CHARACTERIZATION OF GROUNDWATER RECHARGE IN A CRYSTALLINE WATERSHED THROUGH RECHARGE PROCESS AND GROUNDWATER FLOW MODELS

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ABSTRACT

Parkal watershed with an extent of about 12.35 sq.km. is a hard rock granitic aquifer system and is situated in Warangal district, Andhra Pradesh. The recharge to the aquifer mainly occurs due to rainfall during monsoon season and has been estimated using a recharge process model. The recharge has been estimated as a balance component after accounting for interception losses, surface runoff, evapotranspiration based on agroclimatological conditions and soil moisture status. Surface runoff has been estimated from SCS (Soil Conservation Service) curve number model.

Aquifer parameters viz., transmissivity and specific yield have been estimated through pump tests at four locations. The aquifer system has been modeled as a single weathered leaky aquifer using integrated finite difference method on a nested squares grid. Steady state condition of the aquifer system has been simulated assuming an equilibrium condition during June, 1981. The average annual recharge estimated over 10 years period has been fed as input to the aquifer. During the steady state calibration, the transmissivity values assigned at various meshes have been modified in some pockets to match the computed and observed water level contours. At some places minor changes have been resorted in the draft distribution arrived from well inventory and pumping hours. Irrigation return seepage has been found to be contributing significantly to the groundwater regime in the ayacut area of Damera cheruvu. The monthly recharge estimates of the recharge model have been fed as input to the aquifer model in the transient condition. The aquifer model has been refined after several trials and the monthly recharge estimates were found to be adequate for simulation of the water table behaviour.

INTRODUCTION

Parkal watershed, in crystalline rocks of granitic terrain, covering about 12.35 sq.km. is situated in Warangal district, Andhra Pradesh State and falls under Semi-arid Tropics. The watershed is bounded by Lat. 18 10' 45" to 18 13' 05" N and Long. 79 39' 30" to 79 42' 20" E (Fig.1). The rainfall mostly occurs during South-West monsoon from June to September and the mean annual rainfall is 1090 mm. The groundwater divide coincides with the topographic boundary, thus forming a closed

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groundwater regime. Some outflow occurs across 2.61 km section of the Paidpally Tank in the North. Both excess surface water as well as groundwater leaves the watershed across this section. The streams are emphemeral with intermittent flash flows after good rains and the surface runoff is being stored in three tanks.

Sandy Loams and Loamy sandy clays occur in the watershed with thickness ranging from 0.3 to 1.0 m. Paddy is the only irrigated wet crop grown in the ayacut lands of tanks. Maize and green grams (cereals) are the major rainfed crops grown during monsoon season. The second crop is mostly grown in the ayacut of tanks and is also supplemented with groundwater resources which in turn may contribute irrigation return flow to the groundwater regime.

HYDROGEOLOGY

The watershed is underlain by crystalline rocks of Archean age comprising of grey and pink granites and traversed by quartz and pegmatite. Weathering of rocks has been observed down to a depth of 8 meters below ground surface. Fractures at depths, below the weathered zone have been identified during drilling. Groundwater occurs under water table conditions in the weathered and fractured parts of the hard rocks.

Groundwater levels in the open wells and borewells generally start rising from the last week of June till the first week of october. There are twenty observation wells monitored regularly since 1980. The depth to water level during October varies between 0.5 to 7.0 m.bgl whereas during premonsoon the water levels stand at 2.5 to 9.0 m bgl. Recharge to the groundwater regime mainly takes place from rainfall.

A. Recharge Process Model

The water balance method of estimation of groundwater recharge utilizes the balance among various components of the water balance equation.

$$RE = P + Ir - (Int + Rof + AE + ATR + WC)$$

where

P	=	Rainfall
Ir	=	Irrigation
Int	=	Interception loss
Rof	=	Surface runoff
AE	=	Actual evaporation from soil surface
ATR	=	Actual transpiration
WC	=	Soil moisture storage and
RE	=	Groundwater recharge

The daily rainfall data has been used to estimate the surface runoff whereas pan evaporation measurements have been utilized to estimate actual soil evaporation and transpiration from the vegetation.

Interception Loss: The interception loss in semi-arid tropics has been assumed as 0.5 mm per rainfall event on a rainy day preceded by a dry day. If the precipitation for this rainy day is less than or equal to 0.5 mm, the interception loss is equal to the precipitation. Also for a rainy day followed by previous rainy day, the interception loss has been assumed to be zero.

Ssurface Runoff: The surface runoff from the rainfall has been estimated through use of soil conservation service (SCS) runoff curve Number Model (Ven Te Chow, 1988).

$$Rof = (P - I)^2 / (P - I + S)$$

where I = Initial retention volume
S = Potential maximum surface retention

The initial abstraction I is considered as 0.2 S

The retention volume is given as

$$S = 25400/CN - 254$$

where, CN is the runoff Curve Number, a parameter dependent on soil type, land use, and antecedent moisture condition. Considering the land use pattern a representative weighted average curve number for the entire watershed has been worked out as 60 (CNI), 78 (CNII) and 90 (CN III).

