RESEARCH ON THE CONTROL OF WATERLOGGING AND SALINIZATION IN IRRIGATED AGRICULTURAL LANDS

Recommendations on Waterlogging and Salinity Control Based on Pilot Area Drainage Research

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Haryana, India

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Indo-Dutch Network Project (IDNP). 2002. Recommendations on Waterlogging and Salinity Control Based on Pilot Area Drainage Research. CSSRI, Karnal and Alterra–ILRI, Wageningen. pp. 100.

Published in 2002 in India by
Central Soil Salinity Research Institute, Karnal (India) and
Alterra- International Institute for Land Reclamation and Improvement ,
Wageningen (The Netherlands)

Sponsored by the Ministry of Foreign Affairs of the Netherlands through the Royal Netherlands Embassy, New Delhi and Government of India through the Indian Council of Agricultural Research, New Delhi

Printed at : Intech Graphics, #5, "Ankush Chambers", Opp Dyal Singh College, Karnal-132 001
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EXECUTIVE SUMMARY

The introduction of irrigation in arid and semi-arid regions of the country has resulted in the development of the twin problem of waterlogging and soil salinisation, with considerable areas either going out of cultivation or experiencing reduced yields. Attempts to develop site specific technologies to reclaim such lands to their original productivity have been made in the past, yet a concerted effort to test and verify the solutions under different agro-climatic conditions has been lacking. Under the aegis of an Indo-Dutch Network Project on "Research on the control of Waterlogging and Salinisation in Irrigated Agricultural Lands" 7 pilot areas were established to conduct drainage research. Besides, a large-scale monitoring site was used to monitor and evaluate the drainage system. This report documents the recommendations emerging from these pilot areas and the monitoring site. Basic features of these studies could be summarized as follows:

- The study broadly covers 5 agro-ecological sub-regions of India with soils ranging from sandy loam to heavy clay.
- The study areas are parts of 7 irrigation commands covering the states of Andhra Pradesh (Nagarjuna Sagar and Krishna Western Delta), Gujarat (Ukai-Kakrapar), Haryana (Western Yamuna Canal), Karnataka (Upper Krishna and Tungabhadra Projects) and Rajasthan (Indira Gandhi Nahar Pariyojana). All these sites constitute a part of the semi-arid region of India.
- The pilot areas range in size from 20-188 ha. In some cases only a part of the pilot area is treated with the intervention of drainage. The large-scale monitoring site covered an area of 2,000 ha out of which nearly 1,200 ha has been treated with drainage.

On the basis of these studies several conclusions on the art and science of drainage in India have been drawn. General recommendations on measures to combat waterlogging and salinity, design specifications for horizontal subsurface drainage (both pipe and open drains), supplementary activities in soil and water management and institutional and policy issues have emerged. Besides, several site-specific recommendations for the study sites have been included. Although studies on reuse and disposal of saline drainage effluent have shown the potential of reuse of drainage effluent for crop production, yet further strengthening of research on reuse and disposal strategies is recommended.

In all pilot areas, crop yields improved to justify the cost on drainage intervention. Besides this direct benefit, socio-economic benefits of land reclamation through a drainage-based technology have been documented. The information included in this document is current state-of-the-art on subsurface drainage in India. The recommendations emerging from these studies should be treated as guidelines for other regions.

CONTENTS

1. GENERAL BACKGROUND

Agriculture is a key sector in India's economy, contributing about 35% of the Gross Domestic Product and employing 65% of its adult population. Of the total population of over 1000 million, more than 30% live below the poverty line and about 75% live in rural areas, depending directly or indirectly on agriculture. One-third of the agricultural labour force are women and agriculture is the main source of employment for women in rural areas. Annual agricultural growth has been modest at 2.6% per annum over the last 25 years. Development plans of the Government of India (GoI) and State Governments give priority to alleviating poverty and creating employment, particularly in rural areas. Considerable irrigation potential has been created in India to sustain agricultural production against the vagaries of rainfall that is scarce and unevenly distributed in space and time.

The introduction of irrigated agriculture in arid and semi-arid regions of the country has resulted in the development of the twin problem of waterlogging and soil salinization, with considerable areas either going out of production or experiencing reduced yield. It is estimated that an area of nearly 8.5 million ha is affected by soil salinity and alkalinity, of which about 5.5 million ha in the irrigation canal commands and 2.5 million ha in the coastal areas. The problem of increasing salinity caused by the rise of the water table and the lack of drainage is considered as a major environmental problem that threatens the capital investment in irrigated agriculture and its sustainability.

GoI's long-term strategy is to stimulate agricultural growth and promote rural development through improved water and land management, enhanced efficiency of irrigation and drainage networks, strengthened research activities, increased attention to environmental protection, and improved rural infrastructure.

Investment programmes, to address these elements and to re-establish growth, are of high priority in the Tenth Five Year Plan of GoI and State Governments. It is planned to double the food grain production in the next two decades. This can only be achieved through a concerted effort on all fronts including the reclamation of waterlogged salt-affected lands in all irrigation command areas. Irrigated agriculture will continue to be the mainstay of progress in the Indian agriculture to ensure food and nutritional security through crop diversification.

2. THE PROJECT

During 1995, the Governments of India and The Netherlands agreed upon collaboration in the Network Operational Research Programme on the Control of Waterlogging and Salinization in Irrigated Agricultural Lands. The programme started on 1 November 1995 upon approval by the Government of India through the Side Letter and ended on 30 April 2002.

The programme aimed at the development of appropriate location-specific drainage and reclamation technologies for solving the problems of waterlogging and salinity in canal commands of India. It also envisaged developing practical survey methods for diagnosis of problems of waterlogging and salinity. Further it aimed at establishing competent Centres in these fields. From here on, the programme is referred to as the Indo-Dutch Network Project for short.

2.1 Project Outline

The Indo-Dutch Network Project was planned and executed with the use of the Objective Oriented Project Planning (OOPP) technique. Based on the overall and project objectives, the results and corresponding activities were formulated in a logical framework (Table 1).

The project had four overall objectives:

1. Increase of agricultural production from salt-affected lands through application of proper soil and water management practices along with other agro-techniques
2. Prevention of deterioration of productive land through adoption of appropriate soil and water management practices
3. Improvement of socio-economic conditions of small and marginal farmers of these lands
4. Developing expertise for handling reclamation projects in India

From these overall objectives, two project objectives were derived:

1. Strengthened research capacity of CSSRI and the four State Centres, especially in the field of waterlogging and salinity control
2. Enhanced awareness on drainage and related water management for the control of waterlogging and soil salinity at State and Central level

The overall and project objectives were translated in eight project results (Table 1). For each result an Objectively Verifiable Indicator was formulated to monitor whether the Project achieved the results as planned. This has resulted in a list with means of verification specifying how the indicators are reported. However, the conditions needed to reach these results were not always within the competence or mandate of the Project, and were therefore, considered as outside factors, although with importance for the Project. These conditions, sometimes also referred to as risks but in this project as important assumptions were listed. The results were translated in a set of activities (Table 2). These activities formed the basis of the research conducted by the participating Network Centres. In the subsequent annual work plans the activities were further specified based on the reported progress.

Table 1. Overall logical framework Indo-Dutch Network Project – objectives and results

	Objectively verifiable indicators	Means of verification	Important assumptions
Overall objectives			
1 Increase of agricultural production from salt-affected lands through application of proper soil and water management practices along with other agro-techniques;			
2 Prevention of deterioration of productive land through adoption of appropriate soil and water management practices;			
3 Improvement of social-economic conditions of small and marginal farmers of these lands;			
4. Developing expertise for handling reclamation projects in India.			
Project objectives			
1 Strengthened research capacity of CSSRI and the four State Centres, especially in the field of waterlogging and salinity control	By April 2002 CSSRI and the four State Centres will have published quality reports on the control of waterlogging and soil salinity	• Review by experts • Check on relevant documents	• Acceptance of Project results at policy level
2 Enhanced awareness on drainage and related water management for the control of waterlogging and soil salinity at State and Central Level	By April 2002 there will be ample documentary evidence of enhanced awareness on waterlogging and salinity control at village, State and Central level		• Investment in improved water management
Results			
1. A methodology for identification of waterlogging and soil salinity conditions using remote sensing	By April 2002 CSSRI and the State Centres will have published a joint report with a methodology to identify waterlogging and soil salinity conditions	• Joint report • Progress reports	• Continued support of ICAR and State Agricultural Universities
2. Recommendations on waterlogging and salinity control based on pilot area drainage research	By April 2002 CSSRI and State Centres will have published a joint report on combating waterlogging and soil salinity	• Joint report • Progress reports	• Continued involvement of trained staff
3. Appraisal of irrigation and drainage practices by computer simulations	By April 2002 CSSRI and at least 2 State Centres will have published a joint report on the appraisal of irrigation and drainage practices by computer simulations tested in the drainage pilot areas	• Joint report • Progress reports	• Involvement of relevant staff available at CSSRI for networking
4. Improved human resource at CSSRI and the four State Agricultural Universities through training	By April 2002, 50% of the project staff and 100% of the scientific staff will have participated in a training activity	• Progress Reports • Interviews • Back-to-office reports • Field check	• Acceptance of project results by end-users (Ministries, farmers, contractors, pipe manufacturers)
5. Operational Training Centre at CSSRI	By April 2002 CSSRI will have developed 3 training modules and conducted at least 2 national training courses in the new training Centre	• Review of curricula • Course evaluation reports • Check of relevant documents	
6. Enhanced awareness at State and Central level on the necessity of an agricultural drainage policy	By April 2002 at least 3 State Governments will have expressed their willingness to prepare an agricultural drainage policy as documentary evidence		
7. Enhanced awareness at farmers' level on improved irrigation and drainage for control of warelogging and salinity	By April 2002 in at least 2 State Centres a Pilot Area Farmers Committees will have been established	• Progress repors • Meeting with farmers	
8. Advice on drainage and related water management	By April 2002 CSSRI and the State Centres have each given at least 20 working days/ year advice to others	• Progress reports	

Table 2. Overall logical framework Indo-Dutch Network Project-activities

	Activities	Important assumptions
1.1 1.2 1.3 1.4 1.5	Identify study area Develop physical facilities for remote sensing Develop a methodology Map waterlogged and salt-affected areas Report on methodology and its applicability	• Qualified staff at Centres • Timely approval of proposals by the competent authorities
2.1 2.2 2.3 2.4 2.5 2.6 2.7	Select pilot areas in farmers' fields Conduct a drainage experiment Conduct a water management experiment Conduct a socio-economic study Conduct a cost-benefit analysis of drainage Conduct other related studies Formulate recommendations	• Qualified staff at Centres • Timely approval of proposals by the competent authorities • No climatic catastrophe • Full co-operation of the relevant organisations • Full co-operation of farmers
3.1 3.2 3.3 3.4	Select computer models Acquire physical facilities Conduct computer simulations for diagnosis and prediction Report on the appraisal	• Qualified staff at Centres
4.1 4.2 4.3	Participate in training activities in India Participate in training activities abroad Conduct or participate in in-service training activities	• Qualified staff at Centres
5.1 5.2 5.3 5.4	Construct and furnish training centre and hostel Prepare a programme for National Training Courses Develop training modules on - Land Drainage - Management of Problem Soils - Use of Poor Quality Water for Agriculture Conduct National Training Courses	• Qualified staff at CSSRI • Identified need for National Training Courses • Full co-operation of the relevant organisations
6.1 6.2 6.3 6.4 6.5 6.6 6.7	Train field-level workers on the need for drainage Conduct workshops & seminars on the need for drainage Include officers from interested agencies in the Project Implementation Committees (PIC's) Prepare and distribute appropriate literature Promote awareness by public relation activities Conduct a desk-study on the institutional and organisational set-up of agricultural drainage in other countries Prepare a background document for State Agricultural Drainage Policies	• Qualified staff at Centres • Co-operation of State and Central organisations
7.1 7.2 7.3 7.4 7.5 7.6	Undertake excursions to drainage projects Train extension workers and farmers on drainage Conduct farmers' days Prepare and distribute appropriate literature Involve local farmers in project activities Establish Pilot Area Farmers Committee	• Qualified staff at Centres • Full co-operation of farmers
8.1 8.2 8.3 8.4 8.5	Assist others with training courses Assist others with drainage design Advise others on drainage and related water management Advise others on diagnosis and mapping of problem soils Report on the advises rendered	• Qualified staff at Centres • Requests for advice

2.2 Implementing Agencies

The Executive Authorities of the Indo-Dutch Network Project were the Indian Council of Agricultural Research (ICAR) and the Royal Netherlands Embassy (RNE), New Delhi. The implementing agencies of the Indo-Dutch Network Project were:

- The Central Soil Salinity Research Institute (CSSRI), Karnal, as coordinating centre (focal point) for the following state centres:
- The Acharya N.G. Ranga Agricultural University (ANGRAU), with office facilities at Bapatla.
- The University of Agricultural Sciences, Dharwad (UASD), with office facilities at Bheemarayanagudi and Gangavathi
- The Gujarat Agricultural University (GAU), with office facilities at Navsari
- The Rajasthan Agricultural University (RAU), with office facilities at Hanumangarh

The Supporting Agency from The Netherlands was the International Institute for Land Reclamation and Improvement (Alterra-ILRI), Wageningen.

2.3 Reporting

Several options were considered to bring out the final report of the project. In the end, it was decided to bring out 4 different volumes. While the first three volumes deal with the Project Results 1 to 3, the fourth volume provides an overview of the accomplishments in the human resource development and establishment of a training center (Project Results # 4 and 5). It was decided that the information on activities related to enhanced awareness and advise on drainage rendered by the centres (Project Results # 6 to 8) would form a part of the individual reports that would be brought out by the Network Centres.

3. THIS REPORT

This is the completion report of Project Result # 2 "Recommendations on waterlogging and salinity control based on pilot area drainage research" of the Indo-Dutch Network Project for Operational Research on the Control of Waterlogging and Soil Salinity in Irrigated Agricultural Lands.

In March 2002, a workshop was held to present the achievements of the Project.

The work for Project Result # 2 has been carried out at CSSRI, Karnal, Bapatla (ANGRAU, Andhra Pradesh), Navsari (GAU, Gujarat), Hanumangarh (RAU, Rajasthan) and Bheemarayanagudi (UASD, Karnataka), centres (Fig. 1). Bapatla and Bheemarayanagudi centres each had an additional establishment at Bapatla and at Gangavathi; these establishments have been designated as co-opted centres.

The salient recommendations emerging out of the work carried out at different centers have been put together at the end of the report. There are few general and few site specific recommendations.

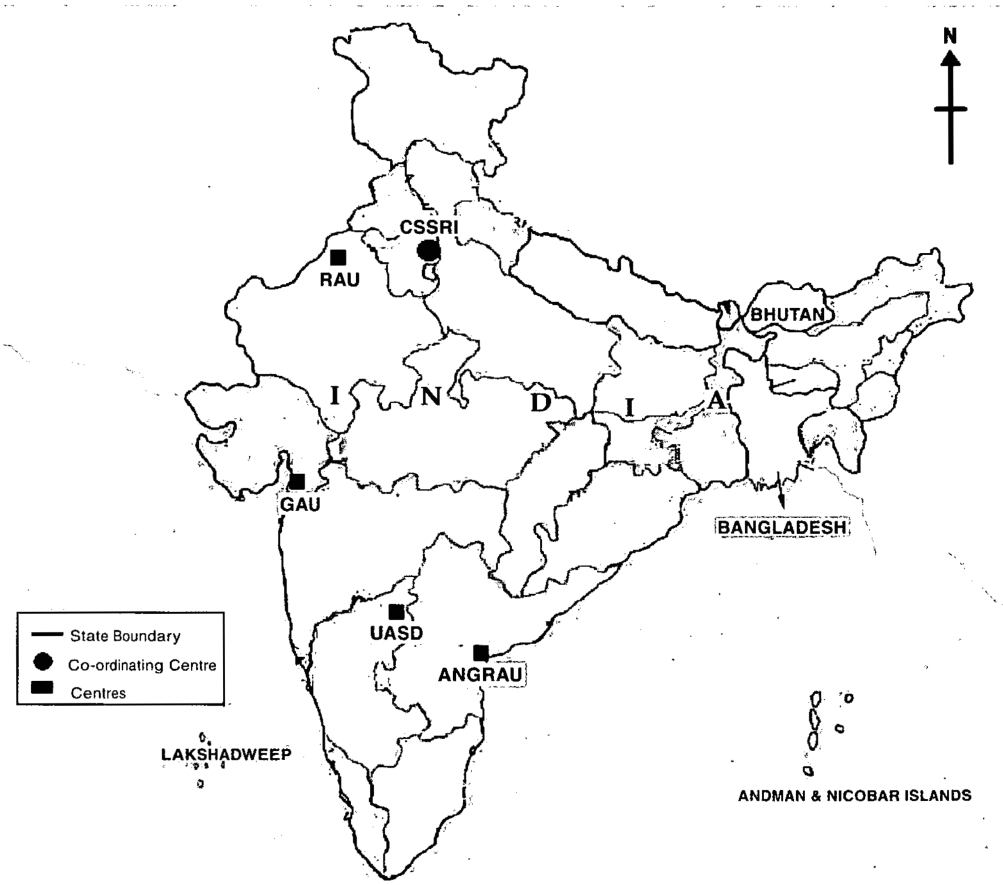


Figure 1. Map of India showing network centres

4. DRAINAGE IN INDIA

4.1 Background

Development of waterlogging is an inevitable consequence of introduction of irrigation without providing for adequate drainage. If the underground water quality is poor, soil salinity develops soon thereafter. As such, waterlogging and soil salinity have emerged as major problems in the irrigation commands affecting the agricultural productivity and sometime becomes too severe such that it becomes imperative to take the land out from crop production. In India, it is estimated that about 6.0 m ha land is affected from various nature and orders of waterlogging and about 8.5 m ha land is affected from different degrees of soil salinity. Following adverse effects of waterlogging and soil salinity have emerged.

- Loss in land productivity
- Decrease in cropping intensity with ultimate decrease in the arable area
- Restricted choice of crops
- High cost of reclamation calling for huge investments
- Migration from the villages
- Increased socio-economic and gender disparity

The improved drainage through artificial means is an essential pre-requisite to reclaim waterlogged salt-affected lands. Conventional surface drainage is essential but to reclaim these lands it needs to be augmented by some kind of subsurface drainage. Horizontal subsurface drainage has been found to be quite effective and eco-friendly technology in areas with poor quality groundwater. The objectives of this chapter are to present a historical background to the drainage activities in India and to review the research results obtained under the Indo-Dutch collaboration during 1984-1995 that formed the background of the present network project.

4.2 Definition of Waterlogging and Soil Salinity

Several agencies have given different definitions of waterlogging and soil salinity. On the basis of criteria given by the National Commission of Agriculture (1976) and Ministry of Water Resources (MoWR, 1991), waterlogged / critically waterlogged areas may be defined where water table is within 2 m from the surface (Table 3).

Table 3. The criteria adopted by different agencies for waterlogging

Waterlogging	National Commission on Agriculture (1976)	Ministry of Water Resources, GoI (1991)
Waterlogged/Critical	Water table < 1.5 m	Water table < 2 m
Potentially waterlogged		Water table 2-3 m
Safe area		Water table > 3 m

The most widely accepted definition of salt-affected soils is as defined by the United States Department of Agriculture, USDA (Richards, 1954). The definition is based on pH_s (pH of the saturated soil paste), EC_e (electrical conductivity of the saturation extract of soil, $dS.m^{-1}$) and ESP (exchangeable sodium percentage of the soil):

- **Saline soils :** These soils have an EC_e more than 4 dS m^{-1} at 25 ^0C, pH_s less than 8.2, an ESP less than 15 and a preponderance of chlorides and sulphates of sodium, calcium, and magnesium.
- **Sodic soils :** Sodic soils have a pH more than 8.5, ESP of 15 or more and a preponderance of carbonates and bicarbonates of sodium. The EC_e may be high if originating from salts capable of alkali hydrolysis; otherwise it should be less than 4 dS m^{-1} at 25^0C.
- **Saline- sodic :** Saline-sodic soils have pH greater than 8.5 at 25 ^0C, EC_e greater than 4 dS m^{-1} and the ESP greater than 15. These soils have formed due to a combined process of salinization and sodication.

A general guideline for the degree of soil salinity / sodicity is given in Table 4, although, the severity may vary with the type of soil and crop.

Table 4. The criteria for soil-salinity/sodicity

Key to degree of salinity/ sodicity	Salinity EC_e ($dS\ m^{-1}$)	Sodicity	
		pH	ESP
Slight	4-8	8.2-9.0	<15
Moderate	8-25	9.0-9.8	15-40
Strong	>25	>9.8	>40

4.3 Drainage Activities in India

The need of drainage in the present context in India was realised as early as 1865 when early reports on development of soil salinity were made by the Punjab Govt. to the then Governor General. It was emphasised in the reports of Drainage Board that irrigation and drainage should go together. Subsurface drainage experiments to reclaim salt-affected lands were conducted towards the 4^{th} quarter of the 19^{th} century by Mr. Robertson. In 1873, stone drains and tile drains were laid out to reclaim the lands. In spite of the use of collars in laying these drains, silting problem was noticed. Another success case study of subsurface drainage utilising tube wells (now commonly referred as vertical drainage) to tackle the problem of waterlogging is in the year 1910. It was necessitated to arrest the migration of people from Amritsar (now in Punjab, India). The large-scale migration started due to increasing menace of mosquitoes as a result of high water table that also resulted in prolonged water stagnation at the land surface. Increasing incidences of Malaria in the city scared the people to migrate to safer areas. Sixteen tube wells of 0.0425 cumecs capacity each were installed to lower down the water table. The scheme operated for 16-17 years was reported to be successful.

During this period a Subsurface Drainage Research Institute functioned at Ibban, now in Pakistan. Four major experiments that were conducted during this period include one at Manjri in present day Maharashtra. Chalkanwali now in Pakistan, Nissang (Haryana) and Baramati (Gujarat). From these experiments, it was concluded that the drainage systems laid out did not control the water table at the desired rate during critical periods, yet the yields were significantly higher in the drained over the undrained, control. As a result of operation of the system, the downward movement of water improved soil aeration during critical periods such that it resulted in increased yield. Recent experiences in India corroborate this observation. The systems at Manjri and Baramati were intensively monitored and on the basis of the experiences gained in Maharashtra, Inglish and Gokhle (1927) brought out a report.

During the late Fifties and middle of Sixties, large areas in various states developed problem of waterlogging. In spite of well-developed main surface drainage system in many states notably Punjab and Haryana (the then old Punjab, India), water table continued to rise affecting production and productivity. It was apparently clear that surface drainage in the absence of appropriate field and collector drains failed to control the rise in water table. It was, however, clear that along the collectors and main drains, rate of rise in the water table was slow and waterlogging conditions developed much later than in other areas. Poor upkeep and maintenance of main surface drains resulted in all round development of waterlogging. Even in later experiments, where deep open drains were used as subsurface drains to minimise investments, it emerged that maintenance of open drains is a difficult task. In view of the fact that these lands were quite productive, a large number of experimental subsurface drainage systems were laid out throughout the length and breadth of the country. These experiments helped to generate valuable information that formed the basis of many drainage installations in the country in future.

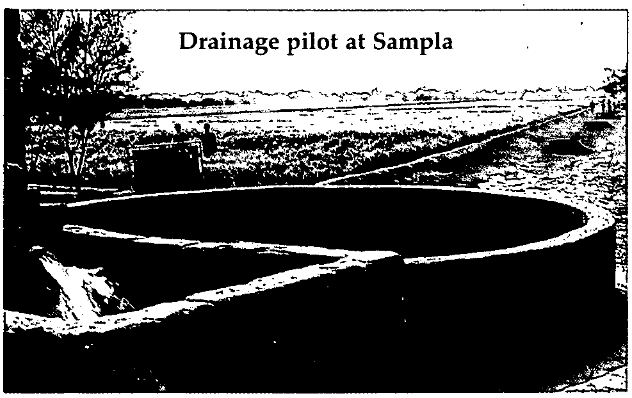
With the expansion of irrigation through inter-basin transfer of water, problems of waterlogging and soil salinity continued to expand. Presently, the area affected by these problems in the irrigation commands alone is estimated to cover about 5.6 million ha. While this figure is for the lands that have turned barren and are aptly described as wet deserts, quite a large area also experiences land degradation to various degrees. These lands continue to be cultivated but the yields are far below the level anticipated for irrigated lands. Experimental evidences led to the realization that subsurface drainage is an essential intervention to reclaim such lands. In order to develop a package of practices for reclamation of waterlogged saline lands, an attempt was made to utilise this strategy at Sampla as early as in 1980. Both open and tile drains functioned well and reclaimed the waterlogged saline land. Operational problems, however led to the conclusion that tile drains are a better alternative to drain such alluvial lands (Gupta, 1985). Realising the potential of this technology, an Indo-Dutch Project was conceived and implemented which continued till 1994. The diagnosis procedures, drainage investigation techniques and design procedures followed have been reported by Rao et al. (1986). This site is one of the longest intensively monitored drainage site in India. The system was handed over to village *Panchayat* in the year 2000 for operation and maintenance. In between came the RAJAD Project with the Canadian support for the Chambal command in Rajasthan. It was closely followed by an Indo-Dutch Network Project and later the Haryana Operational Pilot Project. Central Government took up this activity under Command Area Development. Department of Rural Development also came forward to implement drainage projects. Experiments were also established under the All India Coordinated Research Project on Drainage.

If we look at the overall scenario, recommendations emerged from time to time that drainage is essential. For example, the Royal Commission on Agriculture (1928) mentioned "Now lesson have been learnt and in all future projects, drainage will form an essential component of the irrigation projects". However, it remained on paper and irrigation projects continued to be commissioned without proper provision of drainage even after independence. Irrigation and drainage go together continued to be religiously emphasised by the Second Irrigation Commission (1972) and National Commission on Agriculture (1976). The practice to start the irrigation planning and execution with the available funds continued to be in vogue in the hope that either drainage might not be needed or funds in future would be available for this activity once the project starts yielding income.

It is apparent that concerted effort to integrate various components such as diagnostic procedure and methodology, pilot area drainage research, irrigation water management to minimise drainage need, computer modelling and human resource development and creation of awareness at various levels have not been made so far. The Indo-Dutch network project was conceived and planned with this approach in view.

5. MONITORING AND EVALUATION OF PILOT AREAS AT SAMPLA AND GOHANA, HARYANA (CSSRI)

5.1 Introduction



As per plan, CSSRI was not required to implement any new pilot area. An existing pilot area and a large scale drainage site were used for monitoring and evaluation. These are:

- Drainage Experimental Plots at Sampla laid out in 1984.
- Haryana Operational Pilot Project, Gohana laid out during 1997-99.

For simplicity, both the sites in discussions are referred as pilot areas. Since in the monsoon climatic conditions, surface drainage needs to be integrated with subsurface drainage to minimize cost as well as for cost-effective eco-friendly disposal of drainage water, it was decided to undertake research on surface drainage requirement of crops as well. It should help in preparing an integrated approach to drainage in monsoon climatic conditions.

5.2 Waterlogging/Soil Salinity Problems

Haryana state located between longitude 74°27′ to 77°35′ E and latitudes of 27°39′ to 30°55′ N covers an area of 44,212 sq km. The average annual rainfall is minimum in the Sirsa district with 325 mm while a maximum of 1120 mm occurs in Panchkula. The annual average rainfall for the state is 573 mm. Most of the state has alluvial soils having loamy sand, sandy loam, sandy and loamy texture. With a cultivated area of 37,920 sq km, it has a net sown area of 35,750 sq km. Total cropped area is 59,190 sq km with a cropping intensity of 165%.

A paradoxical situation in Haryana is developing over the years. It is observed that nearly 52% of the state is experiencing rising water table while the remaining 48% area is experiencing decline in the water table due to overexploitation of groundwater.

5.3 About the Sites

5.3.1 Sampla

The site is part of a low-lying basin, which has no natural outlet even for surface drainage. The region has a sub-tropical, semi-arid, continental and monsoon type climate. With an average annual rainfall of 650 mm, the average annual evapotranspiration at 1,650 mm exceeds the rainfall (Fig. 2). The excess of rainfall over the potential evapotranspiration occurs during the monsoon

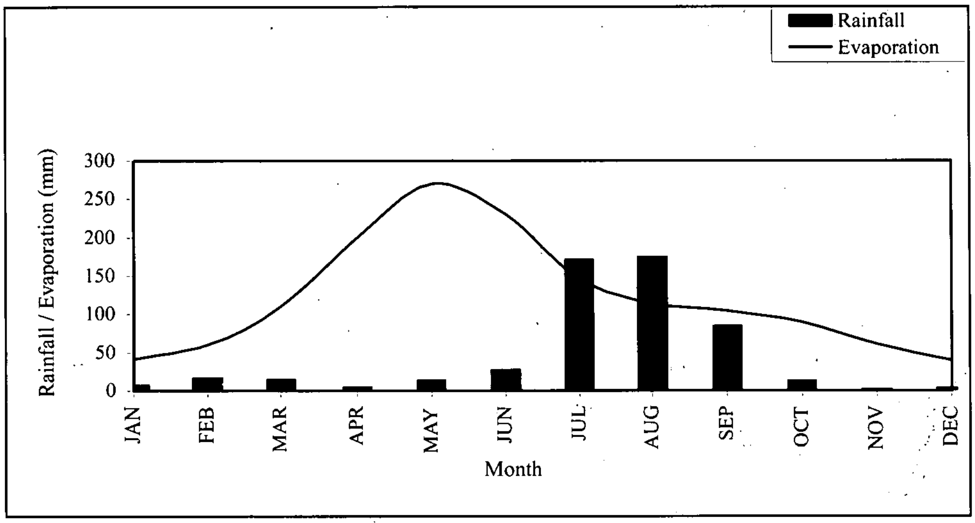


Figure 2. Average monthly rainfall and potential evapotranspiration at Sampla (1985-99)

season particularly during July to September. The water table fluctuates between the soil surface in the monsoon season to 1.8 m below soil surface in the summer season. The sand content in the sandy loam soil of the upper 1.8 m layer varied from 70 to 75%. The hydraulic conductivity of this layer was estimated to be 1.0 m day^{-1}. In the layer below 1.8 m, soil texture varied from sand to loamy sand. The hydraulic conductivity of this layer was estimated to be 7.5 m day^{-1}. Soil texture below this layer at depths varying from 2.5 m to 3.5 m in the entire area is sandy loam with hydraulic conductivity of 1.0 m day^{-1}. It continues down below. Treating this layer as the impervious layer, an average depth to impermeable layer has been taken as 3.0 m below the soil surface. The area has been lying barren for several decades due to high salinity in the root zone. Subsurface drainage system at this site was implemented in 1984 and extended in the later years to test various depth– spacing and drainage material combinations (Fig. 3).

