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Simulation of Spatial Groundwater Behaviour in South-West Punjab

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Abstract : The assessment of groundwater resource of South-West Punjab has been carried out through estimate of seasonal groundwater recharge and water balance study. The season-wise (*kharif/rabi*) quantification of various components of water balance equation has been done for the period from 1990-91 to 1999-2000. The groundwater behaviour of the selected area has been simulated using the finite difference groundwater flow model *'Visual MODFLOW'*. The model was calibrated and validated using observed groundwater heads for the period from 1990-91 to 1999-2000. The groundwater heads obtained using the model compares reasonably well with the corresponding observed groundwater heads. Thus the model *'Visual MODFLOW'* can be used successfully to simulate the groundwater behaviour of south-western part of Punjab state and to predict the future spatial groundwater behaviour in the selected tract.

Keywords: groundwater; MODFLOW; simulation; south west Punjab

INTRODUCTION

Due to increased agricultural activities in the state of Punjab, groundwater has emerged as an important resource to supplement the increased water needs. For sustainable agriculture, it becomes essential to have scientific assessment of groundwater resource and behaviour of which should be studied considering groundwater basin as a unit. Groundwater flow models are used to understand the behaviour of groundwater systems. In this study, a three dimensional finite difference groundwater flow model 'Visual MODFLOW' has been applied to simulate the groundwater behaviour of a selected region of South-West Punjab.

DESCRIPTION OF STUDY AREA

The study area (Fig. 1) lies between latitude 29^0 55' 34" N and 31^0 09' 47" N and longitude 73^0 50' 31"E and 74^0 58' 38" E. It comprises the parts of district Ferozepur, Faridkot and Muktsar and covers an area of 4,39,496 ha. The study region is bounded on north by Sutlej river, on west Bikaner canal, on east by Sirhind feeder and on south by Rajasthan state boundary. The normal annual rainfall over the study area varies from 250 mm to 450 mm. Due to poor quality of groundwater almost 80 percent irrigation is done by canals and their distributaries/minors. The area is irrigated by Makhu Canal and Sirhind Feeder System. This area has experienced a rise in water table

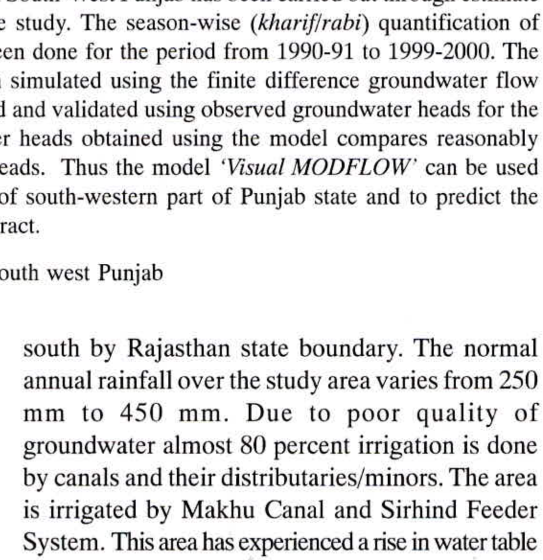

Fig. 1 Location map of study area

due to large scale canal irrigation, seepage from canal network, inadequate drainage network and less exploitation of groundwater because of its poor quality

Assessment of groundwater resource

The seasonal gross groundwater recharge was computed by using the following equation :

$$R_g = R_r + R_c + R_{cia} + R_{ti} \qquad (1)$$

where, R_g is the total groundwater recharge(mm); R_r is the recharge from percolation of rainfall(mm); R_c is the recharge through seepage from canal network(mm); R_{cia} is the recharge due to return flow from canal irrigated areas(mm); R_{tia} is the recharge due to return flow from tubewell irrigated areas(mm)

The parameters appearing in the right hand side of Eq.(1) were estimated season-wise using norms recommended by Ministry of Water Resources, Government of India (Anonymous, 1997) and (Prihar etal.1993). A value of 22 per cent of total rainfall has been taken as recharge contributions to groundwater. It was assumed that there is no recharge, if monthly rainfall is less than 50 mm. The seepage from unlined canals was taken as 26 ha-m/day/million sq.m of wetted area. In case the actual discharge was less than the designed discharge, the wetted perimeter values were revised accordingly. For lined canals the seepage losses were taken as 20 per cent of the value for unlined canals. The seepage from canal irrigated areas was taken as 30 per cent of water delivered at the outlets. The seepage from tubewell irrigated areas was taken as 25 per cent of groundwater draft. In addition, to account for continuous deep percolation from paddy fields a value of 3 mm/day for 106 days of crop season has been used. The season-wise(*kharif*/*rabi*) total gross recharge within the selected area was computed using Eq.(1).