Generally the soils of the watershed are in Antecendent Moisture Condition I (AMC I) prior to the monsoon and after initial monsoon rains the antecedent moisture condition may change to AMC II or AMC III depending on the rainfall pattern during the monsoon period till early October.

Actual Soil Evaporation: The loss of water by evaporation from the soil surface is a major component of the annual water balance of the semi-arid tropics. The actual evaporation from the soil surface nearly equals the potential evaporation when the soil surface is saturated with water. The maximum depth of the soil where soil evaporation will occur depends on the texture of the soil and it is very difficult to measure in the field. The daily actual soil evaporation AE has been estimated as a function of the daily pan evaporation value Ep, the number of days, t, following the rain of sufficient amount to recharge 20 cm thickness of soil zone from surface and fraction B of incoming solar radiation reaching the soil surface (Russel, 1978). The following equation

$$AE = B. Ep /t$$

is used to compute the daily actual soil evaporation from the daily rainfall data and pan evaporation data combinedly. Under uncropped conditions of barren land B = 1.0, but under cropped conditions it is a time dependent function of crop growth that can be measured directly or estimated from the leaf area index (LAI). Also it was found at ICRISAT Campus that the actual evaporation from soil may not be greater than half of the pan evaporation after applying corrections to pan coefficient (Pathak et al, 1990).

Actual Transpiration: To compute ET crop, a three stage procedure has been proposed by Food and Agriculture Organisation (FAO, 1977). The effect of crop characteristics on crop water requirements is given by the crop coefficient (Kc) which represents the relationship between the reference (ETc) and crop transpiration (ET crop)

$$ETcrop = Kc \cdot ETc$$

values of Kc are dependent on the crop, its stage of growth, growing season and the weather conditions.

To convert pan evaporation (Epan) into reference crop transpiration (ETc), emperically derived coefficient (Kp) is given which takes into account climate and pan environment. Reference crop transpiration (ETc) can be obtained from

$$ETc = Kp \cdot Epan$$

where, Epan = Pan evaporation in mm/day and represents the mean daily value of the period considered

Kp = Pan coefficient

Considering average daily pan evaporation at Parkal on yearly basis and the rainfall pattern during monsoon season, the pan coefficient Kp has been selected as 0.8 for moderate wind and medium humidity conditions.

Soil Moisture: Some surface runoff will be generated after a sufficient rainfall event and the remaining rainfall tries to saturate the soil zone upto field capacity and the surplus water if any, leaves the soil zone as groundwater recharge to the underlying water table. The moisture which has remained in the soil zone as the available soil moisture will be lost either as soil evaporation or transpiration by vegetation. A two layer soil zone has been assumed in the water balance model. In the top layer, which is assumed to be upto 20 cm depth from the ground surface both soil evaporation and transpiration could occur, whereas in the second layer, underneath the first layer upto 45 cm from surface, only transpiration by plants could take place as long as the soil moisture is available. The average available moisture holding capacity of the Alfisols of the region ranges from 45-75 mm/45 cm of the soil zone (Randhawa and Singh, 1988). A representative average thickness of 45 cm of soil zone has been assumed to be possesing an average water holding capacity of 60 mm.

The component of groundwater recharge could ultimately be obtained from the water balance computation. Various components of the recharge process model, viz., surface runoff, actual soil evaporation, actual transpiration, soil moisture status, and groundwater recharge have been computed following a daily soil moisture accounting procedure.

Results of Recharge Process Model: The annual ground water recharge and other components of the water balance model during 1976-1990 has been shown in Table 1. Groundwater recharge in the watershed mostly takes place during July to September (Table 2).

The average annual rainfall, the estimated surface runoff and groundwater recharge from the water balance model of the watershed are 1090 mm, 305 mm and 164 mm respectively under normal agroclimatic conditions. The percentage of mean annual groundwater recharge and surface runoff with respect to annual rainfall works out to be 15.0 and 28.0 respectively during 1976-1990. The percentage of the average annual recharge of 15 with respect to the annual rainfall for the Parkal watershed is comparable with the recharge rates of 14.5 of annual rainfall obtained for other granitic watershed viz., Dulapally near Hyderabad (Narasimha Reddy et al, 1991). The recharge estimates of Vadavathi river basin in parts of Karnataka and Andhra Pradesh on a similar granitic terrain are reported to be varying between 13-20 percent of annual rainfall (Sukhija and Rao, 1983).

B. Aquifer Model

The computer code NEWSAM (LEDCUX et al., 1989) solves the system of groundwater flow equations using integrated finite difference methods by implicit discretization of time steps. The linear system is solved iteratively by the point successive over-relaxation method. Figure 1 shows the nested squares meshes of the aquifer model in Parkal watershed. A well distributed 13 representative observation wells have been selected for construction of well hydrographs from June, 1981 to May, 1991. The water level configuration of June, 1981 has been assumed to be in equilibrium condition and therefore, has been considered as initial water level for the aquifer modeling. The water levels between observation wells have been interpolated taking care of surface topography, stream bed elevations and the water level in the surface water bodies. Elevations of beds on surface water bodies have been interpolated to infer stream bed elevations and have been simulated accordingly as known water levels in the model.

