# WATERLOGGING AND SALINITY STUDIES IN NAGARJUNA SAGAR RIGHT BANK CANAL COMMAND

**HARD ROCK REGIONAL CENTRE**
**NATIONAL INSTITUTE OF HYDROLOGY**
**BELGAUM**

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| **DIRECTOR:** | **Sh.R.D.Singh** |
| **TECHNICAL COORDINATOR:** | **Dr.Sudhirkumar, Sc. “G”** |
| **HEAD:** | **Dr.Venkatesh B, Sc. “F”** |
| **STUDY GROUP:** | **Dr.N.Varadarajan, PRA**<br>**Dr.B.K.Purandara, Sc. “E”** |

# 1.0 INTRODUCTION

## 1.1 GENERAL

Water logging is a common feature associated with many of the irrigation commands of surface water projects. In other words, it is excess recharge over discharge of ground water, leading to a rise in the water table. The irrigation command areas are recharged not only by rainfall infiltration, but also by seepage from reservoirs, canals, distributaries and field channels, and return circulation of irrigation water. Water-logging is said to occur when the water table rises to within the root zone of crops. Climate, topography and geology play a dominant role in governing; occurrence, movement and storage of water. Any change in water balance equilibrium of an area, reflects the change in water table, leading to either water logging conditions or depletion of water table depending upon the nature of the change. The rise or decline in water table is not desirable because both the phenomenon degrades the sub surface environment there by ground water regime. Direct evaporation of groundwater from the capillary fringe leads to salinization of soil, and advanced stages, of ground water as well. Lack of aeration in the root zone, coupled with soil salinity; adversely affect crop yields in waterlogged areas.

In India about 60% of food production depends on irrigation. Since, independence, large investments to the extent of almost 10% of the country's total public investment have been made in the development of water resources for irrigation through execution of major and medium irrigation schemes. Nearly 60% of the available cultivable land of 180 million Ha of the country is proposed to be brought under irrigation by the year 2025 AD. The irrigation development is largely a feature of sub humid and semi arid to arid areas, where natural precipitation is inadequate to maintain the desired soil moisture for crop growth. Surface water is transported to such areas from available water supply sources either through diversion of water from springs, streams and rivers or from natural or artificial lakes and reservoirs. Seepage losses occurred along transfer of water from available resources has caused water logging and salinity development in many irrigation commands. It is a fact that in some of the major projects, irrigation is in vogue for more than three decades and the ayacuts have been stabilized with the farmers enjoying all the benefits including access to uncontrolled use of surface water through the canals in the case of those in the upper and middle reaches of the projects. With the availability of surface water throughout the year, farmers found it rarely necessary to use the ground water with the result that ground water utilization became almost negligible. The net result was a rise in ground water levels, gradually building up the water table, giving rise to water logging conditions.

An area under irrigation can be called as waterlogged when the ground water level is within 2.0 m below ground level almost throughout the year. It can be considered as seasonally water logged when the canals are in operation or during the monsoon period when the rainfall also contributes to the water logging. The major causes of water logging and salinity in many parts of the country are due to excessive and indiscriminate uses of water by the farmers in the upper and middle reaches, obstruction to natural drainage courses and seepage losses in conveyance, decline in the levels of oxygen and increase in the content of carbon dioxide in the root zone of plants, thereby affecting the productivity of the crops. In addition, water logging also results in the soil and accumulation of salt in the top soil or ground surface, rendering it infertile. The conjunctive use of surface and ground water has been recognized as an important activity for optimal development, utilization and management of available resources of a region or command.

The ground water development for irrigation in command areas has taken a very late start; because of some distant limitation on account of lack of energy source for lifting of the ground water and also because of technological gaps and understanding socio economic practices of farmers and policies of command area development authorities. However, in the recent past, the ground water development has also taken appreciable lead particularly in the tail ends of commands with the development of electric energy and land development measures under agriculture.

In the command areas where the quality of ground water is poor the ground water development has not taken place and accumulation of ground water has given rise to the problems of water logging and salinity development. These types of situations naturally call for systematic use of surface and ground water based on conjunctive use planning. The conjunctive use of surface and ground water can be sound policy for water resources management to avoid degradation and deterioration of agricultural land, water logging due to rise in ground water table, over and under irrigation and gap ayacut problems in command areas.

A study conducted by the command area division of the Ministry of Water Resources, Govt. of India in 37 canal command areas in the country has revealed that out of about 97 lakh ha under irrigation, an area of about 7.18 lakh ha has been affected by salinity and an area of 7.43 lakh ha by water logging. It has also been estimated that a loss of nearly 10 to 30 percent in agriculture production occurs when the water table rises within 3.0 m from the land surface. The rising salinity of ground water used for water supply and irrigation is a major problem. There are many examples of salinity increase in various parts of the country, particularly in canal command areas. This is generally caused by localized over pumping from wells, boreholes and infiltration galleries. The impact of various management activities on ground water quality is closely related with the quality of water applied for irrigation. Soil water systems in the unsaturated zone are highly complex. Firstly, it is seldom in stable equilibrium and is in constant flux. The degree of saturation of soil water varies both in time and space. This in turn affects flow parameters namely, the suction head and the hydraulic conductivity, which are not unique functions of soil-water, but exhibit hysteresis. In addition, there is the effect of airflow through the soil and compressibility of air, which may have some effect on unsaturated flow, and in some cases, the soil may undergo chemical changes.

Fertilizers are normally applied to agricultural fields to increase the crop yields however; a part of the chemical constituents present in the fertilizer may percolate down to reach the ground water table thereby polluting the fresh water aquifers. It is therefore important to limit the application of fertilizers and monitor their movement in the unsaturated zone. The downward movement of a chemical in the field generally is measured by applying a known amount of the chemical at the surface and then measuring at one or more times latter. The increase for the chemical may be found at different depths in all or part of the unsaturated zone. Alternatively, the downward movement may be represented more simply by the increase in the amount of the chemical below some arbitrary depth, such as the root zone. In most instances, the chemical forms added in fertilizers are the same as those naturally present in soils and absorbed by plants, but in some instances the forms added are transformed after addition to the forms naturally present in soils. Because of the variability from one site to another, measurements at many locations are needed to obtain a good estimate of the downward movement in an area such as agriculture field which is quite expensive and time consuming.

### 1.2 OBJECTIVES

The rising salinity of groundwater used for water supply and irrigation is a major problem. There are many examples of salinity increase in various parts of the country, particularly in canal command areas. In order to achieve the target, the major constraint is with regard to salinity and water logging in various parts of the command area. In the present study, the objective is to study the water logging and salinity problems in one of the most salinity affected command area in the right bank canal of Nagarjunasagar, Andhra Pradesh. Andhra Pradesh State Ground water Department is carrying out conjunctive use studies in major command areas of AP. The studies carried out in Nagarjunasagar command reveal that the areas of water logging and prone to water logging are varied season-wise and year-wise.

## 2.0 REVIEW OF LITERATURE

The increasing demand for food and the scarcity in many regions makes it imperative to increase the irrigated area and improve irrigation management and technology throughout the world, especially in arid and semi-arid regions. Permanent agriculture under conditions of insufficient precipitation depends on water management so that excessive salt does not accumulate in the root zone. The significant contribution of major surface irrigation projects in ushering in green revolution in the country is well known. However, isolated development of surface water, without taking into account the ground water resource within the command area has led to certain undesirable situations like water-logging and salinity. Salt formed in-situ by weathering of soil minerals or salt deposited from applied water tends to accumulate in the soil profile. Thus, when irrigation water is applied, there is a two sided question: whether sufficient supplemental water is given to provide the required leaching and whether the drainage network (natural and man-made) has the capacity to remove sufficient water with its dissolved salts. It is quite important to summarize the various studies conducted to understand the impact of irrigation practices on water-logging and salinity with particular reference to groundwater quality.

The development of water logging and soil salinization upon introduction of irrigation in arid and semi-arid regions is a global phenomenon. The data reveal that about 10-13% of irrigated lands in various countries have adversely been affected due to water logging and soil salinization (Gupta et. al 2001). It is believed that on global scale, as much area goes out of cultivation is brought under irrigation every year. Salt affected soils occur extensively in different agro-ecological and soil zones of India, particularly the arid, semi-arid and the sub-humid regions. The first attempt to focus the attention on this vital problem in India was made by the Irrigation Commission (1972) which tried to collect the information on state wise areas affected by the water-logging due to irrigation. The areas where the depth of water table varies from 0-2.0 meters were taken as waterlogged areas. It was reported that 4.84 million hectares were affected by water logging in the States of Punjab, Haryana, Uttar Pradesh, Bihar, West Bengal, Maharashtra, Rajasthan, Madhya Pradesh and Karnataka. The second attempt at National level was made by the National Commission on Agriculture (1976) which compiled the information and put the figures at 6 million ha. as the extent of waterlogged area in the country, out of which 3.4 m ha. is subjected to surface flooding, mostly in the States of West Bengal, Orissa, Andhra Pradesh, Punjab, U.P., Gujarat, Tamil Nadu and Kerala and the remaining 2.6 m. ha as the area having high water table particularly in Punjab, Haryana, U.P., and in some parts of Rajasthan, Maharashtra etc. The Commission also indicated that alkaline and saline soils, together, constitute an area of 7 m. ha out of which 4.5 m. ha under salinity and 2.5 m. ha under alkalinity. Saline soils include 1 m. ha. in arid and semi-arid regions of Rajasthan and Gujarat and 1.5 m. ha in the black cotton soils. According to the estimate made by the Ministry of Agriculture (1991) about an area of 8.53 m. ha, is believed to have been subjected to water-logging, whereas the extent of Alkali soil and saline (including coastal saline) areas are 3.58 m. ha and 5.50 m. ha respectively. Left bank canal of the Tungabhadra Irrigation Project in Karnataka was commissioned in 1953. A study made 30 years later showed that about 33000 hectares had been severely affected by water-logging and salinity. It was further estimated that this area was extending at rate of 6000 hectares annually. Production from about 20000 hectares had already reached zero level forcing the cultivators to abandon their land.

In the Nagarjunasagar command area, it was estimated that about 25000 hectares and 140000 hectares had been affected by salinity and water-logging respectively in a period of 14 years. Abrol, I. P. (1992) studied the problem of salinity in India. According to Abrol in early thirties, a dry farming station of the Government of India was set up at Rohtak in Haryana state. At that time the water table was several meters deep. Introduction of irrigation from the western Yamuna Canal system in the forties has caused wide spread salinity and water-logging in the district. In fact Rohtak is one of the worst affected districts in the country. Jayasankar D. C. and Setty Rajasekhara (1993) have examined the problem of salinity and alkalinity in the Tungabhadra Command Area in Karnataka and Andhra Pradesh States. They find out that in Moka, a village near Bellary, the entire land of the village had become saline and not a single blade of grass is traceable on the vast tract. Most of the farmers have left these lands follow and requested the irrigation authorities to localize their land. It is not only a great loss for the individual farmers but also for the state. It was great loss for the states exchequer, due to unproductive land. It was estimated that near about Rs. 45.5 million loss of revenue to the state exchequer was occurred due to salinity and alkalinity.

According to recent estimates the salt affected soils occupy about 8.6 million Ha of land in India (Table.1) all of which does not lie in the irrigation commands.

**Table. 1. Extent and Distribution of salt affected soils in India (000, ha)**

| | Waterlogged Area | Salt Affected Area | |
|---|---|---|---|

| State | Canal Commands | Un Classified | Total | Canal Commands | Outside | Coastal Commands | Total |
|---|---|---|---|---|---|---|---|
| Andhra Pradesh | 266.40 | 72.60 | 339.00 | 139.40 | 390.60 | 283.30 | 813.30 |
| Bihar | 362.60 | NA | 362.60 | 224.00 | 176.00 | NIL | 400.00 |
| Gujarat | 172.60 | 311.40 | 484.00 | 540.00 | 327.10 | 302.30 | 1169.40 |
| Haryana | 229.80 | 45.40 | 275.20 | 455.00 | NA | NIL | 455.00 |
| Karnataka | 36.00 | NA | 36.00 | 51.40 | 266.60 | 86.00 | 404.00 |
| Kerala | 11.60 | NA | 11.60 | NA | NA | 26.00 | 26.00 |
| Madhya Pradesh | 57.00 | NA | 57.00 | 220.00 | 22.00 | NIL | 242.00 |
| Maharashtra and Goa | 6.00 | 105.00 | 111.00 | 446.00 | NA | 88.00 | 534.00 |
| Orissa | 196.30 | NA | 196.30 | NA | NA | 400.00 | 400.00 |
| Punjab | 198.60 | NA | 198.60 | 392.60 | 126.90 | NIL | 519.50 |
| Rajasthan | 179.50 | 168.80 | 348.30 | 138.20 | 983.80 | NIL | 1122.00 |
| Tamil Nadu | 18.00 | 109.90 | 127.90 | 256.50 | NA | 83.50 | 340.00 |
| Uttar Pradesh | 455.00 | 1525.60 | 1980.60 | 606.00 | 689.00 | NIL | 1295.00 |
| West Bengal | NA | NA | NA | NIL | NA | 800.00 | 800.00 |
| Total | 2189.40 | 2338.10 | 4527.50 | 3469.10 | 3027.00 | 2069.10 | 8565.20 |

The development of water logging and soil salinization upon introduction of irrigation in arid and semi-arid regions is a global phenomenon. The data reveal that about 10-13% of irrigated lands in various countries have adversely been affected due to water logging and soil salinization (Gupta et. al 2001). It is believed that on global scale, as much area goes out of cultivation is brought under irrigation every year. Salt affected soils occur extensively in different agro-ecological and soil zones of India, particularly the arid, semi-arid and the sub-humid regions. Uttar Pradesh, Gujarat, Rajasthan, West Bengal and Andhra Pradesh are the states which are severely affected by soil and water salinity. The estimates of the extent of salt affected soils in the country vary widely. Narayana, V. V. Dhruva and Abrol, I. P. (1981) in their article examined effect of alkali soils in Indo-Gangetic Region. They pointed out that in India-Gangetic plains approximately 250000 hectares land were alkali soils. These soils were lying uncultivated for the last 80 years or so on due to the accumulation of excess exchangeable sodium in the soils profile. They suggested that alkali land reclamation procedures by various methods such as land levelling, applications of gypsum, growing of rice crops during the rainy seasons and wheat during the winter seasons with appropriate cultural and agronomic practices. Agarwal and Khanna (1983) reported that a large area in Western and South- Western parts of Haryana and Punjab was threatened with rising trend of saline groundwater. The water table of research farm of the Haryana Agricultural University has risen at the rate of 90 cm annually. It rose from about 16.7 meters in 1967 to less than 3 meters in 1983 causing serious problems of water-logging and soil salinity. Bithu (1983) estimated that about 7.33 per cent and 5.39 per cent of the area was affected, respectively, by salinity and water-logging problems in canal areas of Rajasthan. It was projected that, out of 7 lakhs hectares of irrigated area about, 24 per cent was liable for water-logging if the rise in water table was allowed at the present rate.

Kumar *et al.* (1986) in their study on management of rising water table in semi-arid regions of Haryana reported that in the areas of poor groundwater quality, water table continued to rise and the problem assumed a serious proportion. Nearly 15 per cent of the total geographical area of the state was under 4 meters water table depth. Sinha (1986) estimated land degradation from the data collected by Command Area Development Wing of Ministry of Water Resources and indicated that, in 41 major and medium canal command areas, an area of 743 thousand hectares has been affected by water-logging and 718 thousand hectares together by soil salinity and alkalinity. Joshi, P. K. (1987) has studied in village Demol of Kheda district in Gujarat under the Right Bank of Mahi Command Area showed that the productivity of important crops like paddy, wheat and tobacco were declined as the rising concentration of salt. Similarly, the productivity of important crops in Gauriganj block of the Sharda Sahayak Command Area showed a declined trend. Such a declined trend in crop productivity, and kept the land fallow. Consequently decreased farm production and income and led to more unemployment of the rural labourers. He also pointed out that the productivity of wheat declined by 8.57 percent and that of paddy by 4.83 percent of due to witnessing the problem of salinity. They also suggested that central measures of salinity and water-logging such as horizontal drainage, canal lining and proper farm water management etc.

