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CONJUNCTIVE USE STUDIES IN PENNAR DELTA CANAL SYSTEM : AQUIFER RESPONSE MODELLING FOR SOUTHERN CHANNEL COMMAND AREA

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ABSTRACT

In a hydrological system surface water flows, low or high, does not necessarily coincide with the low or high levels in groundwater, because of the sluggishness of the groundwater flow compared to surface water flow. Also excessive development of groundwater in the deltas and coastal areas may lead to salt water ingress into the freshwater aquifer and may contaminate it, if unchecked. This may happen when sufficient surface water supplies do not reach the tail ends of command areas.

With the increasing knowledge of the hydrogeological features of potential aquifers being identified with latest geophysical investigations, the scope for better conjunctive use practices are very good. The prospects of practicing conjunctive use of surface and groundwater will be better provided one understands the hydro-climatology of the study area along with hydrogeology of the region. Collaboration between different government authorities and non-governmental organisations, is also essential. As a farmer switches over to using groundwater when there is frequent shortage of dependable surface water supplies the practice of conjunctive use is user-friendly natural resort as far as practicing is considered. Hence cultivators will be accommodative to suggestions on conjunctive use provided maximum benefit is assured.

A study on aquifer response modelling was undertaken for the Southern Channel command area (118 sq. km.) in the Pennar delta canal system in Andhra Pradesh to understand the potential or the dependability of groundwater supplies in the study area so that limited surface waters can be supplied to other much deserved areas.

The conjunctive use modelling at seasonal level, i.e., for water supply under canals during monsoon season and under wells during non-monsoon season is studied as a lumped model based on the water balance studies undertaken earlier for the study area. An attempt is made to simulate the drawdown due to pumping of ground water around a single well. Finally top aquifer is simulated using a finite difference method at a grid level of 1kmX1km. Pumping at different nodes is derived based on the number of filter points and extent of geographical area served by the village falling with in the grid. The aquifer parameters are adopted as those used for water balance study.

1.0 INTRODUCTION

The demand for water is increasing from year to year with the ever-growing population. For masses water is basic requirement for drinking and food production. Providing assured water supply for irrigation is becoming a difficult task with limited sources and uneven distribution of water in space and time. Depending on a single source for any purpose is very much unreliable and the idea of using water from two or more alternate sources in conjunction with one another safely and economically is drawing attention of planners, engineers and decision-makers. The source can be surface water impounded in a reservoir or runoff in the river extracted through diversion schemes like wiers, barrages etc., or groundwater lifted from unconfined aquifers and deep confined aquifers or water imported through inter basin transfer. Conjunctive use is also being practiced to mitigate the problem of water logging by going in for more pumping of groundwater wherever groundwater table is above or very nearer to ground surface. When enough fresh water is not available to meet the demands, conjunctive use of effluent water or return flows and fresh water can be practiced.

Maximum or minimum amounts of surface water do not as a rule coincide with those of groundwater levels (Buchan, 1962). This fact can be used to increase supplies of water to meet shortfalls. In inland areas, aquifers may be used for drawing water in summer and are allowed for recharge during monsoon before they are pumped again. Seasonal over-development of this sort will be a problem near the seacoast. Withdrawals of water should be done keeping the water balance of the region in mind. In water logged areas, which result because of excess canal irrigation, conjunctive use practice by giving suitable priority to groundwater exploitation may be a remedy.

In deltas, which form an important part of coastal zone, the practice of conjunctive use must give due consideration to the sensitive equilibrium of fresh groundwater and saline seawater. Investigations should be conducted to identify the interface and its movement with time. Since this is the zone where fresh surface water in rivers meet the sea, sea water intrusion may take place through the river mouths also. In this region all fresh water outflows leaving the last storage structure join the sea and become waste during monsoon season. With increasing number of storage reservoirs on the upstream of catchment flows will be insufficient, often, in the downstream where agriculturally rich deltaic plains exist. Authorities concerned fail to provide assured water supply to farmers forcing them to search for an alternate source. Sincc controls on groundwater exploitation are limited, it is being exploited in an unplanned way. Over exploitation of ground water in shallow coastal and deltaic region will disturb the equilibrium of fresh -saline water interface leading to sea water intrusion into coastal aquifers. The impact of saline water ponds of aquaculture along the coastal region should also be taken care off. Once an aquifer is contaminated it will be very expensive to bring it to normalcy. This may make the aquifer unfit for further use and also other sources of water might be under threat. Hence practice of conjunctive use in these areas should not only keep the demands of users but also keep an eye on the dynamic fresh-saline water interface. Water resources should be exploited by assessing the safe yield of the source.

Safe yield from any source is the quantity that can be withdrawn without impairing its function like causing contamination or creating economic problem or leading to declining supplies etc., It is difficult to define the safe yield in real terms. For example safe yield of an aquifer depends on the location and number of wells with respect to recharge and discharge boundaries, it's geology, topography, sources of pollution, socio-economic development of the region and many other factors.

In Pennar delta canal system, which is one of the oldest canal system in the Nellore district of Andhra Pradesh, due to availability of potential alluvial aquifers farmers depend on groundwater. The recent trends of irrigation practices in the delta suggest that farmers depend on groundwater than on surface water in some command areas due to decreasing dependability of traditional canal supplies. This is because of increasing diversions on the upstream as more areas are being brought under cultivation from time to time. Attempts should be made to study the present practices in a scientific way for optimum use of surface and groundwater to evolve at most suitable conjunctive use practice. This requires proper understanding of the hydrogeology of the region, for which extensive hydrogeophysical investigations need to be attempted, to know the geological features of the aquifer, river-aquifers-sea connectivity, and other aquifer characteristics like permeability, transmissivity, storativity etc., The investigations should describe the three dimensional variations of the characteristics for better assessment of surface water ground water interaction.

2.0 REVIEW:

Any conjunctive use scheme can be successful if the supporting studies are based on a reliable long-term database. Irrigation facilities, practices and cropping pattern should be systematic in the region. A properly planned and designed conjunctive use system must include trained personnel, good physical facilities for water distribution and drainage, updated data and information of water balance of the system, for successful operation. Since most of groundwater wells are privately owned, co-operation of cultivators is mandatory requirement in a conjunctive use scheme. There should be collaboration at village level between revenue, irrigation and groundwater authorities from government and farmers, co-operatives and non-governmental organisations from public.

A number of combinations of practices in space and time should be considered for planning the conjunctive use of surface and groundwater in command areas of canals under any river diversion scheme along the coastal areas. A combination of canal irrigation exclusively for some parts and groundwater exclusively for other parts in a command area will make it conjunctive use in space. This may be a suitable combination of conjunctive use practice in deltas and coastal areas. Allowing dependable canal water to tail end reaches, located close to the coast, may control over exploitation of groundwater and will retard seawater intrusion in to coastal aquifers. Interior areas may be allowed to go in for exclusive ground water utilisation. The combination of practicing conjunctive use in time is to allow rotation of use of canal water and ground water from time to time in a season or season to season in a year. Any decision on adopting a particular combination must be carried out duly supported by detailed scientific studies. The knowledge of long-term water balance of the system is very important. A conjunctive use practice based on erroneous water balance will be futile. Detailed modelling studies should be carried out before any proposed plan of conjunctive use is put into practice. Modelling and water balance studies must become an integral part of any conjunctive use scheme.

