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SENSITIVITY ANALYSIS OF AQUIFER PARAMETERS IN ANANTPUR DIST. (A.P.)

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Abstract

Pumping and Recovery test data of six open wells of Anantpur District in Andhrapradesh have been analysed through various existing methods of pumping and recovery test data analysis. The sensitivity feature of corresponding drawdown or recovery to these estimated parameters have been checked to suggest most reliable method of test design for the region. The most reliable values have been suggested. Kumaraswamy's method of recovery test design have been found out most sensitive out of the methods that are used.

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1.0 Introduction:

Estimation of groundwater balance and flowpaths requires appropriate aquifer parameters, representing the study domain. In hard rock region these parameters are highly heterogeneous and/or anistropic. Even a very fine network of lithologs and monitoring wells is not sufficient to define the spatial variation of these parameters. In addition to that complete uncertainty prevails regarding selection of suitable method for the analysis pumping and recovery test data. Various analytical methods and corrections are available for estimating aquifer parameters(NIH,85 and CGWB,86) but selection of suitable match is a tough job.

Dug wells are the prime source of ground water in hard rock areas, which generally draw water from the shallow aquifer. It is difficult to decide the extent of penetration and the condition under which groundwater flow in to the wells. These wells are mostly used to estimate the aquifer parameters, with pumping and monitoring being carried out in the same well. Assumptions like Dupit's approximation and effect of well storage is yet to be ascertained correctly. More-over problems associated with the analysis of fractured media would always be there.

Most interesting point in knowing any groundwater system is the transformation of a steady state domain to unsteady condition due to various disturbances. One of them and most regular feature is the effect of well pumping and subsequent recovery. What is the most sensitive parameter to replicate the existing scenario is of prime importance. Mathematically, the sensitivity is a partial derivative which represents the change in head resulting from change in a model parameter. System response may be designated by the drawdown or recovery in the well.

Anantpur district of Andhra Pradesh faces acute groundwater shortages, almost every year atleast during summer. Most of the open wells get dried up due to over-exploitation as compared to safe yield which depends upon the aquifer parameters. Present study is a try to gain in-depth knowledge of the behavior of the open wells in this region through sensitivity analysis of the aquifer parameters and its method of pumping test design. The same analysis can be applied to other regions and/or to other type of wells also in future.

2.0 Problem definition:

Research objectives behind this study are as follows;

1. To analyse pumping and recovery test data using various existing methods.
2. To analyse theoretically the sensitivity of drawdown and recovery to parameters.
3. To select sensitive parameters and suitable method for parameter estimation.

3.0 Study Area:

3.1 Anantpur District

The geographical area of the district is about 19,135 sq. kms of which 10 percent is under forest and 44 percent of the area is under irrigation. There are 63 Mandals covering 950 villages in the district. The population of the district is 31.03 lakhs as per 1991 census. The annual normal rainfall in the district is 521 mm. The maximum temperature 40 C and minimum 15 C. Penna., Chitravathi, and Hagari are the important rivers which flow through the district. The area irrigated under canal system is 43,222 hectares, 20,891 hectares is under tanks and 1,17,000 hectares under 65,603 dug wells/ borrowers. The area irrigated (year wise) under surface and groundwater along with rainfall is depicted in a Fig 3.1. Most of the area in the district is covered by red and black cotton soils.The district is underlain by Archaeans, Cuddaph, Kurnool group of rocks and valley fill deposits. Granites, gneisses and schists of Archaen Age occur in all the taluks except in Tadipatri taluk. At some places these rocks are intruded by dolerite dykes and pegmatite veins.

3.2 Hydrogeology

In granites, gneisses and schists groundwater occur under water table conditions, and is confined to weathered zones, joints, fractures etc. Dugwells, dug-cum-borewells and at some selected places borewells are feasible. Dugwells to a depth of 7 to 18 m and borewells to a depth upto 35 m are feasible. The yield of these wells varies from 20,000 to 2,00,000 lpd. which can irrigate 0.5 to 5 hectares of land. The quartzites, shales, limestones of the Cuddapah group are seen in parts of Tadipathri, Gooty, and Anantapur taluks, whereas quartzites, limestones and shales of Kurnool group are mainly confined to parts of Tadiptri taluk. Groundwater in these rocks occur in Bedding Planes, fractures and in solution cavities of limestone formations. Dugwells to a depth of 8 to 25 m and at selected places borewells to a depth of 40 to 75 m are feasible in these rocks. The yield of the dug wells varies from 40,000 to 2,00,000 lpd. and of borewells varies from 20,000 to 45,000 lph. which can irrigate 1 to 5 hectares of land. Valleyfill deposits are mainly confined along the rivers, streams etc. In valleyfill deposits dugwells to a depth of 5 to 12 m. and filterpoints to a depth of 10 to 17 m are feasible. The yield of these wells varies from 18,000 to 48,000 lph. with which 1 to 5 hectares of land can be irrigated. Under exploratory drilling programme 486 borewells were drilled within depths range from 30 to 60 m. The yield of the borewells ranges between 6,000 to 25,000 lph.

The Groundwater department has established 142 general observation wells in the district, and 63 observation wells established in canal command area. There are 14 stream flow check points on different stream of districts to measure the base flow. The analysis of last 12 years of average pre-monsoon depth to water levels in the district revealed that there is a net fall of 4.68 m The estimated groundwater resources of the district are 1248.10 MCM of which the utilisable groundwater resource is 1,061.71 MCM and net groundwater draft is 391.20 MCM leaving the balance of 670.51 MCM with which an additional 84,595 wells with pumpsets can be constructed.

Year	Annual Rainfall in mm	Average Pre-monsoon Water Level In m bgl.	Change in water levels in successive years + Rise - Fall
1983-84	**601**	**6.28**	--
1984-85	**411**	**8.11**	**-1.82**
1985-86	**387**	**7.55**	**+0.55**
1986-87	**439**	**10.00**	**-2.45**
1987-88	**718**	**9.24**	**+0.76**
1988-89	**757**	**8.59**	**+0.65**
1989-90	**705**	**6.88**	**+1.71**
1990-91	**482**	**7.60**	**-0.72**
1991-92	**539**	**8.67**	**-1.07**
1992-93	**433**	**9.27**	**-0.60**
1993-94	**593**	**9.23**	**+0.04**
1994-95	--	**9.93**	**-.70**

3.3 Water Resources Utilisation

Ananthapur is one the most drought affected district of Andhra Pradesh. The Normal Annual rainfall of the district is 521 mm compared to the State normal of 925 mm. Analysis of the rainfall occurred during the last 20 years that is from 1974 -75 to 1994-95 reveals that during 8 years the rainfall below normal where as during 13 years the rainfall was above normal Lowest annual rainfall of 377 mm has occurred during the year 1994-95 whereas highest rainfall of 757 mm was during 1988-89. Normal rainy days in the district varies from 31.7 to 34.6 days. Intensity of rainy days occur during the months July to October.

In Anantapur district irrigation is being practiced under surface water bodies and groundwater resources. The area irrigated under surface water bodies constitutes 38.95 % . Interesting phenomena observed is that the constant increase, groundwater irrigation from 1988 irrespective of fall in surface water irrigation and rainfall.

4.0 Theoretical Background

Flow property of a groundwater system is defined by hydraulic conductivity and storage property by specific capacity or storativity, depending upon the condition of groundwater flow. The sensitivity of drawdown/recovery to flow and storage parameters can be defined as :

$$U_T = \frac{\partial s}{\partial T}$$

$$U_S = \frac{\partial s}{\partial S}$$

Where U_T & Us are called sensitivity coefficient or simply sensitivity with respect to flow parameter(T) and storage parameter(S) and s represents drawdown or recovery. For the sake of convenience in comparing the results, units of T & S has to be removed. Which gives:

$$U'_T = \frac{\partial s}{\partial T / T}$$

$$U'_S = \frac{\partial s}{\partial S / S}$$

U'_T and U'_S are the normalised sensitivity which describes the influence of ratio change in parameters and is an absolute magnitude.

4.1 Sensitivity Features of Aquifer Parameters in Analytical Solutions:

4.1.1 Theis Equation:

Theis equation describes radial confined groundwater flow towards a pumping well with negligible well storage in a homogeneous, isotropic aquifer of infinite areal extent:

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

where

$$W(u) = \int_u^\infty \frac{e^{-x}}{x} dx = 0.577216 - \ln u + u - \frac{u^2}{2!2} + \frac{u^3}{3!3} - \frac{u^4}{4!4} + \ldots\ldots\ldots\ldots$$

and $u = \frac{r^2 S}{4Tt}$

Q is the pumping rate; s is the drawdown at radial distance r at time t; and W(u) is the well function. The normalised sensitivities with respect to T and S as per McElwee and Yukler(1978) are:

$$U'_T = T\frac{\partial s}{\partial T} = -\frac{Q}{4\pi T}\left[W(u) - e^{-u}\right]$$

$$U'_S = S\frac{\partial s}{\partial S} = -\frac{Q}{4\pi T}e^{-u}$$

Expression for normalised sensitivities in terms of time 't';

$$U'_T = \frac{Q\left[e^{-\frac{r^2 S}{4Tt}} + Ei\left(-\frac{r^2 S}{4Tt}\right)\right]}{4\pi T}$$

$$U'_S = -\frac{Qe^{-\frac{r^2 S}{4Tt}}}{4\pi S^2 T}$$

where Ei = Exponential Integral for t = - infinity to u.

Cooper and Jacob(1946) restricted the well function series up to second term for large value of 't' or small value of distance 'r'. Hence Theis equation becomes;

$$s = \frac{Q}{4\pi T}\left(-0.5772 - \ln\frac{r^2 S}{4Tt}\right)$$

$$s = \frac{Q}{4\pi T}\left(\ln\frac{4Tt}{r^2 S} - 0.5772\right)$$

$$s = \frac{Q}{4\pi T}\ln\frac{2.25Tt}{r^2 S}$$

$$s = \frac{Q}{4\pi}\left[\frac{1}{T}\ln 2.25Tt - \frac{\ln r^2 S}{T}\right]$$

$$\frac{\partial s}{\partial T / T} = 0.079567Q\left(-\frac{\ln(2.25Tt)}{T} + \frac{1}{T} + \frac{\ln(r^2 S)}{T}\right)$$

$$\frac{\partial s}{\partial S / S} = -0.079567\frac{Q}{T}$$

Papadopulos- Cooper(1967) added the effect of well storage in the early part of pumpage to Theis Equation, which gives rise to following modified equation:

$$s = \frac{Q}{4\pi T} F(\theta, \alpha, \varphi)$$

Where $F(\theta, \alpha, \varphi)$ is a function having $\theta = \frac{4Tt}{r^2 S}$, $\alpha = \frac{r^2{}_w S}{r^2{}_c}$ and $\varphi = \frac{r}{r_w}$. The index "w" stands for "at the pumped well" and, r_c = radius of unscreened part of the well. For Dug wells , $r_c = r_w$ and hence $\alpha = S$.

When $r = r_w$, the drawdown, s_w inside the well of a large diameter is given by ,

$$s_w = \frac{Q}{4\pi T} F(\theta_w, \alpha, 1) = \frac{Q}{4\pi T} W$$

This duration of well storage effect is dependent upon the diameter of the pumped well and transmissivity of the aquifer. The larger the diameter or the poorer the transmissivity of aquifers, the greater is this time.

Normalised sensitivities could be expressed in the same way as in Theis Method with modified transmissivity and storativity values.

4.1.2 Slichter s and Modified Slitcher's Equation for Recovery Phase.

Slitcher (1906) developed following equation for large diameter well having flow only from the bottom.

$$C = \frac{A}{t^!} \ln \frac{S_1}{S_2}$$

where C is the Specific Capacity and A is the Cross Sectional Area of the well. Water level raises from S_1 to S_2 in time $t^!$. Rearranging the equation in terms of recovery h above the final draw down level H ;

$$h = \frac{\left(1 - e^{Ct/A}\right)H}{e^{Ct/A}}$$

$$\frac{\partial h}{\partial C} = -\frac{tH}{A} - \frac{\left(1 - e^{Ct/A}\right)Ht}{e^{Ct/A} A}$$

Muskat(1937) extended the use of Slitcher's equation for estimation of transmissivity by combining it with the Theis solution (1906) for steady state flow.

$$T = \frac{C^{l} A}{2\pi t} \ln \frac{S_1}{S_2}$$

where

$$C^{l} = \ln \frac{r_0}{r_w}$$

A is the Cross Sectional Area of the well, r_0 is the distance at which draw down is negligible at the end of pumping period. r_w is the radius of the well.

Rearranging the above equation

$$h = \frac{\left(1 - e^{2\pi T t / C^{l} A}\right) H}{e^{2\pi T t / C^{l} A}}$$

$$\frac{\partial h}{\partial T} = -6.284 \frac{tH}{C^{l} A} - 6.284 \frac{\left[\left(1 - e^{6.284 T t / C^{l} A}\right) Ht\right]}{\left(e^{6.284 T t / C^{l} A}\right) C^{l} A}$$

4.1.3. Kumaraswamy's Method for Recovery Phase.

Kumaraswmay (1973) observed that the conventional methods of determining the transmissivity and storativity cannot be applied in hard rock areas because of their anisotropy and occurrence of flow in the well through fissure planes and conduits. He felt that open wells in hard rock have appreciable storage capacity, low inflows and no formation of cone of depression during pumping. Mathematically, he expressed it interms of following equation.

$$w = \frac{a}{D} \frac{\ln \sqrt{\frac{1 + d1/D}{1 - d1/D}} - \ln \sqrt{\frac{1 + d2/D}{1 - d2/D}}}{t_R}$$

where w is hard rock well permeability, D is the height of static water column, d_1 is water column after pumping, d_2 is the water column after recuperation, a is the cross sectional area of the well and t_R is time taken for recuperation. Simplifying the above equation and substituting d2-d1=h.

$$\ln\sqrt{\frac{1+{}^{d1}\!/_{D}}{1-{}^{d1}\!/_{D}}}-\sqrt{\frac{1+{}^{d2}\!/_{D}}{1-{}^{d2}\!/_{D}}}=\frac{WDt_R}{a}$$

$$\sqrt{\frac{\left(1+{}^{d1}\!/_{D}\right)\left(1-{}^{d2}\!/_{D}\right)}{\left(1-{}^{d1}\!/_{D}\right)\left(1+{}^{d2}\!/_{D}\right)}}=e^{\frac{WDt_R}{a}}$$

$$\frac{D^2-hD-d1d2}{D^2+hD-d1d2}=\left(e^{\frac{WDt_R}{a}}\right)^2$$

$$h=\frac{\left(D^2-d1d2\right)\left(1-e^{\frac{2wDt_R}{a}}\right)}{D\left(1+e^{\frac{2wDt_R}{a}}\right)}$$

$$\frac{\partial h}{\partial w}=-2\frac{\left(D^2-d1d2\right)te^{\frac{2wDT_R}{a}}}{a\left(1+e^{\frac{2wDt_R}{a}}\right)}-2\frac{\left((D^2-d_1d2)(1-e^{2wD/a})te^{\frac{2wDt_R}{a}}\right)}{D\left(1+e^{\frac{2wDt_R}{a}}\right)^2a}$$

5.0 Analysis of Pumping & RecoveryTest Data

Pumping.and recovery test data of six dug wells in the Anantpur district has been analysed though following methods.

Theis's method of estimation of Storativity and Transmissivity.
Jacob's method of estimation of Storativity and Transmissivity.
Popodopolus & Cooper method of estimation of Storativity and Transmissivity.
Slitcher's method of estimation of Specific Capacity.
Muskat' method of estimation of Transmissivity.
Kumaraswamy's method of estimation of Rock mass Permeability.

These estimations are described well-wise in the following paragraphs.

5.1 Nallampalli Well.

5.1.1 Well characteristics

Total Depth: 7.2 metres.
Dimension : 9 mX 9 m
Geology: Weathered & Fractured Granite.
Type of Lift : 5 hp motor
Discharge : 764 lpm.
Duration of Pumping : 215 minutes
Total Drawdown : 2.41 metres.
Pumping and Recovery phase data is tabulated in Annexure-A.

5.1.2 Storativity & Transmissivity Computation by Theis Method.

..Theis type curve on a double logarithmic plot is prepared from the values given by Wenzel(Mutreja) in Annexure-G.

..Plot for the values of drawdown(s) against r^2/t is shown in Fig 5.1.

..Selection of Match point gives following values.

W(u)= 0.45 , u= 0.6 , s= 0.035 m , r^2/t = 1.5 sq. m / min.

.. Storativity and Transmissivity values are estimated as below.

$$T = \frac{Q}{4\pi s} W(u) = 0.78163 \text{ sq. m / min}$$

$$S = \frac{4Tu}{r^2/t} \qquad = 0.3125$$

5.1.3 Storativity and Transmissivity Computation by Jacob's Method.

. Plot between drawdown 's' against the corresponding time 't' is shown in Fig 5.2.

..Extension of the best fit line to intercept time axis gives t_o= 200 min.

... Slope of the straight line portion of the curve, Δs= 0.125 m/min

.... $T = \frac{2.3Q}{4\pi\Delta s}$ = 0.486 sq. m/min

$$S = \frac{2.25Tt_o}{r^2} = 2.7$$

5.1.4 Storativity and Transmissivity computation by Papadopulos-Cooper's method.

. Type Curve given by Papadopulos and Cooper is drawn and shown in Annexure H.

.. Plot of the observed drawdown 's' versus 't' is shown in fig 5.3.

... Superimposition of the Fig 5.3 on Annexure H , and choosing an arbitrary point gives following corresponding values.

F(θ,α,Φ)= 0.014 , θ= 140 , s= 2.0E-1 m , t= 1.7E+1 min

.... $T = \frac{Q}{4\pi s} F(\theta,\alpha,\varphi)$ = 0.000429 sq. m / min.

$$S = \frac{4Tt}{r^2\theta} \qquad = 0.00000064$$

5.1.5 Specific Capacity Computation by Slitcher's Method.

. Plot between Time since pumping stopped 't`' and ratio of S_1 and s_2 is plotted in Fig 5.4.

.. Corresponding values of 't`' and 'log s_1/s_2' for an arbitrary point is;

t` = 235 min , log s_1/s_2 = 0.02

. $C' = 2.3 \frac{A}{t'} \log_{10} \frac{s_1}{s_2}$ 0.0158 sq. m/min.

5.1.6 Transmissivity Computation by Muskat(1937) approach.

. Plot between Time since pumping stopped 't'' and ratio of S1 and s2 is plotted in Fig 5.4.

.. Corresponding values of 't'' and 'log s1/ s2' for an arbitrary point is;

$t' = 235$ min , log s1/ s2=0.02, $r_0 = 100$ m, $r_w=5.08$ m.

... $C'' = \log_e \frac{r_o}{r_w}$ = 2.9798

.... $T = 2.3 \frac{C''A}{2\pi t'} \log_{10} \frac{s_1}{s_2}$ = 0.0075195 sq. m/min

5.1.7 Rock mass Permeability computation by Kumaraswamy's method.

. Cross-sectional area of the well, a= 81 sq. m.

.. Static water column, D= 2.45 m.

... Water column after pumping, d1=0.04

.... Water column after recovery, d2 = 0.64

..... Time taken to recuperate from d1 to d2, tR = 360 minutes.

...... Rock mass Permeability,

$$w = \frac{a}{D} \frac{\ln\sqrt{\frac{1 + d_1/D}{1 - d_1/D}} - \ln\sqrt{\frac{1 + d_2/D}{1 - d_2/D}}}{t_R}$$ = 0.0230596 m / min.

5.1.8 Abstract of the Estimated Parameters.

Sr.no.	Method of estimation	Flow Parameter	Storage parameter in ratio
1	**THEIS SOLUTION**	**0.78163 sq. m/min**	**0.3125**

2	**JACOB SOLUTION**	**0.486 sq. m/min**	**2.7**
3	**POPODOPULOS-COOPER METHOD**	**0.000429 sq. m/min**	**0.00000064**
4	**SLITCHER SOLUTION**	**0.0158 sq. m/min**	
5	**MUSKAT SOLUTION**	**0.0075195 sq. m/min**	
6	**KUMARSWAMY'S METHOD**	**0.0230596 m/min**	

5.2 Kondampalli Well.

5.2.1 Well characteristics

Total Depth: 8.3 metres.
Dimension : 7.1 m X 10.3 m
Geology: Granite.
Type of Lift : 5 hp motor.
Discharge : 490.6 lpm.
Duration of Pumping : 290 minutes
Total Drawdown : 1.63 metres.
Pumping and Recovery phase data is tabulated in Annexure-B.

5.2.2 Storativity & Transmissivity Computation by Theis Method.

..Plot for the values of drawdown(s) against r^2/t is shown in Fig 5.5.

.. Selection of Match point gives following values.

W(u)= 0.45 , u= 0.6 , s= 0.8 m , r^2/t = 0.1 sq. m / min.

.. Storativity and Transmissivity values are estimated as below.

$$T = \frac{Q}{4\pi s} W(u) = 0.022 \text{ sq. m / min}$$

$$S = \frac{4Tu}{r^2/t} = 0.1006$$

5.2.3 Storativity and Transmissivity Computation by Jacob's Method.

. Plot between drawdown 's' against the corresponding time 't' is shown in Fig 5.6.

..Extension of the best fit line to intercept time axis gives t_o= 400 min

... Slope of the straight line portion of the curve. Δs=0.05 m/min

.... $$T = \frac{2.3Q}{4\pi\Delta s} = 1.7959 \text{ sq. m / min}$$

$$S = \frac{2.25Tt_o}{r^2} = 15.235$$

5.2.4 Storativity and Transmissivity computation by Papadopulos-Cooper's method.

.. Plot of the observed drawdown 's' versus 't' is shown in fig 5.7.

... Superimposition of the Fig 5.7 on Annexure-H , and choosing an arbitrary point gives following corresponding values.

$F(0,\alpha,\Phi)= 2.2$, $0= 2.5$ E+04 , s= 4.0E-1 , t= 1.0E+2

.... $T = \frac{Q}{4\pi s} F(\theta,\alpha,\varphi) = 0.2147$ sq. m/min

$S = \frac{4Tt}{r^2\theta} = 0.000032$

5.2.5 Specific Capacity Computation by Slitcher's Method.

. Plot between Time since pumping stopped 't'' and ratio of S_1 and s_2 is plotted in Fig 5.8

.. Corresponding values of 't'' and 'log s_1/s_2' for an arbitrary point is;

t' = 70 min , log s_1/s_2 0.004.

.. $C = 2.3 \frac{A}{t'} \log_{10} \frac{s_1}{s_2} = 0.00961$

5.2.6 Transmissivity Computation by Muskat(1937) approach.

. Plot between Time since pumping stopped 't'' and ratio of S1 and s2 is plotted in Fig 5.8.

.. Corresponding values of 't'' and 'log s1/ s2' for an arbitrary point is;

t' = 70 min, log s1/ s2=0.004, $r_0 = 100$ m, r_w=5.15 m.

... $C'' = \log_e \frac{r_o}{r_w} = 2.9661$

.... $T = 2.3 \frac{C'' A}{2\pi t'} \log_{10} \frac{s_1}{s_2} = 0.00454$ sq. m/min.

5.2.7 Rock mass Permeability computation by Kumaraswamy's method.

. Cross-sectional area of the well, a= 73.13 sq. m.

.. Static water column, D= 6.1 m.

... Water column after pumping, d1=4.37

.... Water column after recovery, d2 = 4.555

..... Time taken to recuperate from d1 to d2, tR = 150 minutes.

...... Rock mass Permeability,

$$w = \frac{a}{D}\,\frac{\ln\sqrt{\frac{1+d_1/D}{1-d_1/D}} - \ln\sqrt{\frac{1+d_2/D}{1-d_2/D}}}{t_R} = 5.23\text{E-3 m / min.}$$

5.2.8 Abstract of the Estimated Parameters.

Sr.no.	Method of estimation	Flow Parameter	Storage parameter
1	**THEIS SOLUTION**	**0.022 sq. m/min**	**0.1006**
2	**JACOB SOLUTION**	**1.7959 sq. m/min**	**15.235**
3	**POPODOPULOS-COOPER METHOD**	**0.2147 sq. m/min**	**0.000032**
4	**SLITCHER SOLUTION**	**0.00961 sq. m/min**	
5	**MUSKAT SOLUTION**	**0.00454 sq. m/min**	
6	**KUMARSWAMY'S METHOD**	**0.00523 m/min**	

5.3 Gollapalli Well.

5.3.1 Well characteristics

Total Depth: 11.2 metres.
Dimension : 12 m X 12 m
Geology: Granite.
Type of Lift : 5 hp motor.
Discharge : 740 lpm.
Duration of Pumping : 180 minutes
Total Drawdown : 1.28 metres.
Pumping and Recovery phase data is tabulated in Annexure-C.

