CONJUNCTIVE USE PLANNING IN KRISHNA (NAGARJUNASAGAR) - PENNAR (SOMASILA) LINK CANAL COMMAND

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE'S DECLARATION

I do hereby certify that this dissertation entitled " CONJUNCTIVE USE PLANNING IN KRISHNA (NAGARJUNASAGAR) - PENNAR (SOMASILA) LINK CANAL COMMAND" being submitted, in partial fulfillment of the requirements for the award of the degree of Master of Technology in WATER RESOURCES DEVELOPMENT, to Water Resources Development Training Centre, Indian Institute of Technology, Roorkee, is an authentic record of my own work carried out during the period from 16th July to 30th November, 2002 under the guidance of **Dr. Deepak Khare**, Associate Professor, Water Resources Development Training Centre, Indian Institute of Technology, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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SYNOPSIS

The available surface water resources are not adequate enough to cover the entire cultivated area in the country. It is estimated that even on full exploitation, the available surface water resources could cover only half the cultivated area for irrigation. It is, therefore, important that both the surface and groundwater resources have to be used in an integrated manner, by planning conjunctive use rightly recommended by National Water Policy-1987 and further stressed in the recently framed National Water Policy-2002. The policy recommends planning for conjunctive use right at the formulation of the project itself. Even in the existing irrigation projects, the conjunctive use planning has a great scope in optimum utilization of both the resources. Conjunctive use has been practiced in the country in some form or the other, although it may not have been done in a planned manner.

Conjunctive use is the combined and integrated management of surface water and groundwater for optimal utilization of available water resources. Any conjunctive use model consists of an optimization model. This optimization model is required for conjunctive use planning to obtain optimal cropping pattern, allocation of surface and groundwater resources, besides satisfying a series of constraints.

Krishna (Nagarjunasagar) - Pennar (Somasila) link canal is one of the link canals proposed under Peninsular Rivers Development component of National Perspective. The present work is an attempt to apply conjunctive use planning in the proposed command of Krishna (Nagarjunasagar) - Pennar (Somasila) link canal command so that water resources from both the surface water and groundwater are put to use to maximum extent. This results in saving of surface water that has already been allocated for this command area. This saved surface water can be used in other needy areas. Also, another advantage is that water logging problem can be minimized as the groundwater table is at shallow depth in this command area. Various alternatives are studied to arrive at the optimal allocation of water resources under different scenarios.

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

Water is the most essential natural resource next to air, required for sustaining life on earth. It is required for drinking and industrial use, for irrigation to meet the growing food and fiber needs, for power generation, navigation and recreation. The development, utilization and conservation of water, therefore, play a vital role in the country's development planning. Water resources development planning shall aim at assuring accelerated growth by contributing to the country's economic and social advancement, and improving the general social and economic conditions of the population, while keeping the environmental and ecological balance. The water resources in country are, however, limited considering the future demands. The rainfall in the country is mostly confined to monsoon season and is unevenly distributed with respect to both time and space. As a result, some parts of the country are affected by frequent droughts whereas other parts affected by floods. In the very near future, water will become a scare resource due to increasing thrust of population and increasing demands for various uses. Therefore, it need not be emphasized that water should be harnessed in the most scientific and efficient manner.

In India, mainly the irrigation is being done by either surface water or groundwater or combination of the two. Where canal irrigation is introduced in any region, recharge component increases and may cause problem of water logging in absence of proper drainage. In the areas, where canal irrigation has not been introduced, irrigation requirement in general is met by the groundwater withdrawals. However, large groundwater withdrawals can lower the groundwater table excessively. The decline in the level of groundwater is mainly due to withdrawal in excess of annual recharge, variation in the amount and distribution of rainfall, reduction in recharge of groundwater due to increased urbanization, deforestation and adoption of water intensive cropping by farmers. This lowering of the water table can render many shallow wells dry, reduce the base flow in the hydraulically connected rivers and induce salt-water intrusion in the coastal aquifers. The reduction in base flow can adversely affect the ecology of the surrounding regions, operation of the downstream surface water projects and quality of surface water.

It is therefore, important that all the aspects of water resources projects are to be considered in total i.e., combined use of surface water and groundwater so as to maximize the benefits that accrue from the combined use and for effective water management. For this, an integrated and multi-disciplinary approach to planning, evaluation, approval and implementation of irrigation and drainage projects, including river basin management of surface and groundwater is needed.

1.2 Conjunctive Use

The co-ordinated use of surface water and groundwater is likely to reduce most of the above mentioned problems. This also tends to get maximum benefits by adopting the optimal policies. This coordinated development of surface water and groundwater has been referred to as conjunctive use. The main objective of integrated and conjunctive use of surface water and groundwater is to optimize the available water resources and raising the level of reliability of supplies. The coordination in use of surface and groundwater depends on hydrologic, agronomic, economic management and social factors, basic aim being optimum water use.

Surface and groundwater resources can be conjunctively used either in space or in time or in both. Surface water and groundwater resources are considered to have been utilized conjunctively in space when part of the command is irrigated exclusively by surface water and part by groundwater. In conjunctive use in time strategy, parts of the command may be irrigated by surface water at one time of growing period or in one crop season, and by groundwater at another time of the growing period or in another crop season. Further, supplies from one source can be augmented by those from the other source in order to meet the irrigation demands adequately. The best way is to use these resources in space and time jointly.

Conjunctive use of the two resources in time can also be considered as one of the alternative to planning for carry-over especially in drought prone areas where large evaporation from carry over storage reservoirs substantially reduces the effective availability. Groundwater resources provide evaporation free carry over and can supplement the surface supplies whenever shortage are experienced.

In the present study, an attempt has been made to apply this concept to Krishna (Nagarjunasagar)-Pennar (Somasila) link canal project command area. The project is recently planned and the proposed command area is likely to get surface water from link canal. As such, no groundwater component is planned for this project. Therefore in the present work, this study area is considered to evolve the conjunctive planning strategy with the objectives described in the next para.

1.3 OBJECTIVES

The main objectives of the present study are:

1. Review of literature on the models for Conjunctive use planning of surface water and groundwater.

2. Study of the Krishna (Nagarjunasagar) - Pennar (Somasila) link canal project command area and data collection

3. To conduct the water balance of the study area.

4. To conduct the cost analysis of surface water and groundwater.

5. Formulation of Linear programming model to obtain optimal allocation polices for the optimal cropping pattern.

6. Evaluation of optimal allocation polices for the optimal cropping pattern.

7. Study of various alternatives incorporating groundwater component.

1.4 PROLOGUE

The organization of the subsequent chapters of the thesis is as follows:

Chapter 2 deals with the literature review pertaining to different types of conjunctive use models, the previous attempts, various general considerations and planning

Chapter 3 gives brief description of Krishna (Nagarjunasagar)-Pennar (Somasila) link canal project command area including hydro meteorological data of the study area.

Chapter 4 deals with economics of groundwater and surface water. This discusses the systematic procedure to get the unit cost of surface water and groundwater.

Chapter 5 gives conjunctive use model, which include the organization of groundwater model. It further gives various cases considered.

Chapter 6 briefly discusses the results

Chapter 7 gives the conclusions of results, recommendations and scope for further study.

Finally references are given.

CHAPTER 2
LITERATURE REVIEW

2.1 GENERAL

Attempts have been made by different researchers to study the optimal allocation of land, water and other resources for various uses. However, no engineering analysis for conjunctive use of surface and groundwater is available till late 50's. Initially the studies were qualitative in nature while quantitative aspects gained importance afterwards. The problem of selecting the best strategy for conjunctive use of surface water and groundwater is quite complex and can be handled more conveniently with the help of tools of system engineering. A number of approaches to the solution of such problems using formal methods of optimization have appeared in the last four decades, i.e., dynamic programming, simulation, linear and non linear programming etc. The text of the present chapter provides in brief the review of techniques used by various researchers for the Conjunctive use.

2.2 SOLUTION TECHNIQUES

The solution techniques for conjunctive use management are based on different optimization methods viz., Dynamic Programming, Simulation, Linear, Non-Linear Programming etc.

Wills, Finney and Zang (1989) presented a non- linear conjunctive use planning model. The optimization model maximizes the net benefits from the production of three crops over one year planning horizon. The cost of production includes the distribution costs of river water, fertilizers and non-linear groundwater pumping costs. Agricultural production function has been developed from the past studies. The groundwater hydraulic response equations are developed using finite element method

Latif and James (1991) have used a simulation model for maximizing the net income of irrigation through cycles of wet and dry years for long term. The model determines the optimal groundwater extraction for supplementing canal to avoid adverse effects due to high (water logging and salinity) or low (high pumping cost) groundwater levels. Decision variables were the crop area, well size, management of allowable deficit and target depths to water table control zones.

Onta, Gupta and Harboe (1991) have developed stochastic dynamic programming model for conjunctive use planning of Bagmati River basin in Nepal. This model is used to derive the long-term operation guidelines for alternative plans. Then, a lumped simulation model is used to evaluate the alternative plans and finally a multi-criteria decision making method is used to select the most satisfactory alternative plans for water allocation.

Matsukawa, Finney and Wills (1992) have developed an optimization model using non-linear programming algorithm. This model explicitly incorporates the hydraulics of the surface water and groundwater system and water supply, hydropower and groundwater cost and benefit objectives. Operational constraints on the blended surface water and groundwater were used to meet the municipal demand and minimum in-stream flow needs downstream of water supply abstraction point.

Getachew Belaineh et al., (1998) presents a simulation/optimization model that integrates linear reservoir decision rules, detailed simulations of stream/aquifer system flows, conjunctive use of surface and groundwater, and delivery via branch canals to water users. State variables, including aquifer hydraulic head stream flow and surface water/aquifer interflow, are represented through discretized convolution integrals and influence coefficients. Results of application to a hypothetical study area under several scenarios indicate that the more details used to represent the physical system, the better the conjunctive management.

Pamela G. Emch and William W-G. Yeh (1998) developed a model for managing water use within a coastal region. Two conflicting objectives are considered: cost effective allocation of surface water and groundwater supplies and minimization of salt water intrusion. Optimal control of the system is examined by studying the response of these objectives to changes in groundwater pumping rates and transfer of surface water between sources and users. The objectives, some of the constraints and the groundwater flow equations are formulated as non-linear functions of the decision variables. The flow model simulates the flow of the groundwater using quasi three-dimensional finite difference model based on the sharp interface assumption. The multi objective aspect of the problem is solved using constraint method.

Ehsanolah Malek-Mohammadi (1998) carried out a work for developing irrigation system. In this work, surface reservoir capacity, groundwater and spring withdrawal, delivery system capacities (including canals, pumping stations and tunnels), hectares of land to be developed for irrigation and cropping pattern are considered as interacting parts of the system besides cost due to drainage, land leveling and irrigation network construction. The system is optimized by means of a chance constraint optimization model. The model uses mixed integer linear programming to maximize the net benefit associated with the development. Results generated by the application of the model, along with the sensitivity analysis, provide a tool to select the optimum design considering the varieties of criteria involved.

Tracy Nishikawa (1998) has developed a simulation-optimization model for optimal management of the city of Santa Barbara's water resources during a drought. The model which, links groundwater simulation with linear programming, has a planning horizon of 5 years. The objective is to minimize the cost of water supply subject to: water demand constraints, hydraulic head constraints to control sea water intrusion, and water capacity constraints. The decision variables are monthly water deliveries from surface water and groundwater. The drought of 1947-51 is the city's worst drought on record, and simulated surface water supplies for this period were used as a basis for testing optimal management of current water resources under drought conditions. This simulation-optimization model was applied using three reservoir operation rules. In addition, the model's sensitivity to demand, carryover [the storage of water in one year for use in a later year(s)], head constraints, and capacity was tested.

The other people who used this simulation model for maximizing the benefits are Roger, Smith (1970) Chadra and Pande (1975), Lakshminarayana and Rajagopalan (1977), Yoganarasimhan and Chand (1979) Chandi and Sinha (1988), and Kashyap and Chandra (1982).

2.3 CONCLUDING REMARKS

The literature review reveals that in conjunctive use models system approach and its framework of mathematical models have been widely used by various investigators for solving complex problems involving complexity and extensive data requirements. However, these models are still unknown to the practicing engineers and planners, particularly in developing countries like India. In the present study, linear programming technique is used to obtain the various alternative allocation plans of surface water and groundwater.

CHAPTER 3
THE STUDY AREA AND DATA ACQUISITION

3.1 GENERAL

This chapter deals with a general description of the study area i.e., new command area under the Krishna (Nagarjunasagar)-Pennar (Somasila) link canal project identified by National Water Development Agency (NWDA). Salient features of the region and various data acquired for the present study are presented in the subsequent paras.

3.2 ABOUT THE PROJECT

National Water Development Agency (NWDA), a Government of India society under Ministry of Water Resources has proposed a series of link canals as part of Peninsular Rivers Development component of National Perspective for water resources development. The Krishna (Nagarjunasagar)-Pennar (Somasila) link canal project is a component of it and envisages diversion of 12146 Mm^3 of water from Nagarjunasagar reservoir, constructed across the Krishna river. The total length of the link canal is 392.02 km. The canal will run parallel and adjacent to existing NSRBC up to its tail end at 202.75 km, and then traverses a distance of 190.27 km before joining Somasila reservoir on the Pennar River. NWDA has identified a new area that could be brought under irrigation in the districts of Prakasam and Nellore to the tune of 168017 hectare for which water is proposed to be supplied from the link canal. Index map of the proposed link canal is shown in Plate1. The proposed command area under the Krishna (Nagarjunasagar) - Pennar (Somasila) is shown in Plate 2. Plate 3 shows the natural drainage and communications in the command area while Plate 4 is the contour map of the command area.

For identifying the cultivable area and to ascertain irrigability of land, satellite remote sensing techniques were made use of by NWDA with help of National Remote Sensing Agency (NRSA). A cropping pattern was devised by NWDA appropriate to the command area with the intensity of cropping as 100 %. The irrigation water requirement is estimated to be 908 Mm^3 as per climatological approach. Apart from irrigation, it was also proposed to provide for future domestic and industrial water requirements in the command area. Additional domestic and industrial requirements projected to 2050 AD are estimated to be 55 Mm^3 and 69 Mm^3 respectively.

3.3 HYDRO-METEOROLOGICAL DATA OF THE STUDY AREA

The identified new command area lies in the districts of Prakasam and Nellore of Andhra Pradesh. The hydro-meteorological description of the area is as under:

3.3.1 Rainfall: The area receives rainfall from two monsoons viz., the south- west and the north-east. June to December is considered as monsoon period. The maximum, minimum and average annual rainfall are 1022 mm 594 mm and 752 mm respectively. Considering the rain gauge stations situated in and around the proposed command area (study area), the weighted rainfall has been worked out for the last 5 years. Details are given in Table 3.1.

TABLE 3.1: WEIGHTED RAINFALL IN THE COMMAND AREA

Year	Weighted rainfall in mm
1994-95	1236.7
1995-96	564.6
1996-97	1206.0
1997-98	1041.5
1998-99	1036.7

3.3.2 Temperature

The monthly mean maximum and minimum temperatures the study area are 40.3^0 C in the month of May and 19.1^0 C in the month of December.

3.3.3 Relative Humidity

The coastal region is humid through out the year, while the interior is humid during July to November. The maximum and minimum values of relative humidity observed are 84 % and 36 % respectively.

3.3.4 Wind Speed

Winds are generally light to moderate in the late summer and early southwest monsoon, when they strengthen. From November to January the winds generally blow in the north and northeasterly direction. The maximum wind speed in the area is 11.6 km/hr in June and minimum is 4.30 km/hr in December.

3.3.5 Cloud Cover

The sky is generally heavily clouded to over cast during the southwest monsoon season. During the remaining part of the year, clear or lightly clouded sky prevails. The maximum cloud amount is 6.7 Octas in the month of July and minimum is 1.5 Octas in the month of January.

3.4 HYDRO-GEOLOGY OF THE STUDY AREA

Hydro geological studies carried out by Central Ground Water Board (CGWB) in the Prakasam and Nellore districts of Andhra Pradesh indicate that the geological formations in and around the study area vary widely ranging from Achaean to Recent Lateritic Alluvium.

The granites and gneisses, granetiferous biotite gneisses etc. together with migramitites which, represent the Achaean occupy as detached hills. Rocks having Charnockites affinity have been reported in northern part of the study area. Dharawars occur mainly as two north-south elonged beds in the central part of the basin, one along the eastern margin of Cuddapah district and the other between Kanigiri and Kandukur taluks of Prakasam district. The Cuddapah formations represented by the Nallamalai and Kistna series occupy the western margin of the study area. The Upper Gondwana formations occur as isolated patches in the Kandukur taluk. Laterite occurs in parts of Kandukur and Ongole taluks of Prakasam district and Kavali taluk of Nellore district capping Gondwanas and crystallines. Alluvium occurs in the eastern part of the study area.

In the study area, groundwater occurs in all the geological formations from oldest crystalline to recent alluvium. Groundwater occurs under the water table condition in Archean and Lower Precambrian formations in the weathered zones and semi confined and confined conditions in joints, fissures and other weak planes. The depth of wells in the crystallines varies from 3 to 27 m below ground level and the depth of water level varies from 1.5 m to 14.5 m below ground level. The yield of the domestic and irrigation wells observed by CGWB vary from 1 to 1.5 m^3 per hour. Groundwater occurs under unconfined to confined condition in Cuddapah formations. The depth of wells varied from 5.84 to 14.5 m below ground level and depth of the water level ranges from 5 to 12 m below land surface. The laterite occurs as discontinuous patches in the Ongole and Kandukur taluks of Prakasam district and Kavali taluk of Nellore district fringing the Achaeans. As the formations are permeable, it is expected that the yield should be high.

The details of geological formation and command area under each formation is given in Table 3.2. Geological formations in the study area are shown in Plate 5.

TABLE.3.2: AREA UNDER EACH GEOLOGICAL FORMATION

Name of geological Formation	Area in km^2
Schist	1815
Granites and Gneisses	1065
Alluvium	552
Sand stone	513
Total	3945

3.5 GROUND WATER RESOURCES IN THE STUDY AREA

The identified new command area of the Krishna (Nagarjunasagar)-Pennar (Somasila) link canal project is proposed to be irrigated by surface water. Conjunctive use of surface water and ground water is now proposed in the present study for optimum use of both surface water and ground water. The Central Ground Water Board and State Ground Water Department are engaged in measuring the ground water levels at various observations. The water table level is recorded at the end of May/or beginning of June and is known as pre-monsoon water level. The post monsoon water levels are recorded as on 1st of November.

Data of Central Ground Water Board (CGWB) pertaining to levels of observation wells lying in the study area are collected and out of which 11 are considered as ground water nodes. Location of these nodes i.e., location of observation wells is shown in Plate 6. Table 3.3 gives depth of water level of all observation wells and the same is considered for preparation of ground water contours for all the 5 years for pre monsoon and post monsoon season. Considering these nodes and the corresponding water table levels, groundwater contours are drawn and are shown in Plate 7. Also, weighted depth of the ground water table in the study area is worked out. The average depth of groundwater in year 2001 varies from about 4.57 m in pre monsoon to 2.30 m in post monsoon seasons. Details are given in Annexure I.

TABLE 3.3: DEPTH OF WATER LEVEL FOR ALL OBSERVATIONS (IN M)

Well location		Ground Level Above m.s.l (m)	1997		1998		1999		2000		2001	
Block/ Mandal	Village		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Podili	Podili	82.71	2.42	2.04	2.46	1.82	3.80	3.50	2.55	1.95	2.48	1.16
Ponnaluru	K.Agraharam	52.63	4.22	2.67	4.44	5.23	5.30	6.40	7.81	5.25	5.55	3.18
Kandukur	Kandukur	12.52	3.74	0.66	4.26	0.05	5.80	5.25	5.91	2.02	4.90	1.79
Ulavapadu	Ulavapadu	7.07	2.19	1.20	3.78	0.35	4.00	3.61	5.37	2.45	5.15	1.53
Pamur	Pamarru	112.72	2.97	2.59	4.08	1.43	4.60	4.70	5.78	3.86	6.80	2.46
K K Mitla	Chautapalle	135.00	6.21	4.52	6.17	2.02	7.86	7.25	7.68	6.50	5.10	6.70
Tangutur	Tangutur	10.00	2.61	0.50	3.05	0.05	4.30	3.30	6.85	0.34	3.13	0.46
K K Mitla	Peddarikatla	125.00	5.82	5.48	6.74	0.93	6.60	7.25	8.16	1.67	5.97	1.57
P C Palli	Pedda alavapadu	90.00	2.97	1.29	2.98	1.29	3.70	4.40	4.88	2.93	3.45	3.01
Konda Puram	Konda Puram	50.20	5.82	4.10	5.57	2.21	6.90	7.25	6.72	4.96	4.19	2.00
Varikunta Padu	Varikunta Padu	100.60	2.97	2.59	4.08	1.43	4.60	4.70	5.78	3.86	4.38	2.00

Based on the CGWB data, the ground water resource in the study area has been estimated. The details are as under:

Net recharge	: 48210 hectare mater
Draft	: 7380 hectare mater
Net balance	: 40830 hectare mater

3.6 SURFACE WATER RESOURCES IN THE STUDY AREA

The Krishna (Nagarjunasagar) - Pennar (Somasila) link canal project is one of the links under Peninsular Rivers Development component of National Perspective of Govt. of India and envisages diversion of 12146 Mm^3 of water from Nagarjunasagar reservoir to Somasila reservoir. En-route, it is proposed to irrigate an area of 168017 hectare in the districts of Prakasam and Nellore of Andhra Pradesh for which water is proposed to be supplied from this link canal. The geographical area under study is 376067 hectare excluding the land covered by water. The study area is divided into three zones viz., consisting of the following branch canals:

Zone	Name of the branch canal
I	Mangapuram branch canal, Kellampalli branch canal, Kuchipudi branch canal, Kanigiri branch canal
II	Chundi branch canal, Pamuru branch canal, Varikuntapadu branch canal,
III	Narravada branch canal

3.7 EXISTING IRRIGATION IN THE PROPOSED COMMAND

The link canal in its course from Nagarjunasagar to Somasila passes through the basin area covered by the streams between Gundlakamma and Pennar rivers, where the existing irrigation facilities are minimal. Hence, it is proposed to provide these areas falling in the Prakasam and Nellore districts of Andhra Pradesh with irrigation from water diverted through the canal.

The existing irrigation in the proposed command is about 17 % of the gross cropped area, indicating that the agriculture in the area is mainly rain fed. The existing sources of irrigation are mainly tanks and tube wells. There are about 8000 dug wells, 550 tube wells, and 290 tanks and kuntas in the proposed command area. Out of the total area presently irrigated, 39 % is by wells, 34% by tanks, 19% by canals and rest is by other sources.

The source wise irrigation in the proposed command area during the year 1993-94 as assessed from mandal wise statistics is presented in Table 3.4.

Table: 3.4: Source wise irrigation in the command area in the year 1993-94

Sl no.	District	Canals	Area irrigated by (hectare)			Total in hectare
			Tanks	Wells	Other Sources	
1	Prakasam					
	Kharif	-	2272	7162	1268	10702
	Rabi	7418	10908	8455	1369	28150
	Total	7418	13180	15617	2637	38852
2	Nellore					
	Kharif	9	264	1036	6	1315
	Rabi	1346	1984	746	777	4853
	Total	1355	2248	1782	783	6168
3	TOTAL					
	Kharif	9	2536	8198	1274	12017
	Rabi	8764	12892	9201	2146	33003
	Annual	8773	15428	17399	3420	45020

There are four existing medium irrigation projects viz., Bitragunta project, Mopad reservoir, Rallapadu reservoir and Nakkalagandi project with a total designed annual irrigation of 13116 hectares and designed annual utilization of 182 Mm^3. Thus the existing irrigation facilities in the proposed command area are very meagre. A satellite map showing the crop land and other categories in the command area are shown in Plate 8.

3.8 CURRENT AGRICULTURE SCENARIO AND EXISTING CROPPING PATTERN IN THE PROPOSED COMMAND

The total area available for cultivation in the proposed command area as estimated by National Remote Sensing Agency (NRSA) from satellite data is 230808 hectares. The net sown area is 205697 hectares of which 55298 hectares is cultivable during both Kharif and Rabi seasons, 143151 hectares exclusively in Kharif and 7248 hectares in rabi season.

