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CONJUNCTIVE USE STUDIES IN PENNAR DELTA CANAL SYSTEM : GROUNDWATER BALANCE FOR SOUTHERN CHANNEL COMMAND AREA

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Nowadays with the increase in demand of water for competing uses, it is not only difficult to meet the entire demand from a single source but also becoming challenging to plan and distribute different water resources for proper management. In a hydrological system surface water flows, low or high, do 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 hydroclimatology of the study area alongwith hydrogeology of the region. Though practicing of conjuctive use requires collaboration between different government authorities and non - governmental organisations, scientifically and technologically sound planning is also important. Understanding and monitoring the water balance of the system very closely will help in better conjuctive use practice. 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.

The pertinent data from village level of the Southern Channel Command area of Pennar delta system in Nellore district of Andhra Pradesh is utilised and analysed to arrive at the groundwater balance of the system. In this report with a view to take up conjunctive use practice in southern channel command area of Pennar delta canal system, water balance components are estimated on seasonal basis for monsoon and non-monsoon seasons from 1989-1993. The cropwater requirements are estimated for this period to find out the system demand. Various supply and use components are accounted for the study area using suitable techniques based on the availability of observed data. From the water balance equation rainfall recharge during monsoon season is estimated to find out relationship between rainfall amount to recharge coefficient for the area.

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. Conjuctive 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 availble to meet the demands, conjunctive use of effluent water or return flows and fresh water can be practiced.

In deltas, which form an important part of coastal zone, the practice of conjuctive use must give due consideration to the sensitive equilibrium of fresh groundwater and saline sea water. 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 concerened fail to provide assured water supply to farmers forcing them to search for an alternate source. Since controls on grounwater 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 cotaminated 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 assesing 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 supllies 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 developemnt 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 CONJUNCTIVE USE PRACTICES

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 overdevelopment of this sort will be a problem near the sea coast. Withdrawls of water should be done keeping the water balance of the region in mind. In water logged areas, resulting because of excess canal irrigation, conjunctive use practice by giving suitable priority to groundwater exploitation may be a remedy.

Any conjunctive use scheme can be successful if the supporting studies are based on a reliable long term data base. 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-opearation of cultivators is mandatory requirement in a conjunctive use scheme. There should be collaboration at village level between revenue, irrigation and groundwater authorities from govenrment 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 erraneous 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.

3.0 STUDY AREA AND DATA

Pennar delta canal network system is the backbone of prosperity in the coastal Andhra region after Godavri and Krishna deltas. Pennar river originates in Chennakasava Hills, north-west 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 nortern side of Sangam Anicut and entire command is served mainly by two channels originatong from it, namely southern channel and eastern channel, whose command areas are seperared by a natural drain called Malidevi, which again takes root at Kanigiri reservoir (Fig.1).The present study is limited to the command area under southern channel and it's 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 toposheet 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.

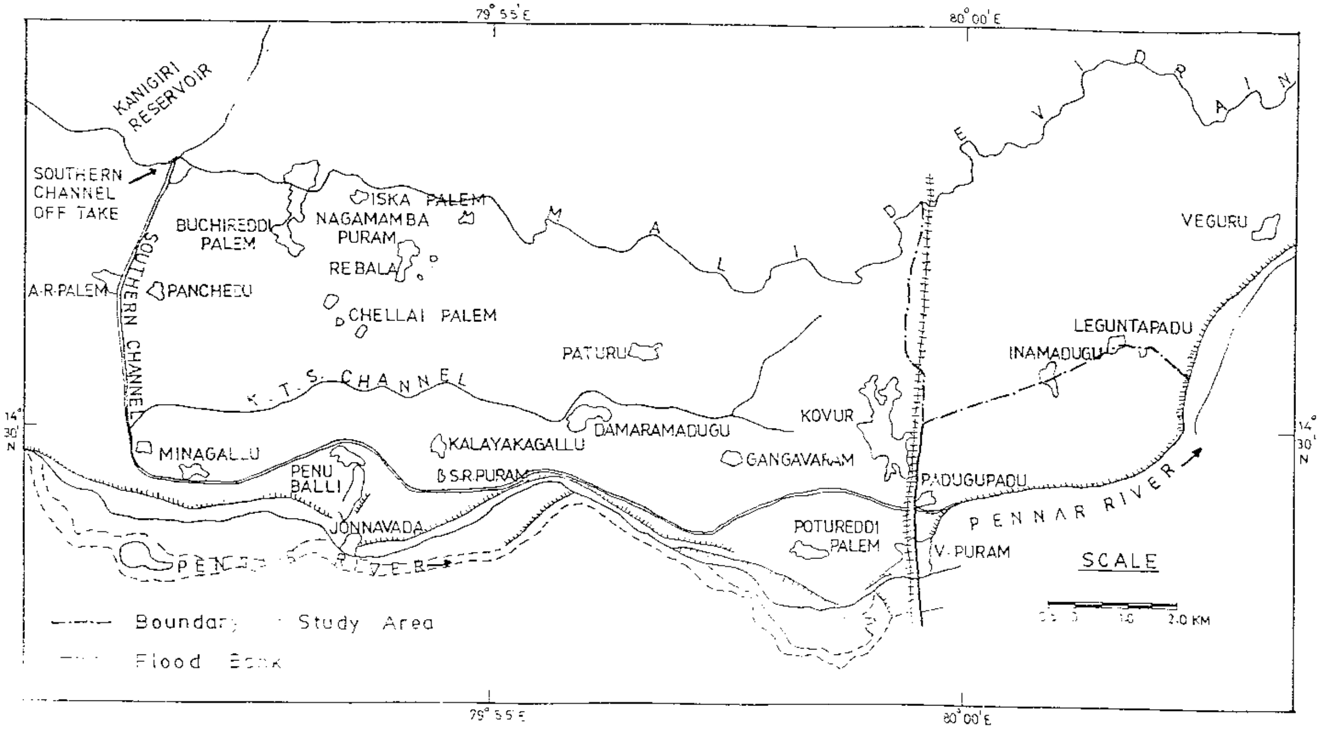

Fig.1 STUDY AREA MAP OF SOUTHERN CHANNEL COMMAND AREA OF PENNAR DELTA CANAL SYSTEM

3.1 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 coastwards, 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.