Aquifer parameters viz, transmissivity and storage coefficient were estimated by conducting pumping tests on four dug wells in the area. Transmissivity value are varying from 14 to 42 m2/day (Table 8) and the average specific yield is 0.054. The transmissivity values have been assigned to the corresponding nested square meshes and at the remaining meshes the 'T' values have been assigned through interpolation considering geomorphologic and subsurface geological features. The boundaries have been realised by terminating the meshes with no flow boundary condition by assigning zero transmissivity values in the model.

Recharge to the groundwater regime due to monsoon rainfall forms the main input to the aquifer system. Seepage from surface water bodies and irrigation return seepage from paddy fields also contributed as input stresses to the flow regime. The outflow is mainly through groundwater withdrawal from open wells and borewells during non-monsoon season mainly for irrigation and intermittent base flow towards streams during monsoon season. The base flow joins the outflow and levels the watershed at Paidpally tank outlet.

Steady State Calibration: The groundwater draft has been estimated based on well inventory and average running hours of pumps and the cropping pattern, and unit draft is of 0.67 ham/annum has been considered initially. Draft values have been assigned to each mesh based on density of wells falling in a particular mesh. The average groundwater recharge estimated from the water balance model (164 mm/per annum) has been uniformly fed at all the meshes, except at those meshes falling on the stream courses and surface water bodies. The seepage from surface water bodies through beds of the tanks at a rate of 46 cm/year is distributed appropriately over 9 months in a year in the model.

The transmissivity values modified during the steady state model calibration are varying from 15 to 45 m2/day which are comparable with the estimated transmissivities from pumping tests. The computed water levels in the steady state calibrated model are found to be matching with the observed water levels within 1.0 m. It was noticed during the processes of model fitting that the variation of transmissivities produced negligible changes in the computed water levels and only the input and output stresses determined the water level configuration.

The water balance of the groundwater regime of Parkal watershed for steady state condition is summerised in Table 3. An average annual input stress 2.18 MCM (Million Cubic Metres) consists of recharge due to rainfall, seepage from surface water bodies and irrigation return flow from paddy fields under tank ayacut areas. The output stresses consist of groundwater pumpage from open wells and borewells to the tune of 1.67 MCM, a base flow of 0.27 MCM towards streams and a subsurface outflow of 0.24 MCM across the Paidpally tank bund.

Transient State Calibfation: The average specific yield (0.054) determined through pump tests have been assigned at all the mesh nodes. The dynamic variation of draft as well as the groundwater recharge estimated earlier has been fed to the aquifer model in monthly time steps during transient condition (Table 4). The groundwater flow model has been calibrated for a 10 year period from June 1981 to May 1991 through comparison of computed and field well hydrographs at the observation wells. The time-variant draft of 1.5 MCM/annum was maintained till 1986-87 and later on a draft of 1.6 MCM/annum, which is 6 percent more has been given in the model. Some relative reduction of annual draft has been effected during good rainfall years using monthly rainfall information and availability of surface water in the tanks.

The input and output stresses used for the transient simulation are shown in table 3. The draft has been redistributed at some meshes and the specific yield values have been localised and assigned to meshes to obtain a close match between computed and observed well hydrographs particularly at well no.168, 33 and 1. At this stage the computed and observed well hydrographs are found to be not matching during 1986 and 1987 at most of the observation wells. This may be attributable to some extraordinary recharge occurring during August 1986 and it could not be simulated in the model due to lack of understanding on the preferred path ways flow, which is happening after two years of drought period. Hence, some additional recharge has been given during August 1986 to bring the computed well hydrographs during 1986 closer to the observed one in the transient model. The comparison of computed and observed well hydrographs at the observation wells is shown in Figure 2.

3.0 CONCLUSIONS

The average groundwater recharge estimated from the recharge process model of Parkal watershed is 164 mm/annum for the corresponding 15 years average annual rainfall of 1090 mm. The average annual surface runoff and actual evapotranspiration in the region workout to be 305 mm and 606 mm respectively. The estimates of monthly groundwater recharge have been found to be adequate for simulation of the dynamic behaviour of the water levels in the aquifer model during 1981-90. The aquifer parameter estimates from the pumping tests on large diameter wells are found to be fairly representing the aquifer characteristics except in small pockets. It has been felt that a periodical review of the unit draft estimates is necessary in the context of the recent increase in well population. The estimated unit draft of 0.67 ham/annum seems to be higher and a less unit draft of 0.60 ham/annum is found enough for obtaining the water table configuration as existed in the watershed.