In many a parts, conjunctive use of surface water and ground water is the immediate need. Groundwater irrigation is prevalent in command areas of large-scale canal systems. If uncontrolled, this may lead to serious environmental problems.

Sakthivadivel (1994) put fourth the following actions for the sustainable conjunctive management of water.

1) Development of methodologies and techniques for effective resource management through conservation and utilization, select appropriate tubewell technology for conjunctive use of groundwater with surface water, integrate groundwater activities with surface water utilization, treat groundwater as a common property resource through legal provisions and sanctions.
2) Assess the interactions between groundwater and surface water recharge in terms of groundwater abstraction and water quality and suggest measures to control them.
3) Identify sources of pollution of surface water and groundwater and arrest deterioration of water quality.
4) Assess the linkages existing among groundwater groups, surface water Farmer Managed Irrigation Systems (FMIS) and public agencies, and suggest measures to improve their linkages and performance.
5) Develop and field-test a suitable organizational structure for conjunctive use of surface and groundwater systems.
6) Stipulate proper regulatory and control mechanisms for water table control and prevent water logging and pollution.
7) Provide adequate training; cost effective technology, adequate input services, market and credit facilities.

At a workshop held in Dhaka, Bangladesh on groundwater farmer managed irrigation systems and sustainable groundwater management, the following recommendations were made (Sakthivadivel, 1994):

1. Groundwater zoning be introduced into areas where only shallow tubewells can be used, areas where only deep tubewells can be allowed and areas where both can be allowed, for groundwater extraction.
2. A three phase approach be adopted which initially emphasizes shallow tubewells and groundwater management for stabilizing the drawdown level at an appropriate depth by regulating the use of shallow tubewells; second, to go for deep-set shallow tubewells and, finally, attempts may be made to go for deep tubewells where other methods of extraction have failed or inefficient.

3. Under watershed conservation, the micro-aquifer should be the unit for groundwater conservation. A water balance study of the micro-aquifer be carried out to study the impact of surface water on groundwater and to design appropriate extraction mechanisms.

4. In all irrigation systems groundwater extraction and use should be controlled so as to minimize environmental problems, such as water logging and salinization, sea water intrusion, reduction in agriculture production, health hazards, groundwater quality deterioration due to pesticides and fertilizers, land subsidence, etc.,

Malik and Strosser (1993) in a study in the Mananwala distributory command area, Punjab, Pakistan, undertook the management of private tubewells in conjunctive use environment. Though the main emphasis was on the operation of private tube wells, public tubewells and canal water supplies were considered in the analysis. Private tubewells increase the irrigation water supply available to farmers and play a stabilization role to mitigate unpredictable fluctuations of the canal water supply. The role of groundwater pumped by private tubewells for irrigation purposes is particularly important where farmers grow crops with high water requirements, such as rice and where tubewell owners have installed electric tubewells with comparatively low operation cost. For tail watercourses, with hardly any canal supply, tubewells are operated to provide irrigation water as needed.

Saline water intrusion due to over extraction from aquifers hydrologically connected to the ocean is emerging as a major point of concern in many coastal regions according to Moench (1996). Along the eastern coast of India, saline intrusion now extends as much as 60 km inland to the Baitarini, Brahmani and Mahanadi river basins (Ray, 1994). Basic data on the hydrological dynamics of coastal aquifers and the degree to which groundwater extractions related to saline intrusion are, however, now generally available.

3.0 STUDY AREA

Pennar delta canal network system is the backbone of prosperity in the coastal Andhra region after Godavari and Krishna deltas. Pennar River originates in Chennakasava Hills, northwest of Nandidurg in ex-Mysore state and enters the coastal plains after passing through a gorge between Jonnavada and Narasimhula Konda in

Nellore district. Two anicuts or wiers, namely, Sangam Anicut constructed in 1877 and Nellore Anicut constructed in1853 are the main diversion works on the river before and after this gorge and these control the entire pennar delta canal system.

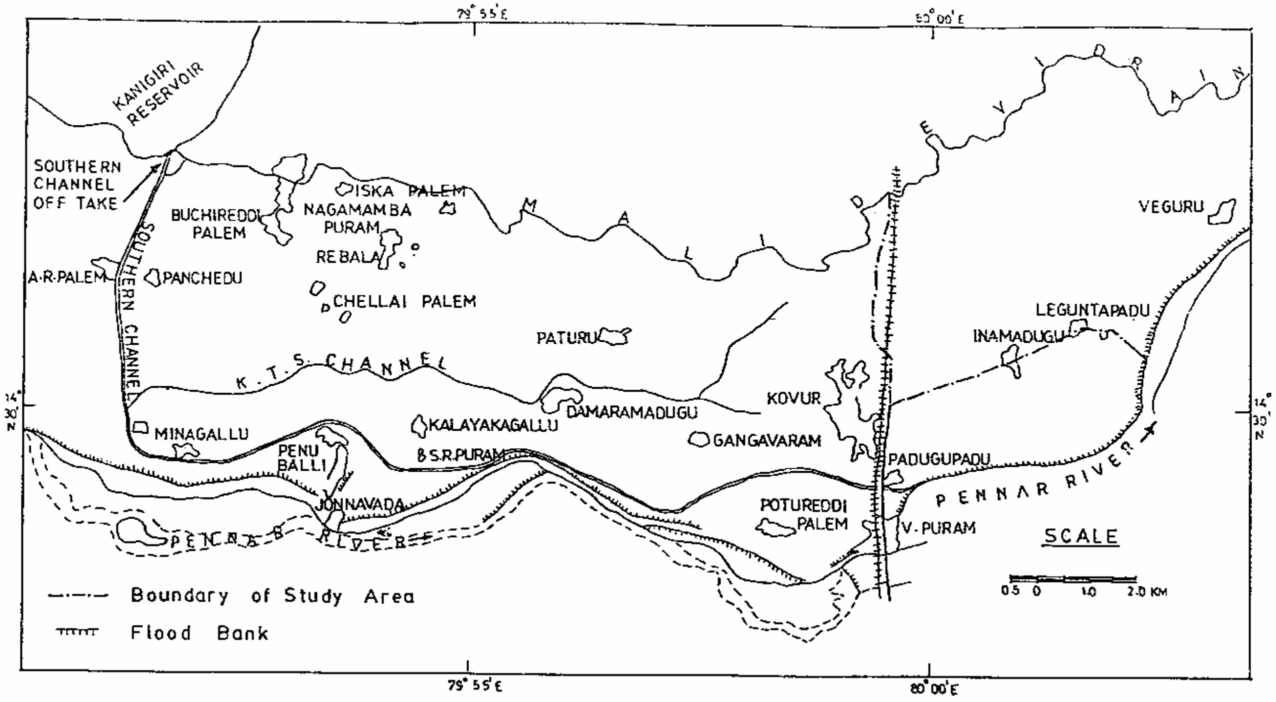
Kanigiri reservoir is the main terminal storage reservoir on the northern side of Sangam Anicut and entire command is served mainly by two channels originating from it, namely southern channel and eastern channel, whose command areas are separated by a natural drain called Malidevi, which again takes root at Kanigiri reservoir (Fig.3.1). The present study is limited to the command area under southern channel and its particulars are as below:

Sill level:	+23.535m
Number of vents:	4
Size of vent:	1.422m X 1.829m
Command area:	7625 ha
Length:	23.86 km

The study area falls in the Survey of India Toposheets Nos. 57 N/14,15 & 66 B/2, 3 between 79° 50' E to 80° 02' E and 14° 28' N to 14° 33' N. It covers a geographical area of about 118.2 km^2 in the revenue mandals of Buchireddy palem and Kovur in Kavali revenue division of Nellore district in Andhra Pradesh. The study area falls under arable land as far as land use pattern is considered and can be classified as agriculturally developed and constitutes of coastal alluvial soils. The study area gently slopes from west-northwest to east-northeast.

Geology

Dharwars comprising amphibolites, gneiss, schists, quartzites formed about 3600 million years ago are found in Nellore district, as isolated bands within granites. The Cuddapahs of upper Precambrian to early Cambrian age are also found in Nellore district. Commencement of gondwana period brought in a series of changes resulting in redistribution of land and sea and gondwanas are found as disconnected outcrops along the coast in the district. Deposits of recent to sub-recent times, such as, alluvium, beach sands, laterite soils and cave deposits occur along the coastal region. Beds, sloping coastward, of clay, sand, gravel and boulders belonging to alluvial deposits not only swells along the delta but also penetrates deep inland in narrow patches from apex of the deltaic deposits along the river.



3.1 STUDY AREA MAP OF SOUTHERN CHANNEL COMMAND AREA OF PENNAR DELTA CANAL SYSTEM

Hydrogeology

Along the coast laterites occur as thin capping on granite gniesses towards the interior. Alluvium comprising of clay sand and gravel along the river stream and alluvial fans along the coast. Groundwater occurs under water table conditions in the weathered zones of the laterites and is developed by dug wells with yielding capacities of the order of 50 m^3/day. In the recent deposits, coastal sands occur as linear ridges along the coast varying between 50 to 500 meters in lateral extent with thickness varying from 5 to 40 meters. Fresh water in limited quantity from shallow aquifer can be extracted through small pit and ring wells. Coastal and deltaic alluvium comprise of multiple aquifers and are highly potential and extends to about 15-30 km. The groundwater occurs both under water table and semi-confined conditions and is being developed by filter points ranging depth from 15 to 30 m and by shallow tube wells from 50 to 200 meters. The yield from filter point is varying from 40 to 70 m^3/day.

The alluvial aquifers have high porosity and permeability and hence constitute promising aquifers. The water is extracted through filter points, commonly. The study area contains fairly thick but discontinuous recent alluvium down to 150 m below ground level and transmissivity of about 1685 m^2/day is estimated during pumping tests (CGWB, 1985). The specific yield varies from 0.05 to 0.20. Bore holes drilled down to 15 to 30 m yield copious supplies of water. Deeper aquifers are found to contain highly brackish water. Groundwater quality is alkaline in general in the region. The percentage of development is more than 23% in Pennar delta region.

Salinity Ingress

The fresh water-saltwater relation in coastal aquifers is not merely one of hydrostatic equilibrium, but is one involving movements of fresh and saline water adjusting to a hydrodynamic equilibrium. The interface is a transitional zone. Groundwater extraction changes the dynamic balance between the flow of fresh water and the interface so that the interface will move and attain an equilibrium position governed by the quantity extracted and the balance outflow of fresh water to sea. Heavy pumping of groundwater through filter points, in coastal areas, during lean months can contaminate the aquifer.

Quality

The contamination of fresh water aquifer by seawater ingress is understood by studying the chloride-bicarbonate ratio and EC of groundwater samples. A study was undertaken during 1984 and 1994 by Groundwater Authorities to locate the interface. The studies indicated that fresh water aquifers are limited to a depth of 85 meters. The ratio contour bends landward south of Nellore town, which falls, outside the present study area. The EC contour also follows similar trend.

Climate and Rainfall

The study area falls in moist tropical climate as per Koppan's classification and in semi-arid region of Peninsular India under Thornwaite's classification. Four climatic seasons cycle the region. From March to May - summer season or pre-monsoon season; June to September - southwest monsoon season; October to November - northeast monsoon season; December to February - winter season occur in the study area. The study area recieves rainfall during both the monsoon seasons with major contribution from the northeast monsoon season. October and November are the most rainy months. The rain gauge stations having influence over the study area are Buchireddy Palem and Kovur. The normal rainfall in the region is about 982 mm out of which 950 mm occurs during monsoon season. Average temperature in the region is around 29°C with a maximum of about 34°C and a minimum of about 24°C.

Study Period:

This study is carried out on seasonal basis from 1989 to 1993 for a period of 5 years. The cropping seasons in this area are different from the normal practicing seasons mainly because of the peculiar setting of monsoon over this region as described in earlier section, and to derive the full benefit of useful rainfall from active northeast monsoon.

Cropping Pattern:

There are three main cropping seasons in the area. Early kharif season starts from 15th April to 15th July and short duration paddy crop is raised under filter points and tube wells. During main kharif season from 15th September to 15th January, the predominant crop is 'MOLAGOLUKULU', a variety that is resistant to damages from water logging during cyclones. Rabi season commences from 15th January to 15th April and irrigation will be provided to a limited area based on water availability.

Other areas have to again depend upon filter points. Apart from paddy, sugar cane is also grown as a main crop, in limited areas.

Based on the cropping pattern, rainfall distribution and groundwater levels the season from July to December is taken as 'monsoon season' and from January to June is considered as 'non-monsoon' season in this study.

Data:

Agricultural data is collected from study area at village level from statistics wing of revenue administration. The villages falling in the study area are Vavveru, Rebala, Nagamamba puram, Iskapalem, Kavetipalem, Panchedu, Chellaya palem, Minagallu, Penuballi, Zonnavada, Sri rangaraja puram, Kalayakakagallu and Damaramadugu in Buchireddy palem mandal; Paturu, GangaVaram, Potireddy palem, Kovur, Padugupadu, Inamadugu and Leguntapadu in Kovur mandal. Monthly rainfall data at Buchireddy palem and Kovur rain gauge stations is also collected. Irrigation data is collected from the PWD circle office of Irrigation and Command Area Development. I& CAD, sub-division at Buchireddy palem provided all the details on southern channel system and arranged a filed visit from head to tail end of the command which helped useful in demarcating the study area, under southern channel. Groundwater level data is collected for observation wells in Buchireddy palem and Veguru from State Groundwater Department, Nellore. The study area is delineated from Toposheets provided by them.