5.3.2 Gohana

The HOPP-Gohana area located between 29° to 29° 10′ N and 76° 42′ to 76° 52 E represents flat to very gently sloping terrain (Fig. 4). The groundwater is saline and both high water table and surface stagnation of water during monsoon season are common in the area. The water table is varying from surface in rainy season to within 1.5 m even at the end of summer. The climate of the area is characterised as semi-arid. Average annual rainfall of the last 80 years is about 550 mm and average potential evapotranspiration is assessed at 1650 mm. The monthly distribution is similar to the one at Sampla shown in Fig. 2. The rainfall being less, the deficit of water at this site is more than that at Sampla. Capillary rise of water along with salt has resulted in widespread secondary salinization. The soils are calcareous in nature. The water table depths have influenced the colour and mottling of the subsurface soil layer as evidenced by the presence of red and yellow mottles and nodules of hydrated iron and manganese oxides. In most cases, a 25-30 cm thick calcium carbonate concretion layer around 1 m soil depth is encountered. Soil texture varies from sandy

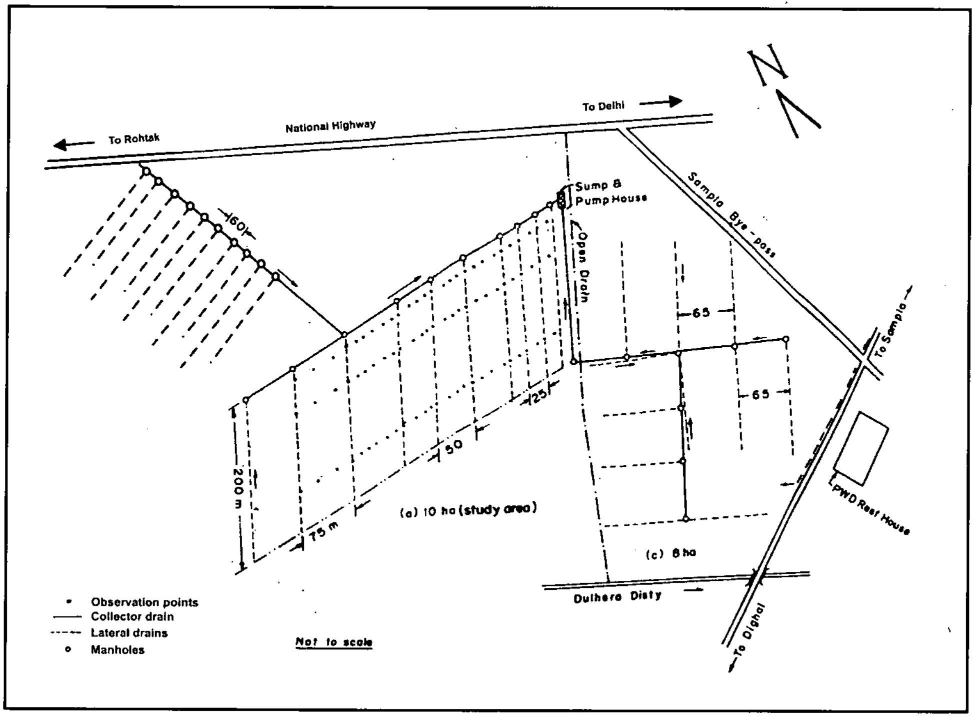


Figure 3. Layout plan of subsurface drainage systems at Sampla

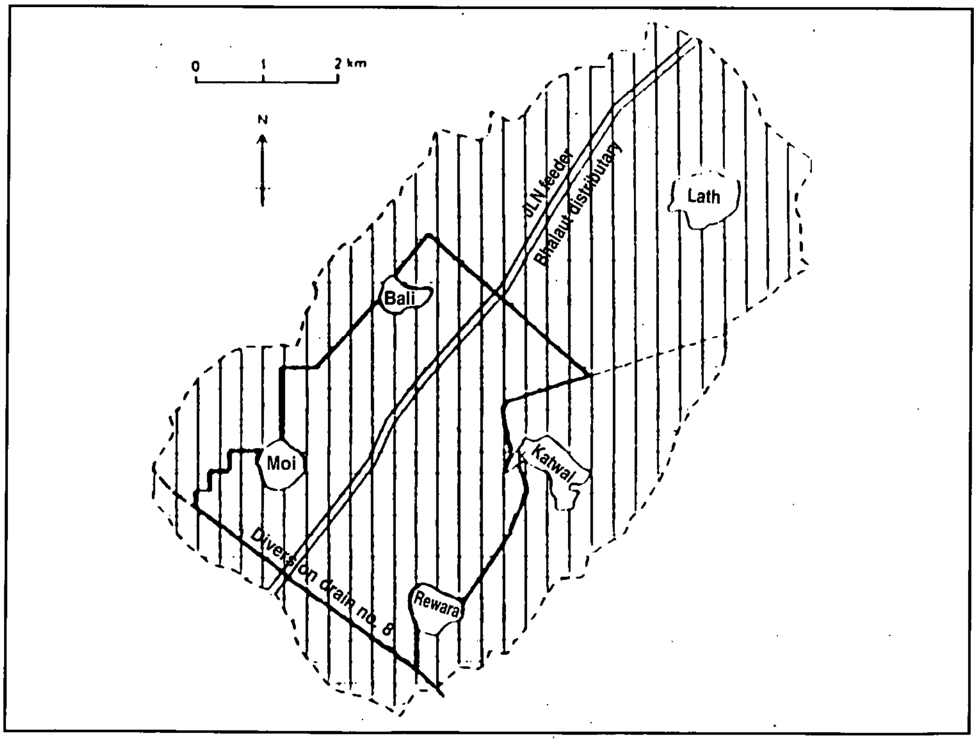


Figure 4. Drainage monitoring site, HOPP-Gohana

loam to sandy clay loam. The main crops are rice, sorghum, pearl-millet and sugarcane during the rainy season (*kharif*) and wheat, mustard, barley and berseem during the winter season (*rabi*). The percentage area affected by waterlogging and soil salinity varied from 46 % in Bali to 26 % in Rewara with an average of 33 % (Fig. 4 and Table 5).

Table 5. Extent of salt- affected area in HOPP-Gohana during 1994-95

Village	Non- affected area (ha)	Salt -affected area (ha)
Katwal	699	383
Lath	1025	417
Moi	455	182
Rewara	460	161
Bali	441	375
Total	3080	1518

5.4 Soil Salinity Limits for Adverse Impact on Crops Yield

Crop cutting experiments on a grid basis have been conducted at Sampla and Gohana. Yield data have been plotted against salinity (0-30 cm). The break-point salinity, the salinity values at or below which no adverse effect on crop yield is anticipated, for various crops have been assessed using SEGREG (Table 6). It is apparent that break- point salinity beyond which adverse effects of soil salinity starts appearing vary from crop to crop. Since wheat is the major crop of the area, it appears that lands could be designated as saline, if average bulk EC of the soil exceeds 4 dS m^{-1}. It may be mentioned that these values are average of the season. Since the crops are more susceptible at germination stage, a lower value might need to be prescribed for defining soil salinity.

Table 6. Break-point or threshold salinity for various crops at Sampla/Gohana

Crop	Break-point soil salinity (EC, dS m^{-1})	
	Sampla	Gohana
Barley	7.0	-
Mustard	6.0	-
Wheat	4.0	4.5
Sorghum (Green fodder)	5.6	6.0
Basmati rice	-	2.5

5.5 Intervention for Land Reclamation

In order to devise guidelines for design and to develop post drainage cultural practices pilots areas were monitored for the hydraulic performance, land reclamation, crop yield and cost-benefit analysis. These issues are briefly discussed in the following paragraphs.

5.5.1 Drainage Investigations

The information collected as related to drainage design is presented in Table 7.

Table 7. Drainage design parameters (Sampla)

Particulars	Information/value	Source/evaluation technique
• Kind of problem	Waterlogging/soil salinity	• Reconnaissance • Water source investigations • Soil investigations
• Groundwater fluctuation	0-1.8 m	Average water table during monsoon and pre-monsoon
• Soil texture	Sandy, loamy sand and sandy loam (Layered profile)	Mechanical analysis
• Infiltration rate	5 cm day^{-1}	Double ring infiltrometer study
• Hydraulic conductivity	1.15 m day^{-1} (0-110 cm) 0.85 m day^{-1} (110-180 cm) 7.50 m day^{-1} (180-300 cm)	Auger hole method
• Hydraulic characteristics	Anisotropic	Ratio of Horizontal to vertical hydraulic conductivity
• Drainable pore space	0.14	-
• Surface drainage coefficient	15 mm day^{-1}	Frequency analysis and excess rainfall analysis
• Subsurface drainage coefficient		Water balance analysis
-Steady state	10 mm day^{-1}	
-Non-steady state	Lower WT by 30 cm in 2 days time	
• Kind of drainage system	Combination of surface and subsurface drainage (horizontal pipe drainage)	• Groundwater studies • Secondary data on aquifer properties
• Kind of outlet	Pumped	• Reconnaissance survey
• Depth of drains	1.75-1.80 m	At the interface of two layers, soil texture studies
• Disposal strategy	Disposal in canal system, reuse for crop production and disposal in evaporation tank	Reconnaissance survey and preliminary data analysis

5.5.2 Drainage System Characteristics

The subsurface drainage systems were laid out at Sampla and Gohana to reclaim waterlogged salt-affected lands. The salient characteristics of the systems are reported in Table 8.

5.6 Salt Leaching and Crop Production

The Sampla pilot area was monitored till the end of the year 1999 when the system was handed over to the village *Panchayat* for operation and maintenance. The following salient results have been obtained.

Table 8. Climatological and drain characteristics of the drainage systems

Parameters	Drainage system (Sampla)		Drainage system (Gohana)
	Deep	Shallow	
Drain depth (m)	1.75	1.20	1.6
Drain spacing (m)	25, 50, 75	66	60-67
Drain material	Concrete, 0.30 m long, 0.1m diameter	PVC corrugated	PVC corrugated
Filter	Gravel	Synthetic	Synthetic
Depth to impervious layer (m)	3.0	3.0	5.0
Outlet	Pumped	Pumped	Pumped

- As a result of drainage operation, efficient leaching of the salts could take place. The salt leaching was maximum in the case of drain spacing of 25 m followed by 50 m and 75 m in that order (Fig. 5) Over a long-term basis leaching was sustainable in all the drain spacings. On this basis guidelines on leaching for land reclamation were formulated (Table 9).
- The increased crop yield could be obtained in all the drain spacings. Since, in the beginning land was barren, the technology demonstrated that even such lands could be reclaimed. Yields as high as the regional average (4.4 t ha^{-1}) could be obtained in 25 m and 50 m spacing in the first year itself. The yields improved in the 75 m plots over the years and were almost at par

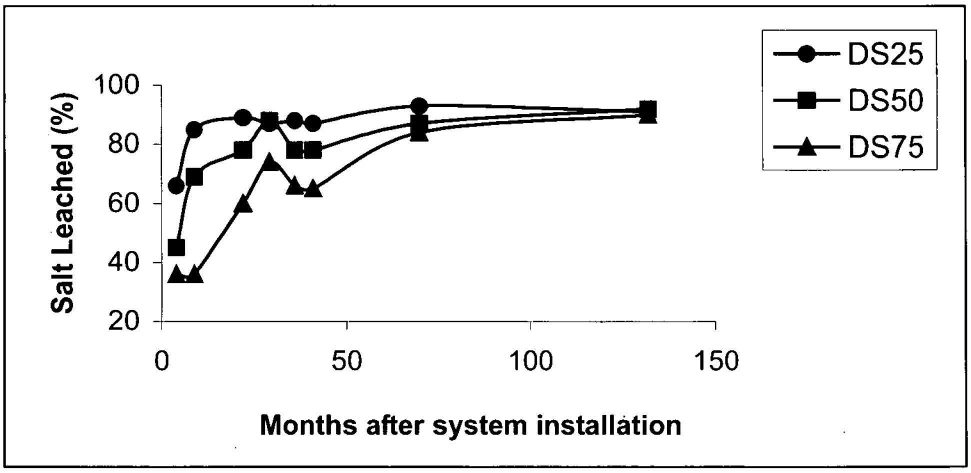


Figure 5. Leaching of salt since drainage installation in different drain spacings

Table 9. Leaching requirements of soils for one time reclamation

Soil type	Leaching requirement (cm/cm of soil depth)
Coarse textured	0.5 – 0.6
Medium textures	0.6 – 0.8
Heavy textured	0.8 – 1.0

Note: The above requirement is to leach down 80% of salts initially present in the profile.

with 25 m and 50 m spacing in the third year (Table 10). The yield obtained in the first few years could be sustained over a period of 12 years (Table 11). The data reveal that system functioned well and accomplished the reclamation processes in a favourable manner.

- While handing over the system to the village *Panchayat* the system was run thoroughly to check its performance. All the laterals functioned well. It is safe to say that the system has been operating successfully at least for its half-life since the life of the system is assumed as 30 years.

Similar results were obtained in the Gohana pilot area. The installation work in this pilot started in 1997 and was completed in June 1999. Soil and crop samples were collected from several locations following a grid pattern and compared with the initial values of 1995-96 of drained and undrained

Table 10. Relative wheat yield in different drain spacings

Year	RY * for different drain spacings (m)		
	25	50	75
1984-85	1.12	0.93	0.57
1985-86	0.97	0.89	0.82
1986-87	0.91	0.82	0.77
1987-88	1.16	1.23	1.11
1990-91	1.09	1.00	0.93
1991-92	1.54	1.20	1.30
1992-93	1.14	1.02	0.95
1993-94	1.25	1.20	1.14
1994-95	0.95	0.99	0.94
1995-96	Flooded due to unprecedented rain		
1996-97	1.09	1.14	1.07
Average	1.12	1.04	0.96

*RY is calculated by dividing the actual yield with average of the Rohtak district (4.4 t ha^{-1})

Table 11. Changes in soil salinity (0-15 cm) and crop yield at Sampla (Haryana)

Particulars and Years	Reclamation and yield in different drain spacings (m)			
	25	50	75	Undrained
	Soil EC_e (dS m^{-1})			
0 year	52.2	59.4	49.5	55.2
14 years after	2.1	2.6	4.4	66.0*
	Wheat yield (t ha^{-1})			
0 year	0.0	0.0	0.0	0.0
12 years average	4.9	4.6	4.2	**

* After 8 Years, Monitoring stopped, ** Not cultivated

area. The block-wise analysis of EC and crop yield indicated that decrease in soil salinity ranged from 9.7 to 66.3% while increase in wheat yield ranged from 9.7 to 54.0% as compared to *rabi* 1995-96. The average values of the drained blocks and undrained area are summarized in Table 12 and Table 13. It could be seen that while there is minor increase in the soil salinity in the untreated area, more than 1/3 rd of salts present in the soil profile leached down in the treated area. Similarly, the wheat yield on an average declined in the untreated while an increase in yield was observed in the treated area.

Table 12. Impact of SSD on soil salinity (EC_e, dS m^{-1}) during 1999-2000 at Gohana

Area	*Rabi* 95-96	*Rabi* 1999-2000	% salt increase (+)/ decrease (-) over 1995-96
Un-drained	9.0	9.2	+ 2
Drained	7.1	4.6	- 35

Table 13. Impact of SSD on wheat yield (t ha^{-1}) during 1999-2000 at Gohana

Area	*Rabi* 1995-96	*Rabi* 1999-2000	% yield increase (+)/ decrease (-) over 1995-96
Undrained	2.94	2.82	-04.1
Drained	3.07	3.61	+17.6

5.7 Drainage Material Research

CSSRI as a coordinating center was also assigned the task of carrying out research on drainage materials as well as provide necessary backstopping to the network centers on this issue. Should a drain envelope be used? If yes, how to choose a right envelope? Whether the envelope has been rightly installed and is performing the task for which it was applied? These are few questions agitating the designer and the executor alike. Since the cost of the envelope material on an average could be around 10 % of the total cost of the system, answers to these questions become important.

Data on soil properties from various drainage sites were obtained to work out various indices to decide on the need for an envelope. According to the present guidelines, no envelope is required provided the clay content of the soil at the drain depth is more than 30%. However, if the SAR of the soil is more than 15 than this value is increased to 40 %. If the plasticity index (PI) is equal to or more than 15, even then the envelope is not necessary. The Indices verification results revealed that the indices based on the soil texture (clay percentage) and the PI gave identical results in the case of Gohana, Segwa and Lakhuwali. It appears that the third index, the coefficient of uniformity (Cu) is inappropriate to assess the need for an envelope. As per guidelines, if Cu is are equal to or more than 15, there is no need for an envelope. Apparently in the case of sandy loam soil C, such a conclusion would be clearly doubtful (Table 14).

Investigations to test/develop guidelines for the design of envelopes were carried out both under laboratory and field conditions. O_{90} / d_{90} and hydraulic gradient ratios for different drainage

Table 14. Calculated values of indices for different soils

Indices	Gohana A	Segwa B	Lakhuwali C	Lunkaransar D	Islampur E	Konanki F	Uppugun-duru G
Clay %	10	42	10	3	58	25	26
SAR $(meq\ l^{-1})^{1/2}$	13	8	16	28	18	31	19
Cu	21	*	16	5	•	*	•
PI	10	20	10	-	-	-	-

* Cu = d_{60}/d_{10} (d_{10} values were not known in these cases)

materials and soils were determined in the laboratory (Table 15 and Table 16). Here O_{90} represents the diameter of the opening in the filter material of which 90 percent of the openings have a smaller diameter and d_{90} the diameter of the opening on which 90 percent of the soil material is retained. As per the existing guidelines, O_{90}/d_{90} in coarse textured soils could be less than 1 provided the O_{90} value of the envelope material is greater than or equal to 200 μm. The O_{90}/d_{90} values for the tested envelope materials and soils varied from 0.5 –1.2 (Table 15). Since the O_{90} values of the envelope materials are more than 300 μm, it is concluded that these materials can be safely used for sandy loam soils.

Table 15. O_{90}/d_{90} values for the five selected envelopes in Gohana, Segwa and Lakhuwali

Envelope No.	Gohana (soil A)	Segwa (soil B)	Lakhuwali (soil C)
1	320/600=0.5	-	-
2	366/600=0.6	-	-
3	-	355/300=1.2	355/700=0.5
4	-	-	325/700=0.5
5	450/600=0.8	-	-

The average envelope and soil hydraulic gradient ratios (i_e/i_s) were observed to be in the range of 0.42-0.78 (Table 16). Since the hydraulic gradient ratios are less than one for all the tested materials, it seems that these materials can well serve as envelope materials. The test results also revealed that when no envelope material was used, sandy loam soil got eroded while there was no erosion of the clay soil from Segwa (Table 16).

On the basis of these recommendations, drainage systems were installed. Field assessment of the envelope material at Gohana revealed that drain pipes laid with the envelop material (d_{90}=320) had either no sediments or < 6mm thick layer (Table 17). It indicated that the envelope material functioned well.

In clay soils (Clay content >40 %) at Segwa, the sedimentation in drain pipes with and without envelop, after 1 year of installation showed that either no or < 5mm thick layer of sediments accumulated in the drain pipes (Table 18). Since it is within permissible limits and since the laboratory and field investigated results lead to the same recommendation, it could be concluded that there is no need of the enveloping material in clay soils with a clay content of more than 40%.

Table 16. Hydraulic gradient ratios for different envelope materials with different soils

Material	i_e/i_s ratio					
	Gohana - Soil A		Segwa - Soil B		Lakhuwali - Soil C	
	Range	Mean	Range	Mean	Range	Mean
Envelope 1	0.41-0.98	0.71	-	-	-	-
Envelope 2	0.40-1.30	0.76	-	-	-	-
Envelope 3	-	-	0.56-0.98	0.78	0.46-0.87	0.67
Envelope 4	-	-	-	-	0.22-0.53	0.42
Without Envelope	Soil eroded		No clogging		Soil eroded	

Table 17. Sediment thickness in exhumed drain pipes and envelope material at Gohana

Site number	Length of drain pipe	Soil retained (g m^{-1})		Sediment thickness in drain pipe (mm)
		Envelope	Drain pipe	
3	0.53	152	141	3.0
3	0.48	110	83	1.9
3	0.43	207	97	2.0
14	1.13	191	71	1.5
14	0.55	376	268	6.0
14	0.53	152	141	3.0

Table 18. Sediments in drain pipes at Segwa

Site number	Drain spacing (m)	Drain envelope	Siltation (g m^{-1})	Thickness of layer (mm)
E-1	30	No	8.4	Trace
E-3	30	Yes	Nil	Nil
E-4	30	Yes	Nil	Nil
E-5	60	No	Nil	Nil
E-6	60	Yes	198	4.0
E-7	60	Yes	323	5.0
E-10	45	Yes	Nil	Nil
E-11	45	Yes	15	Trace
E-13	45	No	Nil	Nil

5.8 Nutrient Management

In order to get maximum benefit from an engineering intervention, it must be followed by scientific crop management practices. Since, it is known that nutrient uptake under saline / sodic conditions is depressed, response of additional application of nutrients over and above the recommended doses in normal lands and/or application of some specific macro or micro-nutrient have been reported. In order to develop guidelines on the nutrient requirement of waterlogged saline lands of the Indo-Gangetic plains, several experiments were conducted at the Samlpa pilot area. Studies reveal that a dose of 150 kg N and 50 kg K ha^{-1} should be applied to wheat crop in saline soils (EC_e 8.5 and 6.2 dS m^{-1} at 0-15 and 15-30 soil depth, respectively) to get optimum and sustainable yield (Table 19). Since, for the normal lands of this region, recommended dose of nitrogen is 120 kg/ha, it appears that these soils require about 25 % more nitrogen than the normal lands.

Table 19. Yield of wheat crop (3 years average) under various nutrient application options

Treatment	Yield (t ha^{-1})	Treatment	Yield (t ha^{-1})
$N_{120}K_0$	3.95	$N_{100}P_0$	3.58
$N_{150}K_0$	4.40	$N_{100}P_{13}$	4.13
$N_{120}K_{50}$ b*	4.40	$N_{100}P_{26}$	4.34
$N_{120}K_{50}$ s**	4.51	$N_{150}P_0$	4.16
$N_{150}K_{50}$ b*	4.86	$N_{150}P_{13}$	4.65
$N_{150}K_{50}$ s**	4.95	$N_{150}P_{26}$	4.90

* Basal – Broadcast and mixed at sowing ,
** Split – Half basal + half top dressing before first irrigation.

5.9 Economic Viability

The cost of the drainage system varies widely depending upon many factors but mainly as a function of drain spacing and depth. Depending upon the drain spacing, it is expected to vary from Rs. 20,000 to about 35,000 per ha (1 US $=Rs. 43.50). The cost in seven pilots in Haryana varied from Rs. 18,000/- to Rs. 22,300/- per ha (Table 20). The various components of cost at 1994-95 prices and their relative proportion to the total cost are also shown in the Table. It could be seen that drainage material costs about 50 % of the total installation cost. In spite of the high cost, analysis of financial feasibility of the drainage systems have revealed that benefit-cost ratio is more than one and the internal rate of return is more than the interest being offered by the commercial banks on their term deposits (Table 21). Although drainage investments are the same, benefits at farmers field are much less because drainage is not being supported by the full package of land reclamation (Table 21).

5.10 Additional Benefits of Saline Land Reclamation

Reclamation of waterlogged saline lands besides resulting in direct benefits through increase in yield also helps to achieve the following benefits:

- It helps in generation of employment. As many as 118 to 303 man-days work per hectare is generated in installing a composite subsurface drainage system at a lateral drain spacing of 100 and 25 m.

Table 20. Drainage installation and land reclamation costs, per cost component, per hectare at 1994-95 constant prices

Cost component	Average cost (Rs.)	Relative cost (%)	Range (Rs.)	Remarks
Drainage installation costs	**20,000**	**68.7**	**18,060-22,310**	
Pipes	12,200	41.9	12,010-12,930	
Envelope material	2,870	9.9	1,660-4,750	depending on the material
Labour	4,930	16.9	4,400-5,980	
Connecting costs	**3,250**	**11.1**	**3,250**	
Sump	700	2.4	700	
Pump	800	2.7	800	
Pump house	500	1.7	500	
Connecting drain	1,250	4.3	1,250	
Land development	**3,370**	**11.6**	**1,250-5,890**	
Levelling and bunding	3,370	11.6	1,250-5,890	
Other costs	**2,500**	**8.6**	**2,500**	
Overhead	2,500	8.6	2,500	
Total investment costs	**29,120**	**100.0**	**25,820-33,870**	
Annual operation & maintenance	950	-	800-1,150	

Table 21. Economic feasibility of subsurface drainage

Economic criteria	Data sources for analysis	
	Scientific experiments (Sampla)	Farmers' fields (Sampla)
B-C ratio	3.99	1.26
NPW (Rs. ha^{-1})	7,500	4,659
IRR (%)	52.6	13.3

- Creates an environment conducive to human and animal health.
- Migration from the villages is halted. Social status of the farmers whose lands have gone out of cultivation is restored.
- Since the share of cost of pipes, envelope material, pump and connecting materials is estimated at 59% of the total cost (Table 20), drainage would provide a boost to the industrial sector and encourage rural based industries in the region.
- The drainage effluent in many cases is a good source of water to supplement the uncertain and limited canal water available in arid and semi-arid regions.

5.11 Recycling Drainage Water for Irrigation

Subsurface drainage projects in general improve the environment in the area serviced by them. At the same time, it is feared that some undesirable impacts at the downstream could be caused. Although in few cases, in the absence of appropriate precautions, it could happen but it is found that such fears emerge because the dimension of the heterogeneity of water quality is generally ignored. It is assumed that all drainage waters are of poor quality. Moreover, the change in water quality over the years is not taken into account in determining the reuse potential of drainage waters. In order to devise technologies for the reuse and disposal of drainage water, several experiments have been conducted. Following sections briefly reports the results of these experiments.

5.11.1 Quality of Drainage Water

During this period (1995-99), the salinity of drainage water at Sampla pilot, ranged between 9.6-10.6 dS m^{-1} while at Gohana, it was <5 dS m^{-1} (Table 22). The drainage water at Sampla had traces of iron, manganese, zinc, boron and nitrates. Absence of phosphorus, ammonical and nitrate nitrogen indicated little danger of groundwater pollution as a result of nitrate and phosphorus leaching.

Table 22. Average composition of drainage water at Sampla (1995-99) and Gohana (1999-2001)

Year	EC (dS m^{-1})	SAR $(mmoll^{-1})^{1/2}$	Cl ($meql^{-1}$)
		Sampla	
1995-96	10.6	10.1	140
1996-97	10.0	10.2	145
1997-98	9.6	11.5	122
1998-99	10.5	13.8	108
		Gohana	
1999-2000	4.8	7.5	45
2000-2001	4.5	8.0	40

5.11.2 Reuse of Drainage Water for Irrigation

The salinity of drainage water during the irrigation season ranged from 7.2 to 8.6 dS m^{-1} (SAR, 8.3 to 10.7). Wheat received 5 irrigation including a pre-sowing irrigation. The results indicated that pre-sowing irrigation with drainage water of 8.2 dS m^{-1} salinity decreased the straw and grain yield of wheat significantly (Table 23). Taking the wheat yield obtained with canal water as the potential (100%), the mean relative yield of wheat irrigated with only saline drainage water was 63%, whereas substitution of canal water for pre-plant irrigation and applying thereafter only saline drainage water, increased the yield to 92%. Alternate irrigation with canal and drainage and drainage and canal, resulted in 97 and 77% yield, respectively. The pooled data of several experiments were used to work out the response of wheat to drainage water quality (0.5 to 18.8 dS m^{-1}) with piece-wise linear regression. It revealed that the threshold salinity of water is about 4.0 dS m^{-1} beyond which the yield would decline by 1.82% for every unit increase in the salinity of drainage water. Similar information for sunflower and sorghum fodder is presented in Table 24 and 25. The data reveal that there is vast potential for use of saline water in the drained area. Use of saline drainage water for irrigation in different modes increased the soil profile salinity but the monsoon rains leached these accumulated salts out.

Table 23. Response of wheat to drainage water irrigation in different modes

Treatment		Grain yield (t ha^{-1})	Relative yield (%)
T_1	CW-CW-CW-CW-CW*	5.08	100
T_2	CW-DW-CW-DW-CW	4.95	97
T_3	CW-DW-DW-DW-DW	4.69	92
T_4	DW-CW-CW-CW-CW	4.51	84
T_5	DW-CW-DW-CW-DW	3.92	77
T_6	DW-DW-DW-DW-DW	3.20	63

*CW= Canal Water (EC_{cw} = 0.7 dS m^{-1}); DW = Drainage Water (EC_{dw} = 7.2-8.6 dS m^{-1})

Table 24. Grain yield (t ha^{-1}) of sunflower under different modes of irrigation

Treatment	Mode of application	Grain yield (t ha^{-1})	Relative Yield (%)
T_1	CW-CW-CW-CW-CW	2.81	100
T_2	CW-CW-DW-DW-DW	2.43	87
T_3	CW-DW-CW-DW-CW	2.30	82
T_4	DW-DW-CW-CW-CW	1.79	64
T_5	DW-CW-DW-CW-DW	1.75	62
T_6	DW-DW-DW-DW-DW	1.59	57

Table 25. Response of sorghum to drainage water and effect on the yield of succeeding wheat crop

Treatment	Green fodder yield (t ha^{-1})	Relative yield (%)	Wheat crop yield (t ha^{-1})
CW-CW-CW (T_1)	21.0	100	3.25
CW-DW-DW (T_2)	20.2	96	3.20
DW-DW-DW (T_3)	19.2	91	3.10

5.11.3 Long-term Effects on Soil Properties

Studies carried out under the project indicate that irrigation water containing salt concentration exceeding conventional suitability standards can be used successfully on many crops for at least

6-7 years without loss in yield. However, uncertainty still exists about the long-term effects of these practices on the quality of land resource. Adverse effects on soil could include increased soil dispersion, crusting, reduced water infiltration capacity and accumulation of toxic elements. The magnitude of these effects will however, depend on the quality of drainage water. Effects of irrigation with high salinity drainage water as available at Sampla site were monitored for several years on some soil properties. Leaching of salts by monsoon rains reduced SAR_e and the remaining SAR_e values did not cause any alkali hazard to the succeeding crops (Table 26). Similarly, no significant adverse effects were observed on saturated hydraulic conductivity and water dispersible clay after the monsoon rains. A slight decrease in hydraulic conductivity after monsoon leaching should not pose a problem during the irrigation season since the negative effects of high SAR of drainage water is offset by the high salinity of the drainage water. No variation in water dispersible clay after 6 years of irrigation with drainage water (slight variation at high salinity levels) indicates minimum structural deterioration in soils irrigated with high salinity drainage water. Although, no potential adverse effects were observed in these studies at Sampla site, it is advisable to evaluate this issue at few more sites before devising appropriate guidelines.

Table 26 Physico-chemical characteristics of drained soils with and without reuse of saline drainage effluents

Irrigation Water ($dS\ m^{-1}$)	EC_e ($dS\ m^{-1}$)	SAR_e ($mmol\ l^{-1})^{1/2}$	Hydraulic conductivity ($mm\ h^{-1}$)	Water dispersible clay (%)
Canal water (0.6-0.7)	1.5	2.4	9.6	4.8
Saline drainage effluent (6.0-18.8)	2.7	4.9	9.3	4.8

Note : All values after 6 monsoon seasons.

5.12 Disposal of Drainage Water (Evaporation Pond)

Disposal of saline drainage effluent, a by-product of this intervention, is said to cause environmental degradation at the point of disposal. Although alternate strategies on reuse of drainage effluent are being developed (see section 5.11), yet a fraction of the drainage effluent must be disposed off out of the region to achieve favourable salt balance in a region. In the land locked areas of north-west India, disposal through evaporation ponds seems to be an appropriate means to avoid environmental degradation.

A desk study to determine the size of the evaporation pond was conducted using the water balance approach. Glover -Dumm equation was used to assess the daily discharge from the drains installed at 1.25m depth with a drain spacing of 66 m. Based upon the inflow and outflow components, the required size of the evaporation pond to meet the design criterion came out to be 10, 13 and 18% of the drained area for below normal, normal and above normal rainfall years. The average drainage rate (Annual basis) for these years was found to be 0.60, 0.72 and 1.10 mm day^{-1} respectively. As evaporation pond needs to be designed for the most critical period that is above normal rainfall year, the size of the evaporation pond for semi-arid regions with an average annual rainfall of 600-700 mm should be about 18.0 % of the drained area.

Amongst the various management options that can be adopted to reduce the area under the evaporation pond, two are considered appropriate. The first is an operational strategy, which comprises of shutting the pump operation from a pre-decided month in the winter season. The second is the reuse strategy in which evaporation pond water is pumped to irrigate the *rabi* crops. It may be seen that by adopting either one or the other or both the strategies, some reduction in the area can be achieved (Table 27). In the below normal rainfall year whether we use reuse strategy alone or both, a minimum area of about 5 % of the drained area would be required to store water during the monsoon season.

