CS - 117

SEASONAL GROUNDWATER BALANCE STUDY IN CENTRAL GODAVARI DELTA ANDHRA PRADESH (PART II)

आपो हि ष्ठा मयोभुवः

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PREFACE

Groundwater has assumed a critical importance to meet the everincreasing domestic, industrial and agricultural growth needs of our country. As per the norms of G.W Estimation Committee (March 1984), the total replenishable groundwater resources of the country have been estimated as 45.22 m ha m, of which 38.28 m ha m is meant for irrigation purpose. The present draft is 10.65 m ha m, leaving a balance of 27.63 m ha m available for exploitation.

History shows that the usual practice in ground water development and utilisation has been to treat the problems and initiate the action programmes on an individual and piecemeal basis. This has resulted in the over exploitation of groundwater in certain pockets leading to progressive decline in water table, shortage in supply and sea water intrusion in coastal areas. On the other hand, the excessive seepage from intensive irrigation and poor subsurface drainage in certain canal command areas have given rise to water logging and salinity problems. Development of ground water resources is , therefore, required to be backed up by proper management strategies.

The water balance study serves as a means of solution to important theoritical and practical hydrological problems. On the basis of water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system. Hence, such studies are very important for understanding the behaviour of the hydrologic system and working out the strategies for development and management of water resources of a river basin.

The Central Godavari Delta in East Godavari District of Andhra Pradesh experiences the sea water intrusion and the ground water quality is continuously getting deteriorated. With a view to analyse this problem, the ground water balance study has been carried out in the Central Godavari Delta. The study aims at identification and quantification of various components of groundwater balance and thus to understand the influence of various components and behaviour of the aquifer system under their dynamic changes.

The present ground water balance study has been divided into two parts. the first part pertains to the collection and processing of various relevant data required for carrying out the ground water balance. The present report forming Part II of the study deals with the methodologies adopted for quantification of various components and their quantification. The seasonal ground water balance for monsoon and non-monsoon seasons has been prepared and presented in the report.

The report has been prepared by Sri J V Tyagi, Scientist 'C'. The technical assistance during course of data analysis was provided by Sri T Thomas, SRA and Sri T Vijay, RA. The overall guidance for conducting the study was provided by Dr P V Seethapathi, Scientist 'F'.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Groundwater balance studies are effected in order to ascertain the quantity of water available for development in a region and this can be done only after identification of the various physical features of the hydrologic system involved, their hydraulic characteristics and their hydraulic interrelationships. Clearly, after the groundwater system is fully understood the results can be combined with data regarding the amounts of water transitting the stream network in the relevant region as well as precipitation in it in order to furnish the basis of water balance analysis.

The water balance study has been undertaken in the Central Godavari Delta in East Godavari District of Andrha Pradesh. Being a coastal region, the deterioration in groundwater quality in the study area has been observed over a period of time due to sea water intrusion. This calls for the hydrologic analysis of the groundwater system in Central Godavari Delta. The present study has, therefore, been carried out to identify and quantify the various component processes of the ground water balance and thus to understand the influence of various components and behaviour of the aquifer system under their dynamic changes.

Based on the available data, the seasonal ground water balance for monsoon (June to October) and non-monsoon (November to May) seasons have been worked out for a period of 9 years i.e from 1981-82 to 1989-90. The various components of groundwater balance were identified and evaluated adopting the methodologies

as explained in the report. The recharge from rainfall for different years of study has been estimated during monsoon seasons using water balance approach. The amounts of unaccounted water have also been calculated during non-monsoon seasons.

The groundwater quality data have been analysed and the area under different ranges of TDS values worked out and presented in the report.

1.0 INTRODUCTION

1.1 General

Groundwater has assumed a critical importance to meet the ever increasing domestic, industrial and agricultural growth needs of our country. India is a vast country having diversified hydrogeological settings; variations in the nature and composition of the rock types, the geological structures, geomorphological features and hydrometerological conditions have correspondingly given rise to widely varying ground water situations in different parts of the country. Detailed surveys, exploration and resource evaluation studies, and proper planning of its development, management and conservation are essential for a safe and optimal utilisation of this vital resource of the country.

Based on the norms recommended by the 'Groundwater Estimation Committee' (March 1984), the total replenishable ground water resources of the country have been estimated as 45.22 m ham, out of which 6.94 m ham have been kept for drinking, industrial and other committed uses and the remaining 38.28 m ham of utilisable ground water resources are meant for irrigation purpose. The present draft is 10.65 m ham, leaving a balance of 27.63 m ham of groundwater resources available for exploitation.

Thus, when seen for the country as a whole there is considerable ground water still required to be developed. However, when viewed from micro level angle, there are pockets where intensive development has led to rather critical situations and manifestation of problems like declining ground water levels, shortage in supply, ingress of sea water in the coastal areas etc. On the other hand, in many major canal command areas, the water table is progressively rising because of excessive seepage from surface irrigation and poor sub-surface drainage leading to the creation of water logging and salinity problems. Therefore, there is need for planned integrated development of surface and groundwater resources and their scientific management.

While planning for the development and management of a groundwater basin, it is to be ensured that a balance exists between the recharge to and discharge from the basin and the ground water levels fluctuate within a particular range over the monsoon and non-monsoon seasons. This is best achieved by conducting the ground water balance of the basin. The ground water balance study serves as a means of solution to various important theoretical and practical hydrological problems. On the basis of water balance approach, it is possible to make a quantitative evaluation of water resources and the impact of man's activities on the hydrologic cycle.

The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specific period. The water balance or hydrologic balance of any ground water basin establishes that all waters entering the basin during any given period of time must either go into storage within its boundaries, be consumed or flow out during that period. Clearly, the items of inflow and outflow (or recharge and discharge) can include a number of components depending on the geographic and hydrologic features of the basin.

These various components of inflow, outflow and change in storage are evaluated using proper methodologies and the water balance obtained for the ground water basin.

Knowledge of water balance assits prediction of the consequences of artificial changes in the regime of ground water basins. In coastal areas where sea water intrusion is a common problem, the quantity of fresh water storage in the basin aquifers can be assessed by accomplishing the ground water balance. With water balance data, it is possible to compare individual sources of water in a system over different periods of time and to establish the degree of their effect on variations in the water regime. Further, the intial analysis used to compute individual water balance components and the co-ordination of these components in the hydrologic balance equation make it possible to identify deficiencies in the distribution of observational stations and discover systematic errors of measurements. Finally, water balance study enables evaluation of one unknown component of water balance from all other known components.

1.2 Statement of the Problem :

The sea water intrusion is a common problem in groundwater basin/ aquifers in coastal areas. The extent of sea water intrusion depends upon the exploitation of ground water in excess of its recharge capability. The ground water quality is badly affected due to salt water intrusion and the aquifer system once get polluted becomes rather difficult to reclaim. In order that the aqufier system is maintained and preserved without getting polluted, proper management strategies are to be adopted. For evolving suitable management strategies, it is necessary to understand the hydrological behaviour in the coastal areas.

The Central Godavari Delta in East Godavari Dist. of Andhra Pradesh is a very fertile and rice growing area. The entire area is irrigated through a network of canals and field distribution system. Though there is no heavy ground water draft in the area and borewells are used mostly for drinking purpose, the quality of ground water has deteriorated over a period of time. If this trend continues, a situation may arise when the wells can not be used for drinking water purpose. This deteriorating water quality in the Central Godavari Delta is a matter of great concern and calls for the analysis of the problem.

Keeping the above in view, the seasonal ground water balance has been carried out for the Central Godavari Delta. The main aim of the study is to identify and quantify the various component processes of the ground water balance and thus to understand the influence of various components and behaviour of the aquifer system under their dynamic changes. The study has been carried out for monsoon and non monsoon seasons for a period of 9 years i.e. 1981-82 to 1989-90. Based on the estimates of various components, the rainfall-recharge coefficients during monsoon seasons are also established.

1.3 Presentation of the Study:

The present study has been divided into two parts. The first part pertains to the collection and processing of data and the report titled 'Ground Water Balance Study in Central Godavari Delta of Andhra Pradesh - Processing and Analysis of Data, Part I' has already been brought out. The report deals with the description of the study area, data required, collection and processing of data and identification of various components of water balance in the Central Godavari Delta. The present report forming Part II of the study deals with the methodologies adopted for the quantification of various ground water balance components and their quantification. All other components except rainfall recharge have been estimated independently and the rainfall recharge during monsoon season is estimated using water balance approach. The ground water balance for monsoon and non monsoon seasons for 9 years (1981-82 to 1989-90) is presented in the report. The reasons for deteriorating ground water quality are also analysed in the present report.

1.4 Study Area :

The detailed description of the study area is given in the Part I of the study report. However, for ready reference purpose, the salient details of the study area are briefly given in the following paragraphs.

The study area forms a part of the Delta System of the river Godavari in East Godavari District of Andhra Pradesh. Geographically the study area of Central Godavari Delta is located between 16° 25' to 16° 55'N latitude and 81° 44' to 82° 15'E longitude with its hydrological boundaries as river Gowthami Godavari in the East, river Vasistha Godavari and its branch, Vainateya in the West and Bay of Bengal in the south. The location of study area is shown in Fig 1.1. The total geographical area under study measures to about 825 sq kms, covering partly or fully 11 Revenue mandals of East Godavari District.

The area receives more than half of its annual rainfall during south west monsoon (i.e. June to September), while a large portion of rest occur in October and November. The normal annual rainfall of the district is 1142 mm. The area is prone to frequent cyclones and floods. The climate of the study area is comparatively equitable. The mean maximum temperature varies between 35°C to 37°C during summer and mean minimum temperature varies between 19°C to 21°C during winter.

The study area consists of rich alluvial plains formed by river Godavari. It has a very gentle land slope of about 1m per km. The coastal line along the study area measures to about 40 km and the general elevations vary from about 2m near the sea to about 13 m at upper reach. The topographical map of the study area is given in Fig 1.2 Texturally, a major part of the study area consists of sandy loams and sandy clay loams. The entire area is under the command of the Godavari Central Canal system. The canal network is uniformly distributed in the study area with a main canal, three branch canals, one distributary and several field channels. The canal system remains operational for 11 months with a closure period of one month during April-May. Lift irrigation is also adopted at higher reaches. The map showing canal network in the study area is presented in Fig 1.3. The ground water draft from borewells is not much as these are used for irrigating small areas under various minor crops and for drinking water purpose.

Paddy is the main crop in both the seasons in the study area. Besides, banana and coconut are also the principal crops. Other crops like cereals, millets, sugarcane and vegetables are also grown in the study area. There are no forests as such.

Since the Bay of Bengal forms the southern boundary of the study area, salt water intrusion problem is observed in the area. The TDS values of ground water in the wells located near the two arms of river Godavari are quite high, while a reducing trend in TDS values is observed in the wells located away from the rivers.

1.5 Collection and Processing of Data :

A variety of data pertaining to various hydrologic aspects of the study area were collected from different Govt. Depts , such as A P State Ground Water Dept, Irrigation Dept, Agriculture Dept, and the Statistics Dept. These data were processed and presented in Part I of the study reports. A brief review of available data is presented below.

1. Topographical map of the study area (fig 1.2)
2. Map showing canal network in the area (fig 1.3)
3. Map showing location of rain gauges (fig 1.4)
4. Map showing location of observation wells (fig 1.5)
5. Monthly rainfall data of rainguage stations
6. Monthly ground water levels in observation wells.
7. Canal discharge data
8. Length, cross-sections and other design details of main canal, branch canals and distributaries and their command areas.
9. Yearwise number of wells/tubewells in the study area
10. Stage and discharge data of river
11. Land use pattern data
12. Cropping pattern data
13. Data on geology and aquifer characteristics
14. Data on potential evapotranspiration, and other climatic data
15. Ground water quality data for the study area.