4.0 METHODOLOGY:

Since Eighties, due to the advent of digital computers, groundwater models have become significant tools for groundwater flow analysis. The models are broadly categorized as sand tank models, analog models and mathematical models including both analytical and numerical. The first two categories are replaced by the third one i.e., mathematical models that use numerical techniques. One of the advantages with mathematical models is the flexibility, i.e.; it can be used to model a large number of different problems. With the same program or set of instructions, heterogeneous and isotropic aquifers can be simulated using FD and FE numerical techniques. In this study along with the water balance model, finite difference technique is adopted.

Finite Difference Method:

The two dimensional transient flow of groundwater in a confined aquifer is governed by partial difference equation

$$\partial/\partial x\,(T_x\,\partial h/\partial x) + \partial/\partial y\,(T_y\,\partial h/\partial y)) = S\,\partial h/\partial t + Q \qquad \text{....4.1}$$

Where T_x = Transmissivity in X direction

T_y = Transmissivity in Y direction

h = Piezometric head

S = Storativity

Q = Groundwater recharge or withdrawal

x, y = rectilinear co-ordinates

The equation is valid for a continuous aquifer for which there are values of T, S and h every where, to derive which a detailed hydrogeological surveys are to be conducted. In the absence of detailed knowledge of these, the problem becomes approximated.

Finite difference methods utilize a grid system of points separated by a (small) distance and replace the partial differential flow equations by finite difference equation. Generally, the grid network is specified by an integer pair (i, j) to represent locations in a two dimensional array. The order pair (1,1) is located in the upper left-hand corner of the grid network. Values of i increase in the positive X-direction and values of j increase in the negative Y-direction. The value of head at point (i, j) is indicated by $h_{(i,j)}$. In the finite difference approximation, derivatives are replaced by differences taken between nodal points. In other words, from Taylor series and forward difference techniques,

$$dh/dx = (h_{(i+1,j)} - h_{(i,j)})/\,\Delta x \qquad \text{....4.2}$$

and from central difference techniques

$$d^2h/dx^2 = (h_{(i-1,j)} - 2h_{(i,j)} + h_{(i+1,j)}) / (\Delta x)^2 \qquad ....4.3$$

If $Q_{(i,j)}$ is the net withdrawal at node (i, j) and Q_n is the net leakage or recharge into the aquifer and if the aquifer is homogeneous with transmissivity of T and storativity of S, the head at node (i, j) can be had from the following FD form of equation 4.1 as per the notation from Fig. 4.1 for a known head of $h\phi_{(i,j)}$ at previous time increment. (Prickett and Lonnquist, 1971) when Δx is equal to Δy.

$$h_{(i,j)}(4T) - T(h_{(i-1,j)} + h_{(i+1,j)} + h_{(i,j+1)} + h_{(i,j-1)}) + h_{(i,j)} (S \ (\Delta x)^2 / \Delta t) = (S \ (\Delta x)^2 / \Delta t) h\phi_{(i,j)} - Q_{(i,j)} + Q_n \qquad ....4.4$$

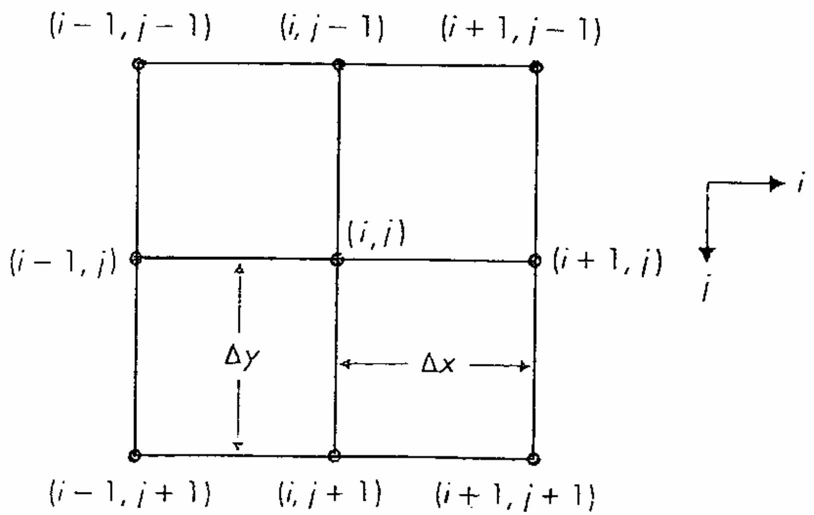
The finite difference equations as above are written for each node in the grid system for every time step and a large number of equations must be solved simultaneously for head at each node. Boundary conditions and initial values are also to be incorporated.

For solving the simultaneous FD equations, different numerical methods are available. In explicit methods an unknown value of h at a node is determined from known values of h at neighboring points. These methods are simple and direct but can become very expensive for small mesh sizes (Bedient & Huber, 1989). Implicit methods are, though complicated mathematically, are preferred to explicit methods.

Drawdown due to pumping for transient condition:

The governing partial differential equation for transient groundwater flow can be solved by either explicit or implicit method. A program for the case of pumping of well at one corner is explained by Bedient & Huber (1989). The program solves the classical well drawdown problem in X-Y co-ordinate system. The second partial derivatives can be represented by weighing terms with α, where $0< \alpha < 1$.For $\alpha = 1$, the numerical scheme is fully implicit. For $\alpha = 1/2$, the equation is balanced between time level n and time level n+1 and is called Crank-Nicolson method. The choice of Δx, Δy, Δt and α will strongly influence the accuracy of the numerical results.

4.1 Finite difference nodal notation



Prickett and Lonnquist Groundwater Model:

Prickett and Lonnquist (1971) presented a program to model the transient groundwater flow equation with heterogeneous and anisotropic conditions. The model can be used to simulate unconfined aquifer by allowing transmissivity to change as the saturated thickness change. The model uses an alternating direction implicit (ADI) method with the gauss-seidel iteration to solve the governing equation for transient groundwater flow. The FD equations are converted into tridiagonal matrix, in the ADI method. The method alternates between columns and rows to compensate for errors generated in either direction and the matrix is solved using Gausian elimination.

Input data are required for the definition of boundary conditions; values of transmissivities T_x, T_y, storativity S and recharge R for each node and initial condition of head at all nodes. Different boundary conditions can be used. Sometimes boundary conditions are difficult to select, in such cases commonly; the model grid area is made large enough so those grids in the interior are not affected by boundary conditions. Usually aquifer characteristics are available at limited places, stratigraphy and recharge patterns combined with aquifer characteristic should give reasonable representation of the area being modelled. Variations that are not properly represented in the model can lead to significant errors.

Another groundwater model that is widely used for two dimensional groundwater flow is of Trescott et.al.(1976). A completely revised and updated version of this model is released by USGS and is called MODFLOW, authored by Mc Donald and Harsbough (1984). It is modular three dimensional finite difference groundwater flow model and can be readily modified, by selecting the modules such as flow from rivers, flow from wells, or flow to drains. It is relatively efficient with respect to memory and speed.

