Chapter 9

Water Balance Studies

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WATER BALANCE STUDIES

The knowledge of the natural recharge to the groundwater is necessary to study the groundwater development. To derive upon the quantitative estimates of groundwater recharge there exist a number of methods viz., (i) base flow recession curves, (ii) flow of water across the recharge and discharge area using either Darcy's Law (Confined aquifer) or Dupit's Equation (Unconfined aquifer) and (iii) Water Budget. It is an established fact that a part of total precipitation which reach the ground percolate down through the soil and contribute to groundwater. The other part may reach to the atmosphere by the means of evapotranspiration and remaining part contributes to the surface storage and/or surface runoff. During this process the aquifer either gains or loses the water. This balance is expressed as Groundwater Budget (Schicht and Walton, 1961), i.e.,

$$P_g = R_g + Et_g + U \pm \Delta S_g$$

Where, P_g = Groundwater Recharge

R_g = Groundwater Runoff

Et_g = Evapotranspiration

U = Sub-surface Flow

□S_g = Change in Groundwater Storage

A water budget is a useful means of determining the groundwater recharge. An advantage of the water budget method is that aquifer does not have to be under dynamic equilibrium i.e. rate of recharge equal to rate of discharge. The groundwater recharge has been attempted using the both inflow and outflow parameters.

INFLOW PARAMETERS

Which attempting the budget, it has been assumed that there is no inflow from the boundary of the command area. The various inflow parameters are, a) seepage from the canal network, b) return irrigation water, c) seepage from paddy field and d) recharge from the rainfall. The indices for rainfall recharge and groundwater draft have been adopted from the standard value for the alluvial soil. The amount of the recharge as canal seepage from the canal network at different level and returned irrigation seepage from the paddy fields have been adopted, after Mahi Irrigation command authorities, available in field studies.

OUTFLOW PARAMETERS

As the area is forming a part of the Gulf of Cambay environ it is necessary to calculate the outflow from the area. As it has been seen in the previous chapter that the outflow in the area is generally in the form of pumping from the dug-wells as well as tubewell and as base-flow from the Watrak River near Palla.

As discussed earlier the MRBC area as a whole and the Matar Branch Command area in particular is recharged not only from rainfall but also from seepage losses from canal at different levels and returned irrigation seepage from the irrigation fields. This adds a substantial amount of the water to the aquifer. In order to study the groundwater budget author has made use of local rainfall infiltration as well as return inflow from irrigated water (both canal and wells) and seepage losses from canals. Therefore the total recharge to the groundwater regime in the study area through the surface water resources have been calculated on the basis of the available factual data.

(A) RECHARGE FROM RAINFALL

The average monthly rainfall data over the command area for 23 years period from the year 1976 to 1999 have been utilized to estimate the average annual rainfall which, stands at 825.58 mm. As it has been already discussed that the area comprises the moderately fine to fine textured soils and considering 20 % and 10 % recharge occurs from rainfall in alluvial sandy loam and clay loam soils respectively (). Therefore, the average index of 18 % recharge from the average annual rainfall has been taken for computing recharge due to rainfall.

Therefore, the average annual recharge from rainfall is

$$\mathrm{Recharge} = \mathrm{Rainfall}(m) \times \mathrm{Rechargefactor}(\%) \times \mathrm{Area}(m^2)$$

825.58 X 0.18 X 22640 X 10^4 X 10^{-6} = **336.44 MCM** .... (1)

(B) RECHARGE AS SEEPAGE FROM CANAL SUPPLY

B. 1 Seepage from Branch Canal

Though the branch canal network is lined, there occurs seepage from the canal segments of damaged lining. Based on canal dimension, length of reaches and average wetted perimeter at different reaches, seepage from the branch canal network has been estimated. As discussed earlier, about 2.6 % of water released in branch canal (seepage factor) contributes to the groundwater. Considering an average annual canal water supply of 5073 MCM for period of the year 1982 to the year 1999. The average annual water loss from the branch canal is

i. e. 5073 x 0.026 = **131.90 MCM**.. (2)