INDEX MAP

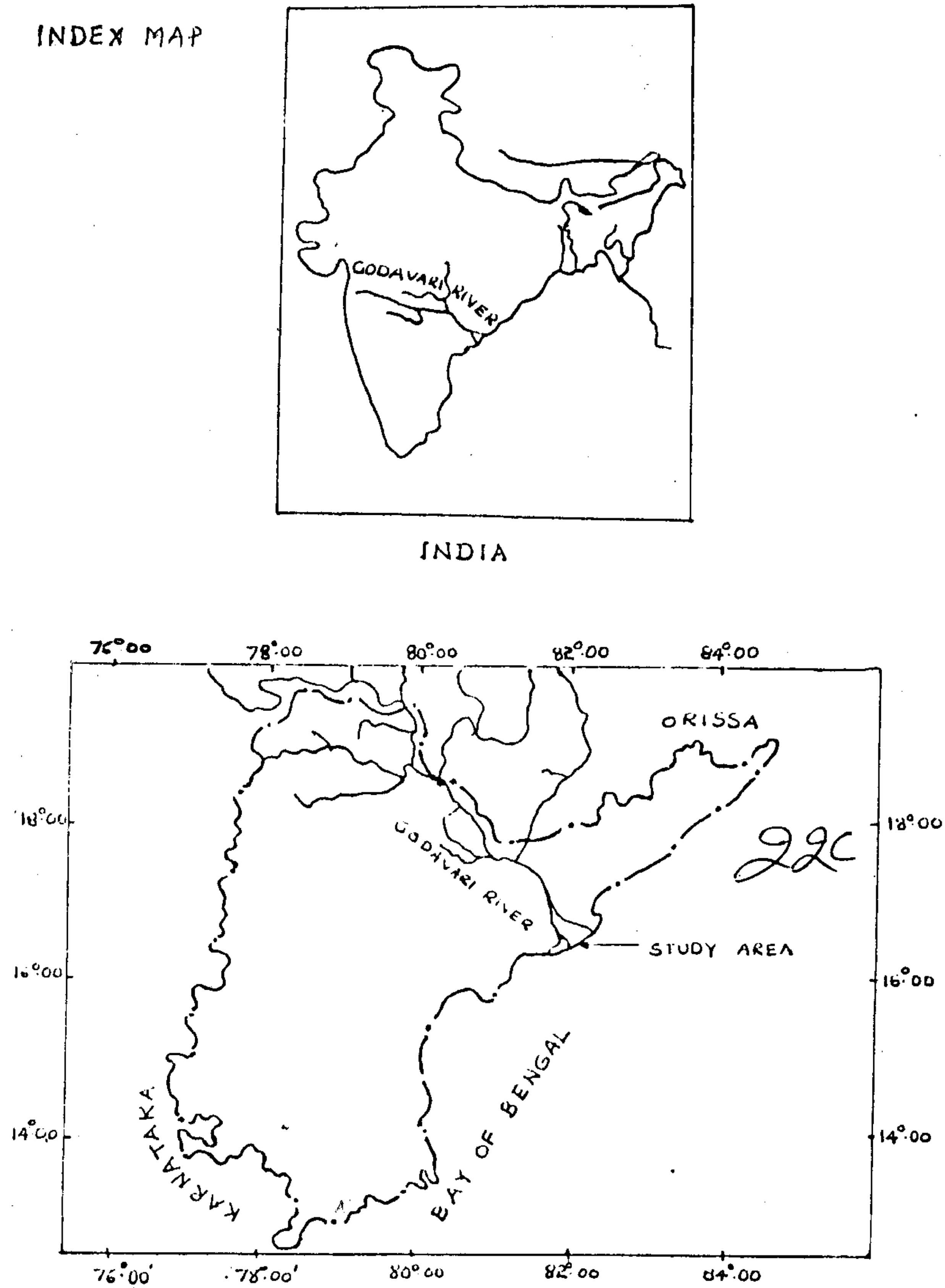
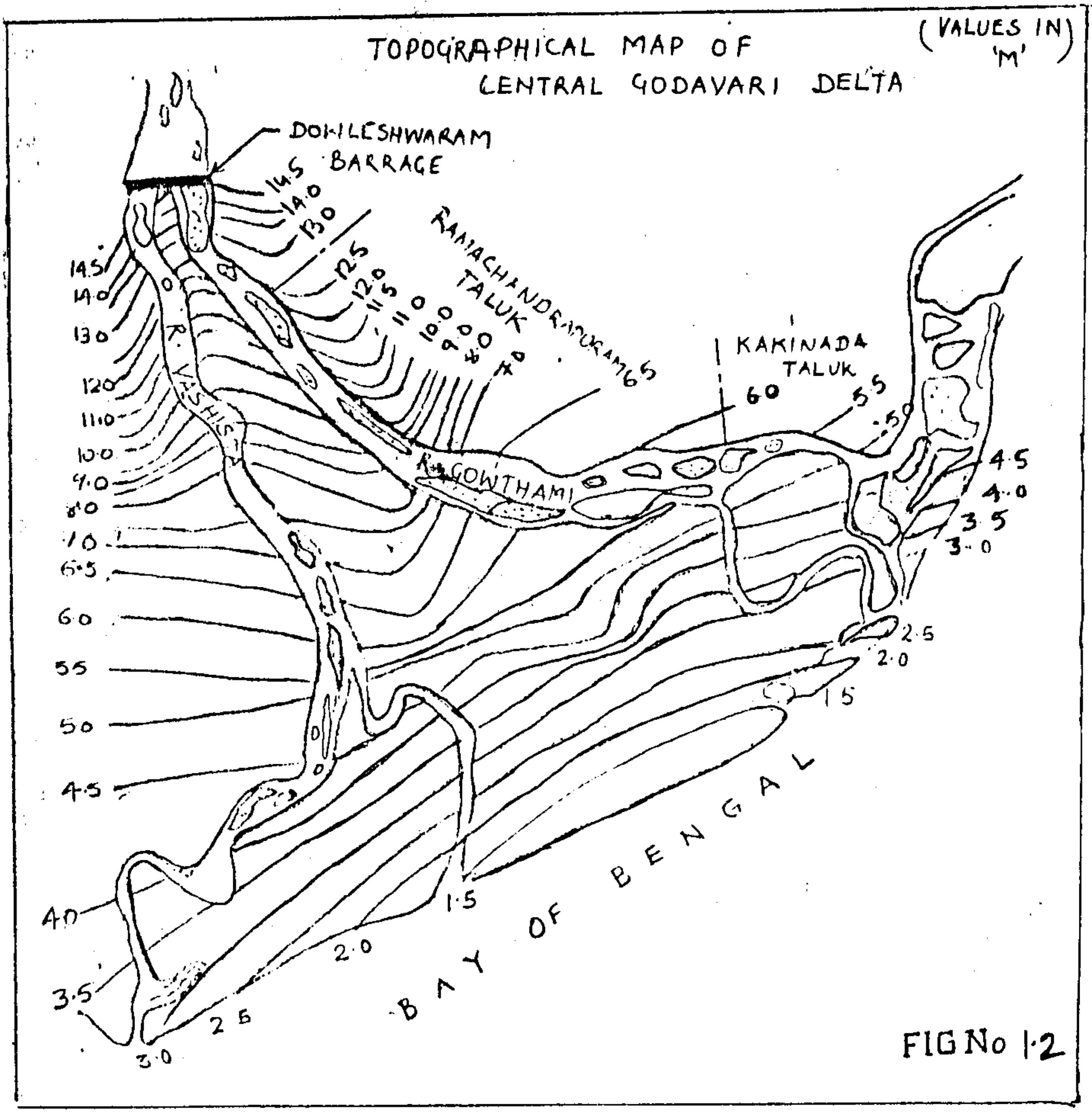


FIG.No. 1.1



TOPOGRAPHICAL MAP OF CENTRAL GODAVARI DELTA

FIG No 1.2

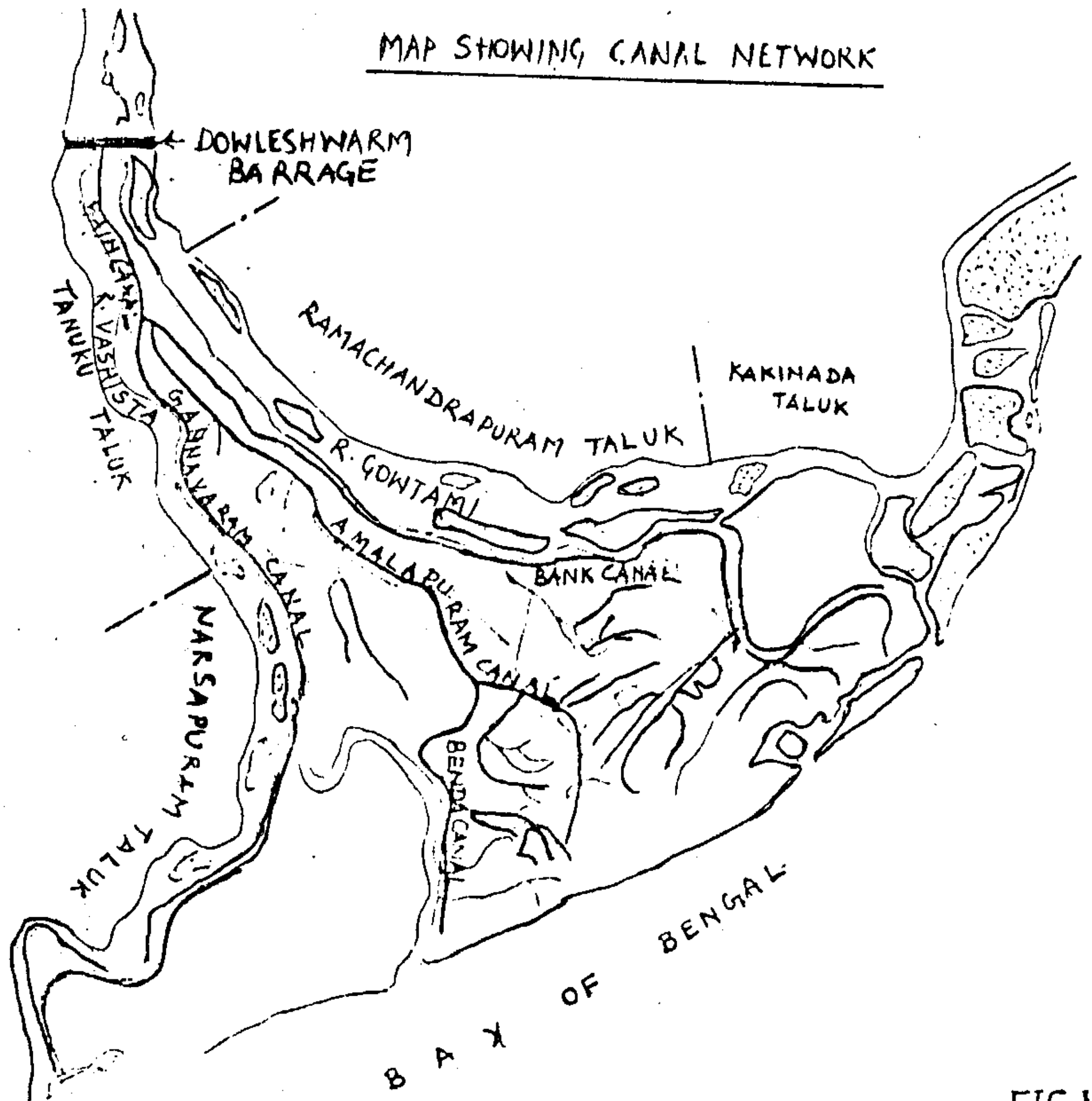

MAP SHOWING CANAL NETWORK
DOWLESHWARM BARRAGE
RAMACHANDRAPURAM TALUK
KAKINADA TALUK
TANUKU TALUK
R. VASHISTA
R. GOWTAMI
GANNAVARAM CANAL
AMALAPURAM CANAL
BANK CANAL
BENDA CANAL
NARSAPURAM TALUK
BAY OF BENGAL