The irrigation return seepage from paddy fields in the ayacut area of tanks, particularly in the Damera cheruvu is significantly contributing to the groundwater regime. A case of rapid recharge phenomenon has been noticed during the transient calibration of the aquifer model during August 1986 and has been to some extent quantified through the aquifer model by feeding additional recharge during that period to obtain a closer match between the computed and observed well hydrographs at most of the well locations. This rapid recharge could possibly may occur through the preferred, pathways flow after drought years. The recharge process model and the aquifer model have provided estimates of groundwater recharge due to rainfall in two different ways. The validation of these estimates could only be confirmed through matching obtained in the well hydrographs at different observation wells. The monthly recharge estimates in particular are very helpful in determining the magnitude of time-variant input due to rainfall to the aquifer system.

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TABLE 1

ANNUAL WATER BALANCE COMPONENTS IN PARKAL WATERSHED

(IN MM)

year	Rainfall	Interception Loss	Surface Runoff	Soil Evaporation	Transpiration	Recharge
1976	1061.4	15.4	352.7	144.2	314.9	234.2
1977	724.6	15.4	57.4	205.8	434.3	11.5
1978	1394.0	18.6	373.5	252.4	540.6	209.2
1979	784.8	15.3	189.2	133.6	341.3	98.7
1980	710.0	15.4	82.8	144.5	381.3	92.6
1981	1144.2	19.8	281.5	191.1	452.3	199.7
1982	1052.0	15.0	205.3	197.6	455.9	177.9
1983	1386.4	14.0	505.7	138.5	359.5	357.5
1984	946.3	14.5	240.6	182.1	426.2	94.3
1985	719.2	14.0	142.2	145.8	359.6	57.7
1986	1087.0	12.5	411.7	137.9	419.5	91.5
1987	873.7	13.4	199.2	212.0	414.6	36.9
1988	1501.4	12.0	549.6	214.4	443.9	281.4
1989	1346.6	7.8	527.5	144.4	394.5	272.4
1990	1628.1	12.5	465.8	262.5	645.3	241.9
AVG.	1090.6	14.4	305.6	180.4	425.6	163.8

TABLE 2

MONTHLY GROUNDWATER RECHARGE DURING 1981-1990

(IN MM)

S.No.	Year	Jan	Jul	Aug	Sep	Oct
1.	1981	16	57	96	20	11
2.	1982		72	106		
3.	1983	3	44	125	108	76
4.	1984		37	23	26	9
5.	1985		3	54		
6.	1986		13	77	2	
7.	1987		37			
8.	1988		152	55	75	
9.	1989	1	239	32		
10.	1990	92	32	72		22

TABLE 3

AVERAGE ANNUAL INPUT AND OUTPUT STRESSES FOR STEADY STATE (JUNE, 1981)

(IN MCM)

RUN	INPUT RECHARGE DUE TO RAINFALL SEEPAGE FROM TANKS AND IRRIGATION RETURN	GROUND WATER DRAFT	OUTPUT BASE FLOW TO STREAMS AND OUTFLOW
1.	2.18	1.80	0.38
2.	2.18	1.61	0.57
3.	2.18	1.67	0.51

(After Narasimha Reddy, et al.1992).

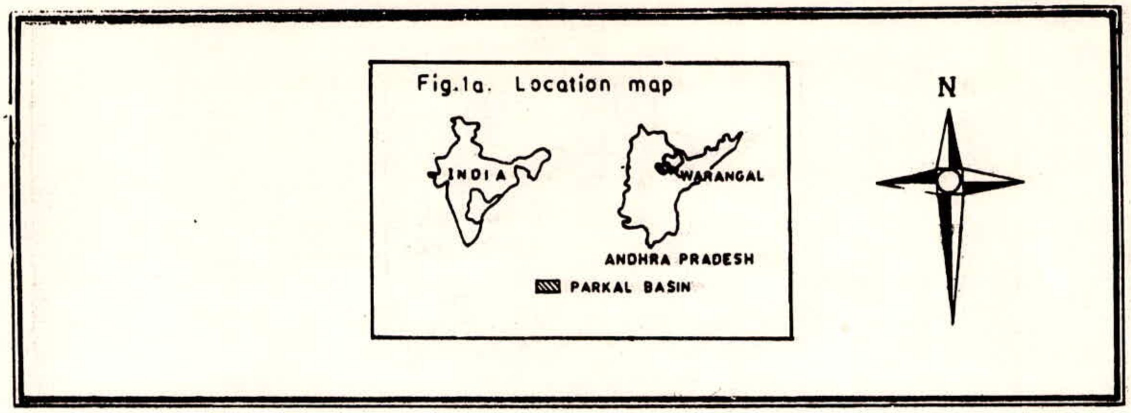
TABLE 4

ANNUAL INPUT AND OUTPUT STRESSES FOR TRANSIENT CONDITION

(IN MCM)

SL. NO.	YEAR	INPUT RECHARGE DUE TO RAIN-FALL SEEPAGE FROM TANK AND IRRIGATION RETURN	GROUND WATER DRAFT	OUTPUT BASEFLOW TO STREAMS & OUTFLOW	CHANGE IN STO-RAGE
1.	1981-82	2.50	1.50	1.00	0.00
2.	1982-83	2.39	1.54	0.86	-0.01
3.	1983-84	4.31	1.51	1.60	+1.20
4.	1984-85	1.40	1.45	0.86	-0.91
5.	1985-86	1.00	1.58	0.30	-0.88
6.	1986-87	1.30	1.57	0.13	-0.40
7.	1987-88	1.20	1.55	0.00	-0.35
8.	1988-89	3.50	1.60	0.81	+1.06
9.	1989-90	4.80	1.60	1.42	+1.78
10.	1990-91	1.70	1.50	1.15	-0.95