Shah *et al.* (1988) reported that not more than one per cent of the Mahi Right Bank Canal Command had water table depth less than 3 meters and 88 per cent had water table depth greater than 9 meters in 1957-58. By 1983, over 32 per cent of the command area had depth to the water table less than three meters and in 7 per cent it was less than 1.5 meters. The author indicated that nearly 40 per cent of the command area was experiencing an average rate of water table rise of over 0.35 meters a year. Chopra Kanchan (1989) studied the degradation of land that irrigation leads to takes the form water-logging and salinity in Punjab. He pointed out that large tract of land in Punjab go out of cultivation due to water-logging and salinity consequently productivity of cultivated area decreased. Joshi, P. K. and Datta, K. K. (1990) has studied Indo-Gangetic Region, consisting of upper and trans Gangetic plains and a part of Middle Gangetic plains. Punjab, Haryana and part of Uttar Pradesh fall in these agro climatic zones, with an annual rainfall ranging from 550-1000 mm. The salt affected soils are widely distributed in these three states. These soils occupy approximately 25 lakh hectares of which 14 lakh hectare are alkali soils and accounting for about 56 percent of the total salt affected area in these states. Roughly, about 12 percent of the net area sown was alkali in Punjab. The corresponding figures for Haryana and Uttar Pradesh were 7 and 4 percent respectively. Approximately 3.32 lakh hectares of alkali affected land has been restored to agricultural production in the India Gangetic plains. Joshi, P. K. and Jha Dayanatha (1992) analyzed the impact of soil alkalinity and water-logging area in Sharda Sahayak Irrigation Project at Sultanpur district in Gulalpur, Bastidei, Majwara, and Bhatgaon villages. According to them paddy, wheat yields decreased by 51 percent and 56 percent respectively on salt affected soils. With a decline in yield of only 18 percent, barley emerged as the most tolerant crop. Net income from HYV of paddy reduced by 54 percent on waterlogged and 87 percent on salt affected lands, for wheat the net income in this situation reduced by 92 percent. They pointed out that due to soil degradation unit cost of production raised by 59 to 61 percent for paddy and by 85 percent for wheat when cultivation is extended on salt affected soils.

Datta, K. K. and Ir. C. de Jang (1997)[1] focused on adverse effect of water-logging and salinity in Haryana. According to them, at the farm level, the productivity of land resources was reduced which in turn reduced the farm level production, cut in the resource use which indirectly threaten the sustainability of land resources and finally abandonment of land. At regional level it was displaced labours from agriculture, widen income disparities and adversely affected the secondary sector. At national level, it was affected the gross domestic product and adversely affect the export import earnings. Chhatwal, G. R. (1999) pointed out that salt affected soil are generally found in poorly drained low lying lands in arid and semi arid regions. In these regions large quantities of salt have accumulated as a result of transport from higher elevations and from shallow water tables. There is usually a good relationship between the dept to the water table; groundwater salinity and the salinity build up in the soils. In addition to these regions the development of large scale irrigation projects with inadequate drainage has also resulted in salinity problems over extensive areas.

Nayak Sanatan (2002) concluded that in his article, that environmental impact is critically linked with sustainable development of an agrarian economy like India in general and the Sriramsagar project command area in Andhra Pradesh particular. He pointed out that impact of salinity and water-logging in terms of loss of production was integrated. The Benefit Cost Ratio declines to 2.15 from the earlier Benefit Cost Ratio of 2.39. In addition, the total value of agricultural output decreased by up to 5 percent. The indirect adverse impact on environment, i.e. impacts on health, rural migration, decline of employment opportunities are much more widespread in this region. Reddy V. Ratna (2003) estimated the cost of salinity and water-logging in case of India. He pointed out that an aggregate estimate for all India, 25 percent productivity losses was due to salinity. He also pointed out that average of 40 percent loss in paddy production because of water-logging. According to him the whole cost of land degradation range between Rs. 448680 million and Rs. 75183 in the case of loss of production whereas the replacement cost of degradation ranges between Rs. 185910 million and Rs. 25597 million. Datta, K. K., C. de Jong and M. T. Rajashekharappa (2004) analyzed the trends of water-logging and salinity and quality of the economic loss especially in agriculture due to water-logging and salinity in North-West India. They also assessed the scope of salinity control measures at the farm level. They showed that incidence of soil salinity is considerably higher in rabi, than in kharif. In kharif 30 to 35 percent of the area was affected by soil salinity. In rabi, it was 50 to 60percent. The farmers reported that crop loss in rabi was mainly due to soil salinity, while in kharif water-logging and poor quality water the main cause of crop loss. They pointed that the damage due to salinity in kharif season for paddy was about 150 kg per hectare. In relative terms the loss was between 8 to 9 percent. In monetary terms, per hectare seasonal loss was about Rs. 1650. The crop loss in rabi season was about 337 kg per hectare. In relative terms it was about 13 percent of the average level of productivity. In values terms the losses was in the magnitude of Rs. 1854 per hectare in rabi season. Jugale, V. B. (2008) studied the problem of salt affected area in the sugarcane belt i.e. Western Maharashtra has seriously affected and varieties of losses arise. The loss due to salinization and cost of amelioration are going beyond imagination. According to him the productivity of sugarcane in study area declined from 103 tonnes per hectare to 80 tonnes per hectare during 1999-2000 i.e. an average falls of 23 tonnes per hectare in productivity. He suggested reclamation measures for salt affected soils such as chemical treatment, agro technical treatment, biological method, hydro technical methods etc.

Shrivastava et al., (2003) applied SALTMOD for the Segwa minor canal command. The model predicted that the region will further get salinized and cultivation of crops would become impossible if suitable drainage system is not provided. The model predicted fairly accurate trends in the region and it is found that SALTMOD is an effective tool to forecast various situations once the model is calibrated and validated for use in a given agroclimatic situations. Khan et al (2004) used SALTMOD for suggesting remedial measures to the highly salt affected areas. The model predicted that the area is approaching safer limits regarding hydro-salinity status, indicating satisfactory performance of all reclamation measures. The predicted values showed very good correlation with the observed conditions thereby indicating the applicability of SALTMOD as a management tool. Idris Bahceci et al., (2006) simulated the effect of different drain depths on the amount of drainage water, root zone salinity, and depth of water table in the Konya–Çumra Plain, Turkey by using SALTMOD. Simulation results indicated that the leaching efficiency is 0.7 and natural drainage is 0.120 m/year in the test area. When drain depth is considered to be as 1.20 m, 80% of the soils would have salinity with electrical conductivity (EC) less than 2.72 and 2.71 dS $m^{-1}$ for the first and second seasons, at the end of 10 year period. In Pakistan, the salt-affected soils are now covering an area of 4.22 M ha, which constitutes about 26% of irrigated rural area.

Central Ground Water Board, Faridabad (1997) carried out studies on Conjunctive use of surface and groundwater of Ghataprabha irrigation command and chemical analysis of the water samples of shallow wells indicated pockets of salinity where the EC is more than 3000 µmhos/cm at 25•C in some parts of the command area. The study was carried out by Water and Power Consultancy Services Limited (1997) on reclamation of affected areas in Ghataprabha irrigation projects. They demarcated the water logging and salt affected areas in Kalloli, Yedahalli and Bisnal in the command and suggested remedial measures like proper drainage plans, control of seepage in canals, cropping patterns and conjunctive use of surface and groundwater. In addition detailed ground water quality investigations have been carried out by Central Ground Water Board in Ghataprabha command. The study revealed that 65% of samples from the canal command area and 78% of samples from non canal command area fall under C2S1 and C3S1 categories of Wilcox classification. Such waters can be used in moderate to high leaching soils and with moderate to highly salt tolerant crops. Purandara et.al, (1997) carried out study on water-logging problems in canal commands of hard rock region of Ghataprabha command and highlighted the problems of water-logging and salinity in the command area. NIH, Roorkee and Remote sensing Directorate, Central Water Commission, New Delhi carried out study of Ghataprabha Command area using remote sensing and GIS (2003) and delineated the water logged and salt affected areas in the command. They predicted the total water logged area is about 1% and salt affected area is distributed in the command area in pre-monsoon season is about 5.5% and water-logging is more in Bijapur than in Belgaum district. Hiremath (2005) carried out a study on water-logging and salinity and impact of major irrigation projects on agriculture land and reclamation of affected areas in Bagalkot and Biligi taluks of Ghataprabha command area.

Hebsur (2005) made a detailed groundwater quality studies in Malaprabha and Ghataprabha canal command areas. Further, a model study using SALTMOD was also carried out by the authors and the model predicted that, there is a decrease in the root zone salinity as the irrigation with number of good quality water increased in the combination with poor quality waters. SALTMOD predictions in subsurface surface drainage plots showed a decreasing trend in the root zone salinity with the application of best available water and became constant after 8 to 9 years. While the same water irrigation in case of non-drained plots, predicted higher EC values indicating in installation of the drainage as a better option for managing poor quality groundwater in command areas.

# 3.0 STUDY AREA

## 3.1 GENERAL

NSRCCA is bounded by the River Krishna in the north, Kommamuru canal of Krishna western delta in the east, the Musi River in the south and Nagarjunasagar project Right canal in the west. It covers in the part of Guntur and Prakasham districts of the state of Andhra Pradesh.

The Command Area lies in between $15^0$-20′-00″ and $16^0$-41′-24″ North Latitude and $79^0$-18′-44″ and $80^0$-25′-56″ East longitude. It is presented in Fig. - 1. It extends 100 KM from west to east and 140 KM from north to south. A total of 61 mandals are covered in the command area comprising 37 out of 57 mandals of Guntur District and 24 out of 56 mandals of Prakasam District. It comprises 376 villages in Guntur district and 279 villages in Prakasam district. It covers a total geographical area of 9.06 lakh ha. having gross command area (GCA) of 7.709 lakh ha, culturable command area of (CCA) of 6.82 lakh ha, net irrigable area (NIA) of 5.96 lakh ha and contemplated (localized) ayacut of 4.75 lakh ha. The district wise localized ayacut is as shown in Table .2.

**Table. 2. District wise localized ayacut**

| S.No | District | Localized area in ha. | | |
|---|---|---|---|---|
| | | Irrigated Wet (IW) | Irrigated Dry (ID) | Total |
| 1 | Guntur | 95,577 | 1,61,229 | 2,56,856 (57%) |
| 2 | Prakasham | 80,005 | 1,16,185 | 1,96,140 (43%) |
| | Total | 1, 75,582 (39%) | 2, 77,414 (61%) | 4,52,996 |

## 3.2 NAGARJUNA SAGAR RIGHT CANAL NET WORK

The Nagarjuna Sagar Right canal (NSRC) called Jawahar Canal, runs over a length of 203 KM. Beyond this point the main canal is continued, further for a length of 82 KM as Ongole branch canal. The command area is divided into 22 blocks spread out in Guntur and Prakasham districts of the State. Each block is served by a branch canal or Major distributory. The net work of distributary system up to out let’s run over a length of 5342 KM within the command area and the field channels run over a length of about 14,400 KM. The main canal comprises a total

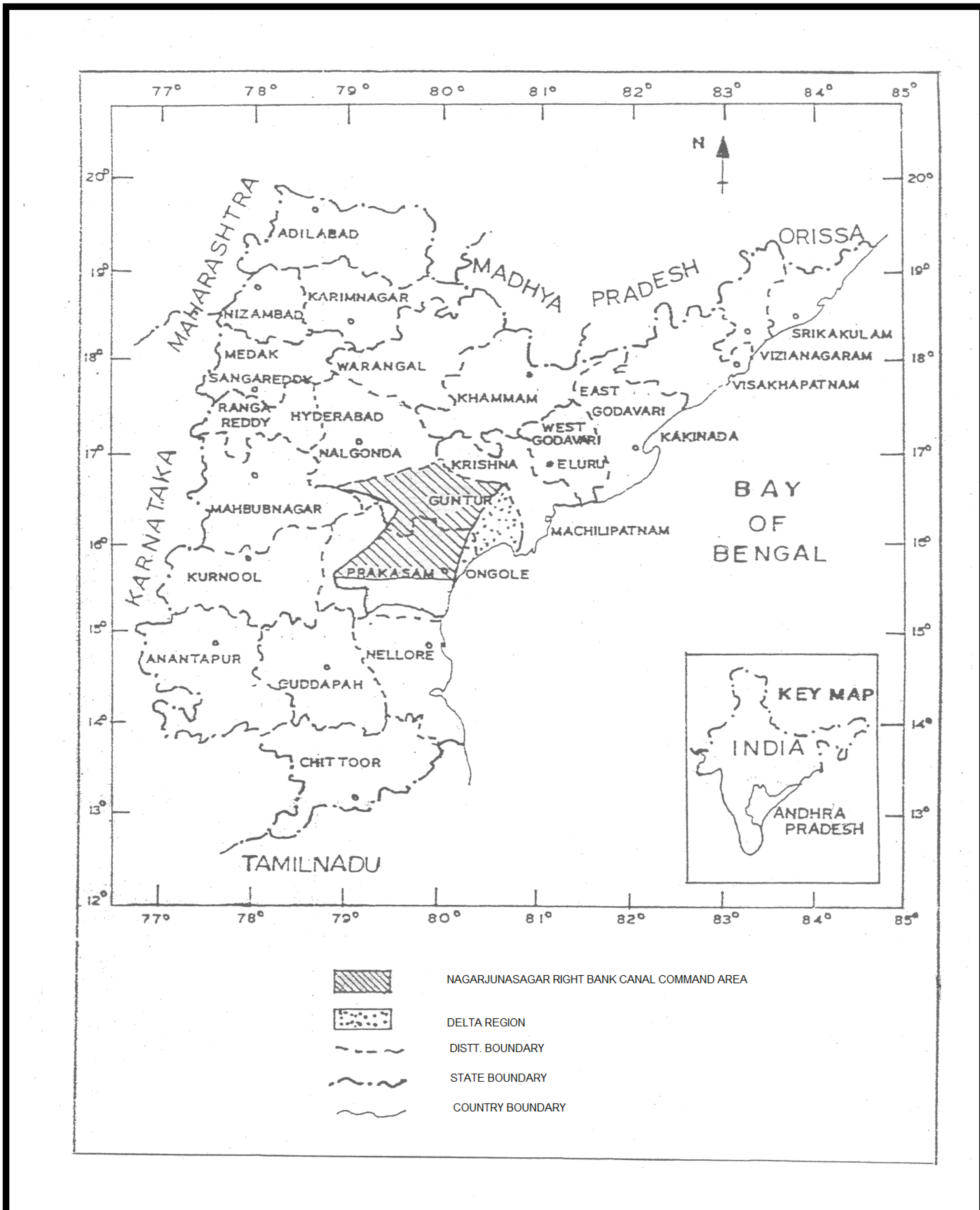


**Figure.1. Location map of NSRBC Command Area**

number of 55 major distributaries namely 6 branch canals, 47 major and 2 direct pipes; followed by minors, sub minors, direct pipes and field channels. The main canal is a contour aligned canal having irrigation to its left side and all other major distributaries are ridge aligned canals having irrigation on both sides.

### 3.3 TOPOGRAPHY AND DRAINAGE

The command area is having adulatory topography with abrupt slopes. The areas away from the hill ranges possess gradient in the range of the 3% to 5% and areas of adjacent nalas and streams possess rugged topography due to adulatory over flow hazards. The reduced levels of lowest and highest topographic contours are +3.6 m. and +140.9m., respectively with reference to mean sea level (MSL). The streams draining in NSRC command includes Naguleru, Edduvagu, Erravagu, Dandivagu, Buggavagu, Kondaveetivagu, Rallavagu, Ogeru, Nakkavagu etc. are main in Guntur district and Gundlakamma, Chilakaleru, Dornapuvagu, Musi etc.are main in Prakasham district. The command of NSRC covers 63 ground water basins among them 36 ground water basins are in Guntur district, and 27 ground water basins are in Prakasham district.

### 3.4 CLIMATE AND RAINFALL

The area is characterized by hot summer with mean maximum temperature of about $40^0$C during May and moderate winter with mean minimum temperature of about $18^0$C during December-January. The annual evapotranspiration is about 2084mm i.e. 5.7 mm of daily evaporation. The command area receives about 55% of rainfall through the south-west (June to September), 36% rainfall through north-east (October to December) monsoons and 9% during winter (January and February) and hot weather period (March to May). Monsoon commences earlier in Guntur and Prakasham districts. The mean annual rainfall of the command area (mean of 23 years in Guntur district and 15 years in Prakasam district) is 824.5mm.

### 3.5 SOILS

The area is mainly comprises two types of soils, the black clayey and red sandy soils. Black soils form major group, occupy about 62% of area and red soils occupy about 32% of area. Black soils (vertisols) extensively met in the first 11 blocks and again in the last $22^{nd}$ block. Red soil (alfisols) encountered is varying from shallow sandy to shallow sandy loams. Gravelly soils are encountered in the lower half of the command area.