5.3.2 Storativity & Transmissivity Computation by Theis Method.

..Plot for the values of drawdown(s) against r^2/t is shown in Fig 5.9.

.. Selection of Match point gives following values.

W(u)= 0.20 , u= 0.8 , s= 0.027 , r^2/t = 8.0. sq. m / min.

.. Storativity and Transmissivity values are estimated as below.

$$T = \frac{Q}{4\pi s} W(u) = 0.436 \text{ sq. m/min}$$

$$S = \frac{4Tu}{r^2/t} = 0.1745$$

5.3.3 Storativity and Transmissivity Computation by Jacob's Method.

. Plot between drawdown 's' against the corresponding time 't' is shown in Fig 5.10.

..Extension of the best fit line to intercept time axis gives t_o= 250 min

... Slope of the straight line portion of the curve, Δs=0.08 m/min

.... $$T = \frac{2.3Q}{4\pi\Delta s} = 1.693 \text{ sq. m / min}$$

$$S = \frac{2.25Tt_o}{r^2} = 6.6133$$

5.3.4 Storativity and Transmissivity computation by Papadopulos-Cooper's method.

.. Plot of the observed drawdown 's' versus 't' is shown in fig 5.11.

... Superimposition of the Fig 5.11 on Annexure-H , and choosing an arbitrary point gives following corresponding values.

F(θ,α,Φ)= 8E-1 , θ= 8E+3 , s= 3.0E-1 m , t= 4.0E+1 min

.... $T = \frac{Q}{4\pi s} F(\theta, \alpha, \varphi) = 0.157$ sq. m/min

$$S = \frac{4Tt}{r^2\theta} = 0.0002181$$

5.3.5 Specific Capacity Computation by Slitcher's Method.

. Plot between Time since pumping stopped 't`' and ratio of S_1 and s_2 is plotted in Fig 5.12.

.. Corresponding values of 't`' and 'log $s_{1/}$ s_2' for an arbitrary point is;

t`= 100 min , log $s_{1/}$ $s_{2=0.03}$

... $C = 2.3 \frac{A}{t`} \log_{10} \frac{s_1}{s_2}$ - 0.09936

5.3.6 Transmissivity Computation by Muskat(1937) approach.

. Plot between Time since pumping stopped 't`' and ratio of S1 and s2 is plotted in Fig 5.12.

.. Corresponding values of 't`' and 'log s1/ s2' for an arbitrary point is;

t`= 100 , log s1/ s2 = 0.03, r_0 = 100 m, r_w=6.00 m.

... $C` = \log_e \frac{r_o}{r_w} = 2.8134$

.... $T = 2.3 \frac{C`A}{2\pi t`} \log_{10} \frac{s_1}{s_2} = 0.0445$ sq. m/min

5.3.7 Rock mass Permeability computation by Kumaraswamy's method.

. Cross-sectional area of the well, a= 144 sq. m.

.. Static water column, D= 3.9 m.

... Water column after pumping, d1=2.62

.... Water column after recovery, d2 = 3.205

..... Time taken to recuperate from d1 to d2, tR = 240 minutes.

...... Rock mass Permeability,

$$w = \frac{a}{D} \frac{\ln\sqrt{\frac{1+{}^{d_1}/_{D}}{1-{}^{d_1}/_{D}}} - \ln\sqrt{\frac{1+{}^{d_2}/_{D}}{1-{}^{d_2}/_{D}}}}{t_R} = 0.1244928 \text{ m / min.}$$

5.3.8 Abstract of the Estimated Parameters.

Sr.no.	Method of estimation	Flow Parameter	Storage parameter
1	**THEIS SOLUTION**	**0.436 sq. m/min**	**0.1745**
2	**JACOB SOLUTION**	**1.693 sq. m/min**	**6.6133**
3	**POPODOPULOS-COOPER METHOD**	**0.157 sq. m/min**	**0.0002181**
4	**SLITCHER SOLUTION**	**0.09936 sq. m/min**	
5	**MUSKAT SOLUTION**	**0.0445 sq. m/min**	
6	**KUMARSWAMY'S METHOD**	**0.1244928 m/min**	

5.4 Tammapuram Well.

5.4.1 Well characteristics

Total Depth: 9.5 metres.
Dimension : 8.5 m X 18.5 m
Geology: Granite.
Type of Lift : 7.5 hp motor.
Discharge : 405 lpm.
Duration of Pumping : 153 minutes
Total Drawdown : 2.36 metres.
Pumping and Recovery phase data is tabulated in Annexure-D.

5.4.2 Storativity & Transmissivity Computation by Theis Method.

..Plot for the values of drawdown(s) against r^2/t is shown in Fig 5.13.

.. Selection of Match point gives following values.

W(u)= 0.35 , u= 0.7 , s= 0.15 m , r^2/t = 2.0. sq. m / min.

.. Storativity and Transmissivity values are estimated as below.

$$T = \frac{Q}{4\pi s} W(u) = 0.0752 \text{ sq. m/min}$$

$$S = \frac{4Tu}{r^2/t} = 0.10528$$

5.4.3 Storativity and Transmissivity Computation by Jacob's Method.

. Plot between drawdown 's' against the corresponding time 't' is shown in Fig 5.14.

..Extension of the best fit line to intercept time axis gives t_o= 170 min

... Slope of the straight line portion of the curve, Δs=0.15

.... $T = \frac{2.3Q}{4\pi\Delta s} = 0.4942$ sq. m/min

$$S = \frac{2.25Tt_o}{r^2} = 2.616$$

5.4.4 Storativity and Transmissivity computation by Papadopulos-Cooper's method.

.. Plot of the observed drawdown 's' versus 't' is shown in fig 5.15.

... Superimposition of the Fig 5.15 on Annexure-H , and choosing an arbitrary point gives following corresponding values.

$F(\theta,\alpha,\Phi)$= 8E-1 , θ= 8E+3 , s= 7.0E-1 m , t= 4.0E+1 min

.... $$T = \frac{Q}{4\pi s} F(\theta, \alpha, \varphi) = 0.0368 \text{ sq. m/min}$$

$$S = \frac{4Tt}{r^2\theta} = 0.00010196$$

5.4.5 Specific Capacity Computation by Slitcher's Method.

. Plot between Time since pumping stopped 't'' and ratio of S_1 and s_2 is plotted in Fig 5.16.

.. Corresponding values of 't'' and 'log s_1/s_2' for an arbitrary point is;

t'= 150 min , log $s_{1/} s_{2=0.5}$

... $$C = 2.3\frac{A}{t'}\log_{10}\frac{s_1}{s_2} = 0.55392 \text{ sq. m/min}$$

5.4.6 Transmissivity Computation by Muskat(1937) approach.

. Plot between Time since pumping stopped 't'' and ratio of S1 and s2 is plotted in Fig 5.16.

.. Corresponding values of 't'' and 'log s1/ s2' for an arbitrary point is;

t'= 150 min , log s1/ s2 = 0.5 , r_0 = 100 m, r_w=4.25 m.

... $$C' = \log_e \frac{r_o}{r_w} = 3.1582$$

$$....T = 2.3\frac{C'A}{2\pi t'}\log_{10}\frac{s_1}{s_2} \quad = 0.2784 \text{ sq. m/min}$$

5.4.7 Rock mass Permeability computation by Kumaraswamy's method.

. Cross-sectional area of the well, a= 72.25 sq. m.

.. Static water column, D= 3.1 m.

... Water column after pumping, d1=0.74 m

.... Water column after recovery, d2 = 1.93 m

..... Time taken to recuperate from d1 to d2, tR = 280 minutes.

...... Rock mass Permeability,

$$w = \frac{a}{D}\,\frac{\ln\sqrt{\frac{1+d_1/D}{1-d_1/D}} - \ln\sqrt{\frac{1+d_2/D}{1-d_2/D}}}{t_R} = 0.0471765 \text{ m / min.}$$

5.4.8 Abstract of the Estimated Parameters.

Sr.no.	Method of estimation	Flow Parameter	Storage parameter
1	**THEIS SOLUTION**	**0.0752 sq. m/min**	**0.1052809**
2	**JACOB SOLUTION**	**0.4942 sq. m/min**	**2.616**
3	**POPODOPULOS-COOPER METHOD**	**0.0368 sq. m/min**	**0.00010196**
4	**SLITCHER SOLUTION**	**0.55392 sq. m/min**	
5	**MUSKAT SOLUTION**	**0.2784 sq. m/min**	
6	**KUMARSWAMY'S METHOD**	**0.0471765 m/min**	

5.5 Basamvaripalli Well.

5.5.1 Well characteristics

Total Depth: 7.6 metres.
Dimension : 11.8 m X 8.2 m
Geology: Granite.
Type of Lift : 5 hp motor.
Discharge : 480 lpm.
Duration of Pumping : 190 minutes
Total Drawdown : metres.
Pumping and Recovery phase data is tabulated in Annexure-E.

5.5.2 Storativity & Transmissivity Computation by Theis Method.

..Plot for the values of drawdown(s) against r^2/t is shown in Fig 5.17.

.. Selection of Match point gives following values.

W(u)= 0.35 , u= 0.7 , s= 0.4 m , r^2/t = 0.80. sq. m / min.

.. Storativity and Transmissivity values are estimated as below.

$$T = \frac{Q}{4\pi s} W(u) = 0.0334 \text{ sq. m/min}$$

$$S = \frac{4Tu}{r^2/t} = 0.117$$

5.5.3 Storativity and Transmissivity Computation by Jacob's Method.

Plot between drawdown 's' against the corresponding time 't' is shown in Fig 5.18.

..Extension of the best fit line to intercept time axis gives t_o= 240

... Slope of the straight line portion of the curve, Δs=0.083

.... $T = \frac{2.3Q}{4\pi\Delta s} = 1.058$ sq. m/min

$$S = \frac{2.25Tt_o}{r^2} = 4.105$$

5.5.4 Storativity and Transmissivity computation by Papadopulos-Cooper's method.

.. Plot of the observed drawdown 's' versus 't' is shown in fig 5.19.

... Superimposition of the Fig 5.19 on Annexure-H , and choosing an arbitrary point gives following corresponding values.

$F(\theta,\alpha,\Phi)$= 8E-1 , θ= 8E+3 , s=9.0E-1 m , t= 100 min .

.... $T = \frac{Q}{4\pi s} F(\theta, \alpha, \varphi) = 0.03395$ sq. m/min

$$S = \frac{4Tt}{r^2\theta} = 0.000122$$

5.5.5 Specific Capacity Computation by Slitcher's Method.

. Plot between Time since pumping stopped 't'' and ratio of S_1 and s_2 is plotted in Fig 5.20.

.. Corresponding values of 't'' and 'log s_1/s_2' for an arbitrary point is;

t = 135 min , log s_1/s_2 = 0.025

... $C = 2.3\frac{A}{t'}\log_{10}\frac{s_1}{s_2} =$ 0.0412125 sq. m/min

5.5.6 Transmissivity Computation by Muskat(1937) approach.

. Plot between Time since pumping stopped 't'' and ratio of S1 and s2 is plotted in Fig 5.20.

.. Corresponding values of 't'' and 'log s1/ s2' for an arbitrary point is;

t'= 135 min , log s1/ s2 = 0.025 r_0= 100 m, r_w=5.5497 m.

... $C' = \log_e \frac{r_o}{r_w} = 2.8914$

.... $T = 2.3 \frac{C`A}{2\pi t`} \log_{10} \frac{s_1}{s_2}$ = 0.019 sq. m/min

5.5.7 Rock mass Permeability computation by Kumaraswamy's method.

. Cross-sectional area of the well, a=96.76 sq. m.

.. Static water column, D= 1.8 m.

... Water column after pumping, d1=0.2 m

.... Water column after recovery, d2 = 0.72 m

..... Time taken to recuperate from d1 to d2, tR =250 minutes.

...... Rock mass Permeability,

$$w = \frac{a}{D} \frac{\ln \sqrt{\frac{1 + d_1/D}{1 - d_1/D}} - \ln \sqrt{\frac{1 + d_2/D}{1 - d_2/D}}}{t_R} = 0.0671035 \text{ m / min.}$$

5.5.8 Abstract of the Estimated Parameters.

Sr.no.	Method of estimation	Flow Parameter	Storage parameter
1	**THEIS SOLUTION**	**0.0334 sq. m/min**	**0.117**
2	**JACOB SOLUTION**	**1.058 sq. m/min**	**4.105**
3	**POPODOPULOS-COOPER METHOD**	**0.03395 sq. m/min**	**0.000122**
4	**SLITCHER SOLUTION**	**0.0412 sq. m/min**	
5	**MUSKAT SOLUTION**	**0.019 sq. m/min**	
6	**KUMARSWAMY'S METHOD**	**0.0671035 m/min**	

5.6 Mechcheri Anantpur Well.

5.6.1 Well characteristics

Total Depth: 9. metres.
Dimension : 13.2 m X 13.2 m
Geology: Highly Weathered with Lime Kankar.
Type of Lift : Oil Engine 5 hp.
Discharge : 782 lpm.
Duration of Pumping : 310 minutes
Total Drawdown : 3.29 m max.
Pumping and Recovery phase data is tabulated in Annexure-F.

5.6.2 Storativity & Transmissivity Computation by Theis Method.

..Plot for the values of drawdown(s) against r^2/t is shown in Fig 5.21.

.. Selection of Match point gives following values.

W(u)= 0.35 , u= 0.7 , s= 0.45 , r^2/t = 0.7. sq. m / min.

.. Storativity and Transmissivity values are estimated as below.

$$T = \frac{Q}{4\pi s} W(u) = 0.0484 \text{ sq. m/min}$$

$$S = \frac{4Tu}{r^2/t} = 0.1936$$

5.6.3 Storativity and Transmissivity Computation by Jacob's Method.

. Plot between drawdown 's' against the corresponding time 't' is shown in Fig 5.22.

..Extension of the best fit line to intercept time axis gives t_o= 330

... Slope of the straight line portion of the curve, Δs=0.06

.... $T = \frac{2.3Q}{4\pi\Delta s}$ = 2.385 sq. m/min

$$S = \frac{2.25Tt_o}{r^2} = 10.1653$$

5.6.4 Storativity and Transmissivity computation by Papadopulos-Cooper's method.

.. Plot of the observed drawdown 's' versus 't' is shown in fig 5.23.

... Superimposition of the Fig 5.23 on Annexure-H , and choosing an arbitrary point giv following corresponding values.

$F(\theta,\alpha,\Phi)$= 7E-2 , θ= 7E+2 , s= 4.50E-1 , t= 8.0E+1

.... $T = \frac{Q}{4\pi s} F(\theta, \alpha, \varphi) = 0.00968$ sq. m/min

$$S = \frac{4Tt}{r^2\theta} = 0.0000254$$

5.6.5 Specific Capacity Computation by Slitcher's Method.

Plot between Time since pumping stopped 't`' and ratio of S_1 and s_2 is plotted in Fig 5.24.

.. Corresponding values of 't`' and 'log s_1/s_2' for an arbitrary point is;

t`= 200 min, log s_1/s_2=0.05

.. $C = 2.3 \frac{A}{t`} \log_{10} \frac{s_1}{s_2}$ = 0.100188 sq. m/min

5.6.6 Transmissivity Computation by Muskat(1937) approach.

. Plot between Time since pumping stopped 't`' and ratio of S1 and s2 is plotted in Fig 5.24.

.. Corresponding values of 't`' and 'log s1/ s2' for an arbitrary point is;

t`= 200 , log s1/ s2 = 0.05, r_0 = 100 m, r_w=6.60 m.

... $C = \log_e \frac{r_o}{r_w} =$ 2.7181

$$....T = 2.3\frac{CA}{2\pi t`}\log_{10}\frac{s_1}{s_2} = 0.04334 \text{ sq. m/min}$$

5.6.7 Rock mass Permeability computation by Kumaraswamy's method.

. Cross-sectional area of the well, a= 174.24 sq. m.

.. Static water column, D= 6.92 m.

... Water column after pumping, d1=5.11 m

.... Water column after recovery, d2 = 5.59 m

..... Time taken to recuperate from d1 to d2, tR = 240 minutes.

...... Rock mass Permeability,

$$w = \frac{a}{D}\frac{\ln\sqrt{\frac{1+d_1/D}{1-d_1/D}} - \ln\sqrt{\frac{1+d_2/D}{1-d_2/D}}}{t_R} = 0.0631166 \text{ m / min.}$$

5.6.8 Abstract of the Estimated Parameters.

Sr.no.	Method of estimation	Flow Parameter	Storage parameter
1	**THEIS SOLUTION**	**0.0484 sq. m/min**	**0.1936031**
2	**JACOB SOLUTION**	**2.385 sq. m/min**	**10.1653**
3	**POPODOPULOS-COOPER METHOD**	**0.00968 sq. m/min**	**0.0000254**
4	**SLITCHER SOLUTION**	**0.1002 sq. m/min**	
5	**MUSKAT SOLUTION**	**0.04334 sq. m/min**	
6	**KUMARSWAMY'S METHOD**	**0.0631166 m/min**	

5.7 Summary

Pumping and Recovery test data of six wells in Anantpur district have been analysed in the previous paras. Most practical problem is to decide the final flow and storage parameters which can be used for flow and storage analysis, due to wide range of values we have come across from various methods of analysis. Three methods of analysis which have been used for the analysis of the pumping phase data are based upon same flow conditions with various corrections. Overall there is certain degree of matching well wise between the values of Transmissivity estimated by Theis and Popodopulus-Cooper method. There is no matching in the values of Storativity calculated by all the three methods for pumping phase analysis. Storage parameters by Popodopulus & Cooper method looks more reliable storativity value for confined aquifers.

In the recovery phase only flow parameters are estimated. Out of three method that has been used, Slitcher's equation has assumed that the flow is from the bottom of the well, where as Muskat's equation is for dug wells tapping confined aquifer with the well ending at the bottom of the confining layer having serious limitation in the value of the distance of a point of zero drawdown. Adyalkar and Mani(1972) assumed this value as 150 to 250 ft for basalt . On the basis of that we have assumed this distance as 100 m in all of our calculations for weathered and fractured Granites. As compared to all these methods Kumarswamy's method considered the flow in the well through fissure planes or conduits. Overall all the three methods have different approaches but yielding to a comparable results. Therefore it makes sense to depend more on the recovery phase data analysis than the pumping phase data analysis for open wells in hard rocks.

6.0 Sensitivity of aquifer parameters

To test the sensitivity of drawdown and recovery on the parameters that have been estimated through six standard methods, certain degree of reliability is needed in the estimated parameters. In the pumping phase, out of the three methods that have been used, Jacobs parameters seem to be most unrealistic in most of the wells, which can not be used for sensitivity analysis. Rest two methods are almost similar baring the fact that Theis method lacks in well storage assumption. To select the parameters out of these two sets of results we would take the help of the sensitivity expression generated for Theis solution. Wellwise following parameters would be used for testing sensitivity feature of drawdown .

Sr. No.	Well Designation	Discharge in cum/day	T in sq. m/day Theis	P &C	Storage Coefficient Theis	P & C
1	**Nallampalli**	**1100**	**700**	**0.618**	**0.3125**	**6.4E-7**
2	**Kondampalli**	**706**	**31.68**	**309**	**0.1006**	**3.2E-5**
3	**Gollapalli**	**1066**	**628**	**226**	**0.1745**	**2.2E-4**
4	**Tammapuram**	**583**	**108**	**53**	**0.1053**	**1.02E-4**
5	**Basamvaripalli**	**691**	**48**	**49**	**0.117**	**1.22E-4**
6	**Mechcheri**	**1126**	**70**	**14**	**0.1936**	**2.54E-5**

Well wise temporal change in normalised sensitivities for both the methods are depicted from fig 6.1 to 6.24 . All these figures show how normalised sensitivity with respect to transmissivity and storativity changes with time and space. Considering all the figures in the second quadrant, U'_S increases rapidly in the initial period and becomes constant after small period of time where as U'_T increases gradually and not tending to become constant although the changing rate becomes smaller and smaller with increasing time. It has been experienced in all the analysis that, Storativity values by Theis method is on higher side and needed to be modified to test the normalised sensitivity against transmissivity. Generally the transmissivity values estimated by Theis method are also higher than those calculated by Popodopulus & Cooper method. It is also evident that the values through P & C method are more sensitive to drawdown. Therefore those are considered to be more reliable and could be suggested for further analysis. Sensitivity expression for Jacob's method shows that there is no temporal variation of sensitivity for storativity existing. Therefore no sensitivity analysis have been carried out for Jacob's solution.

In the recovery phase all the three approaches are quite different to each other and estimated parameters are also symbolically different and having different physical interpretation. Therefore corresponding parameters estimated are considered for each mathematical expression for each method of recovery data analysis.All the distribution shows that the parameters are sensitive to recuperation to almost same trend and extent. Kumaraswamy's Rock mass permeability is most sensitive parameter as compared to others and it is most sensitive to well cross section area also. These would be dealt in detail elsewhere. Wellwise following values have been utilised and results are depicted in fig 6.25 to 6.42.

Sr. No.	Well Designation	Specific capacity in sq. m/day	Transmissivity in sq. m/day	Permeability in M/day
1	**Nallampalli**	**22.75**	**10.828**	**33.12**
2	**Kondampalli**	**13.84**	**6.5376**	**7.53**
3	**Gollapalli**	**143.07**	**64.08**	**179.27**
4	**Tammapuram**	**797.64**	**400.896**	**67.93**
5	**Basamvaripalli**	**59.53**	**27.36**	**96.63**
6	**Mechcheri**	**144.29**	**62.4096**	**90.89**

Conclusion:

Six wells in Anantpur district of Andhrapradesh have been analysed through various existing approaches of pumping and recuperation test data analysis. These parameters are tested for their sensitivities towards drawdown / recovery. In pumping phase Popodopulus method of pumping test data analysis is found most reliable for pumping test design in the study area. In the recovery phase Kumaraswamy's Rock mass permeability has been found most sensitive toward recuperation and as well as well cross section. In hard rock regions most of the pumping tests are being carried out by monitoring the pumping wells only. This gives enormous error in applying the conventional theory for groundwater flow to a well. It is more appropriate to analyse the recovery phase data rather than pumping phase data. Well wise following parameters are suggested to be most sensitive.

Sr. No.	Well Designation	Rock Mass Permeability	Storage Coefficient
1	Nallampalli	33.12	6.40 E - 7
2	Kondampalli	7.53	3.20 E - 5
3	Gollapalli	179.27	2.20 E - 4
4	Tammapuram	67.93	1.02 E - 4
5	Basamvaripalli	96.63	1.22 E - 4
6	Mechcheri	90.89	2.54 E - 5

The methodology adopted in this report may be used for other regions also for necessary reliable aquifer parameters.