B. 2 Deep Percolation from Distributory and Outlets and Field Channels

Experimental studies carried out by the Irrigation Department shows that about 7 % of water is lost as seepage from distributory and 31.86 % of water delivered through outlets and field channels lost as deep percolation. Therefore, total recharge through seepage from distrubutory system and field outlets and channels would be, (i) The average annual water release in the canal is 5073 MCM out of which 131.90 MCM has lost as seepage from branch canal, therefore 7 % of these have been estimated as seepage losses from water at distributory system.

i. e. 4941.10 X 0.07 = **345.88 MCM**.. (3)

(ii) Similarly the water made available for field application through field outlets and other distribution system is 4595.22 MCM. Taking in to account the 31.86 % of water as deep percolation seepage factor the water loss would be

i. e. 4595.22 X 0.3186 = **1464.04 MCM**.. (4)

B.3 Deep Percolation through Returned Irrigation Seepage:

Also, looking to the cropping pattern, the area is practicing the Paddy during the Kharif and the hot season. Therefore, considering the wetting period of 100 days for paddy crop 3 mm/day seepage loss of water through 19105 ha paddy fields predominated by the alluvium soils. The total seepage contribution from the paddy field would be

19105 X 0.003 = **57.32 MCM** .... (5)

(C) DEEP PERCOLATION FROM THE AREA IRRIGATED BY WELLS:

The deep percolation from the area irrigated by well has been considered as after GWRDC as 20 % of the total water applied to the field. The total groundwater draft through the command area wells, as calculated by the GWRDC stands as 19.30 MCM. Therefore the through well irrigation seepage would be

19.30 X 0.20 = **3.8 MCM** .... (6)

The summary on estimate of various components of annual recharge to the groundwater regime of the command area is presented in Table 9.1. The quantified average annual recharge to groundwater regime in the Matar Branch Command area i.e. $\sum A+B+C$ amounts to 2339.38 MCM, which constitutes almost 33.51 % of the total water input viz., rainfall, and irrigation from canal and groundwater wells where in total recharge from canal water supply i. e. $\sum 2+3+4+5$ = 1999.14 MCM i.e. 39.41 % of total water supplied. The total recharge to the groundwater regime in turn gets disbursed in different forms like groundwater pumping, sub-surface inflow/outflow, and the resulting change in storage.

Table 9.1 Average Annual Recharge to Groundwater in Matar Branch Command (1979-99)

Source of Recharge	Volume of Recharge in MCM		
	Annual	Kharif	Rabi & Hot
Rainfall Recharge	336.44	224.54	111.90
Seepage losses from Branch Canal	131.90	70.88	61.02
Percolation losses from Distributory	345.88	193.49	152.39
Deep percolation losses from canal irrigated area including percolation from irrigated paddy field	1521.36	852.92	668.44
Total Losses from Canal Network	1999.14	1117.29	881.85
% losses from the irrigation water supplied	39.41	39.41	39.41
Deep Percolation from area irrigated by Well	3.80		
Total Recharge to the Groundwater	2339.38	1341.83	993.75

GROUNDWATER DRAFT

The groundwater draft from various sources has been estimated by adopting GWRDC norms and data collected after GWRDC. Various sources accounted for groundwater draft in the command area are as under

(i) Draft from Govt. Tube wells

(ii) Draft from Private Tube wells

(iii) Draft from GWRDC Tube wells

(iv) Draft from Open wells

(v) Outflow from area as sub-surface flow (Watrak River)

DRAFT FROM THE WELLS

The average groundwater draft from different wells for the last 18 years has been estimated as 19.30 MCM/year . As detailed breakup for this is give in ensuing table

Mode of Abstraction		Number of Wells	Norms Adopted (MCM)	Draft in MCM
Tubewells	Govt.	3	0.180	0.54
	GWRDC	96	0.280	26.88
	Private	37	0.100	3.70
Wells with Pumpsets		2503	0.018	9.01
Dug wells Operated with the Animal		3561	0.0036	64.10
Total *	104.23			
Draft for Matar Area	19.03			
Return Seepage	3.80			

* Draft includes both Matar & Nadiad Irrigation Commands.

