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Ground Water Modeling for Evaluation of Effect of Water Harvesting Structures on Groundwater Recharge

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ABSTRACT

Many watersheds in state of Andhra Pradesh, India have ground water as the main source of water for agriculture as well as other purposes in absence of any irrigation project. One such watershed named Mondi–Gaurelli lies in semiarid regions of Andhra Pradesh. Geographical extent of watershed is 7.8 sq.km. Agriculture is mainly rainfed. Ground water is the main source of water. Ground water situation is very grim as groundwater development stage is over exploited and only 34 % area has good water potential zones. Geologically the area is underlain by granites. Dolerite dykes occurring as intrusive associated with pink granite are observed as residual hill range on the northern part of the micro watershed running approximately in E-W direction. Joints trending in NNE-SSW and N-S directions are prevalent in the area. There are number of fractures and lineaments conducive for water recharge. Therefore in the present work it was decided to assess ground water potential and situation by carrying out groundwater simulation and to judge the effect of water harvesting structures on ground water levels through modeling. One of the most popular and comprehensive deterministic ground water model VISUAL MODFLOW V 2.61 1995-97 developed by McDonald and Harbaugh of USGS has been used. Groundwater Modeling has shown that water-harvesting structures would increased the ground water storage by 92% during 96-97 for 734 mm of rainfall and 22% during 97-98 for a rainfall of 524 mm for same amount of groundwater withdrawal.

Key words: Groundwater, Modeling, Recharge, Water harvesting structures

1. INTRODUCTION

Water is an essential ingredient for the agricultural development and the places where ground water is the main source of water, it is but essential to estimate ground water potential. This helps in deciding the alternative land use strategies. Quantification or assessment of exact amount of water is a very difficult process. The observation made by CGWB (Southern Region Report 1998) on an observation well in the Yacharam, near Mondi-Gaurelli micro watershed R.R.District, A.P. indicates that ground water levels are falling year after year. In this watershed groundwater is the main source of drinking water. Therefore, it is very important to replenish groundwater by installing water harvesting structures. In this direction, it was decided to first simulate groundwater conditions in the watershed and to understand distribution of aquifer parameters, permeability, yield, draft and suggest remedies for recharging the ground water. In the present study one of the most popular and comprehensive deterministic ground water model VISUAL MODFLOW V 2.61 1995-97 developed by McDonald and Harbaugh of USGS has been used. Modflow software has been used in various case studies and found to be useful. Simulation of groundwater regime is based on finite difference solutions for 3-D flow through porous medium in the Visual Modflow software. The basic module is a block - centered finite difference grid that allows variable spacing of grid in 3 dimensions. Flow can be simulated for steady as well as transient conditions.

2. METHODS

Basin Features

Mondi -Gaurelli watershed covers 7.8 km^2 and lies between 17° to 17°5′ N latitudes and 78°41′ to 78°44′ longitudes E and is situated in southeastern part of Rangareddy district. It falls in drought prone and backward region. The rainfall is scanty and erratic in the region and ground water development is 107 percent.

Physiographic and Drainage

The northern part of the micro watershed is bounded by arch shaped hill range where the elevation is around 600m (amsl). In the central part the elevation is around 550m (amsl) and the gradually reduces to 525m(amsl) near Chintapatla village. The groundsurface elevation in the southeastern part of the watershed is around 555m (amsl). The topographic gradient on the northern side is around 13.7 m/km upto Chintapatla village and reduces to around 2.3 m/km on southern side.

Rainfall and Hydrometeorology

Average annual rainfall in the area is 613mm.The lowest rainfall of 497mm occurred in the year 1986 and the highest rainfall of 1091mm was recorded during 1987. The rainfall during southwest monsoon from June to September constitutes about 78% of annual rainfall. According to rainfall records during 1986 to 2000 the normal rainfall occurred for 7 yrs and in the remaining years it was either surplus or scanty. The area is characterized by hot summer and is generally dry except during southwest monsoon season and October to December due to northeast monsoon seasons. May is the hottest month with mean maximum daily temperature of 40°C and during winter the mean temp falls to 28.6^0 C.