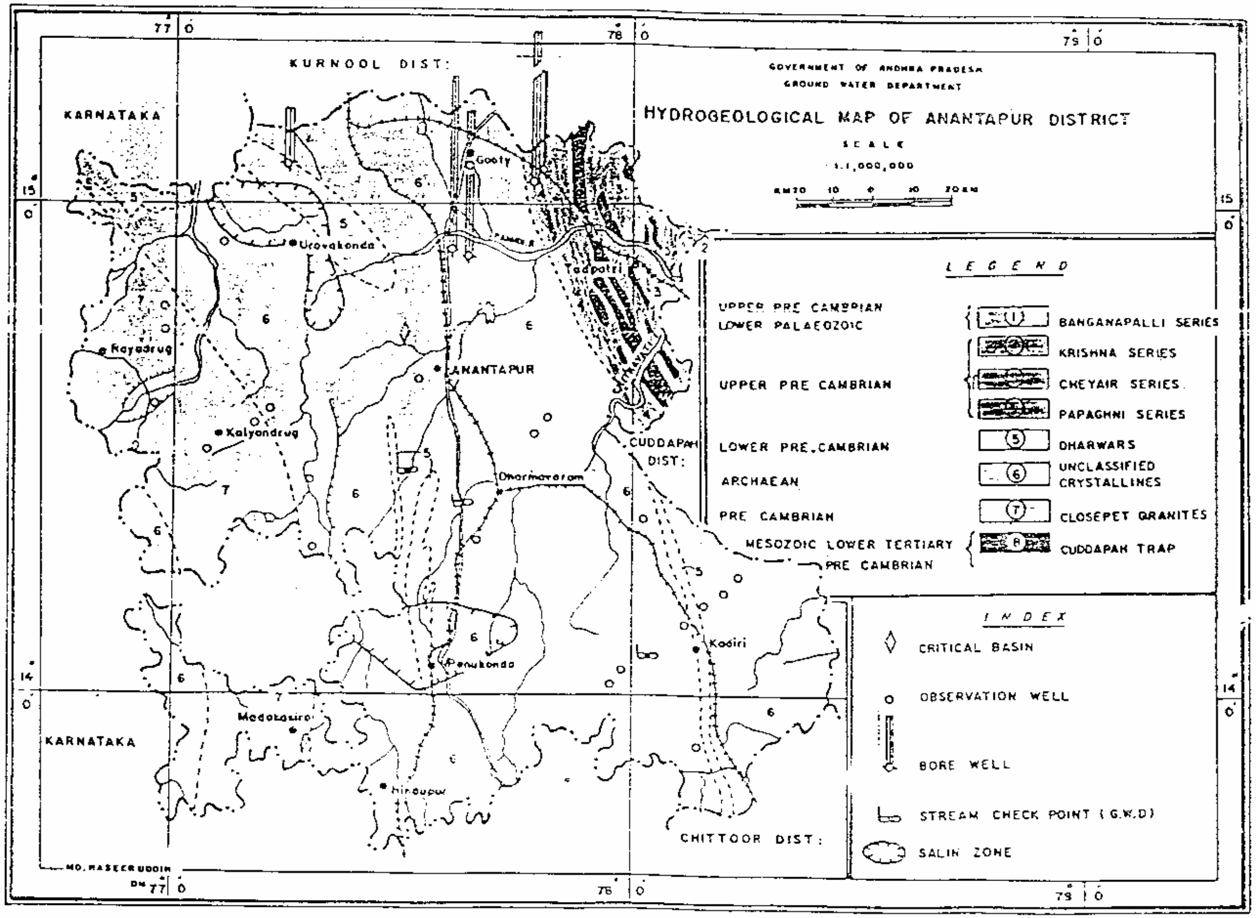


Fig.Study Area Map

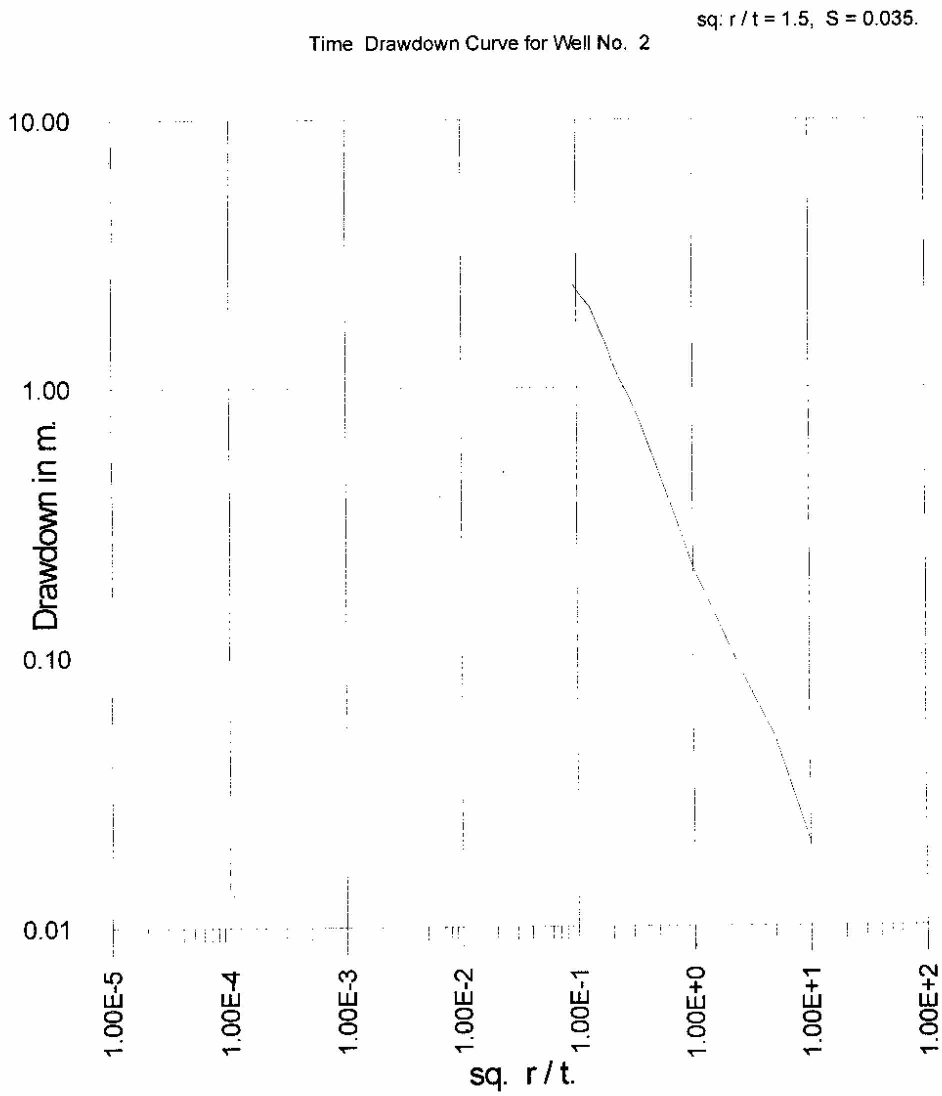


Fig. 5.1 Time drawdown Curve for Nallampalli Well. (Theis Method).

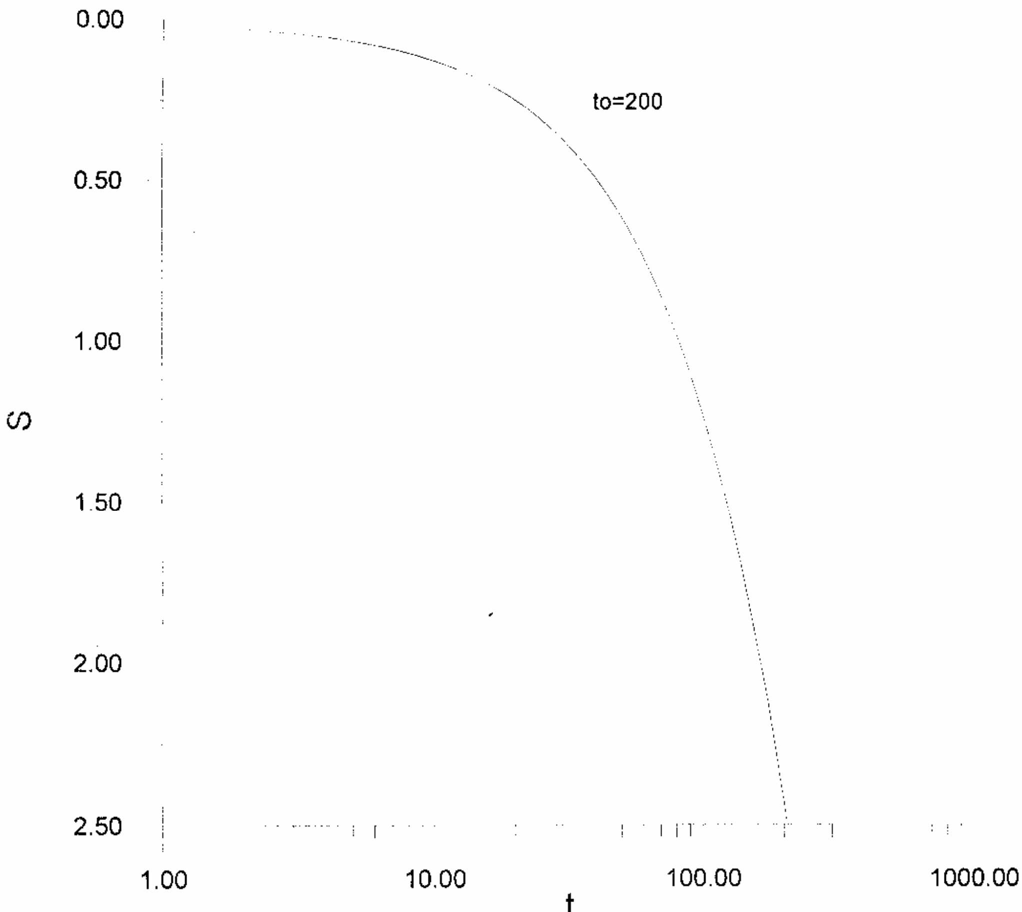


Fig. 5.2 Time drawdown Curve for Nallampalli Well
(Jacob Method).

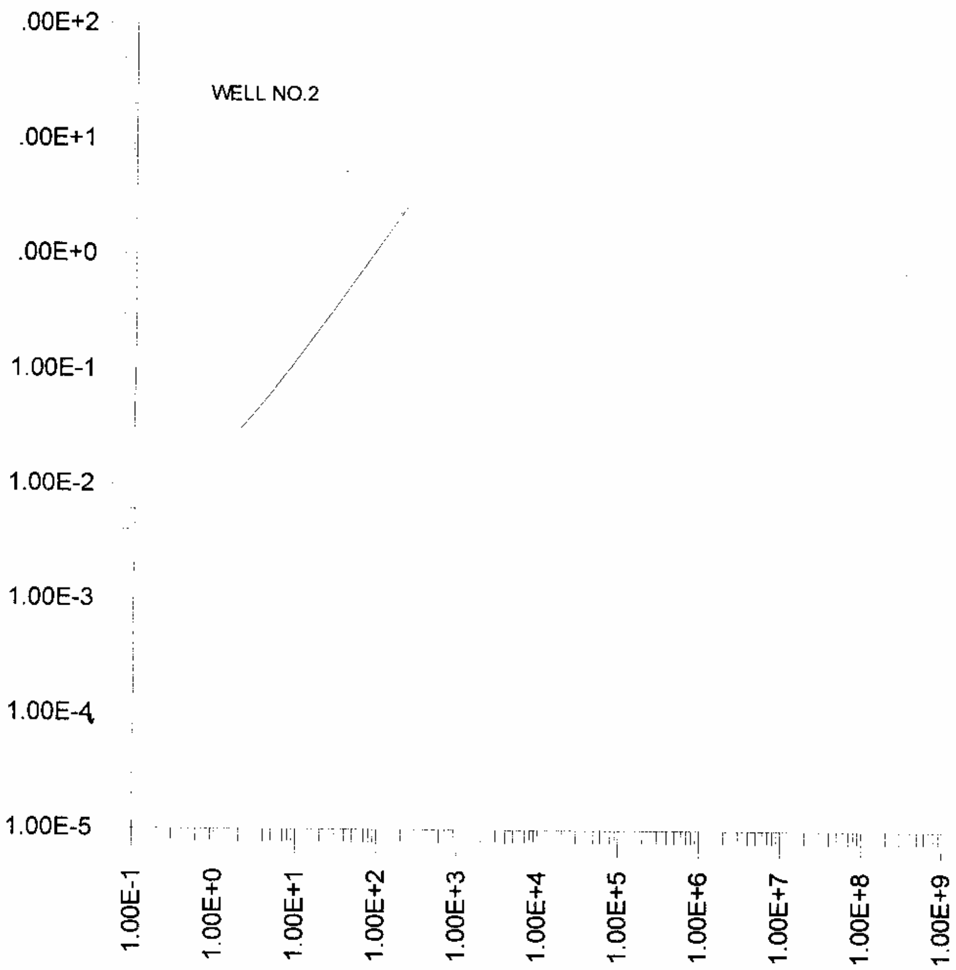


Fig. 5.3 Time drawdown Curve for Nallampalli Well.
(Popodopulus and Cooper Method).

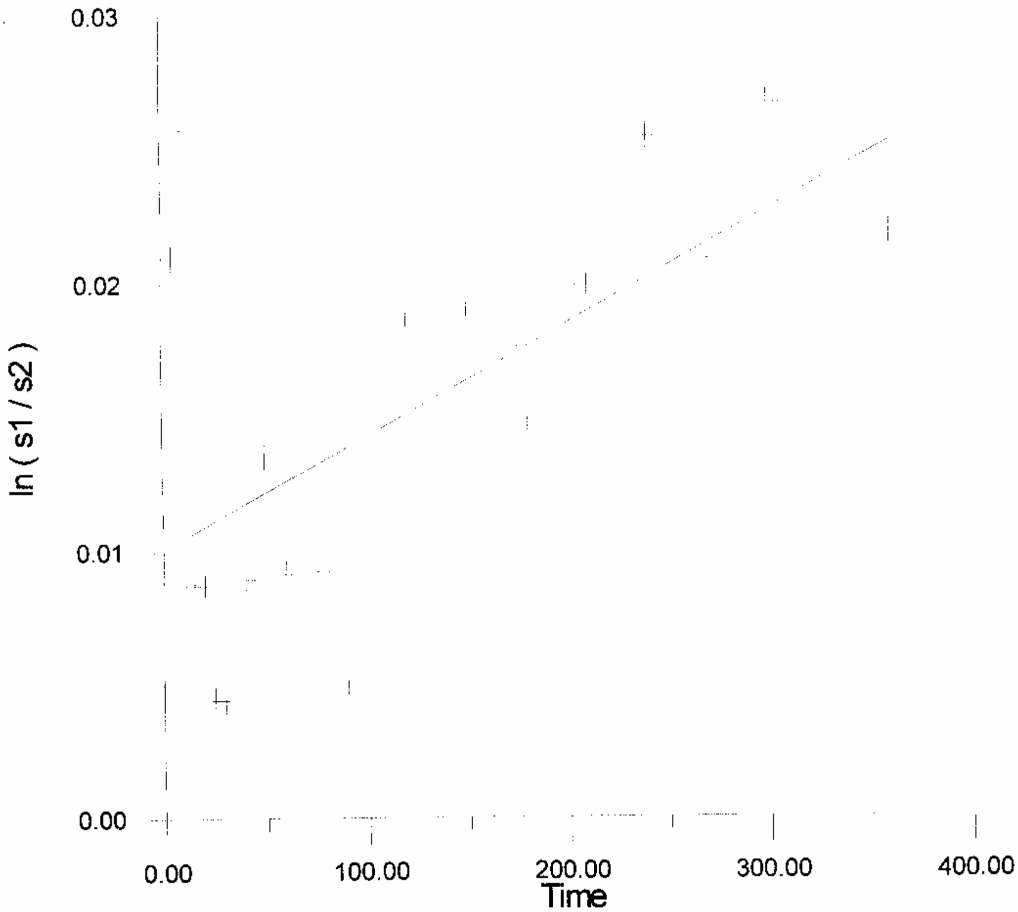


Fig. 5.4 - Time drawdown Curve for Nallampalli Well
(Slitcher's & Modified Slitcher's Method).

Time Drawdown Curve for Well No.4

sq. r / t = 1.0, S=0.8

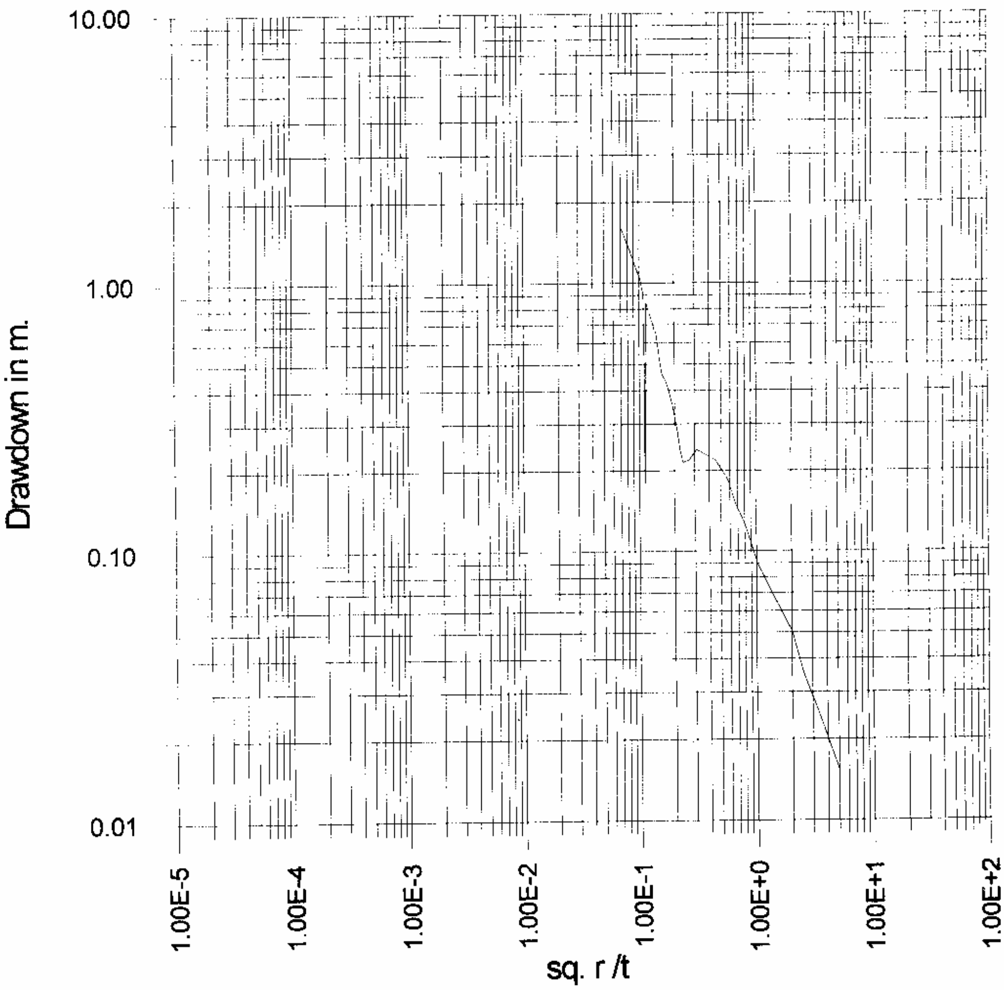


Fig. 5. 5 Time drawdown Curve for Kondampalli Well.
(Theis Method).

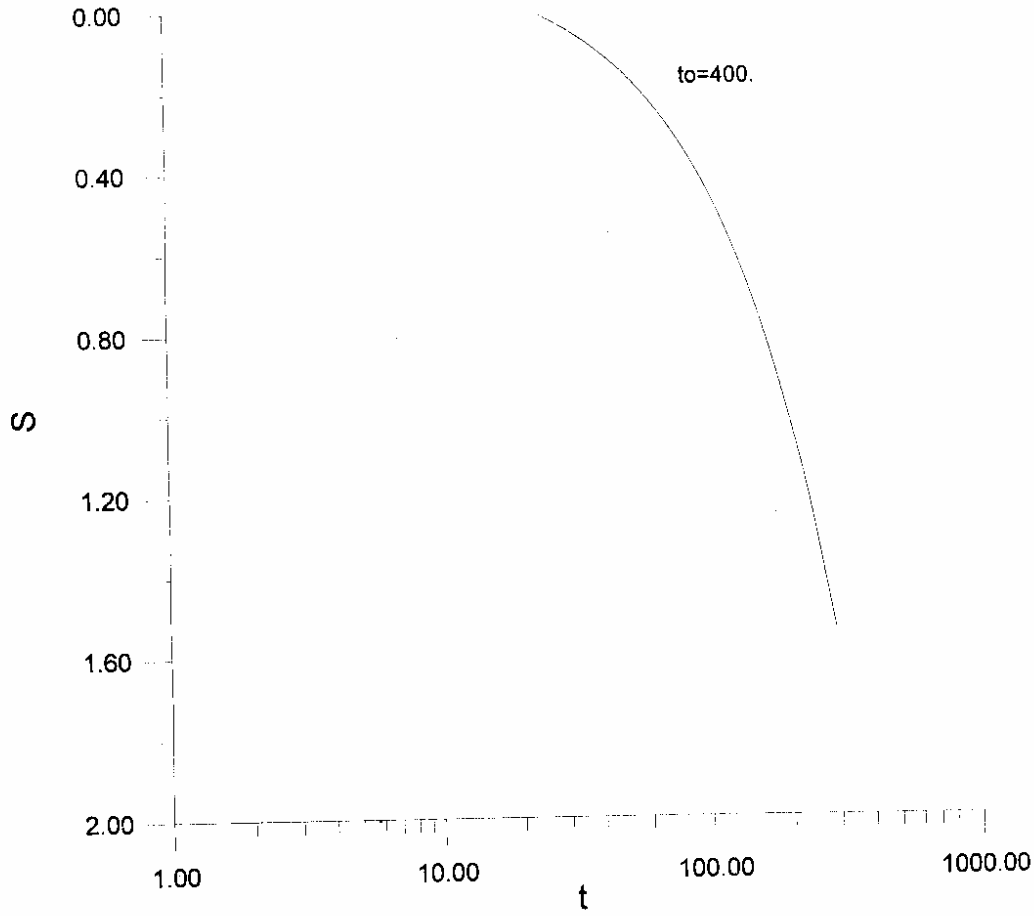


Fig. 5.6 Time drawdown Curve for Kondampalli Well.
(Jacob's Method).

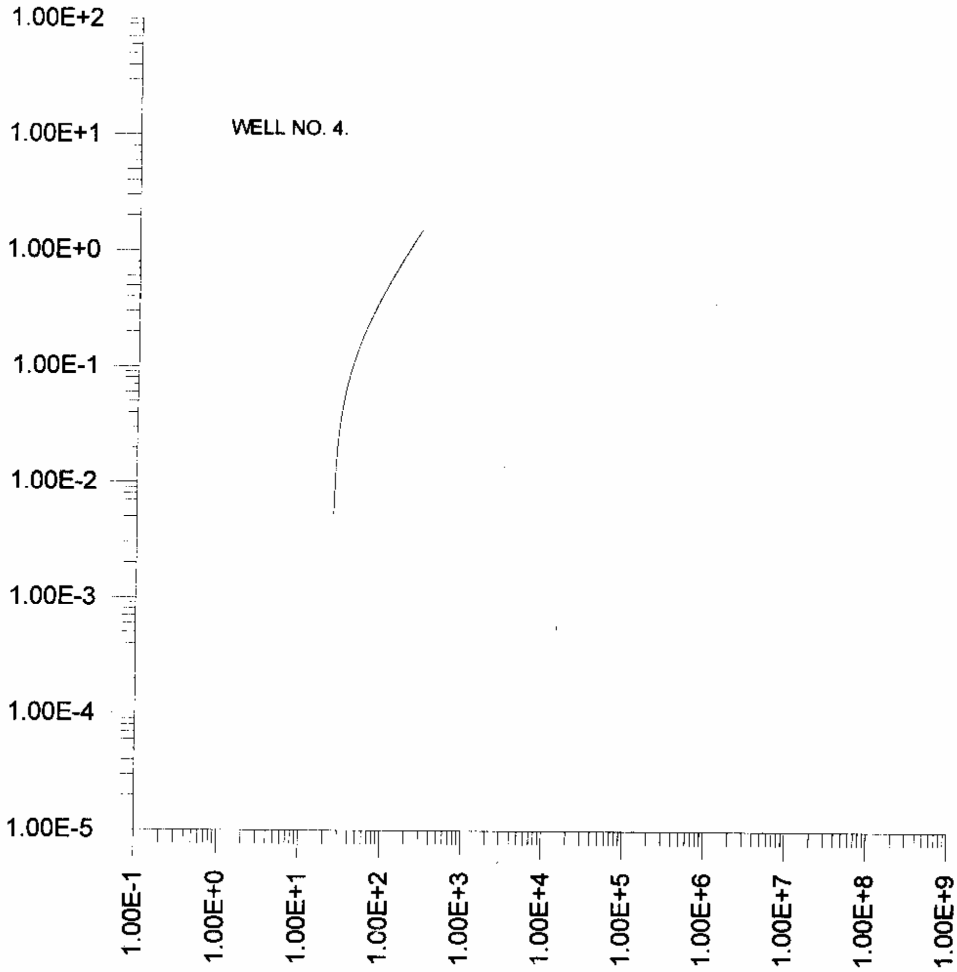


Fig. 5.7 Time drawdown Curve for Kondampalli Well.
(Popodopulus and Cooper Method).