(After narasimha Reddy, et al. 1991)



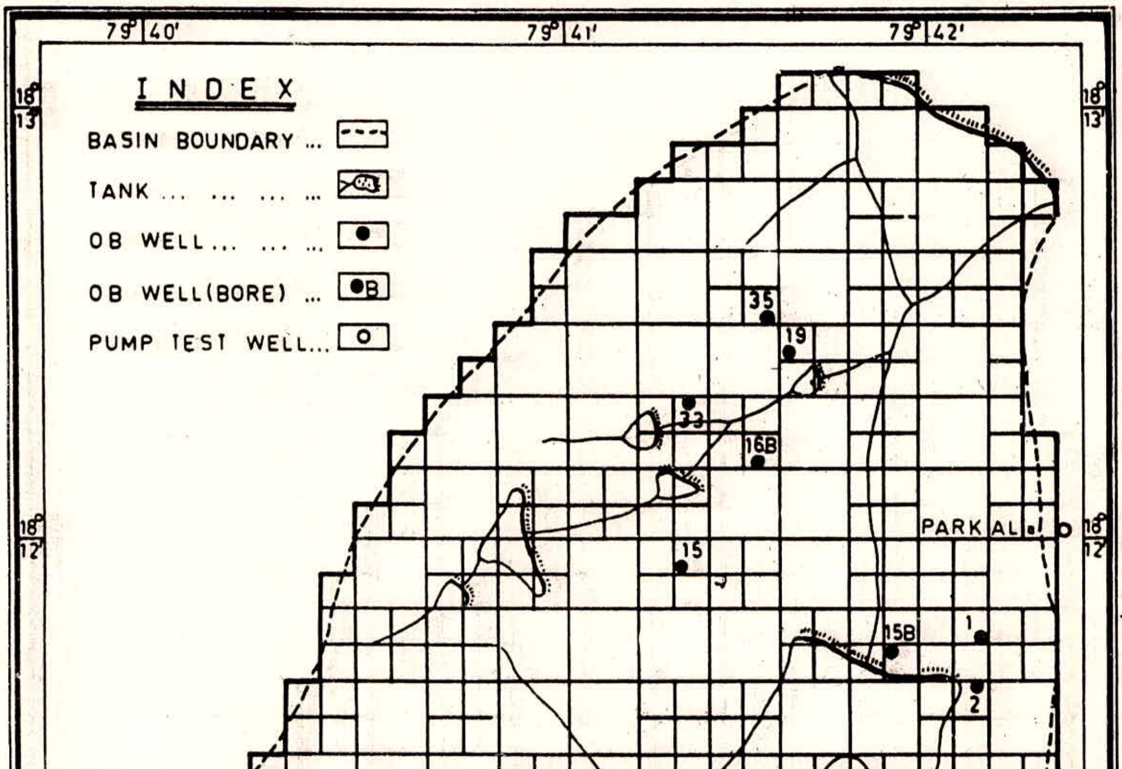


Fig.1b. Grid map of meshes with stream channels, watershed boundary and location of observation and pump tested wells.

