Proceedings WAMIP-2010
M. S. Rao, et al. (eds)
N.I.H., 2010

II-1

Soil Water Infiltration Model (SWIM) for Estimation of Groundwater Recharge in Ludhiana District, Punjab

V.V.S. Gurunadha Rao, L. Surinaidu and K Mahesh Kumar
Ecology and Environment Group
National Geophysical Research Institute, Hyderabad – 500 007

Abstract : Soil Water Infiltration Model (SWIM) has been applied for computation of groundwater recharge from an irrigated paddy field in PAU Campus. Total precipitation and applied irrigation has been about 2460 mm. The model out put consisted of actual evaporation of 1798 mm and with a runoff of 82 mm. The unavailable water in soil zone is 569 mm, with available water at the end of simulation as 499 mm and the groundwater recharge worked out to be 441 mm for 3 m sandy loam profile. The natural recharge estimated by tracer measurements made in Punjab state during 1988 was only about 55 mm/yr. The actual irrigation return flow works out to be 396 mm. The groundwater recharge at the end of one year has been worked out as 149 mm for 6 m sandy loam profile.

Two scenarios of SWIM model results indicate that reduction in potential recharge to the deep water table in the canal irrigated areas may be due to deep water table condition with a large thickness of vadose zone, which in turn may be holding irrigation return flows as available moisture in that zone above the water table, but not contributing actually to the water table. The study warrants imperative need for reduction in the overexploitation of groundwater resources in the area. As overexploitation of groundwater has been resulting in reduction of potential recharge through applied irrigation return flows as well as monsoon rainfall to the groundwater table in various parts of Punjab. It is suggested that farmers may switch over to low water intensive irrigated crops to reduce stress on the groundwater resources, which may keep groundwater table low for faster replenishment of aquifers through natural recharge as well as applied irrigation return flows.

INTRODUCTION

The experiment carried out in PAU Campus of Ludhiana district has indicated large amount of groundwater recharge from the irrigation return flows. Actual water level observations do not support the water balance computations. Daily input like water application as well as rainfall during the one-year period starting from June to May on the experimental paddy-irrigated site in PAU campus has been considered. Sandy loam soils have been considered with variable depth profiles of 3 m and 6 m for recharge computation assuming the groundwater table at those depths. Twice the paddy crop was grown during one-year period have been simulated in the model. Effective irrigation water application @ 10 mm/day in the field has been assumed for paddy. Surface water ponding of 1 to 2 mm depth in the paddy field has been maintained throughout the simulation period. The average evaporation in the area has been assumed as 2090 mm/yr.

SWIM MODEL

SWIM Model is a software package for simulating water infiltration and movement in soils. Water is added as rainfall and removed as runoff, drainage, evaporation from the soil surface and transpiration by vegetation. The simulator assumes that conditions can be treated as horizontally uniform, that flow is described by Richard's equation and that soil hydraulic properties can be described by simple functions.

Soil physicists describe water flow in soils with Richard's equation. Solving this equation mathematically is difficult or impossible for many realistic flow problems and numerical methods have been used extensively. Much effort was put in on flow models that approximated Richard's equation under certain restricted conditions, the most commonly used being the Green-Ampt model for infiltration.

Richard's Equation

Darcy's law governing one-dimensional flow of liquid water in soil is

$$Q = - K\, dH/ dx$$

Where Q is flux density (cm/h), K is hydraulic conductivity (cm/h) and H is hydraulic head (cm) at position x in the direction of flow. This states that the water flows down the hydraulic gradient at a rate proportional to the gradient. The "constant" of proportionality varies with conditions such as type of soil and its water content, but not with the gradient. Darcy's law has proven to be valid undermost conditions of soil water flow provided the soil can be treated as a continuum, i.e., provided a suitable length scale for definition of variables such as Q, K and H can be established (See Bear, J., 1979. Hydraulics of groundwater. McGraw Hill, New York).