The principal crops grown in the area are red gram, jower, groundnut, bajra, paddy and oil seeds during the Kharif season and paddy, tobacco, groundnut, and chillies during Rabi season. Paddy, tobacco and pulses are the main crops each being cultivated in about 20% of the net area sown in the proposed command.

3.9 PROPOSED IRRIGATION IN THE COMMAND

3.9.1 Soil And Land Irrigability Classification

The entire command area was assessed for irrigability classification by NRSA making use of the thematic maps generated from satellite data of the area. The land irrigability classification details of the proposed command area based on the characteristics of both soils and land availability as prepared by NRSA are as given in Table 3.5. Details of soils in the command area are given in Plate 9.

TABLE. 3.5: LAND IRRIGABILITY CLASSIFICATION IN THE STUDY AREA

Sl.No.	Details	Area in lakh hectares
1	Area of land with moderate limitations for sustained use under irrigation	2.03
2	Area of land with severe to very severe limitations for sustained use under irrigation	1.43
3	Area not suitable for sustained use under irrigation temporarily or other wise	0.30
	Total	3.76

The area under item 1 above i.e., 2.03 lakh hectares of the command area is considered to be the possible command area, which could be provided with irrigation. Out of this area, forest, scrubs and barren land occupy 34983 hectares. Thus, the net culturable area available for irrigation is 168017 hectares.

3.9.2 Layout Of Branch Canals/Distributaries In The Command

The 1:25000 scale toposheets with contours at 5 m interval of the command area prepared and supplied by Survey of India were used for this purpose. Considering the information on the ground elevation available on these maps, branch canals network was drawn with the branch canals/distributaries running mostly along the ridges between the local streams, with their commands on both sides extending upto the streams, which in turn form the exterior boundaries of the command under each of the branches. The layout of the branch canals/distributaries so finalized was transposed to the land irrigability maps of the same area in 1: 50000 scale prepared and supplied by NRSA.

3.9.3 Suggested Cropping Pattern

The cropping pattern suggested for future minor projects in the preliminary water balance report of the basin area covered by the streams between Gundlakamma and Pennar prepared by National Water Development Agency has adopted without any change for the proposed command area under link canal. The cropping pattern has been suggested taking into account the soils available in the basin area and prevailing agricultural / irrigation practices. The intensity of irrigation is considered as 100%. The proposed cropping pattern for irrigation of the command area en route the link canal is given in Table 3.6.

TABLE. 3.6: PROPOSED CROPPING PATTERN

Crops	% of CCA
Kharif	
Paddy	15
Jowar	10
Bajra	4
Cotton	9
Fodder	4
Chillies	4
Tobacco	4
Ground nut	5
Pulses	5
Rabi	
Paddy	10
Jowar	10
Groundnut	10
Pulses	5
Fodder	5
Total	**100**

3.9.4 Crop Water Requirement

The proposed command area is falling in the basin of streams between Gundlakamma and Pennar rivers. The crop water requirement has been computed based on climatological approach. There are 3 India Meteorological Department observatories at Ongole, Cuddapah and Nellore around the proposed command area for which data pertaining to normal rainfall, evapo-transpiration and rainfall are available. These have been used in computing the net and gross irrigation requirements of different crops as per the suggested cropping pattern. The gross irrigation requirements of the crops have been worked out to be 907.50 Mm^3. Computation of the month wise water requirement for proposed en-route command area (i.e., study area) as worked out in Feasibility Report of Nagarjunasagar - Pennar (Somasila) link canal project is given in Table 3.7.

Table 3.7: Month wise water requirement in the study area in Mm^3

Crops	Months												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Kh Paddy	-	-	-	-	-	14.7	117.2	90.2	73.0	3.4	-	-	298.5
Jowar	-	-	-	-	-	5.2	9.4	20.3	6.7	1.3	-	-	42.9
Bajra	-	-	-	-	-	2.1	3.7	8.1	2.7	0.5	-	-	17.1
Cotton	-	-	-	-	-	4.3	8.4	9.7	13.2	5.5	4.7	4.2	50.0
Fodder	-	-	-	-	-	2.1	3.7	8.1	2.7	0.5	-	-	17.1
Chillies	-	-	-	-	-	1.1	3.7	8.7	1.9	0.3	-	-	15.7
Tobacco	10.7	10.8	-	-	-	-	-	-	-	0.3	1.4	7.1	30.3
G Nut	-	-	-	-	-	6.5	10.0	2.6	-	-	-	-	19.1
Pulses	-	-	-	-	-	6.5	10.0	2.6	-	-	-	-	19.1
Rb Paddy	65.6	41.6	-	-	-	-	-	-	-	-	55.6	57.3	220.1
Jowar	-	16.7	40.3	25.7	-	-	-	-	-	-	-	-	82.7
G Nut	17.2	-	-	-	-	-	-	-	-	4.5	3.4	16.6	41.7
Pulses	1.2	-	-	-	-	-	-	-	-	1.6	1.7	7.2	11.7
Fodder	-	8.3	20.2	12.9	-	-	-	-	-	-	-	-	41.4
Total	94.7	77.4	60.5	38.6	-	39.1	160.8	157.0	102.3	17.9	66.8	92.4	907.5

CHAPTER 4
OPTIMIZATION OF SURFACE WATER AND GROUNDWATER

4.1 GENERAL

In the present study, it is proposed to evaluate the operational polices of supply of surface water and groundwater in the canal command. As per the project proposal, the entire irrigation is to be met by surface water through the link canal. In general, NWDA does not consider the groundwater component in supplying the irrigation water. Therefore, in the present study, the recently planned scheme "Krishna (Nagarjunasagar) - Pennar (Somasila) link canal" is considered to demonstrate the application of conjunctive use in planning the water resources. The aim of the present study is to optimize the surface water and groundwater allocation in meeting all the irrigation demands of the command area under Krishna (Nagarjunasagar) - Pennar (Somasila) link canal at minimum cost or maximum benefits. For analysis purpose, the study area is divided into three zones. The proposed area for cropping, and water requirement are given in Table 4.1 for each zone.

TABLE 4.1: ZONE WISE PROPOSED IRRIGABLE AREA AND WATER REQUIREMENT

Zone	Irrigable Area in ha	Water requirement in hectare meter
Zone I	103523	47070
Zone II	62153	42150
Zone III	2341	1530
Total	168017	90750

4.2 APPROACH FOR OPTIMIZATION OF WATER RESOURCES

Optimization involves coordinated planning and use of surface and groundwater resources to meet the needs in such a way that the cost is minimum or benefit is maximum. It requires facilities such as surface water distribution and pumping of groundwater. In the present study, the crop-planning model is formulated and various inputs for the model are described in subsequent paras.

4.3 BASIC DATA

4.3.1 Surface Water Availability

The month wise water requirement in the command area is worked out based on climatological approach. Details are given in Chapter 3. (Table no 3.5). This is used in the surface water availability constraints.

4.3.2 Groundwater Balance

Groundwater availability depends on the recharge due to rainfall, surface water utilization for irrigation and other uses.

i) Groundwater availability due to recharge

a) **Recharge due to rainfall**: Recharge due to rainfall depends on rainfall recharge factor. The rainfall recharge factors (R_r) and specific yield (S_y) for each of the geological formation are adopted as given by Groundwater Estimation Committee (GEC) 1997, which are shown in Table 4.2

TABLE 4.2: RAINFALL RECHARGE FACTORS AND SPECIFIC YIELD OF DIFFERENT GEOLOGICAL FORMATIONS

Name of geological Formation	Area In Km^2	Rainfall recharge Factors	Specific yield
Schist	1815	0.11	0.03
Granites and Gneisses	1065	0.05	0.015
Alluvium	552	0.16	0.16
Sand stone	513	0.12	0.03
Weighted		0.102	0.0618

(Source: Groundwater Estimation Committee (GEC)-1997 report.)

The total groundwater recharge due to rainfall is worked out for 5 years. Average of these 5 years is considered as the recharge due to rainfall in the command area as shown in Table 4.3.

TABLE 4.3: RECHARGE DUE TO RAINFALL

Year	Weighted rainfall In mm	Weighted Rainfall recharge Factor	Command Area in ha	Total recharge in Hectare meter
1994-95	1236.7	0.102	394514	49765.3
1995-96	564.6			22719.7
1996-97	1206.0			48530.0
1997-98	1041.5			41910.4
1998-99	1036.7			41717.3
Average				40928.5
			Say	41000.0

Out of 41000 ha m, 70 % is considered to contribute to groundwater i.e., 41000*0.7=28700 hecatre meters. Out of this 85% is accounted for irrigation and remaining 15% for domestic and industrial purpose as per GEC 1984. Thus the recharge available for irrigation will be 24395 hectare meter

b) Recharge due to field losses in canals: The irrigation requirement from surface water is estimated to be 90750 hectare meter at the head of main branch canal. 20% of this considered to be losses and 75% of these losses are assumed to recharge the groundwater. Hence the quantity of water reaching sub-surface is

90750 X 0.20 X 0.75 = 13613 hectare meter

c) Recharge due to field losses in distribution canals : The losses in the distribution channels are assumed as 30% of the quantity i.e., 72600 (90750-90750*0.2) hectare meter flowing through them and out of this 75% is considered to be recharging the groundwater.

72600 X 0.30 X 0.75 = 16335 hectare meter

d) Recharge due to field seepage: The losses due to seepage that recharge the groundwater in the field are assumed as 25% of the remaining quantity i.e., 50820 (72600-72600*0.3) hectare meter

50820 X 0.25 = 12705 hectare meter

e) Recharge due to existing use: The present use of water resources amounts to 53400 hectare meter of which surface water is of the order of 30861 hectare meter and that of groundwater is 22539 hectare meter.

Case I: 30% of the existing groundwater use is considered as losses and 80% of it is considered as recharge. Thus, the recharge to groundwater use works out to =22539*0.3*0.8=5366 hectare meter.

Case II: Total existing use of water resources in the study area is estimated as 53400 hectare meter and 30% of the existing surface and groundwater use is considered as losses and 80% of it is considered as recharge. Thus the recharge to groundwater use works out to 53400*03*08 = 12816 hectare meter.

f) Total recharge:

Case I: Recharge due to rainfall, existing groundwater use and proposed surface water use works out to 24395+ 5366 + 13613 +16335+12705 = 72414 hectare meter

Case II: Recharge due to existing surface water and groundwater use and proposed surface water use works out to12816 + 13613 +16335+12705 = 55469

g) Evaporation losses: Minimum of the above two cases is considered as the net recharge available for development. Evaporation losses @ 20% of total recharge of 55469 hectare meter works out to (55469 * 0.20) 11094 hectare meter.

h) Net groundwater available: Therefore the quantity of groundwater available for irrigation use is = 55469-11094 =44375 hectare meter

ii) Groundwater availability by specific yield method
(Based on fluctuations in water table)

The weighted specific yield of the command area is worked out based on the geological formation and corresponding S_y values. It works out to be 0.0618.

There are many wells whose levels are monitored by CGWB. The pre monsoon and post monsoon groundwater levels of these observation wells are collected for the last 5 years and are given in Chapter 3 (Table no 3.3). The weighted depth of the groundwater in both pre monsoon and post monsoon seasons is worked out. The difference of groundwater levels between successive pre monsoon and post monsoon periods in a year have been used to workout the specific yield of the area. It works out to 42606 hectare meter.

To be on conservative side, the quantity of groundwater that is available for use is taken as the least of the above two methods i.e., 42606 hectare meter and the same has been considered as the total quantity of groundwater available for use. This is used in the groundwater availability constraints.

4.3.3 Water Requirement For Each Crop

The water requirement for each crop is worked out based on climatological approach. The details are given in Chapter 3:(Table 3.7). These are used as crop water requirement constraints.

4.3.4 Cost Of Surface Water

The capital cost of the Krishna (Nagarjunasagar) – Pennar (Somasila) link canal is Rs. 48215 per hectare meter The life of the project is considered as 100 years. Considering the interest rate as 10 %, the capital recovery factory factor (CRF) is worked out by formula

$$\text{CRF} = \frac{i(i+1)^n}{(i+1)^n - 1} = \frac{0.1(0.1+1)^{100}}{(0.1+1)^{100} - 1} = 0.100$$

Therefore The annualized cost = capital cost * CRF

Rs. 48215 * 0.1 = Rs. 4822

Total annual cost of surface water per hectare meter = Rs. 5317

(including prevailing O & M cost)

Prevailing O & M Cost per ha m = Rs. 495

Since the project has many components viz., water supply to Chennai city, inter basin transfer quantity etc., the cost of surface water per hectare meter as worked out is approximate. Hence cost of O & M for surface water per hectare meter i.e., Rs.495 is considered in the analysis.

4.3.5 Cost Of Groundwater

The cost of groundwater is worked out as follows:

Sl No	Details	Amount in Rs.
1	Drilling Charges for 100 mm dia bore up to an average depth of 30 m	5000
2	PVC casing pipe 6 inch size @ Rs 200/ m for 6 m	1200
3	G I Pipe 2" size @ Rs.320/m for an average depth of 25 m with all couplings and other accessories	8000
4	3 HP pump set with all accessories	12500
5	Pump shed with brick wall and tin shed	4000
	Total	**30700**
	Annualized capital cost + Energy charges 30700*0.1315(CRF)+3060	7097
	Power required in kwh = 3HP*0.75	2.25
	Total power required in kwh = 160 day * 10 hr * 2.25	3600
	Minimum tariff per kwh in Rs.	0.85
	Total energy cost 3600*085	3060
	Cost per hectare meter (3060/1.28)	2391
	(for 8000 lps @ 10 hrs pumping per day for 160 days need 1.28 hectare meter draft as per GEC – 1997 Report) from an average depth of 30 m.	
	O & M @ 3 % of capital cost	921
	Total maintenance cost of groundwater in Rs.(2391+921)	3312

The same(O&M cost) is used as cost of groundwater per hectare meter.

4.4 CONJUNCTIVE USE PLANNING MODEL

Linear planning technique is used as an optimization model. The program is used to arrive at the optimal allocation of surface and groundwater with designed cropping pattern, keeping in view the constraints and to maximize the benefit within the frame work of given constraints. In the present study, LINDO 6.1 is used for linear programming solution.

4.4.1 The Lump Model

To solve the linearized model and to get the optimal allocation of the surface water and groundwater, the LINDO program is used. The basic components are;

- **The objective function**

  MAX (Net benefits – cost of surface water - cost of groundwater)

- **The constraints**

  1. Crop water requirement constraint

     Water required = Surface water + Groundwater
  2. Area availability constraint

     Cropping area ≤ CCA
  3. Surface water availability constraint

     Surface water allocation ≤ Surface water available
  4. Groundwater availability constraint

     Groundwater allocation ≤ Groundwater available
  5. Crop area constraint

     Crop area in each zone ≤ CCA in that zone
  6. Crop area constraint

     Area under each crop ≤ Crop intensity X CCA

4.4.2 Formulation of the objective function

a) Benefits from crops can be written as

$$\sum_{i=1}^{nz}\sum_{j=1}^{nc} A_{ij} * (Y_j P_j - ccl_j) \quad \text{or}$$

$$\sum_{i=1}^{nz}\sum_{j=1}^{nc} A_{ij} * NB_j$$

where

nz = No of zones

nc = No of crops

A_{ij} = Area of j^{th} crop for i^{th} zone (ha)

Y_j = Yield of j^{th} crop (q / ha)

P_j = Price of j^{th} crop (Rs / q)

ccl_j = Cost of cultivation of j^{th} crop

NB_j = Net benefits of j^{th} crop

b) Cost of surface water

The total cost of surface water can be expressed as:

$$\sum_{i=1}^{nz}\sum_{k=1}^{12} (CSC_i + CSO_i) SW_{ik} \quad \text{or}$$

$$\sum_{i=1}^{nz}\sum_{k=1}^{12} CST_i * SW_{ik}$$

Where

CSC_i = Unit cost of surface water for i^{th} zone (Rs. / hectare meter)

CSO_i = Unit O & M cost of surface water for i^{th} zone (Rs. / hectare meter)

CST_i = Total cost of surface water for i^{th} zone (Rs. / hectare meter)

SW_{ik} = Surface water allocation for for i^{th} zone during k^{th} time interval (hectare meter)

c) **Cost of groundwater**

The cost of groundwater can be worked out as

$$\sum_{i=1}^{nz}\sum_{k=1}^{12} CGT_i * WGT_{ik}$$

CGT_i = Cost of groundwater for i^{th} zone in k^{th} period (Rs. / hectare meter)

WGT_{ik}= Groundwater allocation for i^{th} zone in k^{th} period (hectare meter)

The objective function is therefore written as

$$\textbf{Max Z} = \sum_{i=1}^{nz}\sum_{j=1}^{nc} A_{ij} * NB_j - \sum_{i=1}^{nz}\sum_{k=1}^{12} CST_i * SW_{ik} - \sum_{i=1}^{nz}\sum_{k=1}^{12} CGT_i * WGT_{ik}$$

The constraints are

a) **Water requirement constraints**

$$\sum_{i=1}^{nz}\sum_{j=1}^{nc}\sum_{k=1}^{12} WR_{ik} * A_{ij} = SW_{ik} + GW_{ik}$$

Where

WR_{jk} = Water requirement for j^{th} crop for k^{th} period (m)

A_{ij} = Area of j^{th} crop for i^{th} zone (ha)

SW_{ik} = Surface water allocations in i^{th} zone in k^{th} peroid (ha..m)

GW_{ik} = Groundwater allocation for i^{th} zone in k^{th} peroid (ha..m)

b) **Area availability**

The area availability constraints can be written as

$$\sum_{j=1}^{nc} \lambda_{jkw} A_{ij} * CCA_i \quad \text{for} \quad kw$$

$$\sum_{j=1}^{nc} \lambda_{jkd} A_{ij} * CCA_i \quad \text{for} \quad kd$$

Where

λ_{jkw} = Land use coefficient for j^{th} crop in $k_w{}^{th}$ time.

λ_{jkd} = Land use coefficient for j^{th} crop in $k_d{}^{th}$ time.

k_w = A month of wet season (Kharif)

k_d = A month of dry season (Rabi)

CCA_i = Culturable command area for i^{th} zone

c) **Surface water availability**

The surface availability constraint can be written as

$$\sum_{i=1}^{nz}\sum_{k=1}^{12} SW_{ik} \quad \leq \quad SWA_K$$

Where

SW_{ik} = Surface water allocation for i^{th} zone in k^{th} time (hectare meter)

SWA_k = Surface water available at canal head (hectare meter) k^{th} time.

d) **Groundwater availability constraints**

The constraints on groundwater availability for all the zones of the study area can be written as

$$\sum_{i=1}^{nz}\sum_{k=1}^{12} GW_{ik} \leq \mu GWA_{ik}$$

Where

GW_{ik} = Groundwater allocation for i^{th} zone in k^{th} time (hectare meter)

μ = mining allowance (=1 when no mining is allowed)

4.5 METHOD OF OBTAINING RESULTS

The cost function and optimization model (Linear Programming) as described above is formulated and has been used for conjunctive use planning. The cost of surface water and groundwater per hectare meter are used in the objective function. The monthly allocation of surface and total groundwater available in the entire study area are taken as constraints. The minimum area under each crop is taken as proposed by NWDA. The different cases and model results of various runs are presented in subsequent chapter.

CHAPTER 5
MODEL RESULTS

5.1 GENERAL

The conjunctive use planning is carried out in the proposed command area of Krishna (Nagarjunasagar) – Pennar (Somasila) link canal in order to optimize the utilization of combined use of surface water and groundwater. Using the linear programming technique, the following cases have been studied.

a. Existing cropping pattern with present conditions, i.e., without the introduction of link canal
b. Considering the proposed cropping pattern, groundwater and surface water
c. Considering the proposed cropping pattern, surface water only and not considering groundwater.
d. Considering the proposed cropping pattern, groundwater and with reduction in surface water by 10 % to 50% in steps.
e. Considering an alternate proposal in which fodder is deleted in both kharif and rabi seasons and including chillies in kharif season.
f. Considering the proposed cropping pattern, groundwater and with reduction in surface water by 55% with mining of groundwater up to 17% more than that available.

5.2 CONSIDERING EXISTING CROPPING PATTERN

At present the cultivation is being done through irrigation only in small areas, and mostly it is through rain fed conditions. To understand the present scenario in terms of benefits and to study the optimal allocation of surface water and groundwater, existing cropping pattern has been considered. With the cost of surface water and groundwater per hectare meter and considering the constraints as explained in Chapter 4, the allocations are worked out from optimization model using LINDO 6.1 package. The benefit is worked out to be Rs. 10765 lakhs. The results are shown in Tables 5.1.and 5.1.1

TABLE 5.1:OPTIMAL AREA UNDER EXISTING CROPPING PATTERN

Crop Code	Crop	Optimal area in zone in hectares			
		Z1	Z2	Z3	Total
C1	**Kharif** Paddy	1546	1847	236	3629
C2	Jowar	697	833	107	1637
C3	Bajra	1248	1491	191	2930
C4	Cotton	935	1117	143	2195
C5	Fodder	70	82	11	163
C6	Chillies	73	88	11	172
C7	Tobacco	56	67	8	131
C8	G Nut	768	918	117	1803
C9	Pulses	83	100	13	196
C10	**Rabi** Paddy	13907	16617	2128	32652
C11	Jowar	1720	2055	263	4038
C12	G Nut	1245	1488	190	2923
C13	Pulses	65	78	10	153
C14	Fodder	1928	2305	295	4528
Total		24341	29086	3723	57150

TABLE 5.1.1:MONTHLY OPTIMUM ALLOCATION OF SURFACE AND GROUNDWATER IN EACH ZONE IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	746	6651	0	7397	4820	0	852	5672
Feb	56	4443	568	5067	3662	0	0	3662
Mar	296	770	99	1165	347	0	0	347
Apr	189	491	62	742	222	0	0	222
May	0	0	0	0	0	0	0	0
Jun	215	39	33	287	0	218	0	218
Jul	0	1122	126	1248	939	0	18	957
Aug	953	168	146	1267	0	971	0	971
Sep	0	743	96	839	631	12	0	643
Oct	105	19	16	140	0	107	0	107
Nov	4659	821	713	6193	0	4745	0	4745
Dec	4903	863	750	6516	0	4995	0	4995
Total	12122	16130	2609	**30861**	10621	11048	870	**22539**

The optimum monthly water requirement of surface water and groundwater needed for meeting the demand of existing cropping pattern is shown in graphical representation in Fig 5.1.

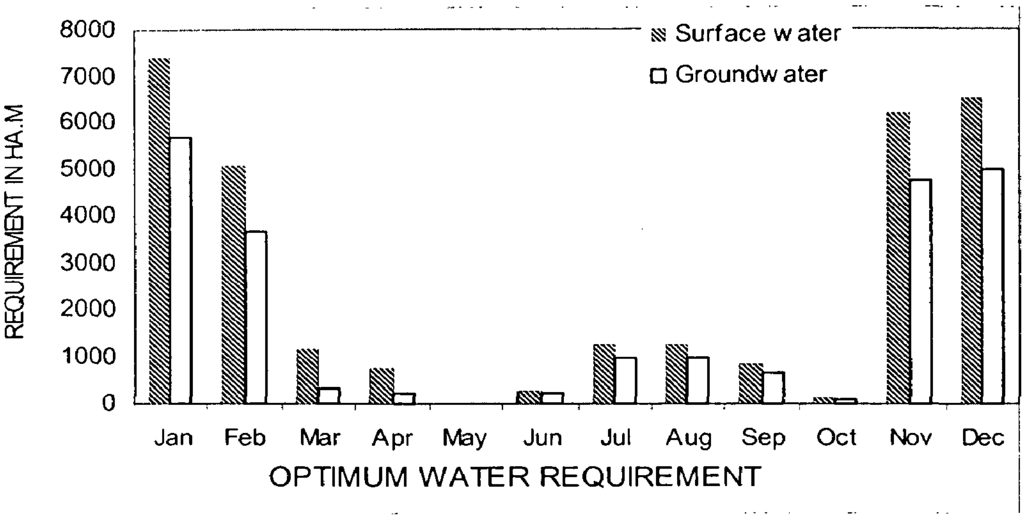

FIG 5.1: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.3 CONSIDERING PROPOSED CROPPING PATTERN

To understand the proposed scenario in terms of benefits and to study the optimal allocation of surface water and groundwater proposed cropping pattern has been considered. As explained in Chapter 4, considering this proposed cropping pattern and other constraints, the optimum area under each crop and surface water and groundwater are worked out. The maximum benefit thus obtained is Rs.73195 lakhs. The details are shown in Tables 5.2. and 5.2.1.