OUTFLOW (SUB-SURFACE FLOW) FROM WATRAK RIVER

Based on the Reduced Water Level contour plans (Fig. 5.12) the outflow of the groundwater from Watrak River has been estimated by following equation:

$$Q = K \times I \times A$$

Where, K= Permeability (m/day)

I = Hydraulic Gradient (m/m)

A= Cross-sectional Area (m^2)

The estimated parameter for Watrak River considering aquifers' hydraulic characteristics

K = 36.58 m/day
I = 1:1266
A = 1931 sq. m.

Therefore Q (Outflow) = 0.4073 MCM/year

Thus the draft from various sources in the area would be

= 19.30 + 0.41 = 19.71MCM

Therefore, the groundwater balance in Matar Command would be

Total Recharge (Pg) - Draft (Rg + U)

i. e. 2339.38 - 19.71 = 2319.67 MCM/yr

The statistical treatment to the data on groundwater regime using correlation coefficient between groundwater recharge and water table fluctuation and regression analysis provides an indirect means of water recharge monitoring (Jain and Sharma, 2000). The correlation matrix for different recharge variables with water table fluctuation is given in Table 9.2. It is evident from the data pattern that least correlation (0.34) exists between groundwater recharge by rainfall and the water table fluctuation. The correlation between water table fluctuation and recharge from the canal seepage and/or return irrigation seepage is also significantly correlated. The correlation of groundwater recharge from the canal losses during kharif and water table fluctuation has shown slightly less as compared to losses including the return irrigation water from fields. These higher values are attributed to paddy cultivation in majority of the area during the kharif season and the maximum irrigation supply of the canal water during the kharif season. The highest values of the correlation i. e. 0.98 suggest that the canal seepage constitute the main source of the groundwater recharge.

Table 9.2 Statistical Correlation Analysis between Groundwater Recharge and Water Table Fluctuation

	SWL R/F	Rainfall	Kharif*	Kharif**	Rabi & Hot *	Rabi & Hot**
SWL R/F	1					
Rainfall	0.34	1				
Kharif*	0.87	-0.76	1			
C-P Seep (K) **	0.98	-0.45	0.92	1		
Rabi & Hot *	0.95	-0.53	0.92	0.93	1	
C-P Seep (R & H) **	0.96	-0.24	0.78	0.89	0.95	1

* = Losses from Canal Seepage
** = Losses from Canal and Return Irrigation Seepage from Paddy Fields

The R^2 values represent the proportion of variation in the dependent variable accounted for the linear regression equation. The highest R^2 values indicate the better performance of the relationship and suitability for computing the dependent variables. The R^2 values of the different factors with water table fluctuation are given in Table 9.3. It is evident than water table fluctuation is most appropriate variable explaining the more than 75% variation in different groundwater recharge sources.

Table 9.3 Water Table Fluctuation vis-a-vis Groundwater Relationship using Linear Regression Approach

Source of Recharge	Regression Statistics	
	R^2	Equation
Kharif *	0.75	y = 0.0044x - 0.8314
C-P Kharif **	0.97	y = 0.0064x - 0.7474
Rabi & Hot *	0.90	y = 0.0039x - 0.9725
C-P Rabi & Hot **	0.92	y = 0.0045x - 0.9107
Annual	0.92	y = 0.0045x - 0.9377
Seasonal	0.97	y = 0.0064x - 0.7845

The linear regression approach was used to develop a relationship between water table fluctuation and groundwater recharge. For this purpose, regression equations were computed for all parameters as given in Table 9.3. The equation can be used for determining the water table fluctuation with respect to different seepage losses through canal discharge. Further to verify the seepage loss and recharge to groundwater, which resulting in water table fluctuation, author has prepared the contour plans for net change in water level at the decinal of five years to calculate the change in groundwater storage (1982, 85, 90, 95, 99). Author has calculated the area under the different categories Table 9.4.

