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STUDY OF DRAWDOWN IN UNCONFINED AQUIFER IN RESPONSE TO PUMPING

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Abstract* – Many ground water studies are carried out to estimate withdrawal of groundwater from the aquifer in the area under safety. For such problems related to ground water, the estimation of aquifer parameter like hydraulic conductivity and storage coefficient is essential. The governing differential equation for the specially uniform and saturated hydraulic conductivities is used in the WTAQ model. It provides dimensionless or dimensional drawdown that can be used with measured drawdown at observation points to estimate hydraulic properties of confined and unconfined aquifer. Comparison of either drawdown or the parameter estimate by traditional method with those estimates by the recent model will be carried out. The important aspect of the study is to identify effect of availability of limited field observation on the uncertainty of the parameter estimation. The outcome will suggest impact of data availability on the drawdown sand parameter estimates by both methods.

***Keywords* – Groundwater, aquifer parameter, WTAQ model**

I. INTRODUCTION

Ground water may be defined as the underground water that occurs in the saturated zone of variable thickness and depth , below the earth's surface. Groundwater is the largest source of fresh water on earth, and was little used until recently. A pumping test is a field experiment which a well is pumped at a controlled rate and drawdown is measured in one or more surrounding observation wells. This pumping test used to determine the hydraulic properties of aquifers, evaluate well performance and identify aquifer boundaries.

The estimation of aquifer parameters like permeability , storage coefficient and transmissibility is required to solve many problems related to the ground water. The traditional and most frequently used techniques to estimate the aquifer parameter is graphical type curve analysis. In this method dimensionless type curves based on analytical model of ground water flow towards a pumping well are used. This method analyzed time-drawdown observation taken in observation well and piezometer. This analysis provides estimation of transimissivity and storativity of confined aquifer. For unconfined aquifer the analysis provides the hydraulic conductivity and specific yields. An alternative approach to dimensionless type-curve analysis is to generate dimensional time-drawdown curves from the analytical model that are compared directly to the measured values. In this approaches the hydraulic properties of the model are adjusted in a series of model simulations until the model calculated drawdowns closely match the measured values. This procedure is called model calibration and can be done graphically, as in the dimensionless type-curve approach, or automatically by use of a parameter estimation technique. Many analytical models have been developed for evaluation of axial-symmetric flow to a well that pumps from a confined and water-table aquifer.

In a confined or unconfined aquifer analytical model for axial-symmetric flow is defined by Moench's(1997).WTAQ calculates dimensionless or dimensional drawdown that can be used with measured drawdown at observation points to estimate hydraulic properties of confined and unconfined aquifer. Moench et al.(2001) developed a model that used a linear combination of exponential functions to simulate release from above the water table to obtain a more general mathematical approximation of the drainage process.

II. LITERATURE REVIEW

Akindunni et al. (1992) To explain variations in the storage property of an unconfined aquifer during pumping numerical methods are used to explain the capillary fridge hypothesis proposed. Based on field observations, the hypothesis suggested that the response of an unconfined aquifer to the stress imposed by pumping is largely controlled by the magnitude of vertical hydraulic gradients developed above the moving water table. Numerical parameters used for the simulation were chosen from experiments independent of the pumping test. Agreement between the late time results of the numerical simulation and the neuman model with a specific yield of 0.3 suggests that a value close to the drainable porosity of the aquifer material would be obtained from type-curve analysis if pumping tests were conducted for a sufficiently long period. The suggestion that unconfined aquifer have much higher compressibility values than similar confined aquifer appears to be incorrect.

A.F.Moench (1994) suggested that when values obtained by volume-balance equation compared with type-curve analysis of water-table aquifer pumping test data has often resulted in values of specific yield that are unrealistically low. It suggest that this type of values are not properly represent the drainage process in the unsaturated zone. Type curve analysis based on the neuman model will result in estimates of specific yield that agree with volume-balance calculation.

A.F.Moench (1996), For the problem of flow to a partially penetrating well in a water-table aquifer an improved mathematical solution has been derived. This Laplace transform solution is simpler and requires less computation time and same level of accuracy.

A.F.Moench (2003) This aquifer test was used to compare results of analyses that involve two variants of the same model that differ by the mathematical description of the upper-boundary condition. One variant assumes that drainage from the vadose zone occurs instant in response to a decline in the elevation of the water table and the other assumes that the drainage declines gradually with time in a manner that is not constrained by functional relationship. A primary failure of models for flow to a well in water table aquifer that are based on the assumption of instant drainage is that specific yield is commonly considered. To reduced these difference, an analytical model was developed that can fully account for time-varying drainage given that aquifer is not strongly mixed. By this flexible approach, measured and simulated drawdown agree over the complete time range and the estimated parameters are consistent with prior studies and with what is known about the aquifer geometry and composition.