Seasonal Groundwater inflow/outflow across the basin boundaries was calculated from the water balance studies, using the following equation :

$$(P+I)-(ET+E+Qp+Qg+Qs+DSm+DSs)=DSg \qquad (2)$$

where, P is the total rainfall over the area, mm

I = irrigation water applied over the area from all sources, mm

ET = evapotranspiration from canal irrigated and unirrigated areas, mm

E = evaporation from uncultivated areas, mm

Qp = quantity of the groundwater pumped (draft), mm

Qg = inflow/outflow of the groundwater across the basin boundaries, mm

Qs = surface runoff from the area, mm

DSm = change in soil moisture storage, mm

DSs = change in surface storage in the canal distribution system, mm

DSg = change in groundwater storage, mm

To estimate the total groundwater resource available for utilization, it is necessary to know the net change in groundwater storage. The net change in groundwater storage was estimated as :

Net change in groundwater storage =
Gross recharge to groundwater
± Sub-surface inflow/outflow
- groundwater draft
- evaporation from shallow water table area (3)

After computing the net change in groundwater storage, 85 per cent of this is taken as net recoverable recharge, which may be termed as additional utilizable resource available for irrigation.

The season-wise(*kharif*/*rabi*) quantification of various parameters appearing in the right hand side of Eq.(2) were carried out for a period of 10 years using the necessary information collected from various agencies such as Irrigation

Department, Agriculture Department, Economic Advisor Govt. of Punjab and Regional Research station(PAU) Abohar. The computation procedure used and the norms adopted for estimating components of equation (2) are given below :

The average seasonal rainfall was computed from the monthly weighted average values. The irrigation water applied was calculated from the seasonal canal water available and the quantity of groundwater pumped in different seasons from the total number of tubewells as per unit draft norms (Anonymous,1997) with modifications, due to variations in rainfall from the normal seasonal rainfall as per actual pumping schedule based on field survey conducted for different *blocks*. The monthly reference crop evapotranspiration was calculated using Papadakis method (Mavi,1994) and the actual monthly crop evapotranspiration was computed by multiplying with corresponding crop coefficient. Surface runoff was taken as 5 per cent of the weighted average seasonal rainfall. Based on the field water balance studies conducted at PAU(Ludhiana) for different crop rotation cycles under sandy loam soil conditions, the soil moisture changes were computed(Jalota and Arora,2002). After observing the actual canal water releases data, the change in surface water storage in canal network was considered as negligible. Based on the groundwater levels for the pre monsoon and post monsoon periods, the average seasonal rise/fall in water level was calculated, correspondingly the change in groundwater storage was estimated by using an average value 0.15 as specific yield. Substituting the values of various components in Eq.(2), the season-wise groundwater inflow/outflow across the boundaries was obtained.

Evaporation from shallow water table was computed by using the following relationship :

$$E_{lim} = \mathbf{2.4} \times \mathbf{a} \times \mathbf{d}^{-2} \qquad (4)$$

where,

E_{lim} = Evaporation from water table (cm/hr)

d = depth of water table (cm)

a = a constant whose value depends upon the soil conditions.

The net change in groundwater storage was estimated from Eq.(3) by substituting the values of gross recharge, groundwater draft, groundwater inflow/outflow and evaporation from shallow water table areas.