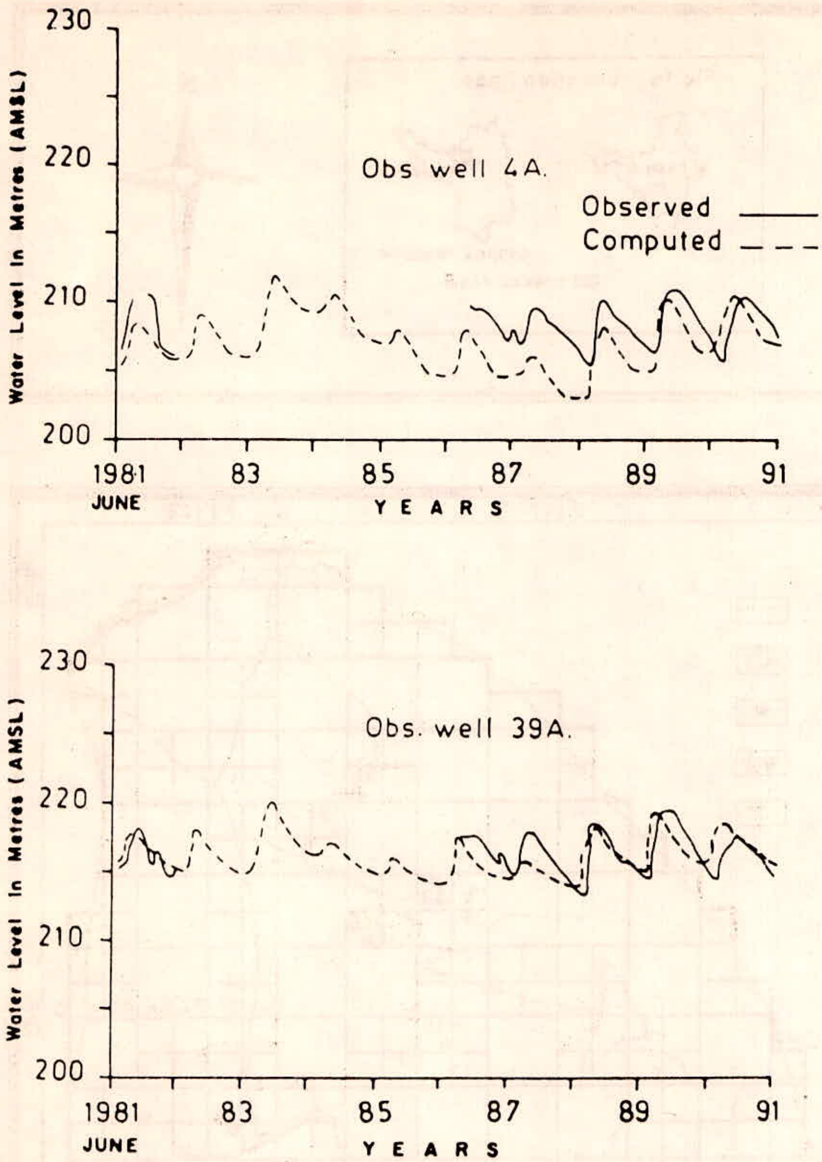


Fig. 2(a) Comparison of computed and observed hydrographs Transient