5.0 ANALYSIS &RESULTS:

To undertake the aquifer response modelling at seasonal level for the study area an attempt is made to use the results of the ground water balance studies undertaken for the study area (Vijaya Kumar, 1997) earlier. Since the water balance model is a lumped approach and the estimates of a number of components are empirical, an attempt is also made to undertake groundwater modelling using finite difference method. Since the area consist of a network of about 3250 filter points for agricultural use an attempt is made to simulate using FD method the drawdown due to pumping of ground water at a single well, as if all the wells are uniformly distributed in space, which is not so in reality. Also, top aquifer is simulated using a finite difference method at a grid level of 1km X 1km. These are explained in detail in the following section.

Water balance model:

To undertake conjunctive use modelling in time a lumped model based on the seasonal water balance studies conducted for the study area is applied. The averaged seasonal inflows and outflows estimated for the system from 1989-94 are used along with the rainfall-recharge relation developed for the study area (Vijaya kumar, 1997). For the conjunctive use of water from canal water during monsoon and from ground water during non-monsoon for the whole command area the draft potential of the aquifer for the non-monsoon season is estimated from the seasonal groundwater balance model. The purpose is that all the recharge of monsoon season to the aquifer is planned to be used for the non-monsoon season's water requirements. The relationship developed is

$$(I - O + R)_M + (I - O + R - D)_{NM} = 0 \qquad ....5.1$$

$$D_{NM} = R_M + R_{NM} + M_p \qquad ....5.2$$

R_{NM} = 35% of draft as per the Groundwater estimation committee's norms (MOWR, 1983)

$$D_{NM} = (R_M - M_p) / 0.65 \qquad ....5.3$$

where

I, O, R are averaged inflows, outflows and recharges over the study period from the seasonal groundwater balance study.

D is draft potential

M_p is model parameter giving the net value of inflow and outflow components estimated from the water balance study

Here subscripts M and N indicate monsoon and non-monsoon seasons.

For the present case the relationship based on the water balance study developed is

$$D_{NM} = (R_M - 8.8) / 0.65 \qquad ....5.4$$

where R_M is the rainfall recharge (Fig 5.1) obtained from the seasonal water balance study undertaken for the area (Vijaya Kumar, 1997). The year-wise draft potential based on the water balance model is presented here with units in MCM:

Year:	1989	1990	1991	1992	1993
$Rain_{Monsoon}$	77.1	114.0	151.0	104.0	143.1
$Draft_{Potential\,(NM)}$	54.6	79.1	76.3	62.2	64.6

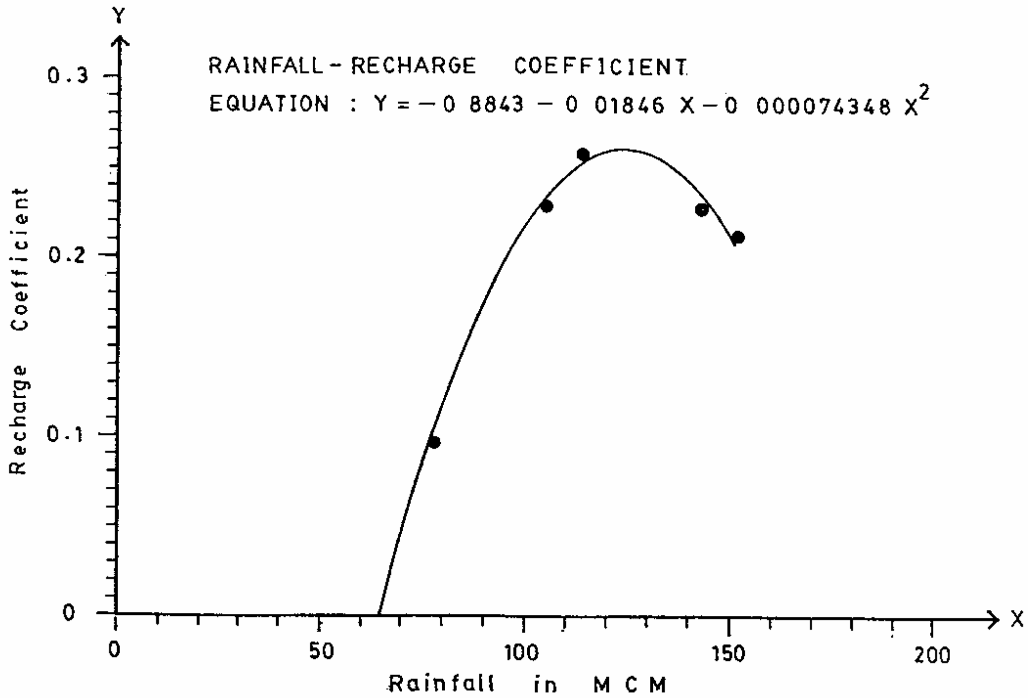
Drawdown around a well:

To understand the drawdown due to pumping at seasonal level an attempt is made to simulate the groundwater flow around a well using the governing partial differential equation 4.1 explained in earlier section. The time variant drawdown is found around a well for the non-monsoon season adopting aquifer characteristics with a transmissivity of 200 m^2 /day with the depth of filter point as 20 metres and storativity of 0.125, same as those used in the water balance study. Methodology and program as suggested by Bedient & Huber (1989) and explained in the earlier chapter is applied to find the modelled drawdown for the non-monsoon drafts of 1989-93 and the resulting drawdowns in the first quadrant at a nodal interval of 20 m is presented as Table in Annexure -I. An envelope curve giving the modelled drawdown around well due to non-monsoon draft pumpages is shown in Fig. 5.2. Here the interference of neighboring well is also considered. Since the study area is having only two wells where water level data is monitored the modelled drawdowns can not be verified satisfactorily with observed drawdowns.

Here it is to be noted that this methodology is undertaken, since the area consists of about 3250 filter points for agricultural use. This attempt is made to simulate, using FD method, drawdown due to pumping of ground water at a single well, as if all the wells are uniformly distributed in space, which may not be so in reality.

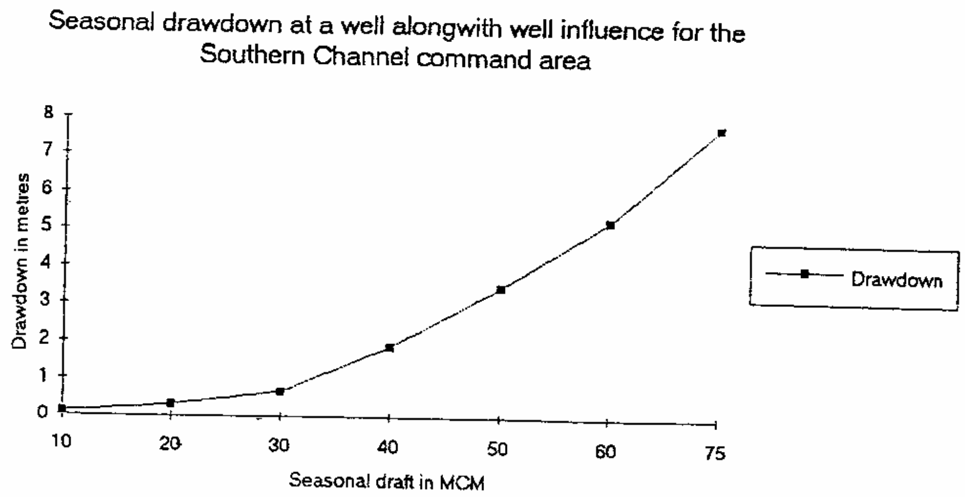
Regional FD modelling:

Where as an attempt is made to simulate the drawdown around a well as explained in the earlier section, the analysis adopted to simulate the drawdown over the whole study area to bring in the effect of distributed, though at grid level, pumpages at seasonal level is explained here.