Table 27. Area under evaporation pond with various options of closure of pumping or reuse for 3 selected years at Sampla

Particulars	Required size of the evaporation pond (% of the drained area)		
	Below normal rainfall year	Normal rainfall year	Above normal rainfall year
Free flow conditions throughout the year	10.2	13.0	18.7
Closure of pumping from February to June (b)	7.8	9.6	16.9
Reuse for 4 irrigation equivalent in *rabi* season (c)	4.8	6.9	13.1
Combination of (b) and (c)	4.8	5.7	11.6

5.13 Surface Drainage Requirement of Crops

Effect of water stagnation on the yield of 6 crops was investigated. The data in general reveal that water stagnation for more than one day is harmful to various crops (Table 28). It has also been observed that the adverse effects of water stagnation are relatively more in case water stagnation occurs at the early growth stages than at the later. The general pattern of Oxygen Diffusion Rate (ODR) depletion following water stagnation showed that it decreased with increasing duration of water stagnation and increased with increasing duration following water stagnation. Almost similar results were obtained for Redox Potential (RP), which also decreased with increasing duration of water stagnation and increased with increasing duration following water stagnation. It is believed that poor aeration due to water stagnation and imbalance in the nutrient uptake might have caused yield reduction of the crops. Several other factors such as reduced root growth, ionic imbalance and/or nutrient stress might have contributed to the overall decline in the yield.

It has been shown that by applying additional nitrogen following the water stagnation can mitigate adverse effects of short-term water stagnation. The data set in respect of two crops reveal that increasing the rate of top-dressed urea- N from 80 to 100, 120 and 140 kg ha^{-1} in the case of sorghum significantly increased the grain yield in treatment with 4 days of water stagnation (Table 29). More than 37 % increase in the grain yield was achieved by additional application of N over the conventional dose of nitrogen. Similarly, increasing the rate of N from 80 to 90, 100 and 110 kg/ha significantly improved the grain yield of sunflower (Table 28). Water stagnation for 4 days decreased the grain yield by 12.9% which was offset by 7.4, 10.8 and 12.5%, with additional doses of N (Table 29).

Table 28. Response of various crops to short-term water stagnation

Duration of water stagnation (days)	Grain yield (t ha^{-1})					
	Mustard	Sorghum	Pigeon pea	Sunflower	Barley	Berseem (Seed)
Drained	1.43 (100)	4.11 (100)	1.41 (100)	1.86 (100)	3.65 (100)	0.48 (100)
1	1.31 (93)	4.03 (98)	1.35 (96)	1.62 (87)	3.52 (96)	0.47 (98)
2	1.20 (84)	3.73 (91)	1.22 (87)	1.50 (81)	3.39 (93)	0.38 (79)
4	1.12 (78)	3.48 (85)	1.16 (82)	1.38 (74)	3.18 (87)	0.31 (65)
6	1.02 (71)	3.30 (80)	1.11 (79)	1.29 (69)	2.75 (75)	0.25 (52)
CD (p=0.05)	0.22	0.11	0.13	0.06	0.28	0.045

Values in parenthesis are the relative yield

Table 29. Grain yield (t ha^{-1}) as affected by additional application of urea-N in sorghum and sunflower

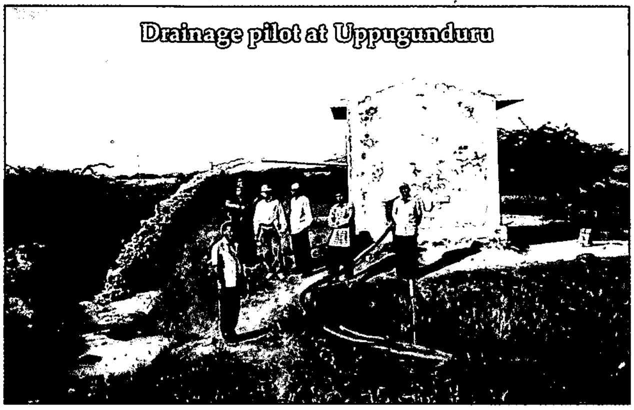
Treatments	Sorghum yield (t ha^{-1})			Sunflower yield (t ha^{-1})		
	grain	% decrease/ increase over F_1	% increase over F_2	Grain	% decrease over F_1	% increase over F_2
F_1, Control	4.37	-	-	2.02	-	-
F_2, stagnation of 4days +80 N	3.24	(-) 25.85	-	1.76	12.9	-
F_3, 4days+100N	3.69	(-) 15.56	13.88	1.89	6.4	7.4
F_4, 4days+120N	4.11	(-) 5.94	26.85	1.95	3.5	10.8
F_5, 4days+140N	4.45	(+) 1.83	37.34	1.98	2.0	12.5
CD at (p=0.05)	0.12	-	-	0.10		

Note: In the case of sunflower urea-N was 90, 100 and 110 in the last three treatments

Although these results suggest that increasing the rate of top-dresses urea N helps to alleviate the adverse effects of temporary water stagnation, it seems that such a strategy can neither be adopted on a large-scale nor is a long-term solution to the problem. Besides, it would lead to goundwater pollution and other adverse environmental impacts. As such, improved surface drainage would be essential for areas with monsoon climate. Overall results revealed that an integrated drainage system consisting of surface and subsurface drainage would be the most cost-effective and eco-friendly solution to the problems of waterlogging and soil salinity.

6. ESTABLISH, MONITOR AND EVALUATE PILOT AREAS AT KONANKI AND UPPUGUNDURU IN NAGARJUNA SAGAR AND WESTERN KRISHNA DELTA COMMANDS, ANDHRA PRADESH (ANGRAU)

6.1 Introduction



As in many canal command areas in India, there has been a rise in the groundwater table and consequent degradation of land through waterlogging and secondary salt build-up in most irrigation commands in Andhra Pradesh. Of the total geographical area of 274.4 lakh ha of the state, 57.7 lakh ha is irrigated and 3.4 and 8.1 lakh ha are waterlogged and salt-affected respectively (Table 30). In the canal commands alone the areas affected by waterlogging and salinity are estimated to be 2.7 and 1.2 lakh ha, respectively. The waterlogged area in few important irrigation projects in the state is reported in Table 31. Except for the Nagarjuna Sagar Left Bank canal, the affected area in the others 4 commands equals or exceeds 15% of the total CCA.

Table 30. Irrigation status of Andhra Pradesh

Particulars	Area (lakh ha)
Total geographical area	274.4
Total cultivable area	93.0
Area under irrigation	
-Canals	22.1
-Tanks	7.2
-Tube wells	14.4
-Other wells	11.5
-Other sources	2.5
-Total	57.7
Waterlogged area	3.4
Salt-affected area	8.1

In order to suggest location specific solutions for combating waterlogging and salinity problems in Nagarjunasagar Sagar Right Canal Command (NSRCC) and Krishna Western Delta (KWD), an Operational Research Project has been established at Bapatla. As a part of the operational research, a pilot area of 21.6 ha has been selected near Konanki village in Prakasam district within NSRCC.

Table 31. Area waterlogged (Depth to water table 0-2 m bgl) in five irrigation projects in Andhra Pradesh

Name of the project	Year of commencement	Area waterlogged (,000 ha)	CCA (,000 ha)	Percentage area waterlogged to CCA
1. Sriram Sagar	1976	75.6	270	28
2. Nagarjuna Sagar Left Bank Canal	1969	19.8	395	5
3. Nagarjuna Sagar Right Bank Canal	1969	114.0	475	24
4.Tungabhadra	-	57.0	300	19
5. Krishna Delta	1957	73.5	490	15
Average waterlogged				18

The pilot area is affected with problems of waterlogging (depth to water table in the range of 0 to 3.74 m), salinity and sodicity (EC_e, 1.3 to 30 dS m^{-1}; pH 7.2 to 10.0; ESP 14.1 to 54.6). Water table generally remain at the ground surface during the monsoon (crop) season. Because of the problems of waterlogging, salinity and sodicity, poor yields of paddy crop (average of 2.61 t ha^{-1}) are recorded. There are 37 farm holdings in this pilot area ranging in size between 0.1 to 1.4 ha. The average annual rainfall in the NSRCC command area is 850 mm. The monthly rainfall and evaporation in the command area are presented in Fig. 6. Apparently, the rainfall is more than the evaporation during August to November while evaporation exceeds the rainfall during the remaining part of the year.

Another pilot area of 21 ha was selected near Uppugunduru village under Krishna-Western Delta. This pilot area is also affected by waterlogging and salinity problems. Paddy is grown during monsoon season. However, very low yields varying between 1.9 to 3.0 t ha^{-1} are observed. Both the pilot areas are mostly mono-cropped and are kept fallow after paddy.

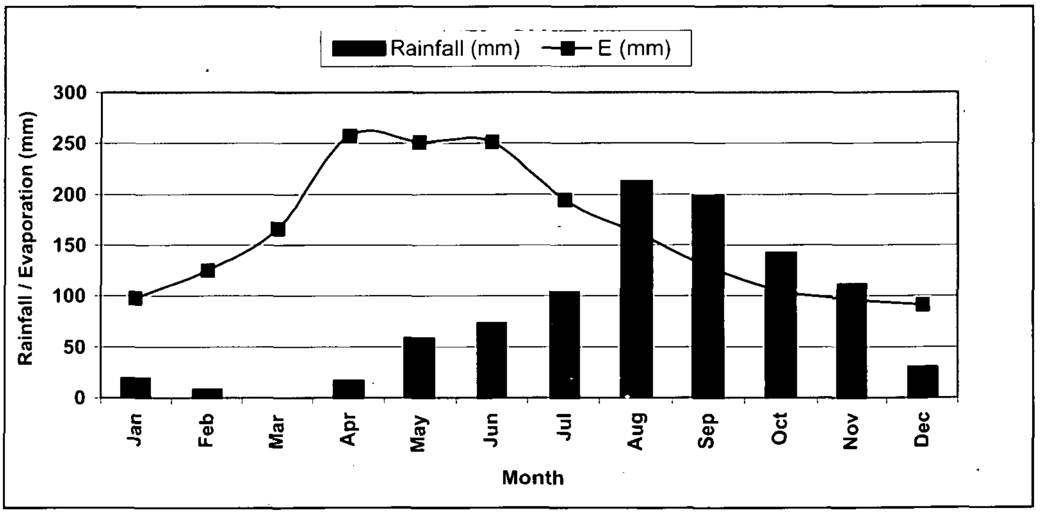


Figure 6. Average monthly rainfall and evaporation in the command

6.2 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 waterlogging and secondary salt build-up.

The hydrograph of a well showing groundwater table fluctuations in an observation well near Konanki pilot area indicate that the water table is with in 0.6 m below the ground surface towards the end of the monsoon season and goes deeper but remain less than 2 m deep at the beginning of the monsoon period (Fig. 7).

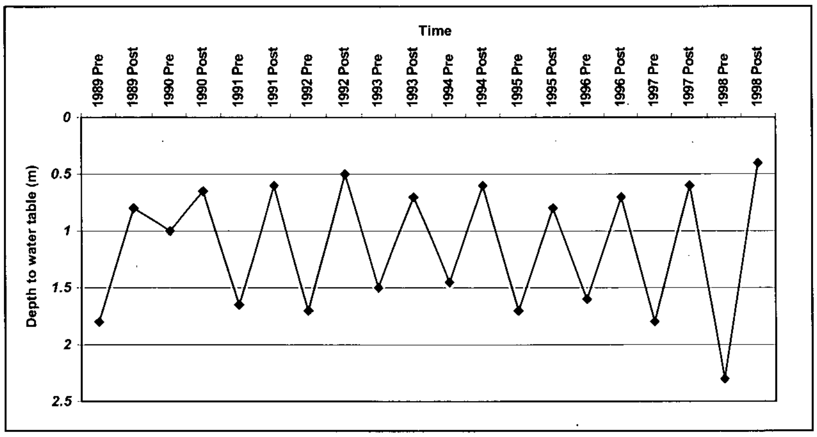


Figure 7. Pre and post monsoon water table fluctuations in an observation well near Konanki pilot area under NSRCC

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:

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

6.3 Packages to Combat Waterlogging and Soil Salinity

6.3.1 Pre- drainage Investigations

The drainage investigations in the pilot areas have led to the fixation of several design parameters for the drainage systems (Table 32).

Table 32. Results of pre-drainage investigations

Parameters	Konanki pilot area		Uppugunduru pilot area	
Hydraulic conductivity (m day^{-1})	0.2		0.43	
Rainfall (mm)	800 - 900		900 - 1100	
Hydraulic head above the drains (m)	0.40		0.30	
Depth to water table (Sep'97-Sep'98) (m)	0.0-3.74		0.0-2.04	
Depth to impervious layer (m)	9		10	
pH	7.7-10.3		7.9-8.5	
EC (dS m^{-1})	0.6-18.2		1.1-49.5	
Soil texture	Sandy clay-clay loam		Sandy clay loam	
SAR (mmol l^{-1}) $^{1/2}$	2.3-108.1		1.4-51.9	
ESP	14.1-54.6		--	
CEC (meq/100g)	5.8-36.6		--	
Cropping pattern	Rice		Rice and fodder crop with poor performance	
Cropping intensity (%)	70		130	
Varieties adopted	NLR-T-145		NLR series	
Method of irrigation	Wild flooding		Wild flooding	
Weed control	Manual		Manual	
No. of farmers	30		41	
Literacy (%)	men	women	men	women
-illiterates	36	58	32	54
-primary	20	11	32	24
-secondary	40	24	27	20
-college	4	7	9	2
Caste composition (%)				
-Other castes	40		77	
-Backward castes	39		21	
-Schedule castes /tribes	21		2	
Average farm size (ha)	0.54		0.49	
Average family size (No)	4		4	
Land value (Rs. ha^{-1})	41,000		1,13,000	
Paddy yield (t ha^{-1})	2.7		3.6	

6.3.2 Design and Construction of Drainage Systems

Konanki pilot area: The pre-drainage investigations, discussions with farmers and the field visits to the pilot area led to a decision to construct a horizontal subsurface drainage (SSD) system. It was decided to construct SSD in the central section (8 ha) and an open subsurface drainage system in the northern section (5 ha) of the pilot area. It was also decided to leave the remaining area untreated as either it did not require artificial drainage or was unsuitable to drainage (Fig. 8).

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 pilot area, the drainage coefficient is estimated as 2 mm day^{-1}. Based on the parameters determined during pre-drainage installations (Table 32), the spacing of drains and the sizes (diameters) of the

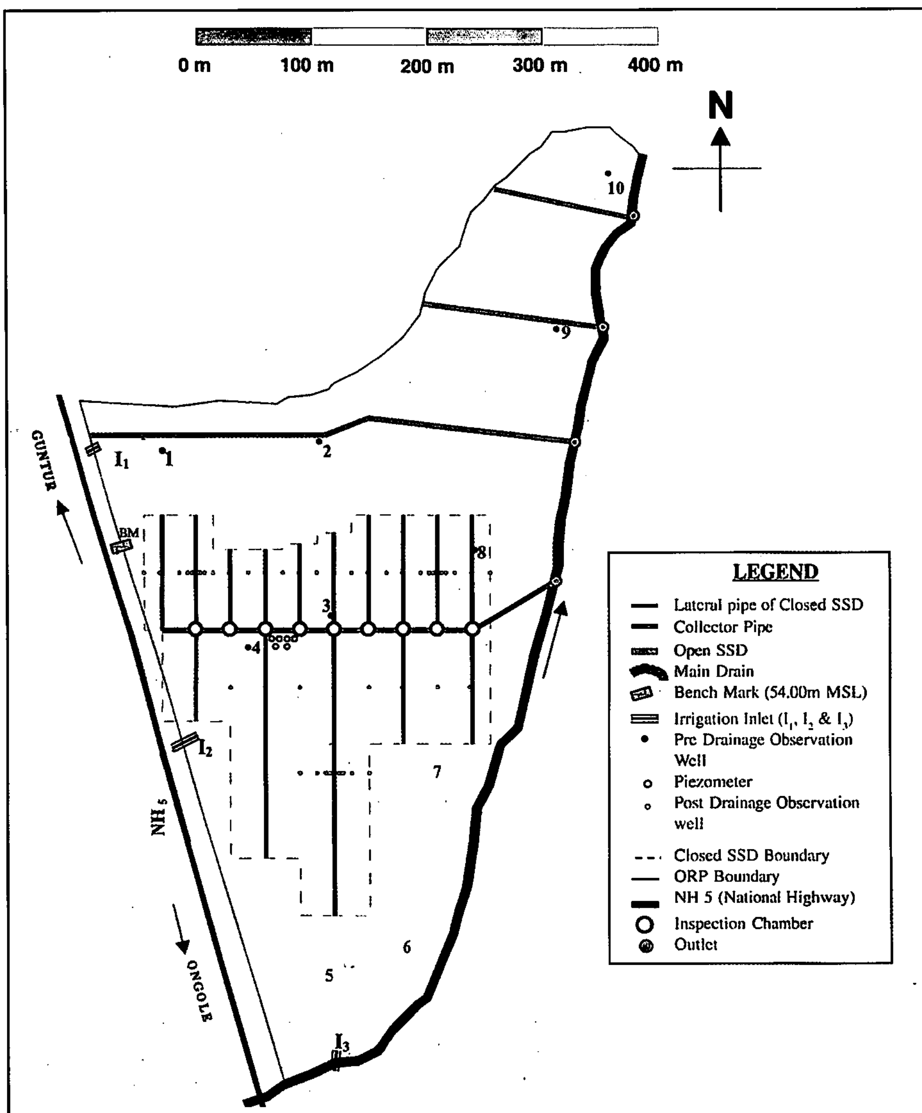


Figure 8. Layout of the subsurface drainage system in Konanki pilot area

lateral and collector pipes were calculated. The values selected / calculated for various parameters considered in the design and specifications of the materials used are given in Table 33.

Table 33. Details of subsurface drainage systems in the pilot areas

Serial No.	Particulars	Konanki		Uppugunduru	
		Closed system	Open system	Closed system	Open system
1	Area (ha)	8	5	7	5
2	Year of installation	1999	1999	1999	1999
3	Type of system	Composite	Singular	Composite	Composite
4	Spacing (m)	30 and 60	100	30, 45 and 60	50
5	Drain depth (m)	0.9 to 1.1	1	1.2 to 1.35	1
6	Lateral pipe drain	Diameter 0.08 m Slope 0.1 to 0.2%	-	Diameter 0.08 m Slope 0.1%	-
7	Collector pipe	Diameter 0.16 m Slope 0.6%	-	Diameter 0.16 m Slope 0.14%	-
8	Envelope material	Geo textile and Nylon mesh	-	Geo textile and Nylon mesh	-
9	Inspection chambers	Total No. 9 Depth 1.8 m Diameter 0.75 m		Total No. 7 Depth 1.8 m Diameter 0.75 m	
10	Sump cum inspection chamber	-	-	Total No. 1 Depth 2.4 m Diameter 1.2 m	
11	Dimensions of open drains	-	Bottom width 0.4 m Side slope 1:1		Bottom width 0.4 m Side slope 1:1
12	Type of outlet	Gravity	Gravity	Pumped	Pumped
13	Method of installation	Trencher and manual labour	Trencher and manual labour	Trencher and manual labour	Trencher and manual labour

In May 1999, a closed subsurface drainage system was installed with a layout of a grid iron pattern. On the northern side of the collector drain, ten pipe drains at a spacing of 30 m and on the southern side, five pipe drains at 60 m spacing (for sensitivity analysis) were installed at a depth varying from 0.9 to 1.1 m below the ground surface. Flexible, corrugated, perforated PVC pipes of 0.08 m diameter with 6 rectangular openings of 5x1.3 mm size in each cross-section on the periphery were used as laterals. 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 envelop material of 60 mesh) were used. Blind PVC pipes of 0.16 m diameter were used in the construction of collector drain.

An open drainage system with three drains of 1 m depth at a spacing of 100 m was constructed in the northern part of the pilot area. The topography of the pilot area permitted gravity outflow to dispose off the drain water into the natural drain, which flows north at the eastern side of the pilot area (Fig. 8).

Uppugunduru pilot area: Based on the pre-drainage investigations, open and pipe subsurface drainage systems were designed and laid in the Block III (Eastern part) and Block I (Western part), respectively (Fig. 9). The design parameters and specifications of materials used are given in the Table 33.

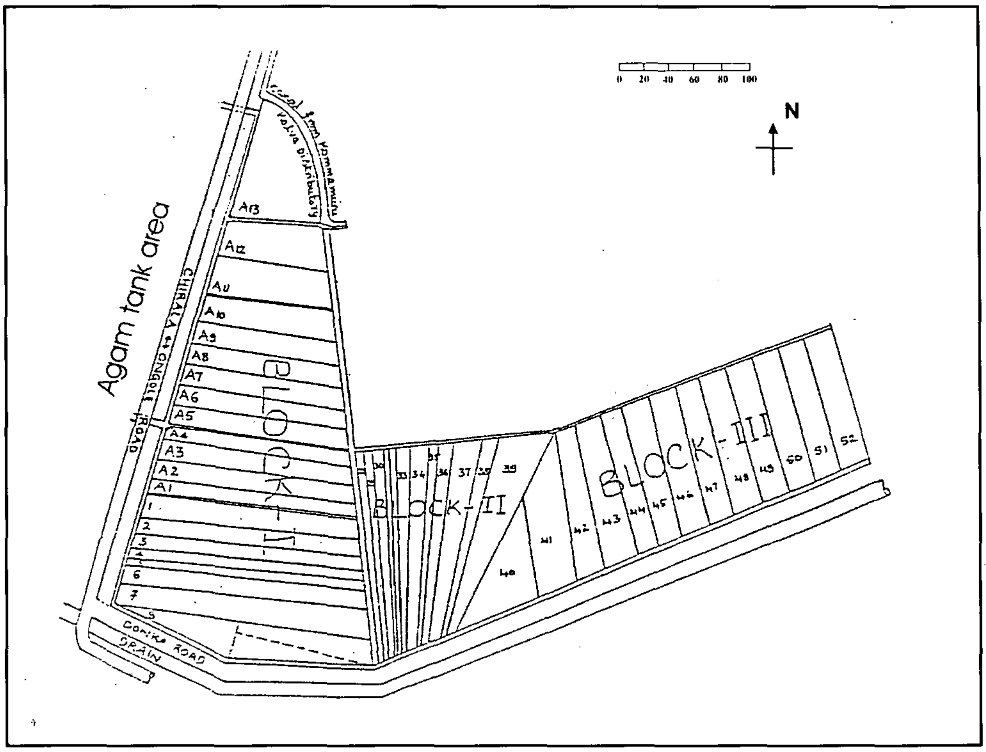


Figure 9. Layout of the subsurface drainage system in Uppugunduru pilot area

Three different spacing (30, 45 (designed) and 60 m) were adopted with two types of envelope materials namely geo-textile (synthetic material, 2.6 mm thick with O_{90} value of 300 microns) and nylon mesh with the same specifications as in the case of Konanki pilot area. A composite parallel system with 10 lateral drains for draining water from one side into the collector was designed and laid in an area of 7 ha. The first 4 laterals were spaced 30 m apart followed by 45 and 60 m spacing between subsequent 3 laterals each. The 1st, 3rd, 4th, 6th and 9th laterals from the left hand side were enveloped with nylon mesh and the remaining laterals were enveloped with geo- textile. Seven inspection chambers were constructed at several junction points with RCC rings of 0.75 m diameter and 0.3 height. A big sump cum inspection chamber was constructed at the end of the system where lateral No. 10 joins 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 subsurface drainage system with four open drains at a spacing of 50 m was constructed initially in the year 1999 in the Block I (3.65 ha). The system was extended to bring another 1.35 ha under reclamation in the year 2000. Because of existence of open drains at a lower level than the drain leading into the natural drain, a pumped outlet was constructed near the open subsurface drainage system also to dispose off the collected drain water into the natural drain. At both the sites, a semi-mechanical method of construction was adopted using a poclain, tractor-operated blade and manual labour.

6.3.3 Post-drainage Investigations

The depth to water table was measured to assess the effect of drainage on waterlogging in the area. The discharge from the laterals and outlet of closed system and the open drains were measured daily to evaluate the performance of drainage systems and to estimate the quantity of water drained and salts leached out of the pilot area. The data from peizometers were also collected daily to see the upward seepage/ downward movement of water in the groundwater reservoir.

Soil samples were collected from three depths (0-20, 20-50 and 50-100 cm) at 60 points covering the entire pilot area and holdings of all the farmers. Samples were analysed for pH, EC, gypsum requirement, SAR, and all important anions and cations. Surface soil samples collected during summer –1999, 2000 and 2001 were analysed for pH and EC. Maps were drawn to observe the changes in pH and EC before and after the installation of the system. Water samples collected from ten observation wells, six piezometers, inlets, outlet and laterals at fortnightly interval were analysed for pH, EC, cations and anions. The performance of drainage systems on rice crop yields before and after installation of drainage systems was evaluated based on the crop cutting data. A brief comparison of purposes and costs of packages adopted in pilot areas is given in Table 34.

Table 34. A comparison of packages to combat waterlogging and salinity

Serial No.	Package		Purpose	Unit cost (Rs ha^{-1}) Konanki	Unit cost (Rs ha^{-1}) Uppugunduru
1	Open drainage system		Control of waterlogging and soil salinity by removing drainable surplus	3,600	7,700
2	Pipe drainage system		Control of waterlogging and soil salinity by removing drainable surplus		
	Spacing & Envelope material				
	60 m	Geo textile		18,200	21,300
		Nylon mesh		17,100	17,300
	45m	Geo textile		-	28,300
		Nylon mesh		-	22,500
	30m	Geo textile		30,300	37,800
		Nylon mesh		28,100	29,800
	Equipment for disposal of collected drain water			(Gravity outlet)	20,800 (For 1 pumping unit)
3	Amendments				
	Gypsum		Reclamation of sodic soils	1,250	—
	Green manuring		To improve the soil physical properties	340	—

6.4 Benefits of Drainage

The analysis of data collected from open and closed subsurface drainage system (OSSD and CSSD) are presented to highlight various issues for both the pilot areas in order to clearly bring out the benefits of drainage.

6.4.1 Konanki Pilot Area

The average water table depth under CSSD and OSSD systems are presented in Table 35 and Fig. 10 respectively showing a fall in the water table. The performance of drainage system in reducing soil salinity (Table 35 and 36), on rice crop yield before and after installation of drainage system (Table 35) and economic parameters (Table 37) was evaluated. The benefit-cost analysis indicated that the B-C ratio is 2.82 and the investments could be realized in a period of three years (Table 38). Farmers could realize Rs. 0.81 per rupee investment, which was only Rs. 0.05 before the system was installed.

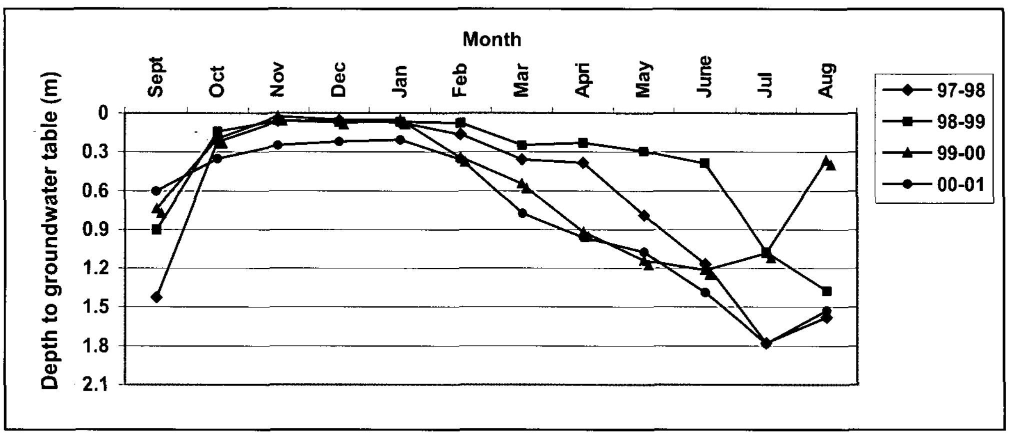


Figure 10. Yearly groundwater table fluctuations at Konanki pilot area

Table 35. Changes in hydrological parameters, soil salinity and crop yield at Konanki due to pipe drainage system

Particulars	Control		Pipe drainage system			
			30 m spacing		60 m spacing	
	Pre	Post	Pre	Post	Pre	Post
Water table (m)	0.4	0.56	0.03	0.12	0.24	0.32
Drain discharge (mm day $^{-1}$) for the year 2000-01				0.71		1.14
Drain discharge quality (dS m $^{-1}$)				1.30		2.36
Soil EC_e (dS m $^{-1}$)	3.11	3.10	4.00	2.60	7.50	3.00
Yield (t ha $^{-1}$)	3.10	4.10	3.52	5.53	3.86	5.73

Table 36. Area under different EC classes (%) over years in pilot area at Konanki

Range ($dS\ m^{-1}$)	Year		
	1999	2000	2001
0-2	25	40	46
2-4	44	35	40
4-8	20	23	12
8-12	4	2	2
>12	7	—	—

Table 37. Changes in economic parameters due to pipe drainage system

Particulars	Control		Pipe drainage system	
	Pre	Post	Pre	Post
Cropping intensity (%)	75.1	72.5	70.3	96.0
Land value ($Rs\ ha^{-1}$)	42,500	60,150	41,250	1,25,000
Fodder quality	Red	Red	Red	Normal
Time variation in land preparation ($hr\ ha^{-1}$)	7.5	7.5	7.5	3.5

Table 38. Economic analysis of pipe drainage system with 60 m spacing at 10 % discount rate for 30 years life of the system

Particulars	Konanki
B-C Ratio	2.82
NPW(Rs)	36,655
IRR	32
Payback period (years)	3

6.4.2 Uppugunduru Pilot Area

The reduction in average water table depth from ground surface at the pilot area under CSSD and OSSD system areas are presented in Table 39 and Fig. 11. The water table during the cropping season begining October is deeper during post drainage period as compared to pre-drainage period. The performance of drainage system in reducing soil salinity (Table 39 and 40), in increasing rice crop yield after installation of drainage system (Table 39) and economic parameters (Table 41) was evaluated based on the crop cutting data. The benefit-cost analysis of paddy crop indicated that the B-C ratio is 2.54 and the investments are realized in a period of three years (Table 42).