Singh (2008) by matching the diagnostically plotted drawdown to one of the diagnostic curve the aquifer parameter can be estimated. The proposed method is simple and easy to apply. It yields good estimate from only early drawdowns, gives more insight in to the calculation process with similar visualization of errors and can easily identify conditions.

A.F.Moench (2008) analytical and numerical analyses conducted with different models designed for the purpose of estimating both saturated and unsaturated zone hydraulic parameters show that the relative hydraulic conductivity function must contain a fitting parameter that is different from the fitting parameter used in soil moisture distribution function.

III. METHDOLOGY

In the present study, as defined in the objects of the study it is intended to estimate the aquifer parameters using model in methods where the Laplace transform solution (by Moench , 2001) using WTAQ software.Comparison of the results are made for the for the estimated parameter by both the approaches. The important aspect of the study is to identify effect of availability of limited field observations on the uncertainity and uniqueness of the parameters estimation. This will help specially in parameter estimation in country like ours, where extensive data of drawdown are usually not available. The outcome of the study may be suggestive of minimum data size necessary for reliable parameter estimate using the recent techniques. Program WTAQ implements the Laplace-transform solutions for drawdown at a pumped well or observation piezometer that are presented in equations in Moench(1997). The program calculates dimensionless or dimensional drawdown for a given set of input conditions that are specified by the user in a data-input file. Instructions for the preparing the data-input files are provided in this section, as are a summary of the simplifying assumptions used in the program, a description of selected program options and variables, and a description of the result and plot files generated by the program.

IV. FIELD VERIFICATION

Singh V.S.(2000) has studied well bore storage effect during pumping test in an aquifer of low permeability. Time drawdown data published in that paper was referred to verify the model studied in this work. The observed time-drawdown data (shown in figure 6 of V. S. Singh paper) was used for the verification purpose. He has used the following parameters in the model:-

1)	Saturated thickness of aquifer	= 28 m
2)	Hydraulic conductivity in horizontal direction	= 1.57 × 10^{-5}m/s
3)	Hydraulic conductivity in vertical direction	= 1.57 × 10^{-5}m/s
4)	Storage coefficient	= 0.0012
5)	Radius of pumping well	= 0.08 m
6)	Distance of observation well from pumping well	= 10 m
7)	Type of pumping well	= Fully penetrating

8) Type of observation well = Fully penetrating
9) Discharge = 51.23 m^3/day
10) Specific yield = 0.2

Using the above parameters the time-drawdown data are plotted and shown in fig 4.1. Inspection of the figure shows that observed data of drawdown is in close agreement with the model predicted drawdown. However, the slightly less value of model predicted drawdown as compare to observed drawdown to indicate effect of delayed drainage.

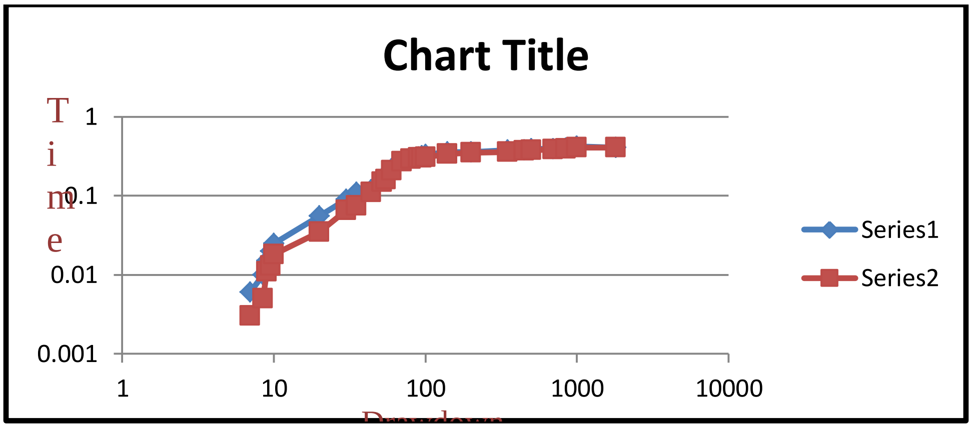

FIG. 4.1 observed and calculates drawdown for paper 1

2)N. Samani et.al.(2007) has studied well bore storage effect during pumping test in an aquifer of low permeability. Time drawdown data published in that paper was referred to verify the model studied in this work. The observed time-drawdown data (shown in paper) was used for the verification purpose.