5.1 GRAPH PLOT FOR RAINFALL - RECHARGE COEFFICIENT FOR SOUTHERN CHANNEL COMMAND AREA

(VIJAYA KUMAR, 1997)



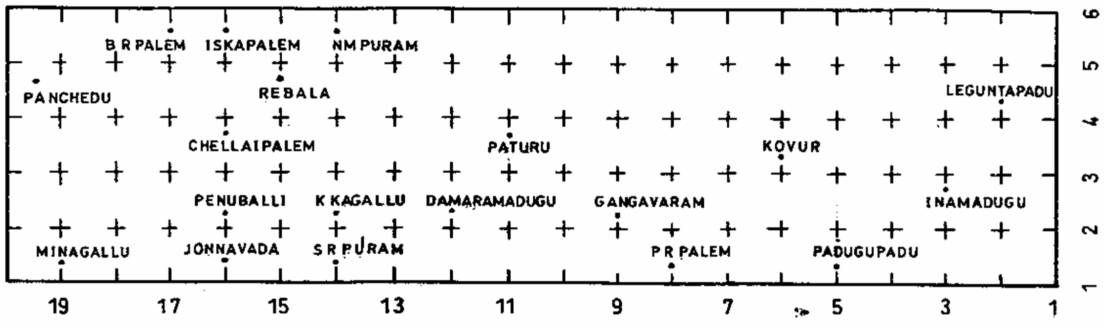
5.2 Envelope curve of the modelled drawdown for non-monsoon pumping

Prickett and Lonnquist (1971) presented a procedure to simulate the drawdown in an aquifer as explained in the previous chapter. The present study area is approximated as a 20 X 6 grid having 120 nodes at a grid interval of 1 km. Aquifer characteristics, as adopted in the earlier case, with a Transmissivity of 200 m^2 / day and Storage coefficient of 0.125 are used. The study area, which is elongated in the east west, is approximated to fit into the grid network. The approximated grid network along with the village locations is show in Fig. 5.3.

Distribution of Pumping:

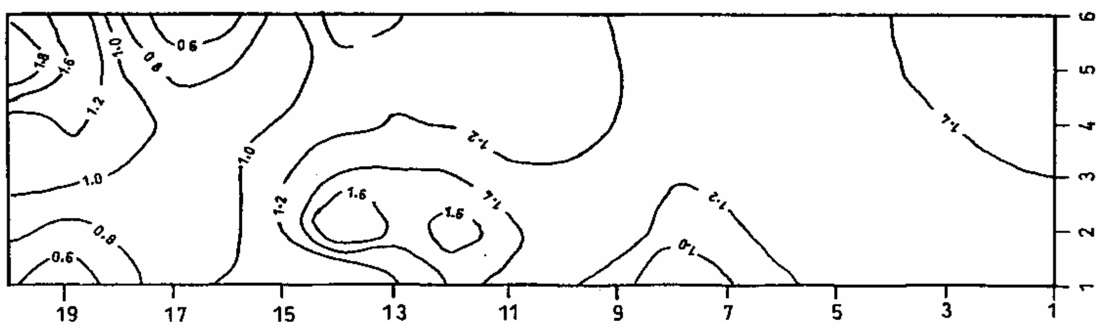
To surface fit the pumpages, pumping at different nodes is derived based on the number of filter points and extent of geographical area served by the village falling with in the grid. A pumping index factor, which is the ratio of the % no. of pumps and the % geographical area served by the village, is used and a surface of these factors is fitted (Fig. 5.4) and the value falling in each node is used to distribute the total seasonal pumpage at each node. Input is prepared as required for the program developed by Prickett and Lonnquist (1971). Seasonal drawdown is estimated from the above study for the estimated seasonal pumpages for the non-monsoon seasons of 1989-93 and these are presented as drawdown contours from Fig. 5.5 to Fig. 5.9. Since the records are available at only two OB wells in the study area, that too one well falling outside the study area, difficulties occurred to draw the observed drawdown contours for the study area. Hence the modelled drawdown couldn't be validated.

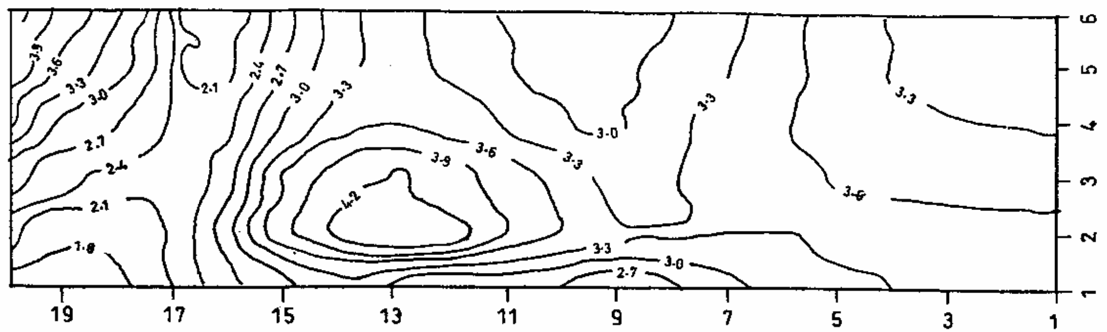
The groundwater drawdown modelled for the pumpage or water requirements of non-monsoon season may be helpful in understanding the potential of the aquifer at the end of monsoon season. Depending on the groundwater table level at the beginning of non-monsoon season, the drawdown can be obtained from the model for the pumpage to meet the non-monsoon demands for the given pumping pattern. This may be of help to the decision-makers in fixing the cropping pattern for the non-monsoon season.