6.5 Supplementry Measures

6.5.1 Gypsum Application

Apart from the drainage pilots, experiments to work out the gypsum requirement of soils were

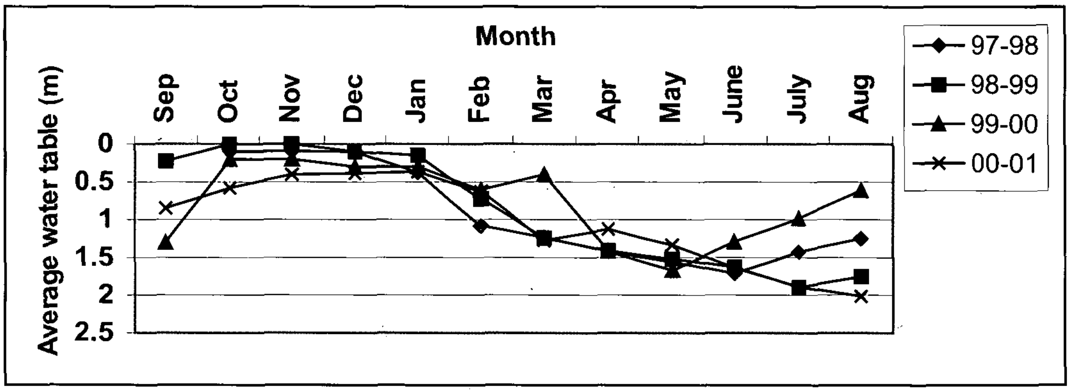


Figure 11. Yearly groundwater table fluctuations at Uppugunduru pilot area

Table 39. Changes in hydrological parameters, soil salinity and crop yield at Uppugunduru

Particulars	Control		Pipe drainage system					
			30 m spacing		45 m spacing		60 m spacing	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Water table (m bgl)	0.54	0.70	0.5	0.75	0.44	0.67	0.46	0.53
Drain discharge (mm day $^{-1}$) for the year 2000-01	-	-	-	1.57*	-	1.01*	-	0.56*
Drain discharge quality (dS m^{-1})	-	-	-	6.6	-	3.7	-	14.2
Soil EC_e (dS m^{-1})	28.0	25.5	4.7	2.6	3.9	2.2	3.5	1.5
Yield (t ha^{-1})	3.20	4.70	4.50	5.60	4.50	5.80	4.50	5.11

The discharges are calculated for the duration equal to hours of pumping (average of 4 hrs/day)

Table 40. Change in area under different EC ranges in the pilot at uppugunduru

Range (dS m^{-1})	Year		
	1999	2000	2001
0-2	28	67	78
2-4	30	21	12
4-8	5	10	8
8-12	3	2	2
>12	3	—	—
>16	31	—	—

conducted for the reclamation of alkali soils by applying gypsum based on soil testing (25 %, 50% and 100% gypsum requirement + FYM). Maximum grain yield was recorded in a treatment, which received 50 % GR based on soil tests (Table 43). A field study was also conducted in sodic/saline soils of the Konanki pilot area to screen suitable rice varieties for sodic soils, which revealed that MTU-4870 and NLR-33641 cultivars give superior grain yield, which was on par with NLR-T-145 (local check).

Table 41. Changes in economic parameters due to pipe drainage system

Particulars	Control		Pipe drainage system	
	Pre	Post	Pre	Post
Cropping intensity (%)	115	125	130	170
Land value (Rs ha^{-1})	75,000	1,25,000	12,500	2,50,000
Fodder quality	Oily	Oily	Oily	Normal

Table 42. Economic analysis of pipe drainage system with 60 m spacing at 10 % discount for 30 years life of the system

Particulars	Uppugunduru
B-C ratio	2.54
NPW(Rs.)	50,872
IRR	36
Payback period (years)	3

Table 43. Crop yield as affected by gypsum treatment

Parameter	50% gypsum application	Control
Yield (t ha $^{-1}$)	4.2	2.8
Price of paddy (Rs)	22,400	14,933

6.5.2 Introduction of Green Manure Crop in the Pilot Areas

The green manure crop like *dhaincha* has been introduced as second crop after the reclamation of the sodicity/salinity problem, which will also facilitate the introduction of income generating pulse crops like black gram and green gram in the pilot area.

6.6 Socio-economic and Gender Studies

Socio-economic including gender studies were conducted in both the Pilot Areas. All 30 farmers of the Konanki and 41 farmers of the Uppugunduru pilots, including the women, participated in the surveys. Farmers in both the pilot areas are poor with an average farm size of 0.54 ha in Konanki and 0.49 ha in Uppugunduru. They are poorly educated with an illiteracy of about 34% for the men and 56% for the women (Table 44). In Konanki, only 11% of the farmers own the land against 51% in Uppugunduru. Farmers in Konanki are younger (age group 32 to 45 years) compared to the farmers in Uppugunduru (age group 55 to 65 years).

6.6.1 Farmers Attitude to Drainage

The attitude of the farmers and farm women was analyzed by conducting base line survey on socio-economic and gender aspects at both the Konanki and Uppugunduru pilot areas. This survey helped to understand the attitude of the farmers and farm women towards new technology. The main observation of the base line survey has been that all the farmers fully agreed that their lands need to be treated with drainage to overcome waterlogging and salinity problems.

Table 44. Literacy level (%) of the respondents in the pilot areas

Education level	Konanki		Uppugunduru	
	M	F	M	F
Illiterate	36	58	32	54
Primary (1 to 7 St.)	20	11	32	24
Secondary (8 to 12 St.)	40	24	27	20
Diploma and above	4	7	9	2

Important observations following installation of the subsurface drainage systems are:

- Farmers were fully convinced that drainage technology brings prosperity as technology has increased the yields considerably after system installation. More than 60% of the farmers indicated that the increase in income was due to the positive effects of the installation of subsurface drainage, although it was also opined that improved weather conditions (31%) and better crop management (21%) also played an important role in increasing yield.
- The improvement in land quality was experienced by all the farmers.
- All the respondents agreed that cropping intensity and yields increased, quality of fodder improved as a consequence of improvement in waterlogging and salinity conditions.
- Asset value increased by 175 %.

6.6.2 Impact Analysis of Subsurface Drainage

Four years after the implementation of subsurface drainage, a survey was conducted in and around Konanki and Uppugunduru to assess farmer's views on the technical feasibility, economic viability and perceptions towards subsurface drainage. The survey revealed that:

- Farmers are convinced that drainage acts as a tool to reclaim waterlogged and salt-affected soils as they have experienced direct and indirect benefits like improvement in land and fodder quality, cropping intensity, reduction in cost of cultivation and increase in crop yields.
- Farmers favour installation of SSD on a large scale.
- Farmers feel that there is a need for Government intervention in solving the problems.
- Farmers are willing to participate in future drainage projects, but expect that a fair share of the costs is paid by the Government.

- Farmers understood fully that the operation and maintenance and pumping of drainage effluent is a collective activity in which they have to cooperate among each other.
- Farmers are willing to take up the operation and maintenance of the field drainage systems, but feel that the maintenance of main drains is the responsibility of the government.

6.6.3 Labour Requirements for Paddy Cultivation

Both the male and female farmers spent 6 to 7 hours per day on farm related works. The men are mainly engaged in irrigation (33% of their time), winnowing (23%) and the women in planting (31%), weeding (42%) and harvesting (15%). Of all the activities related to paddy production, 75% of the labour input is provided by the women. The introduction of subsurface drainage resulted in a significant reduction in labour input (11 to 25%). As a result, the women benefited the most. Although more time was needed for harvesting (5 days ha^{-1}), considerable savings (35 days) in labour input could be obtained in activities like planting, weeding and winnowing etc. (Fig. 12).

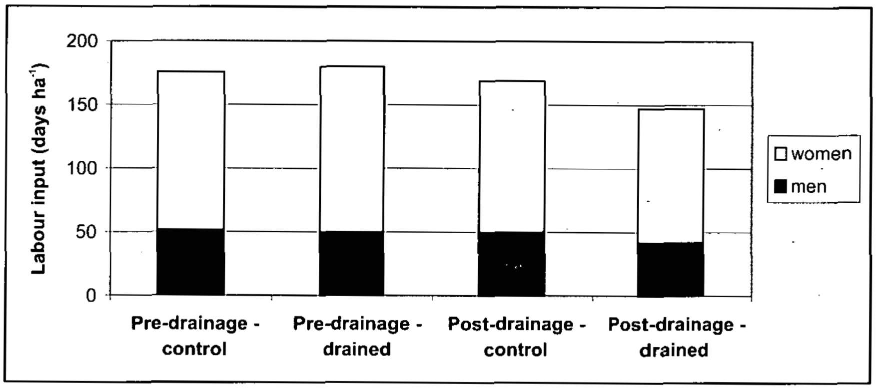


Figure 12. Pre and post-drainage labour input for paddy cultivation

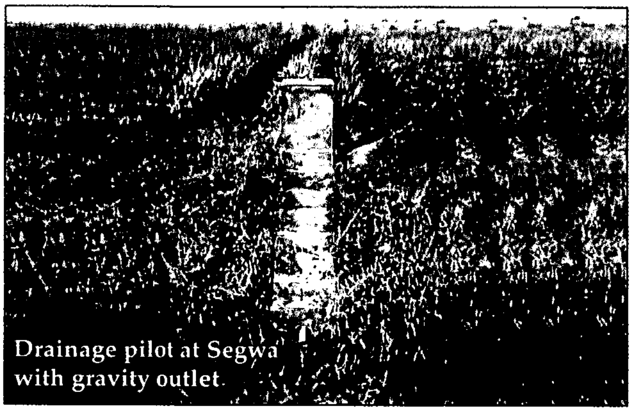
6.6.4 Gender Issues

A survey on gender related issues indicated the following:

- Women access to agricultural information through TV and radio is very low (< 7%).
- All women know about the problems of salinity and waterlogging, most of this knowledge was obtained through their own assessment (80%), discussions with husbands (66%). Only a minority coupled this to disparity in yield (16%).
- Women perception towards technology has changed positively.
- Knowledge on waterlogging and salinity consequences like effects on yield, farm income and standard of living has increased among women.
- The drudgery of women in agricultural operations has considerably reduced.
- The farm women preferred more and more interactions with scientists as it helped to address some of their farm and home management problems.

7. ESTABLISH, MONITOR AND EVALUATE PILOT AREAS AT SEGWA AND SISODARA IN UKAI-KAKRAPAR COMMAND, GUJARAT (GAU)

7.1 Background Information



Drainage pilot at Segwa with gravity outlet.

The state of Gujarat, situated on the West Coast of India has a total geographical area of about 196 thousand sq km with an average population density of 174 per sq km. The state has about 25 major irrigation projects of which 6 are situated in South Gujarat, 7 in middle Gujarat, 8 in North Gujarat and 4 in Saurashtra. The Mahi-Kadana Project on river Mahi in middle Gujarat with a CCA of 2.6 lakh ha and Ukai-Kakrapar Project on river Tapi in South Gujarat with a CCA of 3.31 lakh ha contribute to the bulk of canal command area in the state. Apart from this, the proposed Narmada Project will bring an additional area of about 18 lakh ha under irrigation. In South Gujarat, the canal irrigation contributes to about 80 per cent of the irrigated area while in middle Gujarat it is around 50 per cent. In Saurashtra region, its contribution to total irrigated area is less than 10 per cent. In South Gujarat, Ukai-Kakrapar is the biggest multi-purpose project. Geographically, this area lies between 20^0 34′ E to 21^0 29′ E latitude and 72^0 34′ N to73^0 20′ N longitude Climatically, southern part of the command falls under sub-humid and the northern part in semi- arid zone. The mean annual rainfall in the corresponding parts is 1500 and 850 mm.

The major problem in canal command of Ukai-Kakrapar is the rising water table resulting in considerable area as waterlogged. The high water table and waterlogged conditions exists more in the poorly drained soils and inadequate outfall conditions. At present, 15 per cent of the command area is already waterlogged (<1.5m water table depth) and another about 40 per cent area is critical from a point of view of water table (1.5-3.0m). Build-up in the water table is slowly leading to secondary salinization of the soil. In many places more than 10 per cent of the area have already become secondary salinized. In certain places like those of Sunev Kalla, Parvat and Sisodara villages in the Ankleshwar and Hansot *talukas* more than 5,000 ha of the canal irrigated area have gone out of cultivation due to secondary salinization. The mean monthly rainfall and pan evaporation of a representative location in the command reveal that during monsoon months, evaporation invariably is less than the precipitation (Fig. 13). This implies that during monsoon season, excess water will accentuate the problem of waterlogging in the command area. This is also evident from the gradual increase in the area under critical waterlogging group from almost nil in 1957-58 to about 40 per cent in 1998 during pre monsoon period. Similarly, the prevailing cropping pattern dominated with sugarcane and paddy has not only created the waterlogging conditions but also led to increase in the soil salinity (Fig. 14).

Adoption of proper water management practices coupled with provision of appropriate drainage can mitigate these problems. The Water Management Research Project at Navsari campus had developed water management technologies for various mandated crops of this command. They have also estimated 30 to 40 per cent yield losses due to high water table conditions. In addition to this, the viability of subsurface drainage for cane production has been tested on a small scale and effect of deep surface drainage for improving sugarcane production and control of soil salinity has been tested at farmers' fields.

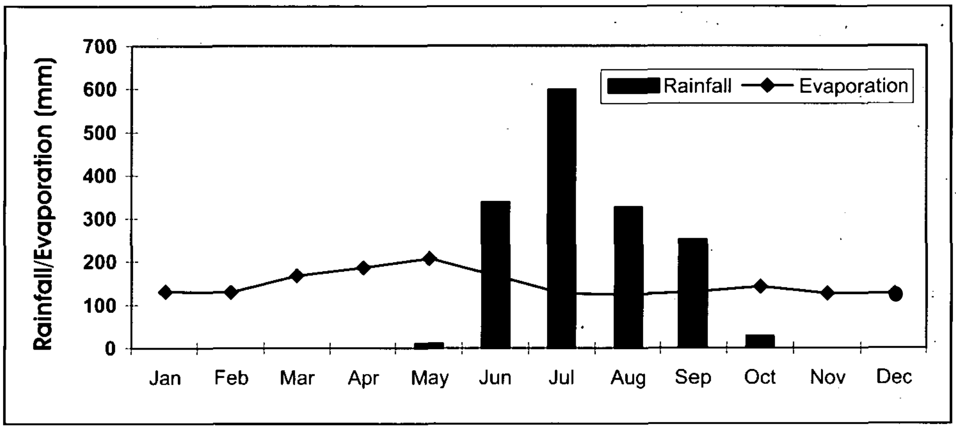


Figure 13. Mean monthly evaporation and rainfall (1985-1994)

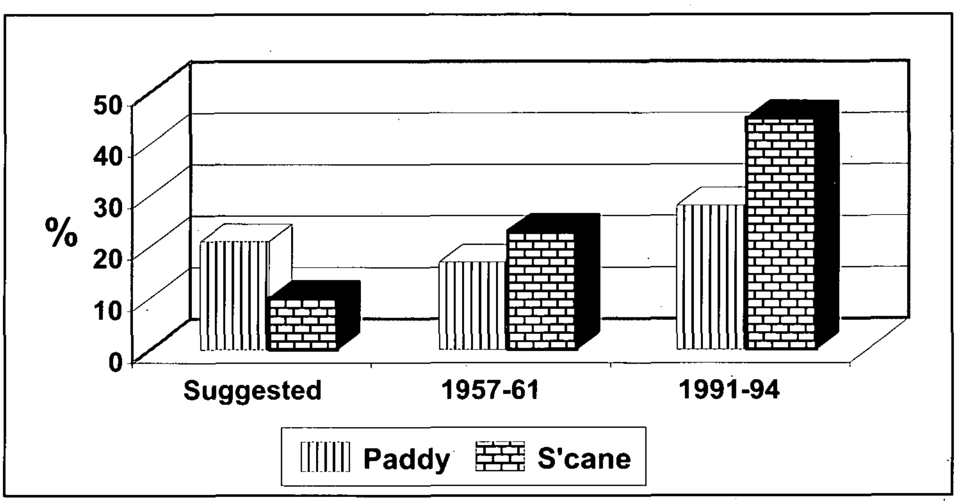


Figure 14. Deviation from suggested cropping pattern in UKC

7.2 Need for Drainage

The information presented so far brings out the fact that drainage along with appropriate water management practices can improve the affected lands and thereby increase the crop productivity of these areas. Previous studies conducted in this command showed that the cane yield is getting reduced by 30 to 40 per cent in high water table areas depending upon the water table levels.

The irrigation requirement can be reduced by about 50 per cent in high water table conditions. Apart from this, small scale demonstrations on farmers' fields have shown 30 to 45 per cent increase in the cane production due to provision of open subsurface drainage. Hence, to test and demonstrate the economic viability of close and open subsurface drainage systems, it was decided to establish two pilot areas at Segwa and Sisodara.

7.3 Establishment of Pilot Areas

7.3.1 Pre-drainage Investigations

In order to fix the drainage design criteria, pertinent parameters were studied during pre-drainage investigations in both the pilot areas (Table 45).

Table 45. Drainage related parameters in the pilot areas

	Particulars	Pilot areas	
		Segwa	Sisodara
1.	Climate	Sub-humid	Semi-arid
	a). Rainfall (mm)	1500	850
	b). Evaporation (mm)	1765	1670
2.	Size of pilot area (ha)	188	169
3.	Topography	Flat with gentle slope towards south	Flat with gentle slope towards north-west
4.	Slope (%)	0.27	0.08
6.	Type of outlet	Gravity	Gravity
7.	Mean water table fluctuation (m)	0.2 – 1.3	0 – 1.3
8.	Hydraulic conductivity (m day^{-1})	0.19	0.21
9.	Depth of impermeable layer (m)	7	10
10.	Irrigation status (ha)		
	Irrigated	143	76
	Unirrigated (Barren/pasture)	45	93
11.	Irrigation resources (ha)		
	Canal alone	76	76
	Well alone	37	-
	Drain	4	-
	Conjunctive use	26	-
12.	Infiltration rate (mm hr^{-1})	2.0	1.1
13.	Extent of problems(% area)		
	Waterlogging	56	10
	Salt-affected	13	13
	Salt-affected and waterlogged	30	77
	Normal	01	-

7.3.2 Particulars of Drainage Works in the Pilot Area

Based on the pre-drainage investigations, appropriate drainage systems were installed in both the pilot areas (Fig. 15 and Table 46).

Table 46. Details of drainage systems installed in the pilot areas

Particulars	Drainage system							
	Singular CSSD			Composite CSSD			Open SSD	
	30m	45m	60m	30m	45m	60m	30m	60m
Area (ha)	4.2	5.6	5.4	2.6	5.7	4.6	2.0*	14.0*
Year of installation	2000	1998	2000	1999	1999	1999	2000	2000
Drain depth (m)	0.9	0.9	0.9	1.2	1.2	1.2	0.7	0.8
Envelope material	No	No	No	Yes (few laterals)	Yes (few laterals)	Yes (few laterals)	-	-
Soil amendment	No	No	No	Yes (few laterals)	Yes(few laterals)	Yes (few laterals)	-	-
Method of installation	M	M+E	M	M+E	M+E	M+E	M+E	M+E

M= manual , M+E= Manual + Excavator, * = net area

7.4. Post-drainage Investigations

7.4.1 Water Table Fluctuation

Segwa: To monitor the impact of drainage on groundwater table, observation wells were installed on the drain, immediately adjacent to the drain, (at 0.7 m), at 1/8th of the spacing between the drains and at middle of the two drains. The block wise and the spacing wise fluctuations were measured periodically. In the control area of the B block, the average water table was 35 cm bgl during pre and post-drainage period, whereas in CSSD area the water table receded from 32 cm to 46 cm bgl (Table 47). In the C Block, water table receded in all the treatments including control during post-drainage period. The main reason for decrease in water table in the control block was that the plots remained fallow because of canal closure, while in CSSD area the farmers applied irrigation to sugarcane crop through bore well. In the E block, there is no regular control plot for 30 and 60 m spacing as the area under these two drains were completely barren. The area covered with drains at 45 m spacing was always under cultivation. The F block, which has also been under cultivation, was treated as the control block. The fluctuations reveal that most of the time the water table in CSSD block was lower than the control block (Fig. 16). It is apparent that the fall in water table after monsoon in CSSD block is very steep while in the control block it is more gradual.

The data depicting the water table fluctuation during 2000-2001 clearly indicate a gradual decrease in the water table with time. This could be due to the fact that only a part of the block was brought under cultivation during 2001. The water table during monsoon 2001 was much deeper as compared to 2000, since the rainfall during 2001 was subnormal.

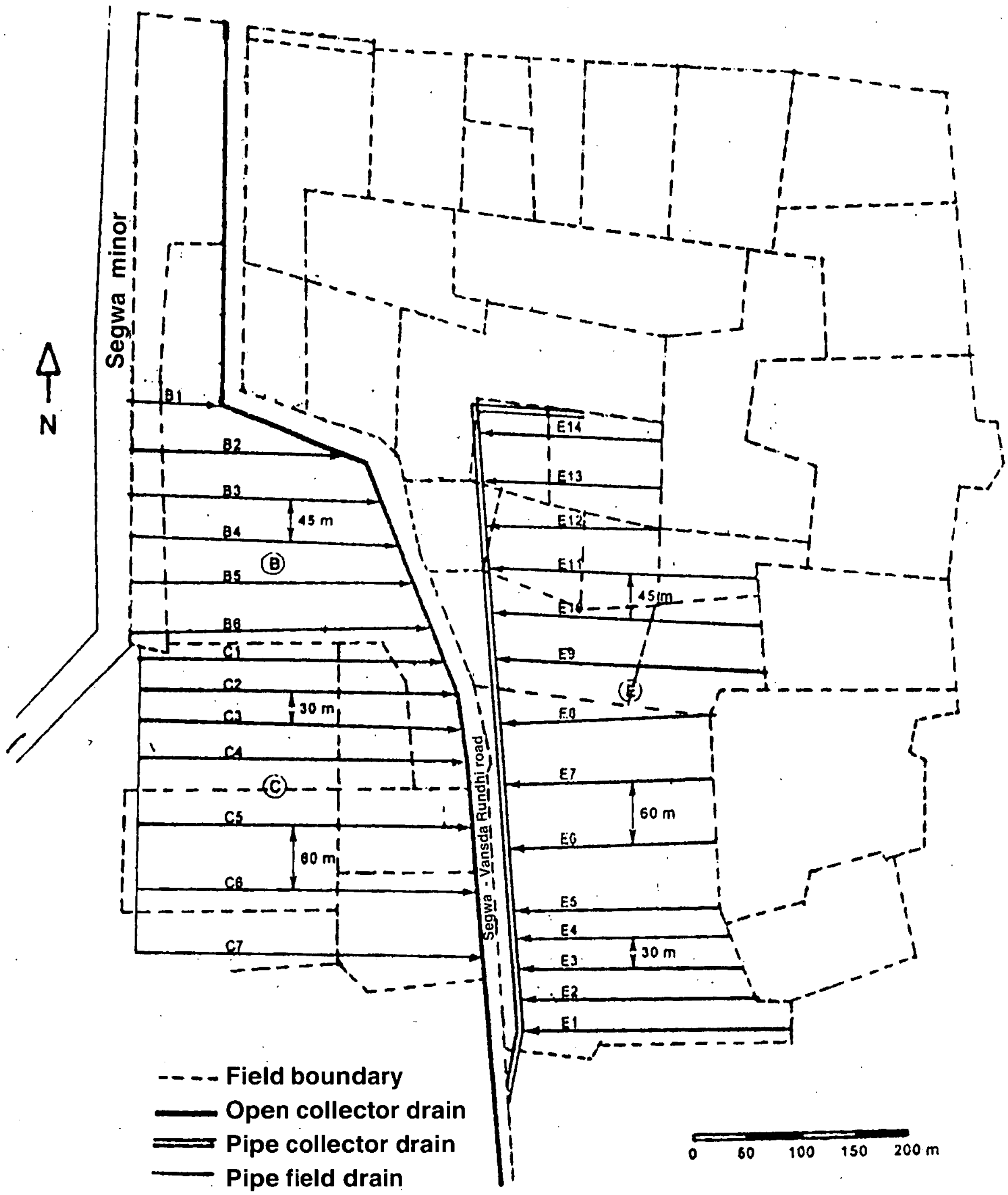


Figure 15. Line diagram showing layout of the drainage pilot at Segwa

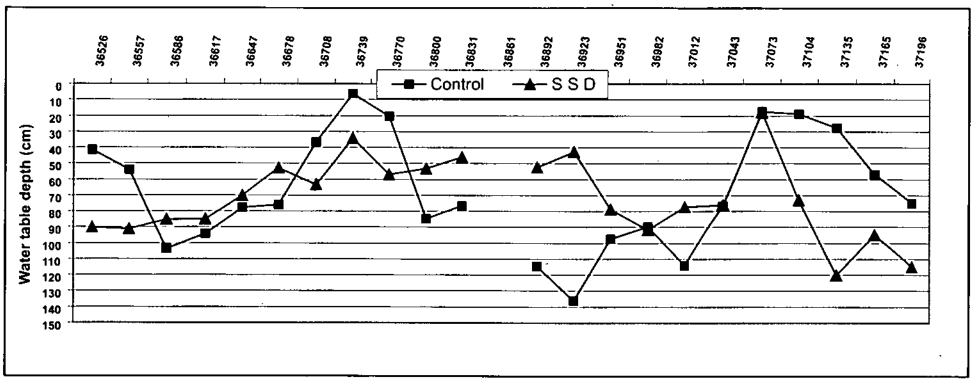


Figure 16. Periodical water table fluctuation in E block of Segwa (45m)

Sisodara : To monitor the impact of cleaning the existing main drains on water table fluctuations, observations wells were installed in different blocks. The fluctuations were measured periodically. The annual water table receded from 55 to 88 cm bgl during post-drainage period (Table 47).

Table 47. Changes in hydrological parameters, soil salinity/sodicity and crop yield in CSSD and control blocks

Segwa : *Block-B (Singular)*

Particulars	Control		Drain (45 m)	
	Pre	Post	Pre	Post
Water table (cm bgl)	35	35	32	46
Drainage discharge (mm day^{-1})	-	-	-	1.9
Drain water quality :EC (dS m^{-1})	-	-	18.2	1.4
Soil EC_e (dS m^{-1})	3.3	5.0	1.5	1.2
Soil ESP	5.0	7.0	14.7	9.3
Cane yield (t ha^{-1})	75	80	42	105

Block-C *(Singular)*

Particulars	Control		CSSD spacing			
			30 m		60 m	
	Pre	Post	Pre	Post	Pre	Post
Water table (cm bgl)	33	58	53	74	53	72
Drainage discharge (mm day^{-1})	-	-	-	2.4	-	2.3
Drain water quality :EC (dS m^{-1})	-	-	-	1.3		2.4
Soil EC_e (dS m^{-1})	3.32	5.02	6.4	1.2	6.0	1.1
Soil ESP	5.0	7.0	21.2	14.4	21.2	19.7
Cane yield (t ha^{-1})	75	80	78	115	78	84

Table 47 contd.......

Block-E *(Composite)*

Particulars	Control		CSSD spacing					
			30 m *		45 m $		60 m *	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Water table (cm bgl)	64	68	70	88	78	71	71	85
Drainage discharge (mm day^{-1})	-	-	-	1.35	-	0.36	-	0.2
Drain water quality :EC (dS m^{-1})	-	-	-	6.6	-	3.7	-	14.2
Soil EC_e (dS m^{-1})	4.46	5.64	23.0	6.4	5.9	3.8	23.0	8.6
Soil ESP	15.0	17.0	23.0	6.4	5.9	3.8	23.0	8.6

* As these blocks were completely barren, no appropriate control was available in the pilot area;
$ The land was fallow before drainage

Sisodara

Particulars	Pre-drainage	Post-drainage
Water table (cm bgl)	55	88
Soil EC_e (dS m^{-1})	16.3	12.3
Soil ESP	10.3	18.7
Paddy yield (t ha^{-1})	0.6	1.8*
Cropping intensity (%)	46	102

* One year after drainage

7.4.2 Drain Water Quality

Segwa : In order to study the periodical changes in quality of drain water from representative drains from all the blocks, samples were collected fortnightly. Out of the three blocks, three years data are available for block B, which has been affected by both the problems of salinity and waterlogging. The results clearly indicate regular reduction in the salinity/sodicity of the drain water. During June 1998, the EC of the drain water was 18.2, which reduced to 1.4 dS m^{-1} during October 2001. Similarly, the corresponding RSC values were 9.7 and 3.1 meq l^{-1}. In the C block an upward trend in the salinity of the drain water could be noticed. It could be due to the fact that this being the first year after drain installation, the process of salt removal is in progress. On the other hand, in block E definite reduction in the salinity is observed to the tune of 50 per cent, yet the variation in drain water quality indicate that even after two years complete salt removal has not taken place (Fig. 17). The probable reasons for such a scenario could be that basically the block had very high salinity, only a part of the block is under irrigation and in some fields saline-sodic water is used for irrigation.

Sisodara: Root zone water samples were collected from 29 bores spread over the whole pilot area. From the quality point of view, root zone water was found to be extremely saline (average EC = 15.9 dS m^{-1}) with predominance of Na and Cl ions.

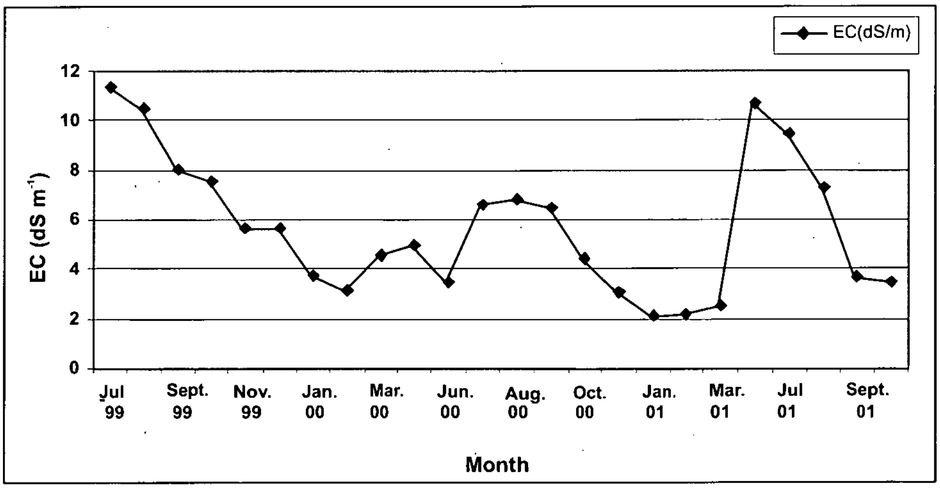


Figure 17. Periodical changes in drain water quality (Block E-Segwa)

7.4.3 Soil Salinity / Sodicity

Segwa: Block and spacing wise soil samples were collected to 90 cm depth at 30 cm depth interval (0-30 cm, 30-60 cm, 60-90 cm). Similarly, samples were also collected at different locations at regular distance from the drain (7.5, 15 and 22.5 for 45 m spacing and an additional distance of 30 m for 60 m spacing) during pre and post-monsoon periods. Since the effects become nullified due to heavy monsoon, the results are presented and discussed only for the pre-monsoon period.

In block B, three years after system installation, there was a regular decrease in salinity at all the depths due to drainage. The initial values were 4.7, 3.6 and 3.1 dS m^{-1} during pre-monsoon 1998 at 30, 60 and 90 cm depth, which got reduced to 0.95, 0.84 and 1.20 dS m^{-1}, respectively during 2001. The soil salinity at different distances from the drains indicated that there is a regular decrease in soil salinity up to 15 m distance from the drain but with further increase in the distance, there has been a tendency for slight increase in soil salinity.

In block E, two different situations exist. The 30 and 60 m spaced CSSD plots were previously barren while 45 m spaced block was always under cropping. Because of this, the initial salinity was very high in the first case (27 dS m^{-1}) while it was only 7 dS m^{-1} in the cultivated block. Due to CSSD, there was reduction in the salinity values at all the depths ranging from 27.4 to 6.0 dS m^{-1} at 30 cm, 24.2 to 8.8 dS m^{-1} at 60 cm and 17.4 to 10.2 dS m^{-1} at 90 cm depth. The trend in the reduction of soil salinity with the distance from the drain remained similar to that of B block. In the block C, the drains are only one year old and the initial data indicate a reduction in soil salinity from 3.9 to 0.9 dS m^{-1} at 30 cm, 4.6 to 1.0 dS m^{-1} at 60 cm and 5.1 to 1.7 dS m^{-1} at 90 cm depth. Overall it could be seen that the salinity is increasing in undrained control whereas it is decreasing in plots where SSD has been provided (Fig. 18)

Sisodara: The soil samples were collected from the pilot area during pre (BM-2000) and post (BM-2001) cleaning of the main drain. While soil salinity tended to decline, the sodicity showed slight increasing trend.