Hydrogeology

Geologically the area is underlain by granites. Dolerite dykes occurring as intrusives associated with pink granite are observed as residual hill range on the northern part of the micro watershed which is running approximately in the E-W direction. Joints trending in NNE-SSW and N-S directions are prevalent in the watershed. There are 52 are dug wells, 14 are bore wells and 27 are the dug cum bore wells used for irrigation and domestic purpose. The depth of the dug wells varies from 10 -15m below ground level. Overburden thickness is more than 15m in the northwestern parts of Mondi-Gaurelli village and also in small patches north of Chintapatla village. The average thickness of overburden is 10 to 15m. On the northern and southeastern part of the watershed average thickness of overburden is less than 10m. Partly weathered formation and the fractured formations are found to be the groundwater yielding zones in the area. The dug wells are yielding 19 to 23m^3/hr and sustaining 6 to 8 hrs of pumping during kharif season and 2 to 4 hrs of pumping during rabi season. The bore wells and dug-cum-borewells are yielding 20 to 25m^3/hr sustaining 8 to 10 hours of pumping during kharif season and 4 to 6 hrs of pumping during rabi season.

Geomorphology

The detailed description of the various hydro geomorphic units is as below.

Pediplain

Gently undulating plain of large areal extent often dotted with inselbergs formed by the coalescence of several pediments. In hard rocks, they form very good recharge and storage zones depending upon the thickness of weathering /accumulated material, its composition and recharge conditions. Based on the depth of weathering and dissection, weathered pediplains are present in the area. For Pediplain moderately weathered (PPM-83) depth of weathering is 10-20 m bgl and yield of well is 100 - 200 lpm. Pediplain shallow weathered (PPS-83). Depth of weathering is 0 to 10m. Ground water prospects are moderate. Yield of wells ranged between

50- 100 litres per minute. Pediment (PD-83) gently undulating plain dotted with rock out crops with or without thin veneer of soil cover. It forms runoff and recharge zone with limited prospects along favourable locations. Residual hills (RH-83) a group of hills occupying comparatively smaller area than composite hills. Limited prospects along valleys and limited recharge potential to the surrounding plains. Curvilinear Dyke ridge and dyke (CR-72,D-D) a narrow curvilinear resistant ridge formed by dolerite dyke.in the northern part forms groundwater divide for groundwater movement . They act as run off zone and barrier for ground water. It has better water prospects on the upstream of the dyke.

Infiltration rates

Major part of the area is covered by red soil followed by black cotton soil. It is mostly confined along the stream courses and tank bed. The *insitu* infiltration rate measurement indicates that infiltration varied from 6 to 38 cm/hr. The infiltration rate was high in north and southern part of the area whereas in central part i.e. in the tank bed the infiltration rate was 0.5 cm/hr.

Groundwater modeling

Groundwater modeling was attempted for understanding the distribution of aquifer parameters in the area and thereby assess the groundwater potential of the watershed. Further to select suitable sites for installment of water harvesting structures for increasing groundwater recharge and to assess impact of water harvesting structures on groundwater regime.

Input --output Stresses & Conceptual model

Conceptual model consists of unconfined and semi confined zone weathered zone of thickness about 20m in the area. Below the weathered zone there is fractured zone for about 20-25m (Figure 1). The watershed is bound by range of residual hills and dykes on the northern part which makes the ground water divide to coincide with basin divide. It is considered as Constant head boundary in the groundwater flow model. There is a lake on south west boundary and subsurface outflow of water through lake has been simulated by general head boundary condition of 510 m(amsl). Ground water outflow is 200 m^3/day which is calculated based on the width, depth of aquifer, coefficient of permeability, hydraulic gradient water contours and no flow enters through dykes and residual hillsin the north. The landuse landcover map of the watershed prepared from satellite imageries of IRS-1C LISS III 27/1/1996, March 1998 using ARCGIS 3.1 has been taken for distribution of evapotranspiration Area under is rice is 2.43 Sq. km and grown in PPM zone and in PPS Kharif unirrigated crops are taken. Ground water flows parallel to the surface water flows in streams. The ephemeral stream courses only flow during the rainy season. They have been simulated using river package. The groundwater levels of the flow model mesh between the observation wells have been interpolated taking care of the streambed elevations. Elevations of tank bed have been incorporated at the corresponding meshes. Mesh size for the grid adopted was 125m X 125m.The grid size is selected based on the fact that there is no change in heads even if further reduction in mesh size is effected. A groundwater recharge was assumed as 9% -10% of the rainfall and same was assigned in the model. For steady state condition groundwater recharge of 180mm/year was assigned based on norms established for Ground water resource estimation methodology 1997.Return flow from irrigation was taken into consideration for irrigated land as per C.G.W.B norms. The groundwater recharge values have been assigned appropriately to the cells June 1996 to November 1998 on monthly basis. The output stress due to ground water withdrawal from open, dug and dug cum bore wells for irrigation and domestic purposes was assigned appropriately in the model. The ground water draft has been estimated based on well inventory, average running hours of pumps and cropping pattern. The ground water withdrawal takes place throughout the year. The draft values ranged between 20m^3/day to 160m^3/day based on landuse. Hydraulic permeability and specific yield values have been considered as 2 m/day, 0.03m/day and 1m/day and 0.03 and 0.05 m/day and 0.009 in PPS, PPM and Pediment zone respectively.