condition - (Obs. well 4A and 39A).

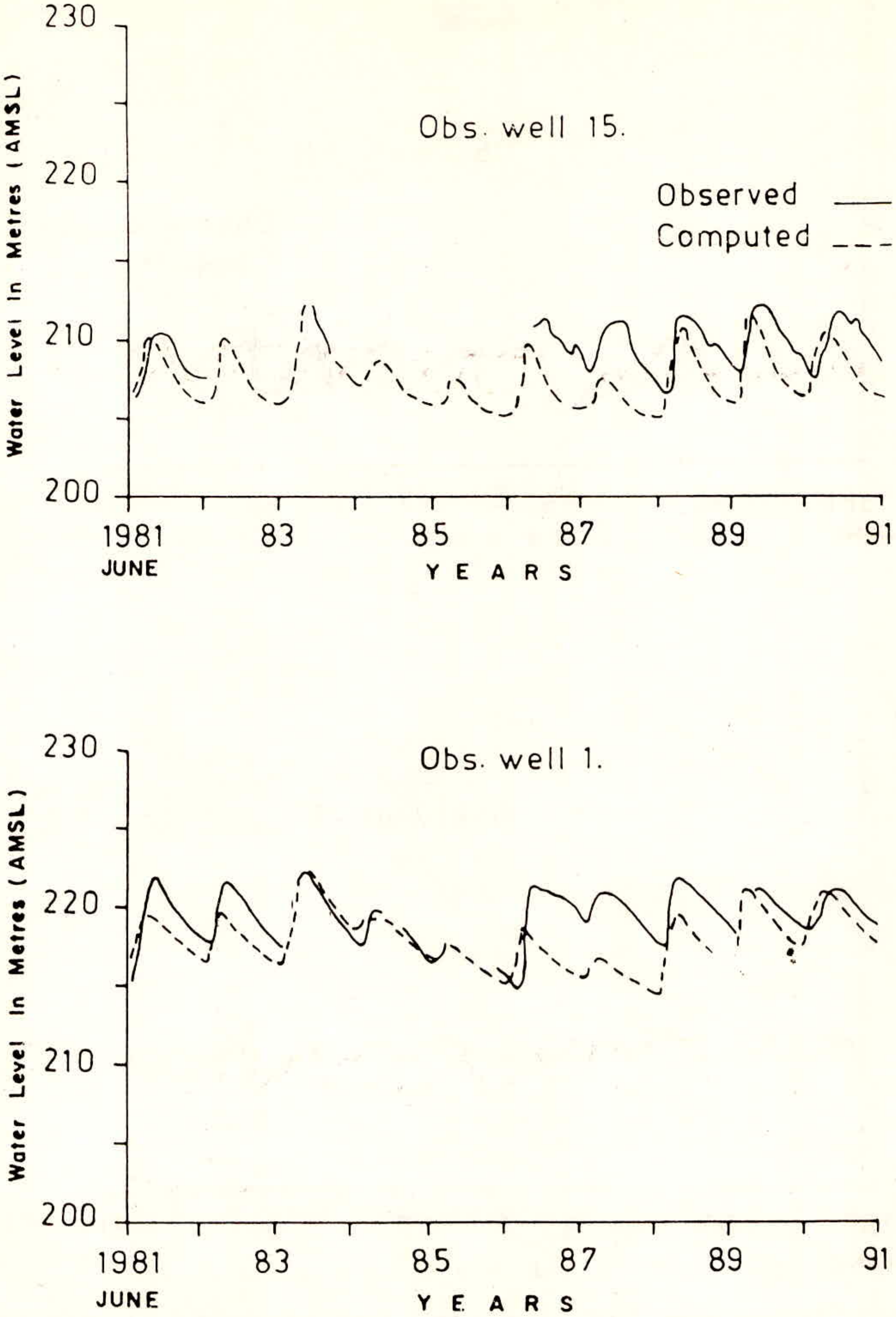
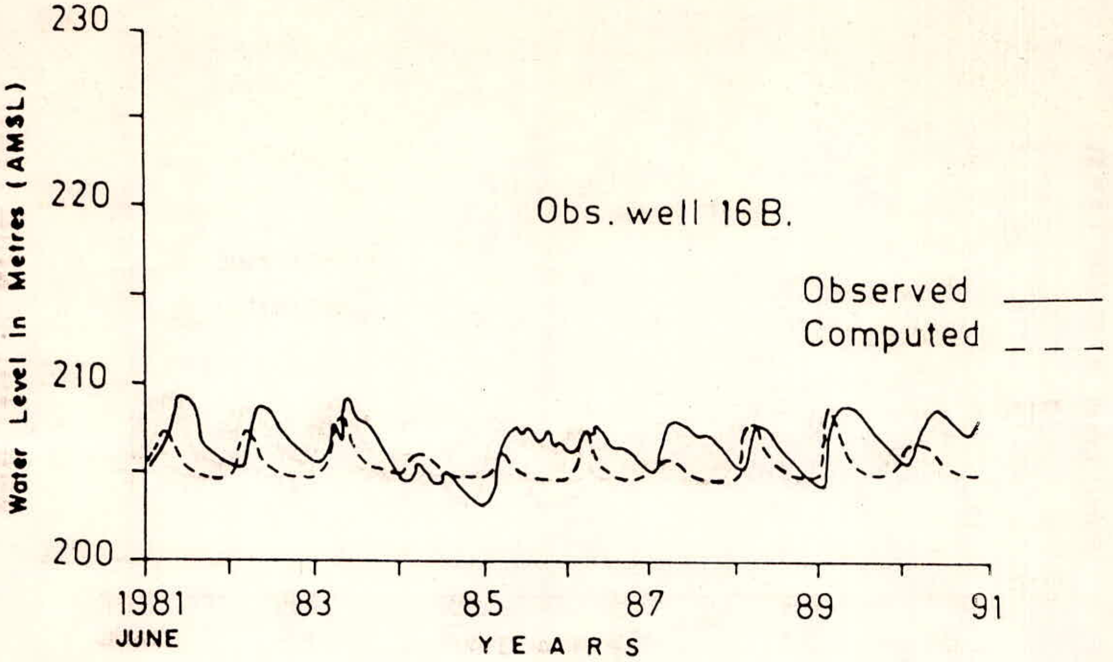