The period of analysis was taken as 1990-91 to 1999-2000. The results presented in Table 1 and Table 2 show that the average annual recharge during the period from 1990-91 to 1999-2000 was 205.1 mm in *kharif* and 157.15 mm in *rabi* season. The computed rise/fall in water table compare favorably well with corresponding observed values. The average computed rise in water level was 0.299 meters, corresponding to the observed rise as 0.362 meters in *kharif* and the average computed fall in water level was 0.182 meters, corresponding to observed fall in water level as 0.202 meters in *rabi* season. The positive value of net change in groundwater storage shows that the groundwater resource is under exploited. Thus there is further scope of groundwater development in south-west Punjab to control rise in water table.

Groundwater simulation model

The finite difference based groundwater flow model Visual MODFLOW has been used to simulate the ground water behaviour in the study area. The model solves the governing partial differential equation for three dimensional groundwater flow :

$$\frac{\partial}{\partial x}\left[Kxx\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial x}\left[Kyy\frac{\partial h}{\partial y}\right]-w=S_s\frac{\partial h}{\partial t}$$

where,

Kxx, Kyy are the hydraulic conductivity along x and y coordinate axis (L/T) ; h is the hydraulic head (L) ; w is the volumetric flux per unit volume

Table 1 : Net change in groundwater storage in kharif season

Year	Total recharge (mm)	Groundwater draft (mm)	Outflow (mm)	Evaporation from shallow water table (mm)	Net recharge (mm)	*Computed rise/fall (m)	Observed rise/fall (m)	Net difference (m)
1	2	3	4	5	6	7	8	9
1990-91	182.53	126.42	-87.8	52.42	91.49	0.610	0.404	-0.206
1991-92	180.99	169.65	-48.41	44.03	15.72	0.105	-0.061	-0.166
1992-93	184.32	156.53	-99.15	39.71	87.23	0.582	0.354	-0.228
1993-94	177.74	139.53	-55.23	61.67	31.77	0.212	0.283	0.071
1994-95	215.26	78.23	35.28	49.39	52.36	0.349	0.569	0.220
1995-96	219.29	69.18	96.92	27.09	26.10	0.174	0.449	0.275
1996-97	198.30	92.32	46.12	29.34	30.52	0.203	0.354	0.151
1997-98	209.34	87.23	-6.29	38.09	90.31	0.602	0.865	0.263
1998-99	247.12	98.15	94.67	33.70	20.60	0.137	0.377	0.240
1999-2000	236.11	126.16	78.37	29.80	1.78	0.012	0.027	0.015
Average	205.10	114.34	5.45	40.52	44.79	0.299	0.362	0.064

(6) = (2)-(3)-(4)-(5)

* specific yield value taken as 0.15

Table 2 : Net change in groundwater storage in rabi season

Year	Total recharge (mm)	Groundwater draft (mm)	Outflow (mm)	Evaporation from shallow water table (mm)	Net recharge (mm)	*Computed rise/fall (m)	Observed rise/fall (m)	Net difference (m)
1	2	3	4	5	6	7	8	9
1990-91	148.04	128.16	2.54	29.22	-11.88	-0.079	-0.330	-0.251
1991-92	164.79	139.52	-8.49	39.65	-5.89	-0.039	-0.230	-0.191
1992-93	162.00	127.06	6.11	65.11	-36.28	-0.242	-0.340	-0.098
1993-94	153.56	154.60	-7.53	57.96	-51.47	-0.343	-0.590	-0.247
1994-95	148.29	97.86	7.60	41.34	1.49	0.010	-0.120	-0.130
1995-96	155.26	85.81	29.82	34.51	5.12	0.034	-0.070	-0.104
1996-97	174.68	93.46	34.75	37.96	8.51	0.057	0.150	0.093
1997-98	149.23	91.25	92.93	35.80	-70.75	-0.472	-0.270	0.202
1998-99	150.20	82.05	84.96	31.55	-48.36	-0.322	-0.070	0.252
1999-2000	165.48	102.48	102.18	24.93	-64.11	-0.427	-0.150	0.277
Average	157.15	110.23	34.49	39.80	-27.36	-0.182	-0.202	-0.020

(6) = (2)-(3)-(4)-(5)

* specific yield value taken as 0.15

representing source/sink (1/T) ; S_s is the specific storage of porous media (1/L) ; t is the time (T).