3. RESULTS AND DISCUSSION

The results of the simulation of the existing conditions in the watershed are as follows:

Steady State Condition

Aquifer parameters such as permeability and specific yield were adopted from the C.G.W.B for granitic gneiss basin and GEC norms published in 1997 by C.G.W.B. Permeability values vary in the model between 0.05 m/day in the hard rock area to 2m/day along river bed. It is taken as 1m/day in the watershed and 3m/day along and around fractures. Specific yield values ranged from 0.007 to 0.03 in the watershed. Specific yield and permeability values were assigned to the meshes as per the hydrogeologic, geomorphologic, structural and lithologic features. The groundwater model boundaries have been realized by terminating the grid with no flow boundary condition by assigning zero permeability value. For Steady state condition the groundwater levels of June 1996 have been taken as the initial heads (Figure 1 & Table 1).

Table 1
Comparison of observed and computed Ground Water levels steady state condition

S.No	Well no.	Water levels m (AMSL) Observed levels	Water Level (AMSL) m computed levels
1	90	523.38	522.68
2	89	519.44	518.70
3	61	531.05	530.30
4	50	532.92	532.23
5	59	532.77	531.89
6	47	534.60	534.69
7	79	535.84	534.91
8	80	536.34	535.91
9	22	548.76	547.45
10	15	550.93	549.94
11	6	553.75	554.11
12	10	555.12	555.40
13	9	557.99	558.01
14	28	552.61	554.31

The values obtained from correlation are as below.
Mean error : 0.0434, Mean absolute error: 0.654, RMS error: 0.834

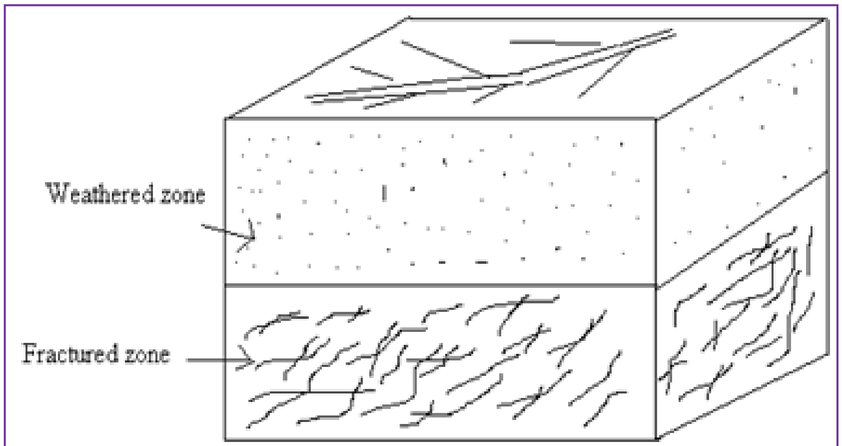

Fig.1 Conceptual model of strata

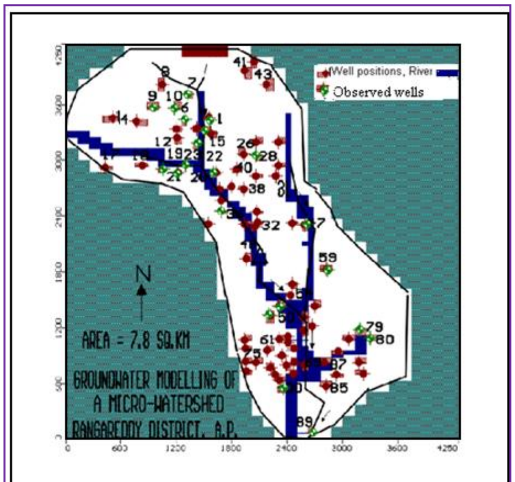

Fig. 2 Watershed, Well positions and river

Transient Condition
The ground water flow model is calibrated from June 1996 to Nov.1998 during transient condition through comparison of computed and field hydrographs at the observation wells. The draft for the year 1996 has been collected from field data, and for year 1997 they are assigned by increasing the draft values by 5% of 1996.The draft values as per land use land cover map of the area have been assigned during 1998.