3.2 Hydrogeology

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.

3.3 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 premonsoon season; June to September - southwest monsoon season; October to November - northeast monsoon season; December to February - winter season. 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 guage 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.

3.4 Study Period

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

3.5 Cropping Pattern

There are three main cropping seasons in the area. Early khariff season starts from 15th April to 15th July and short duration paddy crop is raised under filter points and tube wells. During main khariff season from 15th September to 15th January, the predominant crop is 'MOLAGOLUKULU', a variety which 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 availabilty. 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 croopping 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.

3.6 Data

Data required for accounting different water balance components is collected from different sources and are discussed in detail.

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 delianated from toposheets provided by them. Cental Ground Water Board, Hyderabad provided well data for Kovur and Buchireddy palem. Also Cental Water Commision, Nellore is contacted for obtaining stage-discharge data of Pennar at Nellore.

4.0 METHODOLGY

Water balance study serves as a means of solution to important theoritical and practical hydrological problems. The study of water balance is defined as systematic presentation of data on the supply and use of water with in a region, basin, or command area for a specific period of time. Richard et. al (1980) prepared a manual for preparation of water balance which describe in detail the selection of parameters, boundaries, time period, and level of detail for different applications. The groundwater estimation committee of union ministry of water resources (MOWR, 1983), after making a review of various aspects has made certain recomondations for evaluating the groundwater potential of any region.

The principle of water balance or water budget states that, with in any system difference of all the supply components and use components should balance the change in storage of the system. Depending on the water resources develpoment of the system, water balance should be conducted area wise for canal water, ground water and rain water. In deltas and coastal areas, where rainfed and public lift irrigation schemes are hardly found, components of rain water balance and groundwater balance are of less importance compared to water balance components of canal water. Once conjunctive use practice of surface water and ground water commences the components of groundwater balance becomes important in areas where exclusive extraction of groundwater is expected to occur. Canal water balance should be taken up when canal water is the main source of supply supplemented by groundwater from private wells.

The hydrologic water balance for an area is carried out by estimating or calculating the water balance of individual supply components of the system and abstraction or use components of the same. Precipiatation or rainfall; stream flows; storages in tanks and reservoirs; groundwater pumpages; changes in groundwater storages; groundwater inflows; imported water; return flows are some of the supply components. Agricultural water for irrigation; municipal and commercial uses for drinking and industry; compensation releases; water rights and legal entitlements for drawing water; natural depletions through evaporation, evapotranspiration, groundwater outflows and seepages are some of the use components. Standard techniques and methods of estimating most of the components is disscussed in brief here. Some of the supply components and use components are being continuosly monitored by various State and Central Government organisations, whereas difficulties are bieng faced in estimating those components which require detailed experiments. Because of this when each experimental information is not available, a suitable emperical relation should be sought in estimating such parameters.

4.1 General

The basic concept of water balance, as mentioned earlier, is

$$\sum I - \sum O = \Delta S \qquad \text{-------------------4.1}$$

where I is input or supply components of the system, O is output or use components of the system and ΔS is change in storage of the system. The detailed input and output components for groundwater balancing are listed below and the methodologies for assessment are described.

I. Supply components:

A) Natural recharge:

1) Rainfall recharge
2) Recharge from river
3) Recharge from other basins

B. Artificial recharge:

1) Induced recharge from rivers
2) Recharge from Canals and fields
3) Recharge by injection and spreading

II. Use components:

A. Natural

1) Evapotranspiration
2) Regeneration in rivers
3) Outflow to other basins

B. Artificial

1) Groundwater draft through public and private openwells, filter points and tubewells. Some times legal aspects need to be consdidered.

Consdering various inflow and outflow components, the ground water balance can be formulated as

$$(R_i + R_c + R_r + S_i + I_g + R_t) - (E_t + T_p + S_e + O_g) = \Delta S \qquad \text{------------}4.2$$

where,

R_i = Recharge from field irrigation
R_c = Recharge from canal seepage
R_r = Recharge from rainfall
S_i = Recharge from influent seepage from river
I_g = Recharge from groundwater inflow
R_t = Recharge from tanks
E_t = Evapotranspiration from deep rooted trees and water-logged areas
T_p = Draft from groundwater
S_e = Discharge due to effluent seepage to drain
O_g = Disharge due to groundwater outflow
ΔS = Change in groundwater storage

4.2 Assessment of water balance

Different techniques of evaluating water balance components in general are discussed here.

4.2.1 Recharge from canal seepage:

Seepage refers to the process of water movement from a canal into and through the bottom and the sides. It constitutes a significant part of total recharge to aquifer system. This is more so in case of newly developed command areas compared to old systems. So one should be very careful while estimating this component. The investigations carried out in different parts by a number of organizations suggest the following ways and means of assessing seepage losses.

In Uttar pradesh, losses per million square meter of wetted area in unlined channels are considered as 2.5 cumecs for ordinary clay-loam to about 5 cumecs for sandy loam, in general, with an average of 3 cumecs. The groundwater estimation committee has recommended 1.8 to 2.5 cumecs for normal soils with clay and sands, 3 to 3.5 cumecs for sandy soils for unlined canals per million square meters of wetted area. It may be taken as 20% of the above values in case of lined canals aproximately. Empirically the seepage losses can be computed as

$$\text{Losses in cumecs/ km} = C/200 * (B+D)^{2/3} \qquad 4.3$$

where B and D are the bed width and canal depth in metres being with C=1.0 for intermittent running channels and 0.75 for constant running channels.