TABLE 5.2:OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN

Crop	Crop	Optimal area in zone in hectares			
Code		Z1	Z2	Z3	Total
C1	**Kharif** Paddy	0	0	0	0
C2	Jowar	0	0	0	0
C3	Bajra	0	0	0	0
C4	Cotton	0	0	0	0
C5	Fodder	0	0	0	0
C6	Chillies	62111	37292	1405	100808
C7	Tobacco	0	0	0	0
C8	G Nut	00	14522	936	56869
C9	Pulses	41411	0	0	0
C10	**Rabi** Paddy	0	0	0	0
C11	Jowar	0	0	0	0
C12	G Nut	0	0	0	0
C13	Pulses	0	10339	0	10339
C14	Fodder	0			
Total		103522	62153	2341	168016

TABLE 5.2.1:MONTHLY OPTIMUM ALLOCATION OF SURFACE AND GROUNDWATER IN EACH ZONE IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	3652	5817	0	9469	12514	0	365	12879
Feb	7740	0	0	7740	2513	3596	232	6341
Mar	0	0	0	0	0	0	0	0
Apr	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0
Jun	1019	612	23	1654	0	0	0	0
Jul	3422	2055	77	5554	0	0	0	0
Aug	8043	4829	181	13053	0	0	0	0
Sep	1758	1055	39	2852	0	0	0	0
Oct	279	366	6	651	0	0	0	0
Nov	1666	0	310	1976	12037	0	310	12347
Dec	3402	5838	0	9240	10719	0	319	11038
Total	30981	20572	636	**52189**	37783	3596	1226	**42605**

The optimum monthly water requirement of surface water and groundwater required for the proposed cropping pattern is shown in graphical representation in Fig 5.2.

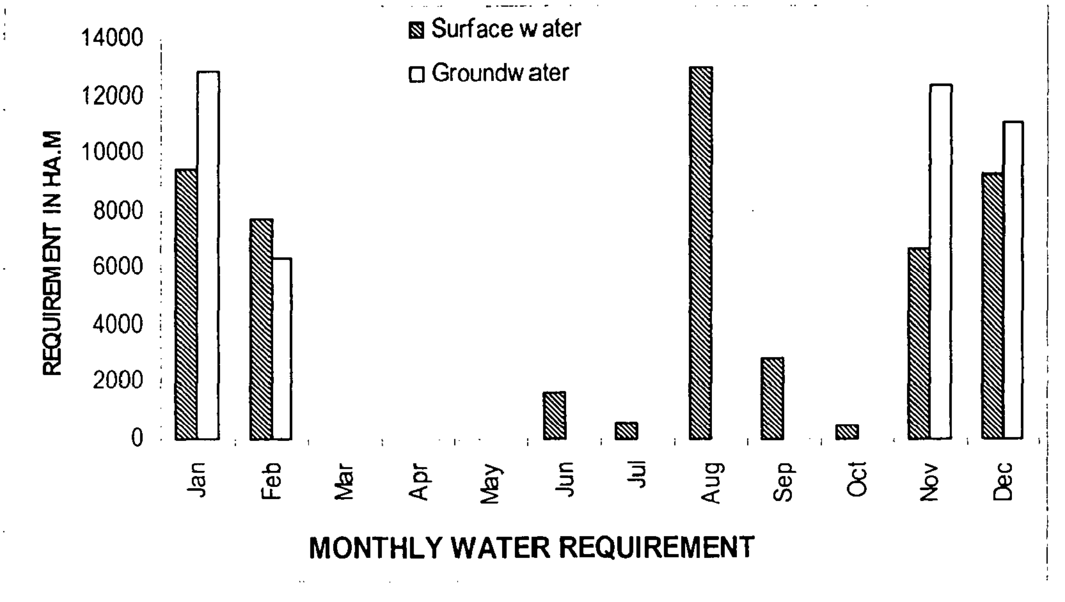

FIG 5.2: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.4 PROPOSED CROPPING PATTERN WITHOUT GROUNDWATER

The benefits and the optimal allocation of surface water are worked out with no groundwater component and considering the proposed cropping pattern in this model. The optimum area under each crop and surface water and groundwater required is worked out in this model. The maximum benefit worked out under the condition is Rs.31702 lakhs. The details are shown in Tables 5.3 and 5.3.1.

TABLE 5.3: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH NO GROUNDWATER)

Crop	Crop	Optimal area in zone in hectares			
Code		Z1	Z2	Z3	Total
C1	**Kharif** Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4140	2486	94	6720
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	**Rabi** Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	2340	168017

TABLE 5.3.1: MONTHLY OPTIMUM ALLOCATION OF SURFACE WATER IN EACH ZONE IN HECTARE METER

	Surface water			
Zone / Month	Z1	Z2	Z3	Total
Jan	5835	3503	132	9470
Feb	4769	2863	108	7740
Mar	3727	2237	85	6049
Apr	2377	1427	54	3858
May	0	0	0	0
Jun	2409	1446	55	3910
Jul	9907	5948	224	16079
Aug	9672	5807	219	15698
Sep	6303	3784	143	10230
Oct	1103	662	25	1790
Nov	4115	2471	93	6679
Dec	5693	3418	129	9240
Total	55910	33566	1267	**90743**

The optimum monthly water requirement of surface water required for the proposed cropping pattern is shown in graphical representation in Fig 5.3.

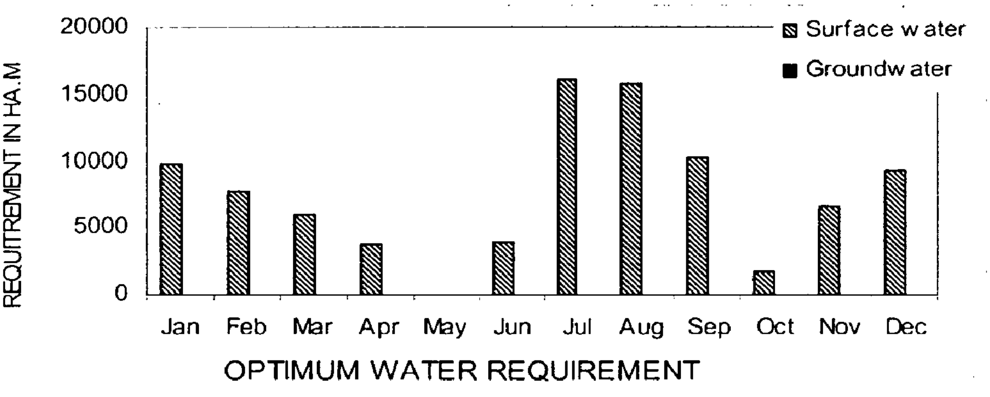

FIG 5.3: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.5 PROPOSED CROPPING PATTERN WITH GROUNDWATER AND REDUCING THE SURFACE WATER QUANTITY BY 10 %

In an effort to conserve the surface water and to use the groundwater to the maximum extent, the surface water requirement in the study area is reduced by 10%. Considering the same constraints as above, the benefit is worked and optimal allocation of groundwater and surface water quantity is obtained. The optimum area under each crop and surface water and groundwater required is obtained. Maximum benefit worked out under the above condition is Rs.31446.55 lakhs. The details are shown in Tables 5.4. and 5.4.1

TABLE 5.4: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH 10% REDUCTION IN SURFACE WATER REQUIREMENT)

Crop	Crop	Optimal area in zone in hectares			
Code		Z1	Z2	Z3	Total
C1	**Kharif** Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6719
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	**Rabi** Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	2340	168016

TABLE 5.4.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WTAR REDUCED BY 10% IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	4888	3503	132	8523	947	0	0	947
Feb	4103	2863	0	6966	667	0	107	774
Mar	3122	2239	84	5445	607	0	0	607
Apr	1992	1428	54	3474	387	0	0	387
May	0	0	0	0	0	0	0	0
Jun	2409	1056	54	3519	0	390	0	390
Jul	8300	5948	224	14472	1606	0	0	1606
Aug	9672	4458	0	14130	1350	0	219	1569
Sep	5280	3784	142	9206	1023	0	0	1023
Oct	924	662	25	1611	179	0	0	179
Nov	3448	2471	93	6012	667	0	0	667
Dec	4769	3418	129	8316	924	0	0	924
Total	48907	31830	937	**81674**	8357	390	326	**9073**

The optimum monthly requirement of surface water (reduced by 10%) and groundwater required for the proposed cropping pattern is shown in graphical representation in Fig 5.4.

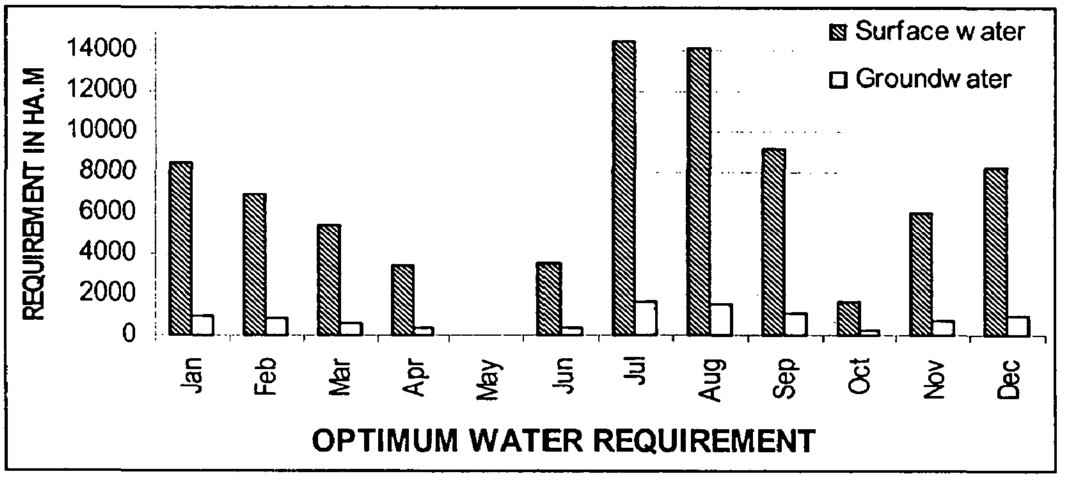

FIG 5. 4: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.6 PROPOSED CROPPING PATTERN WITH GROUNDWATER AND REDUCING THE SURFACE WATER QUANTITY BY 20 %

Considering the available groundwater and reducing the surface water requirement by 20%, the maximum benefit is worked out to be Rs.31191 lakhs in this model. Considering the constraints, the optimum area under each crop and surface water and groundwater required to obtain maximum benefits is obtained under the condition mentioned above and the details are shown in Tables 5.5. and 5.5.1

TABLE 5.5: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH 20% REDUCTION IN SURFACE WATER AVAILABILITY)

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	**Kharif** Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6719
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	**Rabi** Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	2341	168016

TABLE 5.5.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WTAR REDUCED BY 20% IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	3941	3503	132	7576	1894	0	0	1894
Feb	4769	1315	108	6192	0	1548	0	1548
Mar	2517	2239	84	4840	1212	0	0	1212
Apr	1606	1428	54	3088	773	0	0	773
May	0	0	0	0	0	0	0	0
Jun	1628	1446	54	3128	781	0	0	781
Jul	9906	2958	0	12864	0	2990	224	3214
Aug	6534	5807	219	12560	3138	0	0	3138
Sep	4400	3784	0	8184	1903	0	143	2046
Oct	745	662	25	1432	358	0	0	358
Nov	2780	2471	93	5344	1335	0	0	1335
Dec	3974	3418	0	7392	1719	0	129	1848
Total	42800	29031	769	**72600**	13113	4538	496	**18147**

The optimum monthly requirement of surface water (reduced by 20%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.5.

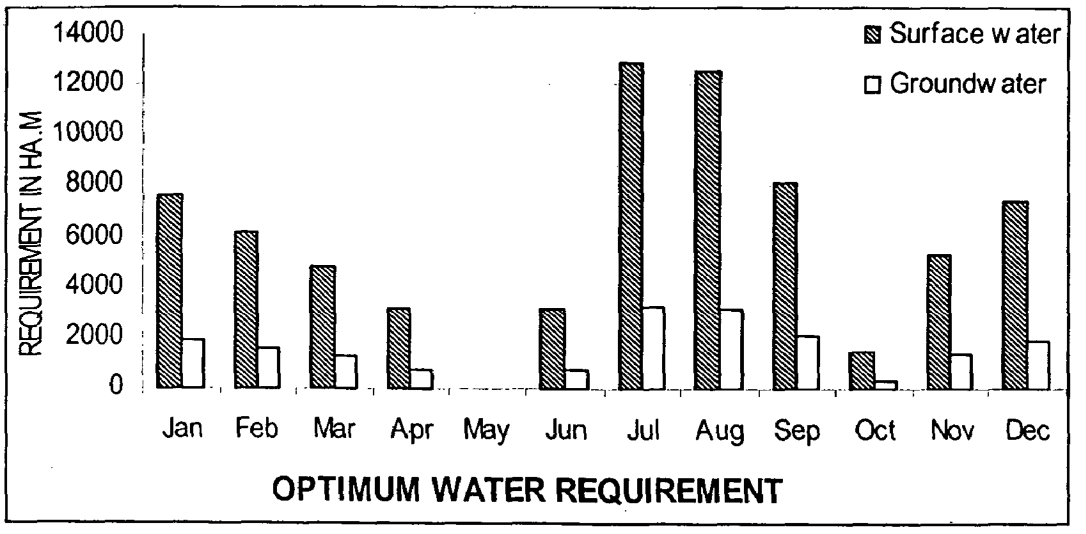

FIG 5. 5: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.7 PROPOSED CROPPING PATTERN WITH GROUNDWATER AND REDUCING THE SURFACE WATER QUANTITY BY 30 %

Considering the available groundwater and reducing the surface water requirement by 30%, the maximum benefit is worked out to be Rs.30935 lakhs in this model. Considering the constraints, the optimum area under each crop and surface water and groundwater required to obtain maximum benefits is obtained under the condition mentioned above and the details are shown in Tables 5.6. and 5.6.1

TABLE 5.6: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH 30% REDUCTION IN SURFACE WATER AVAILABILITY)

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	**Kharif** Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6719
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	**Rabi** Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	2341	168016

TABLE 5.6.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WTAR REDUCED BY 30% IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	2994	3503	132	6629	2841	0	0	2841
Feb	4769	541	108	5418	0	2322	0	2322
Mar	1912	2239	84	4235	1817	0	0	1817
Apr	1220	1428	54	2702	1159	0	0	1159
May	0	0	0	0	0	0	0	0
Jun	1237	1446	54	2737	1172	0	0	1172
Jul	9906	1350	0	11256	0	4599	224	4823
Aug	4964	5807	219	10990	4709	0	0	4709
Sep	3234	3784	143	7161	3069	0	0	3069
Oct	566	662	25	1253	537	0	0	537
Nov	4115	468	93	4676	0	2003	0	2003
Dec	5693	775	0	6468	0	26430	129	2772
Total	40610	22003	912	**63525**	17627	9245	345	**27223**

The optimum monthly requirement of surface water (reduced by 30%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.6.

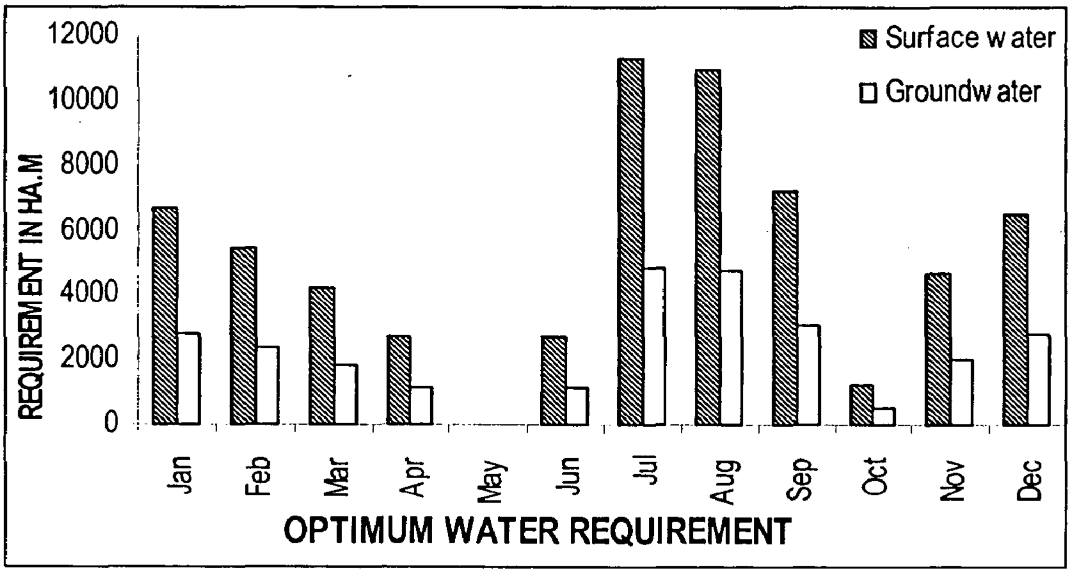

FIG 5.6: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.8 PROPOSED CROPPING PATTERN WITH GROUNDWATER AND REDUCING THE SURFACE WATER QUANTITY BY 40 %

Considering the available groundwater and reducing the surface water requirement by 40%, the maximum benefit is worked out to be Rs.30679.63 lakhs in this model. Considering the constraints, the optimum area under each crop and surface water and groundwater required to obtain maximum benefits is obtained under the condition mentioned above and the details are shown in Tables 5.7. and 5.7.1

TABLE 5.7: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH 40% REDUCTION IN SURFACE WATER AVAILABILITY)

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	Kh Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6719
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	Rabi Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	2341	168016

TABLE 5.7.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WTAR REDUCED BY 40% IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	5682	0	0	5682	153	3503	132	3788
Feb	1673	2863	108	4644	3096	0	0	3096
Mar	1307	2239	84	3630	2422	0	0	2422
Apr	834	1428	54	2316	1545	0	0	1545
May	0	0	0	0	0	0	0	0
Jun	2346	0	0	2346	63	1446	54	1563
Jul	9648	0	0	9648	258	5948	224	6430
Aug	9201	0	219	9420	471	5807	0	6278
Sep	2211	3784	143	6138	4092	0	0	4092
Oct	387	662	25	1074	716	0	0	716
Nov	3915	0	93	4008	200	2470	0	2670
Dec	5544	0	0	5544	149	3418	129	3696
Total	42748	10976	726	**54450**	13165	22592	539	**36296**

The optimum monthly requirement of surface water (reduced by 40%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.7.

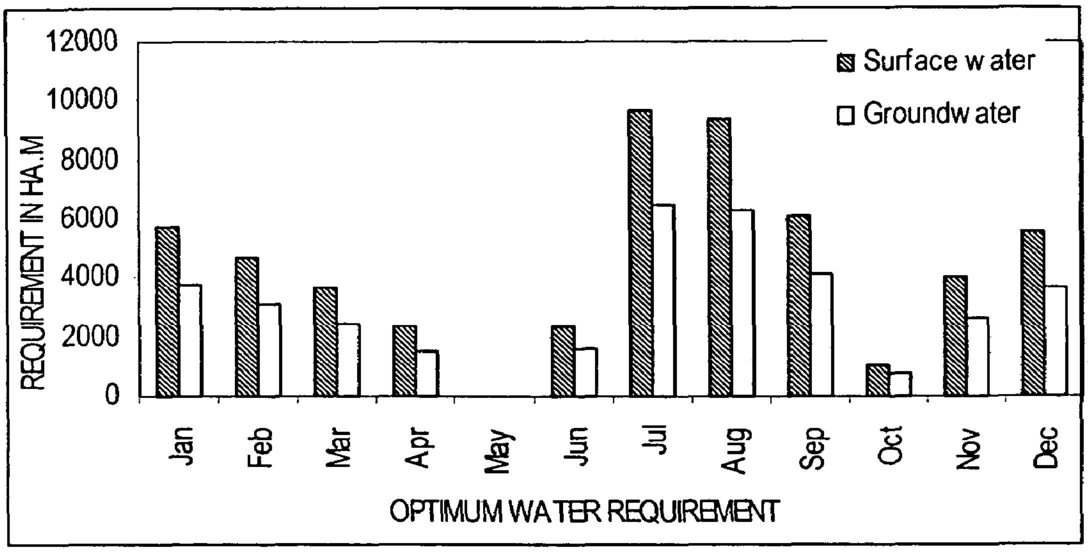

FIG 5.7: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.9 PROPOSED CROPPING PATTERN WITH GROUNDWATER AND REDUCING THE SURFACE WATER QUANTITY BY 45 %

Considering the available groundwater and reducing the surface water requirement by 45%, the maximum benefit is worked out to be Rs.30552 lakhs in this model. Considering the constraints, the optimum area under each crop and surface water and groundwater required to obtain maximum benefits is obtained under the condition mentioned above and the details are shown in Tables 5.8. and 5.8.1

TABLE 5.8: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH 45% REDUCTION IN SURFACE WATER AVAILABILITY)

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	Kh Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6719
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	Rabi Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	£341	168016

TABLE 5.8.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WTAR REDUCED BY 45% IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	5077	0	132	5209	758	3503	0	4261
Feb	4149	0	108	4257	620	2863	0	3483
Mar	1005	2239	84	3328	2724	0	0	2724
Apr	641	1428	54	2123	1738	0	0	1738
May	0	0	0	0	0	0	0	0
Jun	2097	0	54	2151	312	1447	0	1759
Jul	8844	0	0	8844	1063	5948	224	7235
Aug	2609	5807	219	8635	7063	0	0	7063
Sep	1700	3784	142	5626	4603	0	0	4603
Oct	299	662	24	985	805	0	0	805
Nov	1110	2471	93	3674	3005	0	0	3005
Dec	4953	0	129	5082	740	3418	0	9240
Total	32484	16391	1039	**49914**	23431	17179	224	**40834**

The optimum monthly requirement of surface water (reduced by 45%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.8.

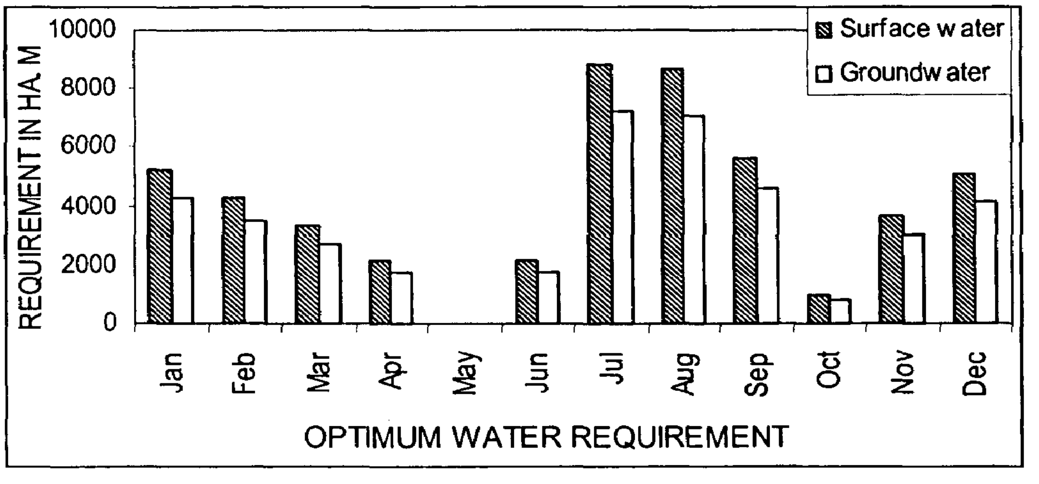

FIG 5.8: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.10 PROPOSED CROPPING PATTERN WITH GROUNDWATER AND REDUCING THE SURFACE WATER QUANTITY BY 50 %

Considering the available groundwater and reducing the surface water requirement by 50%, the maximum benefit is worked out to be Rs.30419 lakhs in this model. Considering the constraints, the optimum area under each crop and surface water and groundwater required to obtain maximum benefits are obtained under the condition mentioned above. It is observed that the combined supply of surface water and groundwater is not sufficient to meet the entire requirement. The details are shown in Tables 5.9. and 5.9.1.