Validation and Calibration of the model
The ground water model was calibrated for the steady state and transient condition for testing its validity.

Validation and calibration under steady state condition

Steady state calibration and validation of the model was calibrated by observed and computed water heads at the observation wells in the watershed during June 1996 (Figure 2). The RMS error for the steady state condition is 0.834 (Figure 3). Further the water table contours for computed and observed water heads are in agreement with each other (Figure 4).

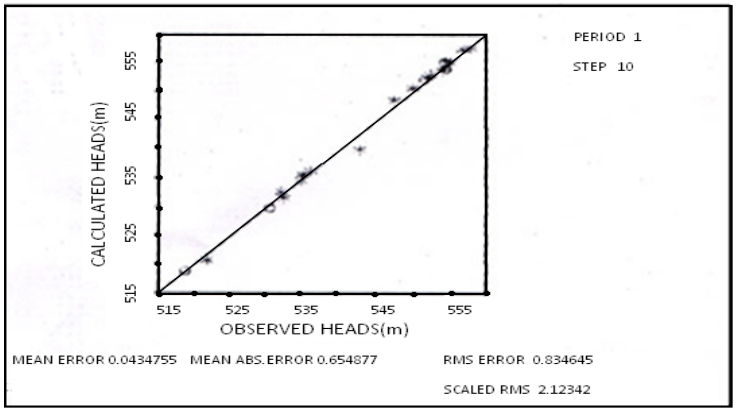

FIG. 3 Graph of observed and computed steady state water levels-June1996

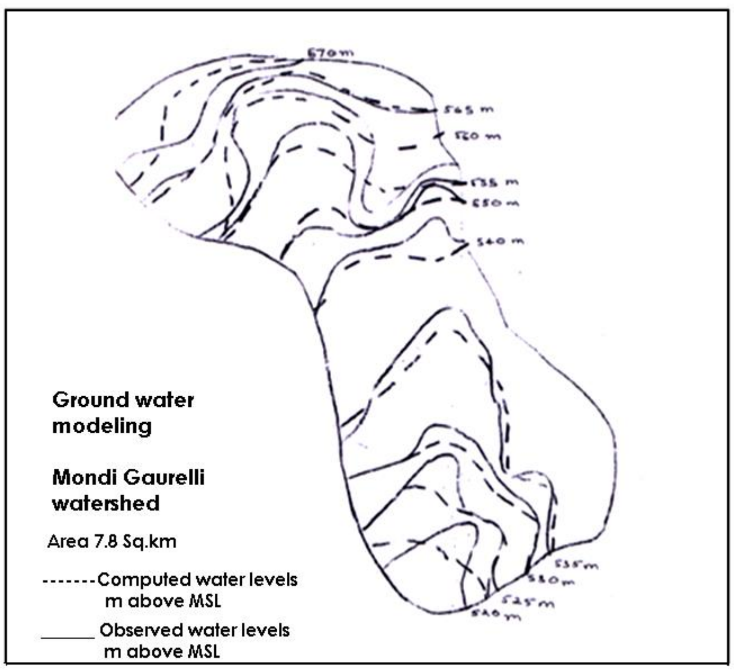

Fig. 4 Contours of observed and computed steady state water levels

Calibration and validation for Transient Condition

The calibration and validation for dynamic condition of the ground water model is provided by the graphs between computed versus observed water levels during pre-monsoon and post-monsoon stages and well hydrographs of observation wells, which are uniformly distributed in the watershed. The comparison graphs between the computed and observed groundwater heads during November 1996 shows RMS error of 1.93. The RMS error was found to be 2.81 during June 1997. RMS error during November 1997 was 2.24 and for June 1998 it was 3.63. From the graphs it is evident that only 2-3 wells are showing appreciable variation in the water heads. The model is further validated by the well hydrographs. Under transient condition at most of the observation wells computed and observed water levels are matching within ±2.0 m.