FIG No. 1·3

MAP SHOWING LOCATION OF RAINGUAGE STATIONS

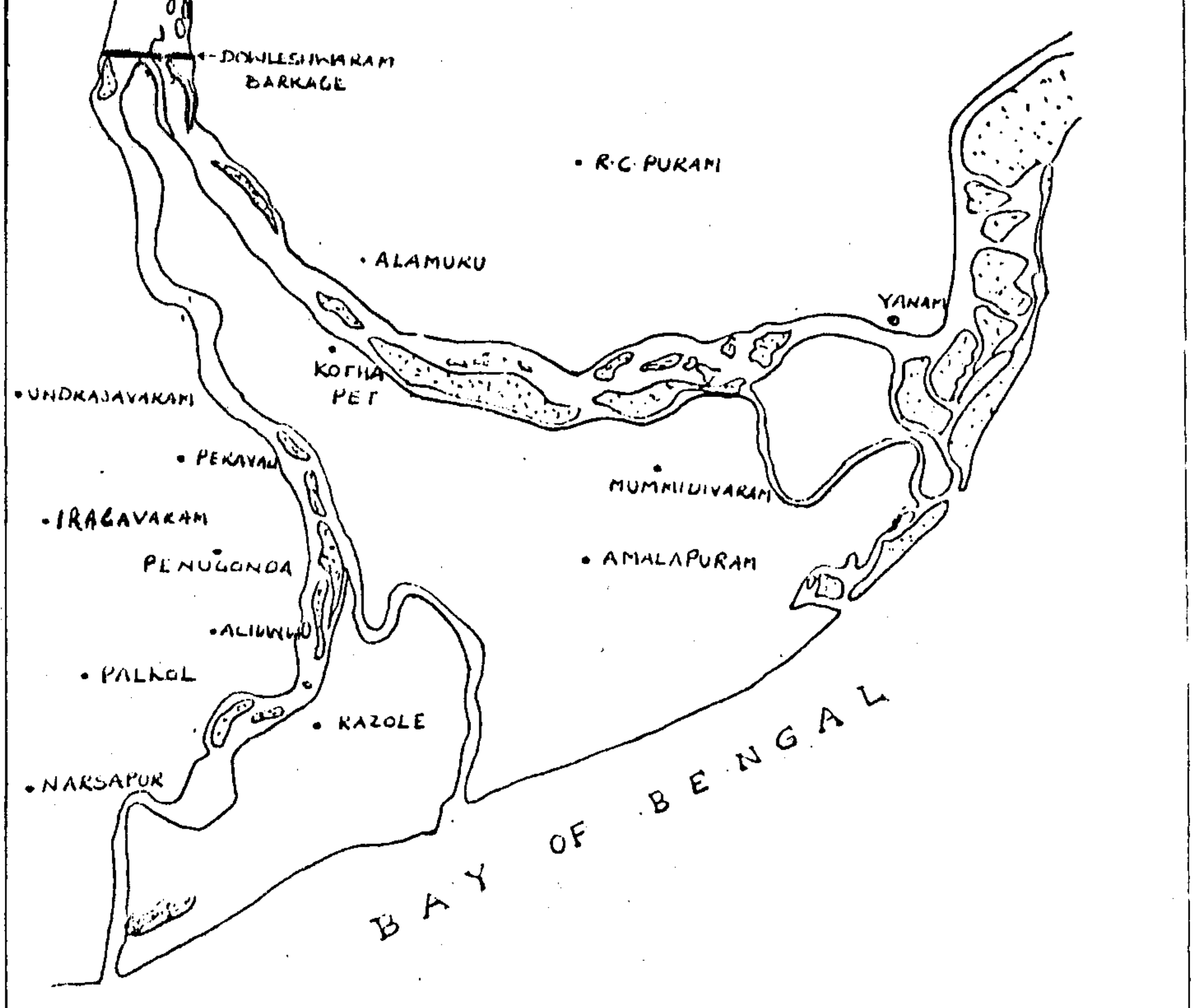


FIG No. 1.4

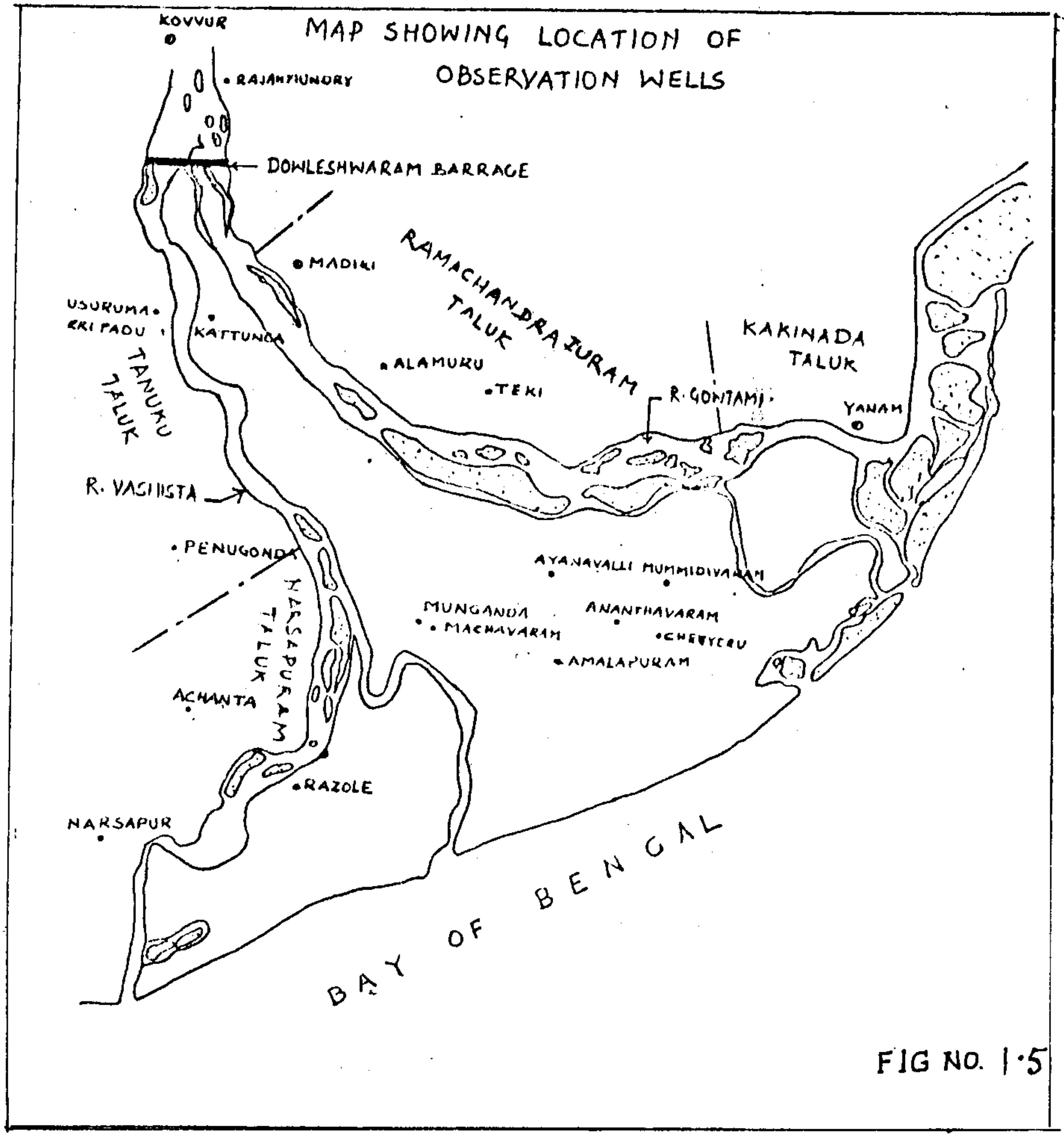

MAP SHOWING LOCATION OF OBSERVATION WELLS
KOVVUR
DOWLESHWARAM BARRAGE
RAMACHANDRAPURAM TALUK
MADIKI
ALAMURU
TEKI
R. GONTAMI
KAKINADA TALUK
YANAM
TANUKU TALUK
R. VASHSTA
PENUGONDA
AYANAVALLI
MUMMIDIVARAM
MUNGANDA
MACHAVARAM
ANANTHAVARAM
AMALAPURAM
NARSAPURAM TALUK
ACHANTA
RAZOLE
NARSAPUR
BAY OF BENGAL

FIG NO. 1·5

2.0. METHODOLOGY FOR ESTIMATION OF GROUNDWATER BALANCE COMPONENTS

2.1. General

The water balance study is carried out to evaluate the net available water resources and to assess the existing water utilisation pattern to plan optimal and efficient management of water resources. The water balance is a statement of the conservation of matter applied to a ground water basin. All waters entering an area during any given period of time must either go into storage within its boundaries, be consumed or flow out during that period. This basic concept of water balance can be expresses as below.

$$I = O + \Delta S$$

where, I = inflow to the system
O = outflow, and
ΔS = Change in ground water storage

The inputs and outputs of a ground water system may include the following components.

1. Inflow:

(A) Natural Recharge:
i) Recharage due to rainfall
ii) Recharge from rivers (influent seepage)
iii) Inflow from other basins
iv) Recharge from tanks & reservoirs

(B) Artificial Recharge:
i) Induced recharge from rivers
ii) Recharge due to seepage from irrigation channels
iii) Recharge from deep percolation of irrigation water from fields
iv) Recharge by injection

2. Outflow:

A) Natural outflow:
i) Evapotranspiration
ii) Regeneration in river or effluent seepage to rivers
iii) Outflow to other basins

B) Artificial Outflow:
i) Pumpage through open wells, and tube wells

Considering the above components, the groundwater balance equation can be rewritten as

$$Ri + Rc + Rr + Rt + Ig + Si = Tp + Et + Og + Se + \Delta S$$

Where,

Ri = recharge from rainfall

Rc = recharge from canal seepage

R = recharge due to deep percolation from field irrigation

= Rrs + Rrg

Rrs = recharge from surface watere irrigation

Rrg = recharge from groundwater irrigation

Rt = recharge from reservoirs & tanks

Ig = subsurface inflow from other basin

Si = influent seepage from rivers

Tp = withdrawal from ground water

Et = evapotranspiration losses
= Etf + Etw

Etf = evapotranspiration losses from forested areas

Etw = evapotranspiration losses from water-logged areas

Og = subsurface outflow from the basin

Se = effluent seepage to rivers

ΔS = change in ground water storage (positive for increase and negative for decrease)

The various components of inputs and outputs used in ground water balance equation have been discussed in part I of the study report. The above expression considers only one aquifer system and thus does not account for the interflows between the aquifers in a multi-aquifer system. However, if sufficient data related to water table and piezometric head fluctuations and conductivity of intervening layers are available, the additional terms for these interflows can be included in the equation. Each item of the equation represents a discharge or volume of water per unit of time. For the purpose of study, any consistant units of volume and time can be adopted. The water year extending from 1 st June to 31st May is preferable to the calender year. Theoritically, the hydrologic equation must balance but it rarely happens in practice as there may be some inaccuracies in the estimation of various parameters. However, the amount of unbalance should not exceed the limits of accuracy of the basic data. If the amount of unbalance (n) is given as a residual term of the water balance equation and includes the errors in the determination of the components and the values of components which are not taken into account, the equation may be written in the following form.

$$Ri + Rc + Rr + Rt + Ig + Si - Et - Tp - Og - Se - S - n = 0$$

In order to avoid huge errors, all the components of water balance equation must be estimated independently and adjustments, if required, should be made in items subject to large errors.

2.2 Methodology :

The above form of groundwater balance equation includes occurrence of all types of water but there may be situations in which it is possible to eliminate certain items from the equation because either they are negligible or they do not affect the solution. So, as a first step in a groundwater balance study, all significant components for the basin need to be identified. The Central Godavari Delta is bounded by river Gowthami Godavari in the east, river Vasistha Godavari and its branch Vainateyam in the west and Bay of Bengal in the south. The interaction between these water bodies and the basin aquifers forms an important component for the purpose of evaluating groundwater balance. Besides, a good network of canals in the study area is an important source of recharge. The recharge from rainfall with its time and space variability also forms one of the major contributions to the ground water. The Central Godavari Delta is predominantly a paddy growing area in both the seasons and a certain depth of irrgation water is maintained in the fields. And as such, the return flow from these irrigated areas also forms quite a reasonable amount of recharge. While considering the discharge components, a good number of tubewells exist in the study area. However, the area irrigated through these tubewells is comparatively small and hence the direct extraction of groundwater through pumping is also low. The indirect extraction of groundwater which is a major component of discharge is mainly through evapotranspiration through deep rooted trees and also through the shallow water table areas. These physical and hydrological characteristics of the study area provide the necessary background information for identification and estimation of different components of ground water balance. The study aims at evaluating the various water balance components on seasonal basis i.e. for monsoon season and non monsoon season from 1981-82 to 1989-90. The methodology adopted for estimating each of the components is discussed below.

2.2.1 Draft from Ground Water (Tp) :

Draft is the amount of water lifted from the aquifer by means of various groundwater structures and devices, e.g.

tubewells, dug wells, rahat or any other means. The draft from these individual sources may vary widely depending upon the yield, type of source, depth of water table, type of water use etc. Thus, a suitable methodology is required to estimate the ground water draft.

The draft is generally estimated by multiplying the number of working hours with the average draft per hour and the number of wells in the particular category. The sum of groundwater draft calculated for each category of sources will give the total draft. The average unit draft for above calculation is determined by conducting pumping tests on wells. Where wells are energised, the average unit draft per unit of electricity or fuel consumed can be determined for different ranges in depth to water levels. By noting the depth to water levels at each distribution point and multiplying the average draft value with the number of units of electricity or diesel consumed, the draft at each point can be computed for every month. Where wells are used for irrigation, agriculture statistics can be used for computation of groundwater draft for irrigation.