Pumping rate of well = 2500 m^3/day
Radius of well = 60 m
Storage coefficient = 2.060
Transmissibility = 1110

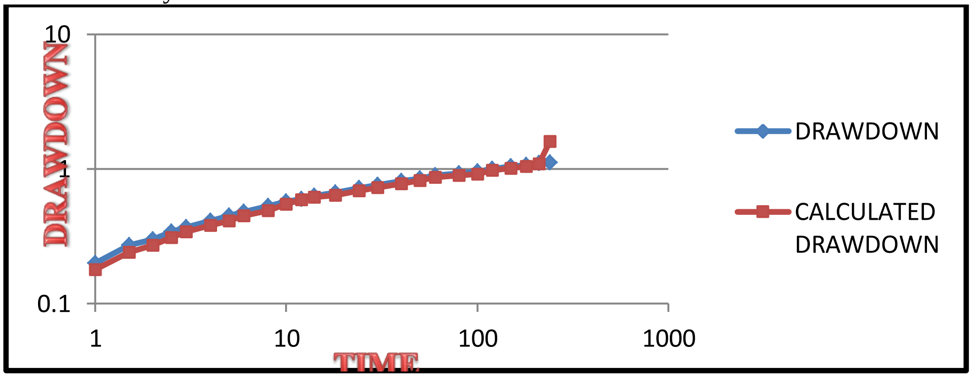

Figure 4.2 Observed drawdown versus calculated drawdown curve for paper 2

Using the above parameters the time-drawdown data are plotted and shown in fig 4.2. Inspection of the figure shows that observed data of drawdown is in close agreement with the model predicted drawdown. However, the slightly less value of model predicted drawdown as compare to observed drawdown to indicate effect of delayed drainage.

V. SENSITIVITY ANALYSIS

The model sensitivity is tested by conducting various models runs with a variety of aquifer parameters. For this runs the following parameters have been assigned.

Specific storage Ss = 2× 10^{-5} Specific yield Sy = 0.2 Pumping rate = 2 × 10^{-3} m^{-3}/s
Vertical hydraulic gradient = 0.5 × 10^{-4} m/s Aquifer thickness = 10 m
Radial distance of observation well 1 = 3.16 Radial distance of observation well 2 = 31.6
Radial distance of observation well 3 = 3.16 Radial distance of observation well 4 = 31.6
Depth of observation well 1 = 7.5 Depth of observation well 2 = 7.5
Depth of observation well 3 = 1.0 Depth of observation well 4 = 1.0

In the section results for observation point 1 are shown. Observation point 1 indicates radial distances r=3.16 m and depth of Z = 7.5 m. This point represents close proximity to the pumping well at a relatively large depth. The results are shown in table 5.1. These results are also shown in figure 5.1. The figure indicates that as value of Kr is increasing values of drawdown reduces. This reduction is observed in all the three segments of the graph. This is quite obviate because with increasing value of horizontal hydraulic conducting horizontal flow increases in vertical flow reduces.

TABLE 5.1

TIME	OBSERWATION WELL1							
	kr = 1	kr= 1.5	kr = 2	kr = 3	kr= 4.5	kr = 6	kr = 9	kr = 12
9.28	0.09071	0.1021	0.1082	0.1129	0.1121	0.1079	0.09705	0.08667
20	0.2106	0.2198	0.2196	0.2086	0.186	0.1649	0.1324	0.11
43.1	0.4018	0.3804	0.3514	0.2971	0.2369	0.1963	0.1468	0.118
92.8	0.5939	0.5008	0.4285	0.3317	0.2498	0.2022	0.1487	0.119
200	0.6816	0.5344	0.4427	0.3348	0.2502	0.2023	0.1487	0.119
431	0.6928	0.5361	0.443	0.335	0.2504	0.2025	0.1489	0.1192
928	0.6951	0.5379	0.4445	0.336	0.2511	0.203	0.1493	0.1194
2000	0.7015	0.5423	0.4478	0.3382	0.2526	0.2041	0.15	0.12
4310	0.7148	0.5512	0.4545	0.3427	0.2556	0.2064	0.1515	0.1211
9280	0.7407	0.5686	0.4677	0.3515	0.2615	0.2108	0.1544	0.1233
20000	0.7875	0.6	0.4913	0.3673	0.272	0.2187	0.1597	0.1273
43100	0.8606	0.649	0.5281	0.3919	0.2885	0.231	0.168	0.1335
92800	0.9572	0.7136	0.5266	0.4243	0.3101	0.2472	0.1788	0.1416
200000	1.068	0.7836	0.6231	0.4613	0.3348	0.2658	0.1911	0.1508

