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DRAINAGE DIGEST

A report based on two decades (1981-2002) of research under AICRP (Drainage) at the Karumady Centre, Kerala

Dr. E. K. Mathew
Sri. Madhusudan Nair, Sri. T. D. Raju, Dr. U. Jaikumaran

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Authors:
Dr. E. K. Mathew
Sri. Madhusudan Nair
Sri. T. D. Raju
Dr. U. Jaikumaran

Edited by:
Dr. A. K. Bhattacharya,
Principal Scientist and Former Project Co-ordinator
(AICRP on Agricultural Drainage)
Water Technology Centre,
IARI, New Delhi

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Kerala Agricultural University
Thrissur

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FOREWORD

Irrigated agriculture in India is confronted with a variety of problems, which include impeded drainage and waterlogging, inherent soil problems that further aggravate due to unscientific irrigation water management, low crop productivity and environmental degradation. Several of these can be controlled by adopting appropriate land drainage measures. Drainage as a reclamation measure was intensively field-tested under the All India Co-ordinated Research Project on Agricultural Drainage under Actual Farming Condition on Watershed Basis. The Project was operated during 1981-2002 through a network of Co-operating Centres located in the State Agricultural Universities in Punjab, Madhya Pradesh, West Bengal, Andhra Pradesh and Kerala.

The agricultural scenario of the Kuttanad region, the so-called rice bowl of Kerala, is a glaring example of manifestation of the problems mentioned above. The landmass of the region lies below the mean sea level and has three distinct ecological situations: Kari, Karappadam and Kayal. Characterized by high organic matter content, high acidity, poor drainage and preponderance of toxic salts in the soil profile, the Kari soil is the least productive. Research efforts on soil drainage to improve and sustain rice yields in this soil were started at Karumady in 1981. A large volume of research data has been generated in this cooperating centre pertaining to agricultural land drainage and associated activities during 1981-2002.

The work was carried out on a research-development-demonstration mode in a rice growing co-operative farm. The various technological interventions, in which sub-surface drainage was the major component, have helped in reclaiming the land and thereby increasing the rice productivity by at least one tonne per hectare in comparison to the rice yield normally obtained by the local farmers without such interventions. Sub-surface drainage is indeed an expensive activity. However, a detailed cost analysis based on actual data has shown the economic viability of sub-surface drainage through a high internal rate of return. Besides demonstrating the rice productivity advantage with sub-surface drainage, the research has also addressed other related issues such as laying the buried drainage system under waterlogged condition, deciding suitable depth-spacing combination, evaluating different drainage material, quantifying the impact of drainage on soil health and on the surrounding environment and identifying most appropriate times for various cultural practices for rice production.

This publication, "Drainage Digest", of the AICRP on Agricultural Drainage at Karumady Centre is a synthesis of the results of the research efforts of the station during 1981-2002. The authors, Dr. E.K. Mathew, Mr. Madhusudan Nair and Mr. T.D. Raju were associated with the project for its entire duration. Dr. U. Jaikumaran had laid the strong foundation of the project during the initial period. The project scientists were helped by a number of technical, administrative and supporting staff. The research work was coordinated all through by Dr. A.K. Bhattacharya, Principal Scientist and Project Co-ordinator at the Water Technology Centre, IARI, New Delhi. I congratulate the team for doing a commendable job of research and documentation, embodied in this Drainage Digest. I am sure that this publication will be read with interest and meaningfully used by researchers, students and the development departments of the state and i hope that the technology is replicated at other places.

(Dr. N.S.L. Srivastava)
Assistant Director General (Engineering)
Indian Council of Agricultural Research
Krishi Anusandhan Bhavan – II, New Delhi – 110 012

PREFACE

Kuttanad, the rice bowl of Kerala, is a highly complex ecosystem, unique in its topography and ecology. This region encompasses two deltaic formations – one at the confluence of Achencoil, Pamba, and Manimala Rivers and the other of the Meenachil River. The low lands on either side of these deltas are characterized by high organic matter content, low pH, preponderance of toxic salts and impeded drainage. These lands are locally known as Kari lands. Rice production in these lands is risky and expensive.