### 3.6 GEOLOGY

The command area is occupied by various geological formations from the Archaeans to Recent. The areas at Alluru, Chejerla, Ammanabrolu, Karawadi and Chowtapapayapalem villages of Ongole mandal of Prakasham district and parts of Chebrolu, Kakumnau, and Pedanandipadu mandals in Guntur district are occupied by coastal alluvium. The command area at Maddipadu, Inumanemalluru, Throvagunta, Keerthipadu villages of Ongole mandal, of Prakasham district is occupied by Gundlakamma river alluvium. The upper Gondwanas equivalent to Gollapally sandstone and Raghavapuram shales occurs at Budawada, Vemavaram, Uppugundam, Machapudi, Pavaluru villages of Prakasham district. Small strips of Upper Gondwana sandstone and clay also occur at Sekur, Anumarlapudi, Vadlamudi and parts of Guntur villages of Guntur district. Out crops of pure and white colour quartzite's equivalent to panyam quartzite's occurs at Kamepally, Madugula, Manchikallu areas and at places along Krishna River. The quartzite's are hard and compact in nature.

About 25% of the command area is occupied by palnadu series of Kurnool group such as limestones, shales and quartzite's. Dark grey Narji limestones of lower kurnool group occur in the area of Dachepally, Macherla and Gurazala villages of Guntur district. Shally greylimestones are found at Goli, Mittagudipadu, Rentachintala, Macherla and Dachepally villages. Massive limestone of same age is exposed at Nadikudi, Dachepally, Tangeda and Macherla villages. Small strips of grey and yellow colour and owk shales are exposed in Durgi, Patlaveedu, Machavaram, Pinnelli, Guttikonda villages of Palnadu region.The major part of Command area comprises of crystalline rocks, which includes granite gneisses, schists, charnockites and khondalites. The command area at Narasaraopeta, Chilakaluripeta, part of Guntur and Sattenapally mandals of Guntur district and Addanki, Darsi mandals of Prakasham district is covered by Granites and micasious horn blend schist. Massive granite gneisses occupied in parts of Vinukonda, Guntur and Sattenapally erstwhile taluks and Addanki in Prakasham district. Charnockites of acidic nature occurs as concordant bodies in parts of Chilakaluripet, Vinukonda, Mangalagiri mandals of Guntur district and Prakasham district. Metamorphosed khondalites and garnet sillimanite gneisses occupied in parts of Mangalagiri mandal of Guntur district.

### 3.7 HYDROGEOLOGY

The ground water occurrence and movement in crystalline rocks of command area is confined to the nature and depth of weathering and extension of fractured zone. Ground water in these rocks occurs under water table conditions in weathered portion and semi-confined in fractured and jointed portions. The thickness of weathered zone is varying in thickness from 8 to 15m. and fractured zone varies from 40 to 60m. The yields of dug wells pierced the weathered zone ranges from 30 to 50 cubic meters / per day and the yields of bore wells ranges between 4,000 to 10,000 liters per hour. The bore wells drilled in khondalites down to a depth of 40 to 60 m are found to be in the yield range of 5,000 to 10,000 liters per hour.

In Narji limestones the ground water occurrence is mainly controlled by bedding planes, joints and solution channels. The weathered zone thickness varies from 10 to 15m. Ground water occurs under semi-confined to confined conditions. The depth of bore wells drilled in this area varies from 60 to 90m. and the yield of bore wells ranges from 5,000 to 25,000 liters per hour. The bore wells drilled in the cavernous limestones are found to give high yields. The area occupied by Owk shales in command area is showing poor water yielding capacity due to its poor permeability. Ground water occurs under water table conditions chiefly in the weathered portion. The depth of the wells ranges from 5 to 17m. and the yields varies from 20 to 40 cubic meters/day.

Ground water in localized patches of upper gondwana occurs under water table conditions in weathered zone and confined conditions in deeper aquifers. Tube wells drilled in sandstone patches at Sekuru, Anumarlapudi, and Vadlamudi in Guntur district ranges from 55 to 65m. with yields varying from 45,000 to 60,000 liters per hour. Shally formations are not potential as they are intermittent with clay layers. The occurrence and movement of ground water in alluvial formation is mainly controlled by thickness of sand zone and content of sand and clay. The maximum thickness of alluvium is found to be 25m. The area is feasible for Filter points. The ground water occurs under water table and confined conditions and is generally extracted by means of shallow filter points and ring wells. The yields of filter points range from 20,000 to 40,000 liters per hour and the quality is generally good.

## 3.8 CROPPING PATTERN

Before inception of the irrigation project in 1967-68, negligibly small areas received wet irrigation through minor irrigation tanks which are fed by vagus/streams. Koppukonda, Pinnelli, Dondapadu and Tadikonda are a few tanks worth mentioning. Paddy was grown in small patches here and there, receiving some water from these tanks but largely depending on the scanty rainfall and hence, the yield was low. The chief food crops grown were Jonna (Jowar), Sajja, Ragi and Variga. Commercial crops were extensively grown that, include tobacco, chillies, groundnut etc. Pulses and fodder crops of various kinds were also grown.ID crops like cotton and chillies are more susceptible to pests, diseases and cyclone etc. and also require more attention and labour; hence, the farmers are not very keen in cultivation of these crops. Whereas the crop like paddy which can sustain more of these constrains is being liked by the farmers and is being grown more and more in the ID areas. As a result of this, ID crops are grown only in a portion of the tail end ayacut.

## 4.0 METHODOLOGY

### 4.1 Monitoring Net Work in NSRC Command Area

To study the water level fluctuations in the command area ground water department has initially established 138 observation wells in the year 1979 and gradually increased to 189, 225 and 300 during the year 1984, 1987 and 1989 respectively. All 300 observation wells are regularly monitored for the periods of Pre (during May) and Post (during Nov) monsoons in every year. At present the monitoring is being carried out six times per year including pre and post monsoon periods, to assess the regional ground water trend and its behavior with respect to the relative changes in the ground water level and quality. In addition to the above observation wells, 50 piezometer observation wells have been constructed under World Bank assisted Hydrology Project, out of which 31 are equipped with Automatic water level recorders and are being monitored monthly. Stream flow check points were established at 10 locations covering the important streams to know the discharges during Pre and Post monsoon periods. 30 soil sample stations were also established to assess the soil salinity, alkalinity and salinity alkalinity periodically.

### 4.2 Groundwater Levels and Delineation of Water-logging Zones

The groundwater behavior has been studied from 1995 to 2011. Water logging and prone to water logging zones for Pre and Post monsoon periods have been delineated by drawing depth to water level (DTW) contour maps. To study the sustained (continuous) water logging and prone to water logging areas in NSRCCA pre monsoon monitored data from 1995 to 2011 has been critically studied. Average depths to water levels (DTW) are worked out and used for delineating water logging zones. Average depth to water level contours have been drawn and water-logging (0.0 to 2.0 m.), prone to water logging (2.0 to 3.0 m) and safe areas (above 3.0 m) have been worked out.

### 4.3 Quality and Delineation of Poor Groundwater Zones

To study the irrigation suitability of the ground water, electrical conductance (EC) data of 300 water samples of 300 observation wells pertaining to pre and post monsoon periods have been analyzed. The data has been critically analyzed to assess irrigation suitability in terms of excellent to good, good to permissible, permissible to doubtful and unsuitable categories, by drawing EC contour maps in the EC ranges of 0 to 750, 750 – 1500, 1500 to 2250 and above 2250 microsiemons/cm. respectively.

### 4.4 Ground water resources Estimation

Water balance study serves as a means of solution to important theoretical and practical hydrological problems. The study of water balance is defined as systematic presentation of data on the supply and use of water within a region, basin, or command area for a specific period of time. The principle of water balance or water budget states that, within any system difference of all the supply components and use components should balance the change in storage of the system. Depending on the water resources development of the system, water balance should be conducted area wise for canal water, ground water and rain water. Ground Water resource has been estimated on the basin approach using the principle of Ground water balance (as per GEC 1997 methodology) for command area considering the Monsoon and Non-monsoon Rainfall, Canal seepages, Applied surface and ground water irrigation, Surface water bodies, Ground water draft under irrigation, Annual allocation for domestic and industrial water supply.

The basic concept of water balance is

$$\sum I - \sum O = \Delta S$$

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

I. Supply components:

   Natural recharge: 1. Rainfall recharge 2. Recharge from river 3. Recharge from other basins

   Artificial recharge: 1. Induced recharge from rivers 2.Recharge from canals and fields 3. Recharge by injection and spreading

II. Use components:

   Natural: Evapotranspiration 2. Regeneration in rivers 3.Outflow to other basins

Artificial: Groundwater draft through public and private open wells, filter points and tube wells. Considering various inflow and outflow components, the ground water balance can be calculated as

$$(R_i + R_c + R_r + S_i + I_g + R_t) - (E_t + T_p + S_e + O_g) = \Delta S$$

Where,

$R_i$ = Recharge from field irrigation

$R_c$ = Recharge from canal seepage

$R_r$ = Recharge from rainfall

$S_i$ = Recharge from influent seepage from river

$I_g$ = Recharge from groundwater inflow

$R_t$ = Recharge from tanks

$E_t$ = Evapotranspiration from deep rooted trees and water-logged areas

$T_p$ = Draft from groundwater

$S_e$ = Discharge due to effluent seepage to drain

$O_g$ = Discharge due to groundwater outflow

$\Delta S$ = Change in groundwater storage

## 4.5 Theoretical Background of SALTMOD

SALTMOD is a computer program for the prediction of the salinity of soil moisture, ground water and drainage water, the depth of the water table, and the drain discharge in irrigated agricultural lands, using different (geo) hydrologic conditions, varying water management options, including the use of ground water for irrigation, and several cropping rotation schedules. The water management options include irrigation, drainage, and the use of subsurface drainage water from pipe drains, ditches or wells for irrigation. The computer program was originally made in FORTRAN by R.J. Oosterbaan and Isabel Pedroso de Lima at ILRI. A user shell in Turbopascal was developed by H. Ramnandanlal, and improved by R.A.L. Kselik of ILRI, to facilitate the management of input and output data. Now, a Windows version is available, written in Delphi by Oosterbaan. Schematic representation of SALTMOD is shown in figure 2.

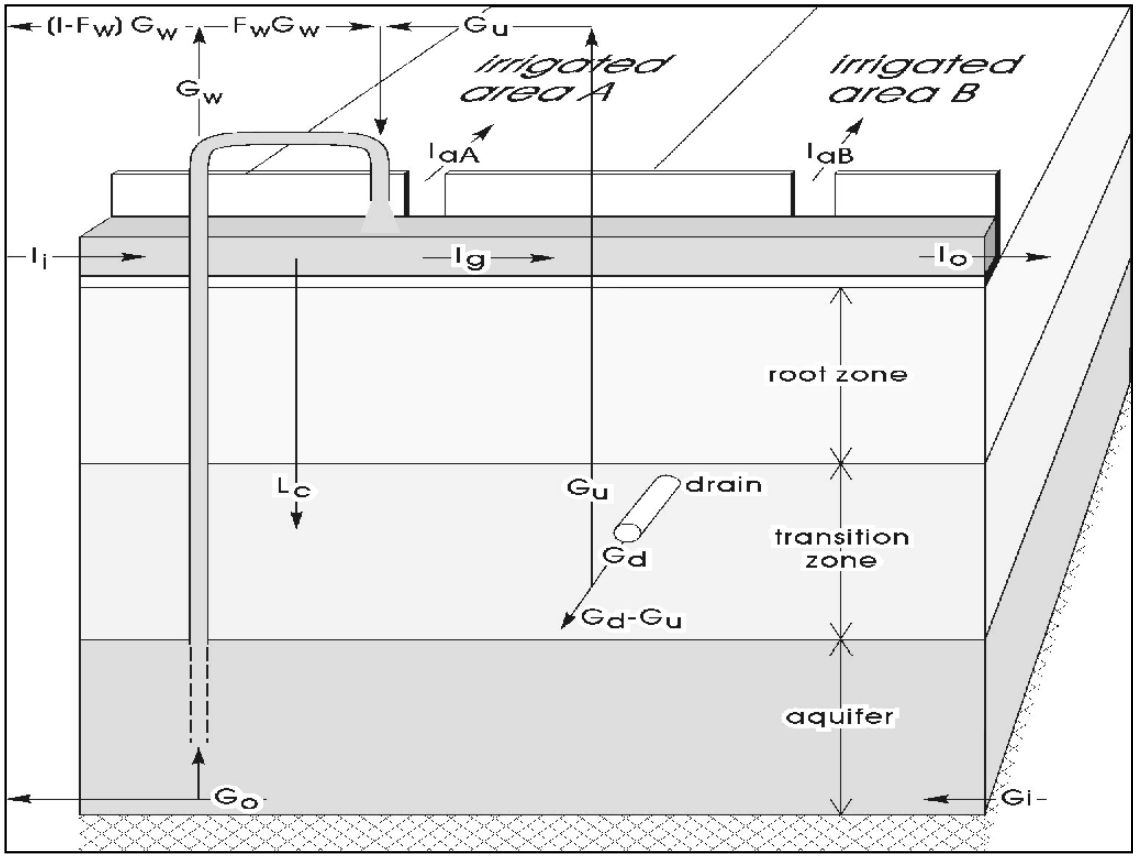


**Figure. 2. Schematic diagram of SALTMOD**

A = Fraction of total area occupied by irrigated group A crops

B = Fraction of total area occupied by irrigated group B crops

Fw = Fraction of pumped well water used for irrigation

Gu = Subsurface drainage water used for irrigation in season ($m^3$/season/$m^2$ total area)

Gd = Subsurface drainage water ($m^3$/season/$m^2$ total area)

Gi = Horizontally incoming ground water flow through the aquifer in season ($m^3$/season/$m^2$ total area)

Go = Horizontally outgoing ground water flow through the aquifer in season ($m^3$/season/$m^2$ total area)

Gw = Ground water pumped from wells in the aquifer in season ($m^3$/season/$m^2$ total area)

IaA = Irrigation water applied to the irrigated fields under group A crop(s) in season ($m^3$/season/$m^2$ total area under group A crops)

IaB = Irrigation water applied to the irrigated fields under group B crop(s) in season ($m^3$/season/$m^2$ total area under group B crops)

I = Inflow of Irrigation water ($m^3$/season per $m^2$ total area)

Io = Water leaving the area through the irrigation canal system in season (bypass, $m^3$/season per $m^2$ total area)

Ii = The quantity of irrigation water or surface flow entering the area (bypass, $m^3$/season per $m^2$ total area)

Ig = The gross irrigation inflow including the natural surface inflow, the drain and well water used for irrigation, but excluding the percolation losses from the canal system,

Lc = Percolation from the irrigation canal system in season (bypass, $m^3$/season per $m^2$ total area)

Saltmod accepts a maximum of four seasons, the durations of which are expressed in months. The total duration of the seasons is 12 months. During the year, the agricultural land use may change from season to season and the distribution of the water resources depends on the agricultural land use. To accommodate the rotational land use, Saltmod distinguishes 3 types of land use:

A: irrigated land under group A crops

B: irrigated land under group B crops

U: non-irrigated land (U)

The distinction between group A and B crops is made to introduce the possibility of having lightly and heavily irrigated crops. Examples of the second kind are submerged rice and sugarcane. The latter crop may cover more than one season. The distinction also gives the possibility to introduce permanent instead of arable crops like orchards. The non-irrigated land may consist of rain fed crops and temporary or permanently fallow land. Each land use type is determined by an area fraction A, B, and U respectively. The sum of the fractions equals unity:

$$A + B + U = 1$$

The computation method Saltmod is based on seasonal water balances of agricultural lands. Four seasons in one year can be distinguished, e.g. dry, wet, cold, hot, irrigation or fallow seasons. The number of seasons (Ns) can be chosen between a minimum of one and a maximum of four. The larger the number of seasons becomes, the larger is the number of input data required. The duration of each season (Ts) is given in number of months ($0 < Ts < 12$). Day to day water balances are not considered for several reasons:

1. Daily inputs would require much information, which may not be readily available;
2. The method is especially developed to predict long term, not day-to-day, trends and predictions for the future are more reliably made on a seasonal (long term) than on a daily (short term) basis, due to the high variability of short term data;
3. Even though the precision of the predictions for the future may still not be very high, a lot is gained when the trend is sufficiently clear; for example, it need not be a major constraint to design appropriate salinity control measures when a certain salinity level, predicted by Saltmod to occur after 20 years, will in reality occur after 15 or 25 years.