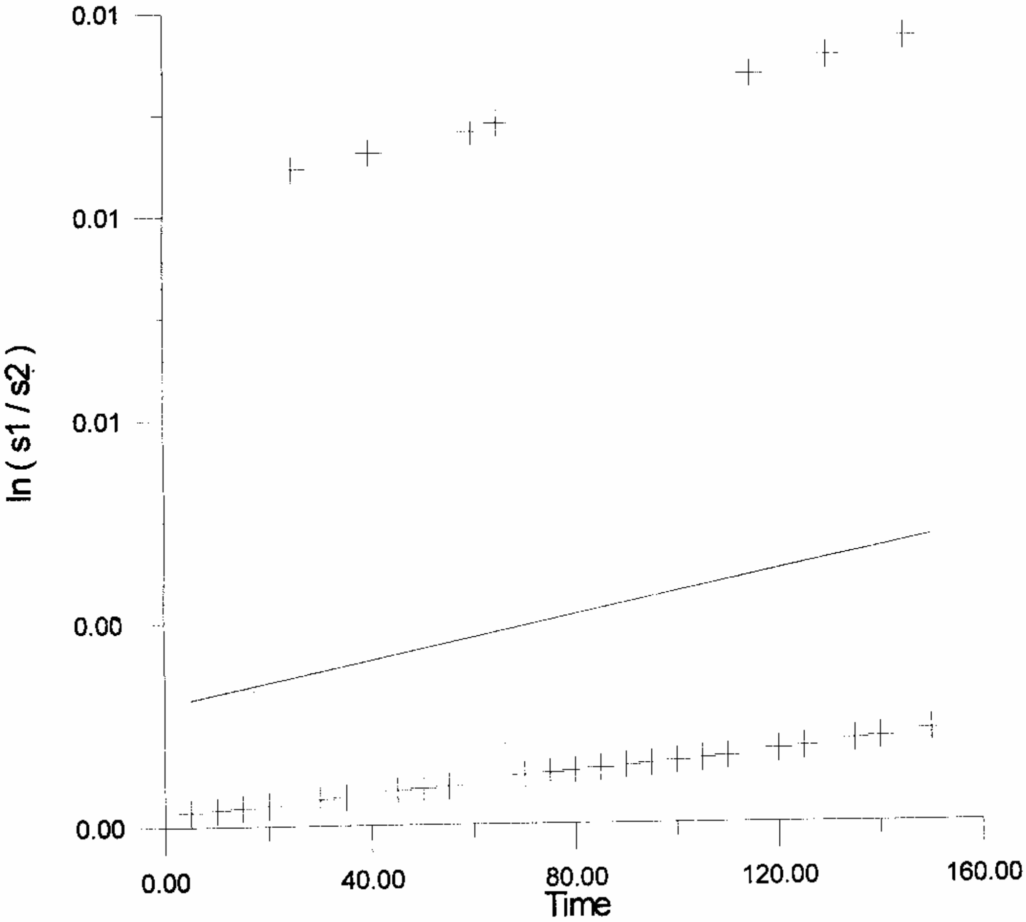


Fig. 5.8 Time drawdown Curve for Kondampalli Well.
(Slitcher's & Modified Slitcher's Method).

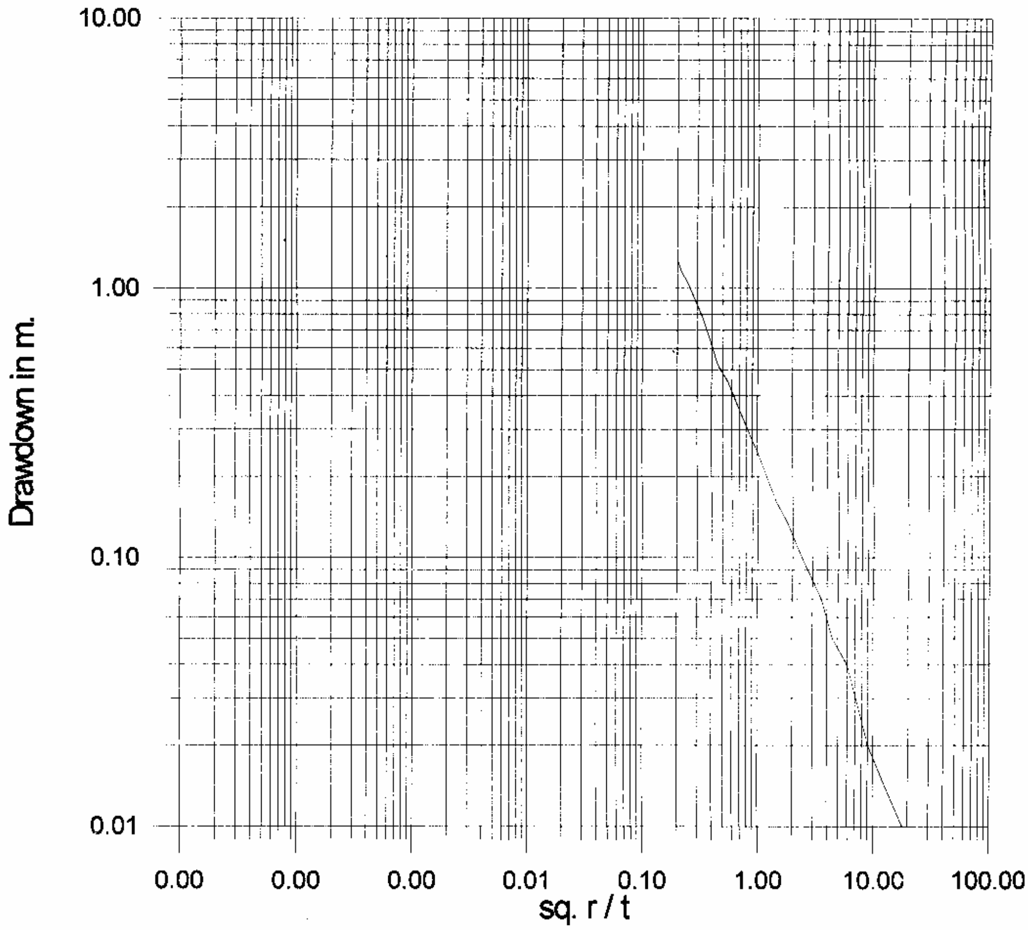


Fig. 5.9. Time drawdown Curve for Gollapalli Well.
(Theis Method).

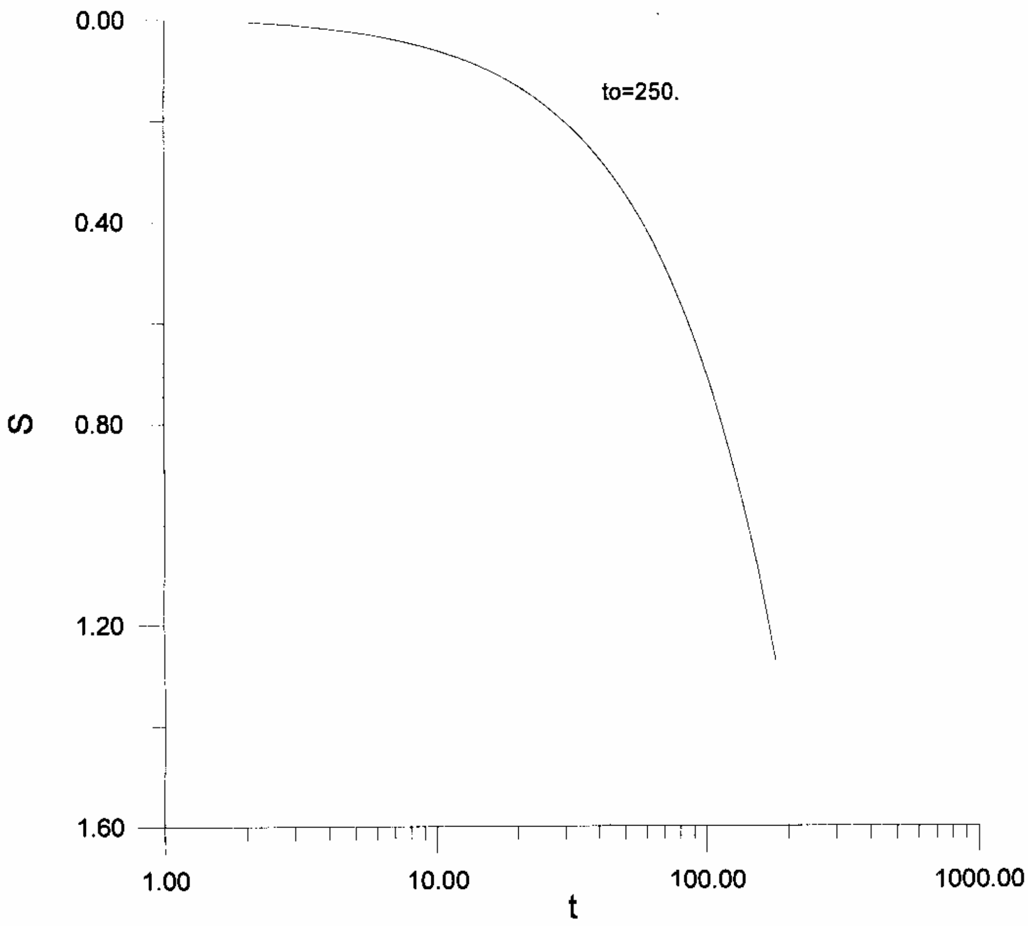


Fig. 5.10. Time drawdown Curve for Gollapalli Well.
(Jacob's Method).

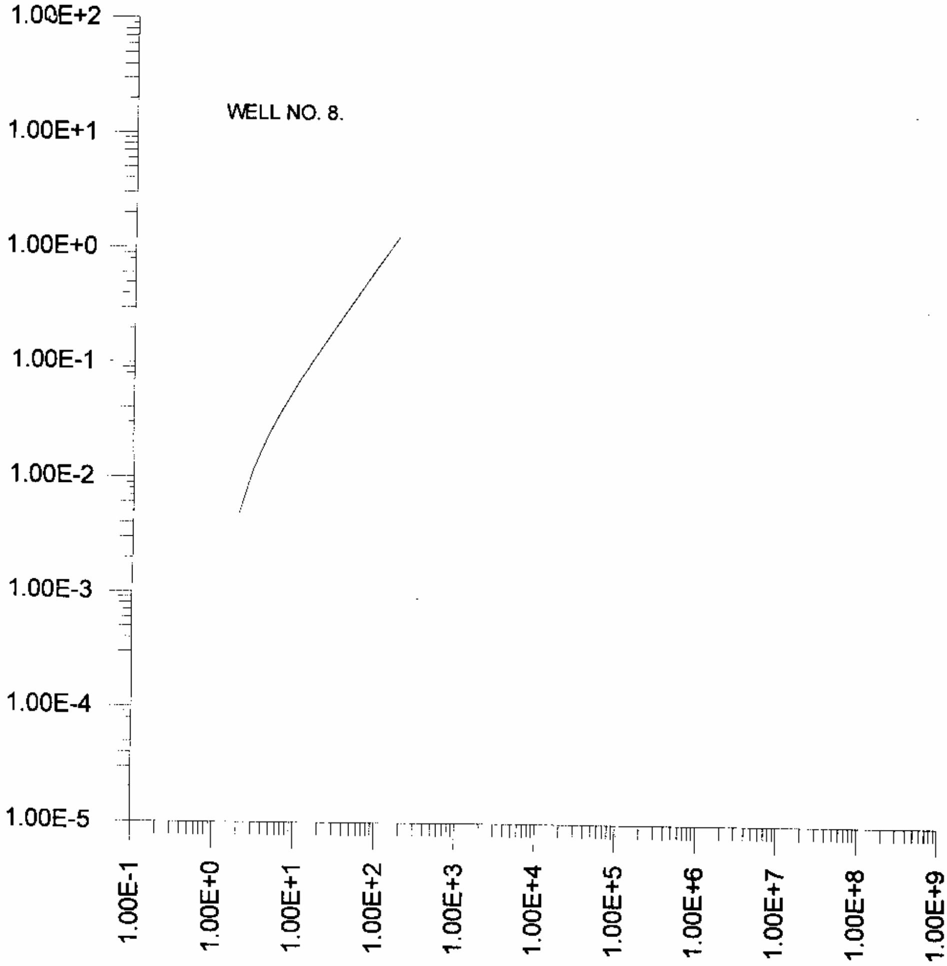


Fig. 5.11 Time drawdown Curve for Gollapalli Well.
(Popodopulus and Cooper Method).

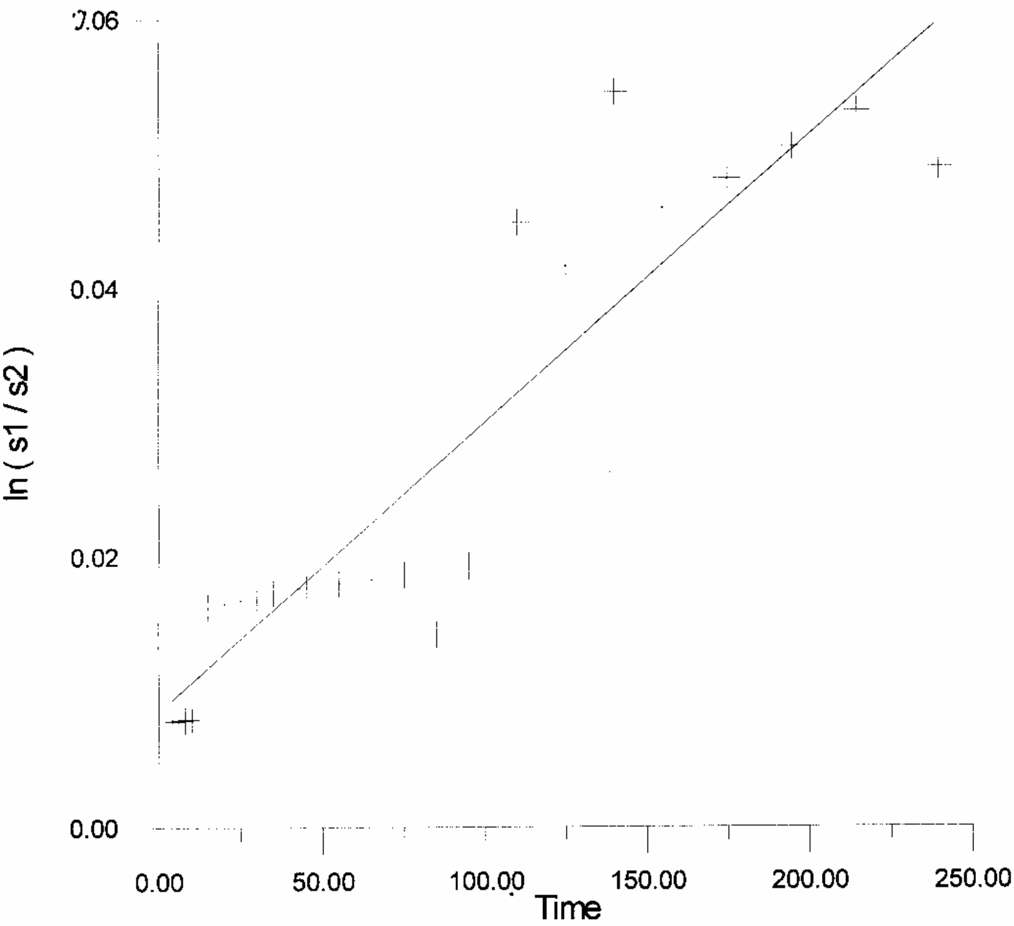


Fig. 5.12 Time drawdown Curve for Gollapalli Well.
(Slitcher's & Modified Slitcher's Method).

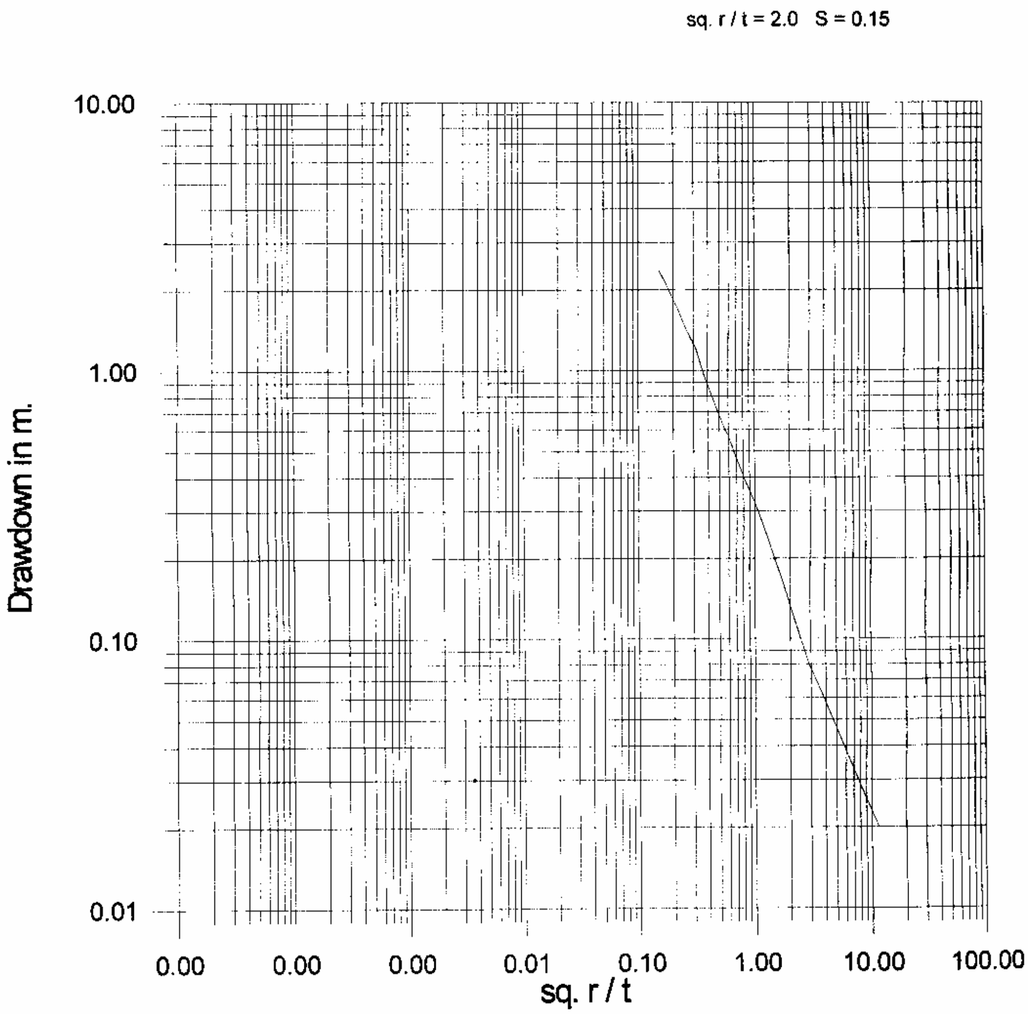


Fig. 5.13 Time drawdown Curve for Tammapuram Well.
(Theis Method).

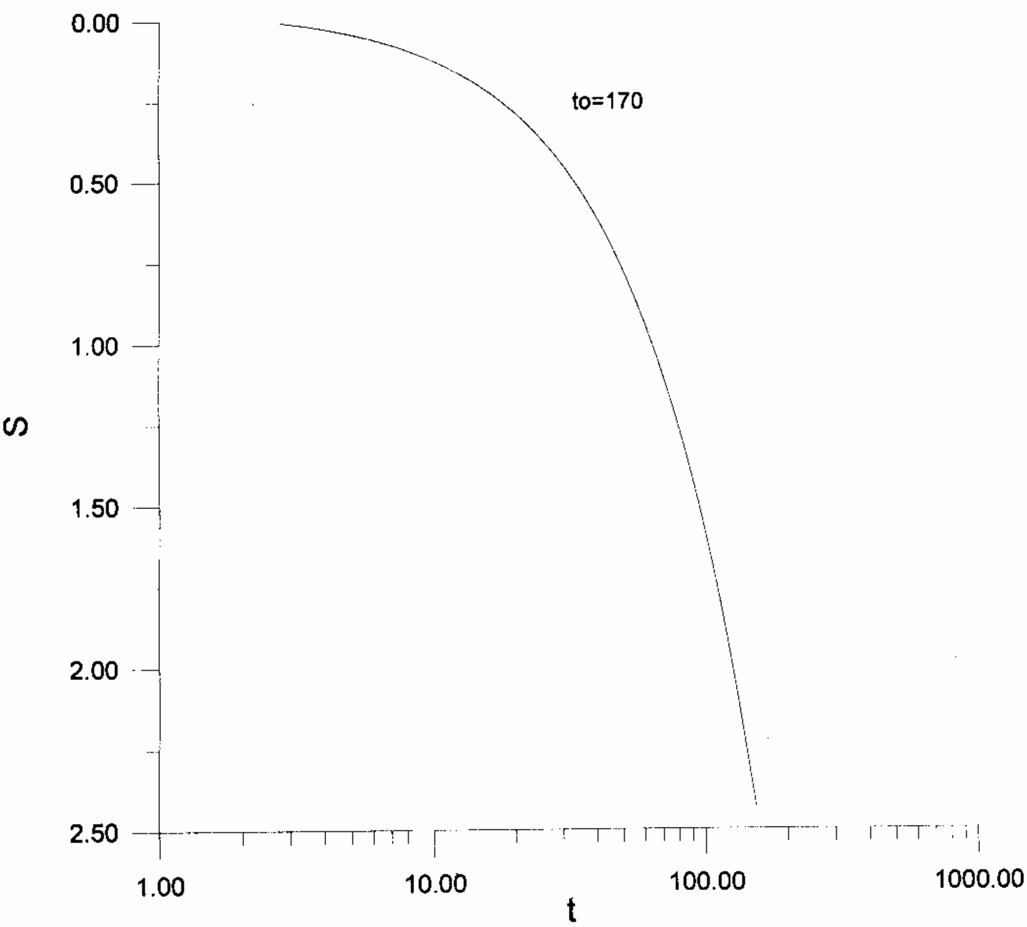


Fig. 5.16 Time drawdown Curve for Tammapuram Well.
(Jacob's Method).

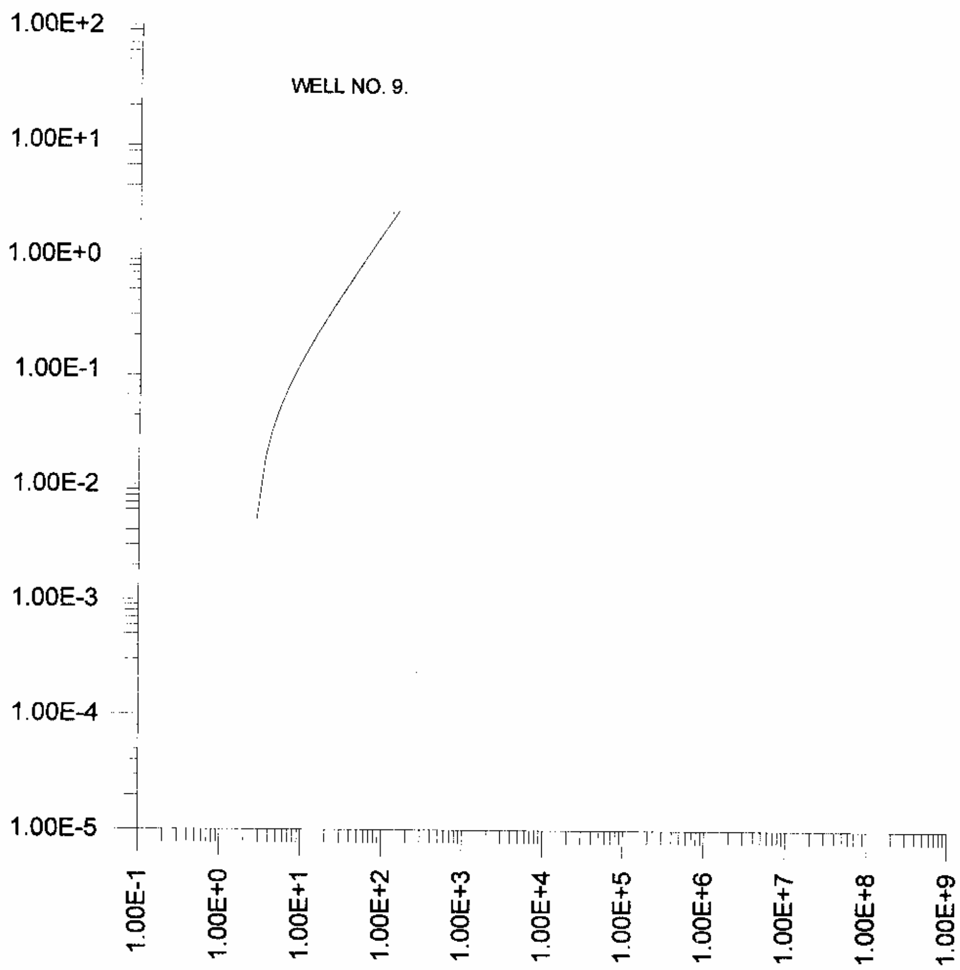


Fig. 5.15 Time drawdown Curve for Tammapuram Well.
(Popodopulus and Cooper Method).