Considering the severity and magnitude of the problems confronting rice cultivation in the Kari lands, The Kerala Agricultural University launched a research project on sub surface drainage under actual farming situation at Karumady in Alappuzha district in 1981 with the active support of and guidance of the ICAR. The project has now completed two decades of research. Very valuable research data have been generated at Karumady on soil hydrologic constants like hydraulic conductivity, drainable porosity etc that are very important for drainage designs. Detailed studies have been conducted on optimum drain spacing required in these types of soils. Crop performance and soil quality improvement under drainage have been studied extensively. The studies have proved that subsurface drainage is a technically and economically viable proposition in the Kari lands.

This publication "*Drainage Digest*" at Karumady centre embodies a broad summary of the research work done at the station and is intended for researchers, students, planners and practicing farmers to acquaint themselves with the problems facing rice production in Kari lands and the solutions to overcome these constraints.

I congratulate the scientists Dr. E. K. Mathew, Sri. Madhusudan Nair, Sri. T. D. Raju and Dr. U. Jaikumaran and the supporting staff for their sincere efforts in generating and compiling valuable information. I also thank the Indian Council of Agricultural Research, New Delhi for the generous financial assistance to bring out this publication.

Dr. K. V. Peter,
Vice Chancellor,
Kerala Agricultural University

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We take this opportunity to express our deep sense of gratitude to Dr. A. K. Bhattacharya, Project Co-Coordinator, All India Co-ordinated Research Project on Agricultural Drainage, Water Technology Centre, New Delhi for his valuable guidance and immense help since the inception of the research project and throughout the preparation of this publication. Without his inspiration, this publication would have been impossible.

We are indebted to Dr. K. V. Peter, the Honourable Vice-Chancellor of Kerala Agricultural University for his constant interaction with the authors in developing this publication. The special interest he has shown in the field of agricultural drainage is thankfully acknowledged.

Dr. A. M. Michael, former Director IARI, and former Vice-Chancellor, Kerala Agricultural University, was the beacon behind the project at Karumady. The keen interest shown by him by visiting the project several times even before he became the Vice-Chancellor of the Kerala Agricultural University is gratefully remembered.

The moral support given by Dr. Anwar Alam, Deputy Director General (Engg), Dr. N. S. L. Srivastava, Assistant Director General (Engg) for bringing out this publication deserves special mention.

We also thank Prof. C. P. Muhammad, the Dean, Kelappaji College of Agricultural Engineering and Technology, Dr. Vikraman Nair, the Director of Research, Prof. T. P. George, Dr. John Thomas, Dr. P. C. Sivaraman Nair, Dr. M. Aravindakhan, Dr. N. Mohanakumaran, Dr. R. R. Nair, Dr. C. C. Abraham, Dr. P. J. Joy, Dr. U. Mohammed Kunju, and Dr. C. A. Joseph for their keen interest in the project during and after their tenure at various levels in the Kerala Agricultural University.

The technical help and guidance received from Dr. P. Rajendran and Dr. P. Babu Mathew, Dr. Sosamma Cherian, and Smt. Annie Koruth are thankfully acknowledged.

The contributions rendered to the project by the scientists Dr. M. S. Haji Lal, Sri K. R. Anil and Sri P. H. Latif are also remembered.

The encouragement given by the scientists of the International Institute for Land Reclamation and Improvement (ILRI), especially Ir. Jacob Vos, Ir. Hendrik Ritzema, Dr. Oosterban and Dr. Boonstra greatly inspired the research conducted at Karumady and the authors express their gratitude to them.

The authors are also thankful to the Central Soil Salinity Research Institute and their scientists for the valuable help given by them. The interests shown by Dr. KVGK Rao, Dr. N. T. Tyagi and Dr. S. K. Gupta are kindly remembered. The valuable suggestions offered by Dr. R. K. Panda, Professor, IIT, Kharagpur during the preparation of this document, is also thankfully acknowledged.

The research was conducted in the farmers' fields of *Kavil Thekkumpuram Padasekharam*. The support and co-operation of the farmers was the key factor behind the success of the project. We express our gratitude to them and also to the *Padasekhara* Committee for providing us all the helps from time to time.