### 4.5.1 Hydrological data

The method uses seasonal water balance components as input data. These are related to the surface hydrology (like rainfall, evaporation, irrigation, use of drain and well water for irrigation, runoff), and the aquifer hydrology (like upward seepage, natural drainage, pumping from wells). The other water balance components (like downward percolation, upward capillary rise, subsurface drainage) are given as output. The quantity of drainage water, as an output, is determined by two drainage intensity factors for drainage above and below drain level respectively (to be given with the input data), a drainage reduction factor (to simulate a limited operation of the drainage system), and the height of the water table, resulting from the computed water balance. Variation of the drainage intensity factors and the drainage reduction factor gives the opportunity to simulate the impact of different drainage options.

### 4.5.2 Agricultural data

The input data on irrigation, evaporation, and surface runoff are to be specified per season for three kinds of agricultural practices, which can be chosen at the discretion of the user:

A: irrigated land with crops of group A

B: irrigated land with crops of group B

U: non-irrigated land with rain fed crops or fallow land

The groups, expressed in fractions of the total area, may consist of combinations of crops or just of a single kind of crop. For example, as the A type crops one may specify the lightly irrigated cultures, and as the B type the more heavily irrigated ones, such as sugarcane and rice. But one can also take A as rice and B as sugarcane, or perhaps trees and orchards. The A, B and/or U crops can be taken differently in different seasons, e.g. A = wheat + barley in winter and A = maize in summer while B = vegetables in winter and B = cotton in summer. Un-irrigated land can be specified in two ways: (1) as U=1-A-B and (2) as A and/or B with zero irrigation. A combination can also be made. Further, a specification must be given of the seasonal rotation of the different land uses over the total area, e.g. full rotation, no rotation at all, or incomplete rotation. This occurs with a rotation index. The rotations are taken over the seasons within the year. To obtain rotations over the years it is advisable to introduce annual input changes. When a fraction A1, B1 and/or U1 in the first season differs from fractions are A2, B2 and/or U2 in the second season, because the irrigation regimes in the seasons differ, the program will detect that a certain rotation occurs. If one wishes to avoid this, one may specify the same fractions in all seasons (A2=A1, B2=B1, U2=U1), but the crops and irrigation quantities may have to be adjusted in proportion.

### 4.5.3 Soil strata

Saltmod accepts four different reservoirs, three of which are in the soil profile:

1. a surface reservoir
2. an upper (shallow) soil reservoir or root zone
3. an intermediate soil reservoir or transition zone
4. a deep reservoir or aquifer.

The upper soil reservoir is defined by the soil depth from which water can evaporate or be taken up by plant roots. It can be equaled to the root zone. It can be saturated, unsaturated, or partly saturated, depending on the water balance. All water movements in this zone are vertical, either upward or downward, depending on the water balance. The transition zone can also be saturated, unsaturated or partly saturated. All flows in this zone are vertical, except the flow to subsurface drains. If a horizontal subsurface drainage system is present, this must be placed in the transition zone, which is then divided into two parts: an upper transition zone (above drain level) and a lower transition zone (below drain level). If one wishes to distinguish an upper and lower part of the transition zone in the absence of a subsurface drainage system, one may specify in the input data a drainage system with zero intensity. The aquifer has mainly horizontal flow. Pumped wells, if present, receive their water from the aquifer only.

### 4.5.4 Water balances

The water balances are calculated for each reservoir separately. The excess water leaving one reservoir is converted into incoming water for the next reservoir. The three soil reservoirs can be assigned a different thickness and storage coefficients, to be given as input data. In a particular situation, the transition zone or the aquifer need not be present. Then, it must be given a minimum thickness of 0.1 m. The depth of the water table, calculated from the water balances, is assumed to be the same for the whole area. If this assumption is not acceptable, the area must be divided into separate units. Under certain conditions, the height of the water table influences the water balance components. For example a rise of the water table towards the soil surface may lead to an increase of evaporation, surface runoff, and subsurface drainage, or a decrease of percolation losses from canals. This, in turn, leads to a change of the water balance, which again influences the height of the water table, etc. This chain of reactions is one of the reasons why Saltmod has been developed into a computer program. It takes a number of repeated calculations to find the correct equilibrium of the water balance, which would be a tedious job if done by hand. Other reasons are that a computer program facilitates the computations for different water management options over long periods of time (with the aim to simulate their long-term impacts) and for trial runs with varying parameters.

### 4.5.5 Drains, wells, and re-use

The sub-surface drainage can be accomplished through drains or pumped wells. The subsurface drains are characterized by drain depth and drainage capacity. The drains are located in the transition zone. The subsurface drainage facility can be applied to natural or artificial drainage systems. The functioning of an artificial drainage system can be regulated through a drainage control factor. When no drainage system is present, installing drains with zero capacity offers the opportunity to obtain separate water and salt balances for an upper and lower part of the transition zone. The pumped wells are located in the aquifer. Their functioning is characterized by the well discharge. The drain and well water can be used for irrigation through a re-use factor. This may have an impact on the salt balance and the irrigation efficiency or sufficiency.

### 4.5.6 Salt balances

The salt balances are calculated for each reservoir separately. They are based on their water balances, using the salt concentrations of the incoming and outgoing water. Some concentrations must be given as input data, like the initial salt concentrations of the water in the different soil reservoirs, of the irrigation water and of the incoming ground water in the aquifer. The concentrations are expressed in terms of electric conductivity (EC in dS/m). Usually, salt concentrations of the soil are expressed in ECe, the electric conductivity of an extract of a saturated soil paste. In Saltmod, the salt concentration is expressed as the EC of the soil moisture when saturated under field conditions. Salt concentrations of outgoing water (either from one reservoir into the other or by subsurface drainage) are computed on the basis of salt balances, using different leaching or salt mixing efficiencies to be given with the input data. The effects of different leaching efficiencies can be simulated by varying their input value. If drain or well water is used for irrigation, the method computes the salt concentration of the mixed irrigation water in the course of the time and the subsequent impact on the soil and ground water salinities, which again influences the salt concentration of the drain and well water. By varying the fraction of used drain or well water (to be given in the input data), the long term impact of different fractions can be simulated. The dissolution of solid soil minerals or the chemical precipitation of poorly soluble salts is not included in the computation method, but to some extent it can be accounted for through the input data, e.g. by increasing or decreasing the salt concentration of the irrigation water or of the incoming water in the aquifer.

### 4.5.7 Annual input changes

The program may run with fixed input data for the number of years determined by the user. This option can be used to predict future developments based on long-term average input values, e.g. rainfall, as it will be difficult to assess the future values of the input data year by year. The program also offers the possibility to follow historic records with annually changing input values (e.g. rainfall, irrigation, agricultural practices); the calculations must be made year by year. If this possibility is chosen, the program creates transfer files by which the final conditions of the previous year (e.g. water table and salinity) are automatically used as the initial conditions for the subsequent period.

### 4.5.8 Output data

The output of Saltmod is given for each season of any year during any number of years, as specified with the input data. The output data comprise hydrological and salinity aspects. The data are filed in the form of tables that can be inspected directly or further analyzed with spreadsheet programs. The interpretation of the output is left entirely to the judgment of the user. The program offers the possibility to develop a multitude of relations between varied input data, resulting outputs and time. Different users may wish to establish different cause-effect or correlation relationships. The program offers only a limited number of standard graphics, as it is not possible to foresee all different uses that may be made.

The salt balances are based on the following equation:

Incoming salt = outgoing salt + storage of salt

In addition we have:

- Incoming salt = inflow x salt concentration of the inflow
- Outgoing salt = outflow x salt concentration of the outflow
- Salt concentration of the outflow = leaching efficiency x time averaged salt concentration of the water in the reservoir of outflow
- Change in salt concentration of the soil = salt storage divided by amount of water in the soil

Hence, the salt balances are based on the water balances. In Saltmod, the salt balances are calculated separately for the different reservoirs and, in addition, for different types of cropping rotation, indicated by the key Kr that can reach the values 0, 1, 2, 3, and 4. Kr = 0 indicates that there is no annual cropping rotation and all land use types are fixed to the same areas each year. Kr = 4 indicates that there is full annual cropping rotation and that the land use types are continually moved over the area. The other values of Kr indicate intermediate situations that are explained elsewhere.

### 4.5.9 Salt leaching

When the soil is being desalinized by percolation (leaching) one usually obtains an exponentially decreasing salinity in the course of time. The graphic presentation of this phenomenon is called leaching curve or salinity depletion curve (Figure.5). The salt concentration ($C_1$dS/m) of the water percolating from a reservoir can be taken proportional to the salt concentration in the reservoir (Cr, dS/m):

$$C_1 = F_1Cr \quad (4.41)$$

Where the factor $F_1$ is called leaching efficiency.

The change of salt concentration Cr can be described by the differential equation:

$$P_tD = \frac{dCr}{dt} = - C_1L \quad (4.42)$$

Where: $P_t$ is the total porosity fraction (-) of the reservoir, D is the thickness (m) of the reservoir, L is the percolation velocity (m per unit of time), and t is the time (any unit). Figure 3 shows that the time averaged salinity can be taken as the logarithmic (or geometric) mean of the initial ($C_1$) and final ($C_2$) salinity. Saltmod uses the geometric mean to calculate the leaching. Since the amount of salt removed depends on averaged salinity, which depends on $C_1$ and $C_2$, and since $C_2$ again depends on the amount of salt removed, a trial and error procedure is required to find the correct balance.

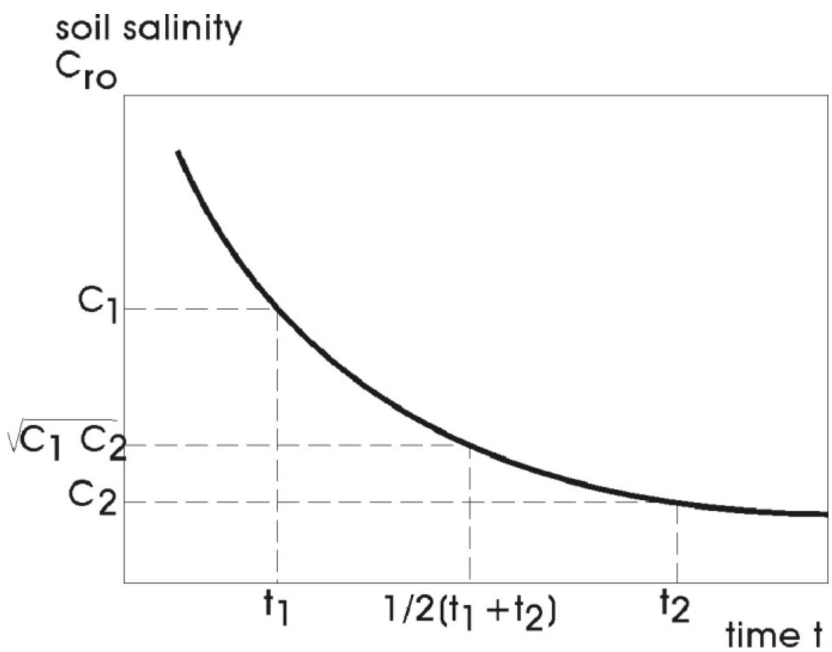


**Figure. 3. The leaching curve and the geometric mean of soil salinity in a time interval**

The salt balance of the root zone is made on the basis of the top soil water balance:

$$Zr_4 = P_p C_p + (I_g-I_o) C_i - S_o (0.2C_{r4i}+C_i) + R_{rT} C_{xki} - L_{rT}C_{L4} \quad (4.43)$$

Where:

$Zr_4$ = salt storage in the root zone when crop rotation Kr = 4 (dS/m/season)

$P_p$ = Rainfall Precipitation ($m^3$/season/$m^2$ total area)

$C_p$ = Salt concentration of the rain water (dS/m),

$I_g$ = Gross irrigation inflow including natural surface inflow, the drain and well water used for irrigation, but excluding the percolation losses from the canal system ($m^3$/season/$m^2$ total area)

$I_o$ = The amount of irrigation water leaving the area through the canal system (bypass),

$C_i$ = Salt concentration of the surface irrigation water including the use of drain or well water for irrigation (dS/m)

$S_o$ = Outgoing surface runoff ($m^3$/season/$m^2$ total area)

$C_{r4i}$ = Salt concentration of soil moisture in the root zone at the start of the season when saturated, equal to salt concentration of the same at the end of the previous season (ds/m)

$R_{rT}$ = Total capillary rise into the root zone ($m^3$/season/$m^2$ total area)

$C_{xki}$ = Salt concentration of the capillary rise based on soil salinity in the transition zone, when saturated, at the end of the previous season and depending on the presence or absence of a subsurface drainage system (dS/m),

$L_{rT}$ = Total percolation from the root zone ($m^3$/season/$m^2$ total area)

$C_{L4}$ = Seasonal average salt concentration of the percolation water (dS/m).

In the above equations it can be seen that the salt concentration of the surface drainage $S_o$ is assumed to be equal to the concentration $C_i$ of the irrigation water plus 20% of the salt concentration of the root zone $C_r$. Hence, the leaching efficiency of the surface drainage water is tentatively set at a low value 0.2.

The data's regarding rainfall, evaporation, runoff, canal release, percolation losses from canals, rate of application of irrigation water, groundwater draft, cropping pattern, plant root characteristics and rate of fertilizers applied have been collected from State Water Resources department, Groundwater Department and State Agriculture Department.

# 5.0 RESULTS AND DISCUSSION

## 5.1 Ground water studies in NSRC command area

As per the details collected from ground water department, to study the water level fluctuations in the command area, ground water department has initially established 138 observation wells in the year 1979. Further, the observation wells have been gradually increased to 189, 225 and 300 during the year 1984, 1987 and 1989 respectively. The monitoring is being done six times per year for the periods of Pre (during May) and Post (during Nov) monsoons in every year to assess the regional ground water trend and its behavior with respect to the relative changes in the ground water level and quality. In addition to the above observation wells, 50 piezometer observation wells have been constructed under World Bank assisted Hydrology Project, out of which 31 are equipped with Automatic water level recorders and are being monitored monthly. Stream flow check points were established at 10 locations covering the important streams to know the discharges during Pre and Post monsoon periods. 30 soil sample stations were also established to assess the soil salinity, alkalinity and salinity alkalinity periodically.

## 5.2 Ground water Resources Estimation

Ground water resources estimation of NSRCCA has been carried out by AP Ground water department based on the guidelines of Ground water Estimation Committee-1997 with the modifications suggested by GEC-2004 and the R & D Advisory committee on the Ground Water Resources Estimation from time to time and following the broad guidelines issued by the Central Ground Water Board, Ministry of Water Resources, Govt. of India. Ground water Resources estimation carried out for both command and non command areas of Guntur and Prakasham districts. The data analyzed for 25 years based on the critical analysis of Hydrological, Hydrogeological and Geophysical data and presented in table 3. It is observed from the analyzed data that, there are about 132 poor ground water quality areas (either with high EC or brackish), covering 94 villages in Guntur district and 38 villages in Prakasham district of command area. It is also observed that, the ground water utilization is more than 65% for all uses in about 89 villages covering 13 in Guntur district and 76 in Prakasham district of the command. The stage of development of the command works out to be 12.46% in which 7.43% is in Guntur district and 48.16% is in Prakasham district. It is observed from the table is that; the Groundwater can be developed in about 569 villages in the command covering 323 in Guntur and 146 in Prakasham districts.

**Table.3. Ground water resource estimation and stage of development**

| S.No. | Description | NSRCCA | | |
|---|---|---|---|---|
| | | **Guntur District** | **Prakasham District** | **Total** |
| 1 | Net Ground water availability | 2,05,902 | 29,013 | 2,34,915 |
| 2 | Ground water draft for all uses | 15,290 | 13,973 | 29,263 |
| 3 | Balance Ground water available for future use | 1,90,612 | 14,835 | 2,05,447 |
| 4 | Stage of Development (%) | 7.43 | 48.16 | 12.46 |
| 5 | No. of villages having Ground water draft more than 65% (Nos.) | 13 | 76 | 89 |
| 6 | No. of villages having Brackish ground water which are not even fit for mixed water management in conjunctive use model | 94 | 38 | 132 |
| 7 | No. of villages tentatively feasible for Ground water development (Nos.) | 323 | 146 | 569 |

### 5.3 Water Logging Area

The groundwater behavior has been studied for the period from 1995 to 2012. Water logging and prone to water logging zones for Pre and Post monsoon periods have been delineated by depth to water level (DTW). The analyzed data has been presented in table 4. It is observed from the table is that, the lowest water level fluctuation is observed during 2002 (0.06 m) and highest during 2005 (3.25 m). The sustained (continuous) water logging and prone to water logging areas in NSRCCA has been critically studied from 1995 to 2012. It may be observed from the analyzed data of table is that the areas of water logging and prone to water logging are varied season wise and year wise which depends upon various hydrological and hydrogeological parameters. Average depths to water levels (DTW) are worked out using these data for each observation well. The water logging (0.0 to 2.0 m.), prone to water logging (2.0 to 3.0 m) and safe areas (above 3.0 m) has been worked out as shown in the table 5 and figure.4.