TABLE 5.9: OPTIMAL AREA UNDER PROPOSED CROPPING PATTERN (WITH 50% REDUCTION IN SURFACE WATER AVAILABILITY)

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	Kh Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6719
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	Rabi Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	0	2670	117	2787
Total		98346	61715	2341	162402

TABLE 5.9.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WATER REDUCED BY 50% IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	4735	0	0	4735	1100	3503	132	4735
Feb	0942	2820	84	3870	3316	0	0	3316
Mar	807	2133	84	3024	1677	0	0	1677
Apr	515	1361	54	1930	1069	0	0	1069
May	0	0	0	0	0	0	0	0
Jun	1955	0	0	1955	454	1466	55	1955
Jul	8040	0	0	8040	1866	5948	224	8038
Aug	7631	0	219	7850	2041	5807	0	7848
Sep	1189	3784	143	5116	5115	0	0	5115
Oct	208	662	25	895	895	0	0	895
Nov	3247	0	93	3340	868	2471	0	3339
Dec	4620	0	0	4620	1073	3418	129	4620
Total	33889	10760	726	**45375**	19474	22593	540	**42607**

The optimum monthly requirement of surface water (reduced by 50%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.9.

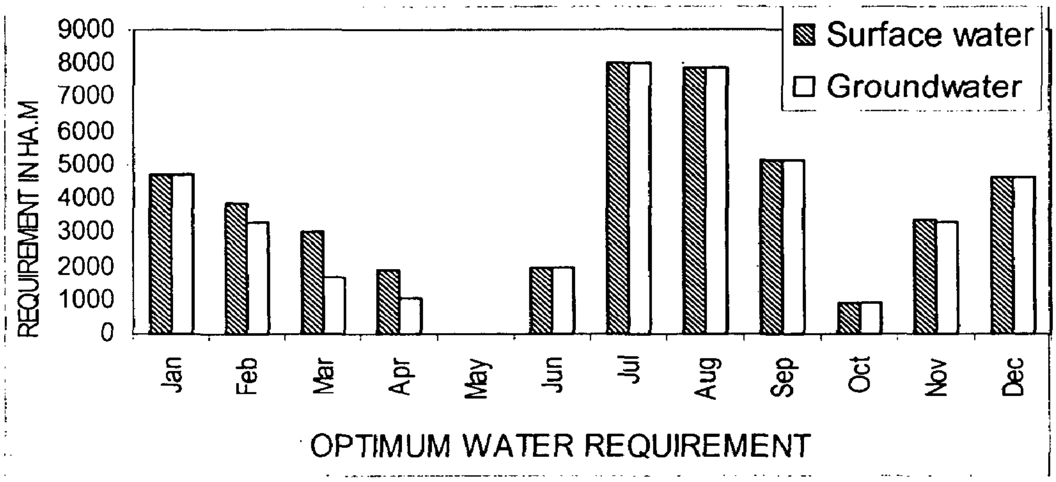

FIG 5.9: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.11 ALTERNATE PROPOSAL -I

An alternate proposal is studied to achieve maximum benefit by deleting the fodder crop in both kharif and rabi seasons and replacing by chillies in kharif season only. The water requirement for all the 13 crops has been worked out. With the constraints as mentioned above and considering the surface water availability as 55% of requirement, the maximum benefit is found out to be Rs.34300 lakhs. The details are shown in Tables 5.10. and 5.10.1.

TABLE 5.10: OPTIMAL AREA IN ALTERNATE CROPPING PATTERN (WITHOUT FODDER AND CONSIDERING CHILLIES IN KHARIF)

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	Kh Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C6	Chillies	8280	4972	188	13440
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	Rabi Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
Total		98347	59045	2224	159616

TABLE 5.10.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WATER IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	1574	3503	132	5209	4261	0	0	4261
Feb	1245	2556	0	3801	3013	0	96	3109
Mar	2160	0	56	2216	324	1492	0	4032
Apr	463	951	0	1414	1121	0	36	1157
May	0	0	0	0	0	0	0	0
Jun	2043	0	53	2096	304	1409	0	1713
Jul	8844	0	0	8844	1063	5948	224	7235
Aug	8668	0	0	8668	1042	5830	220	7092
Sep	1687	3755	141	5583	4567	0	0	4567
Oct	294	655	25	974	796	0	0	796
Nov	1110	2471	93	3674	3005	0	0	3005
Dec	1535	3418	129	5082	4158	0	0	4158
Total	29623	17309	629	**47561**	23654	14679	576	**38909**

The optimum monthly requirement of surface water (reduced by 45%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.10.

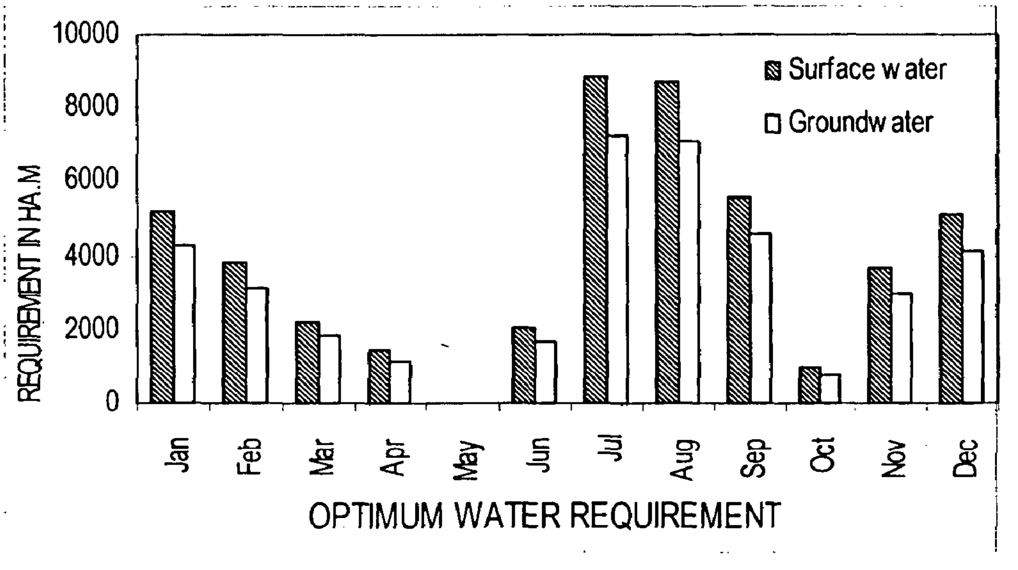

FIG 5.10: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.12 ALTERNATE PROPOSAL -II

Another alternate proposal is studied to examine the utilization of water resources in optimal way. The surface water requirement is reduced by 55% (40840 hectare meter) and groundwater mining up to 17% (42606*1.17) is considered. Using the LP the quantity of optimal allocation of both surface water and groundwater are worked out for all the 14 crops. The maximum benefit is found out to be Rs.30552 lakhs. The details are shown in Tables 5.11 and 5.11.1.

TABLE 5.11: OPTIMAL AREA IN ALTERNATE CROPPING PATTERN

Crop	Crop	Optimal area in zone in ha			
Code		Z1	Z2	Z3	Total
C1	Kh Paddy	15529	9323	351	25203
C2	Jowar	10353	6215	234	16802
C3	Bajra	4140	2486	94	6720
C4	Cotton	9318	5594	210	15122
C5	Fodder	4139	2486	94	6720
C6	Chillies	4140	2486	94	6720
C7	Tobacco	4140	2486	94	6720
C8	G Nut	5176	3108	117	8401
C9	Pulses	5176	3108	117	8401
C10	Rabi Paddy	10353	6215	234	16802
C11	Jowar	10353	6215	234	16802
C12	G Nut	10353	6215	234	16802
C13	Pulses	5176	3108	117	8401
C14	Fodder	5176	3108	117	8401
Total		103522	62153	2341	160816

TABLE 5.11.1: MONTHLY OPTIMUM ALLOCATION OF GROUNDWATER AND SURFACE WATER IN HECTARE METER

	Surface water				Groundwater			
Zone / Month	Z1	Z2	Z3	Total	Z1	Z2	Z3	Total
Jan	5262	0	0	4262	1573	3503	132	5208
Feb	512	2863	108	3483	4257	0	0	4257
Mar	400	2239	84	2723	3329	0	0	3329
Apr	255	1428	54	1737	2124	0	0	2124
May	0	0	0	0	0	0	0	0
Jun	260	1446	54	1760	2149	0	0	2149
Jul	7236	0	0	7236	2671	5948	224	8843
Aug	1039	5807	219	7065	8634	0	0	8634
Sep	4462	0	142	4604	1842	3784	0	5626
Oct	806	0	0	806	297	662	25	984
Nov	442	2471	93	3006	3673	0	0	3673
Dec	4158	0	0	4158	1536	3418	129	5083
Total	23832	16254	754	**40840**	32085	17315	510	**49910**

The optimum monthly requirement of surface water (reduced by 55%) and groundwater for the proposed cropping pattern is shown in graphical representation in Fig 5.11.

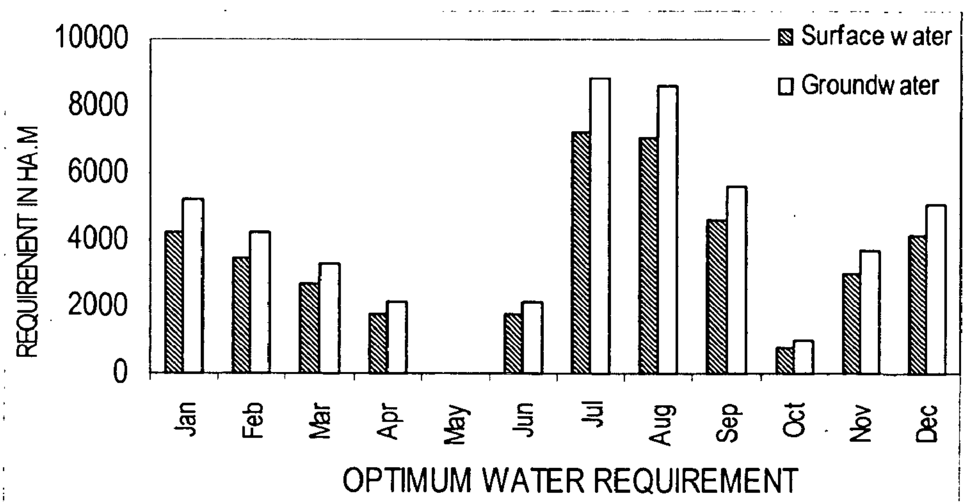

FIG 5.11: OPTIMUM MONTHLY WATER REQUIREMENT IN HA.M

5.13 LINEAR PROGRAMMING MODEL

The source code and results of LP model for two scenarios are appended as annexures.

The LP model used in the scenario in which surface water is reduced by 45% of total requirement is given in Annexure-I and the corresponding results are given in Annexure-II.

The LP model used in the scenario in which surface water is reduced by 45% of total requirement and kharif fodder is replaced by kharif chillies is given in Annexure-III and the corresponding results are given in Annexure-IV.

The total number of decision variables in model is 114, which include cropped area variables in both kharif, and rabi seasons in all the three zones.

CHAPTER 6
RESULTS AND DISCUSSIONS

6.1 GENERAL

Various alternatives are studied using Linear Programming Model to obtain the maximum value of the objective function, i.e., net benefit from the irrigation in the proposed command area of the Krishna (Nagarjunasagar) - Pennar (Somasila) link canal. The entire command area is divided into three zones. The LP model used in the study has about 114 variables and 102 constraints. In the present study attempt has been made to study the various alternatives to incorporate groundwater component in the proposed project of link canal. In view of the importance of this component, groundwater behaviour in the study area is discussed in the subsequent para.

6.2 GROUNDWATER DEPTH

The season wise weighted depth of groundwater in the last few years has been worked out for both per monsoon and post monsoon periods based on the data collected from CGWD for the study area. The average groundwater depth in pre monsoon season varies from 3.80 m to 6.02 m. The same in the post monsoon season is from 1.51 m to 5.32 m. Since groundwater depth is shallow, and the quality is also suitable for irrigation purpose, there is a scope for exploitation of the same. Details of quality of groundwater is given in Annexure V. In addition, as irrigation supplies are proposed to be made from surface water, there is a danger of water logging and the efficiency of the land might come down. It can be minimized by resorting to conjunctive use planning of both surface water and groundwater.

The weighted average depth of groundwater in pre-monsoon and post-monsoon periods in different years is shown in Figure 6.1. In this study area there are many observation wells out of which 12 wells for which data is available are considered for the analysis. Details are already given in Chapter 3. For computation of weighted average depth of the study area, thiessen polygons were prepared and groundwater contours were prepared. Details are given in Annexure VI. The seasonal fluctuation in weighted average depth of groundwater in shown in Fig 6.2

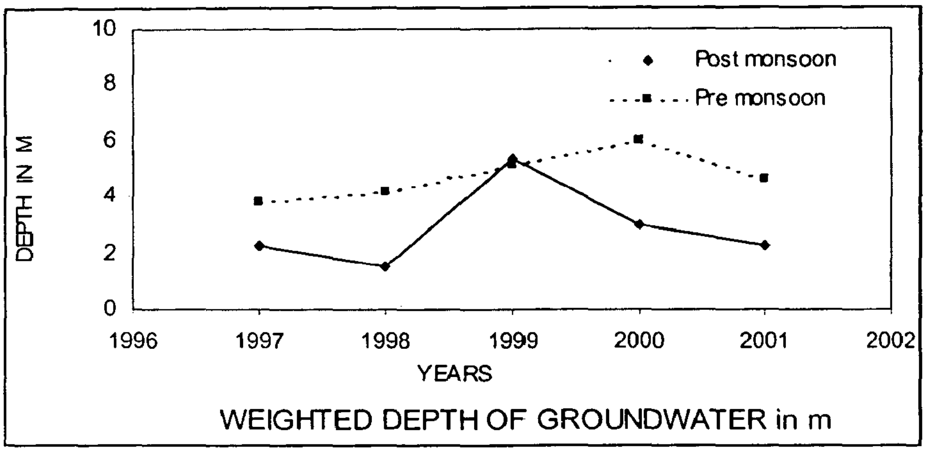

FIG.6.1: AVERAGE DEPTH OF GROUNDWATER IN PRE-MONSOON AND POST-MONSOON

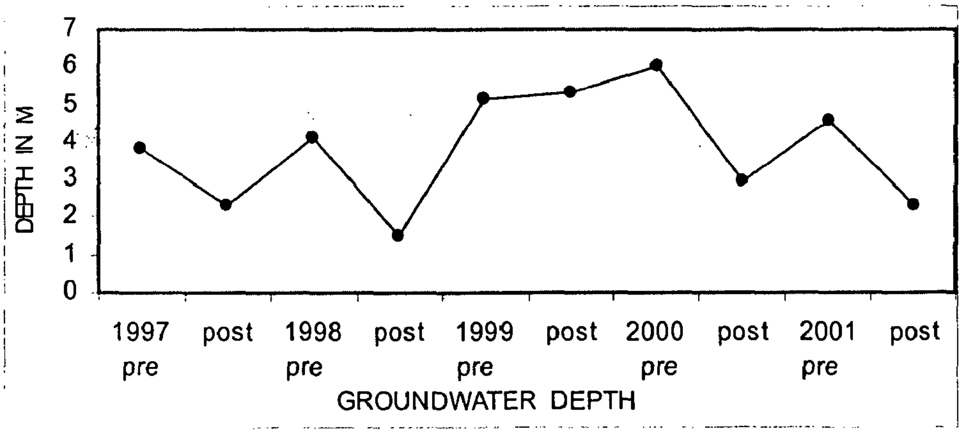

FIG.6.2: SEASONAL FLUCTUATION IN WEIGHTED AVERAGE DEPTH OF GROUNDWATER

6.3 ANALYSES OF RESULTS

The analyses are carried out considering various scenarios to study the trend of benefits under each scenario and corresponding allocation of surface water and groundwater, details of which are given in Table 6.1.

TABLE 6.1: ALLOCATION OF SURFACE WATER AND GROUNDWATER AND CORRESPONDING BENEFITS

Sl no	Scenario No	Description	Surface Water Use	Ground Water use	Benefit value in Rs.lakhs
1	I	Considering existing cropping pattern with present available surface and ground water and crop wise area availability constraints	30861 ha.m	22539 ha.m	10765
2	II	Considering Proposed cropping pattern with surface and ground water and zone wise total area availability constraints	52189 ha.m	42605 ha.m	73195
3	III	Considering Proposed cropping pattern with surface water, zone wise total area availability and crop wise area availability constraints and with no groundwater	90743 ha.m	0 ha.m	31702
4	IV	Considering Proposed cropping pattern with 10 % reduction in surface water availability, and crop wise area availability constraints and with groundwater	81674 ha.m	9073 ha.m	31447
5	V	Considering Proposed cropping pattern with 20 % reduction in surface water availability, and crop wise area availability constraints and with groundwater	72600 ha.m	18147 ha.m	31191
6	VI	Considering Proposed cropping pattern with 30 % reduction in surface water availability, and crop wise area availability constraints and with groundwater	63525 ha.m	27223 ha.m	30935
7	VII	Considering Proposed cropping pattern with 40 % reduction in surface water availability, and crop wise area availability constraints and with groundwater	54450 ha.m	36296 ha.m	30680
8	VIII	Considering Proposed cropping pattern with 45 % reduction in surface water availability, and crop wise area availability constraints and with groundwater	49914 ha.m	40834 ha.m	30552

9	IX	Considering Proposed cropping pattern with 50 % reduction in surface water availability, and crop wise area availability constraints and with groundwater.	45375 ha.m	42607 ha.m	30419
10	X	Alternate-I Considering Proposed cropping pattern with 45% reduction in surface water availability and deleting the fodder crop from the cropping pattern both in kharif and rabi and considering chillies in place of kharif fodder	47561 ha.m	38909 ha.m	34300
11	XI	Alternate-II Considering Proposed cropping pattern with 55% reduction in surface water availability, and crop wise area availability constraints and with mining of groundwater up to 17% more than that available	40840 ha.m	49910ha .m	30552

For different alternatives, results were obtained for allocation of surface water and groundwater and corresponding benefits. All these alternatives are planned in such a way so as to save the surface water from the link canal and supplementing by groundwater. The consolidated results of variation of surface water and groundwater and corresponding benefits are presented in Fig 6.3. Their corresponding values are presented in the form of bar chart in Fig 6.4

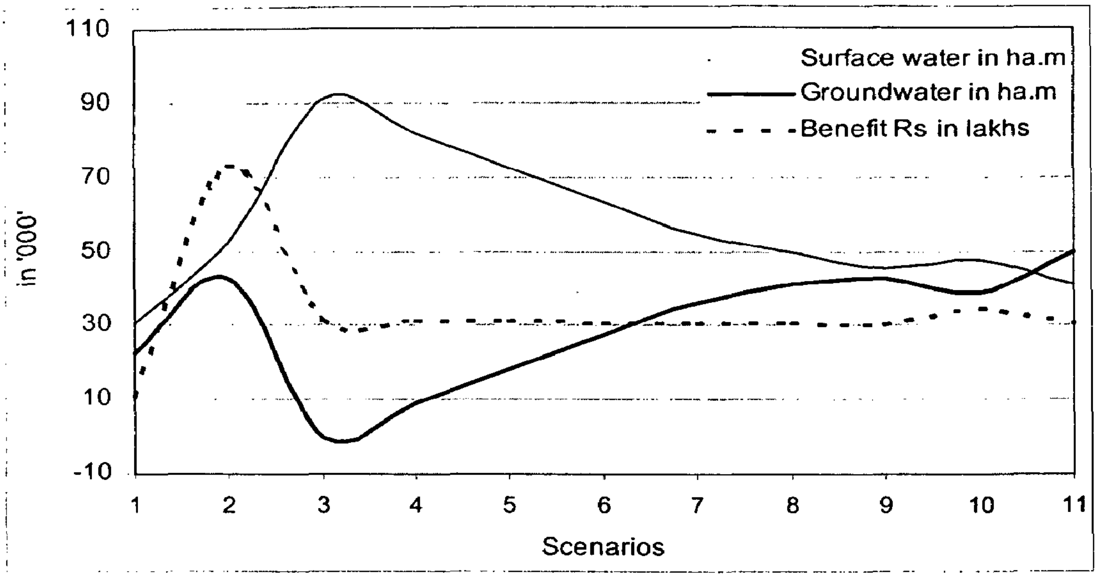

FIG.6.3 : ALLOCATION OF SURFACE AND GROUNDWATER AND CORRESPONDING BENEFITS FOR DIFFERENT SCENARIOS

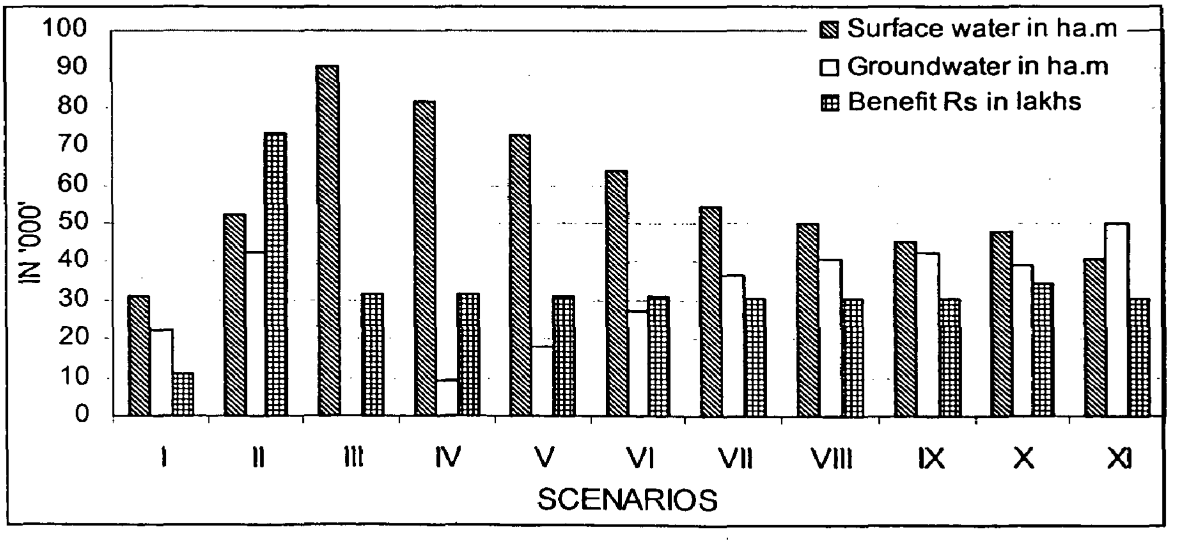

FIG.6.4: BAR CHART SHOWING ALLOCATION OF SURFACE AND GROUNDWATER AND CORRESPONDING BENEFITS FOR DIFFERENT SCENARIOS

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL

Advantage of conjunctive use of surface water and groundwater is to take benefit of both resources. In the present study, efforts are made to conserve the surface water and utilize the groundwater that could be available due to recharge, to the extent possible. The other advantages are reduction in water logging, less evaporation losses.

7.2 CONCLUSIONS

Based on the present study, following conclusions can be drawn;

i) Conjunctive use model consisting of linear programming technique has been formulated.

ii) Various alternatives to include groundwater component in the link canal of NWDA project studied.

iii) The scenario-II of optimising the system consists of total crop area in each zone as a whole. On simulation, the allocation of groundwater and surface water and the benefit works out to be 42605 hectare meter, 52189 hectare meter and Rs.73195 lakhs respectively. But in this case only three crops for which the net benefit is high viz., Kharif chillies, rabi paddy and rabi pulses have been obtained which is not desirable. Hence this scenario is not suggested.

iv) Out of all the proposals, the scenario-X of removing fodder crop from proposed cropping pattern and including the chillies in place of kharif fodder is considered as optimal after many trials as it gives a maximum benefit of Rs.34300 lakhs. This could be achieved with considering surface water quantity as 47561 hectare meter (45% of total requirement as per climatological approach) and groundwater quantity as 38909 hectare meter. Also, other food crops and non-food crops that are needed, are also being considered as proposed by NWDA.

v) The present study would help to utilise saved surface water by adopting conjunctive use policies for other regions having scarcity of water.