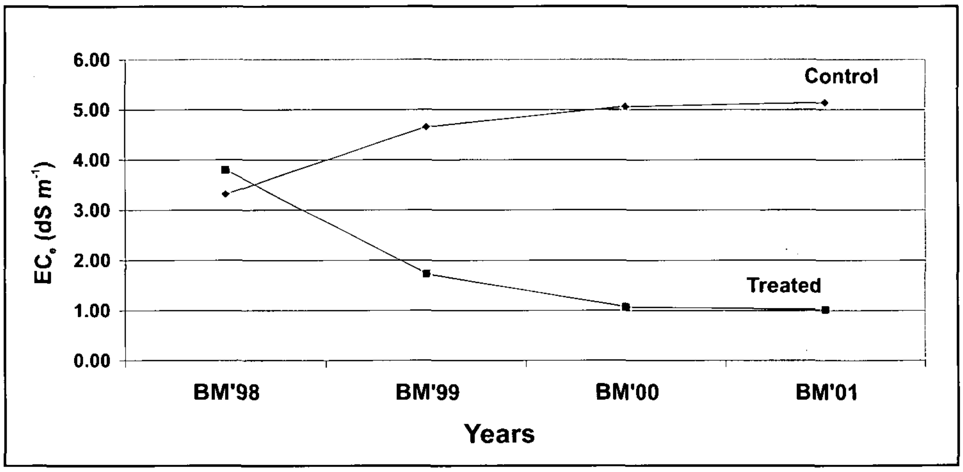


Figure 18. Comparison of soil salinity in treated and control plots

7.4.4 Salt and Water Balances

Segwa : Pre-drainage (1996-97) and post-drainage (1999-2000) estimates of salt balance of the root zone were made on the basis of field measurements. It was observed that during pre-drainage period, about 7 t ha^{-1} (100 per cent) of salts remained in the root zone, whereas during post drainage period about 4.7 t ha^{-1} (67 per cent) of salts remained as balance. This indicates a 33 per cent reduction in the salt content of the soil when only 11 per cent of the pilot area was brought under CSSD and no leaching water was applied. The salt removal could have been even more provided additional water for leaching would have been applied.

7.4.5 Crop Production

Segwa : In order to assess the impact of drainage on crop performance, crop yields were recorded following the standard crop cutting procedures in the pilot area. The extent of improvement in yields was more in CSSD blocks but there was also slightly higher production in the pilot area as a whole because of deepening of the main drains (Table 47).

Sisodara: In order to assess the impact of drainage on the crop performance, crop yields were recorded following the standard crop cutting procedures in the Sisodara pilot area. Here, the impact was dramatic as the fields lying barren since 15–20 years were brought back to cultivation just because of cleaning and deepening of the existing main drains (Table 47).

7.4.6 Land Use Pattern

Segwa: Paddy and sugarcane were the predominant crops in this area during the pre-drainage period. During the post-drainage surveys, no major changes were found in the land use pattern.

Sisodara: Paddy is found to be the predominant crop in this area during pre and post-drainage periods. With the inception of drainage system, even the barren fields could be brought under paddy cultivation.

7.4.7 Cropping Intensity

Segwa: There is no change in cropping intensity in Segwa pilot area during pre and post-drainage surveys because the major crop grown is sugarcane.

Sisodara : Block wise cropping pattern was recorded through field surveys in the area. It was found that the cropping intensity, which during pre-drainage period was only 46 per cent, increased to 102 per cent during post-drainage period (Table 47).

7.5 Testing the Drainage Material (Envelope)

Segwa: A study was conducted in E block to evaluate the effect of geo-textile material as envelope material (non-woven polypropylene filter, HG-30 having thickness of 3 mm and O_{90} of 340 micron) and its effect on the performance of SSD system. For this purpose, some of the pipes were wrapped with filter material while others were left as control. In addition, to reduce the siltation in some enveloped drains, gypsum was applied to the soil during back-filling @ 2.5 ppm. This treatment was effected only in case soil was sodic as per norms.

At the end of each year, the silt samples were collected from representative drains in each block. The thickness of silt in the drains was measured (Table 48). The results indicate that in this type of heavy soil (>40 % clay) irrespective of sodicity, there is no need of envelope material to reduce the siltation. Apparently, it could reduce the cost of the system by about 10%.

Table 48. Thickness of sediments in the drains (cm)

Block	Clay(%)	ESP	Treatment	Sediments layer (cm)	Remark
B	42	8.0	No filter	0.4	At the end of 3 years
C	42	6.0	No filter	0.2	At the end of 1 year
E	46	17.5	No filter	0.1	At the end of 2 years
			Filter	0.1	
			Filter + Gypsum	0.3	

7.6 Economic Viability

For assessing the economic viability of the CSSD, the crop yields and cost of cultivation were recorded in CSSD blocks. Using the yield values and cost incurred towards CSSD, various economic parameters were computed (Table 49). The CSSD laid out at 45 m spacing registered an IRR of 58 per cent and a B-C ratio of 1.74 with a pay back period of 3 years, indicating economic viability of the system in sugarcane growing areas of South Gujarat.

The economic benefits observed from the pilot area research has already attracted the farmers to buy the land in project area at 5 times higher prices than the pre-drainage period (Table 50) .This is further substantiated from the fact that the farmers have brought 3 and 45 ha area under CSSD and OSDD respectively at their own cost. Apart from this, 15 more farmers are ready to invest on OSDD / CSSD.

Table 49. Sugarcane yield and economics of CSSD in Vertisols of Segwa

Serial No.	Particulars	Control	CSSD (Singular) 45m
1	Yield(t ha^{-1})	78	105
2	Cost of cultivation (Rs ha^{-1})*	31,286	41,143
3	Gross income (Rs ha^{-1})*	63,555	85,500
4	Additional revenue (Rs ha^{-1})	-	21,945
5	Additional cost (Rs ha^{-1})	-	9,857
6	Cost of installation (Rs ha^{-1})	-	20,400
7	Net present worth (Rs)	-	74,957
8	Internal rate of return (%)	-	58
9	Benefit-cost ratio	-	1.74
10	Pay back period (years)	-	3

* Cost of cultivation and gross income values are converted to yearly basis from 14 months growing period of sugarcane crop.
Note: Selling price of sugarcane = Rs. 950 per ton.

Table 50. Status of land value and adaptability of drainage

Particulars	Land value (Rs in lakh ha^{-1})	Area (ha) brought under drainage at farmer's cost		No. of farmers ready to install drainage at their own cost
		CSSD	OSSD	
Pre-drainage	0.6-1.0	-	-	-
Post-drainage	3.0-5.0	3	45	15

7.7 Related Studies

7.7.1 Irrigation and Water Management Research

Segwa: Diagnostic studies revealed that water supplies are fairly adequate in the canal command. Irregularity in canal supply is less than 35 percent during *rabi* and summer seasons. However, this irregularity in water supply and cheap availability of water encourage the farmers to over irrigate which results in wastage of good quality water. High application and storage efficiencies and coefficient of uniformity were observed due to high water table resulting in a moist root zone. In spite of sufficient availability of canal water, yield levels are on the lower side of the state average because of poor water management. Farmers have a tendency to cultivate only water loving crops (sugarcane and paddy) throughout the year. Farmers in parts of the pilot area where well irrigation is practiced are compelled to use poor quality groundwater. Saline patches are more prominent in well-irrigated part whereas waterlogging is mostly observed in fields parallel to minor canal.

7.7.2 Gypsum Requirement

Segwa: Studies revealed that gypsum application significantly affects the yield of sugarcane grown on sodic soil (ESP = 18.9). The results revealed that a combined application of gypsum @ 75 per cent of GR with either FYM or press mud or bio-compost (a by-product of the sugar industry), increased the cane yield by about 45 to 55 per cent over the control. The ESP of the soil decreased with the application of gypsum + organic materials.

7.7.3 Impact of Water Table and Sodicity on Cane Yield

Segwa : A study was conducted in 88 fields spread over 33 villages around the Segwa pilot area to assess the impact of water table on sugarcane yield .The result indicated an average decrease in crop yield by about 6 per cent for every 25 cm rise in water table (in the range of 0.25 to 2.0m). From this study , a critical water table depth of 1.27 m was established for sugarcane crop grown on Vertisols of South Gujarat (Fig. 19).

Sisodara : A study was also conducted around the Sisodara pilot area for establishing the relationship between salinity / sodicity and cane yield. Crop yields and soil samples were collected at the time of harvesting from 82 fields covering 19 villages. The results indicated that the adverse effects of ESP were more pronounced than the salinity.

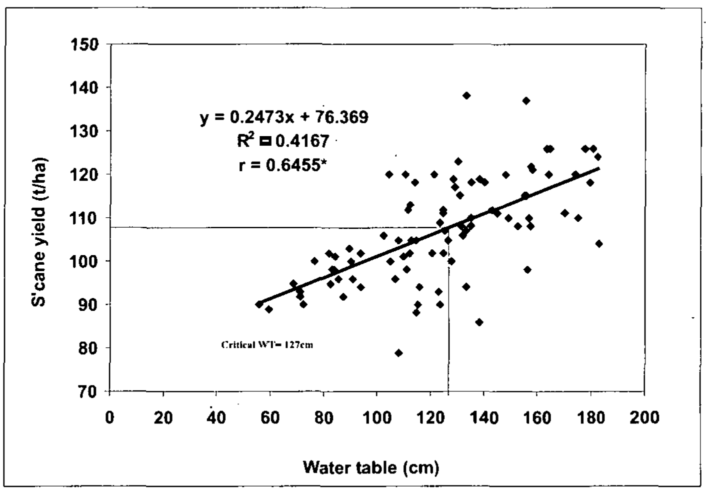


Figure 19. Effect of average water table (overall) on yield of sugarcane

7.8 Packages Emerged

The technologies developed on the basis of pilot area research are reported in Table 51.

7.9 Socio-economic and Gender Studies

Socio-economic including gender studies were conducted in both the pilot areas. All 52 farmers of the Segwa and 47 farmers of the Sisodra including the women participated in the surveys. Farmers in the Segwa are relatively well-educated and well-to-do with an average farm size of 3.6 ha (Table 52) and 62% of the farm households having an income of more than Rs. 2 lakh (US$ 4,000). In the Sisodra, farmers have a lower level of education and are poorer, with a smaller farm size (2.1 ha) and only 11% of farm households having an income of more than Rs. 2 lakh.

Table 51. Packages for ameliorating waterlogging and soil salinity problems

Serial No.	Package		Cost		To mitigate
I	Drainage		Rs m^{-1}	Rs ha^{-1}	
A.	Open deep drain	30 m	33	10,800	Waterlogging and salinity
		60 m	35	5,800	,,
B.	Closed SSD	30 m	77	25,700	,,
	1. Singular	45 m	78	17,400	,,
		60 m	80	13,300	,,
	2. Composite	30 m	85	28,300	,,
		45 m	92	20,400	,,
		60 m	98	16,400	,,

Serial No.	Package	Cost	To mitigate/minimize
II	**Irrigation**		
A.	FIC lining(Rs/m^2)		Seepage
	1. Brick masonry with cement	95.31	
	2. Plaster of precast NRCC laid on ground	59.78	
	3. Plaster of precast NRCC laid on brick foundation	82.72	
	4. Tiles laid over polyethylene sheet	74.13	
	5. Earthen channel	8.26	
B.	Drip method (Paired row planting of sugarcane) (Rs ha^{-1})	63,000	Water loss
III	**Soil management (Rs ha^{-1})**		
	Gypsum application (for removing 1 me Na/100 g)	900	Sodicity
IV	**Crop management (variety)**		
	Sugarcane variety tolerant to		
	-waterlogging	Co 86032	Loss in crop production
	-Salinity / sodicity	Co 8338	

Table 52. Farm holdings and education level (%) among farmers of the two pilot areas

Plot size	Farm holding (%)		Education level	Segwa		Sisodara	
	Segwa	Sisodara		M	F	M	F
< 2 ha	0	34	Illiterate	-	-	13	19
2 – 4 ha	23	28	Primary (1 to 7 St.)	40	34	68	68
> 4 ha	77	38	Secondary (8 to 12 St.)	52	52	15	13
			Diploma and above	8	14	4	-

In Segwa, agriculture is the main occupation for the male population (53%), followed by services (22%). The women are mainly engaged in household activities (51%), animal husbandry (33%) and education (14%) and hardly in agriculture (< 2%). The majority of the farmers are member of the co-operative sugar factory (94% in Segwa and 82% in Sisodra), village co-operative (88% and 73%) and milk co-operative (73% and 33%).

7.9.1 Farmers' Attitude to Drainage

The majority of the farmers in both the pilot areas are convinced that:

- Drainage can be a useful tool to overcome waterlogging and salinity problems.
- The waterlogging and salinity problems are caused by irregular canal water supply (62% of the farmers in Segwa were unaware of canal scheduling), the cultivation of high water-consuming crops and unscientific water management practices.
- That waterlogging and salinity (92%) and poor permeability of the soil (87%) are the major factors responsible for poor crop productivity.

7.9.2 Knowledge and Adoption of Water Management Technologies

The majority of the farmers (> 80%) have more than 20 years experience in irrigated agriculture. In Sisodra, a study was conducted to assess the farmers' knowledge and adoption of water management technologies. The main source of information about water management practices were the farmers' own experience (94%) followed by learning from progressive farmers (85%), *gram sevaks* (58%), literature (48%), research centres (42%) and visiting scientists (18%). Farmers are also very actively participating in extension activities like visits to sugar factory (94%), demonstration plots (48%) and GAU research stations (27%); attending farmers days (42%) and agriculture related training (33%); reading agricultural magazines (33%) and watching/listening to TV and radio (21%). Farmers are very eager to implement their newly acquired knowledge as 24% of them conducted demonstrations on their own farm and implemented recommended irrigation and drainage practices.

7.9.3 Farmers' Input to Implement and Maintain the Drainage System

The farmers of Segwa contributed to these activities in the following manner.

- One farmer, who was initially left out of the project but later included, paid for the construction materials himself.
- Farmers maintain their section of the open drains.
- Farmers will take over the responsibility of the drainage system including the main drain section downstream of their fields from March 2003 onwards.

Although the Farmers of Sisodra are very poor, they contributed to the implementation and maintenance of the open subsurface drainage system by:

- Providing the land for the open drains free of charge.
- Organising and supervising maintenance.

7.9.4 Impact Analysis of Subsurface Drainage

Five years after the implementation of subsurface drainage in and around the Segwa and the Sisodra pilot areas, a survey was conducted to assess the farmer's views on the technical and economical feasibility and their participation in subsurface drainage. The group of farmers included farmers of plots where the subsurface drainage system was installed by the Indo-Dutch Network Project (13) and farmers who installed the system at their own costs (4). The survey revealed that:

- Farmers are convinced about the importance and benefits of drainage as a tool to reclaim waterlogged and salt-affected soils, particularly in terms of improvement in the land value and crop yield.
- They favour installation of drainage system on block basis.
- They are of the opinion that the Government should intervene in solving the problems.
- They are, however, willing to actively participate in future drainage projects either by meeting a part of the cost or by maintaining the system adjacent to their fields.
- They regard maintenance of main drains as a responsibility of the Government.

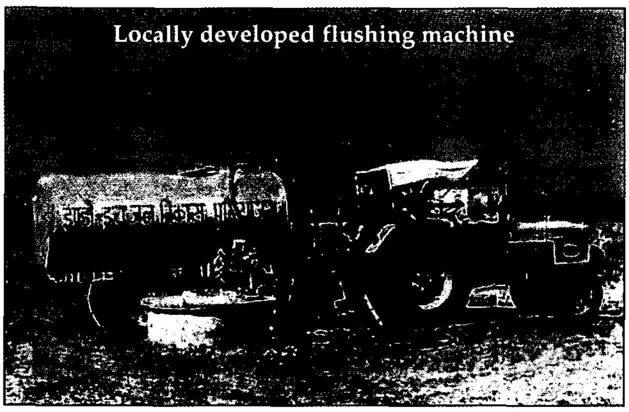
7.9.5 Gender Issues

Following important observations can be made in this respect.

- Although women are actively involved in farming activities, they are not so much involved in agriculture and agricultural water management.
- The knowledge on water management practice is higher amongst the women in Segwa than in Sisodra. Reasons might be higher educational level and longer exposure to drainage works of the IDNP project.
- Generally, fewer women have knowledge and awareness about water management practices compared to men. Even half of the man interviewed showed no or hardly any knowledge and awareness either.
- Women more than men emphasised the need for organisation between farmers and outside support to regulate certain matters.

8. ESTABLISH, MONITOR AND EVALUATE PILOT AREA AT LAKHUWALI IN INDIRA GANDHI *NAHAR PARIYOJANA*, RAJASTHAN (RAU)

8.1 Introduction



The Indira Gandhi *Nahar Pariyojana* (IGNP) is an enormous multi-purpose irrigation and settlement project to transport and use over 10^6 billion cubic meter of water annually (with an actual discharge of 510 m^3 sec^{-1} against a design discharge of 620 m^3 sec^{-1}) to cultivate about 5.40 lakh ha in stage I and 13.19 lakh ha in stage II of semi-arid and desert wastelands of north-west Rajasthan. The water of the Ravi- Beas river system is diverted from Harrike barrage in Punjab through a 204 km long Indira Gandhi Feeder Canal (without off takes) into 445 km long Indira Gandhi Main Canal (IGMC) at Masitawali head works. The water allowance is 0.0371 cumec per 100 ha (5.23 cusec per 1000 acre) which is equal to 3.2 mm day^{-1}. The intensity of irrigation is envisaged at 110% with 60% in *rabi* and 50% in *kharif* seasons. At farm level, the water is distributed through a *warabandi* system. The mean annual rainfall and evaporation are 297 mm and 1,560 mm respectively. The monthly average rainfall and evaporation presented in Fig. 20 reveal water deficit during the whole year including the monsoon months.

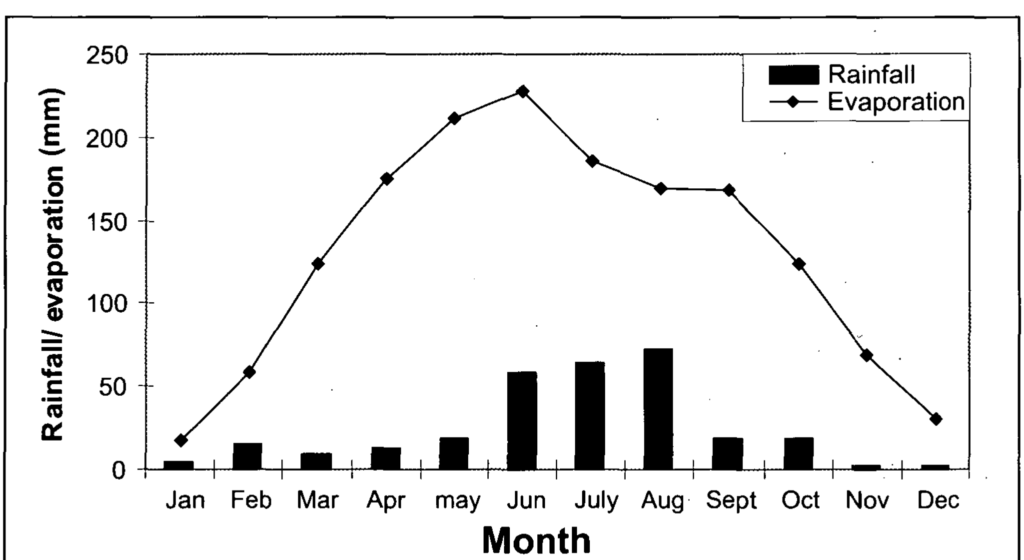


Figure 20. Rainfall and evaporation in IGNP

8.2 Need for Drainage

The area is characterized as semi- arid and arid with annual rainfall being much less than the annual evaporation giving rise to secondary salinization. As a characteristic of arid zone, the inherent salts are present in soil profile, the groundwater is saline and is unsuitable for irrigation. The amount of salts brought by canal water (EC of 0.3 dS m^{-1}) with an inflow of 510 m^3 sec^{-1} are to the tune of 8460 t day^{-1}. The presence of calcareous impervious layer at shallow depth results in formation of perched water table and lack of natural outlets is also evident. The soils of the area are coarse textured with an appreciable amount of sand resulting in low water holding capacity. As a result stagnation of water occurs in the area resulting in rise of water table at the rate of about 1m $year^{-1}$ (Fig. 21). The progressive waterlogging in stage I of IGNP over the years is presented in Fig. 22. Apparently, appropriate water management practices and drainage improvement are necessary to arrest the rising water table and accumulation of salts in the region.

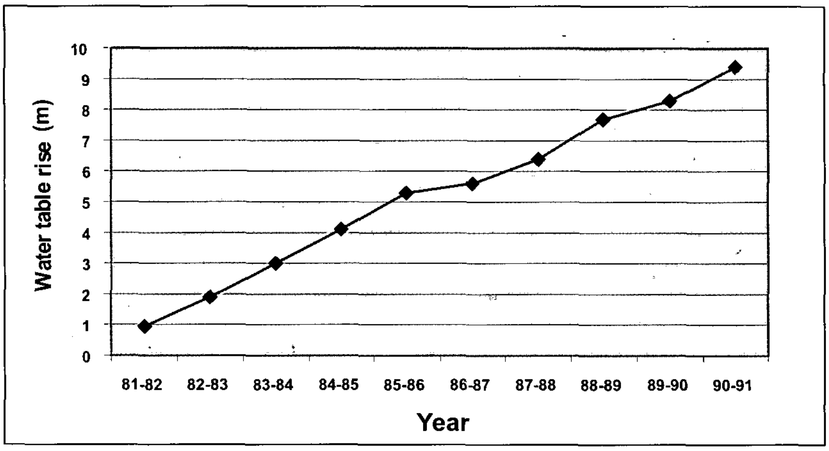


Figure 21. Rise of water table in IGNP

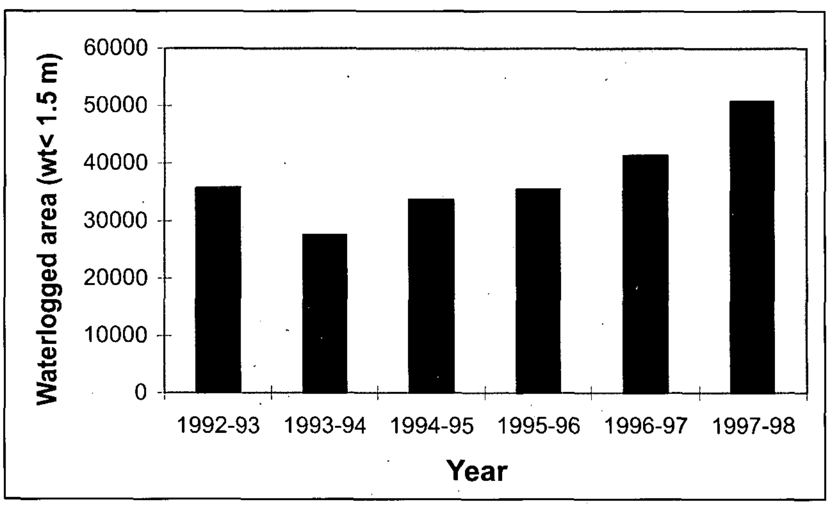


Figure 22. Progressive increase in the area under waterlogging in IGNP

8.3 Physical Setting and Brief Description

To carry out various research activities, an area of 2 km * 3 km was selected in village Lakhuwali about 30 km away from Hanumangarh. On the basis of the extent of the problem, physical infrastructure, easy accessibility, water bodies in three directions and availability of an outlet in the form of Ghaggar Diversion Channel to dispose off the drainage effluent, an area of 75 ha (500m*1500m) was selected as actual experimental site. The pilot area is a typical site surrounded by Hanumangarh to Jaipur Road, Indira Gandhi Main Canal, Suratgarh Branch Canal and Ghaggar Diversion Channel.

8.3.1 Nature of the Problem

Pre- drainage investigations were carried out in the pilot area. The topography of the area is bowl shaped having flat area in the centre. On the basis of field information and the survey conducted for discharging the drainage effluent out of the pilot area it was found that there is absence of natural drainage system and gravity outlet in the area. The soils are sandy and sandy loam with an impervious layer at about 10m depth. The average fortnightly observations revealed that most of the area (about 80%) has water table between 0.0 to 0.60 m. Only 1% area has water table between 1.0 to 1.3 m since it is situated at comparatively higher elevation. No difference was, however, observed in the readings of the observation wells and the piezometers installed at different depths indicating that there is almost negligible contribution of upward seepage. The groundwater has an EC of 6.2 to 32 dS m^{-1} in about 45 % area and 0.9 to 1.3 dS m^{-1} for another 45% area whereas the remaining 10% area has good groundwater quality. The average soil salinity in 55% area is below 4 dS m^{-1} whereas the same was found above 4 dS m^{-1} in an area of about 45%. The area affected by various problems are presented in Table 53.

Table 53. Percent area affected by waterlogging and salinity in Lakhuwali

Water table (m)			Salinity (dS m^{-1})	
< 0.6 m	0.6 – 1.0 m	> 1.0 m	< 4 dS/ m	> 4 dS/ m
80	9	1	55	45

The main *rabi* and *kharif* crops are wheat and cotton whereas the farmers are turning towards paddy as an alternate crop due to waterlogging. The cropping intensity in *rabi* is 46.7% and the same in *kharif* is 43.5% leading to an annual cropping intensity of 90.2% only. The farmers of the area have no option than to cultivate the area even though due to waterlogging and soil salinity the yields (wheat 1.14 t ha^{-1}, cotton 0.53 t $ha^{-1}$and paddy 1.53 t ha^{-1}) are much below than the zonal averages. The net returns are even negative in many cases. An attempt was, however, made to relate the net production value of cotton and wheat to soil salinity and water table depth. The data revealed that the effect on net returns is explained better with water table than soil salinity.

Irrigation water in the Lakhuwali pilot area is received from three sources namely RP11 and RP12 (taking off from Ranjeetpura minor) and a direct outlet LK3 from the main canal. The average water conveyance efficiency in water courses and field channels was found to be 84% and 71%

resulting in a water conveyance efficiency of 60% from outlet to the field head. The water application efficiency for wheat and cotton was found to the tune of 42% and 79% respectively. This means that the irrigation efficiency (from outlet to the root zone) is only 25% for wheat and 47% for cotton.

There are 36 farm families in the pilot area with an average farm holding of 2.3 ha. The economic and social status of the farmers is poor coupled with lower educational status. On the basis of the investigations carried out it may well be concluded that the problems of waterlogging and soil salinity can be solved by subsurface drainage. This can be achieved by laying subsurface pipe drainage system and disposing off drainage effluent into a running source of waste water like Ghaggar Diversion Channel (GDC) by provision of sump and pump in the absence of a gravity outlet.

8.4 Drainage Works

The salient features of subsurface drainage system installed in Lakhuwali are presented in Table 54 while the layout is given in Fig. 23.

Table 54. Salient features of the SSD system installed at Lakhuwali

Serial No.	Parameter	Value/description
1.	Total area under SSD system (ha)	75
2.	Type of drainage system	Drainage system with pumped outlet
3.	Design drainage discharge (mm day^{-1})	1
4.	Drain depth (m)	1.2
5.	Depth to impermeable layer (m)	10
6.	Allowable water table depth (m)	0.8
7.	Hydraulic conductivity (m day^{-1})	1.5
8.	Drain radius (mm)	0.05
9.	Lateral spacing (m)	100 (area 37.5ha), 150 (area 22.5ha), 200 (area 15.0ha)
10.	No of laterals	26 each of 250 m length, perforated PVC pipe of 100 mm diameter
11.	Envelope material	300- 350 microns geotextile non-woven
12.	Length of collector (m)	1500
13.	Collector size (mm)	100, 160 and 200
14.	Manholes	1 m diameter, 17 No
15.	Sump	4 m diameter, 3 m depth
16.	Conveyance system	1112 m with pumped outlet to GDC
17.	Year of installation	15 ha in 2000, 60 ha in 2001

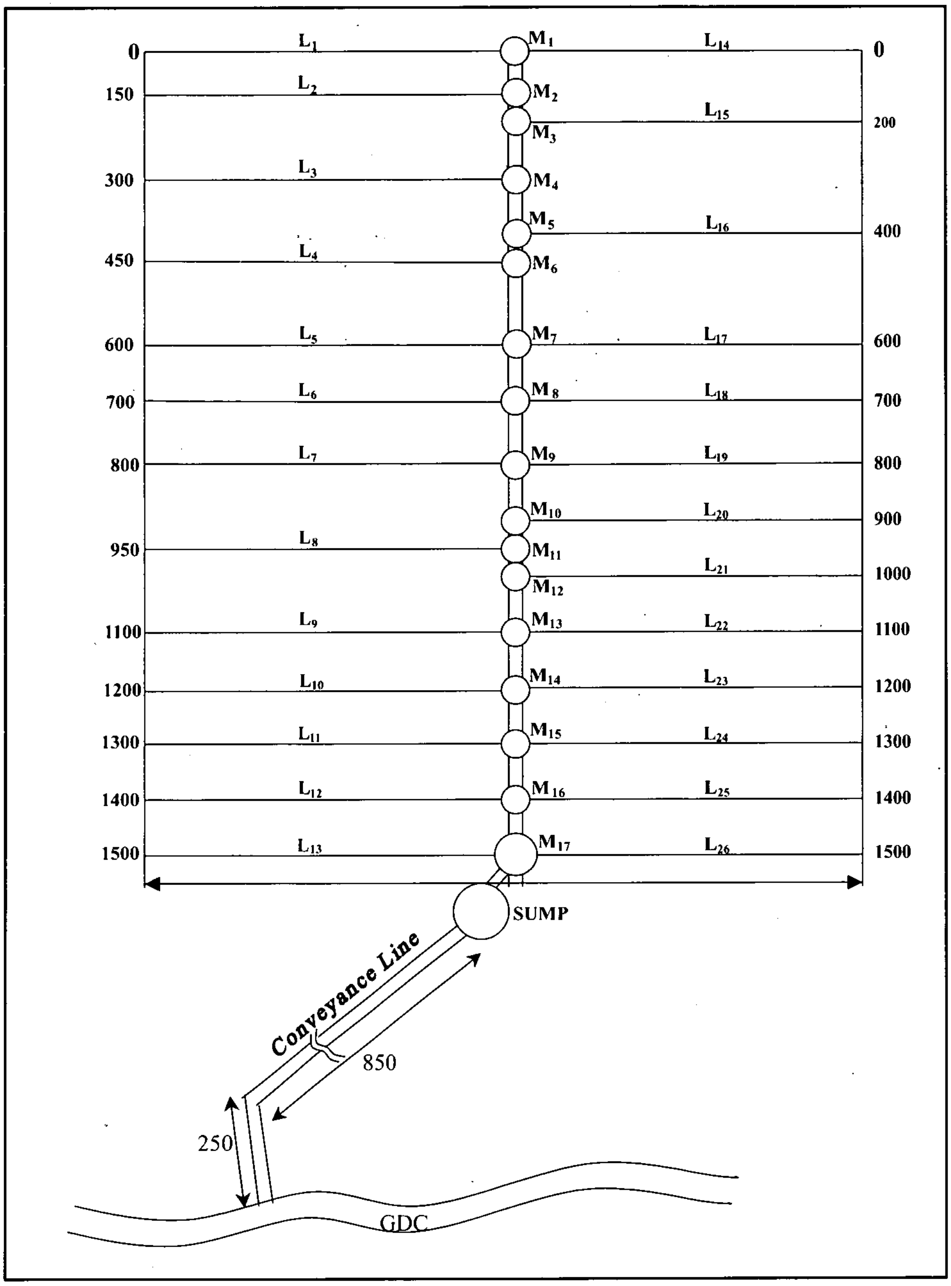


Figure 23. Layout of the subsurface drainage system at Lakhuwali

8.4.1 Installation Techniques

To combat waterlogging and soil salinity, a subsurface drainage system was installed in 75 ha area. During the construction of sump and manholes and installation of collector and lateral drains the problems were faced due to high water table, quick sand phenomena and collapsing nature of soil. These were overcome by improved techniques and may be considered as part of package for installation of SSD system under these conditions.