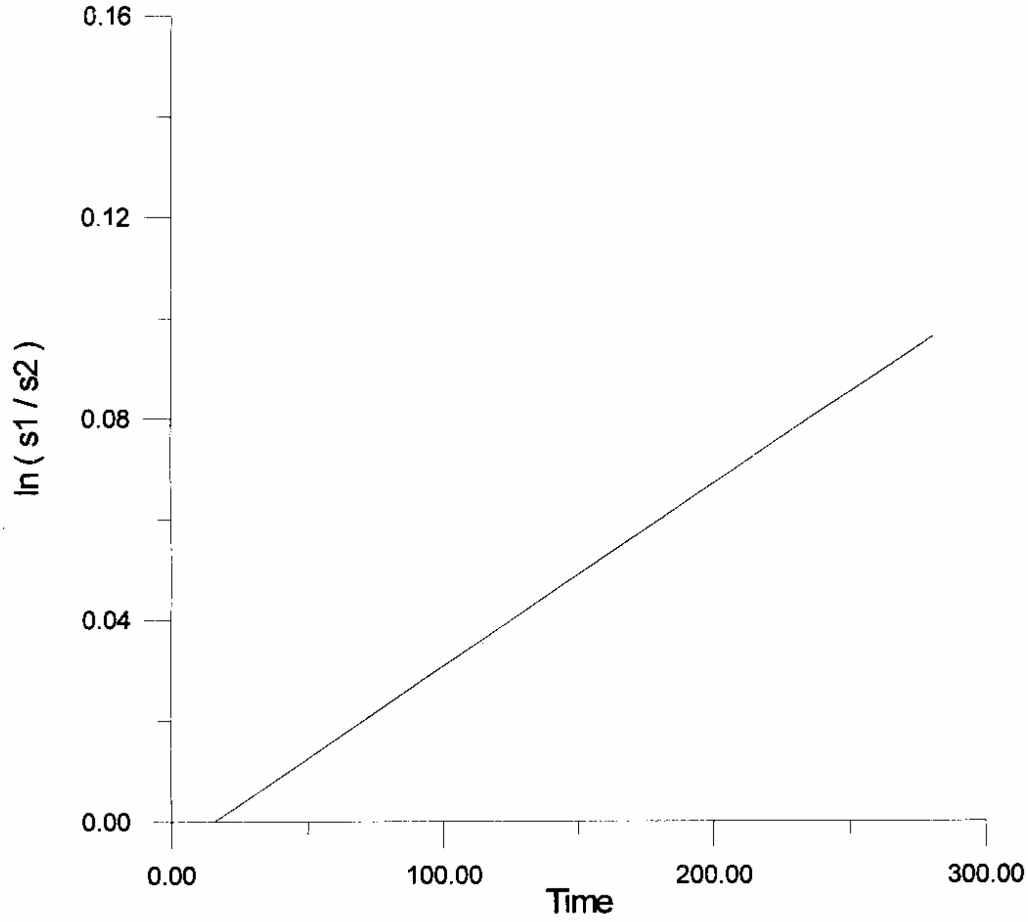


Fig. 5.16 Time drawdown Curve for Tammapuram Well.
(Slitcher's & Modified Slitcher's Method).

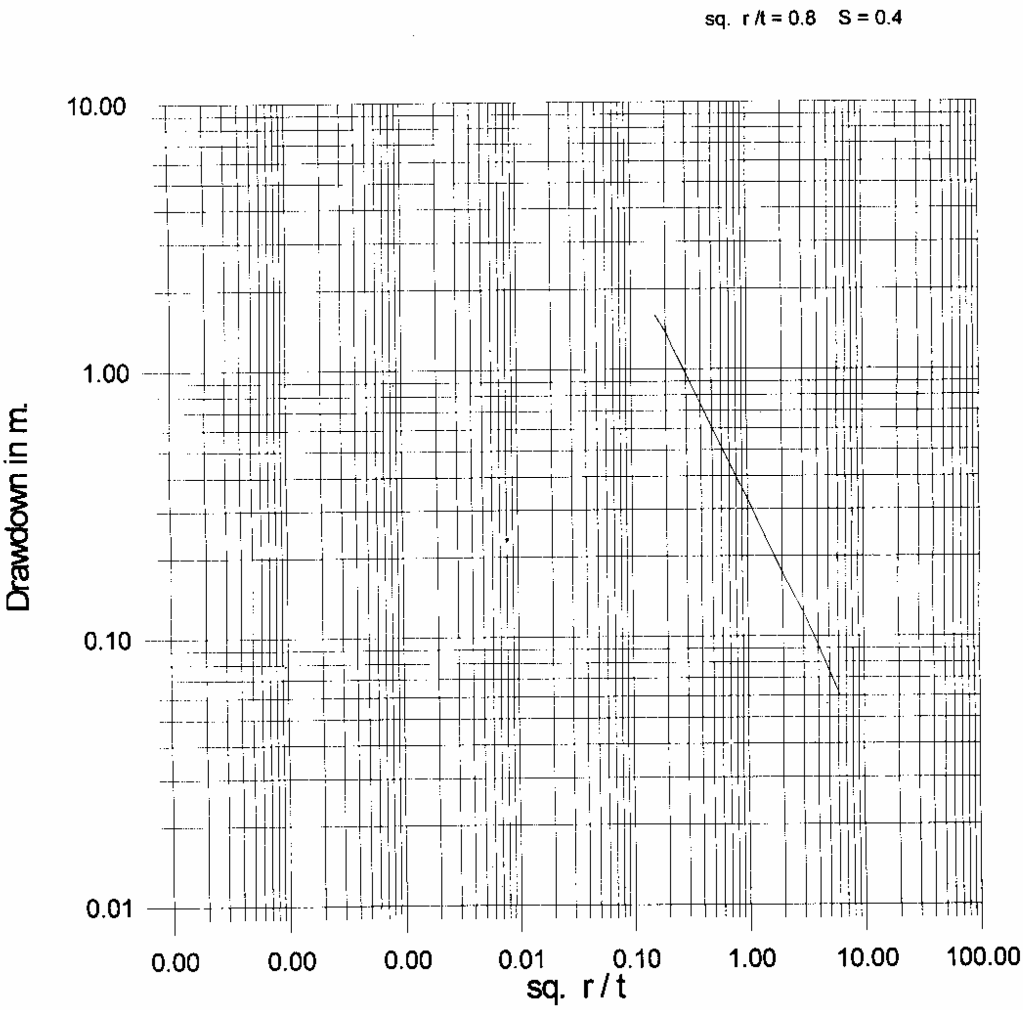


Fig. 5.17 Time drawdown Curve for Basamvariplli Well.
(Theis Method).

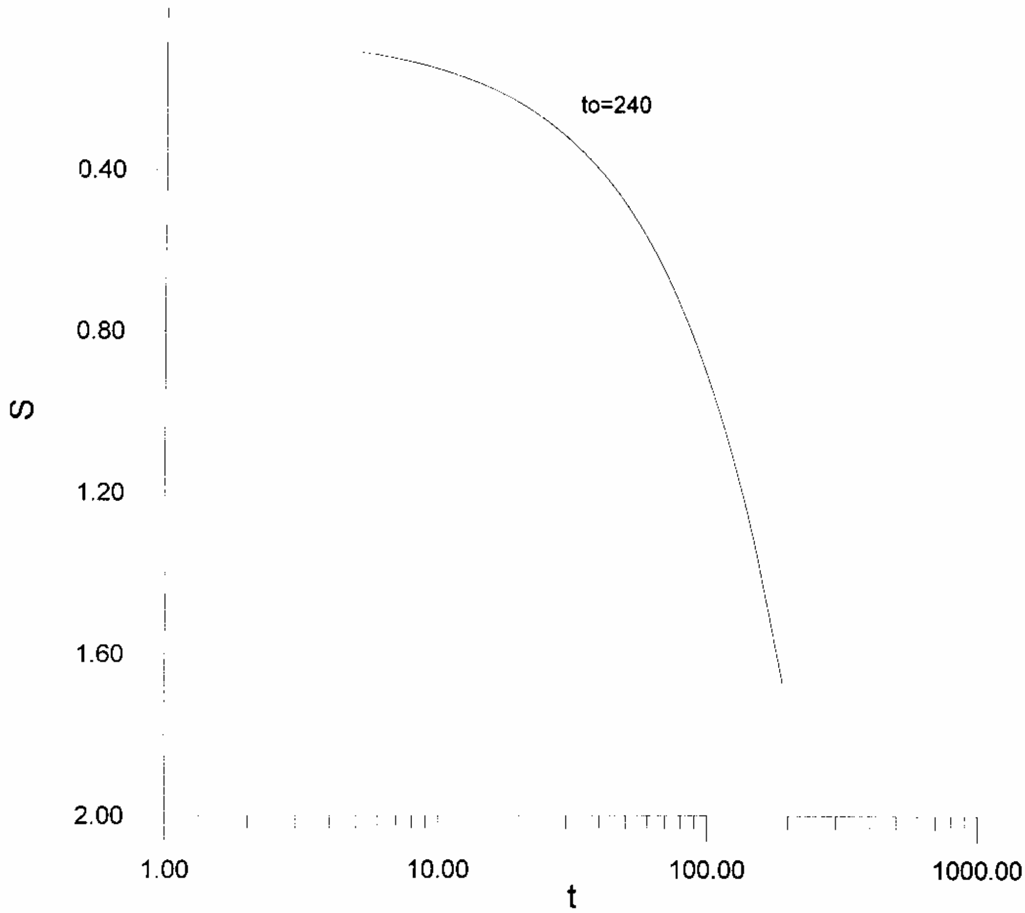


Fig. 5.18 Time drawdown Curve for Basamvaripalli.
(Jacob's Method).

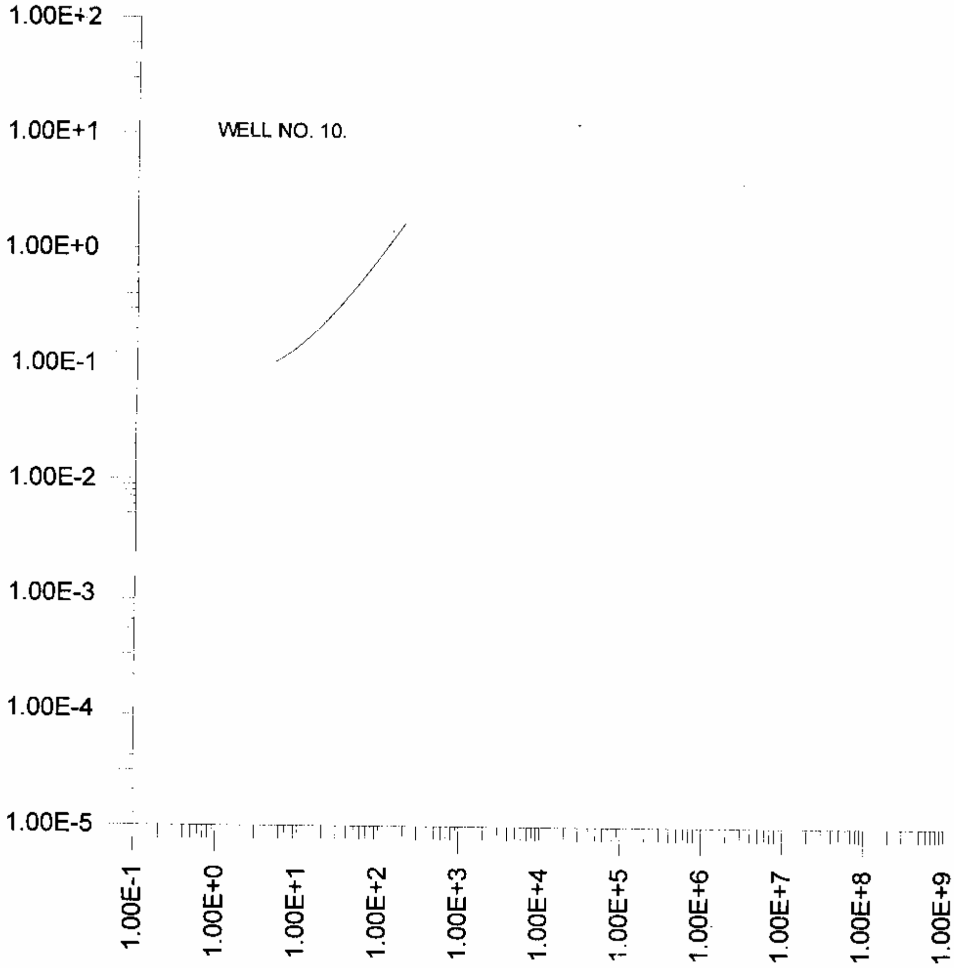


Fig. 5.19 Time drawdown Curve for Basamvaripalli Well.
(Popodopulus and Cooper Method).

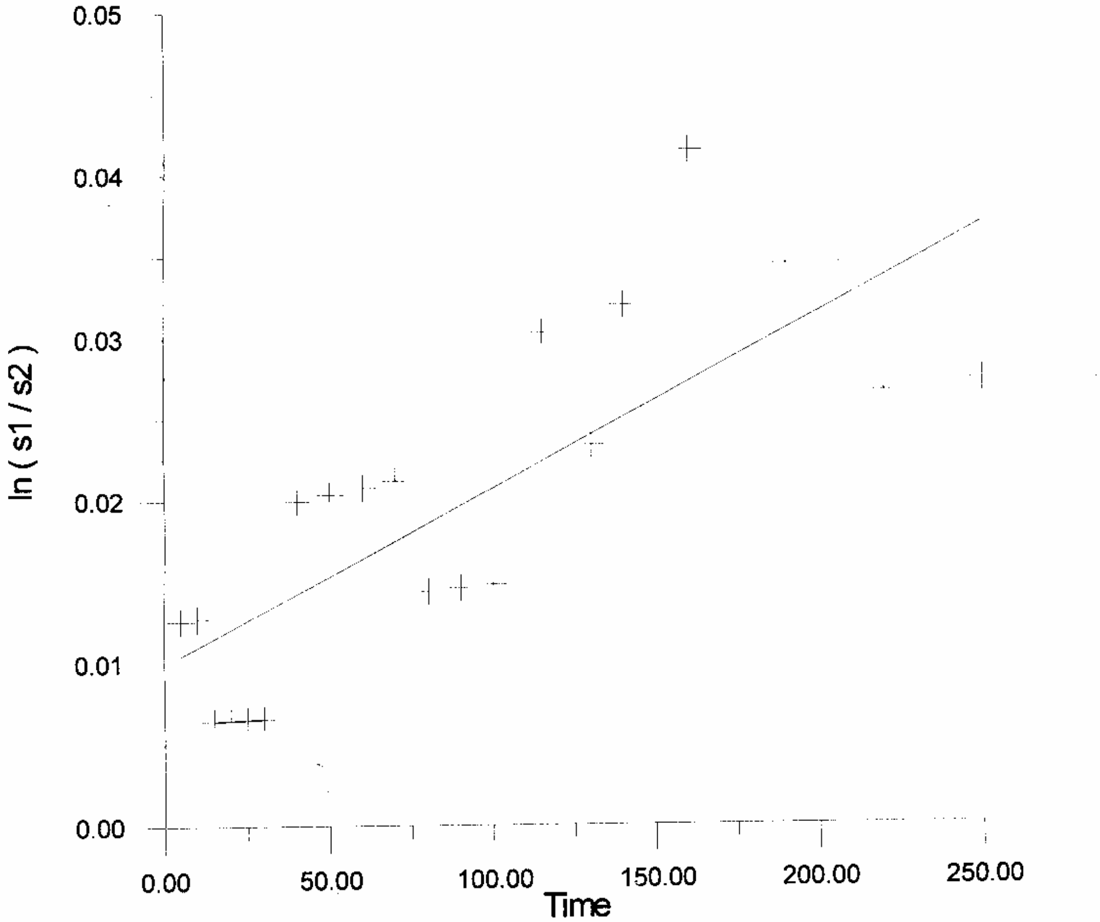


Fig. 5.20 Time drawdown Curve for Basamvaripalli Well.
(Slitcher's & Modified Slitcher's Method).

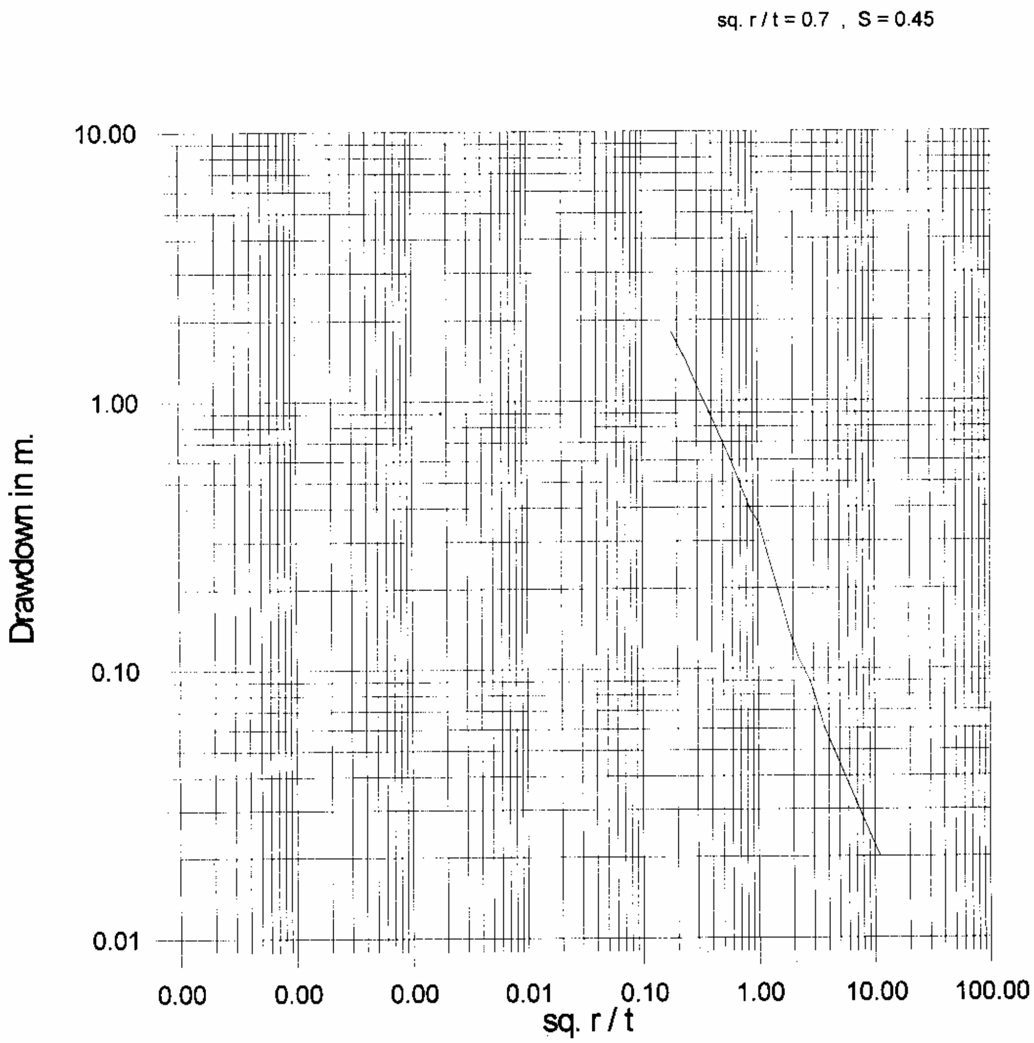


Fig. 5.21 Time drawdown Curve for Mechcheri Well.
(Theis Method).

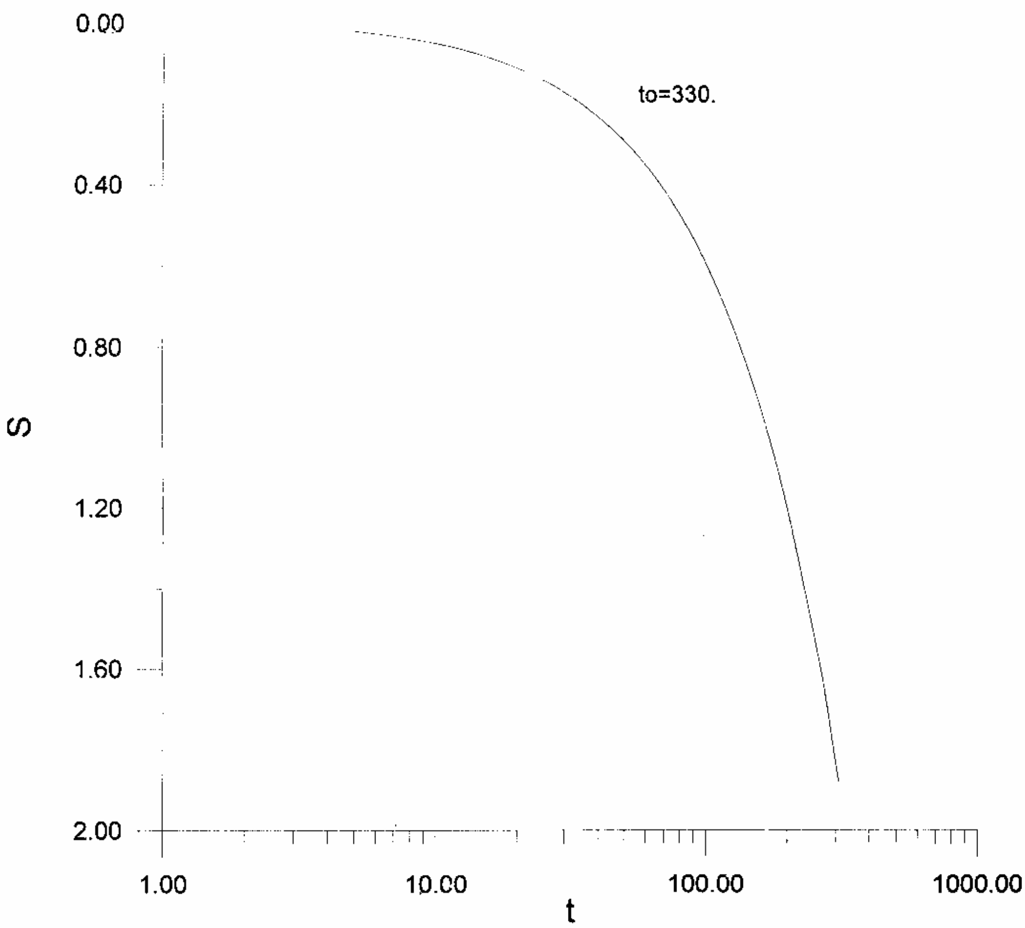


Fig. 5.22 Time drawdown Curve for Mechcheri Well.
(Jacob's Method).