5.3 Approximated FD grid network for the study area

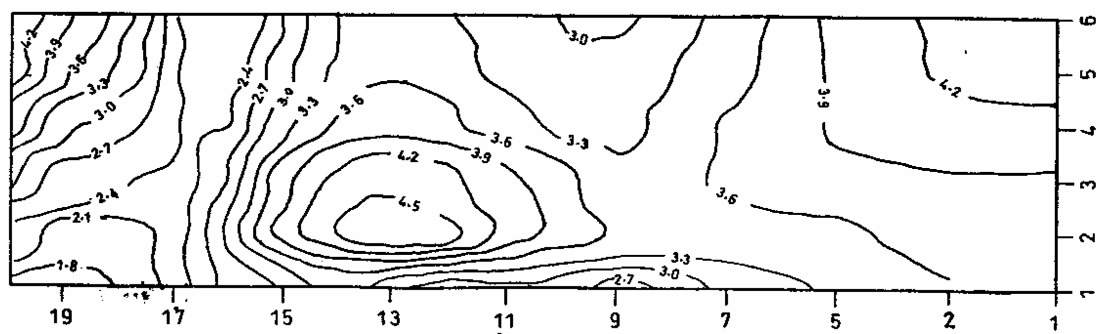
5.4 Surface fitted pumping index contours

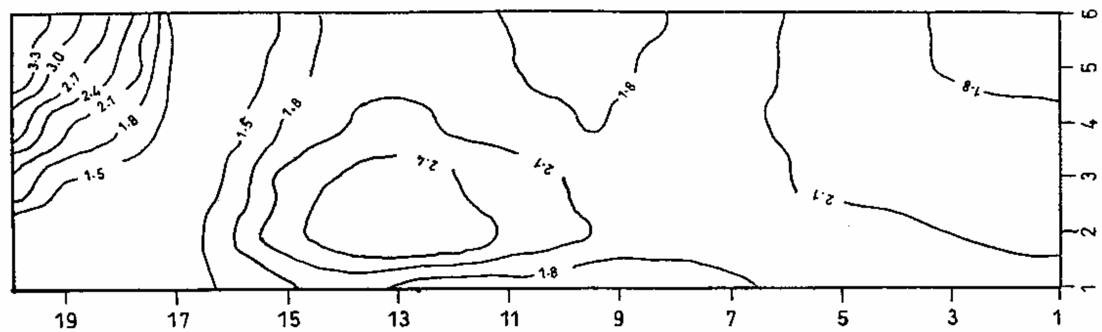




5.5 Modelled drawdown contours due to non-monsoon seasonal pumping of 89-90

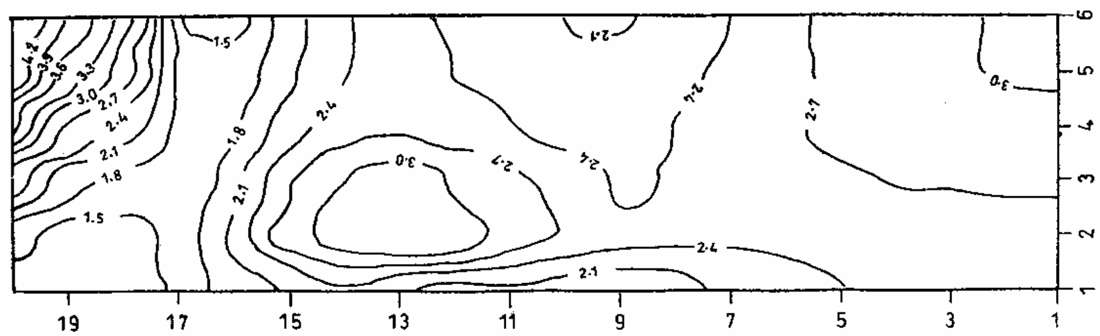
5.6 Modelled drawdown contours due to non-monsoon seasonal pumping of 90-91

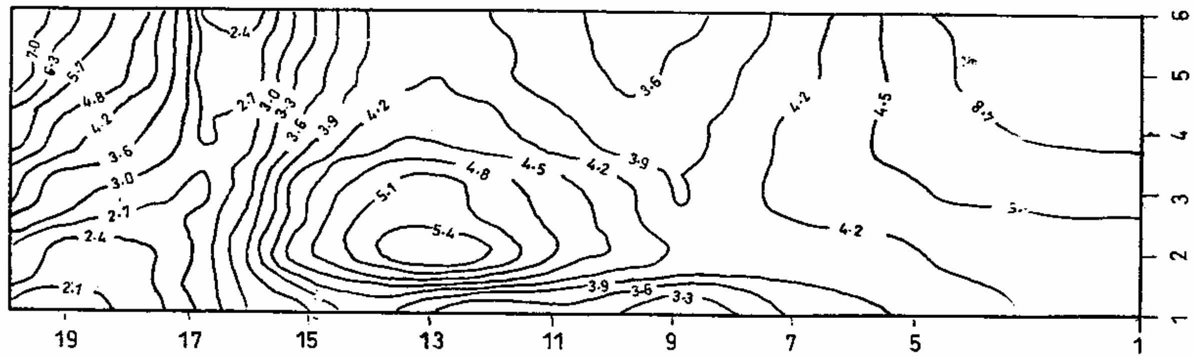




5.7 Modelled drawdown contours due to non-monsoon seasonal pumping of 91-92

5.8 Modelled drawdown contours due to non-monsoon seasonal pumping of 92-93





5.9 Modelled drawdown contours due to non-monsoon seasonal pumping of 93-94

6.0 CONCLUSIONS:

In Pennar delta canal system, which is one of the oldest canal system in the Nellore district of Andhra Pradesh, due to availability of potential alluvial aquifers farmers depend on groundwater. The recent trends of irrigation practices in the delta suggest that farmers depend more on groundwater than on surface water in some command areas due to decreasing dependability of traditional canal supplies. This is because of increasing diversions on the upstream as more areas are being brought under cultivation from time to time. A study on aquifer response modelling was undertaken for the Southern Channel command area (118 sq. km.) in the Pennar delta canal system in Andhra Pradesh to understand the potential or the dependability of groundwater supplies in the study area so that limited surface waters can be supplied to other much deserved areas. The study area is having poor network of observation wells to understand the groundwater level fluctuations in the command area. There are two OB wells recording monthly water levels under state government's Groundwater Dept., Relevant data and information at village level is used in the study.

The conjunctive use modelling at seasonal level, i.e., for water supply under canals during monsoon season and under wells during non-monsoon season is studied as a lumped model based on the water balance studies undertaken earlier for the study area. Since the area consist of a network of about 3250 filter points for agricultural use an attempt is made to simulate the drawdown due to pumping of ground water around a single well. Finally top aquifer is simulated using a finite difference method at a grid level of 1km X 1km. Pumping at different nodes is derived based on the number of filter points and extent of geographical area served by the village falling with in the grid. The aquifer parameters are adopted as those used in the water balance study for the area undertaken earlier.

Though the results couldn't be validated due to the poor network of OB wells in the study area, the procedure adopted in this study of conjunctive use modelling at seasonal level may be useful in undertaking such studies elsewhere and to formulate an operational model for conjunctive use practice of surface and ground water supplies.

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4. Dy. Director, A.P.State Groundwater Department, Nellore.

5. Chief Planning Officer, Govt. of A.P, Nellore.

REFERENCES

Bedient, P B and W C Huber, 1989: 'Groundwater Hydrology' chapter 8 in 'Hydrology of Flood Plains' Addison - Wesley publication co., Reading, Massachusetts.