The canal seepage losses can be estimated by direct methods(Doorenbos, 1963; Klaatz, 1971). The general accepted method of measuring the quantities of seepage is by methods like (a) Inflow - outflow method (b) Ponding method (c) Seepage meter measurement and (d) special methods like tracers, electrical resistivity logging, piezometric surveys and nuclear techniques. The various guidelines for estimating seepage losses are at best approximate unless confirmed directly.

4.2.2 Recharge from field irrigation:

A major part of water applied to fields as irrigation is lost as consumptive use and the balance infiltrates and percolates to recharge the aquifer. The process of re-entry of a part of irrigation is termed as return seepage. Percolation from applied irrigation water derived both from surface and ground water sources constitutes one of the major components of recharge in to aquifer systems. Studies are to be conducted on experimental plots under different crops in different seasonal conditions. The method of estimation uses the water budgeting procedure at plot level. As per the Groundwater estimation committee norms, return seepage is estimated as

(a) 35% of water delivered at the outlet for application in the field in case of surface water sources. For paddy it can be upto 40 %.

(b) 30% of the water delivered at the outlet for application in case of groundwater sources. For paddy it can be upto 35%.

In all the above estimates return seepage includes losses in field channels.

4.2.3 Recharge from tanks

Studies have indicated that seepage from tanks varies from 9% to 20% of their live storage. Since records of data on live storage capacity of tanks is rarely maintained, the recharge from tanks may be taken as 44 to 60 cm per year over the total water spread, taking into account the hydroclimatic conditions in the area. The seepage from percolation tanks is higher and may be taken as 50% of its gross storage. In case of seepage from ponds and lakes, the norms sugested as above for tanks by Groundwater estimations committee may be taken.

4.2.4. Influent and effluent seepage

The stream - aquifer interaction in the study area is to be evaluated in the study area by estimating the influent and effluent seepage components, which are very important components of the groundwater balance equation. The effluent and influent seepage changes from reach to reach along the stream and from season to season during the study period. After understanding the stream - aquifer interaction, the groundwater contribution component, i.e., influent or effluent seepage is to be arrived at from accounting the stream water budget relationship, which considers discharges at upstream and downstream of reach; discharges of tributaries, flows diverted, evaporation from stream surface and flood plain; and change in bank storage. It can be observed that this requires lot of observed data which will be scarcely available. The component can be distributed to either bank depending on the gradient of water table and transmissivity of the formations of either bank.

4.2.5 Groundwater inflow or outflow

To estimate subsurface inflow or outflow of groundwater the hydraulic gradient of water table in the area and permeabilty of the formation and depth of formation are to be investigated in detail. The recharge and discharge boundaries in the study area are to bedelianated. If one wants to use isophreatic lines to arrive at the gradient the observation well network should be a well distributed one. The depth to water table of OB wells of concurrent observations is only to be used. Here comes the importance of the detailed analysis of the groundwater level data. Once satisfactory gradients are established, the inflow outflow can be determined from the following relationship

$$Q = \sum^{L} TI\Delta L \qquad \text{---------------------4.4}$$

where T is the transmissivity, I is the hydraulic gradient averaged over a length ΔL and L is the length of the recharge or discharge boundary.

4.2.6 Evapotranspiration from groundwater reservoir

Evapotranspiration is the amount of water lost to atmosphere by evaporation and that transpired through plants for their sustanance. When the evapotranspiration is from an area where water table is close to the ground surface or say up to 2 m from ground, the evaporation from soil and transpiration from plants can be at maximum possible rate or at potential rate. During well inventory, investigations should be specifically oriented towards accurately delineating water table depth at intervals of 0.3 m for depth less than 1.0 m. From lakes and marshes evaporation takes place at potental rate, i.e., at pan-evaporation multiplied by pan coefficient. For forested areas, fully grown orchards, evapotranspiration can be considered at potential rate because such trees are deep rooted and therefore have better access to groundwater.

4.2.7 Draft from groundwater

Draft is the amount of water lifted from the aquifer by means of various means and methods. The withdrawl for agriculture can be from public tube wells, private tubewells, filter points, dugwells by means of pumps fitted with electric motors or oil engines. Draft from individual well vary widely, depending on the yield, type of well, well design, depth to water table and method of lift, crops grown, land holding, climate, the original source of irrigation and soil-water management practices adopted. An inventory of wells and sample survey of groundwater draft from various types of wells are pre-requisites for computation of draft rate. Where wells are energised, power consumption data give adequate information to account draft.

Where wells are used for irrigation, agricultural statistics can be used for computation of groundwater draft for irrigation. The basic information required for this purpose is cropwise area irrigated by wells, water requirements of crops, cropping seasons, soil moisture conditions and sources of water. The water requirement is the total amount of water required at the field head to mature a crop and inculdes the amount of water required to meet evapotranspiration needs, application losses and other special needs like leaching, puddling, pre-planting irrigation etc.,. The methodolgy suggested by Ministry of Agriculture (1971), Govt. of India for estimating the monthly crop water requirement, using pan-evaporation and crop coefficient is also considered most suitable. The total cropped area available from village level statistical data can be substantiated using remotely sensed satellite information, if feasible.

4.2.8 Change in groundwater storage

The change in groundwater storage is an indicator of the long term availability of groundwater. The change in groundwater storage between begining and end of the the non monsoon season indicates that the total quantity of water withdrawn from groundwater storage and similarly, the change between the begining and end of the monsson season indicates the amount of water gone into the reservoir. Since the accumulated storage of monsoon season is utilized subsequently during non-monsoon season one should be very cautious while assessing the storage. This storage plays a very important role while formulating the conjunctive practice in the study area.