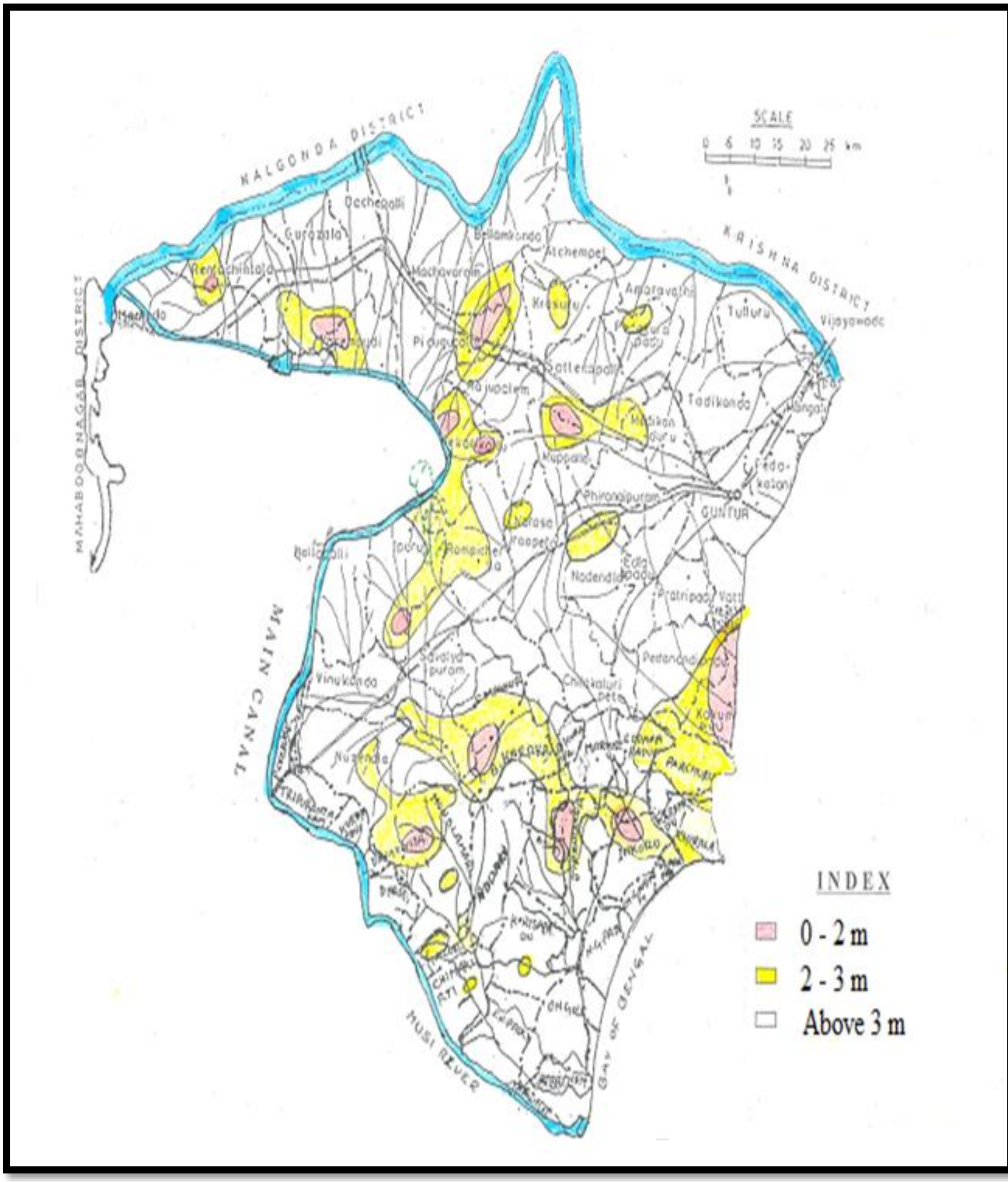


**Figure.4.Permanent Water-logging Area of NSRBC Command Area**

**Table.4. Average DTW in metres of OB wells**

| S.No. | Year | Pre-monsoon | Post-monsoon | Fluctuation |
|---|---|---|---|---|
| 1 | 1995 | 3.49 | 2.58 | 0.91 |
| 2 | 1996 | 4.72 | 2.40 | 2.32 |

| | | | | |
|---|---|---|---|---|
| 3 | 1997 | 4.57 | 2.31 | 2.26 |
| 4 | 1998 | 4.78 | 1.67 | 3.11 |
| 5 | 1999 | 3.80 | 2.86 | 0.94 |
| 6 | 2000 | 4.49 | 2.54 | 1.95 |
| 7 | 2001 | 4.25 | 2.82 | 1.43 |
| 8 | 2002 | 4.68 | 4.62 | 0.06 |
| 9 | 2003 | 6.65 | 5.11 | 1.54 |
| 10 | 2004 | 6.02 | 4.37 | 1.65 |
| 11 | 2005 | 5.42 | 2.17 | 3.25 |
| 12 | 2006 | 3.75 | 2.73 | 1.02 |
| 13 | 2007 | 4.27 | 2.28 | 1.99 |
| 14 | 2008 | 3.95 | 3.23 | 0.72 |
| 15 | 2009 | 4.05 | 3.35 | 0.70 |
| 16 | 2010 | 3.85 | 1.65 | 2.20 |
| 17 | 2011 | 3.47 | 3.15 | 0.32 |
| 18 | 2012 | 4.92 | | |

**Table.5. Year wise Water logged areas in NSRCCA (ha)**

| Year | Water Logging Area | Prone to Water Logging Area | Safe Area |
|---|---|---|---|
| May 2008 | 18,940 | 1,49,708 | 3,06,352 |
| Nov 2008 | 84,530 | 1,65,857 | 2,24,613 |
| May 2009 | 8127 | 68,387 | 3,78,486 |
| Nov 2009 | 66,966 | 1,47,911 | 2,60,123 |
| May 2010 | 14,038 | 87,499 | 3,73,463 |
| Nov 2010 | 3,54,692 | 75,378 | 44,930 |
| May 2011 | 22,209 | 1,72,279 | 2,80,512 |
| May 2012 | 1541 | 19,935 | 4,53,524 |

## 5.4 Ground water quality and delineation of poor ground water zones

The irrigation suitability of the ground water has been studied by analyzing electrical conductance (EC) data of 300 water samples of 300 observation wells pertaining to pre and post monsoon periods. The data has been critically analyzed to assess irrigation suitability in terms of excellent to good, good to permissible, permissible to doubtful and unsuitable categories, by drawing EC contour maps in the EC ranges of 0 to 750, 750 – 1500, 1500 to 2250 and above 2250 microsiemens/cm. respectively. Unsuitable zones in which ground water quality is poor have been drawn and EC data has been compiled and presented in table 6 in terms of % of samples present in each category. It may be observed from the data of table is that the percentage of water samples (observation wells present in unsuitable category) are 35.3% (Pre-monsoon) and 30.3% (Post-monsoon). EC contours pertaining to post monsoon 2001 including contour of EC value equal to 4000 microsiemens/cm has been drawn and presented in figure – 5. The poor ground water quality zones i.e. EC 2250 to 4000 and above 4000 has been delineated and mandal wise areas have been worked out.

**Table.6.Irrigation suitability of Ground water under NSRCCA**

| EC in microsiemens/cm | Suitability for Irrigation | Pre-monsoon | | Post-monsoon | |
|---|---|---|---|---|---|
| | | No. of wells | Percentage | No. of wells | Percentage |
| 0 to 750 | Excellent to Good | 16 | 5.3 | 30 | 10 |
| 750 to 1500 | Good to permissible | 95 | 31.7 | 94 | 31.3 |
| 1500 to 2250 | Permissible to doubtful | 74 | 24.7 | 75 | 25 |
| Above 2250 | Unsuitable | 106 | 35.3 | 91 | 30.3 |
| Leaked over | | 9 | 3.0 | 10 | 3.4 |

### 5.5 Specific locations problems of water-logging and salinity

In order to suggest location specific solutions for combating water logging and salinity problems in Nagarjunasagar Right bank Canal command area, two pilot areas namely Chowtapapayapalem village of Rajupalem mandal and Irukupalem H/o Madala village of Muppala mandal have been

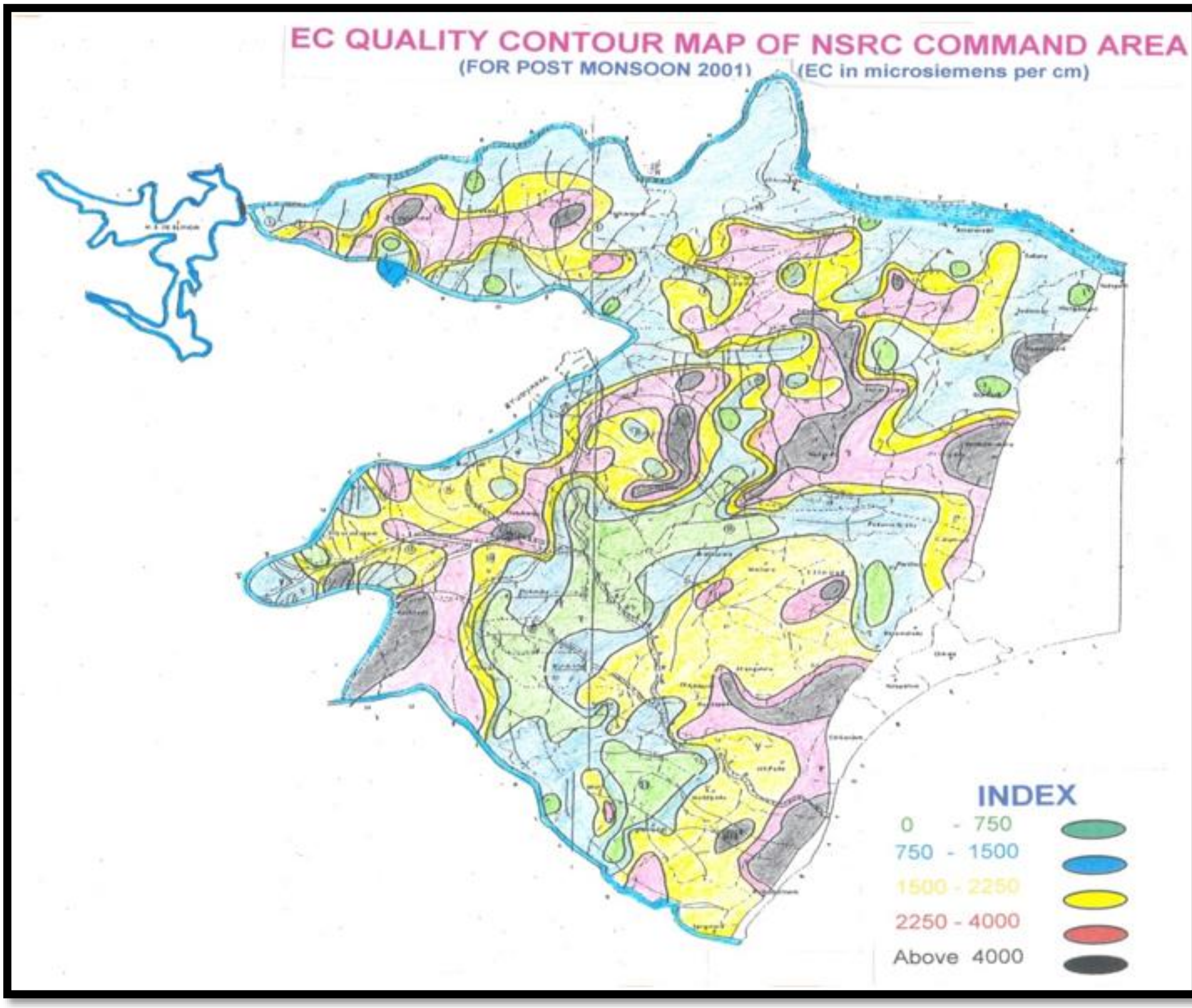


**Figure.5.EC Quality Contour map of NSRBC Command Area**

selected for the present study. The pilot areas are affected with water logging problems (depth to water table in the range of 0.10 to3.10 m) and salinity (EC of 1.0 ds/m to 10 ds/m). Water table generally remains at the ground surface during monsoon season. Because of the problems of water logging and salinity, poor yields of crops are recorded. The average annual rainfall in the Nagarjunasagar Right bank Canal command area is 850 mm. The monthly rainfall and evaporation in the command area are shown in figure.6. Apparently, the rainfall is more than the evaporation during August to November and remaining part of the year evaporation exceeds the rainfall.

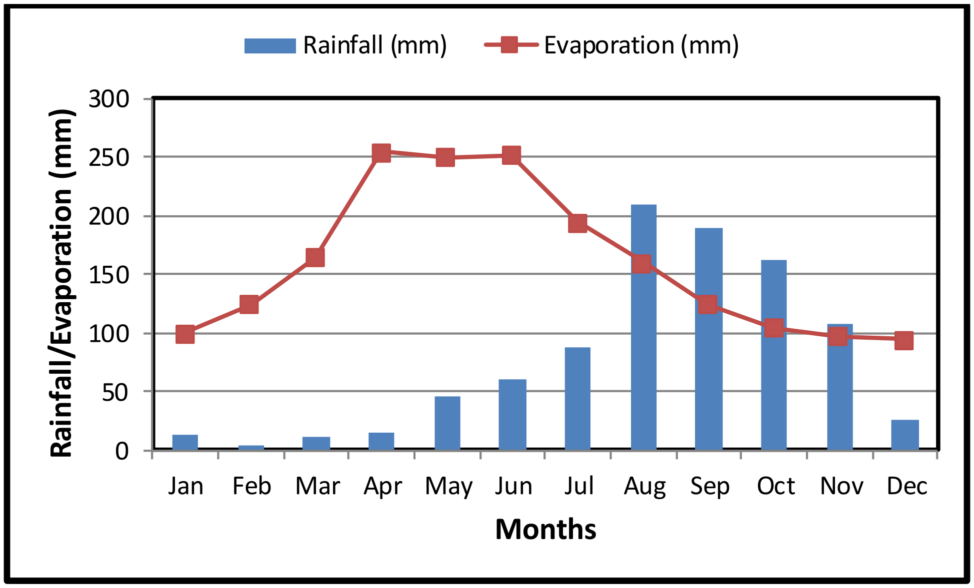


**Figure. 6. Average monthly rainfall and evaporation in the command**

The Chowtapapayapalem village of Rajupalem mandal is situated 3km North-West of the mandal head quarters. The total area of village is 315 ha and population is 1364. The entire lands are irrigating by NSRC canal net work, bore wells and local streams, it comes under NSRC command area. The area is covered by black and red soils, followed by granites of archean age. Groundwater in the area occurs under water table conditions. The present cropping pattern is Paddy, Cotton and Chillies. Erravagu and Bellamkonda canal are influencing the groundwater recharge in the area. The water level range of departmental observation well in pre-monsoon period from 2000 to 2012 varies from 0.83 to 3.20 m below ground level and in post-monsoon period from 2000 to 2012 varies from 0.40 to 1.30 m. The part of village area (about 28 ha) falls under water logged category. As per GEC 2010-11 the total dug wells in the village are 21 and bore wells are 8. The village area is falling in Erravagu -1 ground water basin. The total ground water resource of the basin area is 1069 ha.m stage of development is 42% i.e., 447 ha.m and falls under safe category. The total ground water resource of the Chowtapapayapalem village is 54 ha.m and stage of development of the village is 32% i.e., 17 ha.m and falls under safe category. The trend analysis of depth to water level with rainfall from 2000 to 2012 has been carried out for Chowtapapayapalem village of Rajupalem mandal. The trend is shown in figure 7. It is observed that, the hydrographs of Chowtapapayapalem village of Rajupalem mandal observation well is indicating raising trend due to canal seepage.