CGWB, 1985: 'Hydrogeological Atlas of Andhra Pradesh' Central Ground Water Board, Southern Region, Hyderabad.

Doorenbos, J 1963: 'A literature survey of seepage in canals' Preliminary report, International Institute for Land Reclamation and Improvement, Wagenigen.

Klaatz, D.B 1971: 'Irrigation canal lining, Irrigation and Drainage' paper no.2; pp: 18-50; FAO, Rome.

Malik, Saleem, M and Pierre Strosser, 1993: 'Management of private tube wells in a conjunctive use environment', working paper no.27, IIMI, Colombo.

Mc Donald, M G and A W Harbaugh 1984: 'A modular three-dimensional finite difference groundwater flow model", open file report 83-875, U.S.D.I, U.S.G.S National Centre, Reston, Virginia.

Ministry of Agriculture, 1971: 'A Guide for estimating irrigation water requirement' Department of Agriculture, Water Management Division, New Delhi.

Moench, M. 1996 'Groundwater policy Issues and alternative in India', IIMI Country paper, India no.2, IIMI, Colombo.

MOWR, 1983: 'Recommendations of groundwater estimation committee', Ministry of water resources, Govt. of India, New Delhi.

Prickett, T.A and C G Lonnquist, 1971: 'Selected digital computer techniques for Groundwater resource evaluation', Illinois State Water Survey, Bull. 55, Urbana,Illinois.

Ray, S.P. 1994 'Status of Groundwater resources in critical/semi critical areas of alluvial/semi consolidated formations including coastal aquifers' National workshop on 'Development of Groundwater in critical and semi-critical areas: Alternatives, options and strategies', CGWB & NABARD, New Delhi.

Richard, J. Hayes et. al., 1980: 'Guide manual for preparation of water balance' Hydrologic Engineering Centre, Army corps of engineers, U.S.

Sakhthivadivel, R, D. Parker, S. Manor, 1994: 'Over view of workshop activities, Issues and recommendations' in 'Farmer management of Groundwater Irrigation in Asia; selected papers' Edited by Abhayaratna et. al., International Irrigation Management Institute, Colombo.

Trescott, P.E., G.F. Pinder and S.P. Larson, 1976: 'Finite difference model for aquifer simulations in two dimensions with results of numerical experiments' in Techniques of Water Resources Investigations, Book 7, Chapter C 1, U.S. Geological Survey, Washington, D C.

ANNEXURE -1

DRAWDOWN AT 20M INTERVAL AROUND THE 1ST QUADRANT OF A WELL

time =150.00days
the drawdown (m) array is:

1989-90
Non-monsoon draft= 51.70434 MCM

.37	.37	.37	.37	.36	.36	.35	.35	.35	.35
.38	.38	.37	.37	.37	.36	.36	.35	.35	.35
.39	.38	.38	.38	.37	.36	.36	.35	.35	.35
.40	.40	.39	.39	.38	.37	.36	.36	.36	.36
.42	.42	.41	.40	.39	.38	.37	.37	.36	.36
.45	.45	.44	.42	.41	.39	.38	.37	.37	.37
.50	.49	.47	.44	.42	.40	.39	.38	.37	.37
.56	.54	.50	.47	.44	.41	.40	.38	.38	.38
.68	.61	.54	.49	.45	.42	.40	.39	.38	.38
.94	.68	.56	.50	.45	.42	.40	.39	.38	.38

time =150.00days
the drawdown (m) array is:

1990-91
Non-monsoon draft= 48.88672 MCM

.32	.32	.32	.32	.31	.31	.30	.30	.30	.30
.32	.32	.32	.32	.31	.31	.30	.30	.30	.30
.33	.33	.33	.32	.32	.31	.31	.30	.30	.30
.35	.34	.34	.33	.33	.32	.31	.31	.30	.30
.37	.36	.36	.35	.34	.33	.32	.31	.31	.31
.40	.39	.38	.37	.35	.34	.33	.32	.32	.31
.44	.43	.41	.39	.37	.35	.34	.33	.32	.32
.50	.48	.44	.41	.38	.36	.34	.33	.32	.32
.61	.54	.48	.43	.39	.37	.35	.34	.33	.33
.86	.61	.50	.44	.40	.37	.35	.34	.33	.33

DRAWDOWN AT 20M INTERVAL AROUND THE 1ST QUADRANT OF A WELL

time =150.00days
the drawdown (m) array is:

1991-92
Non-monsoon draft= 36.33301 MCM

.11	.11	.11	.10	.10	.10	.09	.09	.09	.09
.11	.11	.11	.11	.10	.10	.10	.09	.09	.09
.12	.12	.11	.11	.11	.10	.10	.10	.09	.09
.13	.13	.12	.12	.11	.11	.10	.10	.10	.10
.14	.14	.14	.13	.12	.11	.11	.10	.10	.10
.16	.16	.15	.14	.13	.12	.11	.11	.10	.10
.19	.19	.17	.16	.14	.13	.12	.11	.11	.11
.24	.22	.20	.17	.15	.14	.13	.12	.11	.11
.32	.27	.23	.19	.16	.14	.13	.12	.11	.11
.51	.32	.24	.20	.17	.14	.13	.12	.12	.11

time =150.00days
the drawdown (m) array is:

1992-93
Non-monsoon draft= 29.47235 MCM

.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
.04	.04	.04	.04	.04	.03	.03	.03	.03	.03
.05	.05	.05	.04	.04	.04	.03	.03	.03	.03
.06	.06	.05	.05	.04	.04	.04	.03	.03	.03
.07	.07	.06	.06	.05	.05	.04	.04	.04	.03
.08	.08	.08	.07	.06	.05	.05	.04	.04	.04
.11	.10	.09	.08	.07	.06	.05	.04	.04	.04
.15	.13	.11	.09	.08	.06	.05	.05	.04	.04
.21	.17	.13	.11	.08	.07	.06	.05	.05	.04
.36	.21	.15	.11	.09	.07	.06	.05	.05	.04

DRAWDOWN AT 2:M INTERVAL AROUND THE 1ST QUADRANT OF A WELL

time =150.00days
the drawdown (m) array is:

1993-94
Non-monsoon draft= 60.72417 MCM

.54	.54	.53	.53	.52	.52	.51	.51	.50	.50
.54	.54	.54	.53	.52	.52	.51	.51	.51	.51
.55	.55	.54	.54	.53	.52	.52	.51	.51	.51
.57	.56	.56	.55	.54	.53	.52	.52	.51	.51
.59	.59	.58	.57	.56	.54	.53	.53	.52	.52
.63	.62	.61	.59	.57	.56	.54	.53	.53	.53
.68	.67	.64	.62	.59	.57	.55	.54	.53	.53
.76	.73	.69	.64	.61	.58	.56	.55	.54	.54
.89	.81	.73	.67	.62	.59	.57	.55	.54	.54
1.20	.89	.76	.68	.63	.59	.57	.55	.54	.54

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