Fig.2(b).Comparison of computed and observed hydrographs Transient condition - (Obs. well 15 and 1)



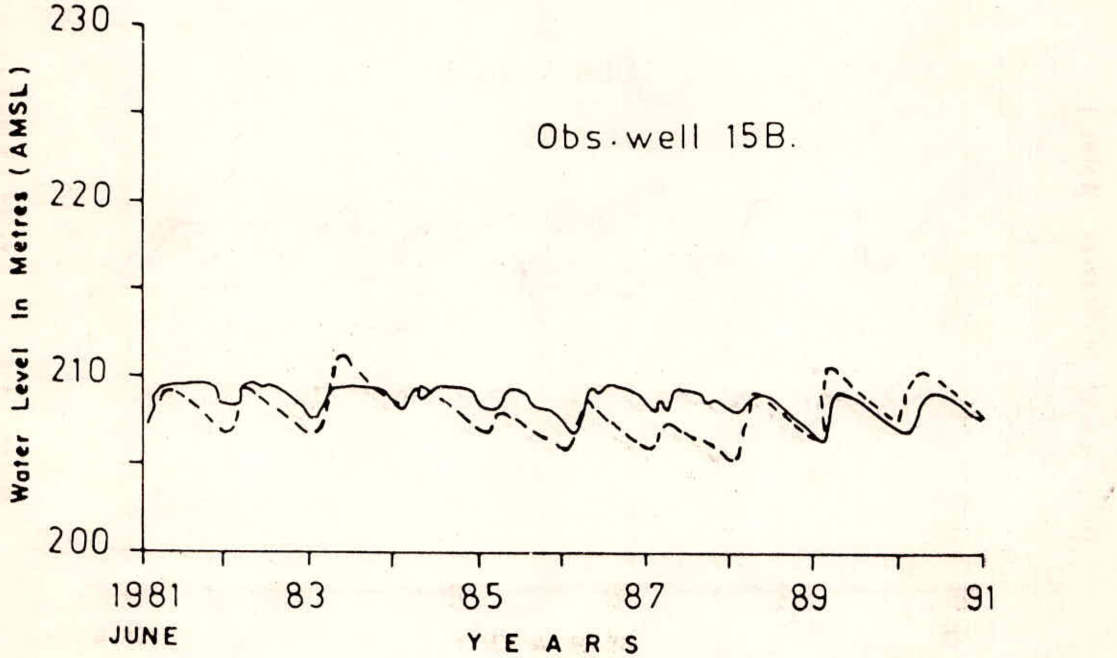
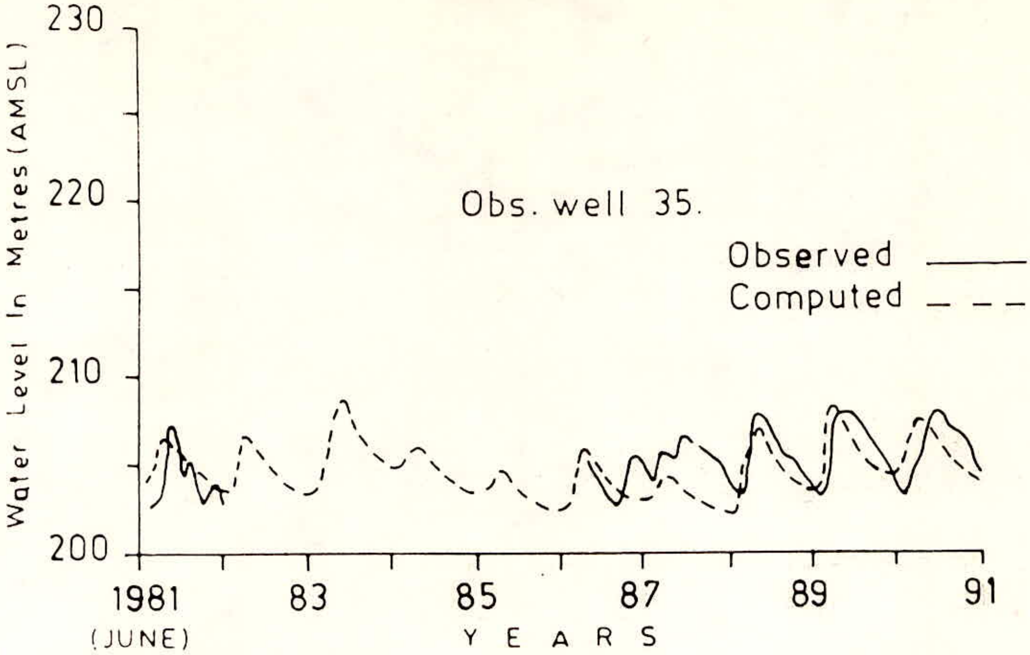


Fig.2(c). Comparison of computed and observed hydrographs Transient condition - (Obs. well 16B and 15B)



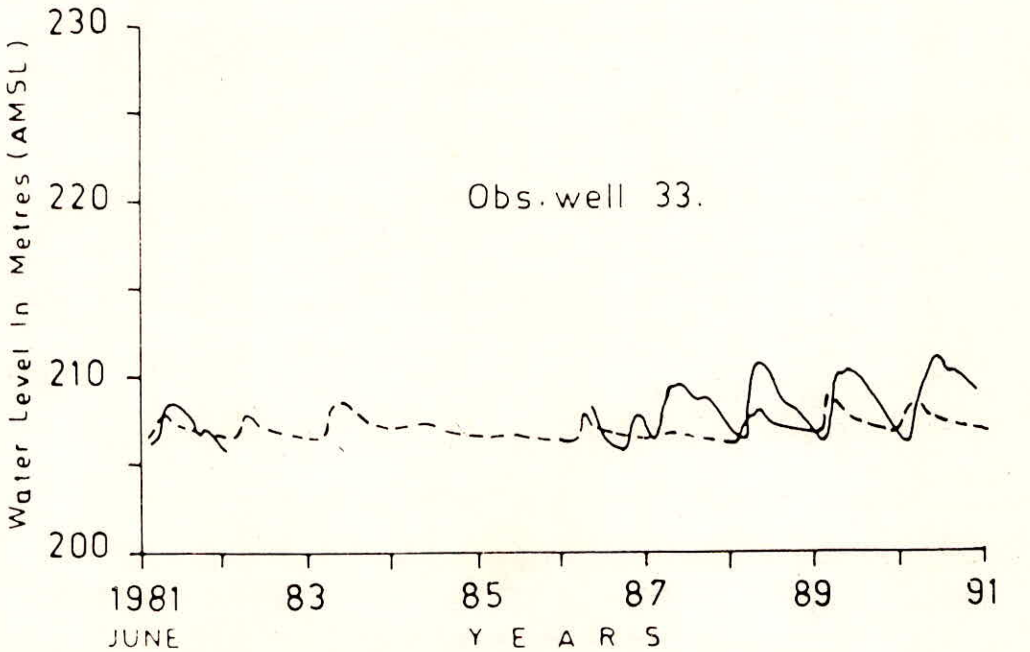


Fig 2.(d). Comparison of computed and observed hydrographs
Transient condition - (Obs. well 35 and 33)