Construction of sump: Looking to the high water table conditions, the sinking technique is considered appropriate. After sinking the sump to about 1 m, the problem of further sinking and taking out the soil and water from the sump is experienced due to quick sand phenomena and creation of hydraulic pressure around the sump. At this depth an appreciable amount of soil enters from the bottom and sides of the sump and further sinking and sealing the bottom is almost impossible with locally available expertise. The method of continuous pumping from the boreholes bored around the sump is one of the solutions to maintain the groundwater table at desired depth. This checks the inflow of groundwater and consequently the fine sand to sump from its sides and bottom. It facilitates further sinking and sealing of the bottom.

Construction of manholes: In order to recommend an appropriate material and technique for the installations of manholes, manholes made of fibre reinforced plastic barrel, pre-fabricated RCC ring with separate and in-built bottom plates and brick masonry were tested. It is recommended that pre-fabricated RCC ring with in-built bottom plates are most suitable and easy to install under high water table conditions.

Installation of collector and laterals: Difficulties were faced during installation of collector and lateral drains due to high water table and collapsing nature of soil. Therefore, shuttering arrangement and dewatering unit are essential to overcome this problem. Although it is possible to put the system manually, but it is time consuming. Hence, use of machinery is essential for installation of collector and lateral drains. Use of excavator and locally available tractor driven trencher not only reduced the time and cost of installation but also decreased the dewatering requirement during the installation. The trencher consists of cup type conveyor belt to dig 25 cm wide trench up to a depth of 175 cm. The trencher costs Rs 2.5 lakhs and can cover about 6 km lateral length in a day.

Fabrication of low cost flushing unit: During the installation of collector pipe under high water table conditions, lot of sand enters and interrupts the flow. Therefore, to flush the sediments, a flushing unit was essentially required. Looking for a cheap flushing unit, a tractor driven flushing unit was developed at the centre. The unit consists of a 3.5 HP centrifugal pump (2.5"/ 2") mounted on tractor taking power from the PTO shaft. It takes water from a tanker attached with the tractor and delivers it through successively reduced delivery pipe size from 5 cm dia to 1.2 cm dia (2" dia to 0.5" dia), thus creating a jet of water through a nozzle. The pressure so developed is sufficient enough to wash out the soil particles. This unit is also helpful in locating the point at which the blockage occurs in the drains.

8.5 Benefits of Drainage

Installation of SSD in an area of 15 ha was completed in Oct., 2000 while the rest 60 ha area could be completed only in September 2001. The monitoring of the system could be undertaken in 15 ha area only for two seasons for water table depth, EC_e of soil, cropped area and crop yield (Table 55 and Table 56). Although, on an average, there is no reduction in soil salinity, yet the yield improvement has been obtained because of improved aeration (see section 8.3.1).

Table 55. Changes in water table and EC_e before and after drainage in 15 ha area in Lakhuwali

S.No	Treatment	Water table bgl (cm)	EC_e (dS m^{-1})
1.	Pre- drainage	30 (0- 60)	8.2 (May, 2000)
2.	Post- drainage	100 (80- 120)	8.3 (May, 2001)

Table 56. Changes in cropped area and yield after drainage in 100 m spacing

Treatment	Season	Crop	Area (ha)	Yield (t ha^{-1})
Pre- drainage	*Kharif*	Paddy	1.1	14.2
		Cotton	2.9	5.3
	Rabi	Wheat	5.0	11.5
	Cropping intensity, %	60		
Post-drainage	*Kharif*	Paddy	12.0	27.7(95%)
		Cotton	-	-
	Rabi	Wheat	8.5	24.4(113%)
		Barley	3.0	18.0
		Mustard	0.5	2.1
	Cropping intensity, %	160		

8.6 Cost-Benefit Analysis

Losses in net production due to waterlogging were estimated as Rs 4,400 ha^{-1} and Rs 9,400 ha^{-1} for cotton and wheat respectively which happen to be the main crops of the area. The net annual loss is Rs 13,800 ha^{-1}. It is expected that the system will work properly and the water table will not be allowed to rise above 90 cm. In such an event, the returns are expected to be equal to the normal water table depth. It means that there will be an annual increase of Rs 13,800 ha^{-1}. This estimate assumes that all the area will be cultivated in both the seasons. To be on safe side, if 75% of this is realized either due to low cropping intensity or low yield at least Rs 10,350 per annum increase in net returns can be expected. With the increase in cropping intensity and yield mentioned in Table 56, it can easily be achieved. Assuming 30 years life of the system with 12 % discount rate some of the parameters of financial viability of the drainage system are reported in Table 57.

Table 57. Financial viability of the subsurface drainage system

Parameter	Lateral spacing			Overall project area
	100 m	150 m	200 m	
Cost of SSD system (Rs ha^{-1})	25,400	21,000	18,900	23,800
Net present worth (Rs ha^{-1})	49,900	54,300	56,400	51,500
Benefit- cost ratio	3.0	3.6	4.0	3.2
IRR (%)	37	45	50	39
Pay back period (years)	4	3	3	4

8.7 Socio-Economic and Gender Issues

A base-line survey of socio-economic and gender related issues was conducted during 1997-98. All the 36 households participated in the socio-economic base line survey while for the gender related issues only 20 households were interviewed. The average size of a household is 8.8 in the pilot area, which seems to be quite large. Nearly 52% of the population is in the age group of 15-60 years while remaining are infants, children and old. The literacy level is quite low as 55% of the male and 83% of female population is illiterate (Table 58).

Table 58. Literacy and educational level (%) of household members above 6 years of age

Education level	Male	Female
Illiterate	55	83
Literate and educated	45	17
- Primary	26	16
- Primary to secondary	18	1
- Higher education	1	-

The average farm size in the Lakhuwali pilot area is 2.3 ha. Since most of the farmers have land even outside the pilot area, the average total land holding per household is 5.2 ha. Around 22% of the farmers have <2 ha of land while 11% have more than 10 ha. Only 41% of the pilot area land is cultivated during *kharif* season while it is 44% during the *rabi* season. Remaining land remains fallow due to high water table and soil salinity. Average yields are very low both in the pilot area and the control.

8.7.1 Farmers Attitude to Drainage

Base line survey revealed that all the farmers have a positive attitude to drainage as a tool to reclaim waterlogged salt-affected lands. Following observations have been made:

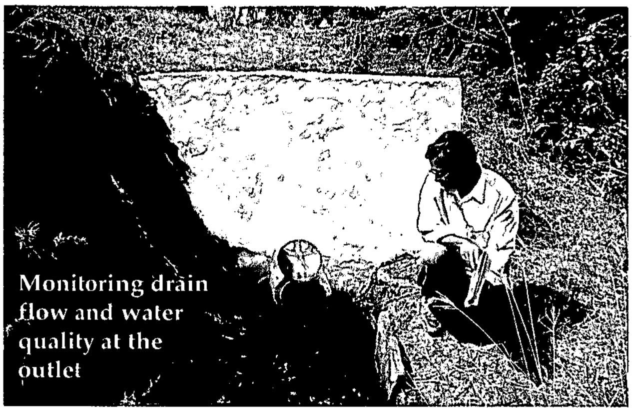
- Farmers in general were quite depressed because a part of their land holding has gone out of cultivation within few years following introduction of irrigation.
- Scrapping of top soil layer by few farmers has not paid the desired dividends and the investment proved largely fruitless.
- Farmers agreed that drainage could help them on a long-term basis and therefore, they were willing to participate in this activity.
- They were convinced of a collective effort in implementing drainage. As a result they organized themselves into a drainage society. This society later on proved quite helpful to the project as it took upon itself the responsibility of watch and ward.
- The drainage society exerted social pressure on one / two farmers who were initially unwilling to allow the collector to pass through their fields.

8.7.2 Gender Issues

In the majority of the households, men were predominantly active in land development, land preparation, sowing, irrigation, maintenance of field channels, fertilizer application, plant protection, packaging and transportation. On the other hand women played a dominating role in activities like weeding, hoeing, bird watching, harvesting, picking and storage of grains. In contrast, in dairy production activities, females played relatively more active role.

9. ESTABLISH, MONITOR AND EVALUATE PILOT AREAS AT ISLAMPUR AND DEVPUR IN UPPER KRISHNA CANAL COMMAND, KARNATAKA (UAS)

9.1 Introduction


Monitoring drain flow and water quality at the outlet

Despite great strides in irrigation development in the country, the problems of waterlogging and salinity have become a major concern in command areas. These problems not only question the credibility of the capital investments in irrigation but also threaten the sustainability of irrigated agriculture. The state of Karnataka is no exception as about 0.141 million ha (about 10.5 per cent of the irrigated command) area has been estimated to be waterlogged saline. Within the state, the Upper Krishna Project (UKP) is one of the major ongoing irrigation projects where the twin problem of waterlogging and soil salinity have been increasing at an alarming rate after the irrigation has been introduced. In order to reverse this trend and to reclaim the affected areas, appraisal of the waterlogging and salinity problems and developing appropriate drainage technology are a must.

9.2 Need for Drainage

The UKP, on full development envisages to command 1 million ha in the chronically drought affected districts of Gulbarga, Raichur and Bijapur. The project was commissioned during 1982 and the potential notified at present is 2.39 lakh ha under Stage-I. The irrigated area lies between 75° 37'- 77° 11' E longitudes and 16° 8'- 17° 28' N latitudes. The envisaged intensity of irrigation for the project is 115 per cent. The climate is semi-arid tropical with a weighted average rainfall of 768 mm, while the potential evapotranspiration is 2,175 mm (Fig. 24). The command area has highly diversified geological formations comprising of peninsular complex-granite gneiss, limestone, shale, sandstone and Deccan trap rocks. The river Krishna and its tributaries Bheema and Don chiefly constitute the drainage system of the area. The soils broadly consist of black soils constituting 86 per cent while red soils cover the remaining 14 per cent. The area under the red soils is amenable to irrigation without much problems of drainage, the black soils do pose problems.

The monitoring of the command area by the State agencies revealed that the water table rose @ 6-13 cm per year during 1984-'95. During the same period, the waterlogged area increased by nearly three times from 3,200 ha (water table < 1m bgl) to 9,400 ha. The area that had water table between 1 and 2 m in 1995 was 34,150 ha. A typical hydrograph of the UKP command at Arkera village is shown in Fig. 25. The pre-irrigation surveys indicate that an area of 26,583 ha was salt-affected. According to rough estimate, the extent of waterlogged and saline area has been put at 11,620 ha. As no systematic survey was carried out, the actual figure could be still higher.

Though the waterlogging and salinity problems pose serious threat to agricultural lands and the environment, the drainage measures have not received the required attention. Only surface field drains of 0.057-0.085 cumec (1-1.5 cusec) capacity have been excavated in an area of 25,120 ha (about 10 to 30 m length/ha) till July, 1998, while the attempts on subsurface drains (SSDs) have been sporadic. The Master Drainage Plan for UKP Stage-I identified 84,215 ha in need of SSDs. The land development works have been carried out in 25 % of the notified irrigation development area only. Looking to the enormity and seriousness of the problems of waterlogging and salinity, the present plans seem to be grossly inadequate. Therefore, mitigative measures are urgently required to halt the further spread of the problems and reclaim the already affected areas.

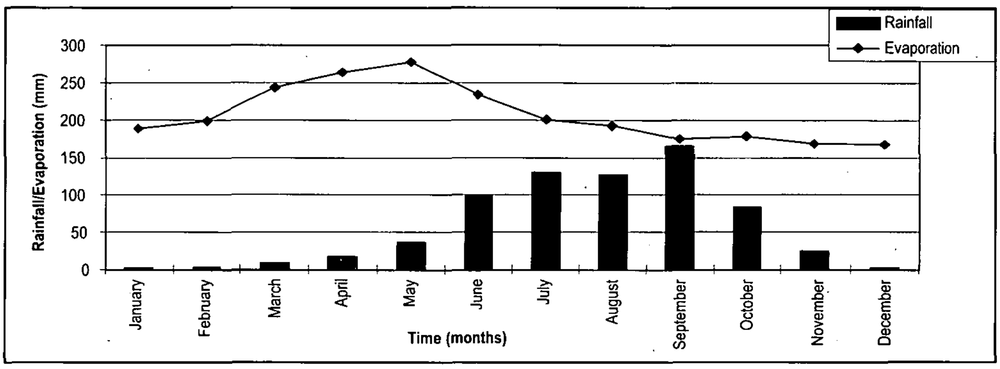


Figure 24. Rainfall and evaporation in the UKP command area

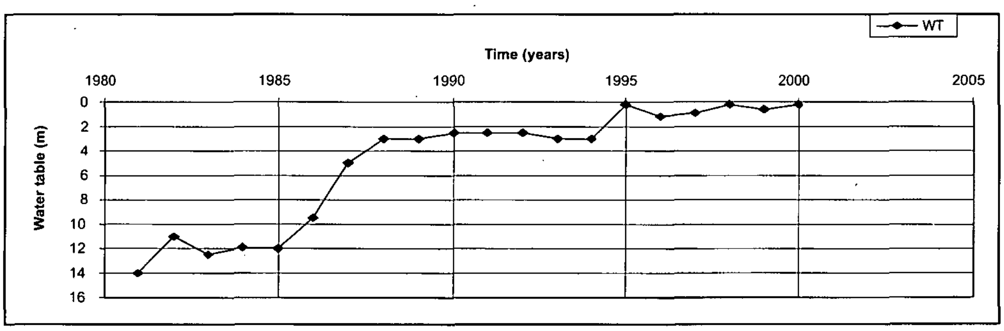


Figure 25. Hydrograph of an observation well at the Arkera village in the UKP command

9.3 Pilot Areas – Physical Setting and Brief Description

The site of the Indo-Dutch Network ORP is a part of the command area in the villages of Islampur-Devapur (J) which is one of the worst hit areas by waterlogging and salinity. It comes under the Narayanapur Left Bank Canal (NLBC) command of the UKP Stage-I Phase-I and is situated in Shorapur *taluk*, Gulbarga district (Fig. 26). The ORP comprises of 180 ha area. On the western side, the NLBC in banking and a *nala* on the eastern side form the boundaries. The average annual rainfall is 573 mm, of which about 80 per cent occurs during June-October. Though drainage network is inadequate, there is sufficient gravity outfall available in the area to facilitate drainage works.

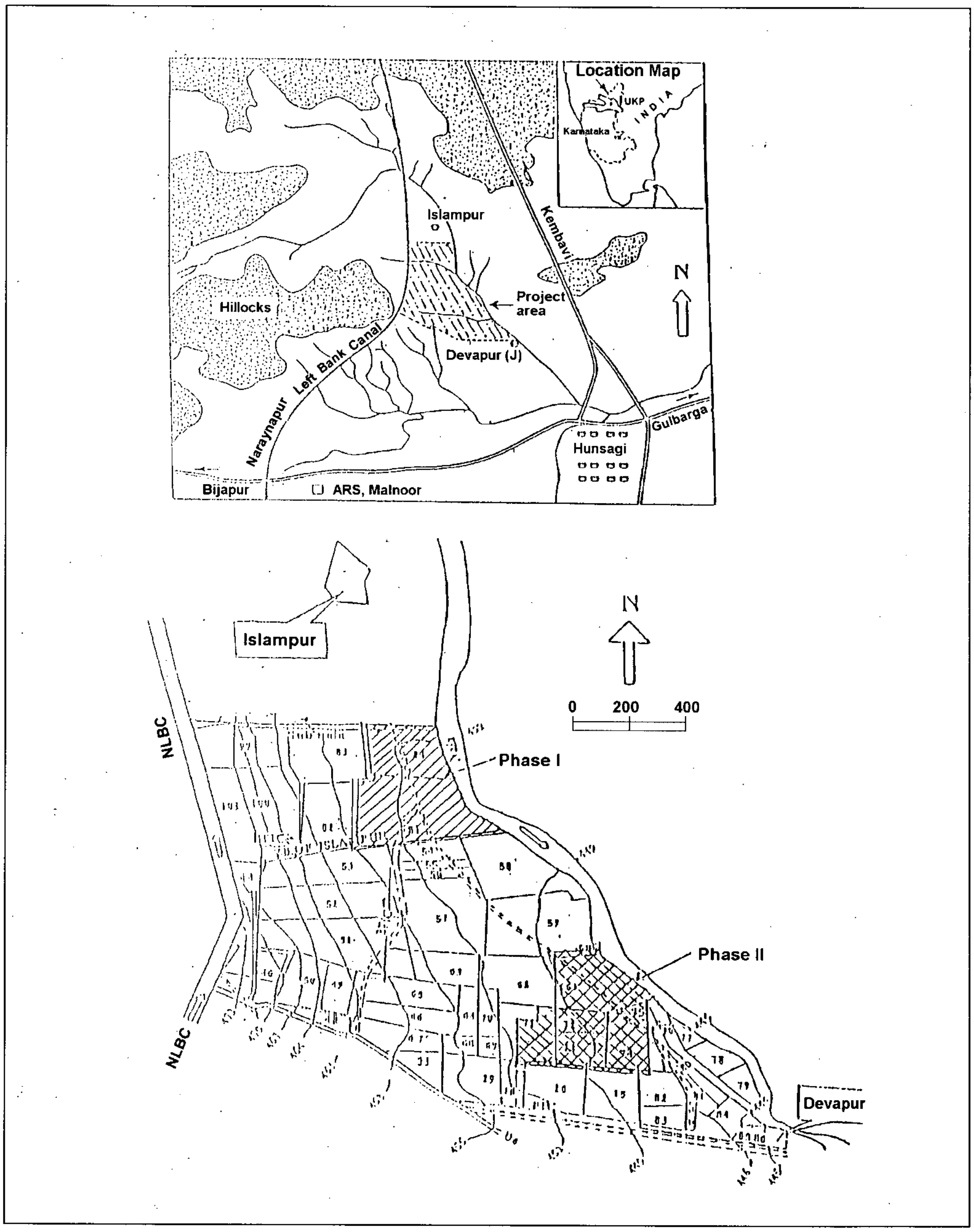


Figure 26. Location of the study area and site map

The soils of the area are deep to very deep black soils and are pre-dominantly clay in texture with swelling and shrinkage characteristics. The clay content ranges from 45 to 72 per cent that increase with depth. Under the USDA classification, these soils have been grouped under *Typic Pellusterts* and belong to Kagalgomb series. The substrata constituting limestone of the Bhima series are bedded and layered in nature and hence are porous.

The Phase-I area is situated near to the Islampur village and spreads over an area of 14.9 ha. The area received irrigation since 1985 and good crops were harvested initially for a period of 1-2 years. The site is an exceptional one in that the continuous dumping of water over the years has converted it into marshy land with *Prosopis*, thorny bushes and dense *Typha* grasses in the absence of adequate drainage. Due to this, the area has not been cultivated since 8-10 years and the farmers had shifted their activities from the area.

The Phase-II area is located in Devapur(J) village and comprises of 14.4 ha. Within 5-7 years of the commencement of irrigation, the problems of waterlogging and salinity/sodicity surfaced and caused significant reduction in crop yields. Both the problems of waterlogging and salinity / sodicity were pre-dominant in the Phase-II area. Since cropping pattern in this area is quite diverse and looking to the nature of the problems being experienced, the Phase-II area could be considered to represent major part of the UKP command in true terms.

9.4 Nature of the Problem

Pre-drainage investigations in the ORP area during 1997-'98 on 150 x 150 m grid basis revealed that the water table was within 1.5 m below ground level (bgl) in 51 per cent area during the *kharif;* while the area under salinity was 11 per cent. In addition, both the waterlogging and salinity problems were together found in 31 per cent of the area. The areas affected by the problems are presented in the Table 59. The analysis also revealed that the salinity problem was more serious during *kharif,* while waterlogging was pre-dominant during the *rabi* season. The pre and post–monsoon depth to water table, and soil salinity maps are shown in Fig. 27 and Fig. 28. The presence of the artesian pressure compounds the drainage congestion. The depth – duration – frequency analysis of the rainfall data revealed that for maximum 3 days consecutive rainfall of 5 and 10 years return periods and for the prevailing cropping system (3 days submergence can be allowed), requirement of drainage capacities is 48 and 63 mm day $^{-1}$ (Table 60).

Table 59. Classification of the problems in Islampur/ Devapur pilot area

Particular	Area affected (%)			
	ORP	Phase-I	Phase-II	
			Drained	Control
Waterlogged	51	52	26	31
Saline	11	0	5	0
Waterlogged and saline	31	48	64	62
Non-problematic	7	0	5	7

Table 60. Drainage capacities required to remove excess rainfall in UKP command area

Return period (Years)	Drainage capacities (mm d^{-1})		
	24 hr	48hr	72hr
5	88	64	48
10	121	85	63

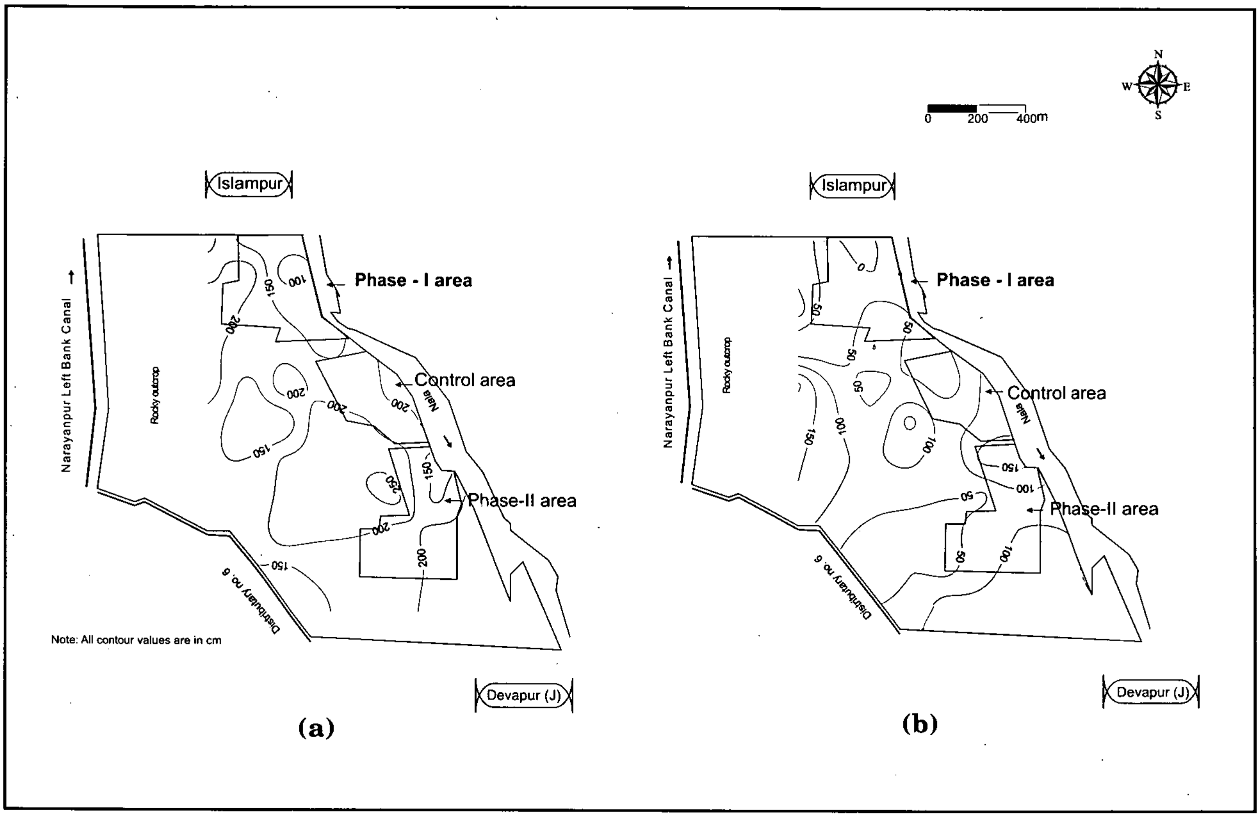


Figure 27. Contour map showing depth to water table in the ORP area (a) June-July, 1997 and (b) October-November, 1997

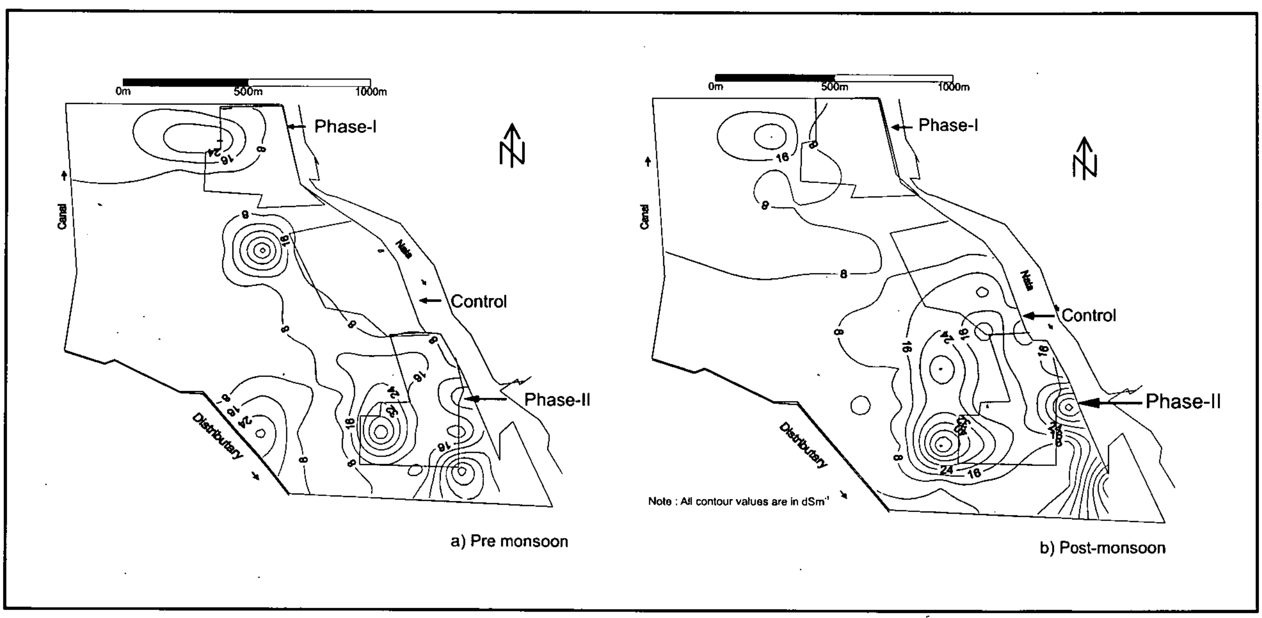


Figure 28. Root zone soil salinity during pre and post-monsoon (1997 and 1998)

9.5 Drainage Works

Based on the pre-drainage investigations, the drainage plans were formulated and the SSDs were executed in two phases-Phase-I and Phase-II during 1998 and 1999 respectively. The important parameters of the pre – drainage investigation are summarised in Table 61.

Table 61. Important basic characteristics of the ORP area

Serial No.	Particulars	Value
1	Climate	Semi-arid
	a. Rainfall (mm)	573
	b. Evaporation (mm)	1909
2	Size of pilot area (ha)	180
3	Topography	Slightly steep sloping near NLBC to very gently sloping to nearly level plain in lower reaches
4	Slope characteristics (%)	1.2 - 3.2
5	Availability of natural drainage channel	In the viscinity of the pilot area
6	Type of outlet	Gravity
7	Water table fluctuation (m)	0-2
8	Average hydraulic conductivity (m day^{-1})	0.077
9	Depth of impervious layer (m)	10
10	Irrigation status (ha)	
	a. Irrigated	66.5
	b. Unirrigated (Barren/ pasture)	113.5
11	Irrigation sources (ha)	
	a. Canal	66.5
	b. Well	nil
	c. Drain	nil
	d. Conjunctive use	nil
12	Infiltration rate (mm hr^{-1})	2.2
13	Salt-affected area (ha)	
	a. Saline	29.8
	b. Sodic	13.6
	c. Saline-sodic	29.8
14	Quality of ground water	
	a. EC (dS m^{-1})	2.7
	b. SAR $(mmol^{-1}l)^{1/2}$	7.0
	c. RSC($meql^{-1}$)	-7.4
15	Soil texture	Clay
16	Design criteria	Lowering water table to 0.8 m depth, with design DC as 9 and 5 mm day^{-1} respectively in high seepage zone (Phase-I) and Phase II respectively
17	Drainable pore space (%)	3-4
18	Surface drainage coefficient (mm day^{-1})	48 for normal crops and 88 for sensitive crops
19	Upward pressure of water	exists

The layout of Phase-I SSDs is singular with the drains directly draining in to the *nala*, while it is composite in the Phase-II area. In Phase-I area, the closed SSDs were laid at 1 – 1.1 m depth adopting 50 m spacing with 8 and 10 cm dia PVC perforated corrugated pipes in 5.6 ha (Table 62). Using the same spacing, the open SSDs, were excavated to 1 – 1.1m depth with 1:1 side slope and 0.4 m bottom width in 9.3 ha. Another 490 m open drain was excavated for draining off the tail-end losses of the field irrigation channels (FIC) and runoff.

Similarly, in Phase-II area, the closed SSD laterals were laid out in 12.7 and 1.7 ha at 1.1 – 1.2 m depth using 50 and 30 m spacing respectively to a length of 2,872 m. The system also consists of 707 m collector line laid at 1.35 - 1.45 m depth. Shallow open field drains were also excavated to remove the excess overland flow.

The monitoring of the Phase-I and Phase-II areas started in September, 1998 and August, 1999 respectively and since then the data on water table, drain discharge, soil salinity, leachate quality, cropped area and yield are being collected as per the standard monitoring plan.

Table 62. Particulars of subsurface drainage systems

System	Spacing (m)	Depth (m)	Area (ha)
		Phase-I area – Singular system	
Pipe drains	50	1.0 – 1.1	5.6
Open drains	50	1.0 – 1.1	9.3
Sub-total			14.9
		Phase-II area – Composite system	
Pipe drains	50	1.1 – 1.2	12.7
Pipe drains	30	1.1 – 1.2	1.7
Sub-total			14.4
Total			**29.3**

9.6 Packages to Combat Waterlogging and Salinity

Based on the post drainage monitoring programme, packages to combat waterlogging and salinity have been developed (Table 63). The packages are briefly discussed in the following sections.

9.6.1 Surface drainage

To remove the excess rainfall and irrigation runoff, shallow open surface drains are recommended. Proper land grading of the fields must be carried out before the excavation of the drains. The surface drainage coefficient of 34.4 - 47.6 mm d^{-1} (4 - 5.5 lps ha^{-1}) is considered appropriate for the design of shallow open field drains serving an area of 5 – 40 ha depending on the topography, local conditions etc. Trapezoidal section with a minimum of 1:1 side slope is recommended in heavy clay soils. Minimum bottom width and depth should be 0.3 m and 0.45 m respectively. The permissible grade is 0.1 - 0.5 per cent while the velocity of flow of water should not exceed the

Table 63. Packages to combat waterlogging and salinity

Packages	Cost (Rs/ha)	To solve
	Drainage	
Surface drainage	3,000*	Water stagnation/ponding
Subsurface drainage system (Singular)		Waterlogging and salinity
Open drains (50 m spacing)	8,600	Waterlogging and salinity
Pipe drains (50 m spacing)	19,500	Waterlogging and salinity
Composite drainage system		
30 m spacing	33,717	
50 m spacing	24,050	Waterlogging and salinity
Envelope (Optional)		
30 m spacing	37,713	
50 m spacing	26,450	waterlogging and salinity
	Irrigation	
Land levelling and bunding	3,780-5,320	
FIC lining	205/RM	
Improved surface irrigation	600**	
Leaching	300***	Salinity and sodicity
Drip irrigation	4,270	
	Soil management	
Gypsum application	300/unit of ESP	Sodicity
Land tillage	2,600	
Green manuring	1,050	Salinity, sodicity & waterlogging

* Cost includes only shallow field and related collector drains only, it does not include related civil structures and link drain connecting to the main nala.