The tubewells in the study area are privately owned and the average unit draft of tubewells is not available. The groundwater draft in the present study has, therefore, been calculated using the agriculture statistics. For this purpose, the seasonwise and cropwise area irrigated by tubewells were collected. The average irrigation requirements for these crops were also estimated. Thus, the draft from groundwater for irrigation purpose was arrived at by multiplying the irrigation requirement with the irrigated area. Similarly, the groundwater draft for drinking purpose was also estimated by multiplying the total population in the study area with the average per capita water consumption.

2.2.2 Effluent and Influent Seepage (Se and Si):

The interaction between a river and the aquifer may be of two types. Depending upon the gradient, either aquifer may be contributing to the river flow (effluent) or river may be recharging the aquifer (influent). since the river stages and the groundwater levels keep on changing with time and space, the river may behave as influent or effluent. The direction of flow is governed by the position of water table in respect to the river stage and the amount of flow depends upon the both hydraulic gradient as well as the transmissivity of the aquifer system.

The effluent and influent seepage for the rivers Gowthami and Vasishta have been estimated reachwise. The entire length of rivers were divided in different reaches depending upon the nearby observat'on well possibly located in the middle of the reach. The hydraulic gradient has been computed as the ratio of difference between the river stage at the point where the normal from the observation well meets river and the water level in the observation well, to normal distance between the points under reference. The value of coefficient of transmissivity for the basin aquifers was provided by the A P State Groundwater Dept. With these parameters, the effluent or influent seepage has been estimated as below :

$$Q = T * I * L$$

where, Q = rate of flow, m**3/day
T = Transmissivity, m**2/day
I = hydraulic gradient
L = length of the reach

By considering proper signs for effluent and influent reaches of the rivers, influent and effluent seepages have been estimated over the entire length of all the rivers. Since the Bay of Bengal forms the southern boundary of the study area and it is observed from the water table contour maps that the flow takes place from the aquifers towards the sea, the effluent seepage for the sea has also been estimated using the same approach as discussed above for rivers.

2.2.3 Evapotranspiration from Groundwater Reservoir (Et)

The amount of water that is directly extracted from the groundwater reservoir and lost to the atmosphere through evaporation and transpiration from plants needs to be computed for preparing the groundwater balance. When the water table is close to the ground surface, the evaporation from the soil and transpiration from plants will be at the maximum possible rate, i.e. at potential rate. Similarly, the potential evapotranspiration will take place in the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone. From lakes and marshes fed by groundwater, evaporation takes place at the potential rate which can be estimated by multiplying the pan evaporation value by the pan coefficient. Since the study area does not have any surface water structures fed by ground water, the evapotranspiration losses from groundwater are estimated for shallow water table areas and deep rooted trees only.

a) Shallow Water Table Areas (Etw) :

The areas where the water table is within 2m from the ground surface have been considered as areas of discharge. In view of the proximity of the water table to the ground surface, the evapotranspiration from these areas have been considered at potential rate. For estimation of these evapotranspiration losses, the depth to water level contours were drawn and areas having water table within 2m were identified. The total amount of water extracted through evapotranspiration was estimated by multiplying the area with the average rate of potential evapotranspiration.

(b) Deep rooted Tree Areas (Etf) :

For deep rooted trees which have direct access to the groundwater, the evapotranspiration has been considered at potential rate. The evapotranspiration for such areas, therefore, have also been estimated by multiplying the area under these trees with the average values of potential evapotranspiration.

2.2.4 Recharge From Field Irrigation (Rr) :

The irrigation water applied to the fields is partly lost by crops for meeting their consumptive use requirements and the balance infiltrates to recharge the groundwater storage. For irrigation of dry crops, the water applied is much less as the soil is required to be saturated for short periods, with the result that the greater part of the water applied is abstracted from the soil and lost to the atmosphere through evapotranspiration leaving only a small fraction, if any, to recharge the ground water. However, in the study area, paddy being the major crop in both the seasons, the amount of infiltration becomes significant in view of continuous submergence of soil for long durations. The amount of recharge from applied irrigation water, derived both from ground water and surface water sources, therefore, needs to be estimated for evaluating the groundwater balance.

For correct assessment of this quantity, studies are required to be taken up in the study area on experimental plots under different crops. However, the results of similar studies conducted elsewhere indicate that the return flow from irrigation by surface water sources varies from 25 to 50% of the water delivered at the outlet and that from irrigation by groundwater sources varies from 20 to 40%. Groundwater Estimation Committee has also recommended the values of return seepage from irrigation fields in the same range. In the present study, the G W Estimation Committee norms are followed and the return flow from fields have been assumed as 40% and 30% of water delivered at the outlet for canal irrigation and groundwater irrigation respectively. The above figures of return flow include losses in field channels also and hence these need not be accounted for seperately.

2.2.5 Recharge from Canal Seepage (Rc):

The seepage water from canals after percolating deep joins the groundwater table and form a significant component in the groundwater balance studies. The recharge through seepage from canal depends on the infiltration capacity of the canal bed and sides, subsuface lithology, extent of wetted area, physical and chemical properties of water and relative position of bed with respect to the water table. There are several methods to estimate the seepage losses from canals. The indirect method include the assessment of the factors affecting the canal seepage. In direct methods, the inflow-outflow method and the Ponding method are most commonly used. The inflow-outflow method consists of measuring the water that flows into and out of the section of irrigation canal being studied. The difference between the quantities of water flowing into and out of the canal reach is attributed to seepage. The evaporation and precipitation being comparatively small can be neglected. In Ponding method, the rate of drop in a pool formed in the canal reach is measured. To maintain the constant water level in the pond, water is added to the canal. The accurately measured volume of added water is considered equal to the total losses and the elapsed time establishes the rate of loss. Besides the above methods, a number of investigation have been carried out elsewhere to study the seepage losses from canals. The Groundwater Estimation Committee has recommended the following norms :

(i) for unlined canals in normal type of soil with some clay content alongwith sand-15 to 20 ham/day/10**6 Sqm of wetted area of canal or 6 to 8 cusec/10**6 sq.ft of wetted area of canal or 1.8 to 2.5 cumec/10**6 sqm. of wetted area.

(ii) for unlined canals in sandy soils- 25 to 30 ham/day/10**6 sqm of wetted area, or 10 to 12 cusec/10**6 sq.ft of wetted area or 3 to 3.5 cumec/10**6 sq.m of wetted areas.

(iii) for lined canals, the seepage losses may be taken as 20% of the above values.

The canal system in Central Godavari Delta is very old and the measuring structures at many locations are not in proper working condition and as such the data on outflow are rough estimates. Besides, there are a good number of lift irrigation schemes operating on the canals, the data of which are not available. With these data gaps, the application of inflow-outflow method may not yield the correct estimates of seepage losses in canals. These losses in the present study have, therefore, been estimated using the G.W Estimation Committee norms.

2.2.6 Change in Groundwater Storage (Δ S)

The groundwater storage responds to two factors, namely recharge and discharge. Where recharge exceeds discharge, groundwater storage increases and on the other hand, groundwater storage experiences decrease in its volume when the discharge exceeds recharge. The change in groundwater storage is exhibited by the changes in water table levels in the aquifers. The water table levels are observed through a network of observation wells spread over the area. Since a major portion of recharge takes place from the percolation of rain water, the groundwater levels are highest immediately after monsoon in the month of October and lowest before the onset of monsoon or in other words at the end of non-monsoon season. For preparing seasonal ground water balance, the net change in storage volume during monsoon (June to October) and non-monsoon seasons (November to May) are worked out. The increase in groundwater storage which is common phenomena in monsoon season is represented by a + ve sign and the decrease during non-monsoon season by -ve sign. For estimating the change in storage, the pre monsoon (June) and post monsoon (October) groundwater level contours were drawn by using the monthly water table observations for the study area. Then, with the help of planimeter the areas between two successive contours were measured and the average position of water table during pre monsoon and postmonsoon seasons calculated by using the following equation :

$$P = \frac{A1(P1+P2) + A2(P2+P3) + A3(P3+P4) + \ldots\ldots + An(Pn-1 + Pn)}{2(A1+A2+A3+\ldots\ldots+An)}$$

where,

P is average position of water table,
P1,P2,P3 are the values of successive contours and
A1,A2,A3 are the areas enclosed by two successive contours.

The difference between average water table positions during premonsoon and postmonsoon season gives the average change in water table position during monsoon season while the difference between water tables of post monsoon and pre monsoon of next year gives the average change during non monsoon season. Once the above excercise was done for all the years, the change in groundwater storage (S)during monsoon and non monsoon seasons were calculated as below:

Change in groundwater storage = Average change in water table * Total study area * Specific yield (Sy)

The specific yield as used in above relationship may be computed from pumping tests. In absence of pumping test results, the following values of specific yield for different types of geological formations in the zone of water level fluctuations may be adopted.

1. Sandy alluvial area ----- 12 to 18%
2. Valley fills ----- 10 to 14%
3. Silty/clayey alluvial area ----- 5 to 12%
4. Granites ----- 2-4%
5. Basalts ----- 1 to 3%
6. Laterite ----- 2-4%
7. Sandstone ----- 1 to 8 %
8. Limestone ----- 3%

(Source: Groundwater Estimation Methodology , 1984)

Since the study area consists of alluvial plains formed by river Godavari, an average value of specific yield has been assumed as 15% for analysis purpose.

2.2.7 Recharge from Rainfall (Ri):

Recharge from rainfall is the most important parameter among a variety of inputs used in the groundwater balance equation. A part of rainwater infiltrates into the soil and after filling the soil moisture deficiency percolates down reaching the water table. This water reaching the water table is known as the recharge from rainfall to the aquifer. This recharge which is a fraction of total rainfall depends upon several factors such as soil characteristics, topography, vegetal cover, land use, soil moisture conditions, depth to water table, intenstiy, duration and seasonal distribution of rainfall and other meteorological factors. Recharge from ranfall, therefore, varies in space and time. There are different approaches for estimation of rainfall recharge. Various types of emperical relationships established over the years between recharge and rainfall for different regions can be used to estimate the recharge. The Groundwater Estimation Committee has also recommended a range of recharge values for different types of geological formations. However, the water balance approach for estimation of rainfall recharge gives fairly better results provided a very extensive and accurate hydrological and meterological data ara avilable and all other components of water balance equation are estimated independently with suitable methodologies.

In the present study, the rainfall recharge is calculated using the water balance approach. In this approach, all the components of water balance equation other than the rainfall recharge, are estimated using the relevent hydrological and meteorological information. Since almost all the rainfall recharge takes place during monsoon season with little or no recharge in non- monsoon, the recharge has been calculated for monsoon season by substituting the estimates of other components in water balance equation. The mean areal rainfall over the basin for monsoon season was computed using Thiessen Polygon method and thus the recharge coefficient i.e. recharge per unit rainfall have also been calculated.

3.0 ANALYSIS

3.1 General

The preparation of groundwater balance consists of identification of water balance components and analysis of relevant data with suitable methodology for quantification of each of these components. The basic data required to carry out the water balance study for Central Godavari Delta were collected from various Government Departments and agencies such as A P State GroundWater Dept, Irrigation Dept, Agriculture Dept, Statistics Dept etc. and after preliminary processing were presented in Part I of the study reports. While the ground water balance components relevant to the study area have been identified and discussed in first report i.e. Part I, the methodologies adopted for their estimation have been presented in Chapter 2 of this report. Using this available information, the seasonal ground water balance has been worked out for 9 years i.e. for the period 1981-82 to 1989-90 for monsoon (June to October) and non-monsoon (November to May) seasons. Except rainfall recharge, all other components of groundwater balance equation like draft from groundwater, evapotranspiration from groundwater, influent and effluent seepage, recharge due to canal seepage, recharge from field irrigation, change in groundwater storage have been estimated by analysing the basic data. Finally, the rainfall recharge during monsoon season was estimated using water balance approach to arrive at the overall groundwater balance of the study area. While this yields an estimate of rainfall recharge co-efficient, the water balance during non monsoon season determines the degree of accuracy with which the components of water balance equation have been estimated.

3.2 Draft from Ground Water (Tp):

In the present study, the drafts from groundwater during monsoon and non-monsoon seasons have been computed using the seasonwise irrigated area by the groundwater structures. The data on seasonwise and sourcewise irrigation, were collected from the District Planning Office, East Godavari Dist. and presented in Part I of the study report. From the irrigation statistics, it is observed that the area is predominantly a canal irrigated area and only 5-6% of the total irrigated area is covered by the wells/tubewells. The crops irrigated by these sources include a part of the area under perennial crops i.e. sugarcane, fruits and vegetables, tobacco in Kharif and rarely gram and other minor crops in Rabi.