Table 9.4 Secular Changes in Groundwater Storage In Matar Command Area

Rise in Water Level	82-85	85-90	90-95	95-99
M	Volume of Water Recharged			
-3.50	-0.13	0.00	0.00	0.00
-3.00	-16.56	0.00	0.00	0.00
-2.50	-48.71	4.45	0.00	0.00
-2.00	-144.12	14.08	0.00	-13.92
-1.50	-301.19	42.52	-1.06	-359.20
-1.00	-169.67	86.49	-2.83	-423.54
-0.50	-31.26	97.32	-1.96	-170.87
0.00	0.00	0.00	0.00	0.00
0.50	6.88	-41.11	10.10	347.01
1.00	10.30	-0.42	48.49	368.77
1.50	2.35	0.63	269.84	101.69
2.00	0.00	2.35	278.33	62.01
2.50	0.00	0.00	18.68	32.69
Total	-692.12	206.31	619.58	-55.38

The volume of the water added to the groundwater storage has been calculated using thc formula

Volume of Water = Difference in contour level X Area under influence X Specific yield of aquifer

Further, in order to evaluated the efficacy and correctness of theoretically computcd groundwatcr rccharge thcrcby, bchavioral changcs in groundwatcr lcvcls; thc author has plotted the secular hydrograph curve (Fig. 9.1) using data along with the observed values of water level fluctuation between 1982 and 1999.

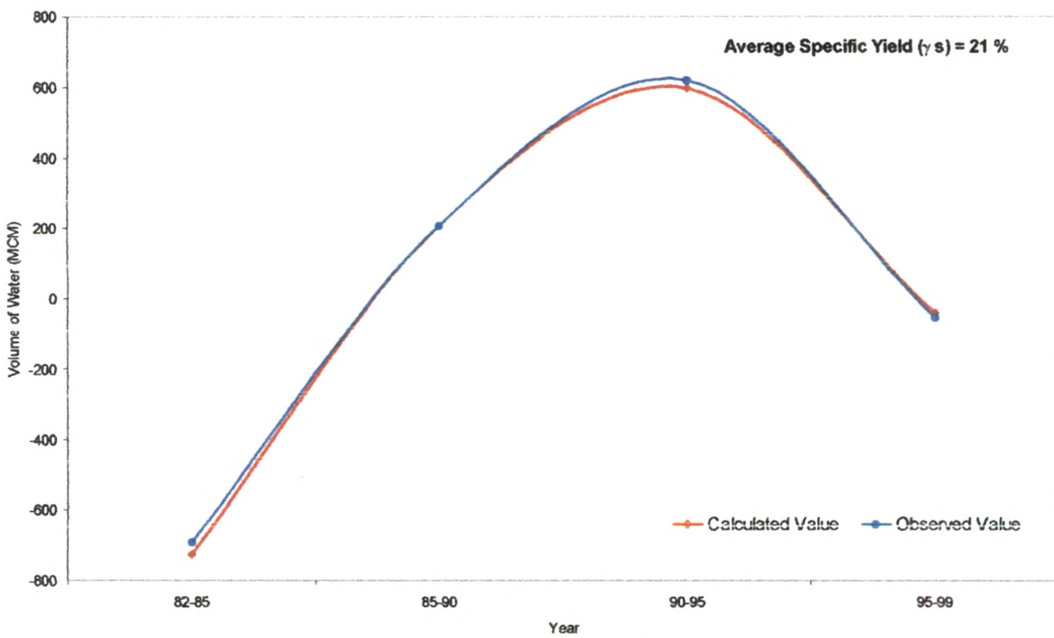

Fig. 9.1 Relationship of Calculated and Observed Value of Water Table Fluctuation with Canal Seepage

The obtained curves using both approaches almost matches and hence authenticate thc obtaincd valucs on groundwatcr rccharge through canal sccpage.