To assess the change in groundwater storage, the water levels are to be observed through a network of observation wells evenly and well spread all over and around the study area. The water levels are highest immediately after monsoon and lowest before monsoon season. In peculiar circumstances, like untimely storms along the coastal areas because of cyclones or some other specific weather phenomena this may vary and is to be duly noted while analysing the water level data. The change in storage can be computed from the follwing equation

$$\Delta S = \sum h A S_y \quad \text{-----------------4.5}$$

where, ΔS is change in storage; h is change in water level; S_y is specific yield; A is area of influence.

The specific yield may be computed from pumping test. In case if there is no pumping test data available for the area, the guidelines as suggested by the groundwater estimation committee for specific yield of different types of geological formations are

FORMATION	SPECIFIC YIELD (%)
Sandy alluvium	12 - 18
Valley fills	10 -14
Silty/ clayey alluvium	5 - 12
Granites	2 - 4
Basalts	1 - 3
Laterite	2 - 4
Weathered phyllites, shales, schist and associated rocks	1 - 3
Sandstone	1 - 8
Limestone	3
Highly karstified limestone	7

4.2.9 Rainfall Recharge

Part of rainwater that falls on the ground is infiltrated into the soil. The infiltrated water is utilized to fill the soil moisture deficiency and part of it is percolated down reaching the water table. This water reaching the water table is known as the rainfall recharge contributing to the aquifer. Recharge due to rainfall depends on various hydroclimatic, topographic, meteorological, soil characteristics and depth to water table. Rainfall recharge can be estimated using empirical relationships, or as per groundwater estimation committee norms.

Another method of arriving at rainfall recharge is from the groundwater balance equation. In this approach all the components of water balance equation are estimated, except rainfall recharge, using whatever best procedure possible as detailed above. The respective estimated values are substituted in the water balance equation, to result in rainfall recharge. A pre requisite for successful application of this technique is the availability of very extensive and accurate hydrogeological, hydrometeorological and agro-climatic data. Also the water balance approach is valid for areas which experience seasonal rainfall. Here water balance study for monsoon and nonmonsoon periods is carried our seperately. The former results in establishing rainfall recharge relationship and later determines the degree of accuracy with which the components of water balance equation have been established.

5.0 ANALYSIS

The present groundwater balance study considers the top unconfined aquifer, thus does not account for the inter flows between the aquifers in a multi aquifer system. However if sufficient data related to water table and piezometric head fluctuations and aquifer characteristics of different layers are avialble, the influence on the overall balance should be taken care off by suitably introducing more components in the balance equation. A schematic representation of water balance of the southern channel command area is shown at fig. 2. For the study area recharge due to tanks is omitted since there are practically no storage tanks existing in the study area. From the ground water table and river level data it is noted that pennar river to the south of the system is influent through out and Malidevi drain on the north is taken as effluent. The final form of the groundwater balance equation is

$$(R_i + R_c + R_r + S_i + I_g) - (E_t + T_p + S_e + O_g) = \Delta S \quad \text{-----------------}5.1$$

the components of which are explained earlier. There are so many methods to evaluate or estimate these components as discussed in previous section. In this study keeping in view the limited data and information on field experiments available for study area of southern channel command area of Pennar delta canal system in Nellore district of Andhra Pradesh, the best possible techniques and procedures are used to evaluate

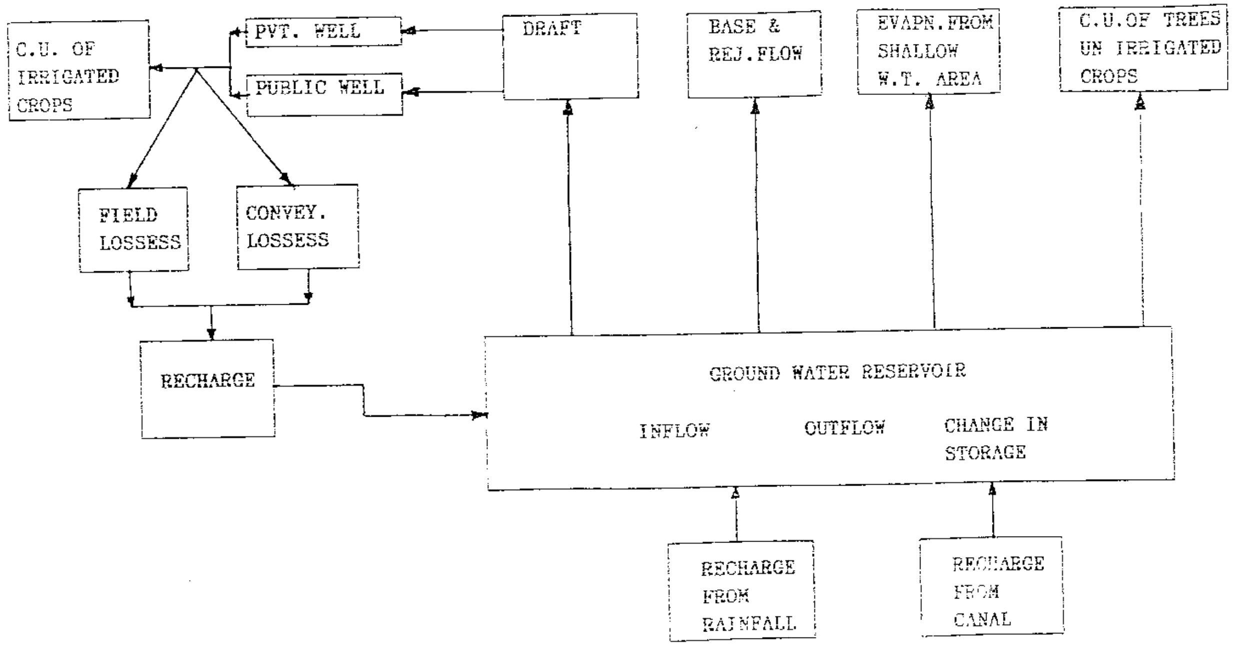

Fig. 2 Schematic Diagram for Ground Water Balance

different components of water balance over the monsoon (July - December) and non-monsoon (January - June) seasons of 1989 to 1993 to find the rainfall-recharge relationship for the region as given below.