For the purpose of estimation of groundwater draft, the average water requirements of crops which are supposed to be met from groundwater have been assumed as 0.15m & 0.6m in kharif (monsoon) and rabi (non monsoon) respectively. The seasonwise draft was then calculated by multiplying the irrigated area with the average water requirements during that season. Similarly, the draft for drinking purpose has also been estimated at the rate of 40 lit/capita/day for a total population of 6,57,000 in the study area. The seasonwise total estimated draft during different years are presented in Table 3.1.

Table 3.1 : Draft from Ground Water

S.No.	Year	Draft (MCM) Monsoon	Non-monsoon
1	1981-82	14.60	20.50
2	1982-83	14.90	18.50
3	1983-84	15.30	16.60
4	1984-85	15.60	14.60
5	1985-86	15.60	16.30
6	1986-87	15.65	18.00
7	1987-88	15.70	19.80
8	1988-89	17.50	13.90
9	1989-90	18.00	14.50

3.3 Evapotranspiration from Ground water reservoir (Et):

As mentioned earlier, the direct extraction of groundwater is calculated for (a) shallow water table areas and (b) deep rooted tree areas.

a) Shallow Water table Areas (Etw):

By the end of the monsoon period, the water table reaches its highest levels and gradually recedes to its lowest levels by the beginning of the next monsoon period. It is assumed that when the water table is at a depth less than 2m from the ground surface, the crop and other vegetation may be able to draw water directly from the groundwater reservoir. For estimation of evapotranspiration losses from such areas, depth to water table contours were drawn and areas with depth to water table below ground level less than 2m identified. The average potential evapotranspiration rates as applicable to the study area were also collected and are presented in Table 3.2. The seasonal evapotranspiration losses from shallow water table areas were then calculated by multiplying the area with the average potential evapotranspiration rates. Table 3.3 shows the estimates of these losses for the study area during different years.

Table 3.2 : Average Potential Evapotranspiration rates for the Study area

S.No.	Month	Average PET (mm/day)
1	January	3.18
2	February	4.18
3	March	5.05
4	April	5.97
5	May	6.51
6	June	5.39
7	July	5.13
8	August	4.86
9	September	3.85
10	October	3.38
11	November	2.88
12	December	2.78

Table 3.3: Evapotranspiration Losses from Shallow Water Table areas

S.No	Year	Evapotranspiration losses (MCM)	
		Monsoon	Non Monsoon
1	1981-82	208.90	360.70
2	1982-83	231.15	384.00
3	1983-84	166.50	413.30
4	1984-85	252.80	410.50
5	1985-86	252.80	345.70
6	1986-87	203.15	395.00
7	1987-88	241.60	419.70
8	1988-89	124.80	365.90
9	1989-90	164.90	327.30

b) Deep Rooted Tree areas (Etf):

The study area has a large number of coconut trees which are expected to draw water directly from the ground water reservoir. The area under these trees in different years of study are given in Part I of the study report. The seasonwise groundwater losses through such areas have been calculated by multiplying the potential evapotranspiration rate with the area under trees. The evapotranspiration losses through deep rooted trees are presented in Table 3.4.

Table 3.4: Evapotranspiration losses from Deep Rooted Tree Areas.

S.No	Year	Evapotranspiration losses (MCM)	
		Monsoon	Non-Monsoon
1	1981-82	78.40	105.90
2	1982-83	81.15	109.60
3	1983-84	83.90	113.40
4	1984-85	86.70	117.10
5	1985-86	86.80	117.30
6	1986-87	87.00	117.50
7	1987-88	87.10	117.70
8	1988-89	95.00	116.60
9	1989-90	97.00	117.00

3.4 Effluent and Influent Seepage (Se & Si):

The effluent and influent seepage in the study area have been computed for (a) River Vashista and Gowthami and (b) sea (Bay of Bengal).

For computation purpose, the rivers and the sea coast were divided into a number of small reaches so that each reach has at least one observation well. The effluent seepage to rivers (-ve sign) and influent seepage from rivers (+ve sign) were then determined for each reach by using the gradient of water table with respect to river stage and transmissivity of the aquifer system as explained in Section 2.2.2. The average value of coefficient of transmissivity for the aquifers of study area was supplied by the A P State Ground Water Dept. as 3580 Sq.m/day. The estimates of net seasonal effluent/influent seepage for rivers and sea are presented in Table 3.5 and 3.6 respectively.

Table 3.5 : Net Seasonal Effluent/Influent Seepage for Rivers Gowthami and Vasishta (Effluent seepage = -ve, Influent seepage = +ve)

S.No	Years	Net Seepage (MCM)	
		Monsoon	Non-Monsoon
1	1981-82	101.00	37.20
2	1982-83	87.40	104.80
3	1983-84	96.30	103.30
4	1984-85	162.90	105.50
5	1985-86	141.50	83.60
6	1986-87	126.20	77.90
7	1987-88	147.50	103.30
8	1988-89	164.90	126.50
9	1989-90	97.50	84.50

Table 3.6 : Net Seasonal Effluent/Influent Seepage for Sea (Effluent seepage = -ve, Influent seepage = +ve)

S.No	Years	Net Seepage (MCM)	
		Monsoon	Non Monsoon
1	1981-82	-8.50	-11.50
2	1982-83	-8.20	-12.80
3	1983-84	-6.50	+5.30
4	1984-85	-9.10	-8.70
5	1985-86	+0.30	-12.70
6	1986-87	-4.50	-11.10
7	1987-88	-6.80	-12.10
8	1988-89	-6.30	-12.30
9	1989-90	-20.40	-22.50

3.5 Recharge from Canal Seepage (Rc):

The study area is served by a very old irrigationsystem. The canal system remains operational for 11 months with a closure period of one month during April-May. As explained in Section 2.2.5, the seepage losses for the canal system in the study area have been estimated using the G W Estimation Committee norms. The cross-sections and lengths of the main canal and four branch canals i.e. Amalapuram, Gannavaram, Bank and Benda canals were collected from the Irrigation Dept and their total wetted area worked out. Based on recommendations of the G W Estimation Committee, the recharge due to seepage from unlined canals in sandy loam soils of the study area was taken as 15 ham/day/10**6 sq.m of wetted area of canals. The estimates of seasonal recharge due to canal seepage are presented in Table 3.7.

3.6 Recharge from Field Irrigation (Rr) :

The recharge from field irrigation or the return flow has been calculated using the G W Estimation Committee norms. In the study area, paddy is the main crop during both the seasons and is entirely irrigated by canals. The data on monthly discharges diverted into the canal system of the study area and on escapes are available. With these data, the quantity of water available for application in the fields was calculated by subtracting the escapes and seepage losses from the total quantity of water delivered into the canal system. The recharge due to return flow from canal irrigation was thus taken as 40% of the water applied in the fields. The recharge due to ground water irrigation was taken as 30% of the groundwater draft used for irrigation purpose. The seasonal estimates of recharge due to field irrigation are presented in Table 3.8.

Table 3.7 : Seepage Losses in Canal System

S.No	Year	Canal Seepage Loss (MCM)	
		Monsoon	Non Monsoon
1	1981-82	73	88
2	1982-83	73	88
3	1983-84	73	88
4	1984-85	73	88
5	1985-86	73	88
6	1986-87	73	88
7	1987-88	73	88
8	1988-89	73	88
9	1989-90	73	88

Table 3.8 : Recharge from Field Irrigation

S.No.	Year	Recharge (MCM)			
		Canal Irrigation		Groundwater Irrigation	
		Monsoon	Non monsoon	Monsoon	Non monsoon
1	1981-82	192	198	3.20	4.50
2	1982-83	192	226	3.20	2.50
3	1983-84	147	160	3.20	4.50
4	1984-85	190	210	3.50	2.70
5	1985-86	176	209	3.50	2.70
6	1986-87	181	194	3.50	2.70
7	1987-88	210	160	3.50	4.20
8	1988-89	139	184	5.20	2.50
9	1989-90	129	161	5.20	2.50

3.7 Change in Groundwater Storage (ΔS):

The methodology as explained in section 2.2.6 was followed for estimating the changes in groundwater storage. The water table contours with 0.5m contour interval were plotted for the study area for June (Pre monsoon) and October (Post Monsoon) of each year. The water table contour maps for pre and post monsoon periods in the years of 1981 and 1988 are given in Figs 3.1 to 3.4. With the help of these maps, the average change in water table levels during monsoon and non monsoon seasons of each year were worked out. Finally, the change in groundwater storage during monsoon and non monsoon seasons were calculated by multiplying the average change in water table levels with the area and the specific yield. The seasonal change in ground water storage during different years of study are given in Table 3.9.

Table 3.9 : Change in Ground Water Storage

S.No	Year	Change in Groundwater Storage (MCM)	
		Monsoon	Non monsoon
1	1981-82	193.80	-146.00
2	1982-83	116.20	-123.10
3	1983-84	199.30	-212.30
4	1984-85	152.20	-184.70
5	1985-86	176.10	-128.40
6	1986-87	192.40	-186.40
7	1987-88	190.80	-257.50
8	1988-89	207.50	-138.10
9	1989-90	154.40	-15.10

3.8 Recharge from Rainfall (Ri) :

The rainfall data from various raingauge stations in the study area were collected and analysed for monthly mean areal rainfall over the area. These were presented in Part I of the study report. With the help of these data, the total volume of

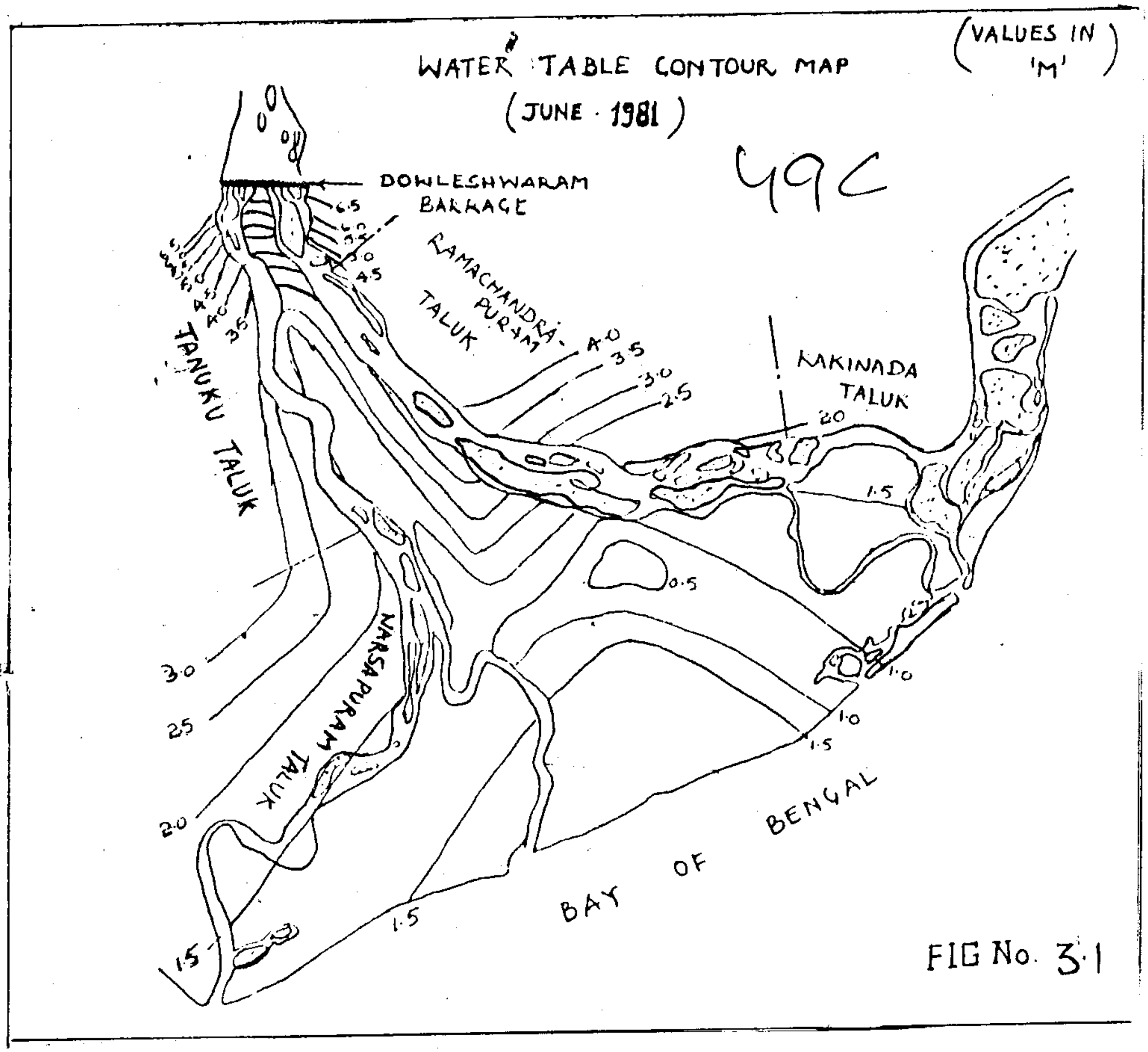

WATER TABLE CONTOUR MAP
(JUNE · 1981)
(VALUES IN 'M')
49C
DOWLESHWARAM BARRAGE
RAMACHANDRAPURAM TALUK
KAKINADA TALUK
TANUKU TALUK
NARSAPURAM TALUK
BAY OF BENGAL
6.5
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
3.0
2.5
2.0
1.5
1.5
1.0
1.5