**The cost includes making ridges and furrows/border strips

***The cost is only for labour. The total cost depends on initial salinity, rain water harvesting and water and pumping charges
RM = Running meter

permissible limit of 1.2 - 1.5 m s^{-1}. The drains should be aligned along the farm/ block boundaries to freely drain the entire area.

9.6.2 Open Subsurface Drains

The trapezoidal sections should be excavated at 50 m spacing to a depth of 1.0 to 1.1 m with 1:1 side slope, 0.5 m bottom width and 0.1 – 0.2 per cent bed slope in clay soils (e.g. cross-section area of about 1.5 sq m). In undulating lands, suitable drops can be provided. The drains be aligned preferably along the field/farm boundaries to avoid any social disputes and interference in the farm operations. The excavated earth should be spread all over the field. Proper maintenance is essential for the free flow of water. Wherever *bunds* are provided, appropriate provisions should be made for water to enter the drains. For this purpose, inlet points at regular interval should be constructed.

9.6.3 Closed Subsurface Drains

Closed pipe SSDs should be installed at 50 m spacing at a depth of 1.1 - 1.2 m with a bed slope of 0.05 – 2.0 per cent. In flat areas where appropriate gradient is not available, to place the laterals at constant depth below the soil surface, herringbone pattern of laterals could be adopted. For the laterals, 8 to 10 cm diameter PVC perforated corrugated drainage pipes are used. Reinforced cement concrete non-pressure pipes (class II) of 15 cm or more diameter are found to be cheaper for collectors. However, considering the transportation, handling and easy installation particularly under unstable conditions, smooth PVC pipes could be preferred although the cost would be slightly high. Based on the topography and proximity of the outlet, either singular or composite type of layout could be selected. In the singular system, the design is simple and the construction of the collectors and manholes are avoided; thus saving about 25 to 30 per cent cost over the composite system. It is always useful to uproot unproductive trees and bushes. Wherever the lateral drains pass through the area with trees, one should use non-perforated pipes in that reach.

9.6.4 Soil Management

Soil management practices to be used as supplementary measures to the drainage package are:

Tillage: The soil needs to be ploughed deep before cultivation to improve infiltration rates, to facilitate free drainage and to effectively leach the salts from the root zone.

Green manuring: For green manuring *dhaincha* should be grown. The recommended seed rate is 50 kg ha^{-1}. The plants should be incorporated into the soil (45 days aftrer sowing) to improve the soil physical conditions and the soil fertility.

Gypsum application: Gypsum should be added to alkali patches where ESP is more than 10. About 0.25 t ha^{-1} gypsum be added to reduce the ESP by one unit. Fine-powdered gypsum should be broadcast on the sodic patches and mixed in a shallow depth for effective reclamation.

9.6.5 Irrigation Management

Similar to the soil management measures, several water management practices are adopted as supplementary to the drainage package.

Land development: The land development includes the clearing of small bushes and typha grass where needed followed by land levelling and bunding. The cost of bush clearance is about Rs. 2,000 per ha and the cost of land levelling varies from Rs. 5,320 to Rs. 3,780 per ha depending upon the initial and final slopes.

Leaching: After the installation of the SSDs, to leach the salts from the root zone, a one-time 30-60 cm depth of water needs to be impounded in increments of 10 cm each depending on initial soil salinity. The leaching should be completed before sowing of *kharif* crops for better establishment of crops. Since in UKP command, the canal water is not generally released before the second fortnight of July, it is suggested to take advantage of the rainfall by impounding the rain water for leaching. It would also help early sowing of crops.

FIC Lining: To minimize the conveyance losses and to increase the stability of the structure in swelling and shrinking type of clay soils, a murrum cushion of 15-20 cm thickness is recommended below lining of the field irrigation channels. As per the UKP-CADA estimates, the cost of construction of the FIC with limestone slabs is Rs. 180 per m without murrum cushion. The cost of murrum cushion is only Rs. 25 per m in addition to the cost while it results in considerable reduction in conveyance losses as well as increase in life of the channels.

Irrigation methods: The most suitable irrigation method for cotton grown in the black soils of the command is alternatively alternate furrow irrigation with 8 cm depth at an irrigation interval of 20 days. Similarly, for the wheat crop border strip method of irrigation (5-7.5 m width) with a stream cut-off at 80 per cent of the border length, 6 cm depth at an irrigation interval of 15 days is suitable.

Drip irrigation: The water application through drip irrigation @ 0.8 ET per plant to brinjal and tomato crops is recommended to obtain higher yields.

9.7 Benefits of Drainage

9.7.1 Cropping Intensity

In pipe SSD (50 m) of Phase-I area, there was considerable increase in the average annual cropping intensity (CI). From nil prior to the drainage works, it increased to 27, 35 and 200 per cent during the 1st, 2nd and 3rd years in the post-drainage period. In Phase-II area, the average CI during pre-drainage situation was 87 per cent against 21 per cent in the control area. After the installation of drains, the cropping intensity increased to 114 and 156 per cent during 1st and 2nd years, while that of the control area increased only marginally to 28 per cent.

9.7.2 Crop Yield

The crop yield in the control and the drained area during pre-drainage was at par. There was considerable improvement in the yield of crops after drainage in the pilot area, whereas the yield reduced or remained almost at the same level in the control area. In phase II area, the average cotton yield during pre -drainage period in drained and control areas were 0.67 t ha^{-1} and 0.68 t ha^{-1}. The same during post- drainage period increased to 1.15 t ha^{-1} and 1.08 t ha^{-1} in 30 and 50 m drain spacing, against 0.69 t ha^{-1} in control area (Table 64). There was improvement in the yield of *kharif* paddy from 1.86 to 3.10 t ha^{-1} in 30 m drain spacing, from 2.00 to 2.95 t ha^{-1} in 50 m drain spacing, whereas in control the same decreased from 2.00 to 1.50 t ha^{-1}. Similarly the *rabi* sorghum yield increased from 0.50 to 0.74 t ha^{-1} in 30 m and 0.53 to 0.71 t ha^{-1} in 50 m drain spacing, while in control area, a reduction in yield from 0.56 to 0.48 t ha^{-1} was observed. The *rabi*/summer paddy yield increased from 2.20 to 4.10 t ha^{-1} in 30 m spacing, and that in 50 m spacing from 2.38 t ha^{-1} 3.95 t ha^{-1}. In control area the *rabi*/summer paddy yield remained almost at the same level i.e 2.40 t ha^{-1}. It was observed that the crop yield is numerically higher in 30 m compared to 50 m drain spacing.

Table 64. Crop yields in drained and control areas in phase-I and phase-II (t ha $^{-1}$)

Situation	Crop	Phase-II			Phase-I
		30m	50m	Control	Pipe SSD 50m
Pre-drainage (1997 to 1998)	Cotton	0.67	0.70	0.68	
	Kharif paddy	1.86	2.00	2.00	Abandoned lands
	R/S paddy	2.20	2.38	2.40	
	Rabi sorghum	0.50	0.53	0.56	
Post-drainage (1999 and 2000)	Cotton	1.15 (72)	1.08 (54)	0.69 (2)	-
	Kharif paddy	3.10 (67)	2.95 (48)	1.50 (-33)	3.50
	R/S paddy	4.10 (86)	3.95 (80)	2.38 (-8)	3.90
	Rabi sorghum	0.74 (48)	0.71 (34)	0.48 (-14)	-

Figures in parentheses indicate per cent increase over pre-drainage

9.7.3 Depth to Water Table

Shallow open drains: These drains were meant to remove the surface runoff. Shallow open drains disposed off the excess rainfall during the monsoon and irrigation losses during the cropping season to make the environment conducive for crop growth. Thus, the temporary water stagnation on land surface was avoided besides reducing the load on the SSD system. Further, improved trafficability conditions helped to complete the farm operations in time and the lands became arable.

Open subsurface drains: By excavating the open SSDs, the water stagnation in some pockets completely disappeared and the average water table depth was lowered from 38 cm below ground level (bgl) before drainage to the 48 cm after the excavation of the drains.

Pipe SSDs: By installing the SSDs, the water stagnation was completely removed. The average water table depth, which was 9 cm bgl before drainage was lowered to 47 cm after the drainage, the reduction being statistically significant. In the Phase-II area, there was not much change in the water table depth in comparison to the pre-drainage conditions. It could be ascribed to the fact that the area under paddy increased from 0.4 to 7.2 ha after the SSDs. Moreover, cropping intensity increased from 87.5 to 156 per cent resulting in more groundwater recharge. On the other hand, the average water table depth was 86 cm bgl in the drained area compared to 63 cm in the control area. This difference was statistically significant. Among the drains of different spacing, the average depth of water table was 89 cm in 30 m compared to 83 cm in the 50 m spacing.

9.7.4 Discharge from the Drains

In the Phase-I area, the weighted average discharge in the closed and open SSDs were 9.0 and 6.6 mm d^{-1} respectively with 90 per cent of the time the drain discharges not exceeding 12.7 and 10.4 mm d^{-1}. In the Phase-II area, weighted average discharge in the laterals and collectors were 0.7 and 1.8 mm d^{-1} respectively and 90 per cent of the time, the drain discharges did not exceed 1.6 and 3.2

mm d^{-1}. While the average drain discharge is recommended for computing the drain spacing, 90 per cent cumulative frequency of non-exceedance should be considered for the design of the pipe sizes.

9.7.5 Soil Salinity

No change in the soil salinity was observed in the drained area by open drains. However, the soil salinity was maintained at a lower level in pipe SSD area of the Phase-I. The root zone soil salinity decreased significantly after installation of pipe SSDs in both 30 and 50 m spacing in the Phase-II area (Fig. 29 and Fig. 30).

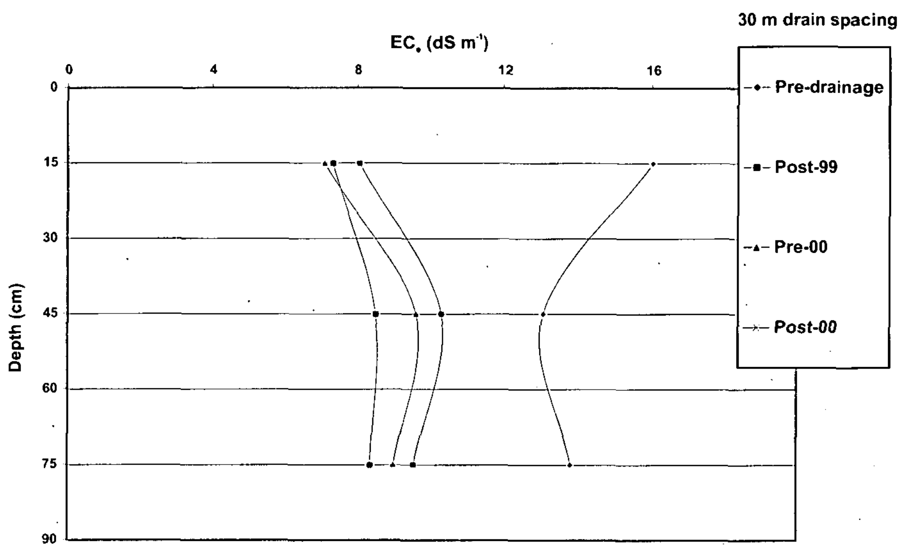


Figure 29. Changes in soil salinity in 30 m spaced drains

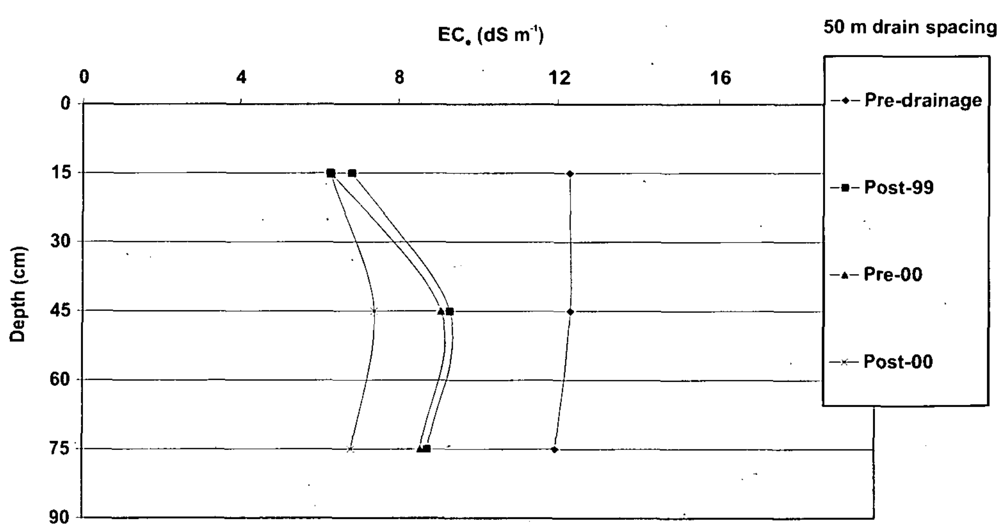


Figure 30. Changes in soil salinity in 50 m spaced drains

9.8 Benefits of Soil/Water Management

9.8.1 Soil Management

Gypsum: Broadcasting and incorporation of gypsum at the rate of 2-14 t ha^{-1} resulted in reduced soil ESP. As such, it improved the soil physical conditions . The sunflower and cotton yields increased by application of gypsum.

Green manuring: *In-situ* incorporation of *dhaincha* after 45 days of sowing into the salt-affected soils by deep plouging improved the soil physico-chemical properties. As a result the wheat yield increased by 21 per cent.

Pre-sowing leaching: The pre-sowing leaching with provision of drainage by impounding 30-60 cm water in the drained area decreased the root zone soil salinity leading to significant increase in the cotton yield.

9.8.2 Water management

Land development: The increase in yield and water saving were 27 and 49 per cent respectively over unlevelled land in cotton and the same were 33 and 35 per cent respectively over unlevelled land in wheat.

FIC lining: The conveyance loss was only 5 per cent of inflow in FICs lined with limestone slabs with 15-20 cm murrum cushion whereas the losses were 10 and 14 per cent of inflow in the existing lining without murrum cushion and unlined (control) FICs. With a small additional investment on murrum cushion, the conveyance losses could be minimized by half (100 per cent reduction). Besides the structure was more stable with murrum cshion and found intact even after 2 years.

Irrigation methods: By adopting alternatively alternate furrow method of irrigation for cotton, 49 per cent water was saved over all furrow irrigation commonly practiced by the farmers. Similarly, in wheat, border strip method of irrigation with cut-off at 80 per cent length of the border saved 35 per cent water over flood irrigation commonly adopted by the farmers.

Drip irrigation: The water application @ 1.5 liters per day per plant through drip irrigation to brinjal and tomato crops recorded the maximum yield of 14.8 and 16.4 t ha^{-1} respectively. However, the yield obtained in surface irrigation method (all furrow) was 12.2 and 13.7 t ha^{-1}. The water saving in case of brinjal and tomato was 56 and 69 per cent over surface method.

9.9 Investment on Drainage and Economic Viability

Though the cost of drainage varies widely, it mainly depends on drain spacing and depth. The project scale cost of the singular drainage system for 50 m spacing was Rs. 19,500 (Table 63) but it would vary from Rs. 30,250 to Rs. 34,250 and Rs. 19,500 to Rs. 21,900 per ha for 30 and 50 m spacing without and with envelope material respectively. Similarly, the corresponding investment cost on composite system ranged from Rs. 33,720 to Rs. 37,720 for 30 m and Rs. 24,050 to Rs.26,450 for 50 m drain spacing without and with envelope materials (Table 63).

Analysis of the financial feasibility of the drainage system at 12 per cent discount rate for 50 m SSD systems for 30-years life period shows that the benefit- cost ratio is more than one in all cases i.e. for both singular and composite types and also for with and without envelope. It was highest at 1.30 for singular type, both without and with envelope material (Table 65). The corresponding BC ratios in case of composite system were 1.20 and 1.15. The net present worth of the investment on singular and composite types for 50 m drain spacing is found to be positive. This implies that the investment is economically viable.

Table 65. Economic viability of subsurface drainage system in UKP command on project scale costs for 30-year project life

Parameter	Without envelope		With envelope	
	Singular pipe SSD (50 m)	Composite pipe SSD(50 m)	Singular pipe SSD (50 m)	Composite pipe SSD (50 m)
Net present worth (Rs. ha^{-1})	34,913	14,164	32,513	11,764
Benefit-cost ratio	1.30	1.20	1.30	1.15
Internal rate of return (%)	35	20	31	18
Pay back period (No. of years)	4	9	5	10

Amongst the other economic parameters, the internal rate of return (IRR) is more than the interest being offered by the commercial banks on their term deposit (Table 65). The same was found to be very high (35 and 31 per cent in case of without and with envelope respectively) for singular system, which was influenced by low investment cost of SSD. Since the lands in the phase-I area were lying barren prior to drainage installation due to high water table conditions, the yields realised after the drainage were net addition due to drainage. The IRRs under composite system without envelope was 20 per cent and that for with envelope material was 18 per cent. This signifies the viability of investment on drainage to reclaim the degraded agricultural lands. The payback periods for both without and with envelope cost for singular pipe drainage system were found to be 4 and 5 years respectively, whereas the same for composite system were 9 and 10 years. Wherever the topography and the local conditions permit, the singular drainage system may be adopted as it reduces the investments. The results of the present study reveal that wider drain spacing at 50 m is economically viable and practically cost-effective. The results also give an indication towards the necessity of testing the performance of even more wider drain spacing so that technology becomes cheaper to adopt. This is particularly true when large-scale land reclamation programmes are taken up involving huge investments.

The assessment of economic viability of the investments on land drainage was purely based on the actual land use pattern and crop yields monitored after the drainage installation that are still on the increase. The per ha average pre and post-drainage costs and returns obtained from the farmers were considered in the analysis. The optimum and the realistic effects on the increase in land use, crop yields and consequently on the net returns as a result of reduction in the soil salinity and the water table depth are yet to come. It would take some more time to achieve optimum yields. It is believed that the indicators of economic performance of the investment on drainage would further improve . The underlying assumption is that with the improvement in soil physical and hydrologic/ hydraulic conditions, there would be improvement in the land use, input use pattern and their efficiency leading to increased crop yields.

9.10 Secondary Benefits of Land Reclamation

The reclamation of waterlogged saline lands besides resulting in direct benefits and sustainability of irrigated agriculture also helps to achieve the following benefits.

9.10.1 Employment

Reclamation programme generates employment opportunities both during drainage execution and during the post-drainage period under crop production programme (Table 66). It generated as many as 127 man days work per ha for installing SSDs. Further, the intervention also offered an annual employment of 597 man days per ha on the reclaimed land under crop production activities. This has led to an annual increase of 84 man days work per ha over the pre-drainage under major crops. Together for all the crops, it generated an additional 72 man days work annually.

Table 66. Employment generated due to reclamation of waterlogged saline lands, mandays

Particulars	Type of labour	Pre-drainage (Average of 1996 to 1998)	Post-drainage (Average of 1999 and 2000)	Gain in employment
Drainage installation	—	—	127	127 (0.35)
Production of major crops	Hired Labour	287	302	
	Family labour	191	260	
	Total	478	562	84
All crops together	Hired labour	300	314	
	Family labour	225	283	
	Total	525	597	72
No. of man years (all crops)		1.44	1.64	0.20

N.B: Major crops include cotton, *kharif* paddy and *rabi*/summer paddy.

9.10.2 Share of Industrial and Non-farm Sector Inputs

Share of the industrial sector in the total cost of installation of SSDs is estimated at 66 per cent. Thus, a boost to the industrial sector and rural based industries may be expected through large-scale land reclamation programme. In addition, after the drainage, the share of non-farm sector input cost in the total production cost such as fertilizers, chemicals, machinery and equipment, transportation and marketing services ranged from 39 to 58 per cent for various crops (Table 67) over the pre-drainage share of 35 - 46 per cent. Among the major crops, there, was a sizable increase in the demand for non-farm sector inputs under paddy production followed by cotton.

Table 67. Share of non-farm sector inputs after land reclamation(%)

CROP	Project area	
	Pre-drainage (Average of 1996 to1998)	Post-drainage (Average of 1999 and 2000)
Cotton	41	51
Kharif paddy	46	56
R/S paddy	44	58
Rabi sorghum	35	39

9.10.3 Market Value of Land and Social Status

The land reclamation also leads to improvement in the social status of the farmers with improvement in the land productivity. There was considerable improvement in the asset value of the land after drainage (Table 68). The increase in land value within three years after the drainage was as high as 142 per cent (from Rs. 36,000 to Rs. 87,000 per ha) over the pre-drainage land value. During the same period, the increase in the land value in the control area, where the problems of waterlogging and soil salinity prevailed, was found to be only marginal (from Rs. 38,000 to Rs. 46,000 per ha). The value of the normal lands in the study area was high and increased from Rs. 1,32,000 to Rs. 1,70,000 per ha indicating an appreciation of 29 per cent during the period.

Table 68. Impact of land drainage on the market value of land (Rs. ha^{-1})

Condition	Project area	Control area	Normal area
Pre-drainage (1996-'97)	Rs. 36,000	Rs. 38,000	Rs. 1,32,000
Post-drainage (2001-'01)	Rs. 87,000	Rs. 46,000	Rs. 1,70,000
Percentage change	(+) 142	(+) 21	(+) 29

9.11 Socio-Economic and Gender Issues

A total of 59 farmers from the project area and an equal number of farmers from the normal lands adjoining to the project area were chosen for base line and impact assessment surveys. This section deals with only the respondents from the project area.

The average family size was 7.1 with male and female percentage as 51 and 49 respectively. More than 50% of the population was illiterate although at least 5% of the population has attended the college. Majority of the farmers lived in independent family system (81%) while only 19% lived in a joint family system. The respondents in the project area have an average holding size of 4 ha. While 39% of the farmers have more than 4 ha, 23 percent of the respondents have less than 1 ha of land holding. The productivity of cotton and paddy during *kharif* season is quite low. However, the *rabi* paddy yield were relatively higher than *kharif* paddy. Agriculture was the primary source of occupation for only 54% of the families in the project area while outside the project area, 80% of the households had agriculture as the primary occupation. Agriculture and non-agricultural labour was the second important occupation of the 40% of the families in the project area.

9.11.1 Farmer's Perception of Waterlogging and Soil Salinity

A total of 59 respondents were interviewed to know the farmers perception of the causes that led to the problems of waterlogging and soil salinity. More than 70% of the farmers were of the view that canal seepage and leakage, lack of attention on drainage and increased weed infestation following introduction of irrigation has caused these problems. Following salient observations could also be made.

- Several coping up strategies adopted by the farmers such as change in the cropping pattern, application of amendments and additional doses of nutrients failed to provide long-term relief.
- After the commencement of irrigation, the land value appreciated in all cases but it was only 32-34% in case of waterlogged / saline lands while it was 194-226% in the case of normal land.
- There has been a spurt of migration from the village after the problems of waterlogging and soil salinity emerged in the pilot area. Reclamation of agricultural land might help to bring these families back to the village

9.11.2 Impact Analysis of Subsurface Drainage

Post project evaluation to assess the farmer's views on the drainage technology revealed that:

- All the respondents agreed that drainage is an effective technology to solve the problems of waterlogging and soil salinity leading to increase in the yield, increase in cropping intensity and switchover from subsistence farming to cultivation of cash crops.
- All the farmers are in favour of pipe drainage systems as compared to open drains. Farmers realized that the anticipated loss in the cultivated area, difficulties in maintaining the open drains and difficulties to undertake farming operations are major impediments in adopting open drains.
- Farmers are willing to maintain field drains at their own cost.

9.11.3 Gender Issues

The gender related issues were studied from a sample of 60 households from Islampur and Devapur(J) villages located in the Operational Research Project area.

- The data revealed that a large work force consists of females and 53% of the families had more than two female earning members.
- The wage rate for women were around 50% of their male counterparts both in peak as well as slack periods.
- According to female population, salinity (88%), waterlogging (87%), obnoxious weeds (45%) and alkalinity (15%) were the main problems of the area resulting in low yields.
- More than half of the females interviewed were aware of the subsurface drainage (55%).

10. MONITORING AND EVALUATION OF INTERCEPTOR AND SUBSURFACE DRAINAGE SYSTEMS IN TUNGABHADRA CANAL COMMAND,KARNATAKA (UAS)

10.1 Introduction

Tungabhadra irrigation project (TBP) is a major inter-state irrigation project of peninsular India. It was commissioned during 1953 with an irrigation potential of 3.63 lakh hectares in Karnataka and 1.6 lakh hectares in Andhra Pradesh. The location map of the TBP is shown in Fig. 31. The project is served by three canals i.e; Right bank high level canal (RBHLC), Right bank low level canal (RBLLC) and Left bank main canal (LBMC). The RBHLC and RBLLC serves the Bellary district of Karnataka as well as the areas in Andhra Pradesh while LBMC only serves Koppal and Raichur districts of Karnataka. The potential command area of RBHLC, RBLLC and LBMC in Karnataka are 80,908, 37,503 and 2,43,900 ha, respectively. Prior to 1990, cotton was the major crop and irrigations were mainly protective after cessation of monsoon rains. However, in recent years frequent failure of cotton due to pests and diseases and secondary salinization of the area, paddy has overtaken cotton and

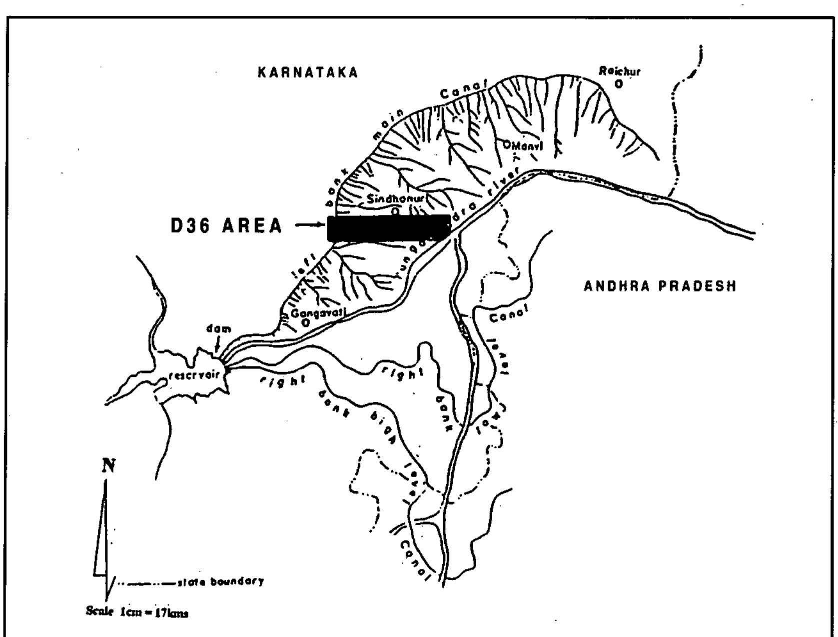


Figure 31. Location map of the TBP command

is continuously grown over the whole year. The project, as said before, was designed for protective irrigation where only light irrigated crops were expected to be grown. As such almost three-fourth of the command was earmarked for light irrigated crops. About 8 percent was proposed for paddy and 4 percent for sugarcane, the remaining being cotton and garden crops, which are two seasonal. This is particularly so in the case of (LBMC). Presently, crops grown in the LBMC area are paddy, sugarcane, cotton, garden crops (vegetable, spices, fruits), "*kharif* light" and "*rabi* light" such as cereals, pulses and oil seeds.

The topography of the Left Bank Command area is rather undulating and only occasionally gives the impression of flat plains. The main canal is a contour canal with a slope of 7 cm km^{-1}, with rocks and hills on the left side and crossing pronounced natural drains, which form the boundary of the command areas of two adjacent distributaries (secondary canals). The distributaries run on well-defined ridges, approximately perpendicular to the main canal. They have a longitudinal slope of the order of 0.2 – 0.5 m km^{-1}.

Soils in the area are mainly black cotton soils, but red soils also occur occasionally, covering about 13% of the area. The latter are coarse to fine sandy loam, yellowish brown to dark brown. Depths usually vary from 15 to 45 cm and the moisture holding capacity of the soil is low. The depth of the black soils vary. Most widespread are the medium (45-90cm) and deep (>90cm) black cotton soils, covering about 28 and 46% of the area, respectively. Shallow soils (15-45 cm) cover about 9% of the area.

The climate is arid to semi-arid. Rainfall is erratic with an average annual of some 500 mm. Nearly half of the annual rainfall occurs in September to October. From December to April the average rainfall is almost zero.

10.2 Extent and Distribution of Saline/Waterlogged Soils

After the introduction of irrigation, the ill-effects of waterlogging and salinity are overwhelming in the command area due to many reasons. The extent of problem, which was just under 20,200 ha during 1979-80 has risen to over 80,000 ha during 1996-97. It seems that since 1979-80, the area under waterlogging and soil salinization is increasing at the rate of 3,000 ha per annum (Table 69). Although, groundwater table generally builds-up in the command area whenever irrigation is introduced but in this case intensive irrigation through paddy helped to hasten the process. The shallow water table curtails the aeration in the root zone as well as leads to accumulation of salts especially in black cotton soil under semi -arid conditions. The recent studies have revealed that depth to water table is rising at the rate of 10 cm per year on the farm of the centre, which has a typical terrain as that of the irrigation command. The water quality surveys revealed that the groundwater quality in the 40% of the project area is good, while in the remaining 60%, it is poor having problems of salinity / sodicity. Because of the limited water available at the tail end, farmers are forced to use drain / *nala* / underground poor quality water and it has added a new dimension to the problem. The productivity and the potential productivity of various crops are shown in Table 70. According to a conservative estimate, the loss in crop production is assessed at about Rs. 250-300 million per year.

Table 69. Area under waterlogging/salinity in selected years

Year	Cumulative area affected by waterlogging/salinity (ha)	Increase over 1979-80 (ha/ annum)
1979-80	20,200	-
1984-85	35,000	3,000
1991-92	54,000	2,817
1996-97	80,000	3,523

Table 70. The production trends of crops grown in TBP area

Crops	Yield (t ha^{-1})	Potential yield (t ha^{-1})
Rice	2.5 – 4.0	5.0 - 6.0
Sugarcane	35.0 – 60.0	90.0 – 100.0
Cotton	1.5 – 2.0	3.0 – 4.0
Sunflower	0.8 – 1.0	2.0 – 3.0
Maize	2.0 – 2.5	5.0 – 6.0

10.3 Packages to Combat Waterlogging and Soil Salinity

10.3.1 Interceptor Drain (Single)

An interceptor drain consisting of clay pipes of 10 cm diameter was laid during summer 1992 at a pre-determined depth of 1.7 m (complete soil solum + half of the murrum depth) from the surface, running parallel to D-36 distributary of the left bank canal. The drain is placed about 250 m away from the natural drain (Halla- halla) and 500m from the distributary, D-36 (Fig. 32). The total length (east to west) of the interceptor drain was 800m with two outlets, one on the eastern and the other on the western side. The outlets were connected to natural drains. A 5 cm thick gravel envelope was used before refilling with black soils. Soil samples (0-22.5 and 22.5-45 cm) were taken before and after each crop and analysed for electrical conductivity and pH. Depth to water table was monitored on grid basis during August/September of each year. Crop performance was studied for both seasons by conducting crop cutting at all the grid point where soil salinity and depth to water table was monitored.