The ardent effort and untiring work contributed by all the staff members who worked at the AICRP on Agricultural Drainage, Karumady at various levels and periods of time deserve unparalleled acknowledgement which the authors are immensely pleased to place on records at this juncture.

Finally, with gratitude, we acknowledge the technical and financial support given to us by the Kerala Agricultural University and the ICAR for this research. Without the generous financial assistance of the ICAR, this publication would not have been possible.

Authors

CONTENTS

1. INTRODUCTION

One of the major factors contributing to the low agricultural production in comparatively high rainfall areas in the plains is inadequate drainage. A major emphasis given on canal irrigation has also given rise to problems of drainage due to water logging. Drainage has been the main limiting factor in crop production in *kharif* season in the predominantly rice growing regions of India. Soil salinity and acidity are the other major problems that are to be tackled effectively to increase the crop yield.

Farm drainage is essentially situation specific and requires to be dealt with on an area basis involving well-defined watersheds. Studies have to be conducted in the major problem areas in order to arrive at suitable criteria for the design of surface and subsurface systems suiting the agro-climatic situations prevailing in the area. There is also a need to evaluate the socio-economic benefits arising out of land drainage activity.

1.1 GENESIS OF THE AGRICULTURAL DRAINAGE PROJECT IN KERALA

Realizing the importance of agricultural drainage, the Indian Council of Agricultural Research (ICAR) approved an All India Coordinated Research Project in the 6th Plan for studies on Agricultural Drainage under actual farming conditions on watershed basis. A committee headed by Dr. A. M. Michael, with Dr. H. S. Chauhan and Dr. R. K. Rai as members was appointed to make recommendations to the council on various aspects of the new project. Based on the recommendations of the committee, the council accorded sanction for the project with five cooperating centres located in the State Agricultural Universities in Punjab, Madhya Pradesh, West Bengal, Andhra Pradesh and Kerala. The coordinating cell of the project was kept at Water Technology Centre, IARI (Indian Agricultural Research Institute), New Delhi.

1.2 BROAD OBJECTIVES OF THE PROJECT

The following were the broad objectives of the project.

- Prediction of runoff characteristics from selected agricultural watersheds with a view to develop suitable criteria for the design drainage systems under monsoon-dominated areas
- Development of methodology for investigations on the causes of water logging and salt accumulation
- Development of criteria for the design of various types of surface and subsurface drains.

- Development of design requirements of subsurface tile drainage systems
- Evaluation of materials for drains (clay, concrete and plastics) and the requirements for tile joint spacings (of sizes of slots in case of plastic drains) as influenced by the soil particle size distribution.
- Development of materials and design criteria for gravel filters for tile drainage (locally available materials to be given preference)
- Development of criteria for the design of ancillary structures for subsurface drains (vertical inlets, outlets etc)
- Evaluate the feasibility of using the return flow for irrigation in relation to water quality ratings
- Determination of drainage requirements of principle crops (under static and fluctuating water levels, including duration of ponding)
- Development of suitable cropping pattern for optimisation of yield and income
- Evaluation of the socio-economic benefits accrued from a drainage project

The major thrust area of the Kerala centre was to develop design criteria for subsurface drainage in the acid-sulphate soils of the Kuttanad tract to improve the soil quality through leaching of toxic salts and thereby to improve paddy yield.

The specific feature of the project was to conduct drainage investigation, execution and monitoring in the farmers' fields, with a view to demonstrate the drainage technologies and their impact to the direct beneficiaries.