The equation of continuity for a fluid of constant density expresses conservation of volume

$$M2/ Mt = -q /Mx + s$$

rate of increase = flux in – flux out + rate of addition

where M2 is volumetric water content, t is time and s is source strength, i.e., cm water per cm distance per hour. Combining this with Darcy's law gives Richard's equation:

$$M2/ Mt = (K (MH /Mx) /Mx + s$$

If we assume that gas pressure in the soil is always atmospheric, i.e., that air can move freely, and that we are dealing with a rigid soil structure, H is given by the sum of the matric potential R (cm) and the gravitational potential z, equal to the elevation in cm from some arbitrary reference level. Then Richards' equation becomes

$$M2/ M0 = (K (MR /Mx + Mz /x) / Mx + s$$

and it is this equation that SWIM solves. Details of the methods and information on numbers of space and time steps likely to be required for given levels of error are as follows

Simplifications and Approximations

- Vapour flux in the soil is ignored, as are temperature effects
- Hysteresis in the relations between R and 2 and between K and 2 are ignored
- Simplified form for hydraulic properties has been adopted, mainly because data are usually too limited to justify more detail, especially when field variability of hydraulic properties is concerned
- "Saturation" refers to the saturation normally attained under field infiltration
- Macro-pores and preferential flow paths included
- Actual evaporation rates are calculated accordingly (Campbell, G.S. 1985)

SWIM Model Input Parameters

Simulation time has been assumed to be 8760 hrs with one-day time step for a water increment of 5 mm. The water increment parameter controls how large a step in time the simulator can take. Vegetation type 1 has been assumed with minimum Xylem potential of –150 m and depth constant for roots being 15 cm. The Xylem potential determines the wilting point. The maximum root length density considered for the simulation being 5 cm/cm^3. Depth constant for roots indicate that at this depth root length density falls to 37%. Maximum root length density implies when crop is fully grown. Fraction of PET intercepted is 0.5, the remaining can be lost through soil evaporation. SWIM allows specifying in some detail the evapo-transpiration pattern imposed on the soil.

The conductance parameters include the initial soil surface conductance, minimum soil surface conductance, precipitation constant and effectiveness parameter. The soil may have thin surface layer that impedes water entry. The water flux through this layer is equal to the surface conductance multiplied by the matric potential difference across the layer. To allow for a reduction of surface conductance due to formation of a crust caused by rainfall, the conductance decreases exponentially with cumulative precipitation energy from the given initial value towards the given minimum. In the present model the initial soil surface conductance of 4/h, minimum soil surface conductance of 0.02 /h, precipitation constant of 0.05 cm and effectivity parameter of 0.184 has been used. For daily input the effectivity parameter is assumed as zero.

Runoff parameters used in the model are with initial soil surface storage of 4 cm, minimum soil surface storage of 3 cm, precipitation constant 5 cm and runoff rate factor of 2, runoff rate power of 2 with initial surface water depth of 1 mm. Runoff occurs when the surface water depth is greater than the surface storage. To allow for a reduction of surface roughness due to rainfall, the storage decreases exponentially with precipitation energy from the given initial value towards the given minimum in exactly the same way as the surface conductance. The model simulates overland flow conditions and simulation to begin with surface ponding.

Soil hydraulic properties include the soil depths of 3 m and 6 m. The parameter theta of 0.45 is water content at field saturation. The parameter b ranges from 2 in sandy soils to 25 in clays and the considered value is 8 representing sandy loams. The minimum soil suction -15 cm and maximum of –300 cm. The hydraulic conductivity has been assumed as 0.033 cm/h. Largely these parameters represent the soil conditions around the PAU site with irrigation for growing paddy crop.