7.3 RECOMMENDATIONS

As the command area lies in the coastal area of Andhra Pradesh, where cyclones occur frequently, the groundwater water recharge is very high. And this recharged groundwater can be exploited advantageously by proposing conjunctive use of both surface water and groundwater.

Thus the surface water that could be saved works out to 43189 (90750-47561) hectare meter. This can be utilised in other needy areas as a part of inter basin water transfer proposals of NWDA.

Though cost of groundwater is high when compared to that of surface water, the Government can provide subsidy to some extent to those who intend to use groundwater so as to make the scheme attractive and feasible.

7.4 SCOPE FOR FURTHER WORK

- Groundwater modelling can be done to predict the level of groundwater fluctuations for a long period.
- Socio-economic studies can be carried out in the study area and incorporated in model.
- Environmental impact assessment can also be done in the study area.

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COMPUTATION OF GROUNDWATER DEPTH IN THE STUDY AREA

There are many observation wells located in the study area and 11 wells for which data is collected, are considered to work out the weighted average depth of groundwater in the command area. The location of wells is marked showing study area boundary, and thiessen polygons are drawn. Plate 6 shows the location of the observation wells and thiessen polygons. The area of each polygon is measured using planimeter. Using observed levels of groundwater of each well during pre-monsoon and post monsoon periods of each year, the weighted average depth of groundwater in the area is worked out. Sample calculations for year 2001 are as given below.

Sl no	Name of observation well	Area in km^2 (A)	Observed depth of Groundwater table in m (D)	
			Pre monsoon	Post monsoon
1	Chautepalle	57	5.10	6.70
2	Podili	423	3.18	1.84
3	Peddarikatla	225	5.97	1.57
4	K.Agraharam	705	5.55	3.18
5	P.C.Palli	605	3.45	3.01
6	Tanguturu	246	3.13	0.46
7	Kandukuru	612	4.90	1.79
8	Ulavapadu	21	5.15	1.53
9	Pamuru	495	4.19	2.00
10	Kondapuram	278	4.38	2.00
11	Vikuntapuram	277	6.80	2.46

Weighted average depth $= \Sigma A_iD_i/A_i$

In pre monsoon 2001

Weighted average depth = [(57*5.10) + (423*3.18) + (225*5.97) + (705*5.55) + (605*3.45) + (246*3.13) + (612*4.90) + (21*5.15) + (495*4.19) + (278*4.38) + (277*6.80)] / [57+423+ 225 +705+605+246+612+21+495+278+277]

= 18034.76/3945

= 4.57 m

In post monsoon 2001

Weighted average depth = [(57*6.70) + (423*1.84) + (225*1.57) + (705*3.18) + (605*3.01) + (246*0.46) + (612*1.79) + (21*1.53) + (495*2.00) + (278*2.00) + (277*2.46)] / [57+423+ 225 +705+605+246+612+21+495+278+277]

= 9047.62/3945

= 2.29 m

Annexure II

LP MODEL

```
! Program for finding the optimal allocation of surface water and
!groundwater, considering ground water and crop area constraints;
!reducing the surface  water supply by 45 % of requirement

MAX   18411C1Z1 + 18411C1Z2 +  18411C1Z3  +
      11597C2Z1 + 11597C2Z2 +  11597C2Z3  +
       9043C3Z1 +  9043C3Z2 +   9043C3Z3  +
      46305C4Z1 + 46305C4Z2 +  46305C4Z3  +
       1729C5Z1 +  1729C5Z2 +   1729C5Z3  +
      58543C6Z1 + 58543C6Z2 +  58543C6Z3  +
      16027C7Z1 + 16027C7Z2 +  16027C7Z3  +
      14696C8Z1 + 14696C8Z2 +  14696C8Z3  +
      17039C9Z1 + 17039C9Z2 +  17039C9Z3  +
     24810C10Z1 +24810C10Z2 + 24810C10Z3  +
     11579C11Z1 +11579C11Z2 + 11579C11Z3  +
     14696C12Z1 +14696C12Z2 + 14696C12Z3  +
     17039C13Z1 +17039C13Z2 + 17039C13Z3  +
      1722C14Z1 + 1722C14Z2 +  1722C14Z3

-495SW1Z1  -495SW1Z2  -495SW1Z3
-495SW2Z1  -495SW2Z2  -495SW2Z3
-495SW3Z1  -495SW3Z2  -495SW3Z3
-495SW4Z1  -495SW4Z2  -495SW4Z3
-495SW5Z1- 495SW5Z2  -495SW5Z3
-495SW6Z1  -495SW6Z2  -495SW6Z3
-495SW7Z1  -495SW7Z2  -495SW7Z3
-495SW8Z1  -495SW8Z2  -495SW8Z3
-495SW9Z1  -495SW9Z2  -495SW9Z3
-495SW10Z1  -495SW10Z2  -495SW10Z3
-495SW11Z1  -495SW11Z2  -495SW11Z3
-495SW12Z1  -495SW12Z2  -495SW12Z3

-3312GW1Z1  -3312GW1Z2  -3312GW1Z3
-3312GW2Z1  -3312GW2Z2  -3312GW2Z3
-3312GW3Z1  -3312GW3Z2  -3312GW3Z3
-3312GW4Z1  -3312GW4Z2  -3312GW4Z3
-3312GW5Z1- 3312GW5Z2  -3312GW5Z3
-3312GW6Z1  -3312GW6Z2  -3312GW6Z3
-3312GW7Z1  -3312GW7Z2  -3312GW7Z3
-3312GW8Z1  -3312GW8Z2  -3312GW8Z3
-3312GW9Z1  -3312GW9Z2  -3312GW9Z3
-3312GW10Z1  -3312GW10Z2  -3312GW10Z3
-3312GW11Z1  -3312GW11Z2  -3312GW11Z3
-3312GW12Z1  -3312GW12Z2  -3312GW12Z3

SUBJECT TO
! WATER REQUIREMENT CONSTRAINT;

0.1592C7Z1 +0.3904C10Z1 +0.1024C12Z1 +0.0143C13Z1 -SW1Z1 -GW1Z1=0
0.1592C7Z2 +0.3904C10Z2 +0.1024C12Z2 +0.0143C13Z2 -SW1Z2 -GW1Z2=0
0.1592C7Z3 +0.3904C10Z3 +0.1024C12Z3 +0.0143C13Z3 -SW1Z3 -GW1Z3=0
```

0.1607C7Z1+0.2476C10Z1+0.0994C11Z1+0.0988C14Z1-SW2Z1-GW2Z1=0
0.1607C7Z2+0.2476C10Z2+0.0994C11Z2+0.0988C14Z2-SW2Z2-GW2Z2=0
0.1607C7Z3+0.2476C10Z3+0.0994C11Z3+0.0988C14Z3-SW2Z3-GW2Z3=0

0.2400C11Z1+0.2404C14Z1-SW3Z1-GW3Z1=0
0.2400C11Z2+0.2404C14Z2-SW3Z2-GW3Z2=0
0.2400C11Z3+0.2404C14Z3-SW3Z3-GW3Z3=0

0.1530C11Z1+0.1536C14Z1-SW4Z1-GW4Z1=0
0.1530C11Z2+0.1536C14Z2-SW4Z2-GW4Z2=0
0.1530C11Z3+0.1536C14Z3-SW4Z3-GW4Z3=0

0.0583C1Z1+0.0309C2Z1+0.0313C3Z1+0.0284C4Z1+0.0313C5Z1+0.0164C6Z1+0.036
9C8Z1+0.0774C9Z1-SW6Z1-GW6Z1=0
0.0583C1Z2+0.0309C2Z2+0.0313C3Z2+0.0284C4Z2+0.0313C5Z2+0.0164C6Z2+0.036
9C8Z2+0.0774C9Z2-SW6Z2-GW6Z2=0
0.0583C1Z3+0.0309C2Z3+0.0313C3Z3+0.0284C4Z3+0.0313C5Z3+0.0164C6Z3+0.036
9C8Z3+0.0774C9Z3-SW6Z3-GW6Z3=0

0.4650C1Z1+0.0559C2Z1+0.0551C3Z1+0.0555C4Z1+0.0551C5Z1+0.0551C6Z1+0.055
9C8Z1+0.1190C9Z1-SW7Z1-GW7Z1=0
0.4650C1Z2+0.0559C2Z2+0.0551C3Z2+0.0555C4Z2+0.0551C5Z2+0.0551C6Z2+0.055
9C8Z2+0.1190C9Z2-SW7Z2-GW7Z2=0
0.4650C1Z3+0.0559C2Z3+0.0551C3Z3+0.0555C4Z3+0.0551C5Z3+0.0551C6Z3+0.055
9C8Z3+0.1190C9Z3-SW7Z3-GW7Z3=0

0.3579C1Z1+0.1208C2Z1+0.1205C3Z1+0.0641C4Z1+0.1205C5Z1+0.1295C6Z1+0.110
7C8Z1+0.0309C9Z1-SW8Z1-GW8Z1=0
0.3579C1Z2+0.1208C2Z2+0.1205C3Z2+0.0641C4Z2+0.1205C5Z2+0.1295C6Z2+0.110
7C8Z2+0.0309C9Z2-SW8Z2-GW8Z2=0
0.3579C1Z3+0.1208C2Z3+0.1205C3Z3+0.0641C4Z3+0.1205C5Z3+0.1295C6Z3+0.110
7C8Z3+0.0309C9Z3-SW8Z3-GW8Z3=0

0.2896C1Z1+0.0399C2Z1+0.0402C3Z1+0.0873C4Z1+0.0402C5Z1+0.0283C6Z1+0.025
0C8Z1-SW9Z1-GW9Z1=0
0.2896C1Z2+0.0399C2Z2+0.0402C3Z2+0.0873C4Z2+0.0402C5Z2+0.0283C6Z2+0.025
0C8Z2-SW9Z2-GW9Z2=0
0.2896C1Z3+0.0399C2Z3+0.0402C3Z3+0.0873C4Z3+0.0402C5Z3+0.0283C6Z3+0.025
0C8Z3-SW9Z3-GW9Z3=0

0.0135C1Z1+0.0077C2Z1+0.0074C3Z1+0.0364C4Z1+0.0074C5Z1+0.0045C6Z1+0.004
5C7Z1+0.0268C12Z1+0.0190C13Z1-SW10Z1-GW10Z1=0
0.0135C1Z2+0.0077C2Z2+0.0074C3Z2+0.0364C4Z2+0.0074C5Z2+0.0045C6Z2+0.004
5C7Z2+0.0268C12Z2+0.0190C13Z2-SW10Z2-GW10Z2=0
0.0135C1Z3+0.0077C2Z3+0.0074C3Z3+0.0364C4Z3+0.0074C5Z3+0.0045C6Z3+0.004
5C7Z3+0.0268C12Z3+0.0190C13Z3-SW10Z3-GW10Z3=0

0.0311C4Z1+0.0208C7Z1+0.3309C10Z1+0.0202C12Z1+0.0202C13Z1-SW11Z1-
GW11Z1=0
0.0311C4Z2+0.0208C7Z2+0.3309C10Z2+0.0202C12Z2+0.0202C13Z2-SW11Z2-
GW11Z2=0
0.0311C4Z3+0.0208C7Z3+0.3309C10Z3+0.0202C12Z3+0.0202C13Z3-SW11Z3-
GW11Z3=0

```
0.0278C4Z1+0.1057C7Z1+0.3410C10Z1+0.0988C12Z1+0.0857C13Z1-SW12Z1-
GW12Z1=0
0.0278C4Z2+0.1057C7Z2+0.3410C10Z2+0.0988C12Z2+0.0857C13Z2-SW12Z2-
GW12Z2=0
0.0278C4Z3+0.1057C7Z3+0.3410C10Z3+0.0988C12Z3+0.0857C13Z3-SW12Z3-
GW12Z3=0

!SURAFCE WATER AVAILABILITY CONSTRAINT;

 SW1Z1+SW1Z2+SW1Z3<=5209
 SW2Z1+SW2Z2+SW2Z3<=4257
 SW3Z1+SW3Z2+SW3Z3<=3328
 SW4Z1+SW4Z2+SW4Z3<=2123
 SW5Z1+SW5Z2+SW5Z3<=0
 SW6Z1+SW6Z2+SW6Z3<=2151
 SW7Z1+SW7Z2+SW7Z3<=8844
 SW8Z1+SW8Z2+SW8Z3<=8635
 SW9Z1+SW9Z2+SW9Z3<=5627
 SW10Z1+SW10Z2+SW10Z3<=985
 SW11Z1+SW11Z2+SW11Z3<=3674
 SW12Z1+SW12Z2+SW12Z3<=5082

!GROUNDWATER AVAILABILITY CONSTRAINT;

  GW1Z1+GW1Z2+GW1Z3
 +GW2Z1+GW2Z2+GW2Z3
 +GW3Z1+GW3Z2+GW3Z3
 +GW4Z1+GW4Z2+GW4Z3
 +GW5Z1+GW5Z2+GW5Z3
 +GW6Z1+GW6Z2+GW6Z3
 +GW7Z1+GW7Z2+GW7Z3
 +GW8Z1+GW8Z2+GW8Z3
 +GW9Z1+GW9Z2+GW9Z3
 +GW10Z1+GW10Z2+GW10Z3
 +GW11Z1+GW11Z2+GW11Z3
 +GW12Z1+GW12Z2+GW12Z3<=42606

!AREA AVALABILITY CONSTRAINT;

 C1Z1+C2Z1+C3Z1+C4Z1+C5Z1+C6Z1+C7Z1+C8Z1+C9Z1<=62111
 C1Z2+C2Z2+C3Z2+C4Z2+C5Z2+C6Z2+C7Z2+C8Z2+C9Z2<=37292
 C1Z3+C2Z3+C3Z3+C4Z3+C5Z3+C6Z3+C7Z3+C8Z3+C9Z3<=1405
 C10Z1+C11Z1+C12Z1+C13Z1+C14Z1<=41411
 C10Z2+C11Z2+C12Z2+C13Z2+C14Z2<=24861
 C10Z3+C11Z3+C12Z3+C13Z3+C14Z3<=936

!CROP AREA CONSTRAINTS;

 C1Z1<=15529
 C2Z1<=10353
 C3Z1<=4140
 C4Z1<=9318
 C5Z1<=4140
```

```
C6Z1<=4140
C7Z1<=4140
C8Z1<=5176
C9Z1<=5176
C10Z1<=10353
C11Z1<=10353
C12Z1<=10353
C13Z1<=5176
C14Z1<=5176

C1Z2<=9323
C2Z2<=6215
C3Z2<=2486
C4Z2<=5594
C5Z2<=2486
C6Z2<=2486
C7Z2<=2486
C8Z2<=3108
C9Z2<=3108
C10Z2<=6215
C11Z2<=6215
C12Z2<=6215
C13Z2<=3108
C14Z2<=3108

C1Z3<=351
C2Z3<=234
C3Z3<=94
C4Z3<=210
C5Z3<=94
C6Z3<=94
C7Z3<=94
C8Z3<=117
C9Z3<=117
C10Z3<=234
C11Z3<=234
C12Z3<=234
C13Z3<=117
C14Z3<=117
```

END

RESULTS OF LP MODEL
(LP model is given at Annexure II)

LP OPTIMUM FOUND AT STEP 104

OBJECTIVE FUNCTION VALUE

1) 0.3055187E+10

VARIABLE	VALUE	REDUCED COST
C1Z1	15529.000000	0.000000
C1Z2	9323.000000	0.000000
C1Z3	351.000000	0.000000
C2Z1	10353.000000	0.000000
C2Z2	6215.000000	0.000000
C2Z3	234.000000	0.000000
C3Z1	4140.000000	0.000000
C3Z2	2486.000000	0.000000
C3Z3	94.000000	0.000000
C4Z1	9318.000000	0.000000
C4Z2	5594.000000	0.000000
C4Z3	210.000000	0.000000
C5Z1	4139.000000	0.000000
C5Z2	2486.000000	0.000000
C5Z3	94.000000	0.000000
C6Z1	4140.000000	0.000000
C6Z2	2486.000000	0.000000
C6Z3	94.000000	0.000000
C7Z1	4140.000000	0.000000
C7Z2	2486.000000	0.000000
C7Z3	94.000000	0.000000
C8Z1	5176.000000	0.000000
C8Z2	3108.000000	0.000000
C8Z3	117.000000	0.000000
C9Z1	5176.000000	0.000000
C9Z2	3108.000000	0.000000
C9Z3	117.000000	0.000000
C10Z1	10353.000000	0.000000
C10Z2	6215.000000	0.000000
C10Z3	234.000000	0.000000
C11Z1	10353.000000	0.000000
C11Z2	6215.000000	0.000000
C11Z3	234.000000	0.000000
C12Z1	10353.000000	0.000000
C12Z2	6215.000000	0.000000
C12Z3	234.000000	0.000000
C13Z1	5176.000000	0.000000
C13Z2	3108.000000	0.000000
C13Z3	117.000000	0.000000
C14Z1	5176.000000	0.000000
C14Z2	3108.000000	0.000000
C14Z3	117.000000	0.000000
SW1Z1	5077.046875	0.000000
SW1Z2	0.000000	0.000000
SW1Z3	131.953094	0.000000

SW2Z1	4149.136719	0.000000
SW2Z2	0.000000	0.000000
SW2Z3	107.863403	0.000000
SW3Z1	1004.950012	0.000000
SW3Z2	2238.763184	0.000000
SW3Z3	84.286797	0.000000
SW4Z1	640.942993	0.000000
SW4Z2	1428.283813	0.000000
SW4Z3	53.773201	0.000000
SW5Z1	0.000000	495.000000
SW5Z2	0.000000	495.000000
SW5Z3	0.000000	495.000000
SW6Z1	2096.542969	0.000000
SW6Z2	0.000000	0.000000
SW6Z3	54.457001	0.000000
SW7Z1	8844.000000	0.000000
SW7Z2	0.000000	0.000000
SW7Z3	0.000000	0.000000
SW8Z1	2609.049805	0.000000
SW8Z2	5807.204590	0.000000
SW8Z3	218.745300	0.000000
SW9Z1	1700.334106	0.000000
SW9Z2	3784.203857	0.000000
SW9Z3	142.462006	0.000000
SW10Z1	297.965881	0.000000
SW10Z2	662.118408	0.000000
SW10Z3	24.915701	0.000000
SW11Z1	1110.442627	0.000000
SW11Z2	2470.550293	0.000000
SW11Z3	93.007004	0.000000
SW12Z1	4953.286133	0.000000
SW12Z2	0.000000	0.000000
SW12Z3	128.713898	0.000000

GW1Z1	758.016174	0.000000
GW1Z2	3502.967529	0.000000
GW1Z3	0.000000	0.000000
GW2Z1	620.041199	0.000000
GW2Z2	2863.175537	0.000000
GW2Z3	0.000000	0.000000
GW3Z1	2724.080322	0.000000
GW3Z2	0.000000	0.000000
GW3Z3	0.000000	0.000000
GW4Z1	1738.099609	0.000000
GW4Z2	0.000000	0.000000
GW4Z3	0.000000	0.000000
GW5Z1	0.000000	3312.000000
GW5Z2	0.000000	3312.000000
GW5Z3	0.000000	3312.000000
GW6Z1	311.982086	0.000000
GW6Z2	1446.082397	0.000000
GW6Z3	0.000000	0.000000
GW7Z1	1062.436035	0.000000
GW7Z2	5947.605469	0.000000
GW7Z3	223.952103	0.000000
GW8Z1	7063.376465	0.000000
GW8Z2	0.000000	0.000000

GW8Z3	0.000000	0.000000
GW9Z1	4602.788574	0.000000
GW9Z2	0.000000	0.000000
GW9Z3	0.000000	0.000000
GW10Z1	804.897888	0.000000
GW10Z2	0.000000	0.000000
GW10Z3	0.000000	0.000000
GW11Z1	3004.952881	0.000000
GW11Z2	0.000000	0.000000
GW11Z3	0.000000	0.000000
GW12Z1	740.184814	0.000000
GW12Z2	3417.995850	0.000000
GW12Z3	0.000000	0.000000

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	3312.000000
3)	0.000000	3312.000000
4)	0.000000	3312.000000
5)	0.000000	3312.000000
6)	0.000000	3312.000000
7)	0.000000	3312.000000
8)	0.000000	3312.000000
9)	0.000000	3312.000000
10)	0.000000	3312.000000
11)	0.000000	3312.000000
12)	0.000000	3312.000000
13)	0.000000	3312.000000
14)	0.000000	3312.000000
15)	0.000000	3312.000000
16)	0.000000	3312.000000
17)	0.000000	3312.000000
18)	0.000000	3312.000000
19)	0.000000	3312.000000
20)	0.000000	3312.000000
21)	0.000000	3312.000000
22)	0.000000	3312.000000
23)	0.000000	3312.000000
24)	0.000000	3312.000000
25)	0.000000	3312.000000
26)	0.000000	3312.000000
27)	0.000000	3312.000000
28)	0.000000	3312.000000
29)	0.000000	3312.000000
30)	0.000000	3312.000000
31)	0.000000	3312.000000
32)	0.000000	3312.000000
33)	0.000000	3312.000000
34)	0.000000	3312.000000
35)	0.000000	2817.000000
36)	0.000000	2817.000000
37)	0.000000	2817.000000
38)	0.000000	2817.000000
39)	0.000000	0.000000
40)	0.000000	2817.000000
41)	0.000000	2817.000000
42)	0.000000	2817.000000
43)	0.000000	2817.000000

44)	0.000000	2817.000000
45)	0.000000	2817.000000
46)	0.000000	2817.000000
47)	1773.364868	0.000000
48)	0.000000	886.096008
49)	0.000000	0.000000
50)	0.000000	0.000000
51)	0.000000	0.000000
52)	0.000000	0.000000
53)	0.000000	0.000000
54)	0.000000	13602.501953
55)	0.000000	9865.681641
56)	0.000000	7314.000000
57)	0.000000	44323.957031
58)	1.000000	0.000000
59)	0.000000	56882.558594
60)	0.000000	13647.523438
61)	0.000000	13053.112305
62)	0.000000	15400.085938
63)	0.000000	20471.611328
64)	0.000000	9948.170898
65)	0.000000	13873.961914
66)	0.000000	16577.968750
67)	0.000000	89.846359
68)	0.000000	14488.598633
69)	0.000000	10751.777344
70)	0.000000	8200.095703
71)	0.000000	45210.054688
72)	0.000000	886.096008
73)	0.000000	57768.656250
74)	0.000000	14533.619141
75)	0.000000	13939.208008
76)	0.000000	16286.182617
77)	0.000000	20471.611328
78)	0.000000	9948.170898
79)	0.000000	13873.961914
80)	0.000000	16577.968750
81)	0.000000	89.846359
82)	0.000000	14488.598633
83)	0.000000	10751.777344
84)	0.000000	8200.095703
85)	0.000000	45210.054688
86)	0.000000	886.096008
87)	0.000000	57768.656250
88)	0.000000	14533.619141
89)	0.000000	13939.208008
90)	0.000000	16286.182617
91)	0.000000	20471.611328
92)	0.000000	9948.170898
93)	0.000000	13873.961914
94)	0.000000	16577.968750
95)	0.000000	89.846359