Comparison of well hydrographs

Well No. 15: The difference between computed and observed water levels is within a range of ◎1.0 m throught the calibration period. Well No. 7 & 9: These two wells are in the vicinity of each other. The computed and observed water heads match within ±1.0 m up to 800 days from starting. i.e. August 1998.Afterwards observed water heads are more than computed once. The reason may be attributed to reduced usage of water as the lands were kept fallow as observed from the satellite imagery. Well No. 6: The difference between computed and observed water levels is within a range of ±1.0 m through the calibration period. Well No.47: The observed water levels are continuously falling down in this area as seen from the well hydrograph. In the first run of the model draft increasing the draft value by 10% as on June 1996 put value from the well. But the computed heads were much above the observed once. Therefore land use land cover map of the area was studied and draft was increased suitably. As per imagery there was double crop in the vicinity of the well. After this modification well hydrographs started matching. Well Nos. 22 & 23: The water levels match 1.5 to 2.0 m of each other. The observed heads are lower than computed once which indicates extraction of water is more than the draft values fed in the model. Well no. 59: The difference between computed and observed water levels is within a range of 1.0 to 1.5 m throught the calibration period. (Ref Figures 5 & 6)**.** The predictions for the water levels in the ground water model were carried upto year 2002. The predictions showed continuously falling water levels the area. The watershed was visited by the author in September 2001and it was found that conditions on the field were very similar to as predicted. The water bodies in the watershed were completely dry even during monsoon. These observations also validate the model. The comparison of the Pre-monsoon computed water level contours for June 1996, June 1997 & June 1998 show that the water levels are declining year after year. The water levels decline was 4-5 meters during June 1997 as compared to June 1996. The water levels further declined by 3-6 meters during June 1998. The comparison among Post- monsoon computed water levels for November 1996 and November 1997 indicate that the water levels decline was 5.0m as the rainfall received during 1997 was less than 1996.

Prediction of Effect of Water Harvesting Structures on ground water levels

As the ground water storage is reducing fast it was thought to introduce water-harvesting structures in the model and see their effect. The water harvesting structures proposed were.

1. Four sunken percolation tanks with water spread area of (250 x 250) m^2 and depth of 3m amounting to 0.18 Mm^3 capacities each.
2. Four Check dams with height of 3m.
3. Two Farm ponds dug upto a depth of 3.0 m

The model was used to assess the impact of the water harvesting structures on groundwater regime. Water harvesting structures would have improved the groundwater levels considerably as is evident from the comparison of groundwater balance with and without Water harvesting structures (Tables 2 & 3).

Table 2

Ground Water Balance (Based on Ground Water Simulation Studies)

Without Water Harvesting Structure (All Units m^3)						
		Model in flow				
Year/stress Period	Rain Fall mm	Storage	Constant Head Boundary	Recharge	River leakage	Total input
June 96-97 (SP 13)	734.7	1007484	201951	411754	1427854	3049044
97-98 SP 24	528.2	700511	244232	411432	1188382	2544556

Without Water Harvesting Structure

Model out flow

Storage	Wells	River leakage	Head dep. Boundary	Total output
198879	2004710	370185	475269	3049044
448525	1604243	169893	321595	2544555

Without Water Harvesting Structure

Ground Water Balance				**Change in storage**	
Base flow	Total Inflow	Total outflow	Diff.= T.I-T.O=ColnS(15-14)	Cum. Change in storage	Change in Storage.
643503	1839609	2648213	-808604	-804604	-165101
247256	1599813	1851499	-251686	-1060290	-813034

2.8. Impact of Water Harvesting Structures

The ground water simulation studies for the watershed indicate that groundwater is fast depleting. In the year 96-97 the rainfall was 734 mm, base flow was 0.645 million cubic meters (mcm), total inflow was 1.84 mcm and outflow was 2.64 mcm. There is reduction of storage volume of water to the tune of 0.808 mcm. The net change is storage was –0.165 mcm. In the following year i.e. 97-98 the rainfall was 528.2 mm i.e. 39% less than previous year. Consecutively base flow, total inflow, total outflow values also reduced. They were 0.247 mcm, 1.599 mcm and 1.85 mcm respectively. Storage reduced further by 0.251 mcm and commutative reduction in storage was 1.06 mcm. After incorporation of water harvesting structures in the groundwater model the groundwater respectively during 96-97. Change in storage would have reduced to 0.0131 mcm from 0.165 mcm. i.e., gain of 0.152 mcm. In the year 97-98, change in storage would have reached only -0.634 mcm instead of -0.8123 mcm and base flow would have increased to 0.386 mcm with water harvesting structures**.**

Table 3

Ground Water Balance (Based on Ground Water Simulation Studies)

With Water Harvesting Structures						
Year/stress Period	Rain Fall mm	**Model in flow**				
		Storage	Constant Head Bound	Recharge	River leakage	Total input
June 96-97 SP 13	734.7	999432	200178	413527	1606523	3219660
97-98 SP 24	528.2	724932	242920	416804	1429503	2814158