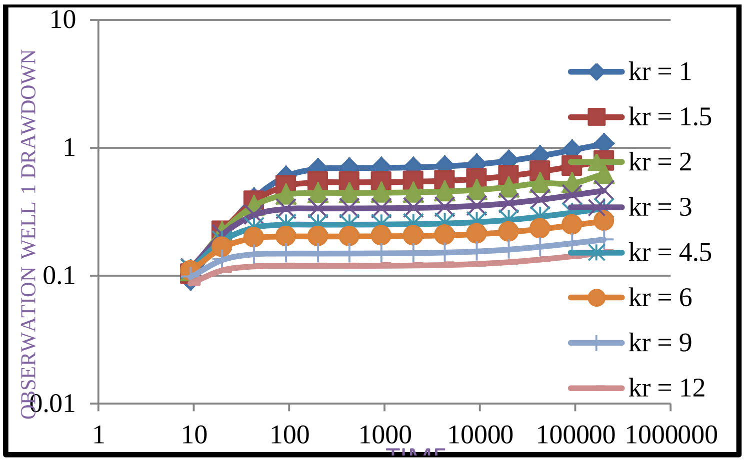

FIGURE 5.1

In the section results for observation point 2 are shown. Observation point 2 indicates radial distances r=31.6 m and depth of Z = 7.5 m. Observation well 2 signifies deep seated peizometer at a large radial distance from the pumping well. For this graph as can be seen from figure 5.2. For segment 1 and 2 drawdown increases as value of hydraulic conductivity reduces various for segment 3.The reverse trained is observed that is when horizontal hydraulic conductivity increases the drawdown reduces. This occurs due to pattern of slop of flow lines in different times at initial intermediate time the effect of horizontal flow is minimum at large distance where as at late times effect of the horizontal flow is quite predominant.

TABLE 5.2

TIME	OBSERWATION WELL 2							
	kr = 1	kr = 1.5	kr = 2	kr = 3	kr = 4.5	kr = 6	kr = 9	kr = 12
9.28	0	0.00	0	0.0006	0.001663	0.002829	0.004822	0.006202
20	0	0.001132	0.002329	0.004942	0.008246	0.0105	0.01276	0.01346
43.1	0.00289	0.006236	0.00934	0.01379	0.01713	0.01897	0.01849	0.0177
92.8	0.007606	0.01238	0.01561	0.019	0.0206	0.0207	0.01973	0.01849
200	0.0101	0.01443	0.01705	0.01968	0.02085	0.02082	0.01978	0.01852
431	0.01059	0.0147	0.01725	0.01984	0.02099	0.02095	0.01989	0.01861
928	0.011	0.01517	0.01773	0.02029	0.02138	0.02129	0.02015	0.01882
2000	0.01194	0.01622	0.01878	0.02126	0.0222	0.02199	0.02069	0.01925
4310	0.014	0.01849	0.02104	0.02332	0.02393	0.02346	0.02181	0.02016

9280	0.01816	0.02341	0.02585	0.02761	0.02749	0.02645	0.02406	0.02196
20000	0.02905	0.034	0.03588	0.03625	0.03442	0.03219	0.0283	0.02531
43100	0.05245	0.05579	0.05549	0.05212	0.04657	0.04199	0.03534	0.0308
92800	0.09934	0.09489	0.08848	0.077	0.06464	0.05615	0.04521	0.03837
200000	0.175	0.152	0.1341	0.1095	0.08725	0.07348	0.05703	0.04737