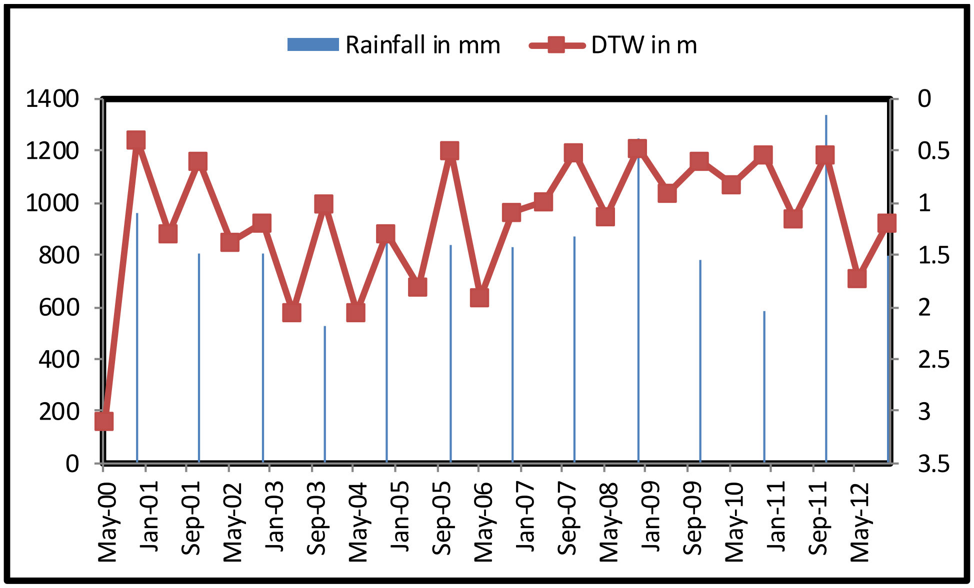


**Figure.7. Hydrograph of Chowtapapayapalem OB well of Rajupalem Mandal**

The Irukupalem H/O Madala village of Muppala mandal is situated 8 km North-Esat of the mandal head quarters and 2.25 km south from Sattenapalli municipality. The total area of village is 3154 ha and population is 10382. The entire lands are irrigating by NSRC canal net work, some lands are irrigating through dug wells and local streams, it comes under NSRC command area. The area is covered by black and red soils and followed by granites of archean age. Ground water in the area occurs under water table conditions. The present cropping pattern is Paddy, Cotton and Chillies. The Guntur channel and local streams are influencing the ground water recharge in the area. The water level range of departmental observation well in pre-monsoon period from 2000 to 2012 varies from 0.02 to 3.02 m below ground level and in post-monsoon period from 2000 to 2012 varies from 0.10 to 2.32 m. The part of village (about 301 ha) area falls under water logged category. As per GEC 2010-11 the total dug wells in the village are 63 and bore wells are 2. The village area is falling in Challagundla vagu ground water basin. The total ground water resource of the basin area is 4593 ha.m, stage of development is 19% i.e., 884 ha.m and falls under safe category. The total ground water resource of the madala village is 601 ha.m and stage of development of the village is 8% i.e., 51 ha.m and falls under safe category. The trend analysis of depth to water level with rainfall from 2000 to 2012 has been carried out for Irukupalem village of Muppala mandal. The trend is shown in figure 8. It is observed that, the hydrographs of Irukupalem village of Muppala mandal observation well is indicating that the water level is neither raising nor falling trend due to canal seepage.

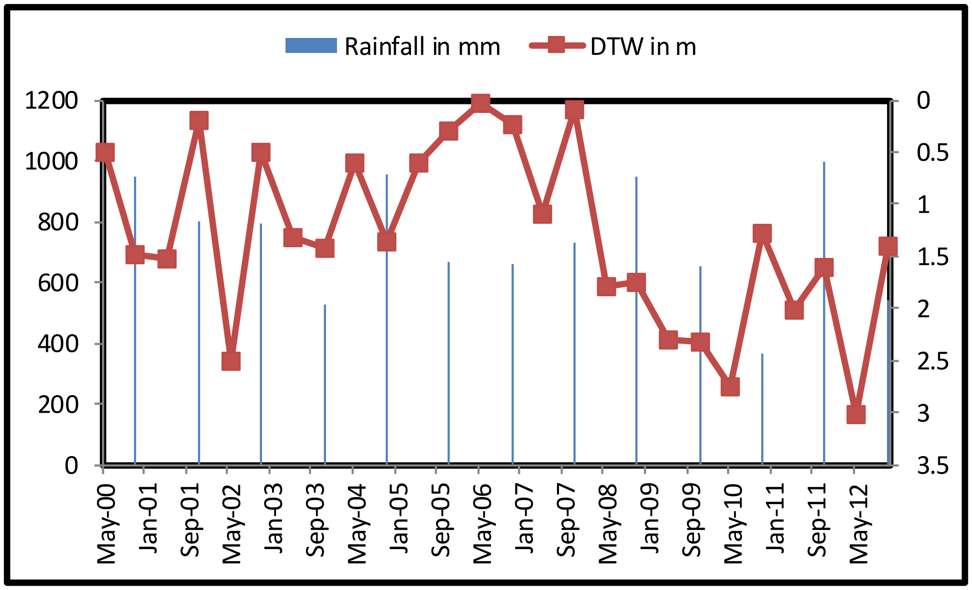


**Figure.8. Hydrograph of Irukupalem OB well of Muppala Mandal**

## 5.6 Prediction of Root Zone Salinity using SALTMOD

The hydro-salinity model 'SALTMOD' was applied for this study area, which computes the salt and water balance for the root zone, transition zone and aquifer zone. The computation method SALTMOD is based on seasonal water and salt-balance of agricultural lands, which can be expressed by the general water balance equation as

$$\text{Incoming water} = \text{Outgoing water} \pm \text{Change in storage}$$

The model was applied to the selected agriculture plots at Chowtapapayapalem village of Rajupalem mandal and Irukupalem village of Muppala Mandal for the prediction of root-zone salinity and leaching efficiency. The model was calibrated and validated by using field based data collected from University of Agricultural Sciences, Dharwad. The detailed method consists of a number of iterative calculations of water and salt-balance equations to find out the final equilibrium in each zone separately. The method calculates the salt-balance for each zone, based on the water-balance of the individual zone and using their respective salt-concentrations of the incoming and outgoing water. The model was run for three seasons (Khariff, Rabi and summer) with full cropping rotations (the rotation index Kr = 4) were adopted. There are two groups of crops viz. A and B per season. The group A crop consists of Paddy, cotton and chillies and group B consists of Wheat, Maize, Bajra, cotton, Pulses and Groundnut.

The data required by the model are seasonal average values of the areal fractions of the crops, rainfall, depth of different soil-layers, leaching efficiency values, initial salinity of the different soil-layers, groundwater and irrigation water, evaporation, surface runoff, and reuse of drainage-water, etc. Model takes input-data of each year as average over two seasons, a wet and a dry season. The leaching efficiency of root zone / transition zone is defined as the salt concentration of the water percolating from the root zone/ transition zone into the underground divided by the average salt concentration of the soil water in the root zone /transition zone. Leaching efficiencies of the root zone (Flr) are given a range of arbitrary values and the corresponding salinity results of the program are compared with the values actually measured. The efficiency producing the best match is assumed to be the actual efficiency. The arbitrary Flr values are taken as 0.05 and 0.10.

### 5.6.1 Calibration and validation of the model

The model was calibrated for local conditions under existing irrigation Practices and varying the leaching efficiencies to establish the validity of the Model in Ghataprabha command area by Varadarajan (2013). After collection of necessary input-data, it was then converted into the input-format as required by the model. The input-data for each year was given as average values over two season’s i.e. wet season (Kharif) and a dry season (Rabi) of each year, given separately to simulate the results for the next year. The model was applied to calibrate for local conditions under existing irrigation and cropping practices, to simulate root-zone salinity. The match of the data was obtained by varying the leaching efficiencies and the natural drainage to the aquifer, establishing the validity of the model. It is found that the model is highly sensitive to leaching efficiency, apart from incoming groundwater and percolation losses.

### 5.6.2 Predictions for Root zone Hydro salinity Status

The root zone salinity is simulated for 20 years using SALTMOD under different conditions such as with sub surface drainage and without sub surface drainage. For the prediction period, it was assumed that, there will be no significant yearly deviations of the input parameters, such as rainfall, irrigation, evaporation, cropping pattern etc., from the observed data given as average input to the model for the period 2012. The seasonal input and other data formats are shown in the table 7 and 8 for all the locations.

**Table.7. Season-wise input parameters of Chowtapapayapalem and Irukupalem**

| S.No. | Parameters | Season 1 | Season 2 | Season 3 |
|---|---|---|---|---|
| 1 | Duration | 4 months | 5 months | 3 months |
| 2 | Crop grown | Paddy, Cotton, Chillies,Wheat, Maize,Ground nut, Pulses, | Paddy, Wheat Cotton, Chillies, Pulses,Groundnut Maize | No irrigation |
| 3 | Water Sources | Canal | Canal | NIL |
| 4 | Fraction of area occupied (irrigated) | 1.00 | 0.35 | 0.00 |
| 5 | Fallow/Barren | 0.00 | 0.00 | 1.00 |
| 6 | Rainfall ($m^{3/}$/season/$m^2$) | 0.80 | 0.00 | 0.00 |
| 7 | Water used for irrigation ($m^{3/}$/season/$m^2$) | 1.20 | 1.20 | 0.00 |
| 8 | Percolation losses from the irrigation canal system ($m^{3/}$/season/$m^2$) | 0.05 | 0.05 | 0.00 |
| 9 | Incoming groundwater flow through the aquifer ($m^{3/}$/season/$m^2$) | 0.50 | 0.20 | 0.00 |
| 10 | Outgoing groundwater flow through the aquifer ($m^{3/}$/season/$m^2$) | 0.30 | 0.10 | 0.00 |
| 11 | Potential evaporation ($m^{3/}$/season/$m^2$) | 0.12 | 0.16 | 0.00 |

| | | | | |
|---|---|---|---|---|
| 12 | Groundwater pumped from wells in the aquifer ($m^{3/}$/season/$m^2$) | 0.50 | 0.50 | 0.00 |
| 13 | Fraction of water pumped by wells from the aquifer used for irrigation ($m^{3/}$/season/$m^2$) | 0.30 | 0.40 | 0.00 |
| 14 | Outgoing surface runoff ($m^{3/}$/season/$m^2$) | 0.80 | 0.00 | 0.00 |

**Table.8. Input Parameters corresponding to Soil and Aquifer properties**

| S.No | Parameters | Chowtapapaya palem | Irukupalem |
|---|---|---|---|
| 1 | Storage efficiency | 0.80 | 0.80 |
| 2 | Depth of root zone (m) | 0.60 | 0.60 |
| 3 | Depth of transition zone (m) | 2.00 | 2.00 |
| 4 | Depth of aquifer (m) | 6.00 | 10.00 |
| 5 | Total porosity of root zone (m/m) | 0.40 | 0.40 |
| 6 | Total porosity of transition zone (m/m) | 0.40 | 0.40 |
| 7 | Total porosity of aquifer (m/m) | 0.50 | 0.50 |
| 8 | Effective porosity of root zone (m/m) | 0.05 | 0.05 |
| 9 | Effective porosity of transition zone (m/m) | 0.05 | 0.05 |
| 10 | Effective porosity of the aquifer (m/m) | 0.30 | 0.30 |
| 11 | Initial salt content of the soil moisture at field saturation in (dS/m) | | |
| | Root zone (ds/m) | 2.50 | 4.50 |
| | Transition zone (ds/m) | 2.15 | 4.10 |
| | Aquifer | - | - |
| 12 | Mean salt concentration of irrigation water in the pilot area (dS/m) | 0.50 | 0.50 |
| 13 | Initial depth of water table from ground surface (m) | 0.40 | 0.20 |
| 14 | Critical depth of water table for capillary rise (m) | 2.00 | 2.00 |

SALTMOD was applied to predict the salinity levels in Chowtapapayapalem and Irukupalem villages. This will be highly useful for taking up management decisions in the salinity affected areas. The salinity level shows a decline with an increase of leaching efficiency. Prediction of root zone salinity for 20 years with subsurface drainage system is shown in figure 9 and 10.

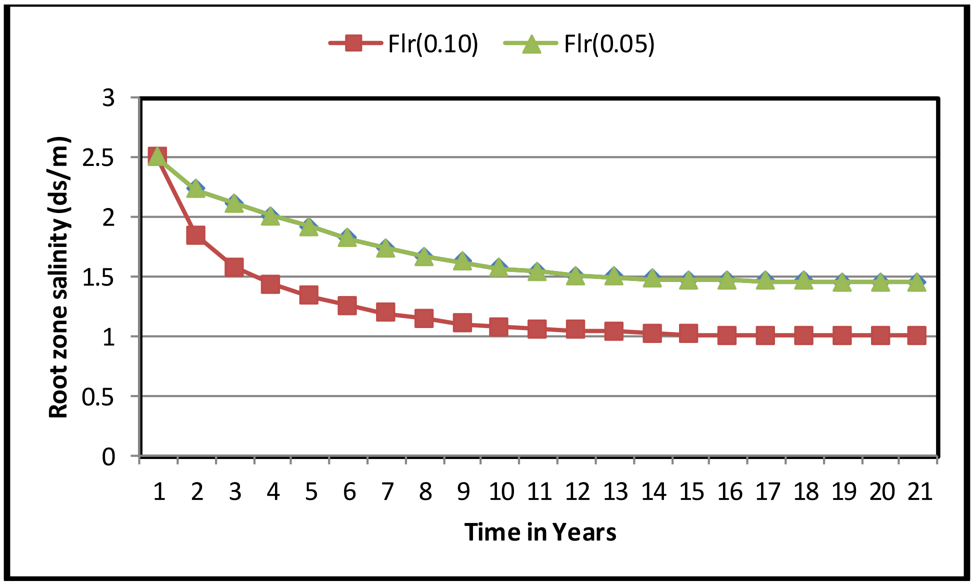


**Figure.9. Predicted Root zone Salinity at Chowtapapayapalem with Drainage**

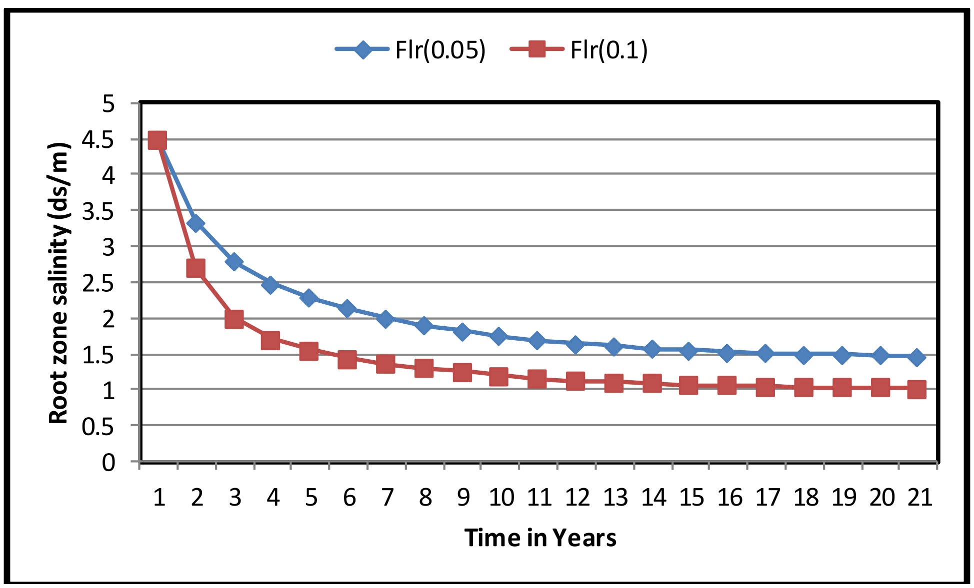


**Figure.10. Predicted Root zone Salinity at Irukupalem with Drainage**

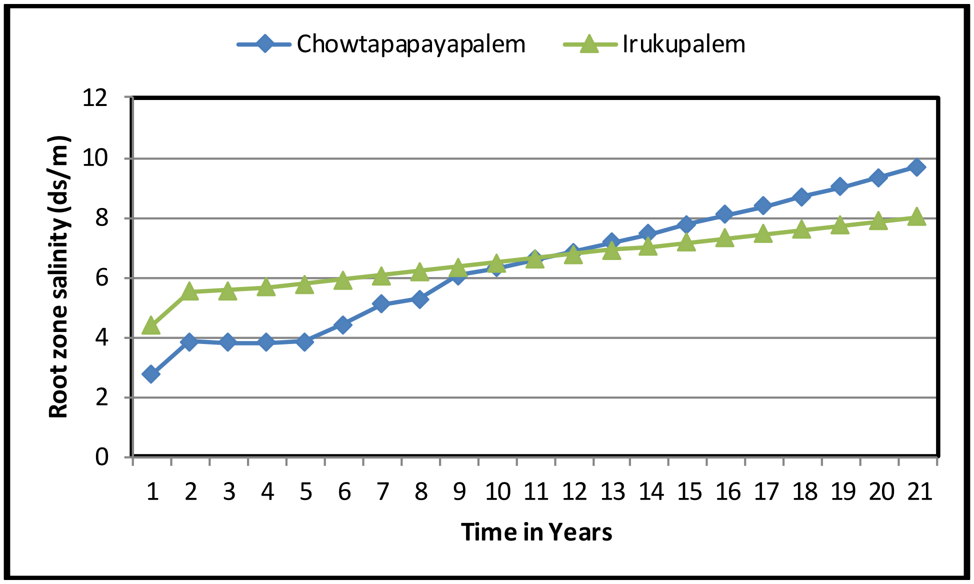


**Figure.11. Predicted Root zone Salinity (without drainage)**

From the above analysis, it is certain that the concentration of root zone salinity decline after 5 years to the acceptable limits of 2.0 ds/m to 3.0 ds/m and became constant after 15 years for both the locations. The leaching efficiency of 0.1 shows the best match with the actual efficiency under adequate drainage conditions. However, without sub surface drainage system there is a drastic increase in salinity over the years there by indicating the necessity of artificial drainage system. The predicted salinity levels of root zone without sub surface drainage system are shown in the figure 11 for both the locations. The model shows a steady increase, though at a slow pace over the years, reaching the levels up to 8.0 ds/m to 10 ds/m at the end of the 20 years period. If suitable drainage system is not provided, canal command areas will further get salinized thus making the land uncultivable. From the present study it is evident that it is necessary to provide proper drainage facilities to control the salinity levels in the command area.