SWIM Model Results

Profile Depth — 3 m

Total precipitation and applied irrigation has been considered to be about 2460 mm/yr in a paddy field in Punjab Agriculture University (PAU) campus, Ludhiana in Ludhiana district. The computed model out put shows an actual evaporation of 1798 mm/yr with a runoff of 82 mm/yr considering bunding etc in a Paddy field plot. The unavailable water in the Vadose (soil) zone has been 569 mm with available water at the end of simulation period of one year to be 499 mm. The computed profile moisture storage and water balance from SWIM Model at the end of simulation period indicate 441 mm of groundwater recharge (Table 1). The natural recharge due to monsoon rainfall estimated by tracer measurements carried out in Punjab state was about 55 mm/yr (Datta et al, 2001). Thus the actual irrigation return flow in a shallow 3 m depth water table condition would be 386 mm.

Profile Depth — 6 m

Total precipitation and applied irrigation has been considered to be about 2460 mm. The model out put gives about actual evaporation of 1798 mm with runoff of 81 mm. The unavailable water in the soil zone is 1139 mm with available water at the end of simulation as1150 mm. Existence of thick vadose zone may be due to heavy groundwater pumping and fast declining water levels. Groundwater recharge at the end of one year has been worked out as 149 mm (Table 2). The natural recharge estimates show about 55 mm

Table 1 : Groundwater recharge Estimates from SWIM Model for 3 m Profile of Sandy loam soils under Paddy crop in PAU Campus, Ludhiana, Punjab

all values in mm (cumulative)*

Month	Rainfall/ Irrigation	Evapotrans -piration (Actual)	Runoff	Surface Water (Ponding)	Available water in profile	Unavai-lable Water in profile	Drainage (Groundwater Recharge)
May	414	353	0	0	420	569	1
June	770	653	0	8	468	569	1
July	1215	953	0	18	602	569	1
Aug	1735	1193	59	32	775	569	36
Sep	2075	1384	82	23	775	569	190
Oct	2334	1584	82	0	675	569	352
Nov	2410	1681	82	0	594	569	412
Dec	2460	1798	82	0	499	569	441

*at the end of the month

Table 2 : Groundwater recharge Estimates from SWIM Model for 6 m Profile of Sandy loam soils under Paddy crop in PAU Campus, Ludhiana, Punjab

all values in mm (cumulative)*

Month	Rainfall	Evapotrans-piration (Actual)	Runoff	Surface Water (Ponding)	Available water in profile	Un available Water in profile	Drainage (Groundwater Recharge)
Jan	34	43	0	0	709	1139	0
Feb	60	96	0	0	682	1138	0
Mar	89	163	0	0	644	1138	1
Apr	100	204	0	0	614	1138	1
May	414	353	0	0	779	1139	1
June	770	653	0	8	827	1139	1
July	1215	953	0	18	961	1139	1
Aug	1735	1193	59	32	1169	1139	2
Sep	2075	1384	81	22	1303	1139	2
Oct	2334	1584	81	0	1384	1139	2
Nov	2410	1681	81	0	1283	1139	83
Dec	2460	1798	81	0	1150	1139	149

*at the end of the month

for Ludhiana area. The actual irrigation return flow works out to be 94 mm, which is hardly 0.2 mm/day. It seems this could be even less when deep water table persists due to over exploitation of groundwater in the area resulting large thickness of vadose zone.

CONCLUSIONS

The SWIM model results of the applied irrigation on a paddy field in PAU campus, Ludhiana indicate that very small amount of actual recharge from the irrigation return flow would be reaching the deep water table in Ludhiana district, Punjab. It seems reasonable to explain that overexploitation of groundwater for intensive crop production in Ludhiana area has resulted in deep water table condition with enlarging vadose zone thickness. The return flow from applied irrigation water is being used for replenishing the vadose zone as available water for plants as well as in the unavailable water storage in vadose zone instead of directly replenishing the groundwater table as deep percolation. The results have implications that ever increasing demand of groundwater pumping would not be sustainable in the region and warrants immediate action for implementation of water conservation measures as well as devising appropriate augmentation techniques of groundwater through water harvesting structures.

ACKNOWLEDGEMENTS

We wish to acknowledge the financial support received from ITSAP-TIFAC, DST project for the study during 2002- 2004.

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