NO. ITERATIONS= 104

LP MODEL

```
! Program reducing the surface  water by 45 %;
! In the cropping pattern fodder crop is removed both in kharif and
rabi seasons and chillies is considered in lieu of Kharif fodder;

MAX    18411C1Z1+18411C1Z2+18411C1Z3+
       11597C2Z1+11597C2Z2+11597C2Z3+
         9043C3Z1+  9043C3Z2+  9043C3Z3+
       46305C4Z1+46305C4Z2+46305C4Z3+
       58543C6Z1+58543C6Z2+58543C6Z3+
       16027C7Z1+16027C7Z2+16027C7Z3+
       14696C8Z1+14696C8Z2+14696C8Z3+
       17039C9Z1+17039C9Z2+17039C9Z3+
        24810C10Z1+24810C10Z2+24810C10Z3+
        11579C11Z1+11579C11Z2+11579C11Z3+
        14696C12Z1+14696C12Z2+14696C12Z3+
        17039C13Z1+17039C13Z2+17039C13Z3

 -495SW1Z1  -495SW1Z2 -495SW1Z3
-495SW2Z1 -495SW2Z2 -495SW2Z3
-495SW3Z1 -495SW3Z2 -495SW3Z3
-495SW4Z1 -495SW4Z2 -495SW4Z3
-495SW5Z1- 495SW5Z2 -495SW5Z3
-495SW6Z1 -495SW6Z2 -495SW6Z3
-495SW7Z1 -495SW7Z2 -495SW7Z3
-495SW8Z1 -495SW8Z2 -495SW8Z3
-495SW9Z1 -495SW9Z2 -495SW9Z3
-495SW10Z1 -495SW10Z2 -495SW10Z3
-495SW11Z1 -495SW11Z2 -495SW11Z3
-495SW12Z1 -495SW12Z2 -495SW12Z3

-3312GW1Z1 -3312GW1Z2 -3312GW1Z3
-3312GW2Z1 -3312GW2Z2 -3312GW2Z3
-3312GW3Z1 -3312GW3Z2 -3312GW3Z3
-3312GW4Z1 -3312GW4Z2 -3312GW4Z3
-3312GW5Z1- 3312GW5Z2 -3312GW5Z3
-3312GW6Z1 -3312GW6Z2 -3312GW6Z3
-3312GW7Z1 -3312GW7Z2 -3312GW7Z3
-3312GW8Z1 -3312GW8Z2 -3312GW8Z3
-3312GW9Z1 -3312GW9Z2 -3312GW9Z3
-3312GW10Z1 -3312GW10Z2 -3312GW10Z3
-3312GW11Z1 -3312GW11Z2 -3312GW11Z3
-3312GW12Z1 -3312GW12Z2 -3312GW12Z3

SUBJECT TO

! WATER REQUIREMENT CONSTRAINT;
0.1592C7Z1 +0.3904C10Z1 +0.1024C12Z1 +0.0143C13Z1 -SW1Z1 -GW1Z1=0
0.1592C7Z2 +0.3904C10Z2 +0.1024C12Z2 +0.0143C13Z2 -SW1Z2 -GW1Z2=0
0.1592C7Z3 +0.3904C10Z3 +0.1024C12Z3 +0.0143C13Z3 -SW1Z3 -GW1Z3=0

0.1607C7Z1+0.2476C10Z1+0.0994C11Z1+0.0988C14Z1-SW2Z1-GW2Z1=0
0.1607C7Z2+0.2476C10Z2+0.0994C11Z2+0.0988C14Z2-SW2Z2-GW2Z2=0
0.1607C7Z3+0.2476C10Z3+0.0994C11Z3+0.0988C14Z3-SW2Z3-GW2Z3=0
```

0.2400C11Z1+0.2404C14Z1-SW3Z1-GW3Z1=0
0.2400C11Z2+0.2404C14Z2-SW3Z2-GW3Z2=0
0.2400C11Z3+0.2404C14Z3-SW3Z3-GW3Z3=0

0.1530C11Z1+0.1536C14Z1-SW4Z1-GW4Z1=0
0.1530C11Z2+0.1536C14Z2-SW4Z2-GW4Z2=0
0.1530C11Z3+0.1536C14Z3-SW4Z3-GW4Z3=0

0.0583C1Z1+0.0309C2Z1+0.0313C3Z1+0.0284C4Z1+0.0164C6Z1+0.0369C8Z1+0.0774C9Z1-SW6Z1-GW6Z1=0
0.0583C1Z2+0.0309C2Z2+0.0313C3Z2+0.0284C4Z2+0.0164C6Z2+0.0369C8Z2+0.0774C9Z2-SW6Z2-GW6Z2=0
0.0583C1Z3+0.0309C2Z3+0.0313C3Z3+0.0284C4Z3+0.0164C6Z3+0.0369C8Z3+0.0774C9Z3-SW6Z3-GW6Z3=0

0.4650C1Z1+0.0559C2Z1+0.0551C3Z1+0.0555C4Z1+0.0551C6Z1+0.0559C8Z1+0.1190C9Z1-SW7Z1-GW7Z1=0
0.4650C1Z2+0.0559C2Z2+0.0551C3Z2+0.0555C4Z2+0.0551C6Z2+0.0559C8Z2+0.1190C9Z2-SW7Z2-GW7Z2=0
0.4650C1Z3+0.0559C2Z3+0.0551C3Z3+0.0555C4Z3+0.0551C6Z3+0.0559C8Z3+0.1190C9Z3-SW7Z3-GW7Z3=0

0.3579C1Z1+0.1208C2Z1+0.1205C3Z1+0.0641C4Z1+0.1295C6Z1+0.1107C8Z1+0.0309C9Z1-SW8Z1-GW8Z1=0
0.3579C1Z2+0.1208C2Z2+0.1205C3Z2+0.0641C4Z2+0.1295C6Z2+0.1107C8Z2+0.0309C9Z2-SW8Z2-GW8Z2=0
0.3579C1Z3+0.1208C2Z3+0.1205C3Z3+0.0641C4Z3+0.1295C6Z3+0.1107C8Z3+0.0309C9Z3-SW8Z3-GW8Z3=0

0.2896C1Z1+0.0399C2Z1+0.0402C3Z1+0.0873C4Z1+0.0283C6Z1+0.0250C8Z1-SW9Z1-GW9Z1=0
0.2896C1Z2+0.0399C2Z2+0.0402C3Z2+0.0873C4Z2+0.0283C6Z2+0.0250C8Z2-SW9Z2-GW9Z2=0
0.2896C1Z3+0.0399C2Z3+0.0402C3Z3+0.0873C4Z3+0.0283C6Z3+0.0250C8Z3-SW9Z3-GW9Z3=0

0.0135C1Z1+0.0077C2Z1+0.0074C3Z1+0.0364C4Z1+0.0045C6Z1+0.0045C7Z1+0.0268C12Z1+0.0190C13Z1-SW10Z1-GW10Z1=0
0.0135C1Z2+0.0077C2Z2+0.0074C3Z2+0.0364C4Z2+0.0045C6Z2+0.0045C7Z2+0.0268C12Z2+0.0190C13Z2-SW10Z2-GW10Z2=0
0.0135C1Z3+0.0077C2Z3+0.0074C3Z3+0.0364C4Z3+0.0045C6Z3+0.0045C7Z3+0.0268C12Z3+0.0190C13Z3-SW10Z3-GW10Z3=0

0.0311C4Z1+0.0208C7Z1+0.3309C10Z1+0.0202C12Z1+0.0202C13Z1-SW11Z1-GW11Z1=0
0.0311C4Z2+0.0208C7Z2+0.3309C10Z2+0.0202C12Z2+0.0202C13Z2-SW11Z2-GW11Z2=0
0.0311C4Z3+0.0208C7Z3+0.3309C10Z3+0.0202C12Z3+0.0202C13Z3-SW11Z3-GW11Z3=0

0.0278C4Z1+0.1057C7Z1+0.3410C10Z1+0.0988C12Z1+0.0857C13Z1-SW12Z1-GW12Z1=0
0.0278C4Z2+0.1057C7Z2+0.3410C10Z2+0.0988C12Z2+0.0857C13Z2-SW12Z2-GW12Z2=0
0.0278C4Z3+0.1057C7Z3+0.3410C10Z3+0.0988C12Z3+0.0857C13Z3-SW12Z3-GW12Z3=0

```
!SURAFCE WATER AVAILABILITY CONSTRAINT;
SW1Z1+SW1Z2+SW1Z3<=5209
SW2Z1+SW2Z2+SW2Z3<=3801
SW3Z1+SW3Z2+SW3Z3<=2217
SW4Z1+SW4Z2+SW4Z3<=1414
SW5Z1+SW5Z2+SW5Z3<=0
SW6Z1+SW6Z2+SW6Z3<=2096
SW7Z1+SW7Z2+SW7Z3<=8844
SW8Z1+SW8Z2+SW8Z3<=8668
SW9Z1+SW9Z2+SW9Z3<=5583
SW10Z1+SW10Z2+SW10Z3<=974
SW11Z1+SW11Z2+SW11Z3<=3674
SW12Z1+SW12Z2+SW12Z3<=5082

!GROUNDWATER AVAILABILITY CONSTRAINT;
GW1Z1+GW1Z2+GW1Z3
+GW2Z1+GW2Z2+GW2Z3
+GW3Z1+GW3Z2+GW3Z3
+GW4Z1+GW4Z2+GW4Z3
+GW5Z1+GW5Z2+GW5Z3
+GW6Z1+GW6Z2+GW6Z3
+GW7Z1+GW7Z2+GW7Z3
+GW8Z1+GW8Z2+GW8Z3
+GW9Z1+GW9Z2+GW9Z3
+GW10Z1+GW10Z2+GW10Z3
+GW11Z1+GW11Z2+GW11Z3
+GW12Z1+GW12Z2+GW12Z3<=42606

!AREA AVALABILITY CONSTRAINT;
C1Z1+C2Z1+C3Z1+C4Z1+C6Z1+C7Z1+C8Z1+C9Z1<=62111
C1Z2+C2Z2+C3Z2+C4Z2+C6Z2+C7Z2+C8Z2+C9Z2<=37292
C1Z3+C2Z3+C3Z3+C4Z3+C6Z3+C7Z3+C8Z3+C9Z3<=1405
C10Z1+C11Z1+C12Z1+C13Z1<=36235
C10Z2+C11Z2+C12Z2+C13Z2<=21753
C10Z3+C11Z3+C12Z3+C13Z3<=819

!CROP AREA CONSTRAINTS;
C1Z1<=15529
C2Z1<=10353
C3Z1<=4140
C4Z1<=9318
C6Z1<=8280
C7Z1<=4140
C8Z1<=5176
C9Z1<=5176
C10Z1<=10353
C11Z1<=10353
C12Z1<=10353
C13Z1<=5176
C1Z2<=9323
C2Z2<=6215
C3Z2<=2486
C4Z2<=5594
C6Z2<=4972
C7Z2<=2486
C8Z2<=3108
C9Z2<=3108
```

```
 C10Z2<=6215
 C11Z2<=6215
 C12Z2<=6215
 C13Z2<=3108
 C1Z3<=351
 C2Z3<=234
 C3Z3<=94
 C4Z3<=210
 C6Z3<=188
 C7Z3<=94
 C8Z3<=117
 C9Z3<=117
 C10Z3<=234
 C11Z3<=234
 C12Z3<=234
 C13Z3<=117
END
```

Annexure V

RESULTS OF LP MODEL

(LP Model is given at Annexure IV)

LP OPTIMUM FOUND AT STEP 93

OBJECTIVE FUNCTION VALUE

1) 0.3430048E+10

VARIABLE	VALUE	REDUCED COST
C1Z1	15529.000000	0.000000
C1Z2	9323.000000	0.000000
C1Z3	351.000000	0.000000
C2Z1	10353.000000	0.000000
C2Z2	6215.000000	0.000000
C2Z3	234.000000	0.000000
C3Z1	4139.000000	0.000000
C3Z2	2486.000000	0.000000
C3Z3	94.000000	0.000000
C4Z1	9318.000000	0.000000
C4Z2	5594.000000	0.000000
C4Z3	210.000000	0.000000
C6Z1	8280.000000	0.000000
C6Z2	4972.000000	0.000000
C6Z3	188.000000	0.000000
C7Z1	4140.000000	0.000000
C7Z2	2486.000000	0.000000
C7Z3	94.000000	0.000000
C8Z1	5176.000000	0.000000
C8Z2	3108.000000	0.000000
C8Z3	117.000000	0.000000
C9Z1	5176.000000	0.000000
C9Z2	3108.000000	0.000000
C9Z3	117.000000	0.000000
C10Z1	10353.000000	0.000000
C10Z2	6215.000000	0.000000
C10Z3	234.000000	0.000000
C11Z1	10353.000000	0.000000
C11Z2	6215.000000	0.000000
C11Z3	234.000000	0.000000
C12Z1	10353.000000	0.000000
C12Z2	6215.000000	0.000000
C12Z3	234.000000	0.000000
C13Z1	5176.000000	0.000000
C13Z2	3108.000000	0.000000
C13Z3	117.000000	0.000000
SW1Z1	1574.079346	0.000000
SW1Z2	3502.967529	0.000000
SW1Z3	131.953094	0.000000
SW2Z1	1148.590942	0.000000
SW2Z2	2556.105225	0.000000
SW2Z3	96.303802	0.000000
SW3Z1	669.239990	0.000000
SW3Z2	1491.599976	0.000000
SW3Z3	56.160000	0.000000
SW4Z1	427.303009	0.000000

SW4Z2	950.894958	0.000000
SW4Z3	35.801998	0.000000
SW5Z1	0.000000	495.000000
SW5Z2	0.000000	495.000000
SW5Z3	0.000000	495.000000
SW6Z1	633.902588	0.000000
SW6Z2	1409.041016	0.000000
SW6Z3	53.056400	0.000000
SW7Z1	8620.047852	0.000000
SW7Z2	0.000000	0.000000
SW7Z3	223.952103	0.000000
SW8Z1	2618.829834	0.000000
SW8Z2	5829.578613	0.000000
SW8Z3	219.591293	0.000000
SW9Z1	5583.000000	0.000000
SW9Z2	0.000000	0.000000
SW9Z3	0.000000	0.000000
SW10Z1	294.447906	0.000000
SW10Z2	654.908997	0.000000
SW10Z3	24.643101	0.000000
SW11Z1	1110.442627	0.000000
SW11Z2	2470.550293	0.000000
SW11Z3	93.007004	0.000000
SW12Z1	1535.290161	0.000000
SW12Z2	3417.995850	0.000000
SW12Z3	128.713898	0.000000
GW1Z1	4260.983887	0.000000
GW1Z2	0.000000	0.000000
GW1Z3	0.000000	0.000000
GW2Z1	3109.197998	0.000000
GW2Z2	0.000000	0.000000
GW2Z3	0.000000	0.000000
GW3Z1	1815.479980	0.000000
GW3Z2	0.000000	0.000000
GW3Z3	0.000000	0.000000
GW4Z1	1156.705933	0.000000
GW4Z2	0.000000	0.000000
GW4Z3	0.000000	0.000000
GW5Z1	0.000000	3312.000000
GW5Z2	0.000000	3312.000000
GW5Z3	0.000000	3312.000000
GW6Z1	1712.936523	0.000000
GW6Z2	0.000000	0.000000
GW6Z3	0.000000	0.000000
GW7Z1	1286.388184	0.000000
GW7Z2	5947.605469	0.000000
GW7Z3	0.000000	0.000000
GW8Z1	7090.856445	0.000000
GW8Z2	0.000000	0.000000
GW8Z3	0.000000	0.000000
GW9Z1	670.856567	0.000000
GW9Z2	3754.620361	0.000000
GW9Z3	141.343399	0.000000
GW10Z1	796.409912	0.000000
GW10Z2	0.000000	0.000000
GW10Z3	0.000000	0.000000

GW11Z1	3004.952881	0.000000
GW11Z2	0.000000	0.000000
GW11Z3	0.000000	0.000000
GW12Z1	4158.180664	0.000000
GW12Z2	0.000000	0.000000
GW12Z3	0.000000	0.000000
C14Z1	0.000000	1632.153687
C14Z2	0.000000	1632.153687
C14Z3	0.000000	1632.153687

ROW	SLACK OR SURPLUS	DUAL PRICES
2)	0.000000	3312.000000
3)	0.000000	3312.000000
4)	0.000000	3312.000000
5)	0.000000	3312.000000
6)	0.000000	3312.000000
7)	0.000000	3312.000000
8)	0.000000	3312.000000
9)	0.000000	3312.000000
10)	0.000000	3312.000000
11)	0.000000	3312.000000
12)	0.000000	3312.000000
13)	0.000000	3312.000000
14)	0.000000	3312.000000
15)	0.000000	3312.000000
16)	0.000000	3312.000000
17)	0.000000	3312.000000
18)	0.000000	3312.000000
19)	0.000000	3312.000000
20)	0.000000	3312.000000
21)	0.000000	3312.000000
22)	0.000000	3312.000000
23)	0.000000	3312.000000
24)	0.000000	3312.000000
25)	0.000000	3312.000000
26)	0.000000	3312.000000
27)	0.000000	3312.000000
28)	0.000000	3312.000000
29)	0.000000	3312.000000
30)	0.000000	3312.000000
31)	0.000000	3312.000000
32)	0.000000	3312.000000
33)	0.000000	3312.000000
34)	0.000000	3312.000000
35)	0.000000	2817.000000
36)	0.000000	2817.000000
37)	0.000000	2817.000000
38)	0.000000	2817.000000
39)	0.000000	0.000000
40)	0.000000	2817.000000
41)	0.000000	2817.000000
42)	0.000000	2817.000000
43)	0.000000	2817.000000
44)	0.000000	2817.000000
45)	0.000000	2817.000000

46)	0.000000	2817.000000
47)	3699.481689	0.000000
48)	0.000000	8200.095703
49)	0.000000	0.000000
50)	0.000000	0.000000
51)	0.000000	0.000000
52)	0.000000	0.000000
53)	0.000000	0.000000
54)	0.000000	6288.502441
55)	0.000000	2551.681641
56)	1.000000	0.000000
57)	0.000000	37009.957031
58)	0.000000	49568.558594
59)	0.000000	6333.523438
60)	0.000000	5739.111816
61)	0.000000	8086.086426
62)	0.000000	20471.611328
63)	0.000000	9948.170898
64)	0.000000	13873.961914
65)	0.000000	16577.968750
66)	0.000000	14488.598633
67)	0.000000	10751.777344
68)	0.000000	8200.095703
69)	0.000000	45210.054688
70)	0.000000	57768.656250
71)	0.000000	14533.619141
72)	0.000000	13939.208008
73)	0.000000	16286.182617
74)	0.000000	20471.611328
75)	0.000000	9948.170898
76)	0.000000	13873.961914
77)	0.000000	16577.968750
78)	0.000000	14488.598633
79)	0.000000	10751.777344
80)	0.000000	8200.095703
81)	0.000000	45210.054688
82)	0.000000	57768.656250
83)	0.000000	14533.619141
84)	0.000000	13939.208008
85)	0.000000	16286.182617
86)	0.000000	20471.611328
87)	0.000000	9948.170898
88)	0.000000	13873.961914
89)	0.000000	16577.968750

NO. ITERATIONS= 93

Groundwater Quality

1.0 HYDRO - CHEMISTRY

No groundwater study is complete without knowing the chemical quality and its suitability for various purposes. The quality of groundwater is of utmost importance as its physical, bacterial, chemical characteristics determine its usefulness for domestic, industrial and agricultural uses. The study of chemistry of water determines the hydro geological environments through which groundwater flow has taken place. The hydro-chemical study involves description of occurrence of various chemical constituents and concentration of salts present in relation to water use. The Central Ground Water Board (CGWB) as a part of its groundwater monitoring studies collects groundwater samples from the National Hydrographic Stations in the month of May for studying the hydro-chemical changes with time. In addition to its above program, the board also collects water samples from the studies of hydro-geological surveys and exploratory drilling programs. The State Groundwater Department also analyses the groundwater samples periodically from their observation wells and in other related studies.

2.0 CHEMICAL QUALITY

The pH is the hydrogen ion concentration in groundwater which determines the acidic or alkaline nature of water. The pH of groundwater in and around the study area vary from 7.6 to 9.09 indicating that groundwater is alkaline in nature. About 80 % of groundwater samples indicate pH of 8 and above and thus are within the maximum permissible limit of drinking water standards prescribed by World Health Organisation and Bureau of Indian Standards.

Electrical conductivity is a measure of degree of mineralization in groundwater represented by total dissolved salts present, based on the electrical conductance values of groundwater samples collected in and around the study area. In general, the electrical conductivity values range from 420 to 8610 micro- siemens/cm at 25 ^{0}C. The coastal and northern part of the study area has high electrical conductivity in the groundwater ranging from 1528 to 7860 micro- siemens/cm at 25 ^{0}C.

Chloride concentration in groundwater increases alkalinity in water and chloride concentration up to 250 mg/l is desirable though it is permissible up to 1000 mg/l for drinking purpose. Only in small patches, the chloride content is very high to the tune of 1134 to 2428 mg/l.

Chemical pollution by way applying the nitrogenous fertilizers in the agriculture sector is the root cause of high nitrate pollution in groundwater. Nitrate concentration of about 45 mg/l is desirable for drinking water standards but in case no alternative source of water is present, nitrate up to 100 mg/l is permissible. Areas around Kandukuru and Ulavapadu along the coastal region and isolated pockets near Darsi and Pedda Alavapadu show high nitrates.

High fluoride concentration of above 1.5 mg/l in groundwater are confined to Kanigiri, Santhamaguluru and Domala areas.

3.0 CLASSIFICATION OF WATER

The analytical data of water samples were plotted on Piper's Tri-linear Diagram to classify water. It is found thar 80 % of the samples are of Na-K type. This type of water with high concentration of Na-K generally imparts low permeability to soils. As a result, the growth of vegetation is restricted. Hence, gypsum treatment to these soils is recommended to reduce the effect. In the remaining 20 % of the area , the water is of Ca-Mg type. This type of water in general is good for the soil as it provides good permeability condition.

4.0 SUITABILITY OF GROUNDWATER FOR IRRIGATION

To study the suitability of groundwater for irrigation, the chemical data is plotted on U.S. Salinity Laboratory Diagram based on the Sodium Adsorption ratio (SAR) and electrical conductivity values. The Sodium Adsorption ratio (SAR) is defined as

$$SAR = \frac{Na^{+}}{\sqrt{\left(Ca^{++} + Mg^{++}\right)/2}}$$

From the data plotted, it is seen samples fell under following categories viz., C_2S_1 (21%), C_3S_1 (15%), C_3S_4(2%), C_4S_2 (5%), C_4S_4 (18%).

The C_2S_1 category indicates medium salinity and low sodium water. This type of water can be used on any type of soil and crops can be grown without any special consideration for salinity control. The C_3S_1type is of high salinity and low sodium water and such water needs good drainage. The C_3S_2 category has good permeability. The water presents appreciable sodium hazard especially under low leaching conditions. The soils need application of gypsum.

The C_3S_3 type water has high salinity and has high sodium water. This category of water may be used on soils with adequate drainage and with special amendments for management. These soils also need application of gypsum and organic matter. The C_3S_4 category indicates high salinity and high sodium content providing harmful levels of exchangeable sodium in most soils. Special amendments such as soil management, good drainage, leaching and addition of gypsum and organic matter are needed. The C_4S_4 category is of high salinity and of vary high sodium and not generally suitable for risk of soil damage. Special reclamation has to be adopted in irrigation practices and soil management with this category of water.

5.0 RESIDUAL SODIUM CARBONATE (RSC)

Keeping in view the importance of proportion of calcium and magnesium in bicarbonate rich water, Residual Sodium Carbonate method is used to study the suitability of shallow groundwater for irrigation. Residual Sodium Carbonate (RSC is given by)

$$RSC = \left(Ca_3^{--} + HCO_3^{-}\right) - \left(Ca^{++} + Mg^{++}\right)$$

Where ionic concentrations are in Milli equivalents per liter.

Irrigation water containing more than 2.5 epm (equivalent parts per million) of RSC is not suitable for irrigation and about 42 % of samples fall in this category. The RSC values of 1.25 to 2.5 epm is represented by 16 samples and below 1.25 epm by 42% samples and these waters are safe for irrigation.

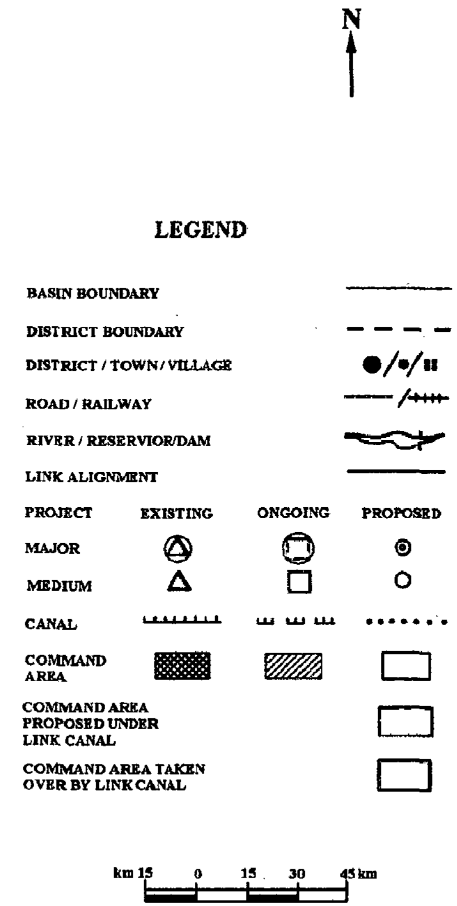
The latest hydro- Chemical data of some of the hydrographic stations (wells) are given in Table.