FIG No. 3·1

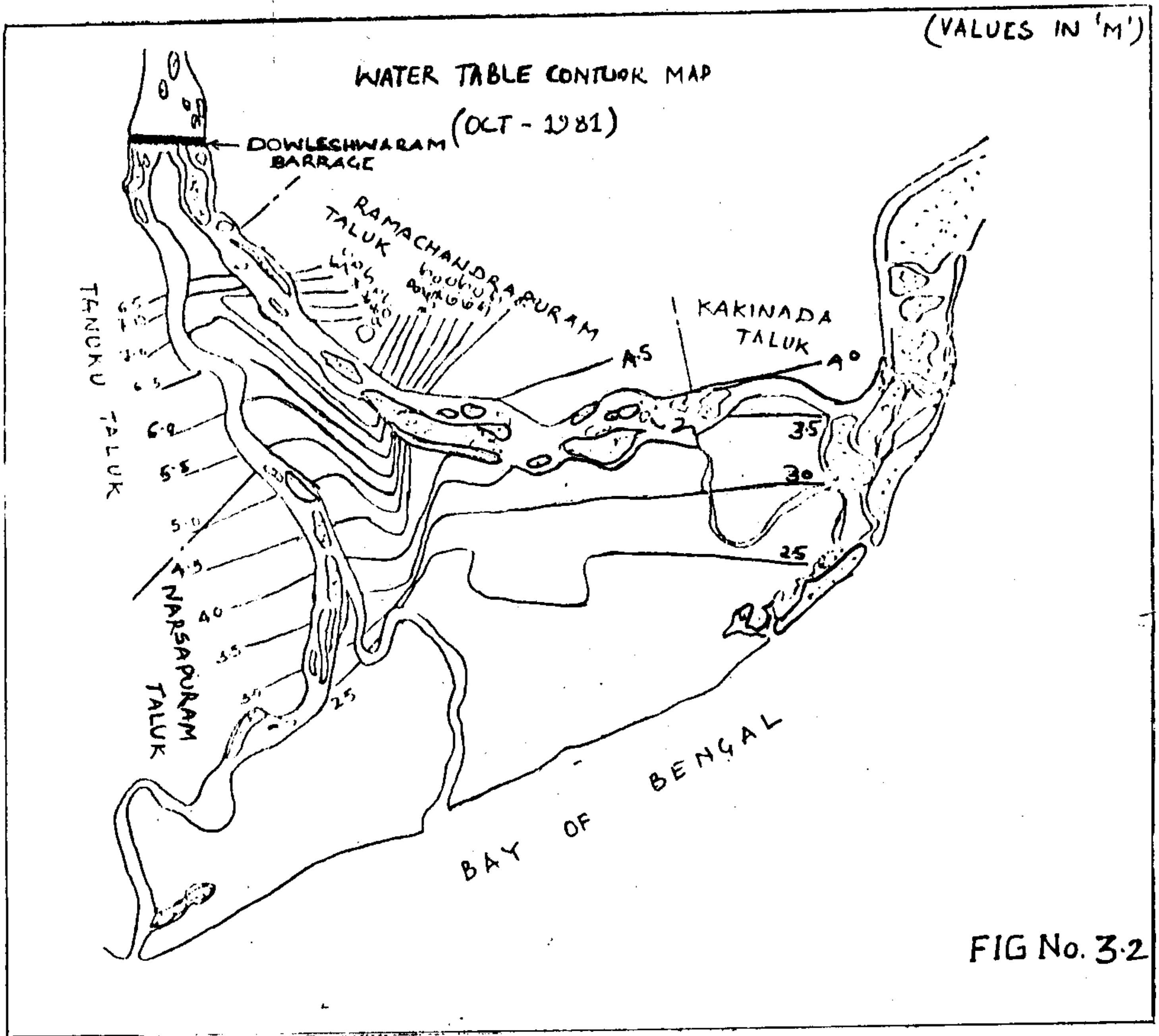

(VALUES IN 'M')
WATER TABLE CONTOUR MAP
(OCT - 1981)
DOWLESHWARAM BARRAGE
RAMACHANDRAPURAM TALUK
KAKINADA TALUK
TANUKU TALUK
NARSAPURAM TALUK
BAY OF BENGAL
4.5
4.0
3.5
3.0
2.5
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5

FIG No. 3.2

WATER TABLE CONTOUR MAP
(JUNE-1988)

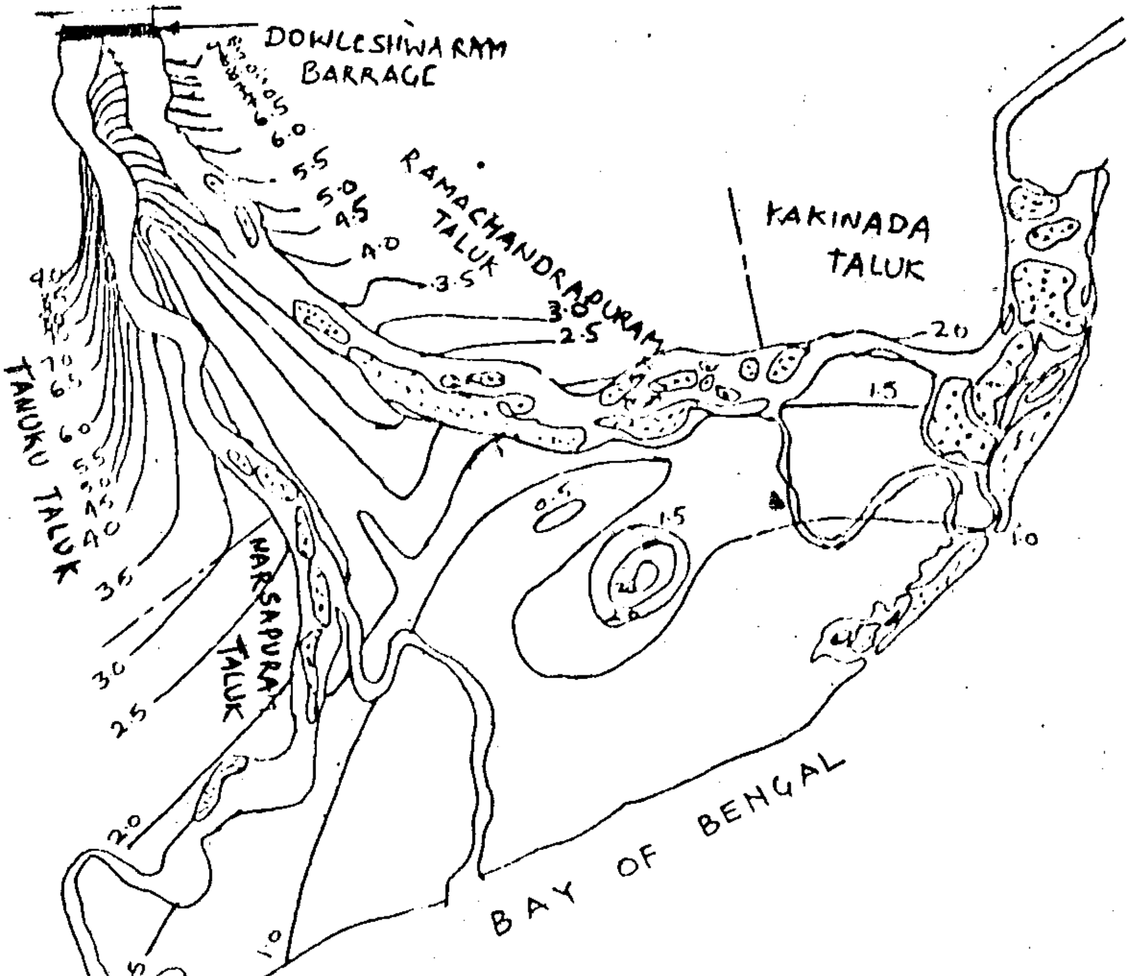


FIG No. 3.5

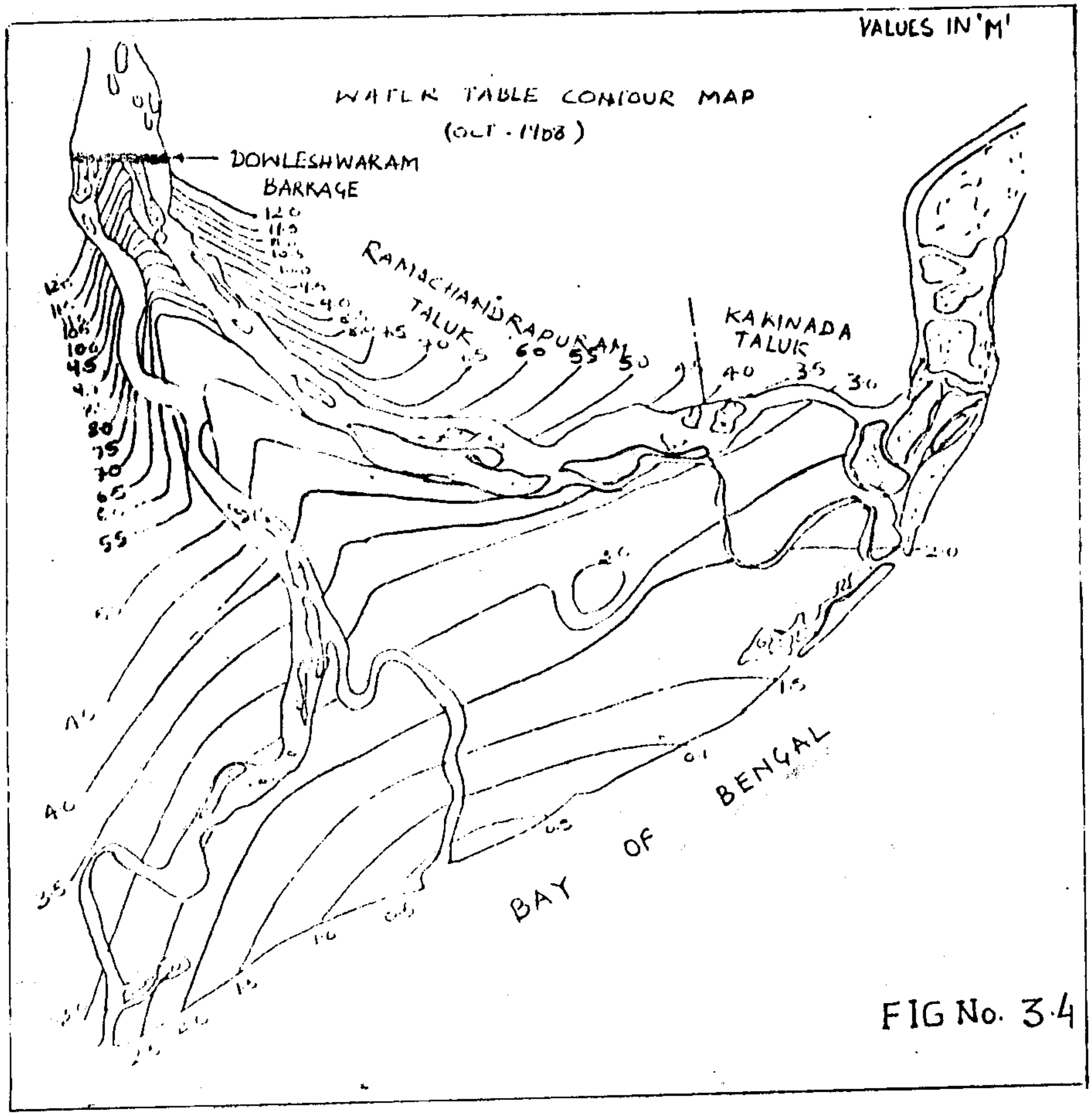

VALUES IN 'M'
WATER TABLE CONTOUR MAP
(OCT - 1988)
DOWLESHWARAM BARRAGE
RAMACHANDRAPURAM TALUK
KAKINADA TALUK
BAY OF BENGAL

FIG No. 3.4

rainfall over the study area during monsoon and non monsoon seasons were also calculated and are presented in Table 3.10.