1.3 BROAD TECHNICAL PROGRAMME

The project envisaged the diagnosis of the causes of water logging, collection of the available data on climate, soils, vegetation, land use, land tenure system and natural drainage of the area. After the required survey and collection of available data, detailed investigations required for the design of an effective drainage system for the problem area were to be made. The watershed approach was to be followed and the problem was to be tackled right from the main outlet. The system comprised of an integrated surface drainage system. Clearing and deepening of existing natural drainage-ways was also to be taken up. Subsurface drainage was to be installed wherever required. A systematic recording of the water table situations before the installation of the drains was to be carried out. The performance of the drains would be monitored through a series of observation wells or piezometers located at suitable intervals through out the problem area and the surrounding areas contributing subsurface flow to the problem area. The project was to be implemented with cooperation of the beneficiary farmers in a well-integrated way. Simultaneous efforts were to be made to develop agriculture on scientific lines in the project area with a view to obtain a high level of production. Water resources for irrigation in the project area were to be developed locally, wherever possible. The programme intended to involve land shaping, water distribution and control systems, suitable irrigation methods and the evaluation of the performance of the various water management measures. Suitable cropping pattern with a view to obtain high level of production and income was to be developed. Socio-economic benefits accruing from the project were to be measured.

1.4 RELEVANCE OF THE PROJECT IN KERALA

With a meagre geographical spread of less than 1.18% of the whole country, the state of Kerala supports over 3.43% of her population. With the increased population pressure, sub division and fragmentation of land, farming in the State is characterized by pre dominance of tiny holdings that are incapable of sustaining the farming communities. With the undulating topography arising from geological formations, rice in Kerala is cultivated in distinct macro environments ranging from 2-3 metres below mean sea level as in coastal lowlands of Kuttanad, to near temperate situations at 2,500 metres height in the high ranges. The coastal low lands provide favourable conditions for rice and fish. Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts. The high rainfall coupled with undulating topography subject the low land rice fields to environmental vagaries of flash floods in the monsoon and tidal saline incursions during the summer. Due to poor drainage, excess water and poor water management, the potential of high yielding variety rice technologies is hardly realized in this region. The situation is further aggravated in acid saline problem soils owing to high acidity, salinity and accumulation of toxic salts etc inherent to these soils. This, coupled with the socio-economic constraints has tempted some of the farmers to switch over to other enterprises. In many areas, lowland rice fields have been systematically converted into coconut plantations, further altering the very ecology of these wetlands. As a result, the cropping intensity in coastal low lands such as *Kari* lands is the lowest (100% as against 161% of the state). The present trend of conversion of low productive rice lands for alternate enterprises will have to be arrested which otherwise would create serious environmental consequences owing to the unique ecological functions of these wetlands. It is envisaged that subsurface drainage technology to improve the soil productivity could be an alternate solution to the problem.

1.5 SELECTION OF THE EXPERIMENTAL SITE AND JUSTIFICATION FOR THE SELECTION

The site selected for the drainage experiments is the *Karilands* of the Kuttanad tract of Kerala. A major area of Kuttanad tract, being located below mean sea level, experiences problems of water logging and salinity. *Kariland* soils are acid-sulphate in nature, as elsewhere in Kuttanad region. The soils are extremely acidic with pH ranging from 3 to 4.5. The salinity levels measured in terms of Electrical Conductivity (EC) sometimes reach as high as 6.0 dSm^{-1} during the summer season. The ionic concentration of different elements *viz.*, Fe, SO_4, Ca, Mg and Cl are found in the range of toxic concentration for paddy cultivation. The soil cracks during the summer season on drying. This makes the subsoil more acidic due to the oxidation of sulphur compounds and later with inundation forming free sulphuric acid. Moreover, in the summer season, the intrusion of saline water in the surrounding water bodies brings down the quality of irrigation water.

Presently, in the *Kari lands* of Kuttanad, paddy is the only crop grown extensively. High yielding varieties of paddy are being used throughout the area. The crop has to overcome the adverse effects of acidity and salinity to register an average yield. Symptoms of iron toxicity on the leaves are predominant. The roots are also found to decay due to sulphide injury. All these factors result in patchy crop growth and a poor grain yield of approximately 1.5 tons/ha even after 100% adoption of high yielding paddy varieties. The farmers, after every harvest, flood their fields with water to contain the acidity by avoiding the drying of soil. Fresh water is available in plenty outside the farming area and can be drawn into the field by gravity. During cultivation, the field is washed with fresh water very frequently to leach the salt. The present method of intermittent washing is found inadequate for a good subsurface salt leaching to boost the yield because of the high water table conditions present in the field. The washing effect extends only up to a few centimetres deep, below which, the salt concentration is very high. The idea behind the selection of this site was to introduce subsurface drainage to bring about substantial leaching of the soil profile and to increase the productivity of the soil. Considering the drainage problems of this area, Karumady was selected as the appropriate site for locating the cooperating centre of the AICRP on Agricultural Drainage.