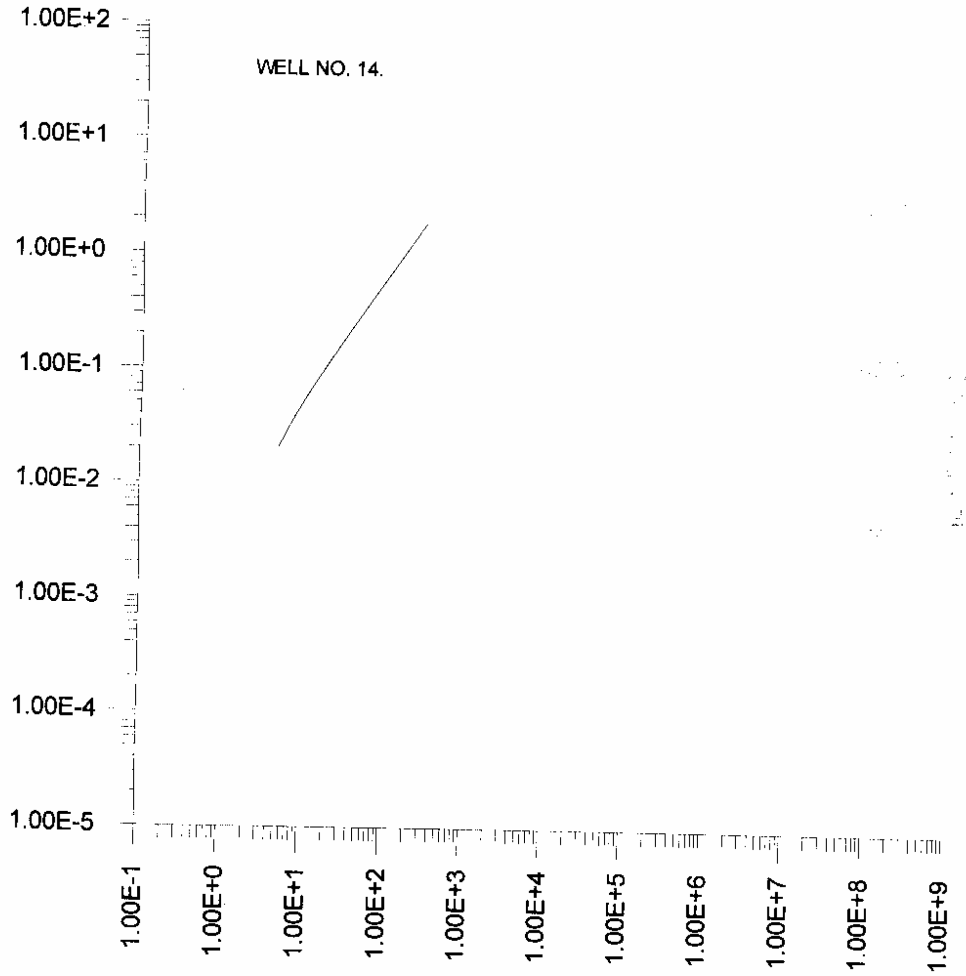


Fig. 5.23 Time drawdown Curve for Mechcherii Well.
(Popodopulus and Cooper Method)

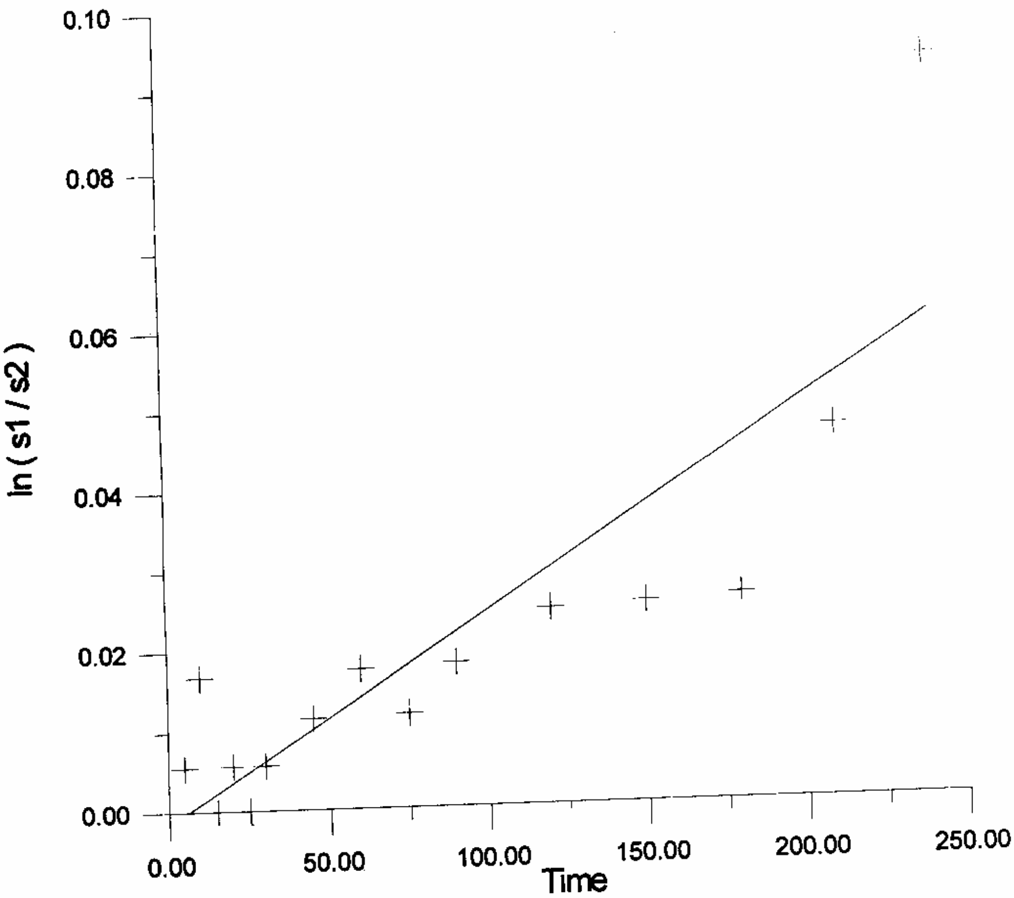


Fig. 5.24 Time drawdown Curve for Mechcheri Well.
(Slitcher's & Modified Slitcher's Method).

(a) Transmissivity

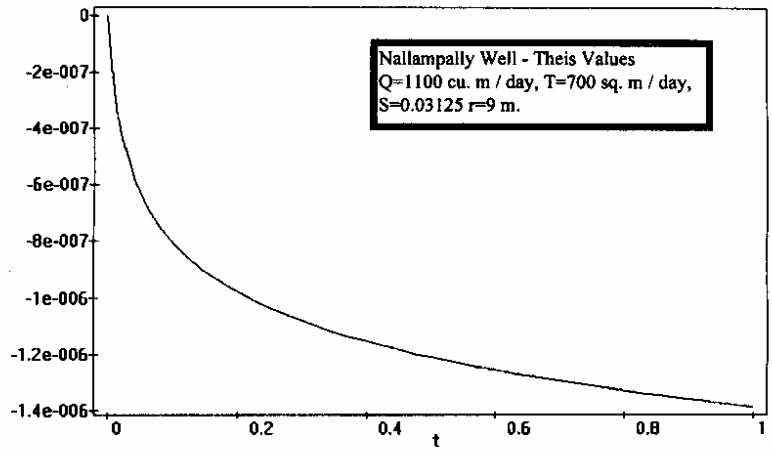


Fig. 6.1 Temporal Variation of Theis Sensitivity to Transmissivity for Nallampalli Well.

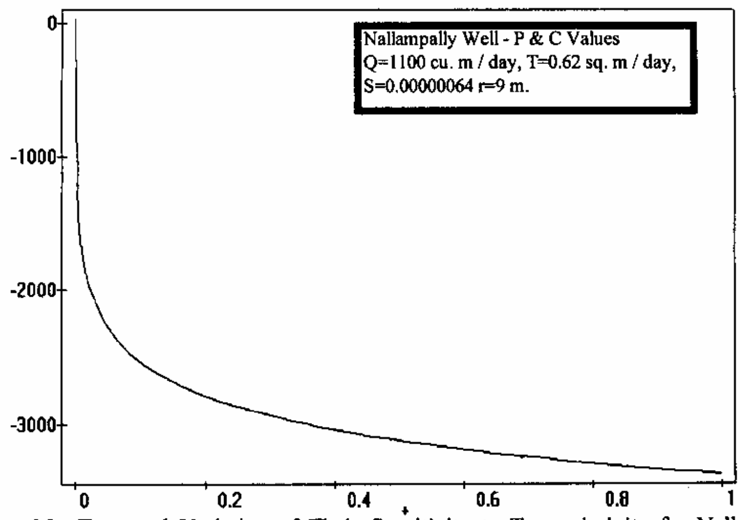


Fig. 6.2 Temporal Variation of Theis Sensitivity to Transmissivity for Nallampally Well.

(b)Storativity

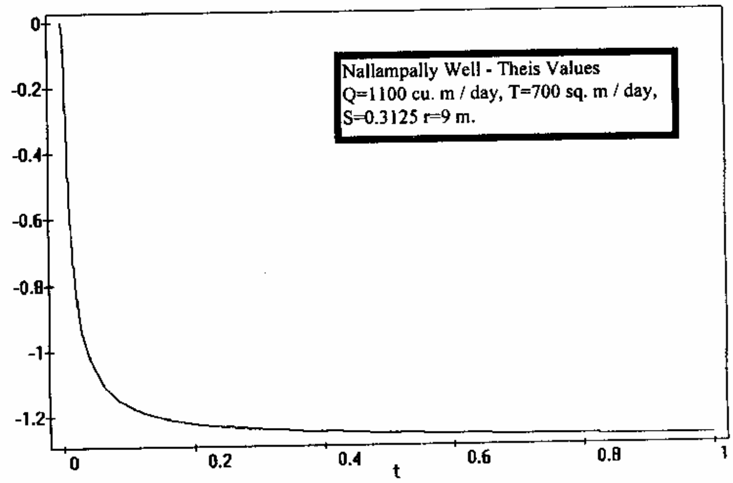


Fig. 6.3 Temporal Variation of Theis Sensitivity for Storativity for Nallampalli Well.

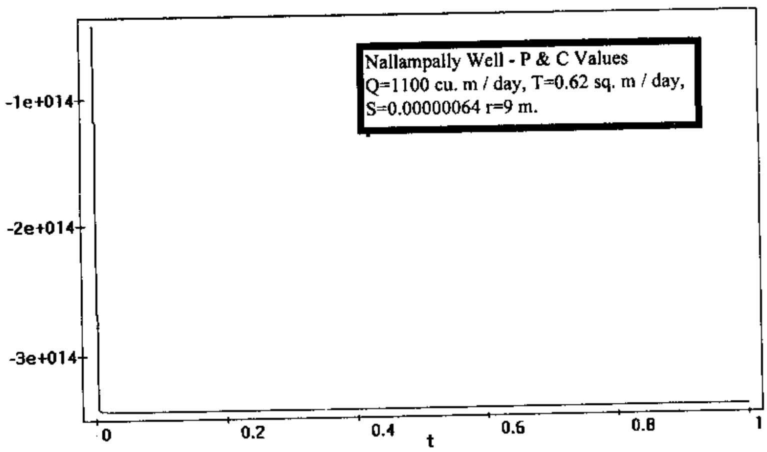


Fig. 6.4 Temporal Variation of Theis Senstivity for Storativity for Nallampalli Well.

(a) Transmissivity

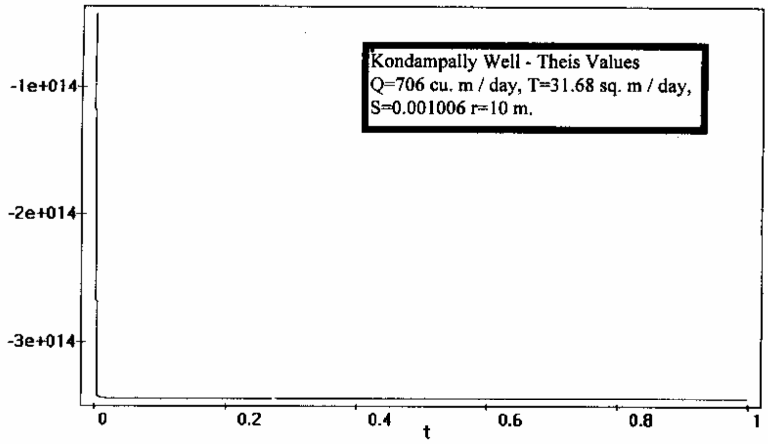


Fig. 6.5 Temporal Variation of Theis Sensitivity for Transmissivity for Kondampalli Well.

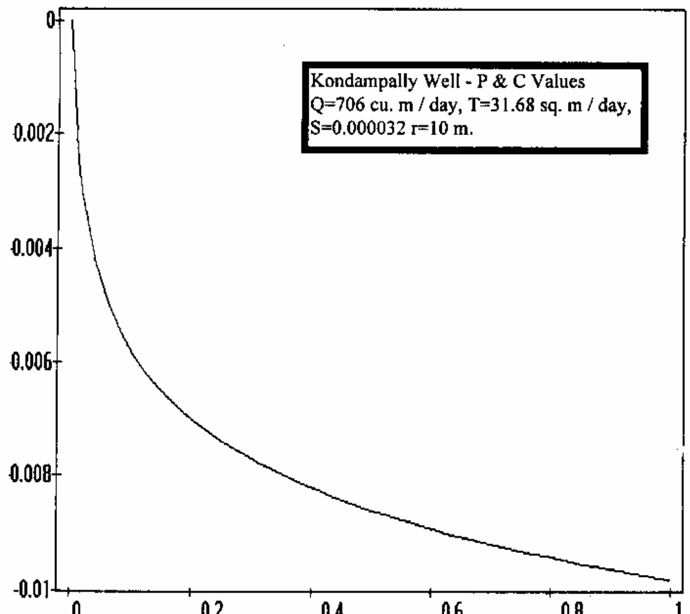


Fig. 6.6 Temporal Variation of Theis Sensitivity for Transmissivity for Kondampalli Well.

(b) Storativity - Kondampally Well

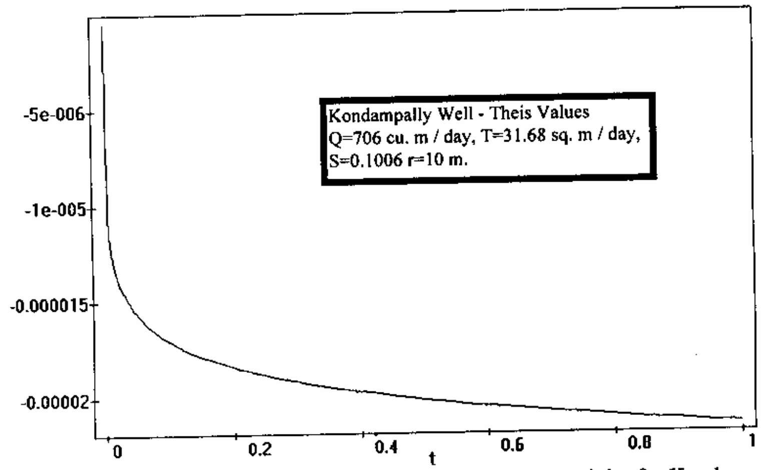


Fig. 6.7 Temporal Variation of Theis Sensitivity for Storativity for Kondampally Well

(b) Storativity - Kondampally Well

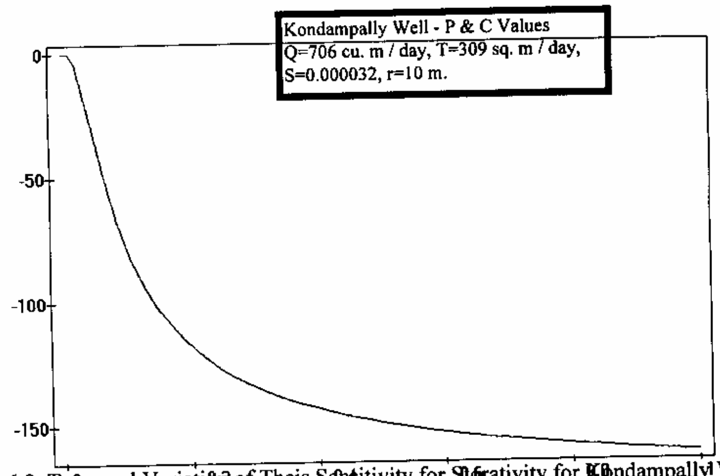


Fig. 6.8 Temporal Variation of Theis Sensitivity for Storativity for Kondampally Well.

(a) Transmissivity - Gollapalli Well

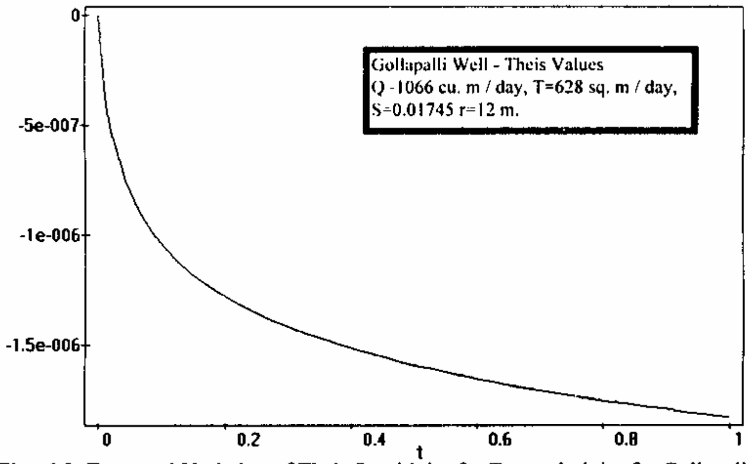


Fig. 6.9 Temporal Variation of Theis Sensitivity for Transmissivity for Gollapalli Well.

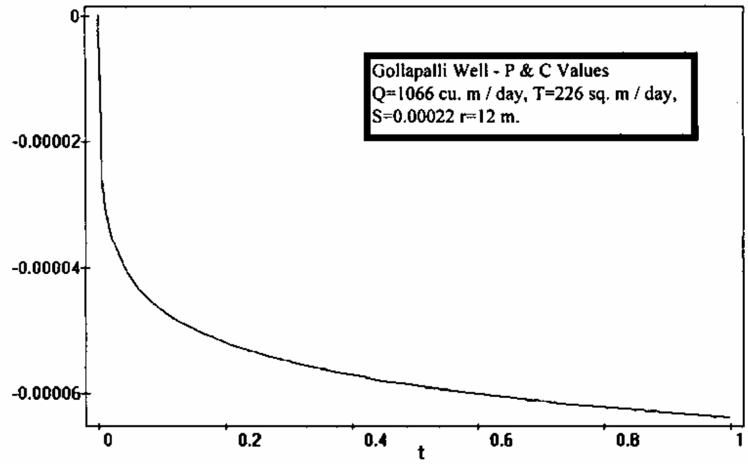


Fig. 6.10 Temporal Variation of Theis Sensitivity for Transmissivity for Gollapalli Well

(b)Storativity - Gollapalli Well

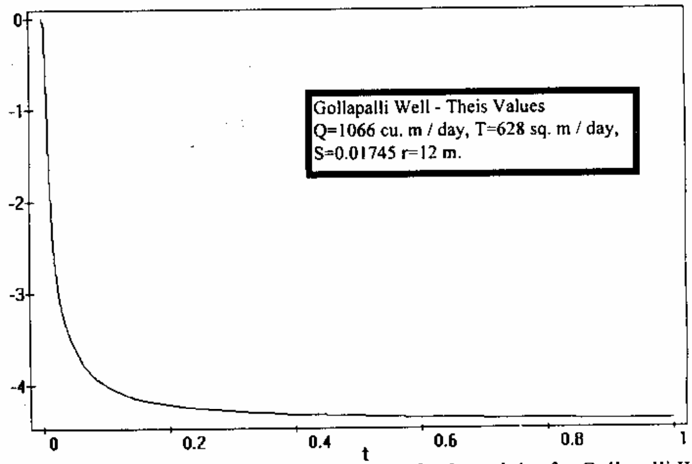


Fig. 6.11 Temporal Variation of Theis Sensitivity for Storativity for Gollapalli Well.

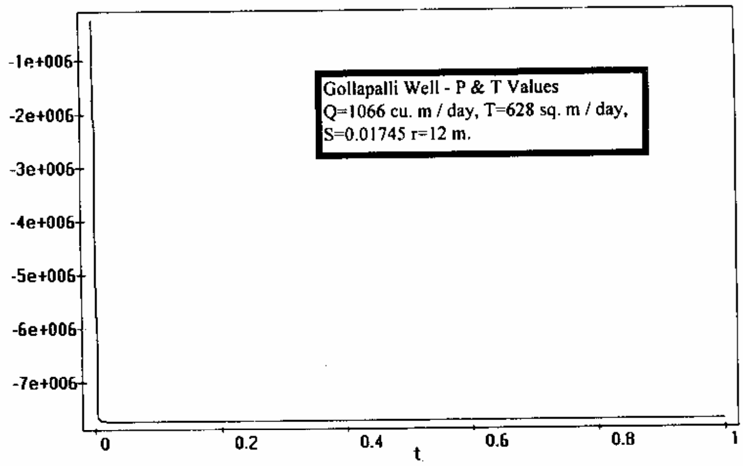


Fig. 6.12 Temporal Variation of Theis Sensitivity for Storativity for Gollapalli Well.

(a) Transmissivity - Tammapuram Well

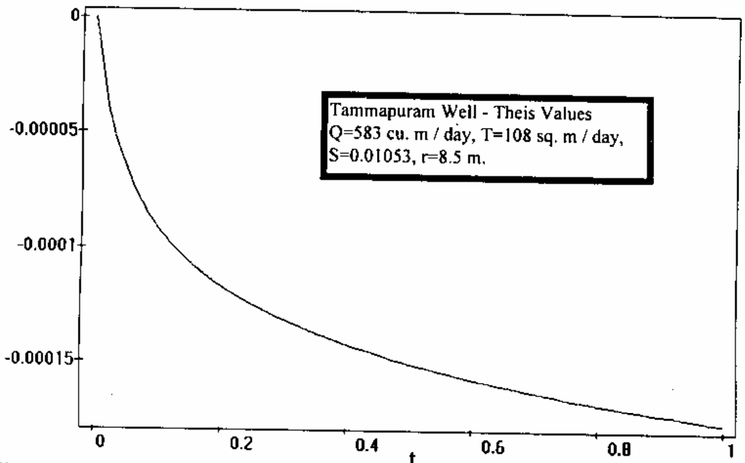


Fig. 6.13 Temporal Variation of Theis Sensitivity for Transmissivity for Gollapalli Well.

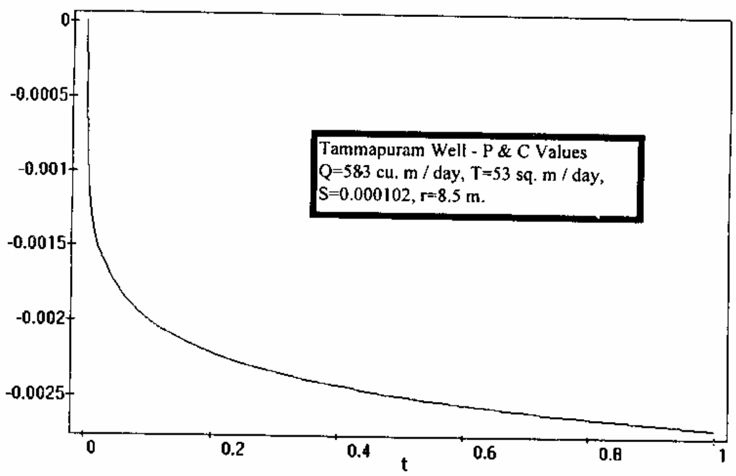


Fig. 6.14 Temporal Variation of Theis Sensitivity for Transmissivity for Gollapalli Well.

(b) Storativity - Tammapuram Well

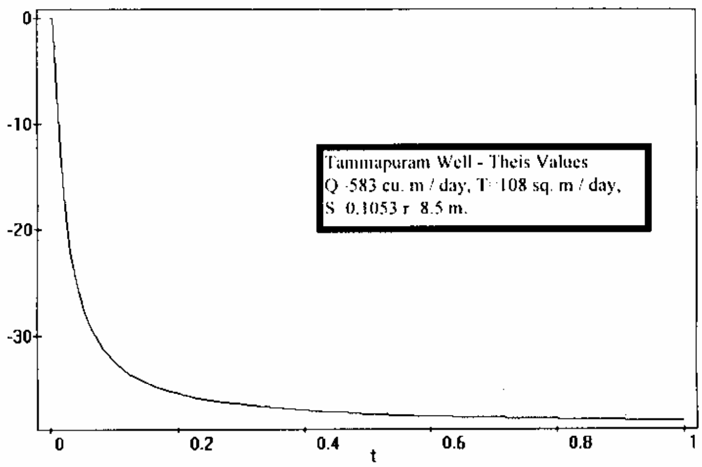


Fig. 6.15 Temporal Variation of Theis Sensitivity for Storativity for Tammapuram Well.

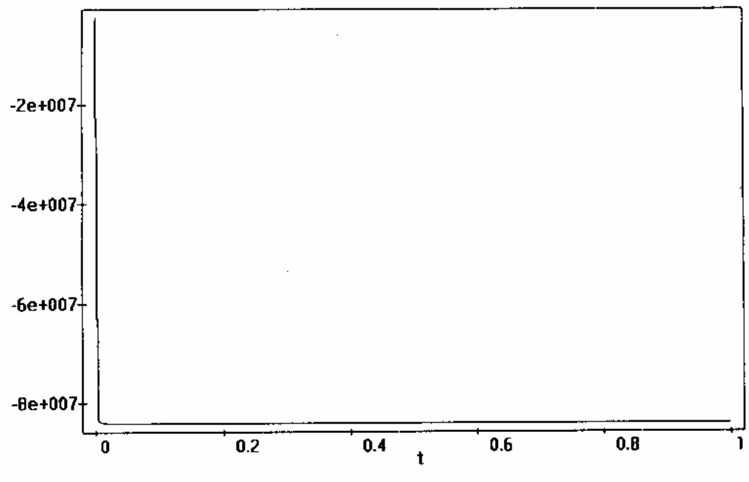


Fig. 6.16 Temporal Variation of Theis Sensitivity for Storativity for Tammapuram Well.