Table 3.10 : Mean Seasonal Rainfall Over the Study Area

S.No	Year	Rainfall (MCM)	
		Monsoon	Non monsoon
1	1981-82	792.80	36.40
2	1982-83	592.70	133.40
3	1983-84	1037.10	89.20
4	1984-85	563.80	130.10
5	1985-86	801.20	138.30
6	1986-87	690.20	174.40
7	1987-88	636.70	207.80
8	1988-89	513.30	58.80
9	1989-90	1019.40	629.50

The recharge from rainfall in the study area has been estimated using the water balance approach as discussed in section 2.2.7. Further discussion on rainfall recharge and recharge coefficient is presented in Chapter 4.

3.9 Sea Water Intrusion:

Intrusion of salt water into aquifer system in coastal areas depends on the exploitation of ground water. The intruding salt water makes large zones of the aquifers unsuitable for all human needs. The increase of TDS values of fresh groundwater caused by its mixing with saline waters makes the water unusable. With a view to study the effects of sea water intrusion on the quality of groundwater in the study area, the chemical analysis data of water samples for a period of 8 years (1982-89) were collected. The data were collected for pre monsoon and post monsoon periods from 26 observation wells, 11 of which fall in the study area. Chemical analysis of water samples includes TDS (Total Dissolved

Solids), SAR (Sodium Adsorption Ratio), Specific Conductance, Carbonate, Bicarbonate, Chlorine, Sodium, Potassium, Calcium, Magnesium, Total Hardness and RSC. These data are presented in Part I of the study report.

Since TDS play a major role in the identification of salinity in water, the TDS values have been analysed for their spatial distribution over the study area. The average of pre and post monsoon TDS values over 8 years were calculated for each observation well. The contours with these average TDS values were then drawn as shown in Fig. 3.5. The area under different ranges of TDS values was measured with the planimeter and is given in Table 3.11.

Table 3.11 : Area under different Ranges of TDS values

S.No.	TDS range	Area (Sq.Km)	Percentage of Total area
1	Upto 500	10	1.20
2	500-1000	427	51.80
3	1000-1500	300	36.30
4	1500-2000	88	10.70
5	above 2000	Nil	Nil

From the Table 3.11, it is observed that a very small area i.e about 1.2 percent has groundwater TDS values upto 500 which is considered safe for drinking purpose. The groundwater with TDS values between 500 to 1500, usable for drinking purpose after proper treatment accounts for about 88 % of the area. The remaining 11 % of area having groundwater TDS values between 1500 to 2000 is not fit for drinking water purpose but can comfortably be used for irrigation water purpose.

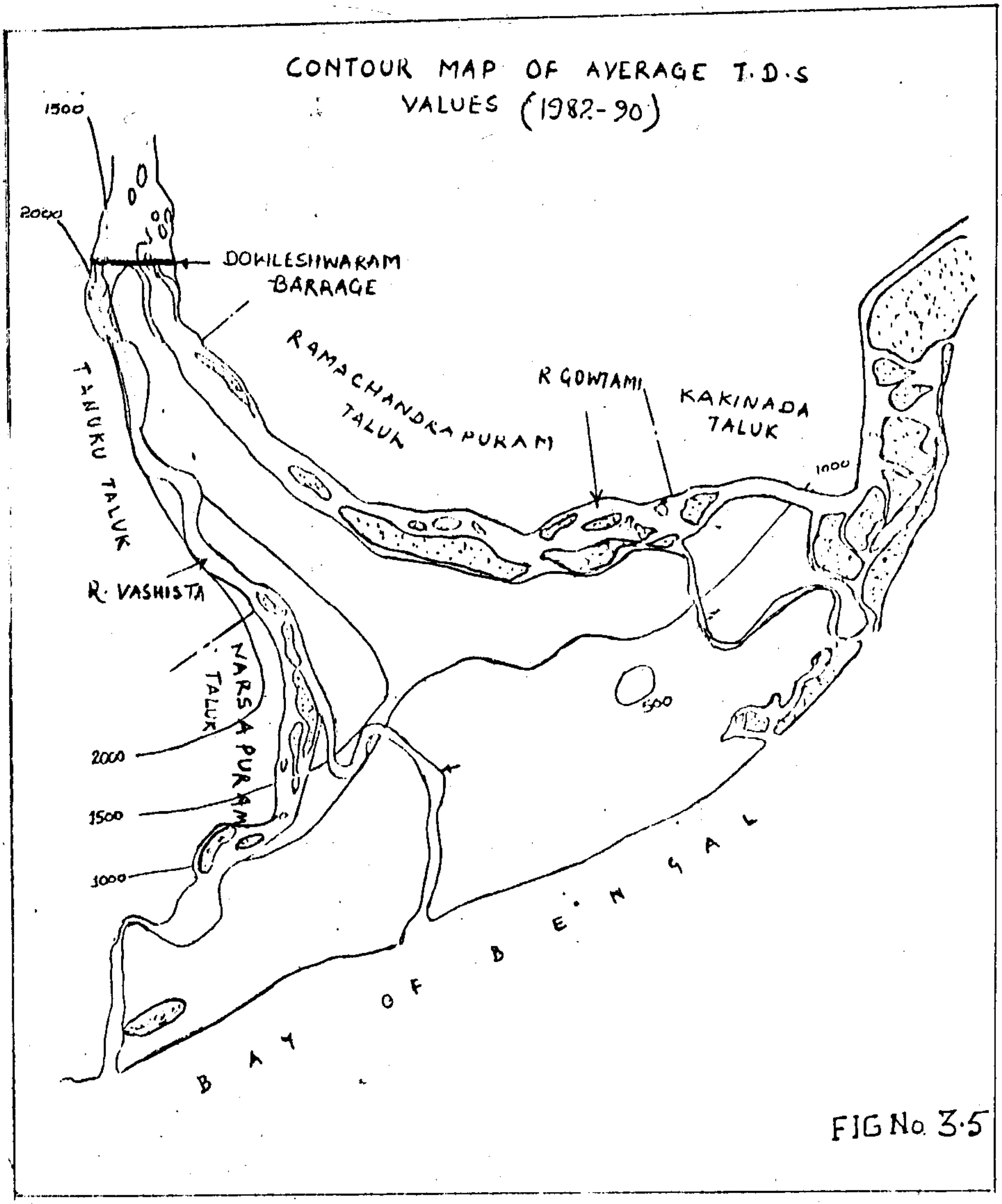

CONTOUR MAP OF AVERAGE T.D.S VALUES (1982-90)
1500
2000
DOWLESHWARAM BARRAGE
RAMACHANDRAPURAM TALUK
R GOWTAMI
KAKINADA TALUK
1000
TANUKU TALUK
R. VASHISTA
NARSAPURAM TALUK
500
2000
1500
1000
BAY OF BENGAL

FIG No. 3·5

Though no large scale groundwater exploitation is practised for irrigation purpose in the study area and bore wells are used mainly for drinking water purposes, the high TDS values in the range of 1500 and above are of great concern. From the water quality data of observation wells, it is observed that the wells near the rivers are having significantly higher TDS values as compared to the wells near the sea.

In the study area, it is noticed that pumpages from the wells located very near to the sea are very meagre and the water from these wells are mainly used for drinking purposes since irrigation in that area is negligibly small. Further, the gradient of water table indicates that fresh water from the aquifers is flowing into the sea. This indicates that there is no sea water intrusion directly from the sea into the aquifers due to reversal of gradients and hence the TDS values in the wells near the sea are comparatively less.

However, in case of rivers, the groundwater table contours indicate that the flow takes place from the rivers into the aquifers. During high tides in premonsoon as well as post monsoon period, sea water rushes through the mouth of the river, upstream for distances upto 40 to 50 kms. It takes few days for this sea bore to recede back to the sea. During this period salt water infiltrates into the groundwater aquifers from the river banks and bed. A falling trend in TDS values is observed in the wells located farther away from rivers and in the middle of the study area.

The foregoing discussion clearly indicates that the sea water intrusion is taking place due to sea bore through the rivers bed and banks. This may probabaly be attributed to the reduction of flows in the two arms of river Godavari due to construction of barrage at Doweleswaram. So, there is need to maintain certain minimum flow in the river arms to prevent the sea bore from travelling into the rivers.

4.0 GROUND WATER BALANCE

The ground water balance for the study area of Central Godavari Delta has been carried out seasonwise for monsoon (June to October) and non monsoon (November to May) seasons from 1981-82 to 1989-90. The groundwater balance during monsoon season yields an estimate of rainfall recharge and that during non monsoon season determines the degree of accuracy with which the components of water balance equation have been estimated. The estimates of various components of groundwater balance equation except rainfall recharge were worked out and presented in chapter 3.0. The seasonwise groundwater balance for the study area is presented in Table 4.1.

Since a major portion of rainfall recharge takes place during monsoon season, the rainfall recharge has been calculated during monsoon season using water balance approach. The estimates of all other components were substituted in the water balance equation and recharge from rainfall calculated during monsoon season for each year. The estimates of rainfall recharge are presented in Table 4.1. Based on the monsoon season rainfall, the recharge-coeffients (recharge/rainfall) were also calculated and presented in Table 4.1. The recharge coefficients for the study area during 1981-82 to 1989-90 are found to vary from 0.134 to 0.172. A graph is drawn between seasonal rainfall (monsoon) and the recharge due to rainfall in monsoon season and is presented in Fig 4.1. From the graph, it is observed that as the rainfall increases, the quantity of recharge also increases in a parabolic manner upto a certain amount of rainfall. Beyond this certain

Table 4.1: GROUNDWATER BALANCE OF CENTRAL GODAVARI DELTA
(All figures in MCM)

Sl No.	Components	1981-82 Mon soon	1981-82 Non-mon soon	1982-83 Mon soon	1982-83 Nonmon soon	1983-84 Mon soon	1983-84 Nonmon soon	1984-85 Mon soon	1984-85 Nonmon soon	1985-86 Mon soon	1985-86 Nonmon soon
1	Draft from GW	14.6	20.50	14.90	18.50	15.30	16.50	15.60	14.60	15.60	16.30
2	Evapotranspiration losses										
	a)through deep rooted trees	78.4	105.90	81.15	109.60	83.90	113.40	86.70	117.10	86.80	117.30
	b) through shallow watertable areas	208.90	360.70	231.15	384.00	166.50	413.30	252.80	410.50	252.80	345.70
3	Net effluent seepage to sea	8.50	11.50	8.20	12.80	6.50	-5.30	9.1	8.70	-0.30	12.70
4	Recharge from canal seepage	73.00	88.00	73.00	88.00	73.00	88.00	73.00	88.00	73.00	88.00
5	Recharge from return flow										
	a)canal irri.	192.00	198.00	192.00	226.00	147.00	160.00	190.00	210.00	176.00	209.00
	b)well irrigation	3.20	4.50	3.20	2.50	3.20	4.50	3.50	2.70	3.50	2.70
6	Net influent seepage from rivers	101.00	37.20	87.40	104.80	96.30	103.30	162.90	105.50	141.50	83.60
7	Change in groundwater storage	193.80	-146.00	116.20	-123.10	199.30	-212.3	152.20	-184.7	176.10	-128.4
8	Recharge from rainfall (Ri) Ri=(7)+(1+2+3)-(4+5+6)	135.00	0.00	96.00	0.00	152.00	0.00	87.00	0.00	137.00	0.0
9	Rainfall (P)	792.80	36.40	592.70	133.40	1037.1	89.20	563.80	138.10	801.20	138.30
10	Recharge Co-efficient (Ri/P)	0.17	--	0.162	--	0.147	--	0.154	--	0.171	---
11	Unaccounted water (non monsoon) = (4+5+6+Ri) - (1+2+3)-(7)	--	-24.8	--	19.50	---	30.10	--	40.00	--	19.70

Contd...