TABLE: HYDRO-CHEMICAL DATA

Sl No	Details	Podili	Kani giri	K. Agra haram	Kan du kuru	Ula va padu	Pa mu ru	V.V Palem	Tan gu turu	Pedari katla	Ba tta gu dur
1	pH	7.8	7.65	2.1	7.7	7.8	8	7.5	7.6	8.06	8
2	Electrical con-conductan-ce micro Siemens /cm at 25 ^{0}C	3730	2660	879	5680	1528	1889	830	7860	1112	1238
3	Total hardness as $CaCO_3$	220	760	140	940	285	120	340	164 5	155	250
4	Ca (mg/l)	32	144	12	64	42	14	54	186	10	6
5	Mg (mg/l)	46	96	26	187	43	20	49	283	31	56
6	Na (mg/l)	720	251	136	844	214	370	1.5	1019	205	161
7	K (mg/l)	24	22	3	52	11	13	4	4.0	9	13
8	CO (mg/l)	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	0	0
9	HCO (mg/l)	781	98	366	275	122	653	330	384	415	683
10	Cl (mg/l)	440	518	60	1361	230	170	35	211 3	78	96
11	NO_3 (mg/l)	218	282	33	75	91	88	45	38	250	135
12	SO_4(mg/l)	403	269	24	610	254	86	58	240	77	48
13	F (mg/l)	0.40	0.21	0.20	1.08	0.51	0.91	0.24	0.18	0.72	0.7

Source: "HYDROGEOLOGICAL FRAME WORK AND DEVELOPMENT PROSPECTS OF PRAKASAM DISTRICT, ANDHRA PRADESH", Southern Region, Hyderabad, Central Groundwater Board, Ministry of Water Resources, Govt. of India.

PLATE I

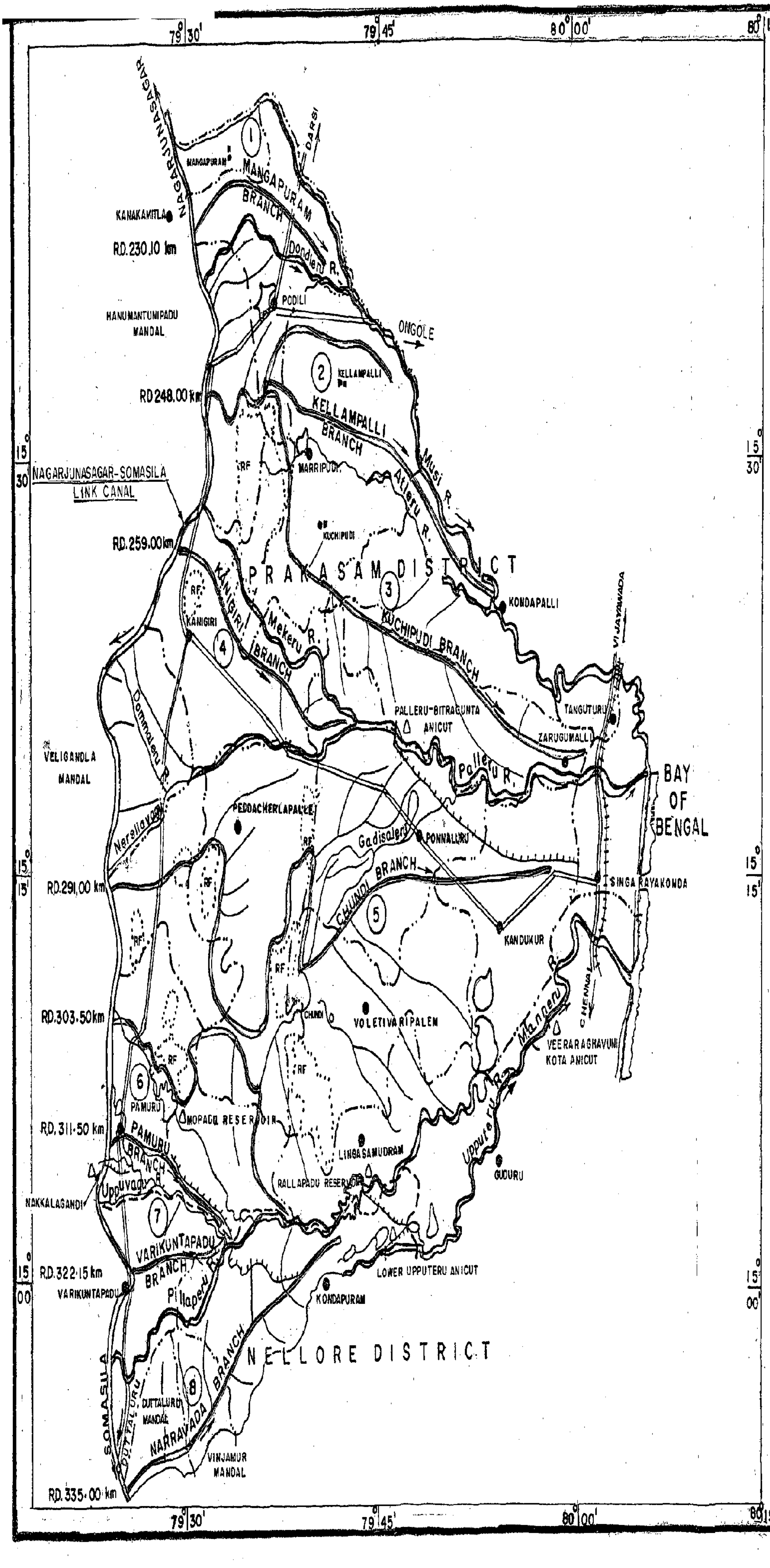


NATIONAL WATER DEVELOPMENT AGENCY

KRISHNA (NAGARJUNASAGAR) - PENNAR (SOMASILA) LINK PROJECT

INDEX MAP

PLATE 2



N

LEGEND

DISRICT / MANDAL BOUNDARY	
MANDAL HQS./ VILLAGES	
RIVER/RESERVOIR/DAM	
ROAD/RAILWAY LINE	
RESERVED FOREST	RF
EXISTING PROJECT/CANAL	
LINK ALIGNMENT	
BRANCH CANAL	
EXISTING COMMAND AREA	

PROPOSED COMMAND AREA UNDER LINK CANAL

MANGAPURAM BRANCH CANAL	1
KELLAMPALLI BRANCH CANAL	2
KUCHIPUDI BRANCH CANAL	3
KANIGIRI BRANCH CANAL	4
CHUNDI BRANCH CANAL	5
PAMURU BRANCH CANAL	6
VARIKUNTAPADU BRANCH CANAL	7
NARRAVADA BRANCH CANAL	8

km 4 0 4 8 12 km

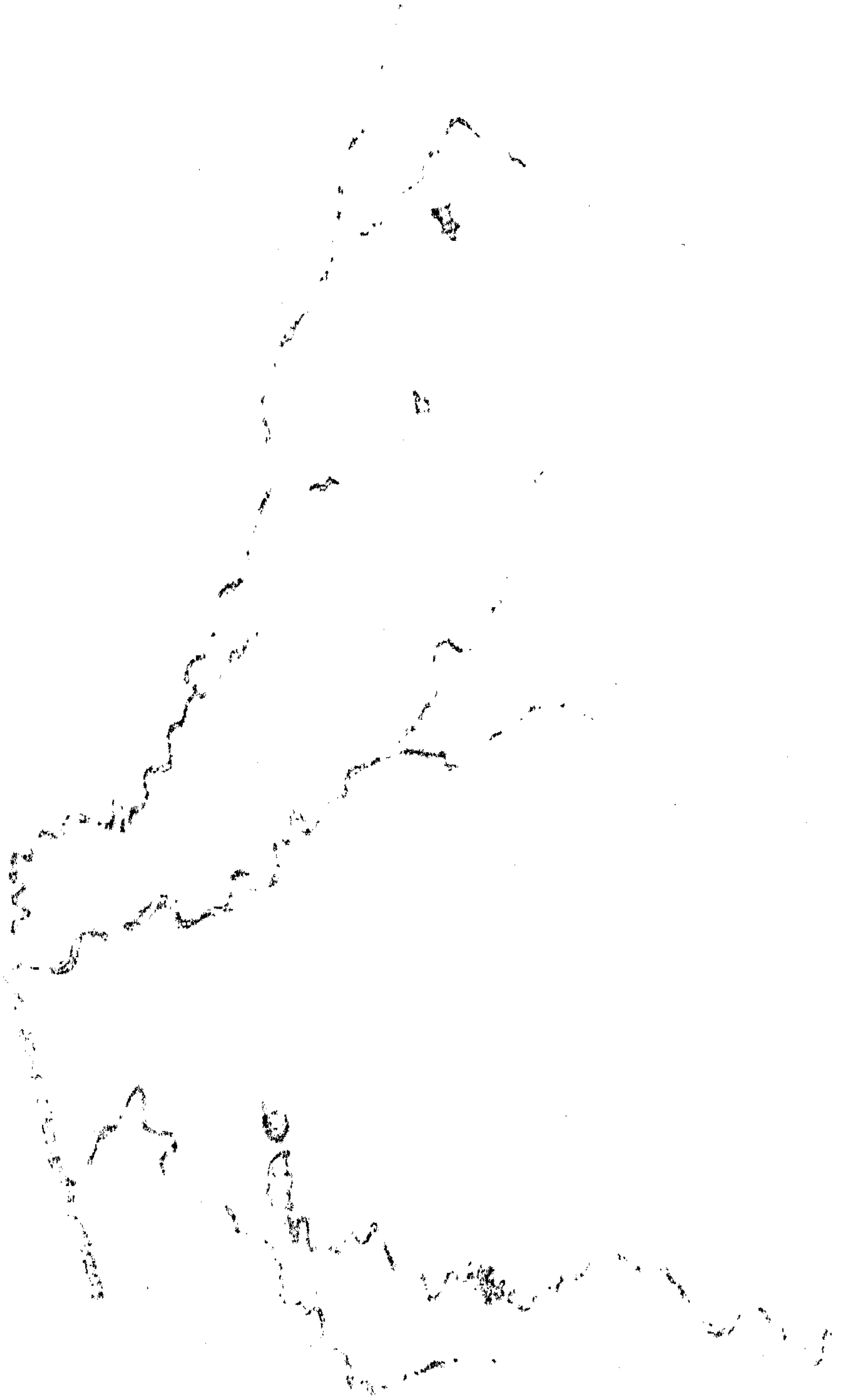
NATIONAL WATER DEVELOPMENT AGENCY

KRISHNA(NAGARJUNASAGAR)-PENNAR(SOMASILA) LINK PROJECT

PROPOSED COMMAND AREA UNDER NAGARJUNASAGAR-SOMASILA LINK

DRAWN BY: B.R.CHANDAR,AE
TRACED BY: M.V.LAKSHMI,DM
CHECKED BY: B.R.CHANDAR,AE

SUBMITTED:
(V.V.RAMANA SARMA)
EE, ID-II, NWDA, HYDERABAD



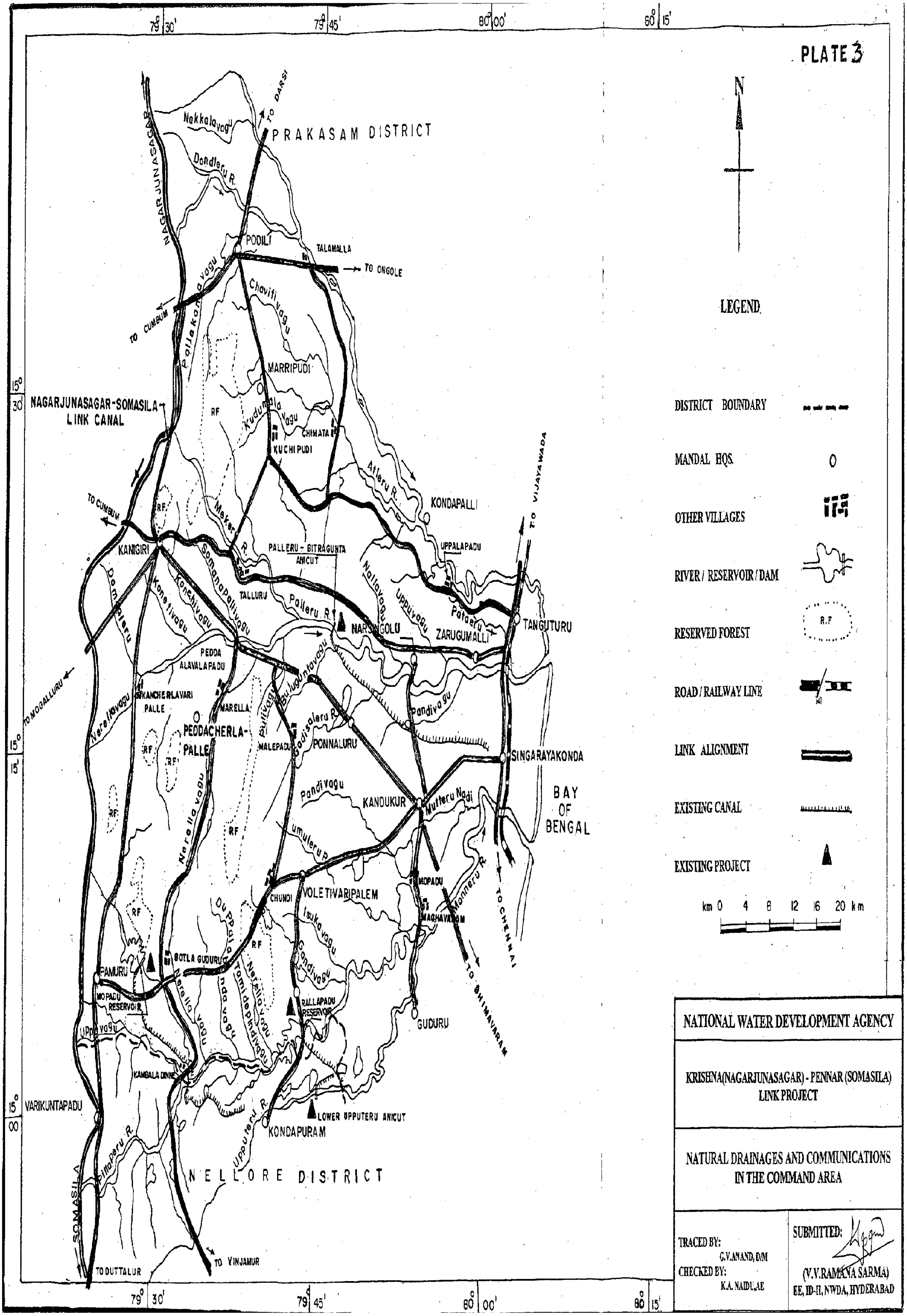


PLATE 3
N
LEGEND
DISTRICT BOUNDARY
MANDAL HQS.
OTHER VILLAGES
RIVER / RESERVOIR / DAM
RESERVED FOREST
ROAD / RAILWAY LINE
LINK ALIGNMENT
EXISTING CANAL
EXISTING PROJECT
km 0 4 8 12 16 20 km
PRAKASAM DISTRICT
NELLORE DISTRICT
BAY OF BENGAL
NAGARJUNASAGAR-SOMASILA LINK CANAL
NAGARJUNASAGAR
SOMASILA
TO DARSI
TO ONGOLE
TO CUMBUM
TO MOGALLURU
TO VIJAYAWADA
TO CHENNAI
TO BHIMAVARAM
TO VINJAMUR
TO DUTTALUR
PODILI
TALAMALLA
MARRIPUDI
CHIMATA
KUCHIPUDI
KONDAPALLI
UPPALAPADU
KANIGIRI
TALLURU
PALLERU - BITRAGUNTA ANICUT
NARSINGOLU
ZARUGUMALLI
TANGUTURU
PEDDA ALAVALAPADU
KANCHERLAVARI PALLE
MARELLA
PEDDACHERLA-PALLE
MALEPADU
PONNALURU
SINGARAYAKONDA
KANDUKUR
VOLETIVARIPALEM
CHUNDI
MOPADU
MAGHAVARAM
PAMURU
BOTLA GUDURU
MOPADU RESERVOIR
RALLAPADU RESERVOIR
GUDURU
KAMBALA DINNE
VARIKUNTAPADU
KONDAPURAM
LOWER UPPUTERU ANICUT
Nakkalavagu
Dondleru R.
Pallakonda vagu
Chavitivagu
Kudumala vagu
Atteru R.
Maneru R.
Somanapallivagu
Konchivagu
Konetivagu
Domaleru
Palleru R.
Nallavagu
Uppuvagu
Pataeru
Buluguntavagu
Paidisaleru R.
Pandivagu
Nerellavagu
Pandi vagu
Mutteru Nadi
Manneru R.
Tsukavagu
Gandivagu
Uppuvagu
Uppateru R.
Sitaperu R.
RF
15° 30'
15° 15'
15° 00'
79° 30'
79° 45'
80° 00'
80° 15'
NATIONAL WATER DEVELOPMENT AGENCY
KRISHNA(NAGARJUNASAGAR) - PENNAR (SOMASILA) LINK PROJECT
NATURAL DRAINAGES AND COMMUNICATIONS IN THE COMMAND AREA
TRACED BY: G.V.ANAND, D/M
CHECKED BY: K.A. NAIDU, AE
SUBMITTED:
(V.V.RAMANA SARMA)
EE, ID-II, NWDA, HYDERABAD

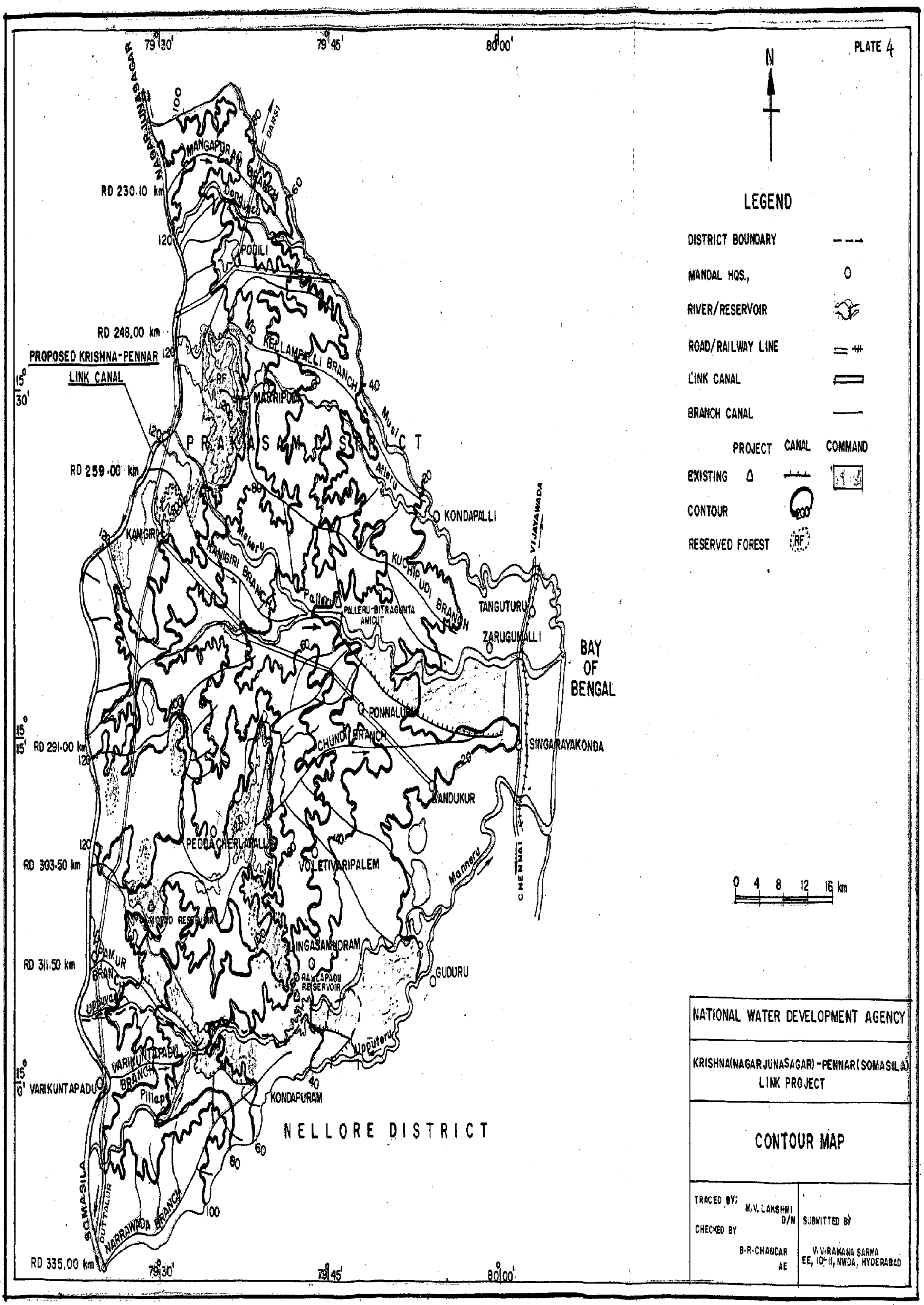
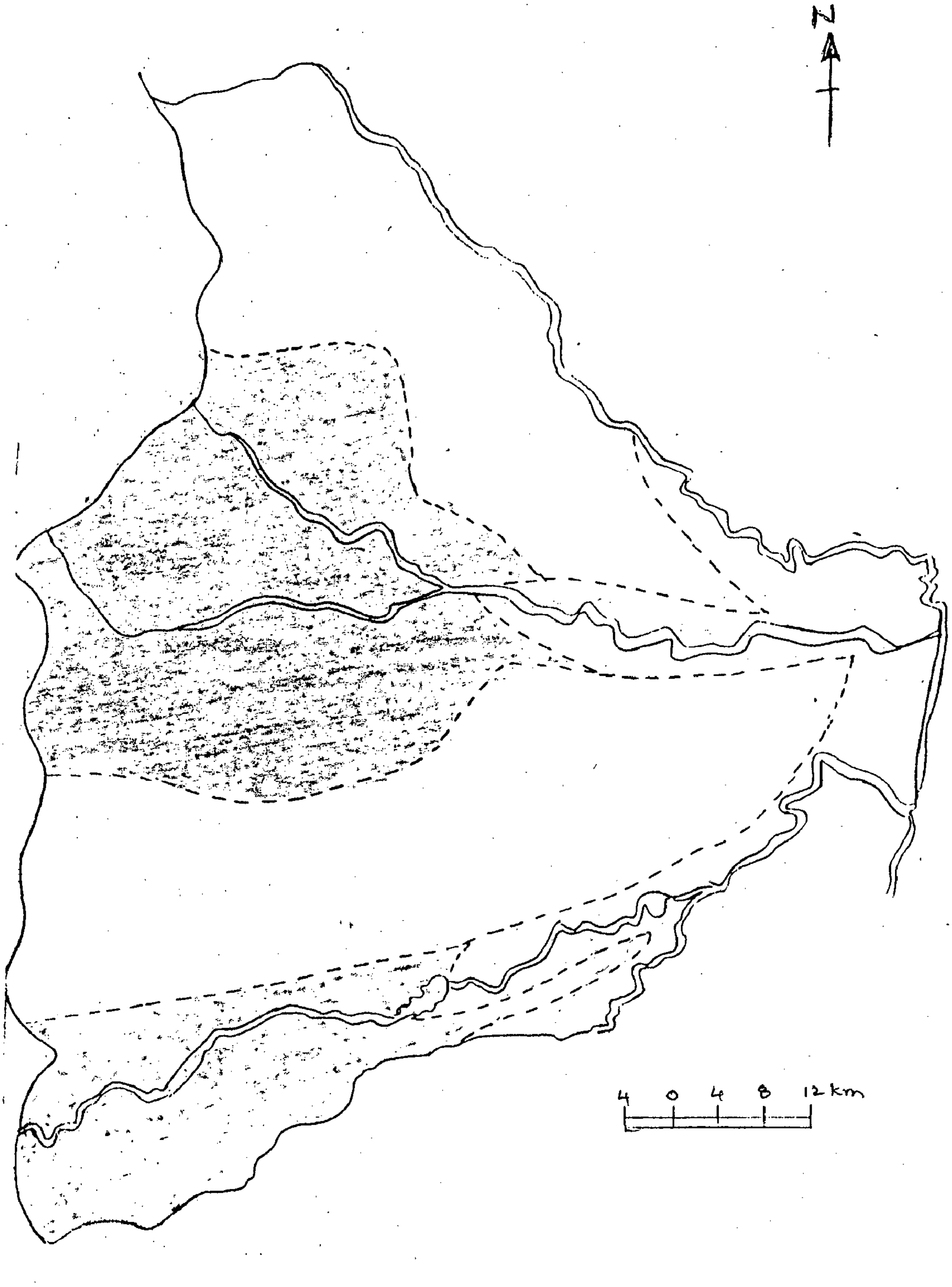
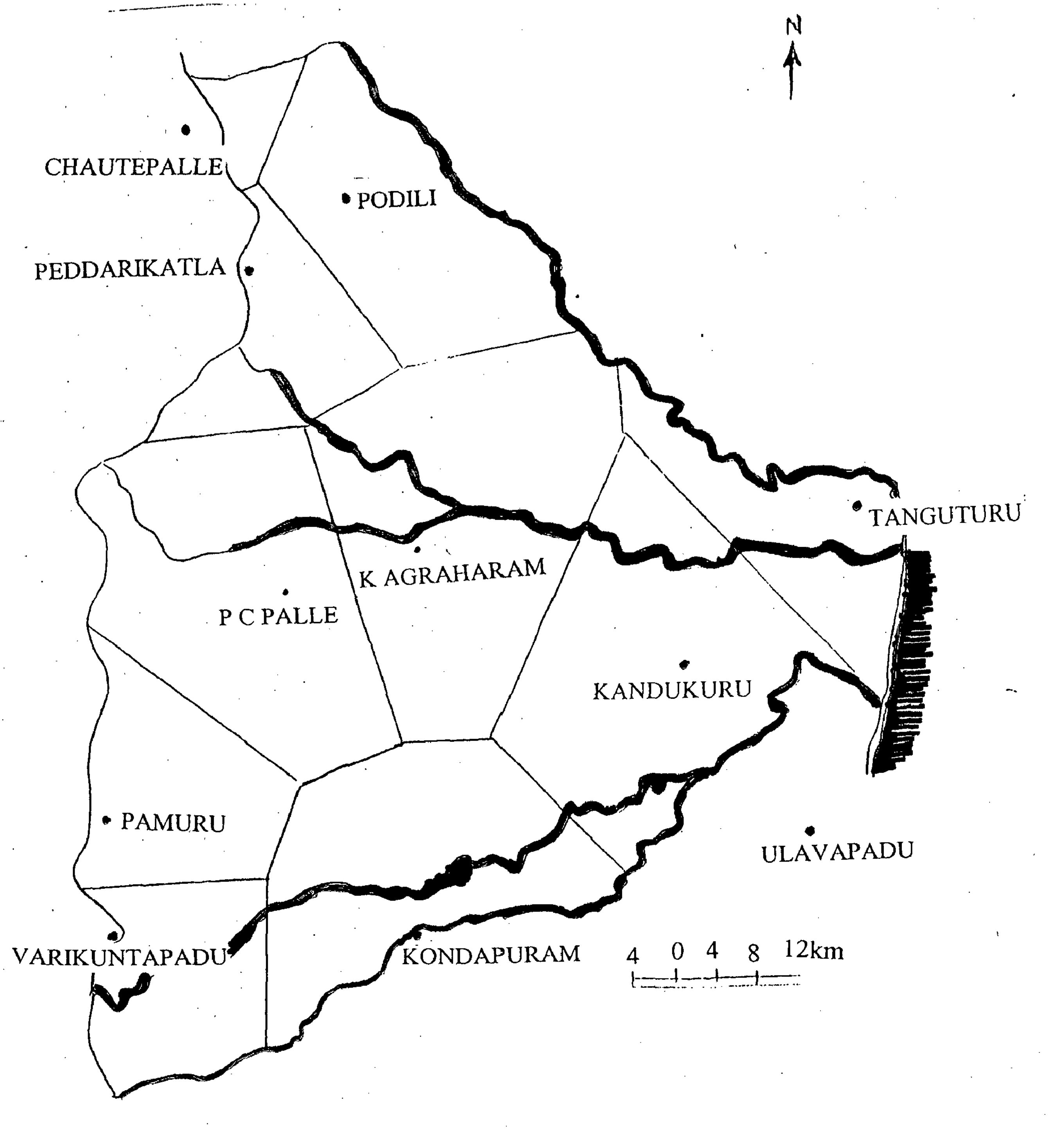