5.1 Recharge from canal seepage

All seepage from the southern channel canal network is recharging the aquifer since entire canal network is bounded by Malidevi drain on the north and Pennar river in the south. Recharge from canal is estimated as per the guidelines of Groundwater Estimation Commitee for unlined canals in sandy alluvium. The souther channel canal network for major part of its length is unlined. The details of different branch canals, wetted perimeter are in Annexure-I. The wetted area is arrived at from considering the channel sections and their lengths. The recharge from canal network is found to be at 0.099 MCM /day. Since the records of canal running days are not available they are indirectly worked out from the total releases at head regulator and the design discharge of the channel. The estimated seasonal recharge due to canal seepage are at Table 1.

Table No.1 Recharge from canal seepage in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	7.13067	0.891334
2.	1990 - 91	3.169187	5.050891
3.	1991 - 92	2.872075	3.961483
4.	1992 - 93	2.872075	1.287482
5.	1993 - 94	1.782667	6.536447

5.2 Recharge from field irrigation

The recharge from field irrigation is estimated seperately for canal supplies and groundwater. In the study area paddy is the major crop with sugarcane grown in certain areas where farmers are encouraged by the existence of a of co-operative sugar factory at Kovur. The component is worked out from the norms of Groundwater estimation committee which account 40% of canal supplies and 35% of groundwater available at field, where paddy is the major crop. In the study, water available at field is accounted from the canal releases and the subsequent canal losses. The groundwater available at field is worked out from estimated water draft including the losses. The estimated recharge from the field irrigation is worked out and presented in Table 2.

Table No. 2 Recharge from field irrigation in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	29.12855	21.37121
2.	1990 - 91	22.13381	35.56844
3.	1991 - 92	19.56712	27.23443
4.	1992 - 93	18.21735	14.88190
5.	1993 - 94	12.46100	44.99941

5.3 Change in groundwater storage

In the study area there are three observation wells. At Buchireddi Palem OB wells are being monitored by both CGWB and State Groundwater Department. At Veguru, just outside the study area but belonging to the same system, a well is being monitored by State Groundwater Department and at Kovur a well is being monitored by CGWB. The SGWD wells are monitored monthly and are connected to mean sea level, where as CGWB wells are monitored four times in a year and are not connected. Due to the limited number of OB wells, it is rather difficult to ascertain the change in groundwater storage of the study area and one should be careful while plotting polygons water level contours. Both the techniques are attempted in this study and fluctuation of water levels are obtained as an avearge.

Since the CGWG reports mention that specific yield of the formation in the study area may vary from 0.05 to 0.20 and in the absence of any pumping test information for the study area of 118.2 km^2, a specific yield value of 0.125 is adopted in the analysis. The estimated change in storage values along with fluctuations are in Table 3.

Table No. 3 Change in groundwater storage in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	41.29613	-29.4318
2.	1990 - 91	19.34048	-15.9422
3.	1991 - 92	19.29615	-25.3244
4.	1992 - 93	20.84753	-29.4761
5.	1993 - 94	34.24845	-14.2579

5.4 Evapotranspiration from groundwater Reservoir

According to statistical information for the study area, the forest cover is spread in very limited area of 264 Ha , and there are some patches of permanent pastures, orchards and plantation gardens in an area of 1042 Ha. This information is obtained from revenue statistics and it is noted that there is not considerable change in its extent over the study period of 5 years. Evapotranspirtion is considered from these areas and is supposed to be occuring directly from the aquifer through the action of deep roots. The evapotranspiration is estimated from the Ministry of Agriculture's procedure of crop coefficient and pan-evaporation, which is also used in this study to find consumptive use of crops. The estimated losses in the form of evapotranspiration from groundwater aquifer, for the study area, are shown at Table 4.

Table No. 4 Evapotranspiration from groundwater Reservoir in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	5.04488	9.26278
2.	1990 - 91	4.74622	9.64499
3.	1991 - 92	4.57124	12.61387
4.	1992 - 93	4.90810	11.78612
5.	1993 - 94	4.98796	11.94910

5.5 Groundwater draft

Since there are no sample surveys on the draft in the study area, which is having about 3350 electricity service connections for agricultural use, and since the agricultural pumpsets were exempt from electricity charges for some years and there was slab rate system for some other period, an indirect method of assessing groundwater draft by computing crop water requirement from the available agricultural statistics at village level is adopted. The methodology recommended by the Ministry of Agriculture of Government of India was adopted which is based on crop coefficient and pan-evaporation. The pan-evaporation information recorded at Rice Research Station of A.P.Agricultural University at Nellore is used in the analysis. A computer program in Fortran, following the guidelines of Ministry of Agriculture is used to estimate the monthly water requirements of crops. Statistical information on sourcewise & seasonwise cropped area at village level is used to estimate the total crop water requirement. The canal supplies available for the study area are obtained from the records of releases at the southern channel head regulator. It is informed by the authorites that all the water is being utilised with in the system and later it is verified by a visit made upto the tailend of the channel. It is obseved that, even during the monsoon season of study period, the canal releases fell short of the total crop water requirements (Annexure-II) computed for the system which indicated that canal water supplies are no longer dependable. In the absence of crop yield information, the groundwater draft is taken as the balance between the total water requirement of the system on field and the canal supplies available. The estimated groundwater draft values are presented at Table 5.