The aquifer domain was discretized into square grids of size 2000 m x 2000 m consisting of 64 rows and 52 columns. The boundary of the aquifer was approximated in a linear stepwise fashion (Fig. 2). As the sides of the study area are bounded by Sutlej river, Sirhind feeder and Bikaner canal, the boundaries along these sides were considered as river boundary condition to simulate the influence of surface water body and the boundary towards south being Rajasthan state was considered as constant head boundary condition for incorporating in the Visual MODFLOW.

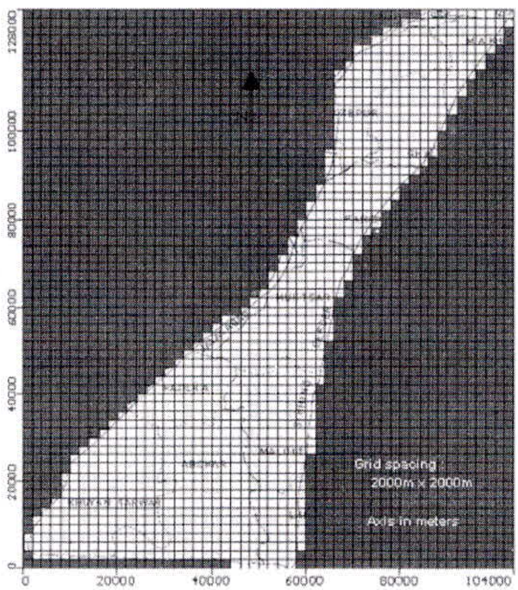

Fig. 2 Discretization of aquifer domain

To solve Eq.(5) a hydraulic head distribution at the beginning of simulation run is required to calculate the hydraulic head distribution at the end of simulation. The other input data for the model include ground surface elevation, bottom elevation of each layer, specific yield, hydraulic conductivity, well pumping schedule(draft), recharge rate distribution and observed head at observation well locations. The values of hydraulic conductivity and specific yield were estimated using the litholog information at different locations over the study area (collected from Department of Agriculture, Govt. of Punjab), by assigning the average values of these parameters to different formation materials. The weighted average values of these aquifer parameters were computed. The *block wise* groundwater draft for each season was distributed to each grid cell, as per the cell area within the *block*. Based upon the actual monthly canal water releases and the established seepage norms, the recharge from canal network was computed for each cell. The recharge due to rainfall and return flow from canal and tubewell irrigated fields was computed for each *block* and distributed as per the *block* area falling within the study area.

Model calibration

The groundwater model was calibrated using the data for the period from 1990-91 to 1994-95. Simulation runs were performed by using the necessary input data including ground surface elevation, pumping schedule(draft), recharge rate, values of hydrologic parameters as obtained from lithologs and corresponding observed hydraulic heads for June month as the initial condition. The computed hydraulic heads for June of the succeeding year were compared with the corresponding observed values for that year. A significant difference was observed between the computed and corresponding observed hydraulic heads. Therefore, a sensitivity analysis of hydrologic parameters was carried out before the model is used for validation. The sensitivity of the model to variations in specific yield and hydraulic conductivity was studied. The values of these aquifer parameters were adjusted within allowable limits, to produce the results that are close in agreement to the historic head values. The hydraulic conductivity values were varied by ±30 percent and specific yield values were changed by half and double of the initial values. The computed hydraulic heads for June,1993 are given in Fig. 3 and a comparison of computed vs. observed hydraulic heads at observation well points (Fig. 4). The difference between the computed and observed heads at the observation well points was worked out as residual. The absolute residual mean during the calibration period varies from 0.644 m to 0.785 m, with an average value of 0.677 metres.