### 5.7 Need for Drainage

The rapid development of irrigation has contributed significantly in enhancing food grains production in Andhra Pradesh. When the imported surface water is made available at a highly subsidized price, the farmers not only refrained from developing groundwater but started applying as much irrigation water as is available with a mistaken belief that the more they irrigate higher would be the yields. This has disturbed the hydraulic equilibrium of the groundwater basin. As a result, there has been a rise in the water table and consequent degradation of soils through water-logging and secondary salt build-up. The hydrograph of a well showing ground water table fluctuation during year 2000 to 2012 for Chowtapapayapalem and Irukupalem locations are shown in figure. 12 &13. The graph indicates that, the groundwater table fluctuations in Chowtapapayapalem shows the water table is within 0.40 m below the ground surface towards end of the monsoon season and goes deeper but remains less than 2.0 m deep at the beginning of the monsoon period. The graph indicates in Irukupalem, the water table is near to the ground surface towards end of the monsoon season and 2 to 3 m below the ground surface deep at the beginning of the monsoon season.

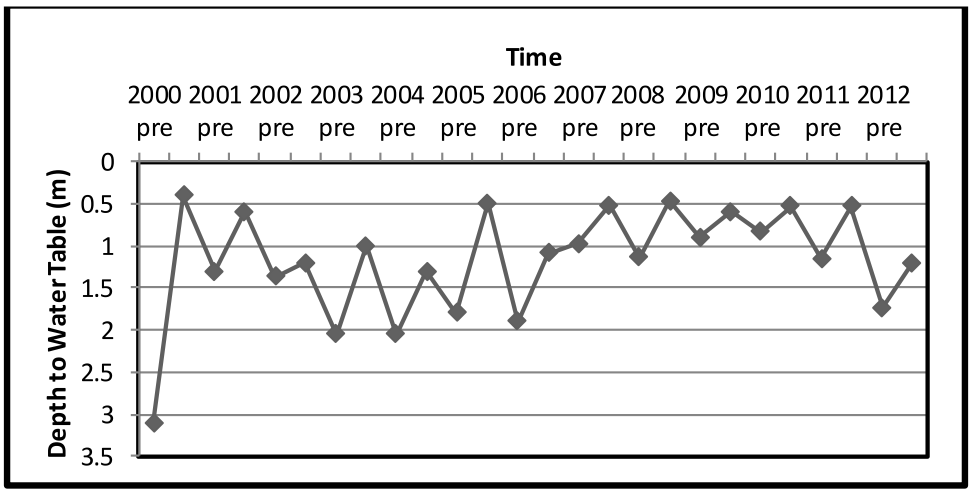


**Figure.12. Pre and Post monsoon water table fluctuations in Chowtapapayapalem**

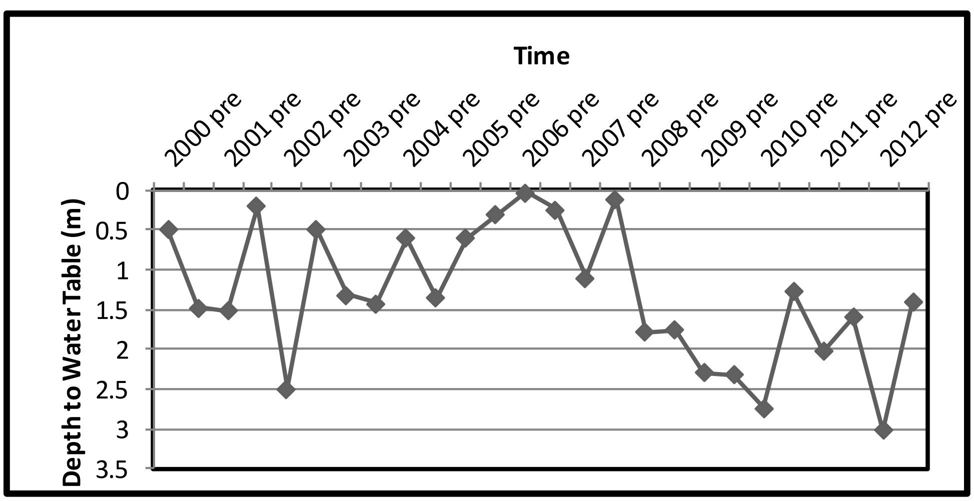


**Figure.13. Pre and Post monsoon water table fluctuations in Irukupalem**

The rise in water table and build-up of salinity has caused the following problems.

- Poor and damaged root system of the crops
- Poor establishment of the rice seedlings
- Need for repeated planting
- Reduction in crop yields and cropped areas
- Reduced possibility for growing second crops

In order to reclaim the already waterlogged and salt-affected land and to prevent further development of these problematic areas, there is a need to do the following:

- Surface drainage to efficiently remove the excess rainfall and flush the surface salts.
- Subsurface drainage to remove excess water from the crop root zone and thereby reducing salinity problems to create favorable conditions for the crop growth.

## 5.8 Drainage Systems

New drainage techniques, viz. multiple well-point system, conjunctive use of canal water and poor quality groundwater, bio-drainage and conventional sub-surface drainage system were developed and adopted by a large number of farmers in the salt affected water logged areas of south west Punjab. In order to combat water logging and soil salinity the following drainage technologies are suggested.

- Multiple well point system
- Cyclic use of canal water and ground water
- Biodrainage system
- Sub-surface drainage system

### 5.8.1 Multiple well point systems

The multiple well point systems consists of number of well points installed in a line connected with each other at about 1 m below land surface, pumped or siphoned centrally. A layer of relatively fresh water gets collected and floats over poor quality ground water at palaces where irrigation is provided through canal water. It is difficult to tap this thin layer of good quality water as it causes up-coning of saline water following the Ghyben-Herzberg principle. Singh suggested the use of multiple well point systems in areas where ground water mounds exist and a fresh water layer forms over a saline water body in the aquifer. The system consists of a number of well points arranged in a line and interconnected to each other through a horizontal pipe line (lateral) buried at about 70 – 100 cm below the ground level. The well point system so developed is pumped centrally. The discharge from the system may be considered to be equally divided over the well points though there may be some variation due to friction loss in pipe flow. The low discharge is withdrawn from each well point. The laterals are brought to the centrally located sump such that the delivery points remain about 15 cm above the sump floor level and the sump floor level should be kept about 2 m below the expected water level in the sump for water movement under siphon action. The moment water is lowered in the sump through pumping, subsurface water starts moving from well points into the sump due to siphon action. This technique has been named as multiple well point siphon system. Systems of wells are installed with spacing of 50 m. These wells are connected by a common polyvinyl chloride (PVC) pipeline of 90 and 110 mm diameter with the help of 'T' sections and bends at 70 cm below the ground surface (figure.14). Each well point had an effective perforated area of about 16% surrounded by pea size, clean, well-rounded riverbed gravel. Another modified and designed for small farmers with four well points spaced at 6 m apart keeping the rest of the characteristics the same (figure.15). It prevents mixing of floating fresh water with poor quality groundwater as the drawdown is distributed over four well points resulting in reduction of up-coning during pumping. It is recommended that the discharge from each well-point should not exceed 0.1 cusecs and that the screen should have effective perforated area of 16-20% surrounded by pea size clean and well-rounded riverbed gravel.

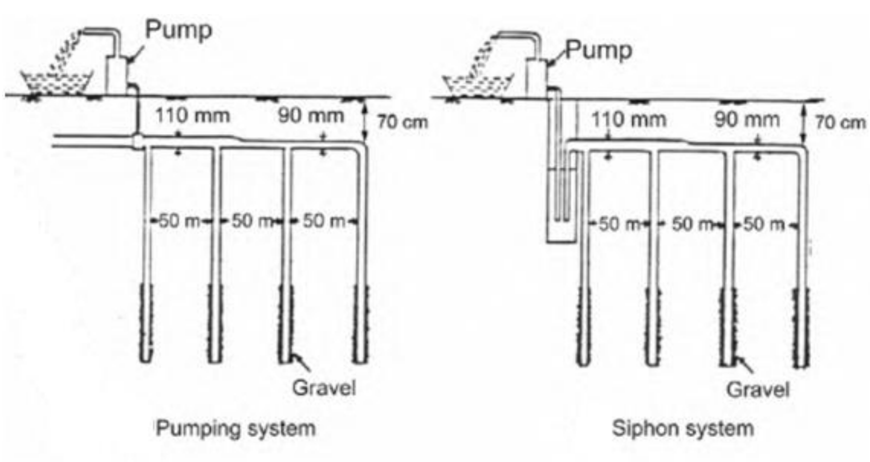


**Figure.14.Multiple Well point pumping/Syphon system**

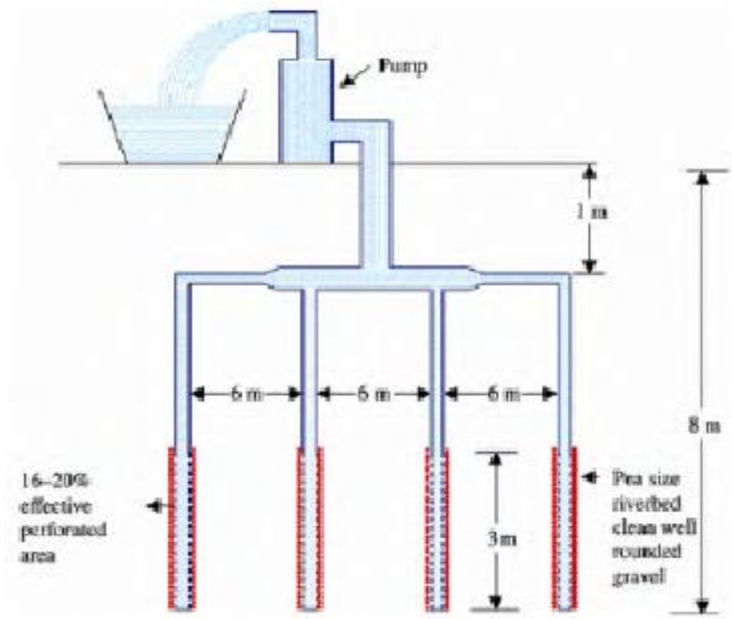


**Figure.15. Modified four well point system for small farmers**

The multiple well point systems were found to be technically feasible and economically viable. This system was recommended to small and marginal farmers, irrigating with the pumped good quality water.

**5.8.2 Cyclic use of canal water and ground water**

Surface and subsurface drainage system has been useful in the reclamation of waterlogged areas. However, such drainage systems produce poor quality effluents and their discharge is a serious problem. With the increasing problem of disposal of saline water and increasing demand for good quality water, the conjunctive use of poor quality groundwater and canal water has gained popularity. Results of various studies have indicated a potential for the use of saline drainage water for crop production and various strategies have been proposed to use this water for irrigation. Minhas and Gupta demonstrated successfully the use of brackish groundwater with canal water in different modes for irrigation in the canal command area. Sodicity in the soil is a major constraint in increasing agricultural production in arid and semi-arid regions. These soils have high levels of pH, exchangeable sodium percentage (ESP), soluble carbonates of Na and are poor in hydraulic conductivity. Gypsum is commonly used to reclaim these soils, which reduces alkalinity and improves soil permeability. Use of poor quality groundwater and available canal water is not only beneficial for raising crops, but also helps in lowering groundwater table. This process ultimately leads to drainage of water logged areas and reduction in the cost of the drainage system.

### 5.8.3 Bio-drainage system

Large scale adoption of bio-drainage along canal sides as preventive measure to check water-logging and salinity. Bio-drainage refers to a technique of lowering ground water in waterlogged areas through the use of raising tree plantations. This technique removes excess soil water through the process of transpiration by trees using solar radiation energy. It is a kind of preventive technique to avoid the development of salinity and water-logging problem in canal command areas. The technique is highly useful when the soils are still in the process of salinization due to rise in ground water level. However, if the soils are already salinized it has limited scope. The transpiration rate of eucalyptus is higher than that of any other plant species and it acts as a biological pump, withdrawing water from the subsurface reservoir and delivering it to the atmosphere. The technology was developed in water logged sodic soils or saline sodic soils to establish eucalyptus plants. It constitutes a wide ridge covered with polythene sheet buried at about 15cm below the soil (Figure.16). The holes for transplanting seedlings are made on the top of ridge at 4 m spacing. Gypsum of 500 gm and farmyard manure of 2 kg/hole are mixed with the soil and added to the hole. The rain falling on the ridge was allowed to percolate through the soil surrounding the seedlings. The undesirable salts leached down below the root and the ridge soil conserved good quality water for the plants. Water table closer to or at the surface did not affect the plants, which were planted on the elevated ridge. It also cuts off the capillary fringe, hence terminating the process of desalinization/resodification

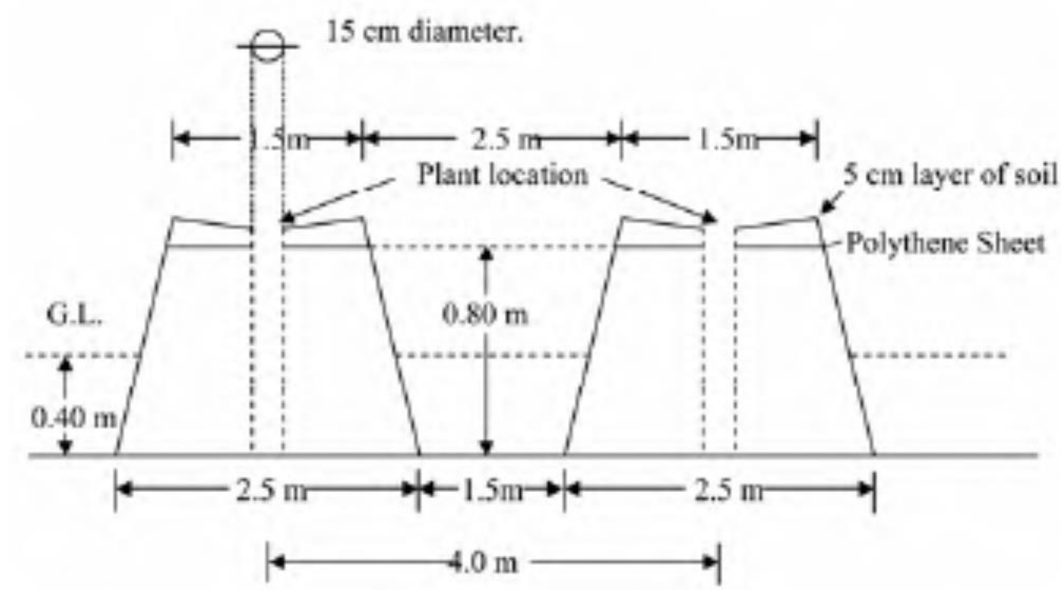


**Figure.16. Layout of Ridges for Bio-drainage system**

### 5.8.4 Sub-surface drainage system

Sub-surface drainage system is a well developed technology, which lowers the water table to a specified depth. Spacing and pattern of the drainage system depends upon the hydraulic conductivity of the soil, specific drainage discharge and water table condition. The three main functions of sub-surface drainage are-

(a) Removal of excess ground water in the root zone of the crop plants during the growing season,

(b) Maintaining the water table below ground level throughout the year, particularly in reclamation areas,

(c) Reducing the levels of salinity and maintaining salinity levels in certain circumstances.