Table No.5 Groundwater draft in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	7.202713	51.70434
2.	1990 - 91	29.807430	48.88672
3.	1991 - 92	26.327230	36.33301
4.	1992 - 93	21.903160	29.47235
5.	1993 - 94	16.884740	60.72417

5.6 Recharge due to influent seepage from river

The study area is bounded on the south by Pennar river which is the fourth biggest east flowing river of deccan plateau and traverses a distance of about 550 km while passing adjacent to study area. Though it is sesonal river some flows are being maintained even during nonmonsoon season due the leakages and low flow releases from diversion and storage structures located upstream. Also the Nellore Anicut which adjoins the study area and located at lower third of the course is being used as a pickup wier. Due to these reasons and from the observation of water level records of the Anicut and near by well at Kovur, the stream is treated as influent. The topgraphy and surface drainage also suggests slopes towards north east. The recharge is estimated from the principle of Darcy (Eq.4.4). In the absence of any pumping test information, a transmissivity value of 1685 m^2/day observed from pumping test information conducted in another area in pennar delta (CGWB, 1985) is used in the analysis. An avearage hydraulic gradient is worked out from the river levels and groundwater levels near by Kovur and Vegur observation wells and it is considered over a length of 29 km. course along the river. The estimated values of recharge due to influent flow from river are given at Table 6.

Table No. 6 Recharge due to influent seepage from river in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	13.34287	1.50358
2.	1990 - 91	2.80701	2.91337
3.	1991 - 92	1.70831	2.42612
4.	1992 - 93	5.67705	5.30943
5.	1993 - 94	12.99219	4.30911

5.7 Groundwater inflow / outfow

As mentioned earlier, the groundwater table is having a gradient towards east northeast, in accordance with the surface drainage slope. Hence the westward boundary is acting as recharge (inflow) boundary over a length of 7.0 km and eastward boundary is acting as discharge (outflow) boundary over a length of 15 km. Recharge and discharge due to groundwater flow is estimated from Darcy's principle as in the above situation. The recharge and discharge gradients are established from the Kanigiri reservoir level and water level in BR Palem well and from the water levels of BR palem and Vegur OB wells respectively. Tranmissivity value of 1685 m^2/day is considered as discused in the above section. The recharge and discharge values due to groundwater inflow or outflow, thus estimated, are presented in Table 7 and Table 8 respectively.

Table No. 7 Groundwater inflow in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	7.27912	6.827620
2.	1990 - 91	6.64977	6.361200
3.	1991 - 92	6.13753	6.534510
4.	1992 - 93	6.71481	5.700158
5.	1993 - 94	7.42672	5.947850

Table No. 8 Groundwater outfow in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	3.261675	2.963275
2.	1990 - 91	2.900800	3.156350
3.	1991 - 92	3.164500	2.975425
4.	1992 - 93	3.134800	3.055250
5.	1993 - 94	3.195175	3.011725

5.8 Discharge due to effluent seepage to drain

The study area is bounded on the north by Malidevi drain mainly receiving irrigation return flows from the command areas of Southern channel and Eastern channel. It is acting as effluent stream all along the course adjoing the study area. Since there are no records on the water level and discharge at any point on the drain the discharges into the drain could not be established. The observation well network also was insuficient to esablish this. Hence an empirical relationship, which considers 5% of the rainwater and canal water coming into the system as outflow to drain, is adopted. The estimated effluent seepage to the drain, thus accounted, is presented in Table 9.

Table No. 9 Discharge due to effluent seepage to drain in MCM

Sl. no.	Year	Monsoon	Non-monsoon
1.	1989 - 90	7.577782	2.644964
2.	1990 - 91	7.340093	4.654593
3.	1991 - 92	9.006022	2.064958
4.	1992 - 93	6.681630	0.779460
5.	1993 - 94	8.073783	3.413529

6.0 RESULTS AND DISCUSSIONS

The components of the groundwater balance for the southern channel command analysed are assembled in the water balance equation to arrive at the rainfall recharge for the region.

6.1 Establishing Rainfall Recharge

Groundwater balance is a convenient way of establishing the rainfall recharge. The study area is demarcated so that a control on the boudaries is possible and boundary conditions are well defined. The study period of 5 years from 1989 to 1993 is divided into monsoon (July - December) and non-monsoon seasons (January - June). The components of water balance of importance to the study area based on boundary conditions are decided first. Except rainfall recharge all the components are estimated with the best possible technique for the entire study period for both the seasons. The entire water balance for the study area is shown in Table 10. Rainfall recharge for monsoon season is acconted for all the years by substituting these equations in the water balance equation adopted for the study area. Recharge coefficient is calculated as the ratio of rainfall recharge to rainfall. The computed rainfall recharge

Table : 10 Ground water balance for the Southern Channel Command area (in MCM)

No.	Component	1989 - 90		1990 - 91		1991 - 92		1992 - 93		1993 - 94	
		M	NM	M	NM	M	NM	M	NM	M	NM
1.	Recharge from canal seepage	[illegible]	0.891334	3.169187	5.050891	2.872075	3.961483	2.872075	1.287482	1.782667	6.536447
2.	Recharge from field irrigation	29.12855	21.37121	22.13381	35.56844	19.56712	27.23443	18.21735	14.8819	12.461	44.99941
3.	Change in ground water storage	41.29613	-29.4318	19.34048	-15.9422	19.29615	-25.3244	20.84753	-29.4761	34.24845	-14.2579
4.	Evapotranspiration from ground water reservoir	5.04488	9.26278	4.74622	9.64499	4.57124	12.61387	4.9081	11.78612	4.98796	11.9491
5.	Ground water draft	7.202713	51.70434	29.80743	48.88672	26.32723	36.33301	21.90316	29.47235	16.88474	60.72417
6.	Recharge due to influent seepage from river	13.34287	1.50358	2.80701	2.91337	1.70831	2.42612	5.67705	5.30943	12.99219	4.30911
7.	Ground water inflow	7.27912	6.822762	6.64977	6.3612	6.13753	6.53451	6.71481	5.700158	7.42672	5.94785
8.	Ground water outflow	3.261675	2.963275	2.9008	3.15635	3.1645	2.975425	3.1348	3.05525	3.195175	3.011725
9.	Discharge due to effluent seepage to drain	7.577782	2.644964	7.340093	4.654593	9.006022	2.064958	6.68163	0.77946	8.073783	3.4113529
10.	Rainfall Rechare (M)	7.501967	-------	29.37525	-------	32.08011	------	23.99392	------	32.72753	------
11.	Rainfall amount	77.11368	43.72218	114.0275	41.33454	151.0478	0.60282	104.0633	2.74124	143.1166	1.64708
12.	Recharge Co-efficient (M)	0.097285	------	0.257615		0.212384		0.230571	------	0.228677	---------
13.	Unaccounted Water (NM)	-----	-6.54981	------	-0.50653	-----	11.49363	---	11.56191	------	-3.04783