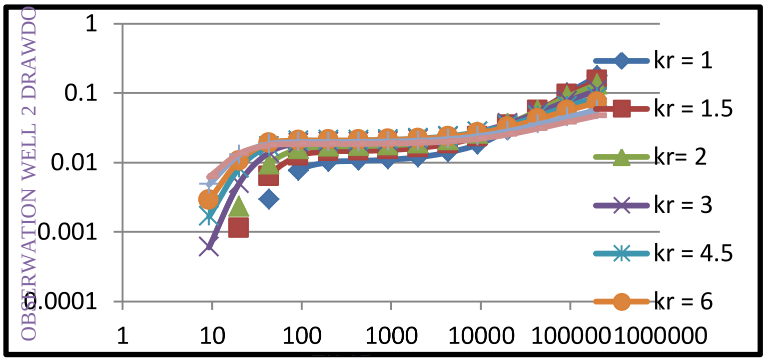

Figure 5.2

In the section results for observation point 3 are shown. Observation point 3 indicates radial distances r=3.16 m and depth of Z = 1.0 m. This observation point depicts shallow piezometer in the vicinity of the pumping well at shallow depth. The result pattern for observation well 3 is quite similar to that of observation well 1. Thus for initial, intermediate and late time segments the drawdown reduces with increasing horizontal hydraulic conductivity. One interesting observation can be made from figure 5.3. That intermediate time segment is minimum when Kr =1 and is maximum when Kr = 12.This is due to variable vertical hydraulic conductivity are nearly same (Kr = 1 , Kz = 0.5) vertical flow is varies sluggish. Due to this drawdown increases at a very slow rate in intermediate time segment.

TABLE 5.3

TIME	OBSERWATION WELL3							
	kr = 1	kr = 1.5	kr = 2	kr = 3	kr = 4.5	kr = 6	kr = 9	kr = 12
9.28	0.006376	0.006297	0.006104	0.005674	0.00509	0.004602	0.003844	0.003286
20	0.01824	0.01704	0.0158	0.01361	0.01112	0.009329	0.006971	0.005521
43.1	0.03858	0.03305	0.02851	0.02197	0.01605	0.01253	0.008625	0.00655
92.8	0.05984	0.04574	0.03651	0.02566	0.01758	0.01333	0.008975	6.76E-03
200	0.07069	0.05015	0.03869	0.02649	0.01797	0.0136	0.00915	0.006895
431	0.07419	0.05242	0.04032	0.02759	0.01872	0.01417	0.009535	0.007184
928	0.08152	0.057	0.04382	0.02759	0.02033	0.01538	0.01035	0.007796
2000	0.09542	0.06656	0.05111	0.0349	0.02366	0.01789	0.01203	0.00906
4310	0.1231	0.08553	0.06554	0.04466	0.03023	0.02284	0.01535	0.01155
9280	0.1739	0.1202	0.09186	0.06242	0.04216	0.03183	0.02136	0.01607
20000	0.2558	0.1757	0.1338	0.0906	0.06105	0.04603	0.03086	0.0232
43100	0.3652	0.2493	0.1892	0.1277	0.08588	0.06469	0.04331	0.03255
92800	0.4878	0.3313	0.2509	0.1689	0.1134	0.08532	0.05707	0.04288
200000	0.6126	0.4146	0.3134	0.2106	0.1412	0.1062	0.07099	0.05332

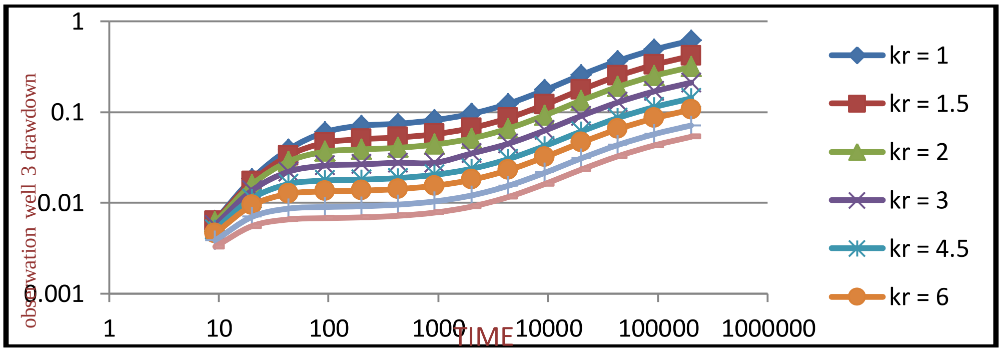

FIGURE 5.3

In the section results for observation point 4 are shown. Observation point 4 indicates radial distances r=31.6 m and depth of Z = 1.0 m. The result pattern for observation well 4 is quite similar to that of observation well 2. This observation point represents shallow observation point at large distance from the pumping well. The pattern of the results as seen from figure 5.4 is almost similar to that shown in figure 5.2 for observation well 2.