Table 4.1 contd...

Sl No.	Components	1986-87		1987-88		1988-89		1989-90	
		Mon soon	Non-mon soon	Mon soon	Nonmon soon	Mon soon	Nonmon soon	Mon soon	Nonmon soon
1	Draft from GW	15.65	19.00	15.7	19.80	17.50	13.30	18.90	14.50
2	Evapotranspiration losses								
	a) through deep rooted trees	87.00	117.50	87.10	117.70	95.00	116.60	97.00	117.00
	b) through shallow watertable areas	203.15	395.00	241.60	419.70	124.80	365.90	164.90	327.30
3	Net effluent seepage to sea	4.50	11.70	6.80	12.10	6.30	13.30	20.40	22.50
4	Recharge from canal seepage	73.00	88.00	73.00	88.00	73.00	88.00	73.00	88.00
5	Recharge from return flow								
	a) canal irri.	131.00	194.00	210.00	160.30	139.00	154.00	129.80	161.00
	b) well irrigat.	3.50	2.70	3.50	4.20	5.20	2.50	5.20	2.50
6	Net influent seepage from rivers	105.30	77.30	147.50	108.60	164.90	125.50	37.50	84.50
7	Change in groundwater storage	192.40	-136.4	190.80	-257.50	207.50	-138.1	154.40	-15.10
8	Recharge from rainfall Ri Ri=(7)+(1+2+3)-(4+5+6)	119.30	0.0	108.00	0.00	69.00	0.00	150.00	106.00
9	Rainfall (P)	690.20	174.40	636.70	207.30	513.30	58.30	1019.4	629.50
10	Recharge Co-efficient (Ri/P)	0.172	--	0.169	--	0.134	--	0.147	--
11	Unaccounted water (non monsoon) = (4+5+6+Ri) - (1+2+3)-(7)	--	7.49	--	43.70	--	30.42	--	-24.20

VARIATION OF RAINFALL RECHARGE WITH RAINFALL

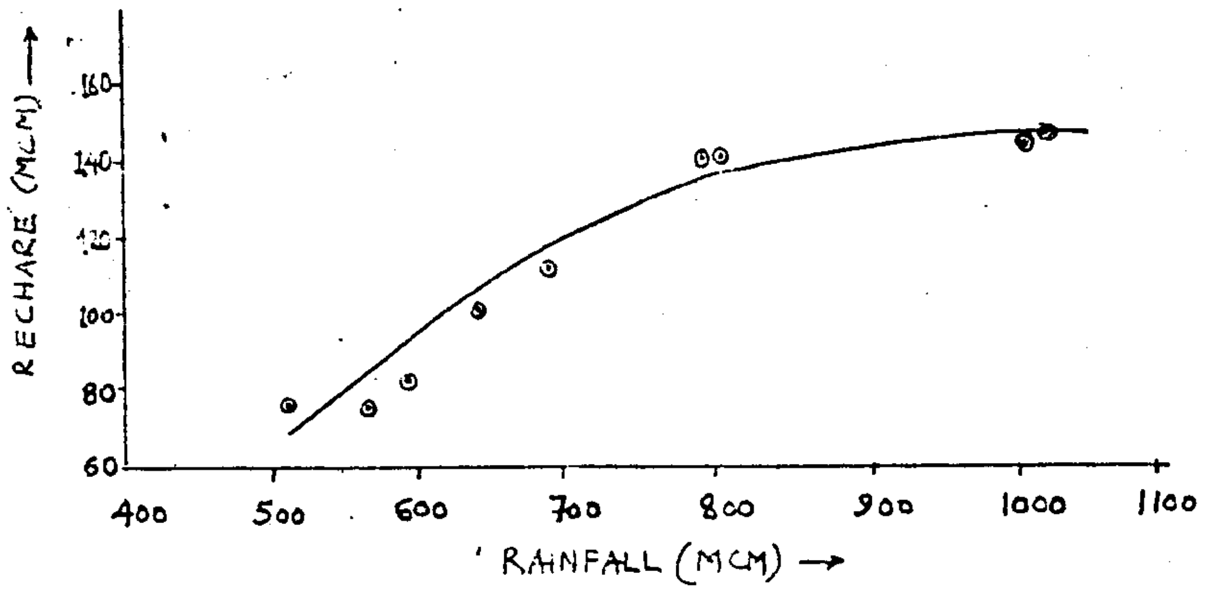


FIG.No. 4-1

value of rainfall i.e. 950 MCM, there seems no significant increase in the rainfall recharge. This means the maximum possible recharge takes place with rainfall of about 950 MCM and water table by this time reaches the ground surface. With further rainfall, there is little or no recharge to ground water and almost all the rainfall goes as runoff.

The extended portion of the recharge-rainfall graph indicate that the rainfall below 450 MCM is used by crops and increase the soil moisture with no recharge to ground water. The values of rainfall during non-monsoon seasons are generlly very low and do not contribute to the ground water reservoir. However, in the year of 1989-90, the non-monsoon season rainfall is observed to be about 630 MCM and is expected to recharge the water table significantly. In the water balance calculations, the recharge from this non-monsoon rainfall has been estimated using the recharge coefficient as established through the recharge-rainfall plot during monsoon season.

In non-monsoon season, the unaccounted water was calculated with the estimated values of all the components. The amount of unaccounted water in all the years works out to less than 31 MCM. Keeping in view the characteristics of the delta and the complications involved in hydrologic interactions between the surrounding water bodies, i.e. rivers, sea and the aquifers, the discrepancy of 31 MCM seems to be reasonable. Though the estimates of individual components may have some errors, the overall ground water balance can be considered to be in order.

5.0 CONCLUSIONS

Water balance approach, essentially a lumped model study, is a viable method of establishing the rainfall recharge coefficient and for evaluating the methods adopted for the quantification of recharge and discharge from other sources.

In the present study, the seasonal groundwater balance, i.e. for monsoon and non-monsoon seasons for the period 1981-82 to 1989-90 has been conducted in the Central Godavari Delta of E.G.Dist of Andhra Pradesh. With the available information on physical and hydrological characteristics of the study area, various water balance components were identified. The independent estimates of these water balance components except rainfall recharge were also worked out by analysing the relevant data. The recharge from rainfall was calculated during the monsoon season using the water balance approach. The recharge coefficients(recharge/rainfall ratio) calculated on the basis of seasonal rainfall (monsoon rainfall) vary between 0.134 to 0.172. It is observed that a maximum possible recharge takes place for a rainfall amount of about 950 MCM. The further rainfall beyond 950 MCM goes as runoff with little or no recharge to ground water reservoir.

For non-monsoon seasons, the unaccounted water has been found to be less than 31 MCM in all the years of study. In view of the complicated hydrologic system and therefore the interactions between various water bodies and the aquifer system of the study area of Central Godavari Delta, the discrepency of 31 MCM can be considered within reasonable limits and further indicates a reasonable degree of accuracy in quantification of the various components.

The chemical analysis data of ground water samples collected from observation wells spread over the study area indicate that the high TDS values to the order of 2000 are also found in about 88 Sq.Kms. i.e. about 11 % of the total study area. Such a high TDS values have been observed especially in the wells located near the two arms of river Godavari i.e. Gowthami and Vasista. The data analysis indicates that there is no sea water intrusion directly from the sea into the ground water aquifers. However, sea water during high tides rushes into the river arms upto a considerable distance and leads to the infiltration of salts through river bed and banks into the fresh water aquifers.

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RECOMMENDATIONS OF THE GROUNDWATER ESTIMATION COMMITTEE (1983)

The ground water estimation committee, after making a review of the various aspects and after considering the data collected by the Central Ground Water Board, State Ground Water Organisations, Research Organisations, Universities and the report of the Ground Water Over Exploitation Committee, have made the following recommendations.

It is recommended that the ground water recharge should be estimated based on ground water level fluctuation method. However, in areas, where ground water level monitoring is not being done regularly, or where adequate data about ground water level fluctuation is not available, adhoc norms of rainfall infiltration may be adopted. As a guideline, following norms may be adopted.

1. Recharge from Rainfall:

(i) Alluvial areas

In sandy areas	20 to 25% of normal rainfall
In areas with higher clay content	10 to 20% of normal rainfall

(ii) Seim-consolidated sandstones-friable and highly porous — 10 to 15% of normal rainfall

(iii) Hard rock areas

Granite terrain-weathered and fractured	10 to 15 % of normal rainfall
Unweathered	5 to 10% of normal rainfall
Basaltic terrain vesicular and jointed basalt	10 to 15% of normal rainfall

Weathered Basalat 4 to 10% of normal rainfall

Phyllites, limestones, sandstones, quartzites, shales, etc 3 to 10% of normal rainfall

The normal rainfall figures may be taken as given by India Meteorological Department. The ranges indicated above are given as a guideline and it does not automatically imply that upper limit can invariably be applied. Based upon the status of knowledge available, a values in between should be chosen.

2. Recharge due to seepage from unlined canals:

The following norms recommended by Ground Water Over Exploitation Committee may be adopted.

(i) For unlined canals in normal type of soil with some clay content along with sand,
15 to 20 ha m/day/10**6 sq.m of wetted area of canal or 6 to 8 cusec/10**6 sq.ft of wetted area of canal or 1.8 to 2.5 cumec/10**6 sq.m. of wetted area.

(ii) For unlined canals in sandy soils,
20 to 30 ha m/day/10**6 sq.m. of wetted area or 10 to 12 cusec/10**6 sq.ft of wetted area or 3 to 3.5 cumec/10**6 sq.m. of wetted area.

(iii) For lined canals, the seepage losses may be taken as 20% of the above values.

3. Return Seepage from irrigation fields:

(i) Irrigation by surface water sources
a) 35 % of water delivered at the outlet for application in the field.

b) 40 % of water delivered at the outlet at outlets for paddy irrigation only.

(ii) Irrigation by ground water sources

30% of the water delivered at outlet. For paddy irrigation 35% as return seepage of the water delivered may be taken.

In all the above cases return seepage figures include losses in field channel and tese should not be accounted for seperately.

4. Seepage from tanks:

Studies have indicated that seepage from tanks varies from 9 to 20% of their live storage capacity. However, as data on live storage capacity of large number of tanks may not be available, see seepage from the tanks may be taken as 44 to 60 cm. per year over the total water spread. 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 as applied to tanks, may be taken. The recharge component from percolation tanks, so computed, should be distributed for utilisation purposes under its (percolation tanks) command only.

5. Contribution from Influent seepage :
Influent seepage from the rivers with a definite influent nature may be computed by using Darcy's law,

$$Q = T * I * L$$

where,

Q = rate of flow,
T = transmissivity of the aquifer
I = Hydraulic gradient, and
L = length of section through which flow is taking place.

Annual recharge:

The annual recharge includes the following components ----

Total annual recharge = recharge during monsoon + nonmonsoon rainfall, recharge + seepage from canals + return flow from irrigation + inflow from influent rivers etc + recharge from submerged lands, lakes etc.

Losses of groundwater from aquifers mainly arise out of the following fators.

1. Outflow to Rivers:

A river may have a losing reach or a gaining reach depending upon the relative water levels in the river and the adjoining aquifers. For losing reaches the effect on ground water regime is additive. In gaining reaches contribution from ground water to the river is confined to a relatively small strip adjoining the stream.

2. Transpiration by Trees:

Transpiration by deep rooted trees results in depletion of ground water equivalent to supplementary water requirement of tree for its growth. This is a loss to ground water and has to be regarded as unrecoverabls.

3. Evapotranspiration from shallow water table :

This is controllable situation. These losses reduce to negligible proportion once the water table falls about 3mts below the ground level. As such these losses need not be accounted for in ground water estimates. It is recommended that in water logged and shallow water table zones, ground water may be developed till the water level reaches 5 mts below ground level. The resources estimated based on the premonsoon water level to 5 mts depth are potential and would be available for development in addition to the annual recharge in these areas.

The total ground water resource computed would be available for irrigation, domestic and industrial uses. The base flow in rivers is a regenerated ground water resource and is some times committed for lift irrigation shemes, and other surface irrigation works. It is, therefore, recommended that 15% of total ground water resources be kept for drinking and industrial purposes for committed baseflow and to account for the unrecoverable losses. The remaining 85% subject to the stipulation specified can be utilized for irrigation purposes.

The norms of development for various types of structures vary from state to state depending upon the existing agricultural practices, local hydrogeological conditions, availability of power etc. and as such it is recommended that regional norms may be developed based on sample surveys. In case of Public tubewells, data for discharge and running hours is already available and that should be used for computation of draft.

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