(M is for Monsoon season and NM is for Non-Monsoon season) from water balance, the amount of rainfall and the recharge coefficient for monsoon season are presented in Table 11. Curves are plotted for rainfall vs recharge (Fig. 3) and rainfall vs recharge coefficient (Fig. 4) for monsoon season. A parabolic equation is fitted for the rainfall -recharge coefficient which is shown in Fig. 4.

For non-monsoon season, all the components of water balance equation are estimated. Here the rainfall recharge is estimated using the relationship developed as per Fig. 4. Most of the times during nonmonsoon season the rainfall recharge is neglible because of small amount of rainfall. The amount of unaccounted water, which is the difference of all the inflow components to outflow components, will give the the degree of accuracy. From Table 10., the unaccounted water during the nonmonsoon season is found to be in acceptable limits.

Table No. 11 Rainfall Recharge in MCM

S.No.	Year	Rainfall	Recharge	Recharge Coeff.
1.	1989-90	77.11368	7.501967	0.097285
2.	1990-91	114.02750	29.375250	0.257615
3.	1991-92	151.04780	32.080110	0.212384
4.	1992-93	104.06330	23.993920	0.230571
5.	1993-94	143.11660	32.727530	0.228677

7.0 CONCLUSIONS AND RECOMMENDATIONS

Water balance approach is essentially a lumped model study and is a viable method of establishing the rainfall recharge coefficient and for evaluating the methods adopted for the quantification of inflows and outflows or recharges and discharges of a system. Its importance will be more so where a single source can not cope up with the demand. Hence in adopting any conjunctive use practice, accounting of the components of water balance is very important.One should be very cautious in estimating different