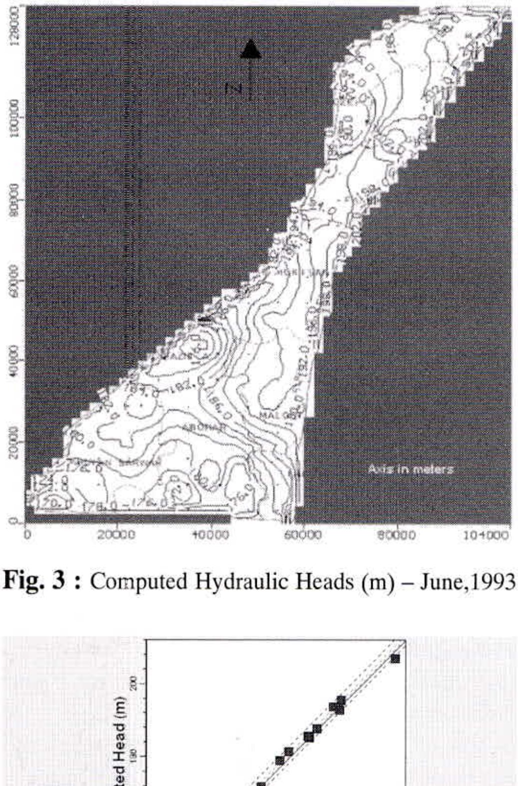

Fig. 3 : Computed Hydraulic Heads (m) – June,1993

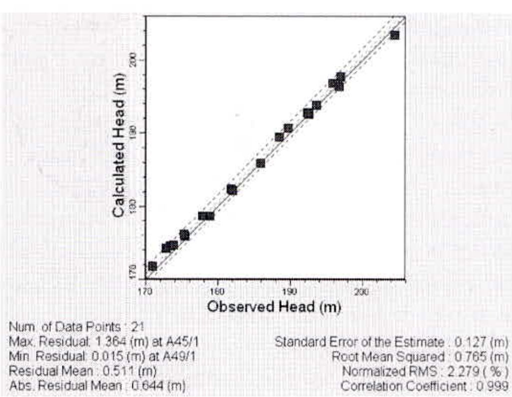

Fig. 4 Computed v/s Observed Heads at observation wells- June,1993

Model Validation

The model was validated for the period from 1995-96 to 1999-2000. The modified hydrologic parameters decided at the time of calibration were used to perform simulations. The computed hydraulic heads for June, 1998 are given in Fig. 5 and a comparison of computed vs. observed heads at the observation wells (Fig. 6). The absolute

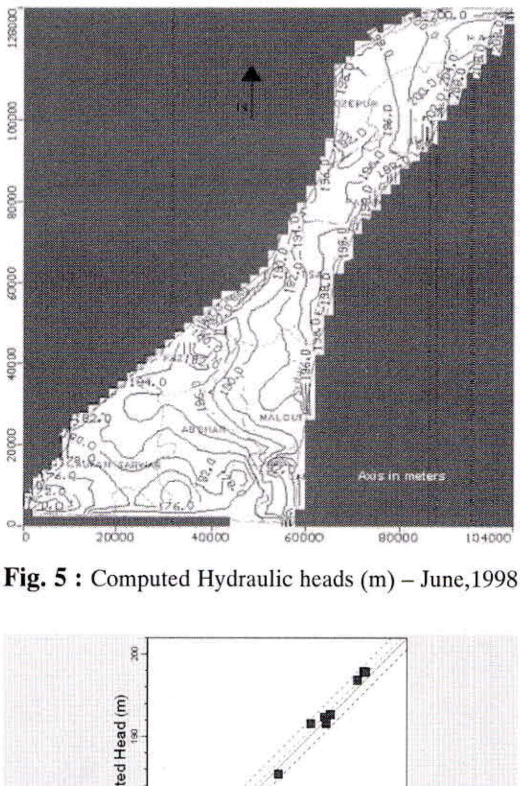

Fig. 5 : Computed Hydraulic heads (m) – June,1998

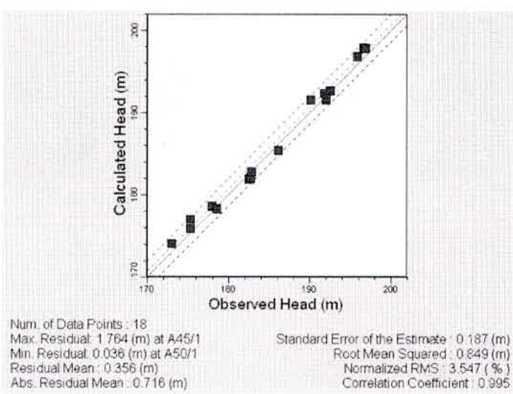

Fig. 6 : Computed v/s Observed Heads at observation wells- June,1998

residual mean for the validation period varied from 0.482 m to 0.753 m with an average value of 0.685 metres, which may be considered as acceptable error. The hydrographs showing the observed and computed hydraulic heads at some of the observation wells are given in Fig 7 and 8.

