	-3.41
150	0.15	4.5	0.45	103.86	-3.86
75	0.075	12	1.2	105.06	-5.06
tray		12			

2.4 Particle size distribution of soil near to Well No. 8

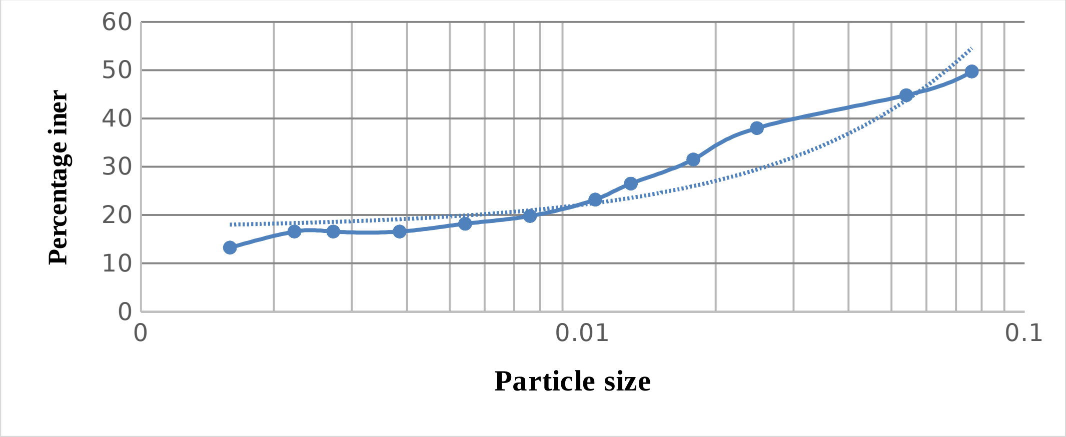
Mass of dry soil sample = 1000g

IS Sieve	**Particle size(mm)**	**Mass retained(g)**	**% retained**	**cumulative % retained**	**cumulative % finer**
4.75mm	4.75	285	28.5	28.5	71.5
2mm	2	391	39.1	67.6	32.4
1mm	1	140.5	14.05	81.65	18.35
600	0.6	66	6.6	88.25	11.75
425	0.425	23.5	2.35	90.6	9.4
300	0.3	18	1.8	92.4	7.6
212	0.212	28	2.8	95.2	4.8
150	0.15	7	0.7	95.9	4.1
75	0.075	17.5	1.75	97.65	2.35
tray		19			

Appendix. 3: Hydrometer Analysis of Farm soil

Time	density	Rh	He	D	Wd	N
30sec	1.015	15	13.6	0.076	$24.868*10^{-3}$	49.73
1min	1.0135	13.5	14.6	0.054	$22.4*10^{-3}$	44.8
5	1.0115	11.5	15.3	0.0248	$19*10^{-3}$	38
10	1.0095	9.5	15.75	0.0178	$15.75*10^{-3}$	31.5
20	1.008	8	16.4	0.01285	$13.264*10^{-3}$	26.5
30	1.007	7	17	0.01068	$11.6*10^{-3}$	23.2
1hr	1.006	6	17.2	0.007598	$9.94*10^{-3}$	19.8
2	1.0055	5.5	17.5	0.005419	$9.11*10^{-3}$	18.2
4	1.005	5	17.7	0.00385	$8.29*10^{-3}$	16.58
8	1.005	5	17.7	0.002725	$8.29*10^{-3}$	16.58

12	1.005	5	17.7	0.002225	$8.29*10^{-3}$	16.58
24	1.004	4	18.1	0.00159	$6.632*10^{-3}$	13.26



Appendix 4: Pycnometer analysis of Farm soil

Dry wt. of pycnometer(g), w_1	493g
wt. of dry soil sample(g), w_d	250g
wt. of pycnometer + soil(g), w_2	743g
pycnometer + soil + water, w_3	1575g
pycnometer + water, w_4	1424g
W_3-W_4	151g
specific gravity=wd/[(w_4-w_3)+w_d]	2.52

ABSTRACT

Aquifer parameters are very important for the solution of ground water flow problems. The knowledge of aquifer parameters to predict the water table variations and the possibility of conjunctive use. A field study was conducted in three open wells tapping laterite, clayey and alluvial formations to determine the aquifer parameters from pumping test data. The aquifer parameters of each well were determined by the time-drawdown analysis using Jacob’s method. The alluvial formation showed high value of hydraulic conductivity than that of laterite and clay formations due to its permeable nature. The specific capacity of the aquifer determined using average head method and Slitcher’s method showed an uneven variation, which may be due to the heterogeneous nature of the formation. Regression analysis of drawdown and recuperation curves was done for three wells. Drawdown and recuperation increase with time. Knowledge of these parameters is helpful in deciding proper utilizing of ground water for irrigation and other purposes.