PLATE 4
N
LEGEND
DISTRICT BOUNDARY
MANDAL HQS.,
RIVER/RESERVOIR
ROAD/RAILWAY LINE
LINK CANAL
BRANCH CANAL
PROJECT
CANAL
COMMAND
EXISTING
CONTOUR
RESERVED FOREST
RF
0 4 8 12 16 km
79°30'
79°45'
80°00'
15° 30'
15° 15'
15° 0'
NAGARJUNASAGAR
DARSI
RD 230.10 km
RD 248.00 km
RD 259.00 km
RD 291.00 km
RD 303.50 km
RD 311.50 km
RD 335.00 km
PROPOSED KRISHNA-PENNAR LINK CANAL
MANGAPURAM BRANCH
PODILI
REPALLAMPALLI BRANCH
MARRIPUDI
PRAKASAM DISTRICT
Musi
Atleru
KONDAPALLI
VIJAYAWADA
KANIGIRI
KANIGIRI BRANCH
KUCHIPUDI BRANCH
Paleru
PALLERU-BITRAGUNTA ANICUT
TANGUTURU
ZARUGUMALLI
BAY OF BENGAL
PONNALURU
CHUNDI BRANCH
SINGARAYAKONDA
KANDUKUR
PEDDACHERLAPALLI
VOLETIVARIPALEM
Manneru
CHENNAI
LINGASAMUDRAM
RALLAPADU RESERVOIR
GUDURU
Upputeru
VARIKUNTAPADU
VARIKUNTAPADU BRANCH
Pillaperu
KONDAPURAM
NELLORE DISTRICT
SOMASILA
NARRAWADA BRANCH
NATIONAL WATER DEVELOPMENT AGENCY
KRISHNA(NAGARJUNASAGAR)-PENNAR(SOMASILA) LINK PROJECT
CONTOUR MAP
TRACED BY: M.V. LAKSHMI D/M
CHECKED BY B.R.CHANDAR AE
SUBMITTED BY V.V.RAMANA SARMA EE, ID-II, NWDA, HYDERABAD



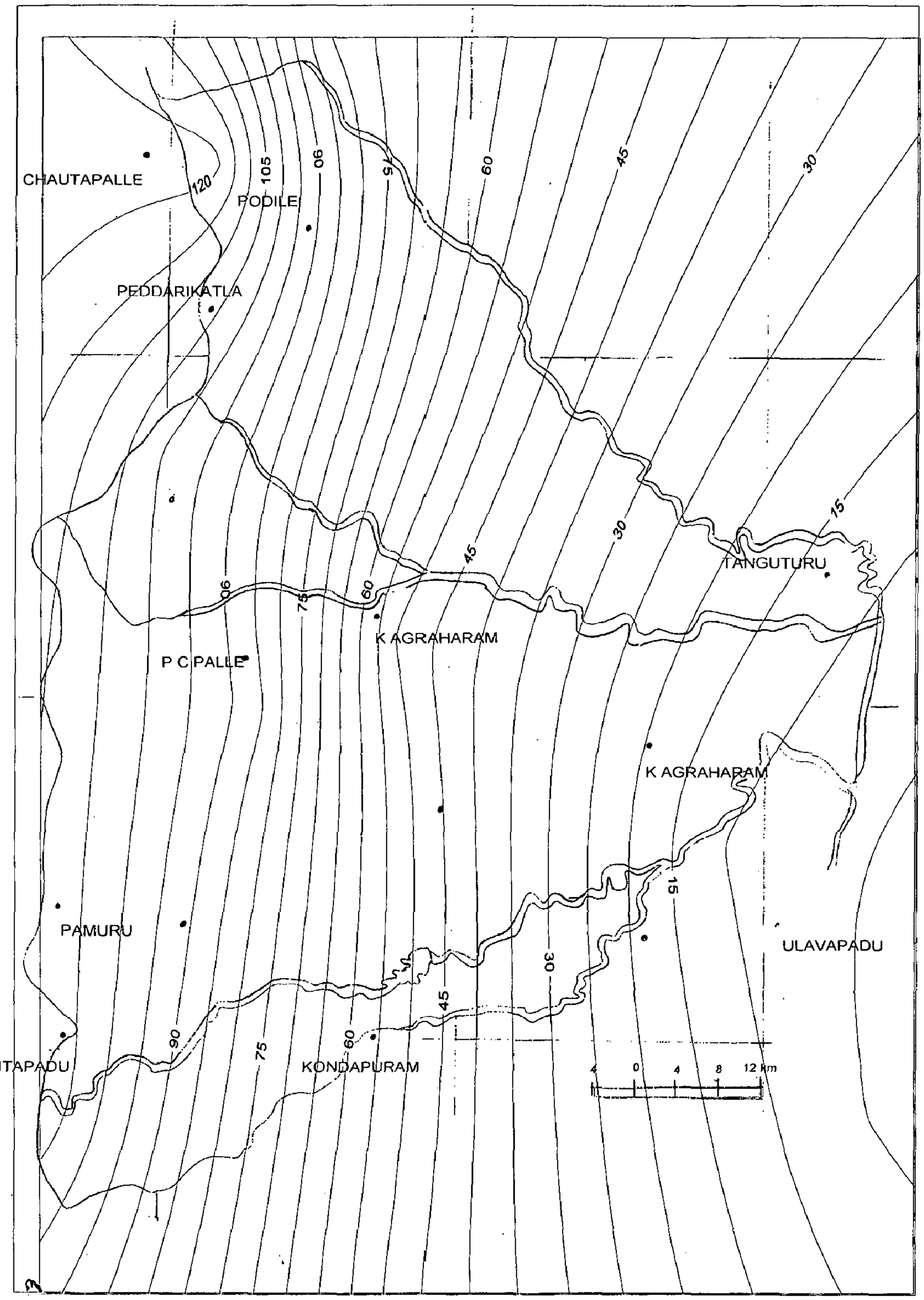
☐ Schist ☐ Alluvium ▣ Granite ☐ Sand Stone

GEOLOGICAL FORMATIONS IN THE LINK CAOMMAD

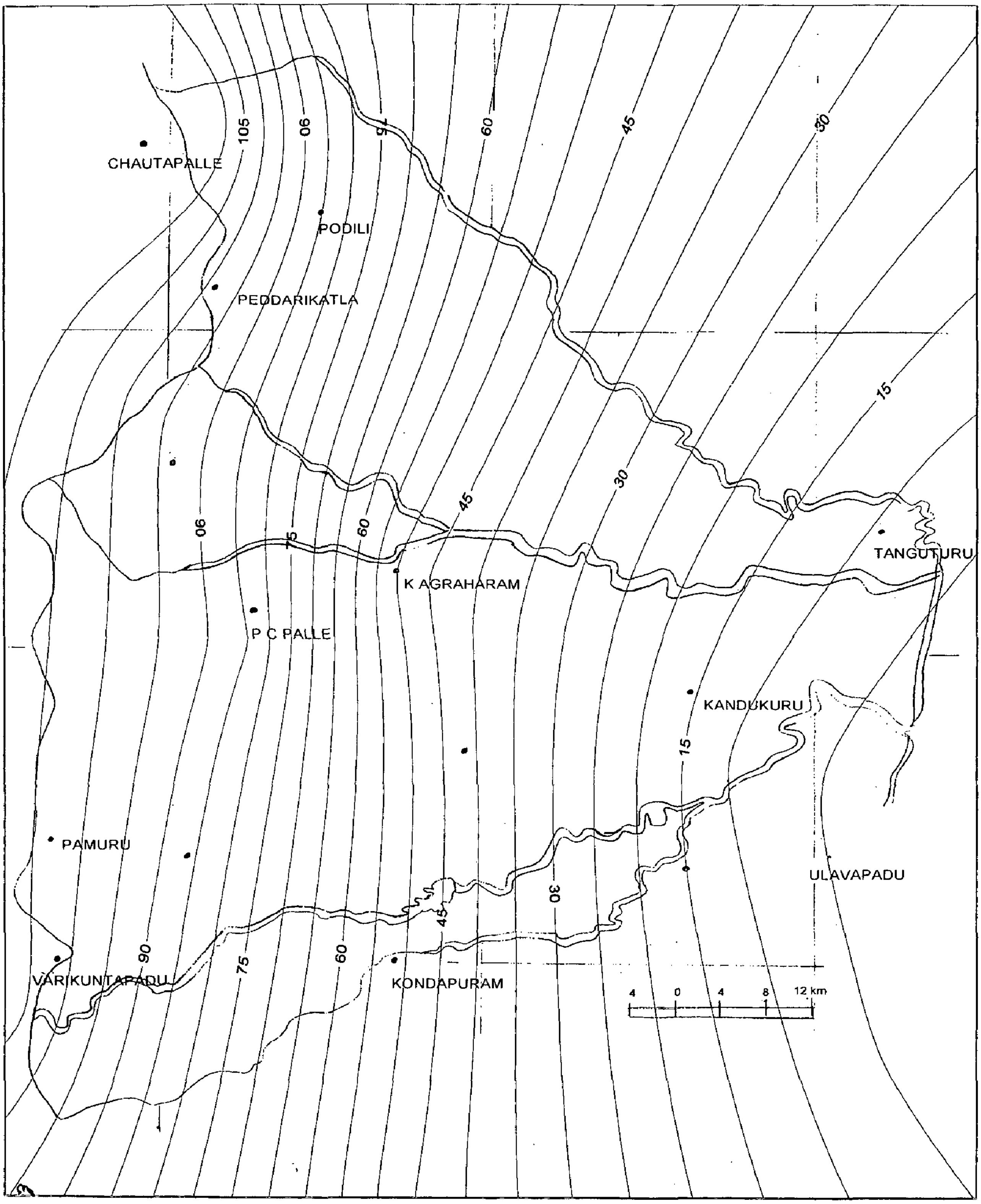


LOCATION OF OBSERVATION WELLS AND THEISSEN'S POLYGONS

PLATE 7



POST MONSOON GROUNDWATER CONTOURS



PRE MONSOON GROUNDWATER CONTOURS

PLATE 8

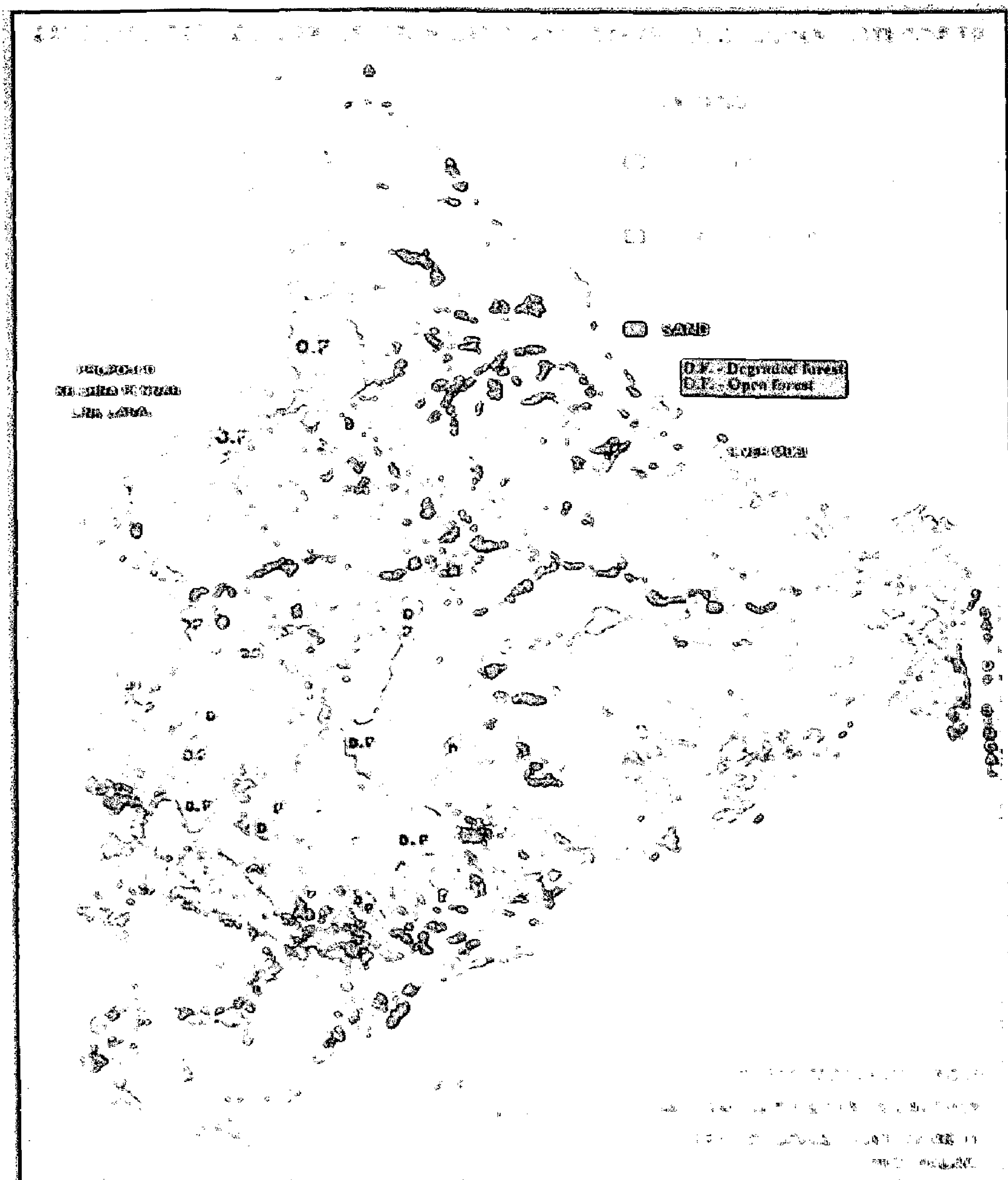


Fig.8 SATELLITE DERIVED MAP OF CROP LAND AND OTHER COVER CATEGORIES OF PROPOSED KRISHNA -- PENNAR LINK CANAL COMMAND AREA

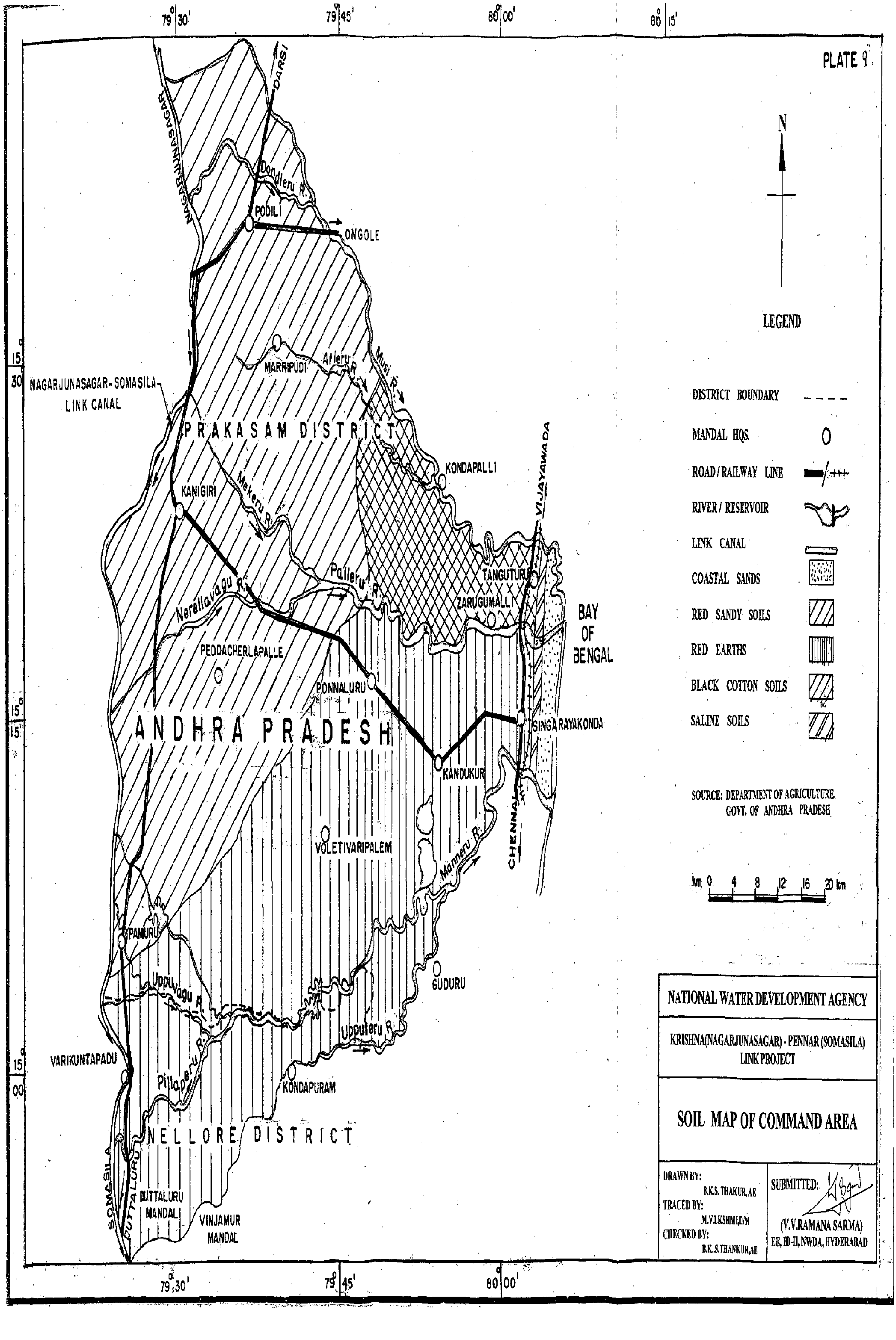


PLATE 9
N
LEGEND
DISTRICT BOUNDARY
MANDAL HQS.
ROAD / RAILWAY LINE
RIVER / RESERVOIR
LINK CANAL
COASTAL SANDS
RED SANDY SOILS
RED EARTHS
BLACK COTTON SOILS
SALINE SOILS
SOURCE: DEPARTMENT OF AGRICULTURE, GOVT. OF ANDHRA PRADESH
km 0 4 8 12 16 20 km
NATIONAL WATER DEVELOPMENT AGENCY
KRISHNA(NAGARJUNASAGAR) - PENNAR (SOMASILA) LINK PROJECT
SOIL MAP OF COMMAND AREA
DRAWN BY: B.K.S. THAKUR, AE
TRACED BY: M.V.LKSHMI,D/M
CHECKED BY: B.K.S.THANKUR,AE
SUBMITTED:
(V.V.RAMANA SARMA)
EE, ID-II, NWDA, HYDERABAD
79° 30'
79° 45'
80° 00'
80° 15'
15° 30'
15° 15'
15° 00'
NAGARJUNASAGAR
DARSI
Dondleru R.
PODILI
ONGOLE
MARRIPUDI
Atleru R.
Musi R.
NAGARJUNASAGAR-SOMASILA LINK CANAL
PRAKASAM DISTRICT
KONDAPALLI
VIJAYAWADA
KANIGIRI
Mekeru R.
Palleru R.
TANGUTURU
ZARUGUMALLI
Nerellavagu R.
BAY OF BENGAL
PEDDACHERLAPALLE
PONNALURU
SINGARAYAKONDA
ANDHRA PRADESH
KANDUKUR
VOLETIVARIPALEM
Manneru R.
CHENNAI
PAMURU
GUDURU
Uppuvagu R.
Upputeru R.
VARIKUNTAPADU
Pillaperu R.
KONDAPURAM
NELLORE DISTRICT
SOMASILA
DUTTALURU
DUTTALURU MANDAL
VINJAMUR MANDAL