The sub-surface drainage system constitutes a system of perforated lateral pipes surrounded by filter materials buried below the root zone depth, collector and pumped outlet if gravity drainage does not exist. All the undesirable salts are leached down and taken out of the field through a network of subsurface drains. During the pre-drainage investigations in the selected areas some design parameters are considered for the drainage systems. The hydraulic conductivity of the soil considered is 0.6 cm /hr for Chowtapapayapalem and 0.80 cm/hr for Irukupalem villages. The average rainfall for both the villages is 850 mm. The hydraulic head above the drains fixed as 0.40

m and depth of impervious layer is considered as 10 m. The depth to water table has been considered 0.0 to 3.10 m for Chowtapapayapalem and 0.0 to 3.00 m for Irukupalem villages.

### 5.8.5 Design and Construction of Drainage systems

**Chowtapapayapalem:** The pre-drainage investigations, discussions with farmers and the field visits to the area led to a decision to construct a horizontal subsurface drainage system. It was decided to construct subsurface drainage in the part of village area about 28 ha. The important parameters required for the design of subsurface drainage systems are drainage coefficient and depth and spacing of the lateral drains. Based on the inflows and outflows in the area, the drainage coefficient is estimated as 6 mm/day. Based on the parameters determined during pre-drainage investigations, the spacing of drains and the sizes of the lateral and collector pipes are calculated. The closed subsurface drainage with layout of a grid iron pattern has been suggested for the selected area. The blind PVC pipe of 0.16 m diameter is suggested for collector pipes with spacing of 30 m and 60 m throughout the affected area. These pipes are to be installed at a depth varying from 1.00 m to 1.20 m below the ground surface with a slope of 0.60%. Flexible, corrugated, perforated PVC pipes of 0.08 m diameter with six rectangular openings of 5 x 1.3 mm size in each cross section on the periphery are to be used as laterals. The lateral pipes are to be laid with a slope of 0.1 to 0.2%. The water inlet area in one meter length of the pipe is 22.1 sq.cm. Two types of envelope materials, namely Geo-textile (synthetic material, 2.6 mm thick with $O_{90}$ value of 300 microns) and Nylon mesh (filter fabric envelope material of 60 meshes) are suggested. The inspection chambers are also suggested at specific junction points with RCC rings of 0.75 m diameter and 1.80 m depth. A big sump cum inspection chamber is recommended at the end of the system where laterals join the collector line. The drainage water from the system is collected into this sump by gravity from where it is disposed off in to the natural drain by pumping. An open drainage system of 1.00 m depth with 100 m spacing is also recommended, if the topography of the area permits gravity outflow to dispose off the drain water into the natural drain.

**Irukupalem H/o Madala Village:** Based on the pre-drainage investigations, subsurface and open drainage systems are suggested for the selected area. It was decided to construct subsurface drainage in the part of village area about 301 ha. Based on the inflows and outflows in the area, the drainage coefficient is estimated as 8 mm/day. Based on the parameters determined during pre-drainage investigations, the spacing of drains and the sizes of the lateral and collector pipes are calculated. The closed subsurface drainage with layout of a grid iron pattern has been suggested for the selected area. The blind PVC pipe of 0.16 m diameter is suggested for collector pipes with spacing of 30 m, 40 and 60 m throughout the affected area. These pipes are to be installed at a depth varying from 1.00 m to 1.20 m below the ground surface with a slope of 0.60%. The laterals are provided with 0.08 m diameter flexible, corrugated and perforated with six rectangular openings of 5 x 1.3 mm size in each cross section on the periphery. Two types of envelope materials, namely Geo-textile (synthetic material, 2.6 mm thick with $O_{90}$ value of 300 microns) and Nylon mesh (filter fabric envelope material of 60 meshes) are suggested. The inspection chambers and big sump at the end are also recommended as in the case of Chowtapapayapalem village. An open drainage system is also suggested where the topography permits gravity outflow to dispose off the drain water into the natural drain. The model layout of subsurface drainage with grid iron pattern is shown in the figure 17.

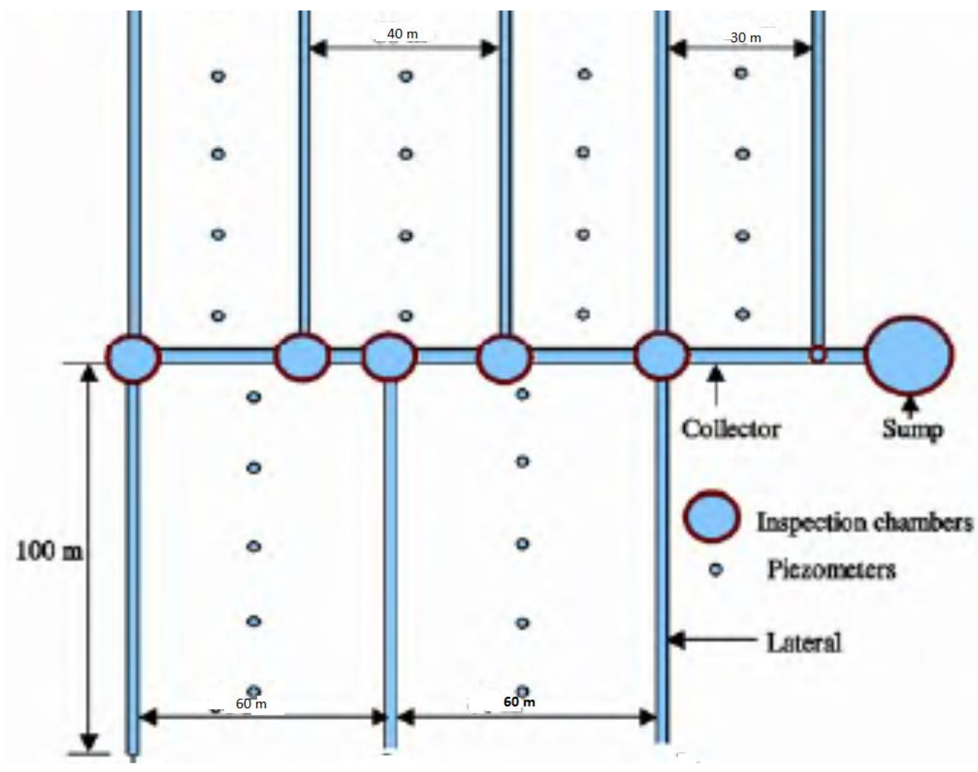


**Figure.17 Layout Plan for subsurface drainage system in Gridiron pattern**

In order to fully characterize the salinity problem, combination of geophysics, quantitative hydrogeology (field studies and hydraulic modeling), and geology are suggested. An integrated approach, incorporating the fields of irrigation and drainage engineering, agriculture and groundwater management is required to mitigate the water logging and salinity problems of the study area. The present study is mainly conceived as a regional case study and has revealed the localized nature of the salinity problem. Studies characterizing the vertical domain of the whole aquifer system would be useful, especially with a focus on the saline zones. Geophysical methods (such as electrical resistivity) and depth sampling would be beneficial, in this regard. To investigate the effects of faults, high-resolution geophysical imagery (e.g. magnetic survey) should be obtained to identify all structural trends underneath the alluvium and colluviums. This should be coupled to the identification of their hydraulic conductivity. In addition, studies on groundwater flow modeling focusing on flow of fluids from the saline zones and effect of the fault zones on subsurface fluid migration are also recommended. Finally, the studies can focus on management of the salinity problem.

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

Water logging is a serious environmental concern. It degrades soils as also deteriorates ground water quality (saline and alkaline) which ultimately results in loss of agricultural production. Ground water resources estimation of NSRCCA has been carried out by AP Ground water department based on the guidelines of Ground water Estimation Committee-1997 with the modifications suggested by GEC-2004 and the R & D Advisory committee on the Ground Water Resources Estimation from time to time and following the broad guidelines issued by the Central Ground Water Board, Ministry of Water Resources, Govt. of India. The following conclusions are drawn from the study:

1. 1.The data analyzed for 25 years observed that, there are about 132 poor ground water quality areas (either with high EC or brackish), covering 94 villages in Guntur district and 38 villages in Prakasham district of command area. The ground water utilization is more than 65% for all uses in about 89 villages covering 13 in Guntur district and 76 in Prakasham district of the command and the stage of development of the command works out to be 12.46% in which 7.43% is in Guntur district and 48.16% is in Prakasham district. The groundwater can be developed in about 569 villages in the command covering 323 in Guntur and 146 in Prakasham districts.
2. The lowest water level fluctuation is observed during 2002 (0.06 m) and highest during 2005 (3.25 m). The areas of water logging and prone to water logging are varied season wise and year wise which depends upon various variable hydrological and hydrogeological parameters. Average depths to water levels (DTW) are worked using these data for each observation well.
3. The irrigation suitability of the ground water has been studied by analyzing electrical conductance (EC) data of 300 water samples of 300 observation wells pertaining to pre and post monsoon periods. It is observed that 35.3% the percentage of observation wells present in unsuitable category during Pre-monsoon and 30.3% Post-monsoon.
4. The water logging and salinity problems carried out in two pilot areas namely Chowtapapayapalem village of Rajupalem mandal and Irukupalem H/o Madala village of Muppala mandal in Nagarjunasagar Right bank Canal command area. In chowtapapayapalem village 28 ha and in Irukupalem village 301 ha falls under water logged category.

5. SALTMOD, a mathematical model is applied to predict the root-zone salinity and leaching efficiency. The model simulated the soil-profile salinity for 20 years under different conditions, viz. with subsurface drainage and without subsurface drainage. The salinity level shows a decline with an increase of leaching efficiency. The leaching efficiency of 0.1 shows the best match with the actual efficiency under adequate drainage conditions. The concentration of root zone salinity shows a decline after a period of 5 years to the acceptable limits and remains constant after 15 years. However, without drainage there is a drastic increase in salinity over the years there by indicating the necessity of artificial drainage system. The model shows a steady increase, though at a slow pace over the years, reaching the levels 8.0 ds/m to 10.0 ds/m at the end of the 20 years period. If suitable drainage system is not provided, canal command areas will further get salinized thus making the land uncultivable.
6. From the present study it is evident that it is necessary to provide proper drainage facilities to control the salinity levels in the command area. Based on the field investigation and analysis of data, some ideal measures are suggested to combat with soil and water salinity issues in the command area. New drainage techniques, viz. multiple well-point system, conjunctive use of canal water and poor quality groundwater, bio-drainage and conventional sub-surface drainage system were discussed.

   The following additional studies and remedial measures are suggested in the area of groundwater quality and salinization.

1. Conduct a landholder survey to investigate local knowledge regarding the first appearance of salinity, in order to attempt to identify primary and secondary saline sites.
2. Tree planting with appropriate native species above the break-of-slope at salt-affected areas, so as to intercept surface and sub-surface water flow to low-lying areas.
3. Tree planting with appropriate native species along drainage lines to reduce the impacts of both salt and erosion.
4. Surface drainage improvements including remodeling (deepening and resectioning) of natural streams and provision of new intermediate drains.
5. Construction of seepage drains to intercept excessive seepage from unlined canals and those with damaged lining and divert to the nearest main/secondary drain.

6. Lining of existing unlined canals and maintenance of damaged canals.
7. Promotion of location specific pond technology for management of water-logging and salinity.
8. Increasing water use efficiency through efficient utilization of available irrigation water in dry areas through large-scale promotion of micro irrigation techniques such as drip and sprinklers. In the irrigation commands which run the risk of water-logging and salinity precision irrigation techniques should be promoted.
9. Choice of salt tolerant crops and varieties. In the saline groundwater regions the salt tolerant and low water requiring crops like pearl millet, cotton or cultivation of salt tolerant varieties of crops could be an effective method for increasing the productivity of salty groundwater. The natural and induced salt tolerance amongst crops and varieties offers scope for minimizing salinity effects.
10. The profitability of the saline groundwater can be increased by the brackish water aquaculture. The results of the experiment conducted at Haryana Agricultural University, Hisar revealed that groundwater of up to 14.5 dS/m salinity level could be used for aquaculture. The profit from aquaculture is much higher than the profit from traditional irrigated agriculture.

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# CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# ABSTRACT

Water logging and Salinity are the common features associated with many of the irrigation commands of surface water projects. In other words, it is excess recharge over discharge of groundwater, leading to a rise in the water table. The irrigation command areas are recharged not only by the rainfall infiltration, but also by seepage from reservoirs, canals, distributaries and field channels and return circulation of irrigation water. The rising salinity of groundwater used for water supply and irrigation is a major problem. There are many examples of salinity increase in various parts of the country, particularly in canal command areas. In order to achieve the target, the major constraint is with regard to salinity and water logging in various parts of the command area.

One of the most salinity affected command area is in the right bank canal of Nagarjunasagar. During the field investigations at Nagarjunasagar right bank canal command, two villages have been identified for detailed investigation i.e. Chowtapapayapalem village in Rajupalem Mandal and Irukupalem village in Muppala Mandal. The entire village shows waterlogged conditions for the last 15 years (groundwater level less than 2 m). Ground water availability studies were done as per the guidelines of Ground Water Estimation Committee 1997. The groundwater level and water level fluctuations of the observation wells in the command area are analyzed. The observations were made from this analysis for water logging conditions. The groundwater quality data were collected for the salinity and water logged areas of the command. The irrigation suitability of the ground water has been studied by analyzing electrical conductance (EC) data of 300 water samples of 300 observation wells pertaining to pre and post monsoon periods.

A computer programme called SALTMOD windows version developed by Oosterbaan has been proposed to study the problem is ongoing. SALTMOD, a mathematical model is applied to predict the root-zone salinity and leaching efficiency. Based on the field investigation and analysis of data, some ideal measures are suggested to combat with soil and water salinity issues in the command area. New drainage techniques, viz. multiple well-point system, conjunctive use of canal water and poor quality groundwater, bio-drainage and conventional sub-surface drainage system were discussed.

## PREFACE

Water in the irrigation command areas is essential for successful agriculture. It is the cause of many associated problems such as water-logging and salinity. Development of water-logging in irrigation commands are experienced world over. Conjunctive use is also being practiced to mitigate the problem of water-logging by going in for more pumping og groundwater wherever groundwater table is above or very nearer to ground surface. The impact of various management activities on groundwater quality is closely related with the quality of water applied for irrigation. Fertilizers are normally applied to agricultural fields to increase the crop yields. However, a part of the chemical constituents present in the fertilizer may percolate down to reach the ground water table thereby polluting the fresh water aquifers. It is, therefore, important to limit the application of fertilizers and monitor their movement in the unsaturated zone.

In order to achieve the target, the major constraint is with regard to salinity and water logging in various parts of the command area. One of the most salinity affected command area is in the right bank canal of Nagarjuna Sagar Project. Andhra Pradesh State Ground water Department is carrying out conjunctive use studies in major command areas of AP. The studies carried out in Nagarjuna Sagar command reveal that the areas of water logging and prone to water logging are varied season-wise and year-wise. Scientists from HRRC, NIH, Belgaum visited some critical areas in the command area along with AP Groundwater Department officials. During the field investigation two villages namely Chowtapapayapalem village in Rajupalem Mandal and Irukupalem village in Muppala Mandal are identified for critical analysis. The entire village shows waterlogged conditions last 15 years as groundwater level less than 2 m. The ground water level fluctuations are studied to identify the water logged areas. The groundwater quality data were collected for the salinity and water logged areas of the command. A computer programme called SALTMOD windows version developed by Oosterbaan has been proposed to study the problem is ongoing.

This report is prepared by Dr.N.Varadarajan, SRA and Dr.B.K.Purandara, Sc. “E” of Hard Rock Regional Centre, NIH, Belgaum.

# WATERLOGGING AND SALINITY STUDIES IN NAGARJUNA SAGAR RIGHT BANK CANAL COMMAND

**HARD ROCK REGIONAL CENTRE**
**NATIONAL INSTITUTE OF HYDROLOGY**
**BELGAUM**

| | |
|---|---|
| **DIRECTOR:** | **Sh.R.D.Singh** |
| **TECHNICAL COORDINATOR:** | **Dr.Sudhirkumar, Sc. “G”** |
| **HEAD:** | **Dr.Venkatesh B, Sc. “F”** |
| **STUDY GROUP:** | **Dr.N.Varadarajan, PRA**<br>**Dr.B.K.Purandara, Sc. “E”** |