(a)Transmissivity - Basamvaripalli

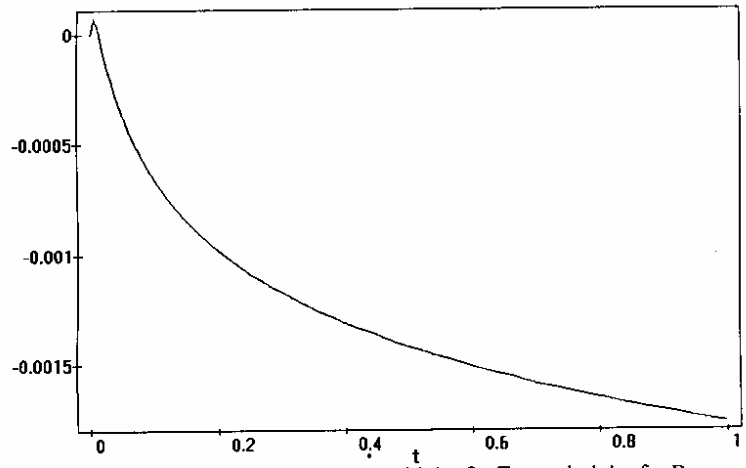


Fig. 6.17 Temporal Variation of Theis Sensitivity for Transmissivity for Basamvaripalli Well

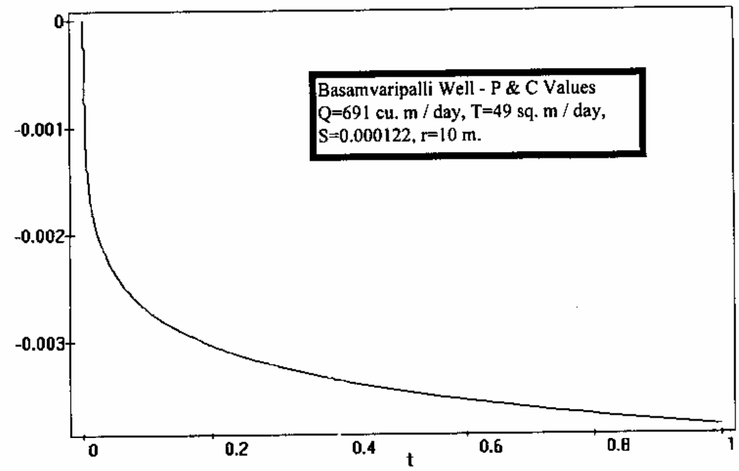


Fig. 6.18 Temporal Variation of Theis Sensitivity for Transmissivity for Basamvaripalli Well.

(b) Storativity - Basamvaripalli Well

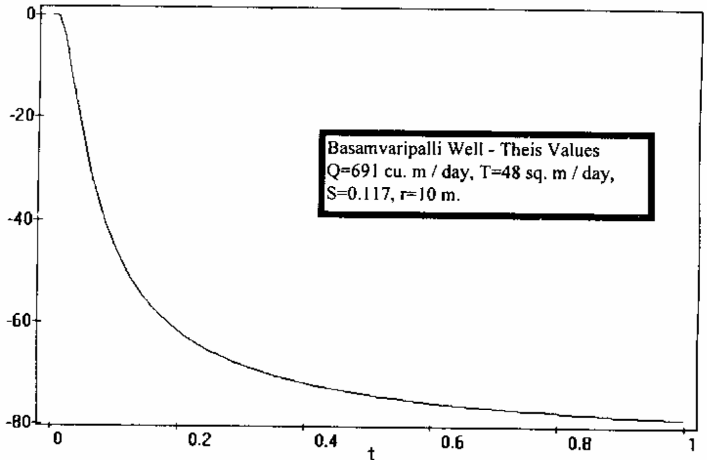


Fig. 6.19 Temporal Variation of Theis Sensitivity for Storativity for Basamvaripalli Well.

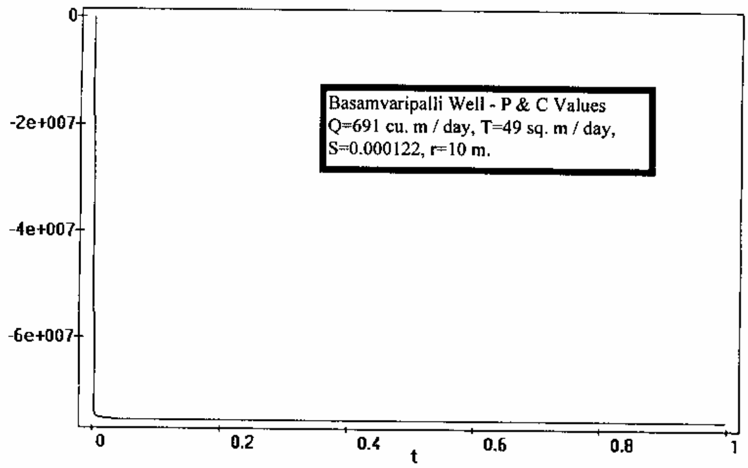


Fig. 6.20 Temporal Variation of Theis Sensitivity for Storativity for Basamavaripalli Well.

(a) Transmissivity - Mechcheri Well

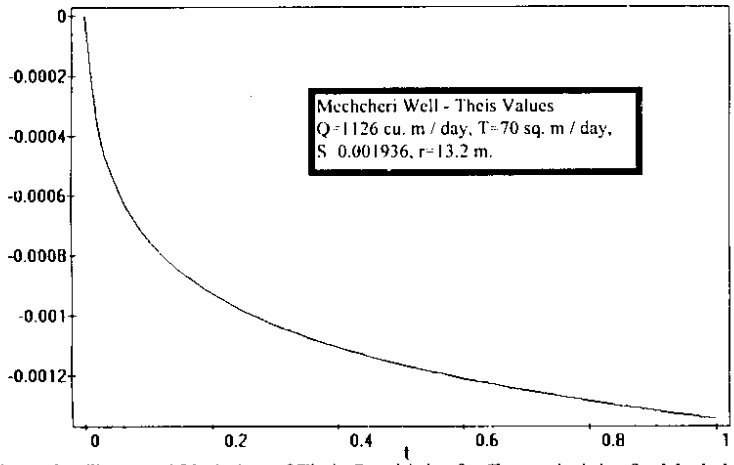


Fig. 6.21 Temporal Variation of Theis Sensitivity for Transmissivity for Mechcheri Well.

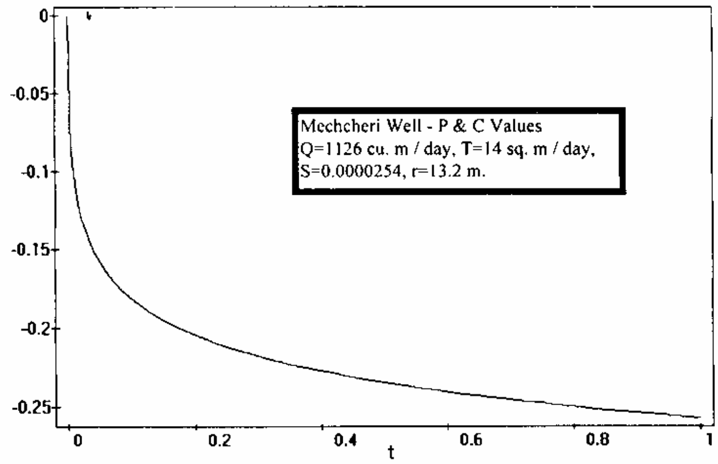


Fig. 6.22 Temporal Variation of Theis Sensitivity for Transmissivity for Mechcheri well.

(b)Storativity - Mechcheri Well

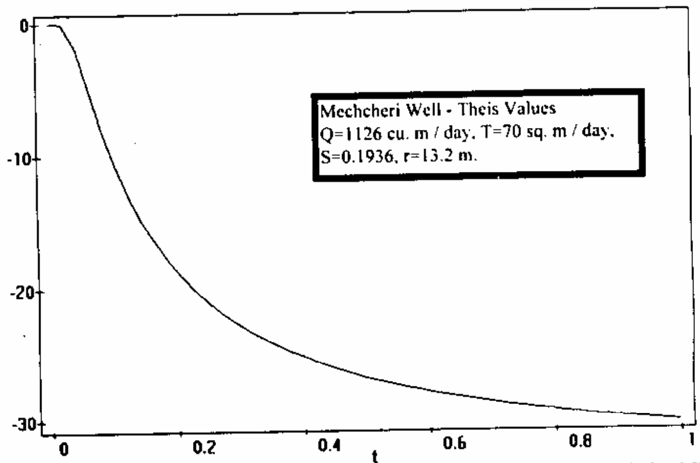


Fig. 6.23 Temporal Variation of Theis Sensitivity for Storativity for Mechcheri Well.

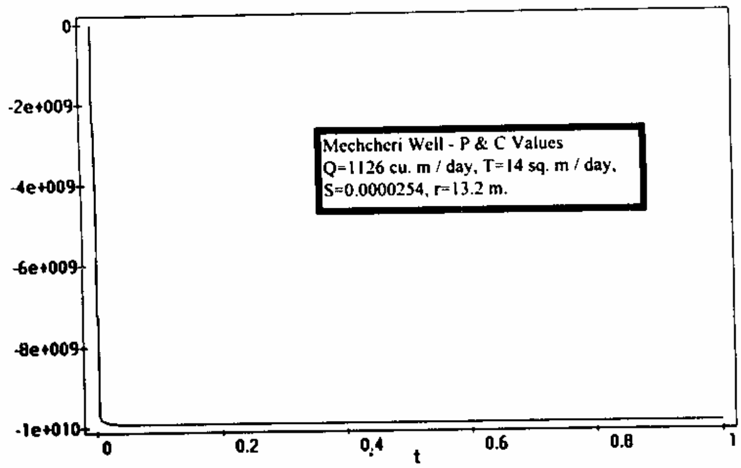


Fig. 6.24 Temporal Variation of Theis Sensitivity for Storativity for Mechcheri Well.

(a) Slitcher - Nallampalli Well

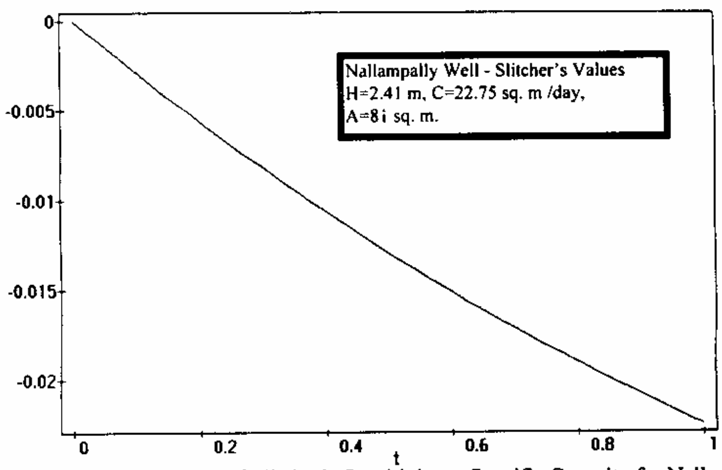


Fig. 6.25 Temporal Variation of Slitcher's Sensitivity to Specific Capacity for Nallampalli Well.

Slitcher's - Kondampally Well

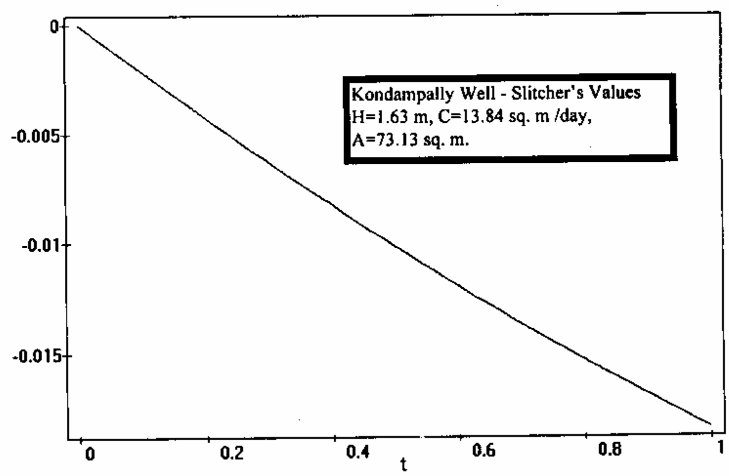


Fig. 6.26 Temporal Variation of Slitcher's Sensitivity to Specific Capacity for Kondampalli Well

Slitcher's - Gollapalli Well

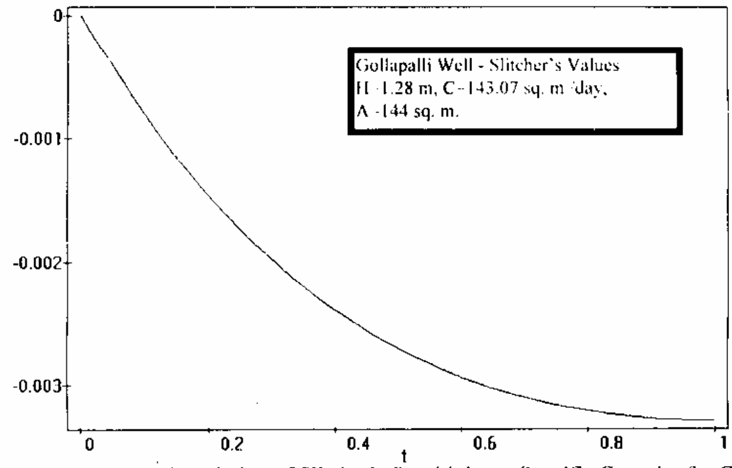


Fig. 6.27 Temporal Variation of Slitcher's Sensitivity to Specific Capacity for Gollapalli Well.

Slitcher's - Tammapuram Well

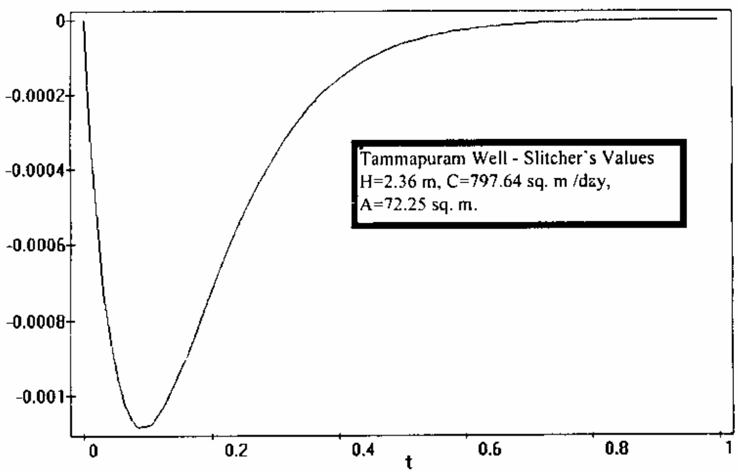


Fig. 6.28 Temporal Variation of Slitcher's Sensitivity to Specific Capacity for Tammapuram Well.

Slitcher's - Basamvaripalli Well

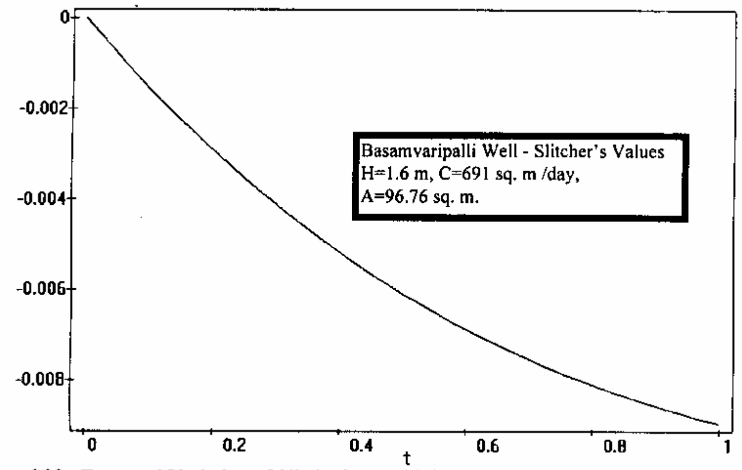


Fig. 6.29 Temporal Variation of Slitcher's Sensitivity to Specific Capacity for Basamvaripalli Well.

Slitcher's - Mechcheri Well

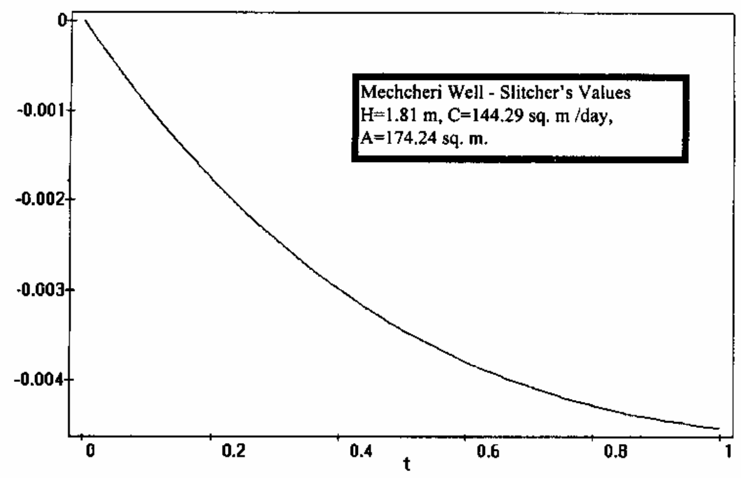


Fig. 6.30 Temporal Variation of Slitcher's Sensitivity to Specific Capacity for Mechcheri Well.

Muskat - Nallampalli Well

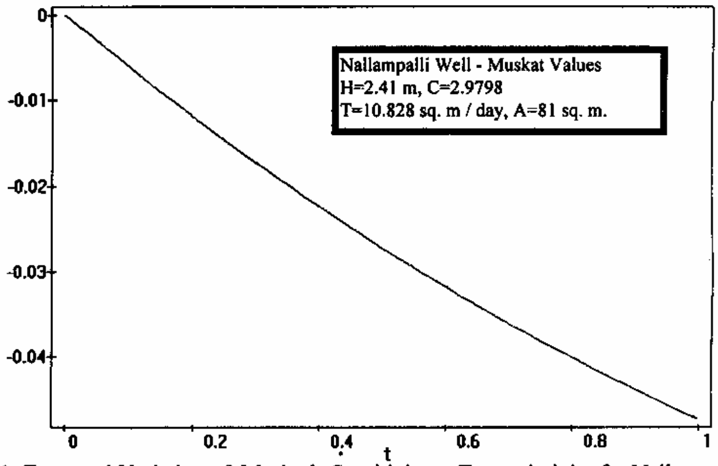


Fig. 6.31 Temporal Variation of Muskat's Sensitivity to Transmissivity for Nallampalli Well.

Muskat - Kondampally Well

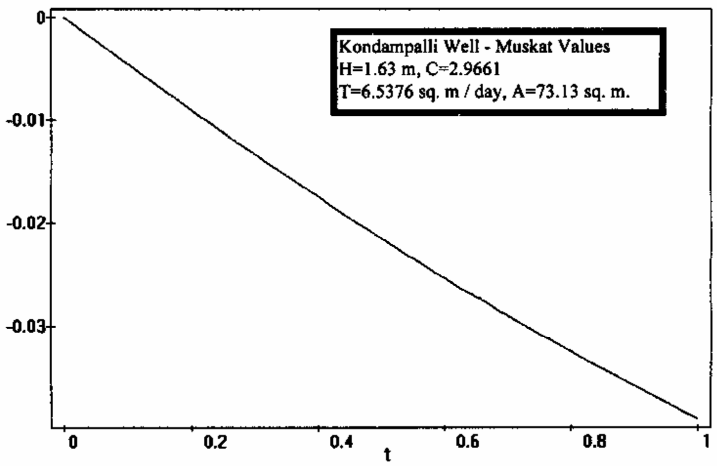


Fig. 6.32 Temporal Variation of Muskat's Sensitivity to Transmissivity for Kondampalli Well.

Muskat - Gollapalli Well

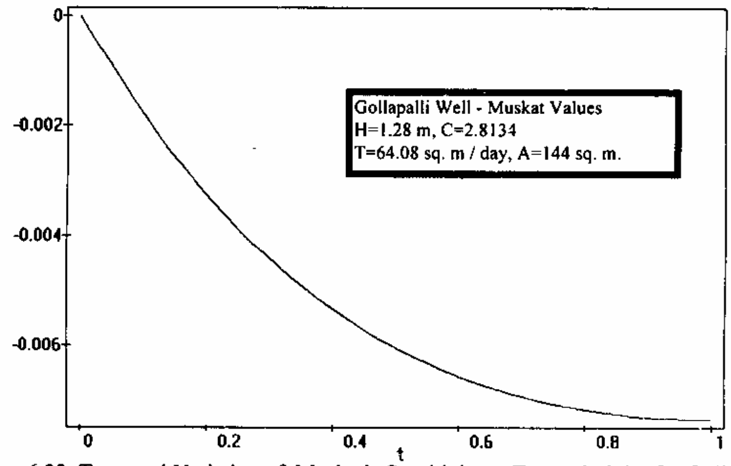


Fig. 6.33 Temporal Variation of Muskat's Sensitivity to Transmissivity for Gollapalli Well.

Muskat - Tammapuram

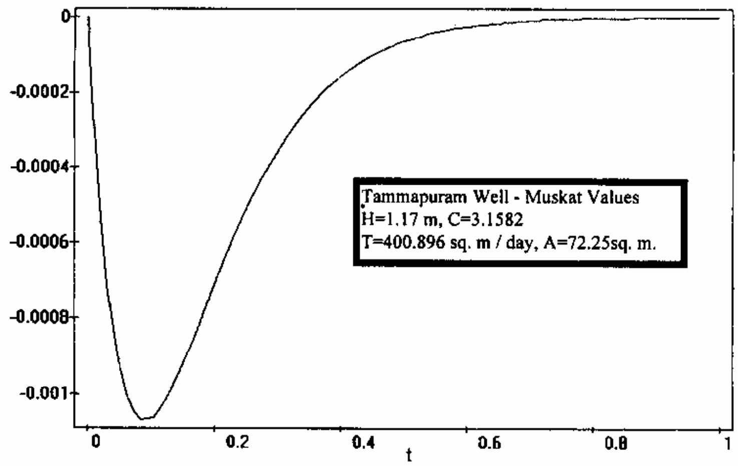


Fig. 6.34 Temporal Variation of Muskat's Sensitivity to Transmissivity for Tammapuram Well.

Muskat - Basamvaripalli Well

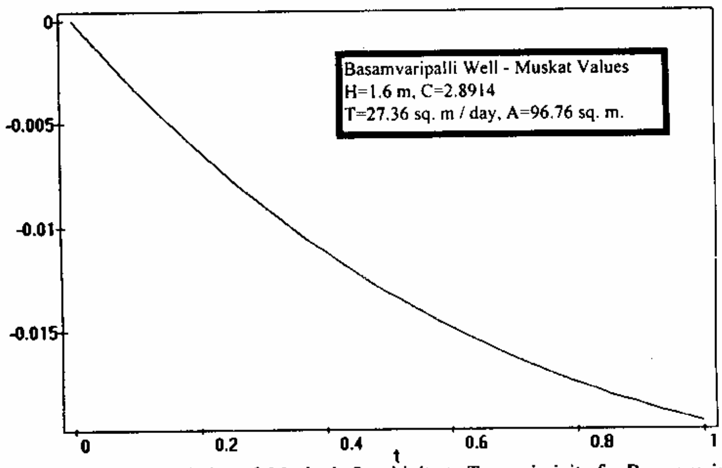


Fig. 6.35 Temporal Variation of Muskat's Sensitivity to Transmissivity for Basamvaripalli Well.

Muskat - Mechcheri

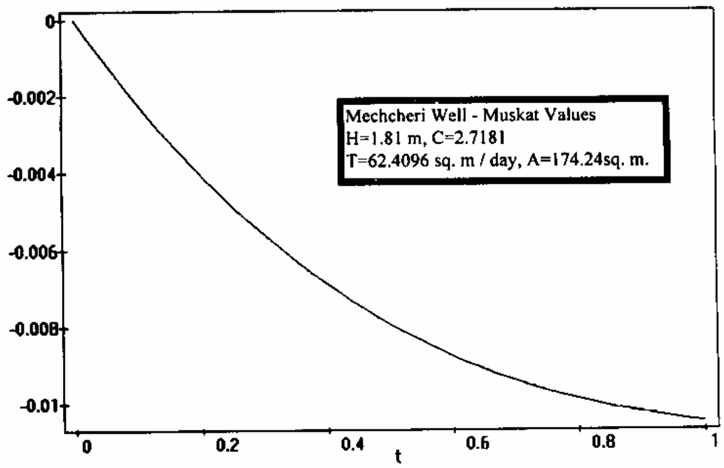


Fig. 6.36 Temporal Variation of Muskat's Sensitivity to Transmissivity for Mechcheri Well.

Kumaraswamy's - Nallampally Well

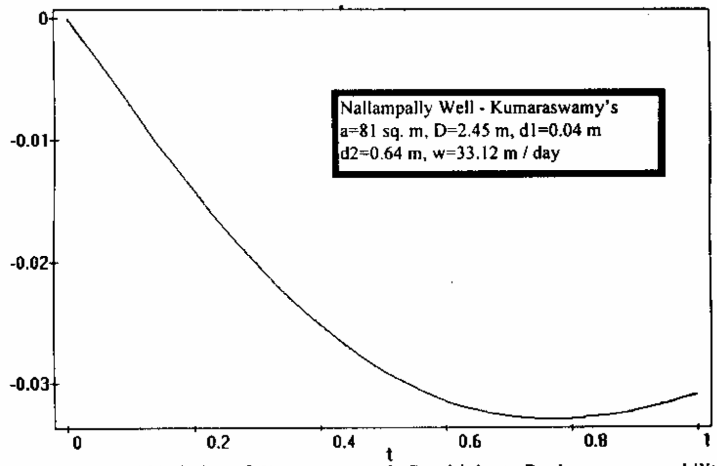


Fig. 6.37 Temporal Variation of Kumaraswamy's Sensitivity to Rock mass permeability for Nallampalli Well.