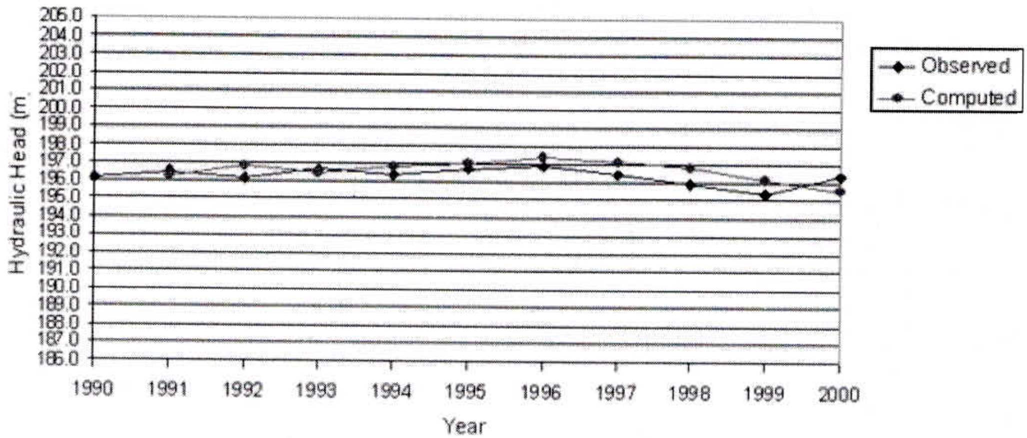

Fig. 7 : Comparison of Observed and Computed Hydraulic Heads

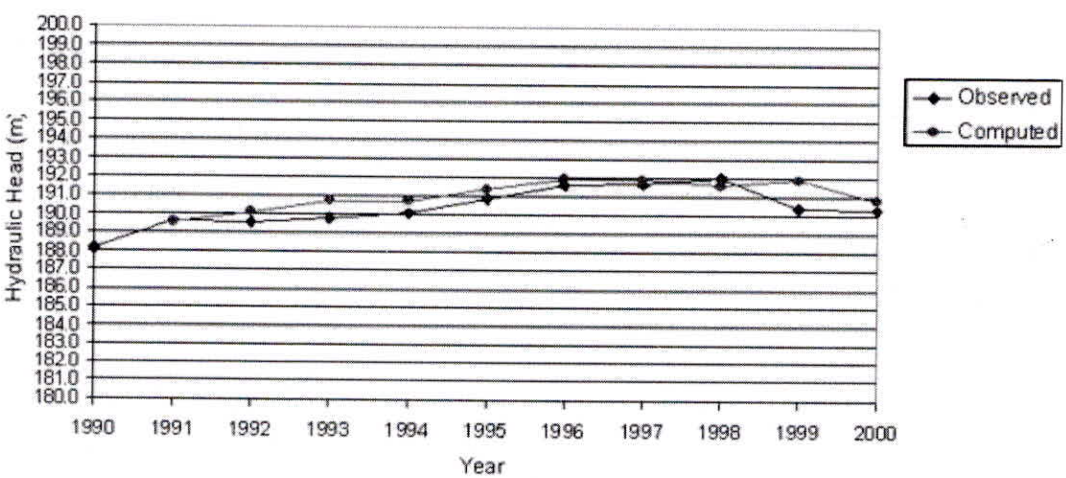

Fig. 8 : Comparison of Observed and Computed Hydraulic Heads

CONCLUSION

The groundwater heads obtained using the model compares reasonably well with the corresponding observed groundwater heads over the study area. The groundwater flow model 'Visual MODFLOW' can be used successfully to simulate the groundwater behaviour of south-western part of Punjab. The model could be used to predict future spatial groundwater behaviour in the selected tract and effect of different management strategies can be studied.

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