TABLE 5.4

TIME	OBSERWATION WELL 4							
	kr = 1	kr = 1.5	kr = 2	kr = 3	kr = 4.5	kr = 6	kr = 9	kr = 12
9.28	0	0	0	0	0	0.000415	0.000674	0.000832
20	0	0	0	0.000815	0.001333	0.001667	0.001955	0.001997
43.1	0	0	0.001576	0.00231	0.00283	0.00299	0.00292	0.002714
92.8	0	0.002112	0.00266	0.003219	0.003448	0.003417	0.003161	0.002876
200	0.001762	0.002514	0.00297	0.00341	0.003568	0.003513	0.003239	0.002944
431	0.001929	0.002684	0.003147	0.0036	0.003762	0.0037	0.003406	0.003093
928	0.002193	0.003031	0.003541	0.00403	0.004129	0.00411	0.003768	0.003412
2000	0.002788	0.003803	0.004406	0.004964	0.005116	0.004986	0.004536	0.004086
4310	0.004125	0.005534	0.00632	0.006994	0.007095	0.006844	0.006142	0.005484
9280	0.007423	0.009526	0.01062	0.01141	0.01127	0.01068	0.009372	0.008249
20000	0.01575	0.01901	0.02039	0.02083	0.01969	0.01814	0.01536	0.01323
43100	0.03728	0.04089	0.04128	0.03911	0.03464	0.0307	0.02481	0.02079
92800	0.08546	0.08303	0.07791	0.06773	0.05603	0.04772	0.03689	0.03014
200000	0.1656	0.1446	0.1276	0.1034	0.08108	0.06701	0.05009	0.04017

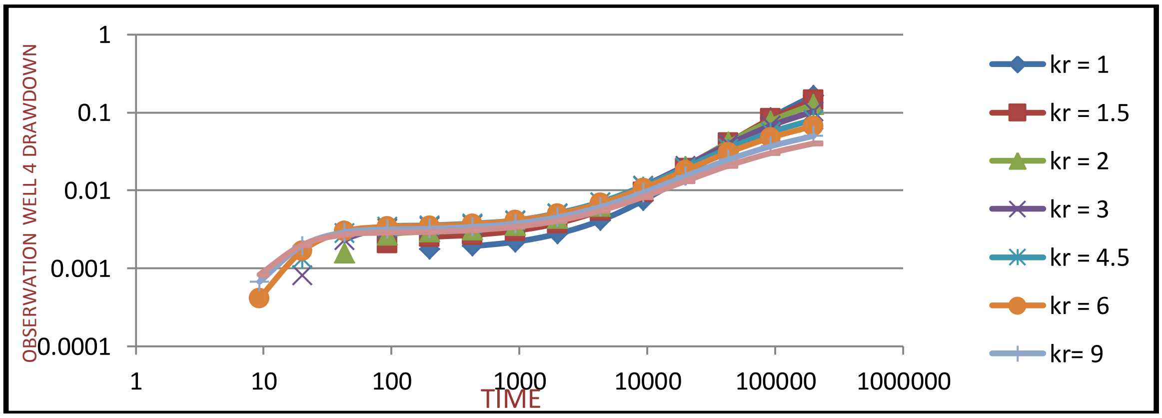

Figure 5.4

VI. CONCLUSION

In this study drawdown in unconfined aquifer in response to pumping are studied. These drawdowns are studied invoking a mathematical model known as WTAQ developed by moench et.al.(2003). This model conceptualizes delayed drainage from the overlying in saturated zone in terms of multiple delayed drainage indices. The model considers exponential decay in gravity drainage with respect to time. The model is conceptually extension of boulton's model (1963). The model considers two dimensional axis-symmetric flow towards a pumping well.
In a part of study, the pumping test data published in literature (V.S.Singh (2000) and N.Samani(2007)) were used to verify the model. It was found that field observed drawdown and model produced drawdowns are in close agreement.
Subsequently, the sensitivity analysis was performed to study of the effect anisotropic of the aquifer on the drawdowns in unconfined aquifer. This was performed because the type curve method does not consider anisotropic of the aquifer. As this method considers the aquifers as isotropic. Thus, there is a definate advantages that the model WTAQ considers vertical flow, partial penetration of pumping and observation wells and delayed gravity drainage from the unsaturated zone. The results of sensitivity analysis show that the drawdown increases as the degree of anisotropic reduces. i.e. when horizontal hydraulic conductivity is nearly equal to vertical hydraulic conductivity. Further , this effect is more predominantly observed in shallow peizometer in the vicinity of the pumping well.

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