Soil salinity: Soil salinity decreased over a period of time at all the grid points (Table 71). The mean decrease in soil salinity at the area upstream to the interceptor drain was from 3.4 to 0.9 dS m^{-1}. Soil salinity at the downstream area of the interceptor drain but away from nala also showed a considerable decline from 5.9 to 0.8 dS m^{-1}. The area near to downstream nala, which was highly salinised earlier, was also de-salinised considerably (from 10.1 to 1.2 dS m^{-1}). Over a period of two years (1996 -98), the total salts removed from the soil rhizosphere were to the extent of 87.4 tonnes.

Water Table : After the installation of the interceptor drain the water table dropped over the whole area. Although the drop was more in the western side, where the pre-drainage watertables were considerably higher compared to the western side.

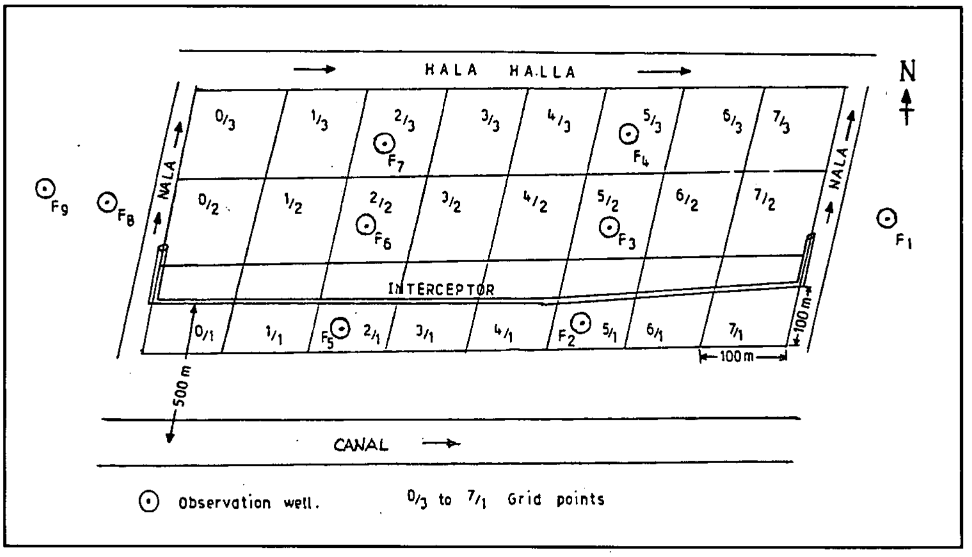


Figure 32. Layout of the interceptor drain (single)

Table 71. Spatial and temporal changes in soil salinity, depth to watertable and crop yield

Location	Pre-drainage (1992)	Post-drainage (1998)
	Soil Salinity (dS m^{-1})	
Upstream	3.4	0.9
Downstream	5.9	0.5
Near Nala	10.1	1.2
	Water table* (m;bgl)	
Upstream	123	158
Downstream	102	140
Near Nala	70	105
	Paddy yield (t ha^{-1})	
Upstream	2.4	7.5
Downstream	2.2	7.5
Near Nala	2.3	6.6

*average of observation wells
** average *kharif* and *rabi*

Crop performance: Rice yield registered a marked improvement, both above as well as below the interceptor highlighting the usefulness of the interceptor drain on crop yield. Performance of crop was understandably much better below the interceptor drain than above the interceptor except during 1997. This was observed both during *kharif* and *rabi* / summer seasons. Paddy yield improved from 2.4 to 7.5, 2.2 to 7.5 and 2.3 to 6.6 t ha^{-1}, respectively at upstream, downstream and near *nala* during *kharif* season (Table 71). While, it increased from 2.5 to 7.6, 2.3 to 7.8 and 2.4 to 6.5 t ha^{-1} during *rabi*/summer.

10.3.2 Interceptor Drain (Multiple)

A multi-tier interceptor drain of 10 cm diameter was laid at a depth of 0.75 m from the surface to intercept the incoming seepage from canal and prevent waterlogging and soil salinisation in low lying areas. The drains were laid at a spacing of 150 m running parallel to D-36/1 near Sindhanur during 1998 covering an area of 62 ha. The drain placement is about 100 m away from the natural drain (Vade halla) and 1500 m from the canal (Fig. 33). The interceptor drains are corrugated perforated PVC pipes with synthetic filter. Performance of multi-tier interceptor drainage system was initiated during *kharif* 1998 and continued up to *rabi* 2000-01.

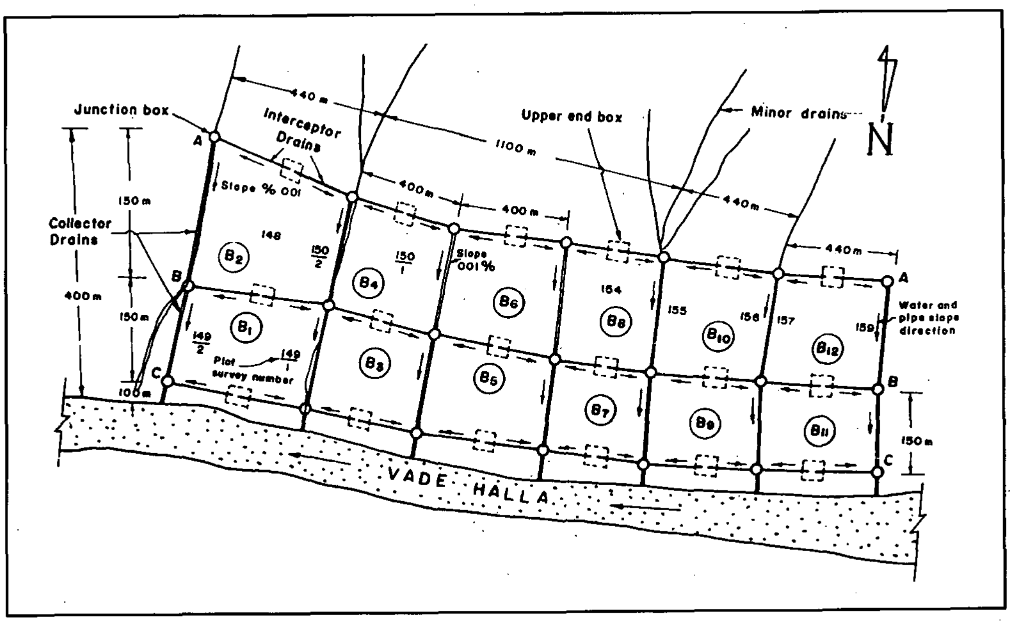


Figure 33. Layout of the multiple interceptor drainage system

In the case of multi-tier interceptor system, a higher drain discharge was recorded during the initial periods due to proper functioning of the drainage system and maximum drain discharge of 370 m^3 day^{-1} was recorded during the month of Sept 98 and 99. This coincided with post-monsoon season and cultivation of paddy crop. However, there was no discharge during June and July months due to canal closure. Due to partial blockage of the system by the farmers, drain discharge was reduced during the year 2000. Higher salt concentration of the drainage effluent (EC> 6 dS m^{-1}) was recorded during summer months (March - May) while, the drainage effluent was less salty during August to February.

To study the performance of all the three parallel interceptor drains (A, B and C), drain discharge and its salinity were measured separately during Aug. 2000 to May 2001. It was evident that all the three drains removed almost same quantity of drainage water and their salt concentration is also more or less similar. It indicates that the drainage water removed through the drains is mostly from the paddy area than intercepted seepage from the canal.

Soil salinity: Sharp decrease in soil salinity at all the 12 grid points was observed during the first season and thereafter salinity remained constant with time (Table 72). The mean soil salinity (0-30 cm) decreased from its initial value of 8.40 dS m^{-1} to 2.64 dS m^{-1} during *kharif* 1998 and decreased further to 2.15 dS m^{-1} during *rabi* 98-99. From *rabi* 98-99 (after one year) onwards, salinity remained constant with time at 2 to 3 dS m^{-1}. The soil salinity in the control (outside the study area) remained of the order of 8.5, 7.9 and 6.8 dS m^{-1} for 0-30,30-60 and 60-90 cm depth, respectively.

Table 72. Effect of multi-layered interceptor drainage system on depth to water table, soil salinity and crop yield

Parameter	Initial	Post drainage (Average of 6 seasons)
Depth to water table (cm bgl)	50	69
Soil salinity (dS m^{-1})	8.40	2.59
Crop yield (tha^{-1})	2.18	5.84

Water table: Water table depth has been recorded in each crop season after the harvest of the crop. The mean water table depth was lowered from 50 cm to 69 cm (Table 72) indicating effective functioning of the interceptor drains. The mean water table depth in the study area during *kharif* is shallower than during *rabi* due to monsoon rains.

Crop yield: The average yield in the study area increased sharply from its initial value of 2.18 t ha^{-1} to 5.84 t ha^{-1} (Table 72) . The paddy yield remained at 60-65 t ha^{-1} level from *kharif* 1999 onwards. The improvement in paddy yield was mainly due to decrease in soil salinity. The cropping intensity was 143 per cent before the installation of the drainage system and it improved to 177 per cent during 1998-99 and further to 191 per cent during 2000-01. This improvement in the cropping intensity is mainly due to reclamation of the salt- affected soils and the awareness created amongs the farmers about the importance of drainage system and the proper utilization of natural resources like land and water.

10.3.3 Closed Subsurface Drainage System

The subsurface drainage systems were installed by CADA – TBP on farmer's field at four different locations viz. Vaddarahatti, Gundur, Siddapur and Gangavathi in an area of 4.9, 11.5, 6.9 and 2.8 ha, respectively during 1988 to 1994. The composite subsurface drainage systems with a uniform spacing of 27 m, had field drains (10 cm diameter) placed at a depth of 0.9 m and connected to a collector (1.05 m depth). Performance of subsurface drainage system was evaluated in terms of changes in soil salinity, pH and crop yield.

Soil salinity: The sites were highly salinised and salinity values remained in the range of 20 – 57 dS m^{-1} (Table 73) with highest in case of Siddapur (57 dS m^{-1}) and the lowest in case of Gundur (20 dS m^{-1}). On the basis of both soil reaction and salinity values, the soils were predominantly saline but the process of sodification was in operation as the soil reaction was around 8.5. However, with installation of subsurface drainage, there was decrease in mean soil salinity from 42.0 to 0.6, 57.0 to 1.6, 38.0 to 0.6 and 20.0 to 2.7 dS m^{-1} in Vaddarahatti, Siddapur, Gangavathi and Gundur, respectively.

Drainage coefficient: Based on one *kharif* and two *rabi* seasons, the average drainage coefficient for the 4 sites worked out as 0.11 (Vaddarahatti), 0.42 (Gundur), 0.16 (Siddapur) and 1.09 (Gangavathi) indicating that the drainage coefficient could be taken as 1 mm d^{-1} at most of these sites (Table 73). Since the drainage discharge is normally higher for the *kharif* season and also depends upon the rainfall during the season, it might be appropriate to increase these values such that drainage coefficient could be taken as 1-2 mm d^{-1}. From the results, it could be seen that even a low drainage coefficient (1 mm d^{-1} or so) could help reclaim saline lands as against a usually higher drainage coefficient required for good aeration in humid/sub-humid climates.

Yield: In general, the crop yield increased at all the locations after installation of the subsurface drainage system. The yield increased from 3.5 to 8.4 t ha^{-1} at Vaddarahatti, 2.8 to 8.1 t ha^{-1} at Gundur, 2.4 to 7.3 t ha^{-1} at Siddapur and 4.0 to 7.9 t ha^{-1} at Gangavathi, after installation of subsurface drainage systems (Table 73 and Fig. 34). The increased yield levels at all the location was mainly due to decreased soil salinity and favorable depth to water table.

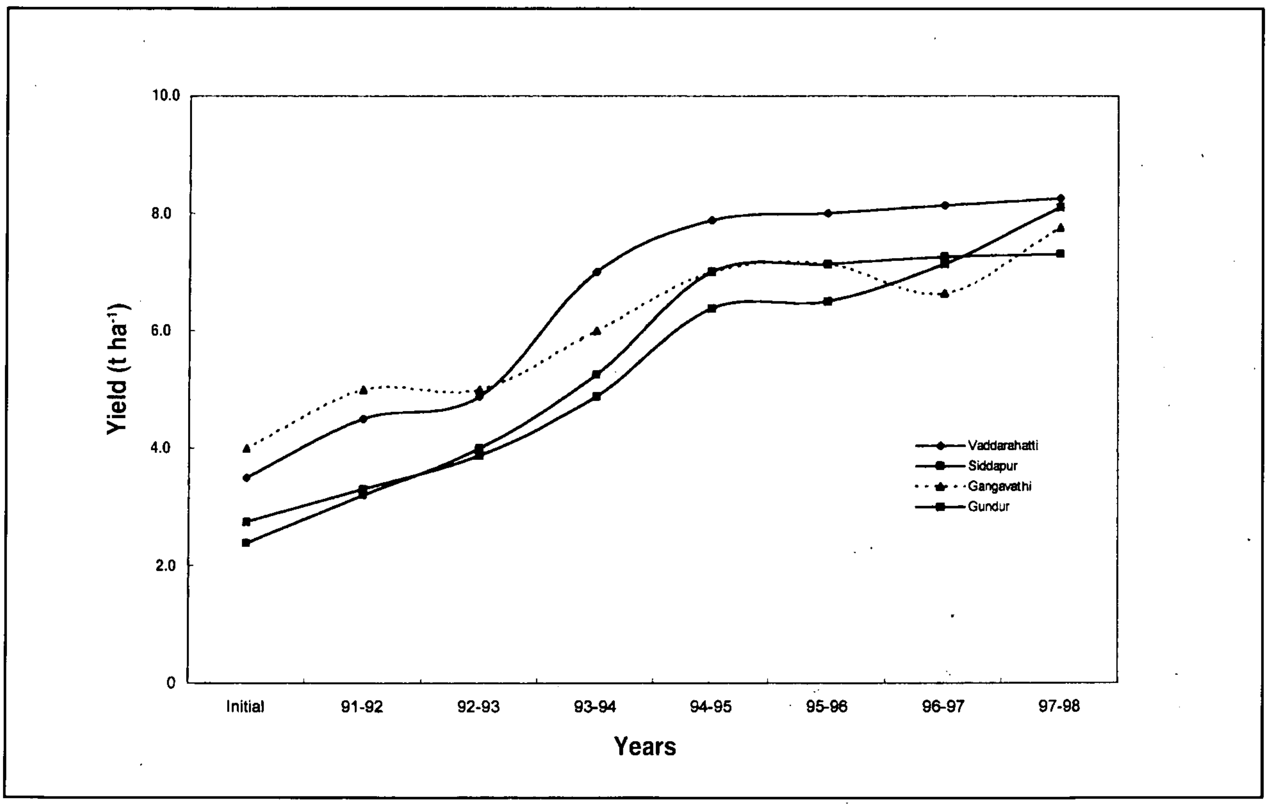


Figure 34. Increase in rice yield over years after installation of subsurface drainage systems

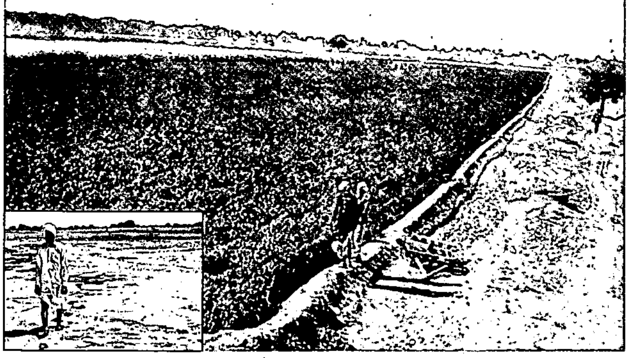
Table 73. Effect of subsurface drainage system on soil properties

Particulars	Location and years of installation			
	Vaddarahatti	Gundur	Siddapur	Gangavathi
	1988-89	1990-91	1993-94	1994-95
Soil salinity (dS m^{-1})				
Pre-drainage	42.0	20.0	57.0	38.0
Rabi (1997-98)	0.6 (98.5)	2.7 (86.5)	1.6 (97.2)	0.6 (98.4)
Mean drainage coefficient (mm day^{-1})				
(3 seasons)	0.11	0.42	0.16	1.09
Paddy yield (t ha^{-1})				
Pre-drainage	3.5	2.8	2.4	4.0
Post-drainage	8.4	8.1	7.3	7.9

Values in the parenthesis indicates % of initially present salts leached

11. CONCLUSIONS AND RECOMMENDATIONS

Barren (inset) and reclaimed land



Under the Indo-Dutch Network Project with the objective "Recommendations on Waterlogging and Salinity Control Based on Pilot Area Drainage Research", 8 studies in 7 irrigation commands areas in 5 agro-ecological sub-regions of India were taken up where waterlogging and soil salinity have assumed serious dimension. Pilots areas covering 13 to 75 ha under SSD were laid out, monitored and evaluated over a period of 1 to 3 years. On the basis of this evaluation some general and few site specific conclusions have been drawn. They reflect the current state-of-the-art and should be treated as guidelines for other regions. Further research may be needed to refine and verify them.

11.1 Conclusions

11.1.1 Measures to Combat Waterlogging and Salinity

1. Horizontal subsurface drainage, either by pipe or open drains, has proved to be a technically feasible, cost-effective and socially acceptable technology to reclaim waterlogged and saline agricultural lands in irrigation commands under various soils, agro-climatic conditions and social settings.

2. Surface drainage is essential to remove excess water from the land surface in monsoon climatic conditions. However, surface drainage alone is often not sufficient. It should be integrated with subsurface drainage.

3. Restoration of the (natural) drainage capacity, which is generally disrupted by the construction of the irrigation network or other development activities, will considerably reduce the need for (or intensity of) subsurface drainage.

4. Horizontal subsurface drainage is an effective tool to remove excess water and salts and to sustain agriculture. Supplementary measures such as:

   - improving farm irrigation efficiency;
   - applying nitrogen (20 to 25% more than the recommended dose for unaffected lands), organic manure or green manure
   - applying gypsum

   enhance the positive effects of horizontal subsurface drainage. A trade off between the additional investments made in irrigation and land management and saving in cost on drainage should be considered.

5. Horizontal subsurface drainage controls:
   - The water table at an optimum depth for crop growth (0.5 - 1.5 m or shallower in paddy fields), and;
   - The soil salinity at a safe level (< 4 dS m^{-1}).

It has been shown that :

- Excellent yields can be obtained with the shallow water tables mentioned while excessive drainage is avoided, and ;
- Harmful salts that are brought in by the irrigation water are effectively removed.

6. Horizontal subsurface drainage can be made still more effective by introducing controlled systems to halt the drainage flow in times of water scarcity and to prevent excessive leaching of valuable nutrients. This will also avoid excessive loss of irrigation water in rice fields.

7. The availability of a good outlet for safe disposal of the drainage effluent (including the leached salts) is a pre-requisite to make subsurface drainage a success. In land locked areas, 10 to 18 % of the land area can be converted into an evaporation/storage tank to store and dispose off the water at a later stage.

8. Subsurface drainage is an eco-friendly technology. The pilot area studies reveal that:
   - Drainage effluent does not contain excessive amounts of nitrate or other toxic elements;
   - Drainage water can be re-used for irrigation either directly or in conjunction with good quality irrigation water; thus it is good water resource at times when water is not available from other sources;
   - During *rabi* and summer, drainage water has a high salt concentration, making it often unsuitable for reuse. In such cases, the option to temporally store the discharge for disposal at a later stage should be considered;
   - During the monsoon season, drainage water quality is much better, because of the dilution effect of the rains. At this time the water is not required for irrigation in many cases. In such circumstances, excess water can be disposed off in the natural drainage system.

11.1.2 Design Specifications for Horizontal Subsurface Drainage Systems

9. Horizontal subsurface drainage systems can be installed with either open or pipe drains with drain spacing between 45 and 150 m and drain depths between 0.90 and 1.50 m. The agro-climatic and soil conditions determine the most appropriate combination of drain depth and spacing. To avoid costs for pumping the drainage effluent, gravity outlets should be preferred by reducing the drain depth and narrowing the spacing.

10. So far only two methods for the construction of subsurface drainage system were available: manual and mechanical. The project has developed and successfully tested a combination of these two methods using conventional machinery. Under Indian conditions, with its abundant labour force, this combined method is most promising and needs to be tried at more places.

11. The presently available guidelines on the need and selection of an envelope material seem appropriate. Pipe drains with and without envelopes designed based on these guidelines performed equally effectively. The only exception is the coefficient of uniformity, that as a criterion for deciding on the need of an envelope, should not be used for the Indian conditions.

12. Flushing of lateral and collector pipe drains is essential when horizontal pipe drainage systems are laid under high water table conditions. A flushing method developed by the Hanumangarh Network Centre is very appropriate for this purpose.

13. Horizontal subsurface drainage can only be successful to combat salinity if sufficient good quality irrigation water or monsoon rainfall is available for leaching.

14. Operational scale subsurface drainage systems can only be installed on community basis and consequently Water Users Co-operatives or Drainage Committees have to be established to implement, operate and maintain these systems.

15. Singular subsurface drainage systems, with (pipe or open) field drains directly discharging in an open main drain or natural stream (*Nala*) proved to be more cost-effective than a composite system. If such outlet conditions are not available, a composite system, consisting of field and collector pipe drains, could be considered. If gravity drainage is not an option, pumping the drainage effluent should be considered.

16. Subsurface drainage systems consisting of (deep) open drains proved to be the most cost-effective method. Adverse soil conditions, operation and maintenance requirements, loss of land, and social settings, however, restrict their use.

17. Costs of horizontal subsurface drainage systems vary between Rs. 5,000-10,000 ha^{-1} for the most simple singular open drainage systems to Rs. 28,000-30,000 ha^{-1} for the most complex composite pipe drainage system depending upon spacing and depth.

18. Horizontal subsurface drainage systems are extremely beneficial; cost benefits ratios are in the range of 1.3-4.0, internal rates of return in the range of 35-60 and pay back periods of 3-5 years except at UKP command where pay back period for composite system was 9-10 years.

11.1.3 Supplementary Activities in Water Management

19. A shallow water table can help to meet part of the irrigation water requirement of crops. As such, irrigation water requirement can be reduced by 20-25%. This can be achieved either by reducing the depth of irrigation water application or by reducing irrigation frequency.

20. Reduction in canal water supply is commonly advocated as a mitigative measure to control waterlogging. Although technically sound, our studies revealed that:
    - So far technical and management measures to improve irrigation water management have not percolated to the farming community in the pilot areas constructed by the project. Therefore, more systematic efforts need to be made to generate awareness on irrigation water management among the farming community;

- In one command, the water supply on an annual basis is more than the demand. However, in spite of the efforts made so far at all levels, it has not been possible to reduce water allowance;
- The well-known supply gap between the head-end and tail end farmers is yet unsolved. Tail-end farmers will never agree to a reduction in the overall water supply, since they are already short of water and any reduction in water allowances would accentuate this gap.

11.1.4 Supplementary Activities in Soil and Land Management

21. It has been shown that in heavy clay soils (clay content > 45%), presently available guidelines on the limits of ESP where adverse effects start appearing (ESP > 15) do not hold true. Sugarcane yields decrease even at an ESP of 8. Drainage installation followed by gypsum application helps in land reclamation of heavy clay soils. Soil tests, however, need to be carried out to establish recommended gypsum application rates.

11.1.5 Institutional and Policy Issues

22. Drainage Policy Papers at National and State Levels should be prepared emphasising time bound action plan to reclaim waterlogged and salt-affected lands.
23. At the National level, CSSRI, with its well-equipped training infrastructure in land reclamation and agricultural land drainage, should be made a nodal agency for imparting training in this area of specialisation.
24. At State Level, the enhanced capacity at the four State Agricultural Universities should be utilised to strengthen both government and private organisations in activities aiming to combat waterlogging and salinity. These activities can include problem identification, creating awareness at State, Central and Farmer level, recommending solutions and dissemination of knowledge through training and advisory services.
25. Implementation of horizontal subsurface drainage should graduate from the pilot scale to full-fledged drainage programs under the relevant Ministries and Departments.
26. The Central Government norm of Rs. 12,000/ha for the execution of subsurface drainage projects needs to be revised as it is highly inadequate at the current prices.

11.2 Specific Recommendations for Different Regions

For the four agro-ecological sub-regions, in which the drainage pilot areas were located, the additional recommendations are valid:

11.2.1 Haryana: Western Yamuna Canal Command

- For areas with medium textured soils as in Western Yamuna Canal and Bhakra Canal commands (annual rainfall : 500-700 mm) having high water table and salinity problems, a composite pipe drainage system with the following characteristics is recommended.

Drain spacing	75 m
Drain depth	1.1-1.5 m
Envelope	Geotextiles

- In addition to the above, following package would help to make the process of land reclamation efficient and sustainable
  - Land levelling and bunding for rainwater conservation and uniform leaching.
  - A heavy pre-sowing irrigation for leaching of salts following leaching through rain water.
  - Application of 20-25% more nitrogen and seed rate compared to the recommended dose for normal soils.

11.2.2 Andhra Pradesh: Nagarjuna Sagar Right Command and Krishna Western Delta

- For areas with sandy loam to clay loam soils as in Nagarjuna Sagar Project Right Canal Command area (annual rainfall: 800 to 900 mm) having salinity, sodicity and waterlogging problems, a pipe subsurface drainage system with the following characteristics is recommended.

- Drain spacing	60 m
- Drain depth	1.0 m
- Envelop	Geotextile

  This package will increase paddy yields by around 50% in 2 years.

- In addition to the above, the following supplementary measure are recommended:
  - Growing green manure crops like *Dhaincha* in combination with application of organic manure @ 5t ha^{-1} along with gypsum @ 50% of requirement, if necessary;
  - Cultivation of salt resistant rice varieties such as MTU 4870 (*Deepthi*), NLR-T-145 (*Swarnamukhi*) and NLR 33641 (*Tellamolakolukulu*).

- For areas with sandy clay loam soils as in Krishna Western Delta (annual rainfall: 900 to 1000 mm) with saline groundwater conditions, a pipe drainage system with deeper drains (depth 1.20 to 1.35 m) is recommended.

- For areas with high salinity problem, open drains lower the salinity levels quite fast. Even though open drains are much cheaper, farmers with small holdings may resist for their installation owing to the loss of cultivable land in construction of drains. Whenever they are acceptable, the open drains with the following characteristics are recommended:

- Drain spacing	75 m
- Drain depth	1.0 to 1.2 m

11.2.3 Gujarat: Ukai- Kakrapar Command

- For sugarcane crop in heavy black soil areas as in Ukai- Kakrapar Command (annual rainfall: 1000 to 1500 mm) with waterlogging and/or salinity problems, a subsurface (open or pipe) drainage system with the following characteristics is recommended:
  - Drain spacing 45 m
  - Drain depth 0.90 to 1.20 m
  - Envelope not required.

This package will increase yield by about 40%.

- In addition to the above, the supplementary measures of applying organic manure @ 5t ha^{-1} along with gypsum @ 5-10 t ha^{-1} (depending upon the ESP) are recommended.
- In commands where sugarcane is the single most important crop and where existing networks of sugar co-operatives play vital role in helping the farmers on all cultivation aspects, these networks should take lead in implementation of drainage system in the command.

11.2.4 Rajasthan: Indira Gandhi *Nahar Pariyojana* Command

- For areas with sandy soils and collapsing soil conditions (quick sand) as in IGNP (annual rainfall: 300 mm), a composite pipe drainage system with the following characteristics is recommended:
  - Drain spacing 150 m
  - Drain depth 1.20 m
  - Envelope material geotextile
- To install horizontal pipe drainage systems under the adverse (quick sand) conditions in IGNP the following techniques are recommended:
  - Dewatering by having bore holes around the sump and continuously pumping for 72 hours for the construction of sumps;
  - Prefabricated RCC rings with in-built bottom plate for manholes;
  - Mechanical installation using machinery like excavators and tractor driven trenchers. Though installation is possible with manual labour, it is much time consuming, costly and hazardous due to collapsing nature of soil.
  - As the system is laid under muddy conditions, flushing of the laterals and collector is essential.
- In the absence of a natural drainage outlet, the creation of safe disposal options is a pre-requisite for successful introduction of subsurface drainage on a large scale in IGNP. To reduce the volume, supplementary measures like evaporation ponds and re-use have to be further developed.

11.2.5 Karnataka: Upper Krishna and Tungabhadra Commands

- For areas with black soils such as in the Upper Krishna command (annual rainfall: 770 mm) and waterlogging and salinity problems, a subsurface drainage system with open or pipe drains with the following characteristics is recommended:
  - Drain spacing: 50 m
  - Drain depth: 1.0 to 1.2 m
  - Envelope: not required for soils with a clay content > 50%.

These drains are to be complemented with surface drains for efficient performance.

- In addition to the above, the following supplementary measures are recommended:
  - Gypsum application @ 5-7.5 t ha^{-1}, if the soil ESP is high;
  - Lining of field irrigation channels by providing a murrum cushion of 15-20 cm thickness. This will minimise the conveyance losses considerably (by half) in comparison with the existing lining without murrum cushion;
  - Application of an additional 30 to 60 cm good quality irrigation water (in 10 cm instalments) for the initial leaching of the soil;
  - Land levelling and bunding to save 35 to 50% irrigation water;
  - *Nala* cleaning.

REFERENCES

- Gupta, S.K. 1985. Subsurface drainage for waterlogged saline soils. Irrigation & Power J. 42, 335-44.
- Inglish, C.C. and Gokhle, V.K. 1928. Report on Land Drainage Experiments at Baramati. Tech. Pub. No.14. Pub. Works Deptt. Bombay State.
- MoWR. 1991. Report of the Working Group on Problem Identification in Irrigated Areas with Suggested Remedial Measures. Ministry of Water Resources, Government of India, New Delhi.
- National Commission on Agriculture, 1976. Ministry of Agriculture and Irrigation, Government. of India, New Delhi.
- Rao, K. V. G. K., Singh, O. P., Gupta, R. K., Kamra, S. K., Padey, R. S., Kumbhare, P. S. and Abrol, I. P. 1986. Drainage Investigations for Salinity Control in Haryana. Bull. No. 10. CSSRI, Karnal. 95p.
- Report of Irrigation Commission, 1972. Ministry of Irrigation, Govt. of India, New Delhi.
- Richards, L.A. (Ed.) 1954. Diagnosis and Improvement of Saline and Alkali Soils, USDA Agricultural Handbook No 60, US Government Printing Office, Washington D.C., USA.
- Royal Commission on Agriculture, 1928. Report of The Royal Commission on Agriculture.

ABBREVIATIONS

ANGRAU	Acharya N.G.Ranga Agricultural University
B-C ratio	Benefit – cost ratio
bgl	below ground level
CADA	Command Area Development Authority
CEC	Cation exchange capacity (meq/100 g)
CI	Cropping intensity
CSSD	Closed subsurface drainage system
CSSRI	Central Soil Salinity Research Institute
EC_e	Electrical conductivity of the soil saturation extract
ESP	Exchangeable sodium percentage
FIC	Field irrigation channel
GAU	Gujarat Agricultural University
HOPP	Haryana Operational Pilot Project
i_e	Hydraulic gradient, envelope
i_s	Hydraulic gradient, soil
IGNP	Indira Gandhi Nahar Pariyojana
IRR	Internal rate of return
K	Potassium
KWD	Krishna Western Delta
MSL	Mean sea level
N	Nitrogen
NRC	Nagarjuna Sagar Right Command
NRCC	Non-reinforced cement concrete
NPW	Net present worth
ORP	Operational Research Project
OSSD	Open subsurface drainage

P	Phosphorous
PSSD	Pipe subsurface drainage
PVC	Poly-vinyl chloride
RAU	Rajasthan Agricultural University
RSC	Residual sodium carbonate
RY	Relative yield
SAR	Sodium adsorption ratio (m mol $l^{-1})^{1/2}$
SSD	Subsurface drainage
TBP	Tungabhadra Project
UAS	University of Agricultural Science
UKP	Upper Krishna Project
USDA	United State Department of Agriculture