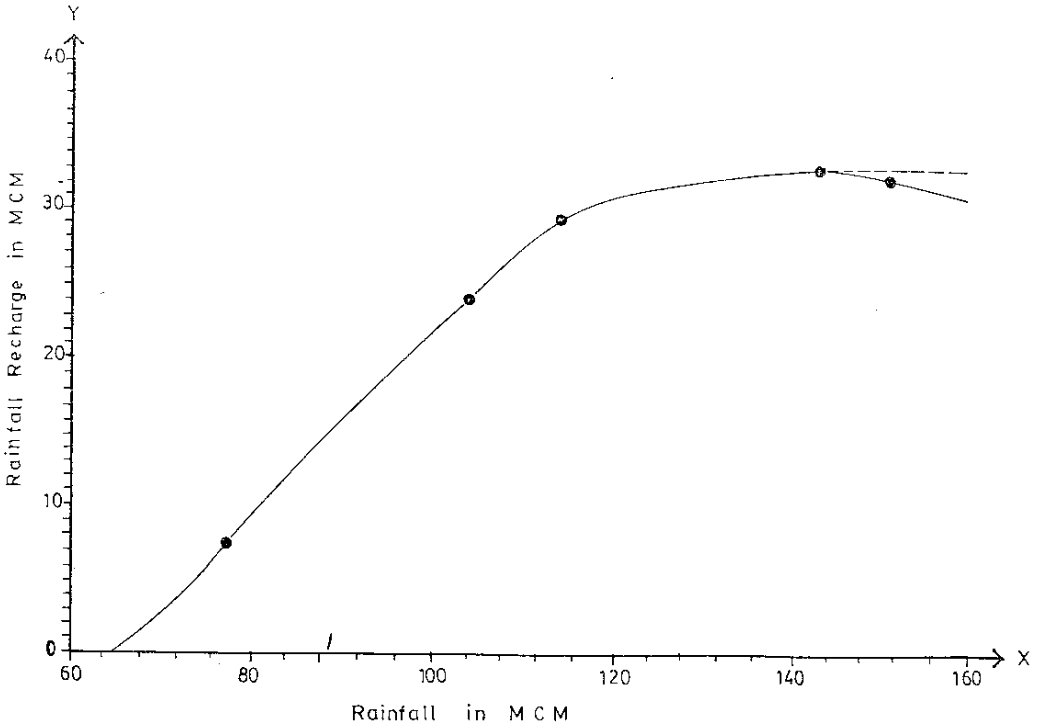

Fig.3

RAINFALL RECHARGE SOUTHERN CHANNEL COMMAND

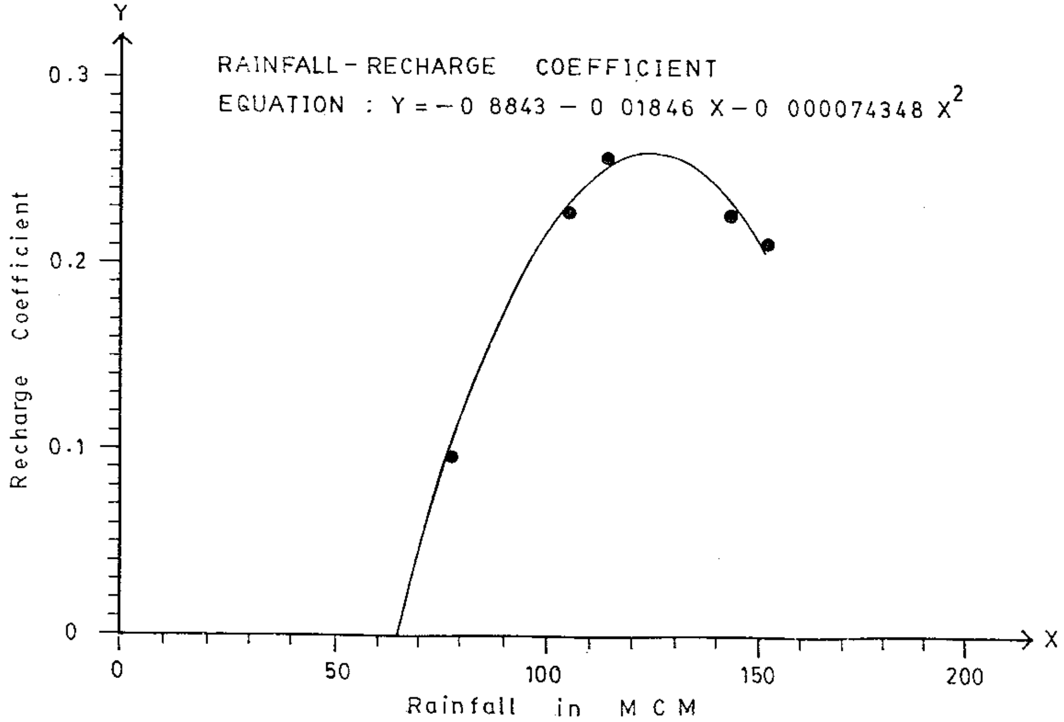

Fig.4

GRAPH PLOT FOR RAINFALL - RECHARGE COEFFICIENT FOR SOUTHERN CHANNEL COMMAND AREA components of water balance and efforts should be made to use the best possible technique.

Water balance studies will facilitate in estimating the rainfall recharge of the study area. As part of conjunctive use studies, in Pennar delta canal system, seasonal rainfall recharge is estimated using water balance technique for the southern channel command area. For this all the inflow and outflow components of water balance equation 5.1 are estimated using the methods and procedures as suggested in earlier sections. Change in groundwater storage is one of the sensitive components, to arrive at which knowledge of specific yield of the aquifer is very important alongwith the groundwater level fluctuation. The results have shown that in coastal areas which experience occasional cyclonic precipitation, often unpredictable in its intensity, one should be cautious before arriving at a relationship of rainfall-recharge, even on seasonal basis. The line drawn for recharge Vs rainfall in fig.3 is dipping for very high amount of rainfall. Whereas, normally, recharge become constant for high amount of rainfall as shown with dashed line in fig.3. It is, therefore, very difficult to arrive at rainfall recharge during a season where events of intense cyclonic precipitation are recorded. One has to conduct water balance at much finer interval, which account for each such event to evaluate the rainfall recharge much reliably. This is because during cyclonic precipitation, there is possibility that entire precipitation may flow out as unaccounted surface runoff, especially if the study area is small. Hence one should be careful in selecting the study period so that the seasonal precipitation can be adjusted for such peculiarities by suitable techniques, before evolving at typical rainfall-recharge relationship for the study area.

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Annexure -I

PARTICULARS OF CANALS UNDER SOUTHERN CHANNEL

S.No.	Canals	Length (m)	wetted Perimeter(m)
1.	N-8 Branch of Gudipalli channel at 0-1-264 (L)	3.50	2.55
2.	Gudipalli channel at 0-2-66 (L)	5.95	2.76
3.	Nagamambapuram channel	5.50	2.09
4.	Kandrika Sluice at 0-3-462 (L)	0.70	2.34
5.	Central channel at 0-3-462 (L)	15.26	4.97
6.	Padava channel at 2-7-330 (L)	2.52	2.64
7.	Kovur tank supply channel at 3-2--264 (L)	12.04	6.19
8.	Zonnavada Kandriga Channel Sluice at 5-1-264 (R)	0.32	2.03
9.	Lingareddy Channel Head Sluice at 5-5-264 (R)	0.32	2.33
10.	Damaramadugu Minor Channel at 7-7-330(L)	4.05	2.51
11.	Gannavaram Minor Channel at 9-4-528 (R)	2.22	2.33
12.	Pothi Reddy Minor Channel Head Sluice at 1-2-198(R)	6.08	2.03
13.	Veguru Tank Supply Channel Head Sluice at 13-5-0 (L)	7.09	2.51
14.	Inamadugu Minor Channel Head Sluice at 14-4-0 (L)	1.65 3.42 0.25	2.73 2.73 2.73
15.	Leguntapadu Minor Channel Head Sluice at 14-5-0 (L)	4.05	2.64
16.	Zammipalem Channel Head Sluice at 14-5-199 (L)	3.99	1.90
17.	Southern Channel	22.87	10.33

Annexure-II

Seasonwise Canal Releases of Southern Channel and Estimated Crop Water Requirement in the Command Area (in MCM)

S.No.	Year	Monsoon		Non-monsoon	
		Canals releases at head regulator	Estimated crop-water requirement	Canals releases at head regulator	Estimated crop-water requirement
01	1989-90	74.44196	80.11359	9.177106	55.55364
02	1990-91	32.77433	67.62124	51.75731	89.36306
03	1991-92	29.07266	58.52449	40.69634	66.11074
04	1992-93	29.56932	54.40700	12.84697	29.48632
05	1993-94	18.35911	37.08051	66.62760	125.49886

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