With Water Harvesting Structures

Model out flow

Storage	Wells	River leakage	Head dep. Boundary	Total output
164728	2033213	537314	484405	3219660
538609	165997	293778	335773	2814157

With Water Harvesting Structures

Ground Water Balance				Change in storage	
Base flow	Total Inflow	Total Outflow	Diff.= T.I-T.O=ColnS(15-14)	Cum. Change in storage	Change in Storage.
821541	2020050	2854754	-834704	-834704	-13163
386631	1846306	2032628	-186322	-1021026	-634395

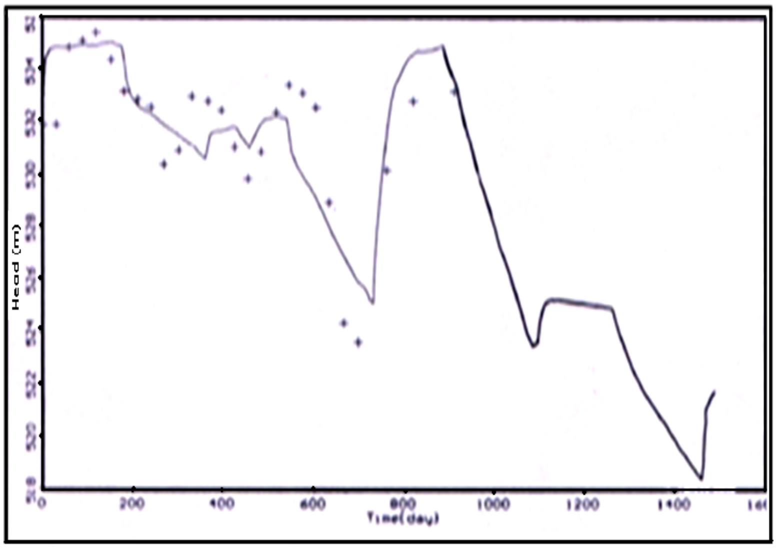

Fig. 5 Transient condition- Hydrograph for well no. 59

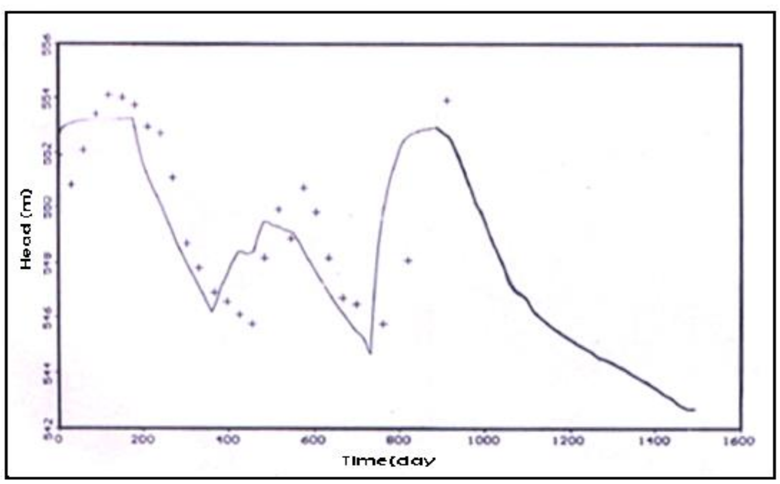

Fig. 6 Transient condition- Hydrograph for well no. 23

4. CONCLUSIONS AND RECOMMENDATION

Modeling for the watershed was successfully carried out and it is found that Visual Modflow software is an excellent tool for simulation with which it is possible to visualize the groundwater system thoroughly. The groundwater flow model was calibrated under steady state condition during June 1996 and was in agreement with natural conditions with RMS error of 0.834 and under transient condition well hydrographs for 14 wells out of 17 wells are matching within +/-2.0 m accuracy. It is concluded that ground water storage is depleting at a faster rate in spite of normal rainfall during last 4-5 years and inspite of ten water harvesting structures incorporated in the model the outflow continues to be more than inflow. It suggests huge outflow in terms of extraction of water for irrigation is leaving the watershed. Measures must be taken to improve groundwater regime in the watershed. First step in this direction should be to provide water harvesting structures, for water conservation stop water mining of groundwater and implement soil and water conservation measures Crops which are drought resistant and require less water should only be grown in the area.

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Ethical approval

Not applicable.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

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