Kumaraswamy's - Kondampally Well

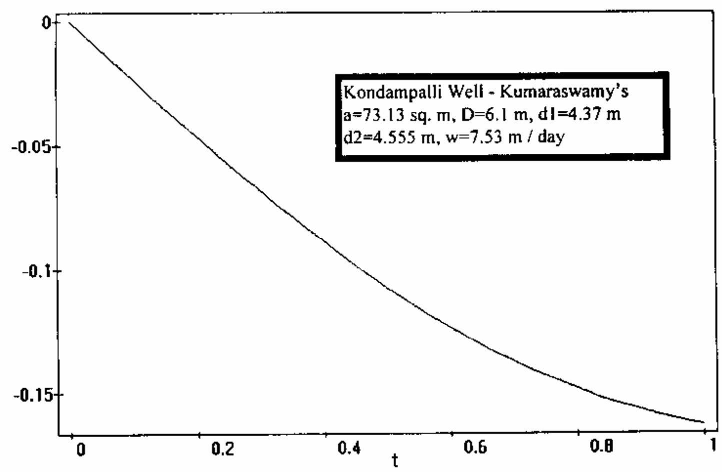


Fig. 6.38 Temporal Variation of Kumaraswamy's Sensitivity to Rock mass permeability for Kondampalli Well.

Kumaraswamy's - Gollapalli Well

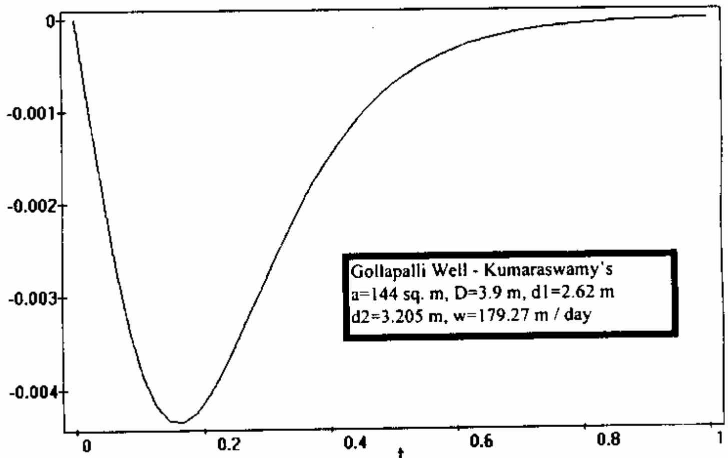


Fig. 6.39 Temporal Variation of Kumaraswamy's Sensitivity to Rock mass permeability for Tammapuram Well.

Kumaraswamy's - Tammapuram Well

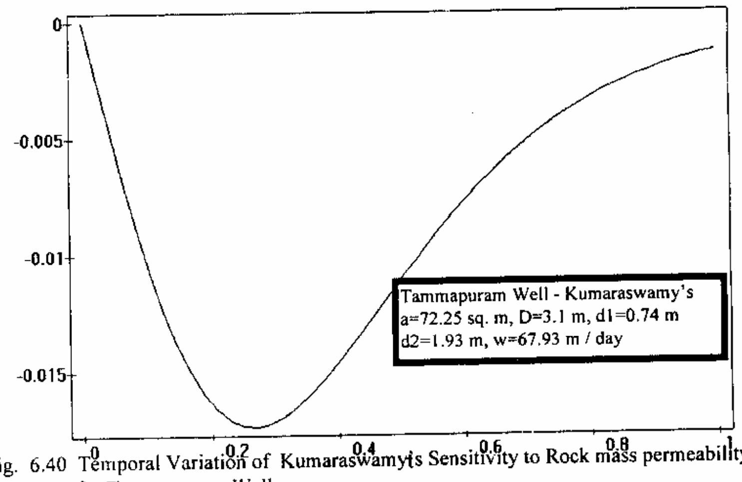


Fig. 6.40 Temporal Variation of Kumaraswamy's Sensitivity to Rock mass permeability for Tammapuram Well.

Kumaraswamy's - Basamvaripalli Well

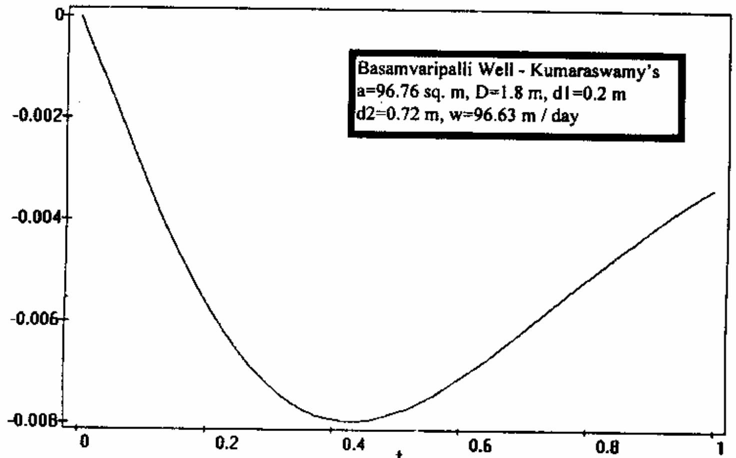


Fig. 6.41 Temporal Variation of Kumaraswamy's Sensitivity to Rock mass permeability for Basamvaripalli Well.

Kumaraswamy's - Mechcheri

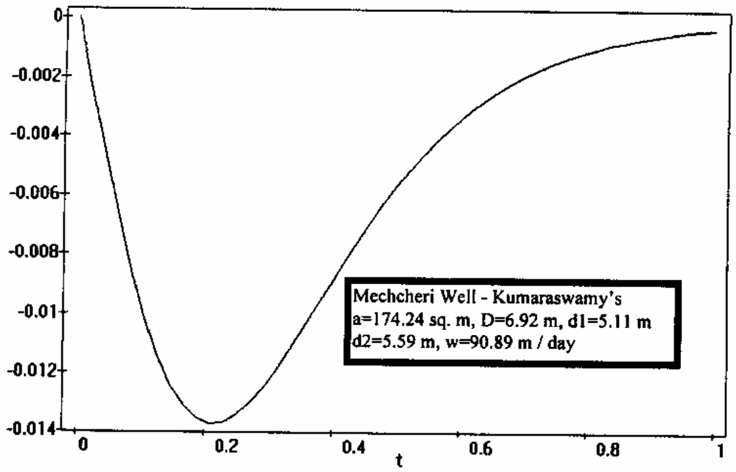


Fig. 6.42 Temporal Variation of Kumaraswamy's Sensitivity to Rock mass permeability for Mechcheri Well.

Annexure-A

Village : Nallampalli.
Owner : Subbe Naik
Date of Testing : 12th June 1980.

PUMPING PHASE data.

Time in minutes	Drawdown in metres
0	0
2	0.02
4	0.05
6	0.07
8	0.09
10	0.11
12	0.13
14	0.15
16	0.17
18	0.19
20	0.21
25	0.28
30	0.35
35	0.42
40	0.49
45	0.56
50	0.63
55	0.7
60	0.77
70	0.9
80	1.01
90	1.12
100	1.24
110	1.41
125	1.6
140	1.8
155	2
185	2.19
215	2.41

RECOVERY PHASE data.

Time in minutes	Recovery in metres
5	2.36
10	2.3
15	2.28
20	2.26
25	2.25
30	2.24
40	2.22
50	2.19
60	2.17
75	2.15
90	2.14
120	2.10
150	2.06
180	2.03
210	1.99
240	1.94
270	1.9
300	1.85
360	1.81

Annexure-B

Village : Kondampalli.
Owner : Subbe Naik.
Date of Testing : 26 November 83.

PUMPING PHASE data.

Time in minutes	Drawdown in metres
2	0.0
4	0.015
6	0.025
8	0.035
10	0.05
15	0.07
20	0.09
25	0.125
30	0.15
35	0.185
45	0.22
65	0.24
75	0.22
85	0.215
90	0.24
95	0.28
100	0.31
105	0.35
110	0.38
115	0.41
120	0.43
130	0.46
135	0.52
140	0.59
145	0.66
150	0.67
155	0.71
160	0.74
165	0.78
170	
175	0.845
180	0.18

185	0.92
190	0.95
195	1.02
200	1.06
205	1.09
210	1.12
220	1.18
225	1.22
230	1.25
235	1.28
245	1.32
250	1.38
255	1.41
260	1.44
265	1.47
270	1.505
275	1.535
280	1.57
285	1.6
290	1.63

RECOVERY PHASE data.

Time in minutes	Recovery in metres
0	1.63
5	1.625
10	1.62
15	1.615
20	1.61
25	1.6
30	1.595
35	1.59
40	1.58
45	1.575
50	1.57
55	1.565
60	1.555
65	1.545
70	1.54
75	1.535
80	1.53
85	1.525
90	1.52
95	1.515

100	1.51
105	1.505
110	1.5
115	1.49
120	1.485
125	1.48
130	1.47
135	1.465
140	1.46
145	1.45
150	1.445

Annexure-C

Village : Gollapalli, Kadiri Taluk.
Owner : Gousi Reddy.
Date of Testing : 17 February 1984.

PUMPING PHASE data.

Time in minutes	Drawdown in metres
2	0.01
4	0.02
6	0.04
8	0.05
10	0.07
15	0.1
20	0.135
25	0.16
35	0.24
45	0.31
55	0.38
65	0.45
80	0.52
95	0.66
110	0.79
125	0.9
145	1.04
165	1.15
180	1.28

RECOVERY PHASE data.

Time in minutes	Recovery in metres
2	1.28
4	1.27
6	1.26
8	1.25
10	1.24
15	1.22
20	1.2
25	1.18
30	1.16
35	1.14

45	1.12
55	1.1
65	1.08
75	1.06
85	1.045
95	1.025
110	0.098
125	0.94
140	0.89
155	0.85
175	0.81
195	0.77
215	0.73
240	0.695

Annexure-D

Village : Tammapuram, Dharmavaram.
Owner : Chinnaramappa
Date of Testing : 14 February 1984.

PUMPING PHASE data.

Time in minutes	Drawdown in metres
0	
2	0.02
4	0.04
6	0.06
8	0.08
13	0.16
18	0.24
23	0.32
28	0.39
33	0.47
38	0.56
43	0.63
53	0.8
63	0.98
73	1.21
88	1.42
103	1.67
118	1.89
133	2.11
153	2.36

RECOVERY PHASE data.

Time in minutes	Recovery in metres
0	2.36
2	2.355
4	2.35
6	2.345
10	2.34
15	2.32
20	2.3
25	2.28
30	2.26

35	2.24
40	2.22
50	2.195
60	2.15
70	2.14
80	2.075
90	2.03
100	1.99
115	1.93
130	1.875
145	1.81
160	1.755
180	1.67
200	1.595
220	1.51
250	1.32
280	1.17

Annexure-E

Village : Basamvaripalli
Owner : Venkatasubbaiah
Date of Testing : 15 February 1984.

PUMPING PHASE data.

Time in minutes	Drawdown in metres
0	
5	0.06
10	0.12
15	0.17
20	0.22
25	0.27
30	0.32
40	0.41
50	0.50
60	0.59
70	0.68
80	0.77
90	0.85
105	0.98
120	1.1
135	1.22
150	1.35
170	1.485
190	1.6

RECOVERY PHASE data.

Time in minutes	Recovery in metres
0	2.36
5	2.355
10	2.35
15	2.345
20	2.34
25	2.32
30	2.3
40	2.28
50	2.26
60	2.24

70	2.22
80	2.195
90	2.15
100	2.14
115	2.075
130	2.03
140	1.99
160	1.93
190	1.875
220	1.81
250	1.755

Annexure-F

Village : Mecheheri, Anantapur
Owner : K.C.Motapa
Date of Testing : 20 August 1979

PUMPING PHASE data.

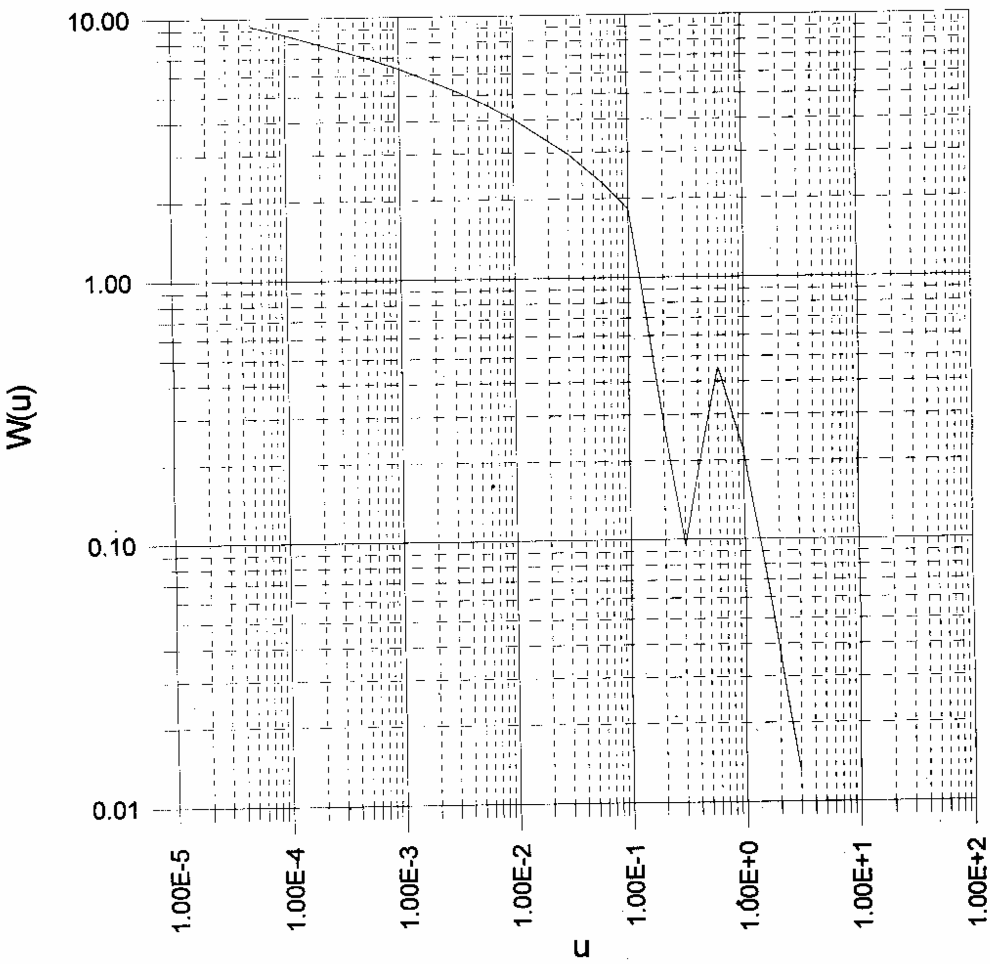
Time in minutes	Drawdown in metres
0	
5	0.02
10	0.04
15	0.06
20	0.09
25	0.11
30	0.14
35	0.18
40	0.22
45	0.26
55	0.35
65	0.39
75	0.46
85	0.53
95	0.60
110	0.69
130	0.82
150	0.94
170	1.05
200	1.23
230	1.41
270	1.61
310	1.81

RECOVERY PHASE data.

Time in minutes	Recovery in metres
0	1.81
5	1.8
10	1.77
15	1.77
20	1.76
25	1.76

30	1.75
45	1.73
60	1.7
75	1.68
90	1.65
120	1.61
150	1.57
180	1.53
210	1.46
240	1.33

Type Curve for Theis Equation.



Type Curve for Popodopulus and Cooper Method

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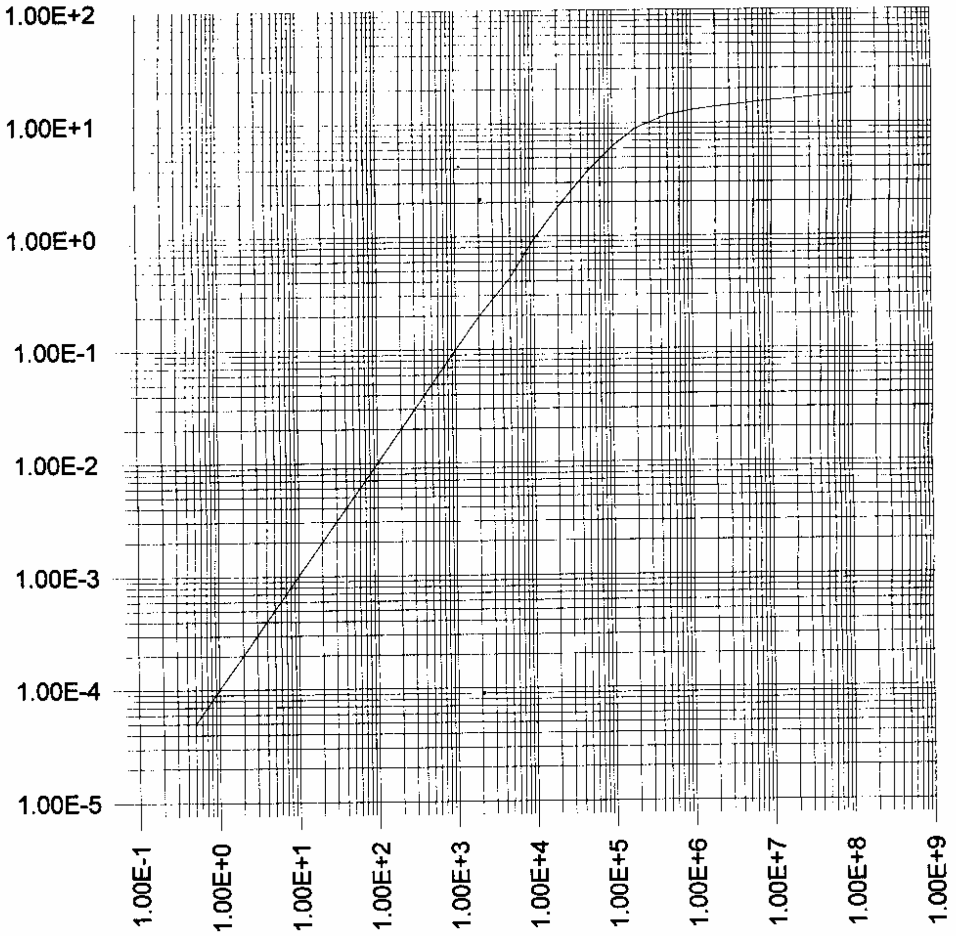

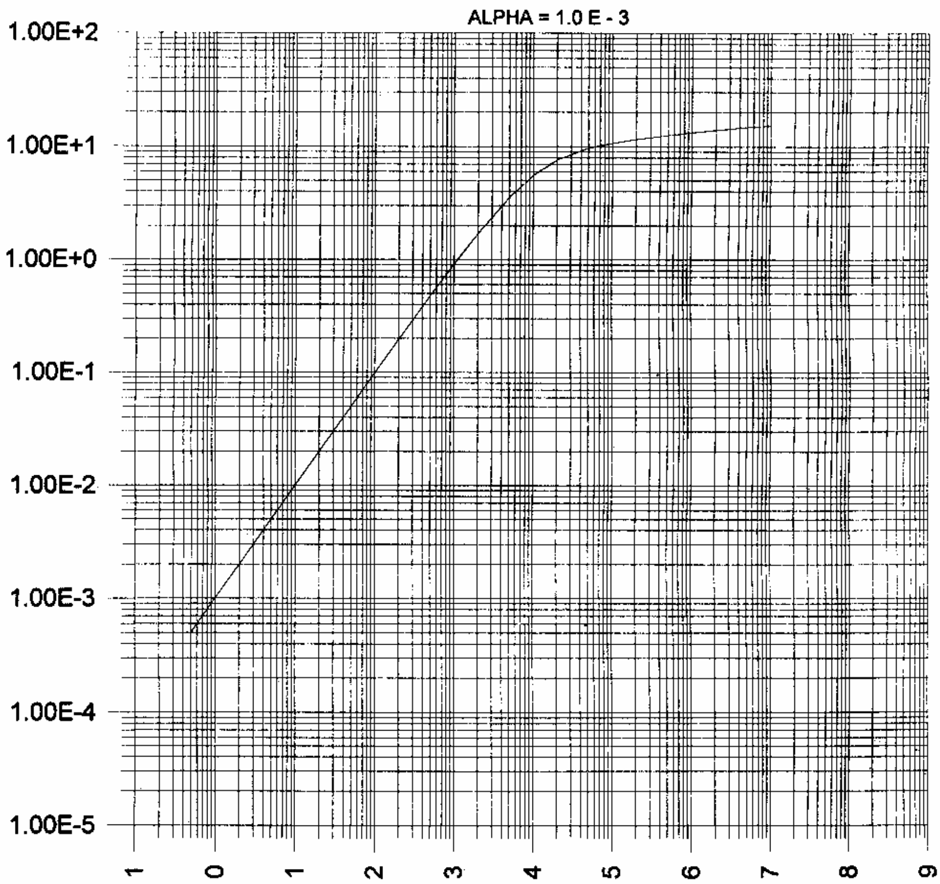
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1.00E+1
1.00E+0
1.00E-1
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1.00E-5
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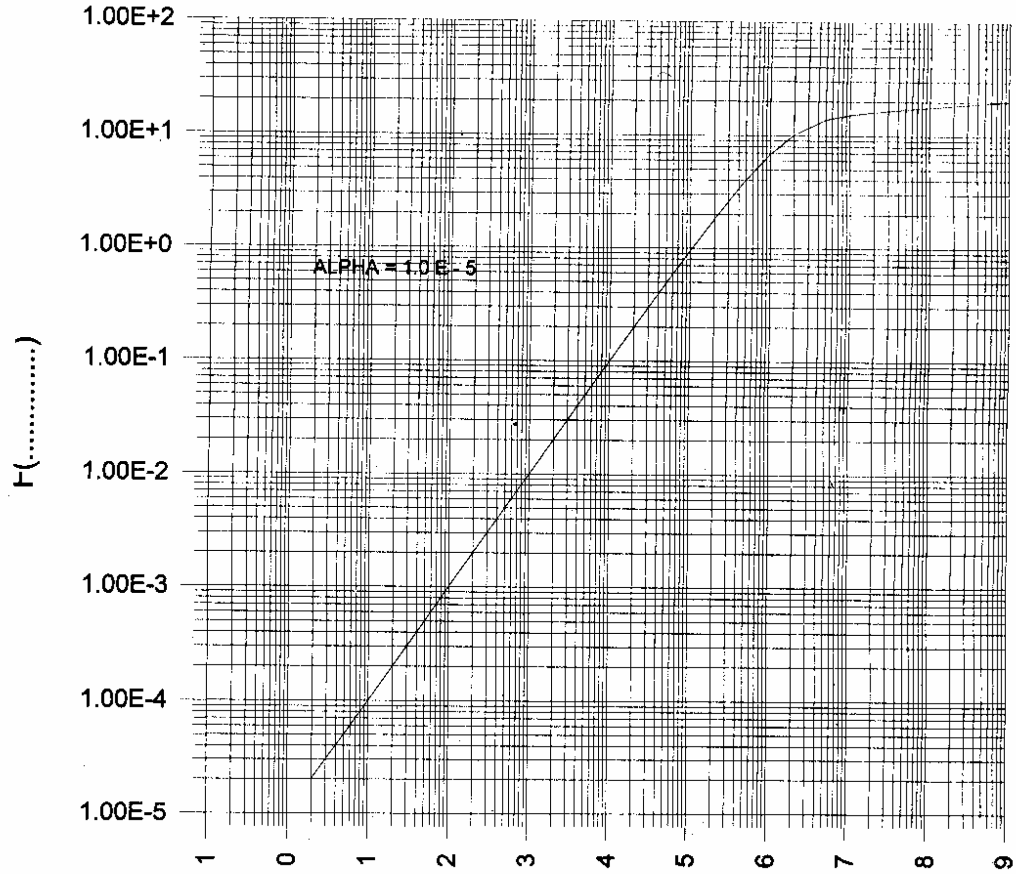
0
1
2
3
4
5
6
7
8
9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1.00E-2
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1.00E-4
1.00E-5
ALPHA = 1.0 E- 5
1
0
1
2
3
4
5
6
7
8
9

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