1.6 SPECIFIC OBJECTIVES

The scheme started functioning from 1.12.1981 in the farmers' fields of the *Kavil Thekkumpuram Padasekharam* with the following objectives.

- To comprehend the effect of surface and subsurface drainage system on the movement of soil liquids

- To study the effect of surface and subsurface drainage in preventing the rise of toxic products from subsurface soil into root zone
- To study the effect of surface drains in removing the toxic products already present in the root zone
- To study the influence of subsurface drains on lowering water table and its effect on growth and development of roots
- To develop a feasible technology for the layout of subsurface drainage suitable to peat and muck soils
- To develop criteria for design parameters of surface drainage
- To develop the drainage pattern required for different crops to optimise yield and income
- To evaluate the feasibility of the return flow for irrigation in relation to water quality ratings
- To evaluate the socio-economic benefits accrued from the drainage projects

1.7 SCOPE OF THE PROJECT

Rice lands in Kerala are mostly confined to valley bottoms in the midlands to coastal lowlands and are frequently exposed to the vagaries of nature. The lowland situations comprising *Kari, Kara* and *Kayal* of Kuttanad and *Pokkali, Kole* and *Kaipad* of coastal fields together constitute 25% of the total rice area of the state contributing over 37% of the rice output. Owing to its innate adaptation to water logging, rice could only be the principal crop in these wetlands for which water table control was not relevant. However, poor drainage had been identified to be the single largest factor limiting the potentials of the high yielding technologies in rice in these tracts. This was particularly true of the *Kariland* region where the elevation of the fields were lower than the mean sea level and natural leaching of the inherent toxic salts from the soil profile under gravity was not feasible. In this context, leaching of the toxic chemicals assumed great importance, as no other method except subsurface drainage would be successful in leaching the root zone. Poor drainage thus had been attributed to the very low profitability of rice cultivation in these tracts. As a result, the cropping intensity in coastal low lands such as *Karilands* was the lowest (100% as against 161% of the state). The present trend of conversion of low productive rice lands for alternate enterprises would have serious environmental consequences owing to the unique ecological functions of these wetlands. The scope of the project was highly relevant in the context to protect these lands at any cost for the various reasons aforesaid.

2. REVIEW OF LITERATURE

Kuttanad, the traditional rice growing area of Kerala, faces many farming constraints due to its peculiar physiography. The problems get aggravated in the *Kari lands* of this region that basically consists of acid sulphate soil. Drainage is the major limiting factor for crop production in the area. Toxic salts present in the soil and severe acidity and salinity development during cultivation are the major alarming problems. This chapter presents a critical review of important studies conducted on acid sulphate soils, toxicity problems, subsurface drainage designs etc. that would be useful for the reclamation of the acid sulphate soils of Kuttanad.

2.1 LAND RECLAMATION OF LOW-LYING AREAS

For centuries man has reclaimed land in estuaries and along the coasts for agriculture and for industrial and urban development. He had to protect the land from tidal inundation and the incursion and seepage of salt water. Land shortages have been exacerbated by erosion and by the sprawl of industries and cities. As population expanded, the pressures to reclaim the land increased and this often led in turn to additional gains of land from the sea. Such land reclamation in the Netherlands has been carried out in a massive scale especially in this century at Zuider Zee. In Europe, the Dutch pattern of accretion of tide-borne sediments and building of dykes and draining the enclosed land was repeated along the low-lying coasts of Brittany and the Camargue in France and the North Sea coast of Flanders in Belgium. In West Germany, this pattern was followed along the coastline of Schleswig-Holstein and in the estuaries of the Ems (Schilthuis, 1941). Nearly 12,000 ha of marine alluvium have been poldered and drained in Weser and Elbe (Duckham and Masefield, 1970).

Cole and Knights (1974) gave a brief review of the work done on estuarine and coastal land reclamation. In the North America, much reclamation has been carried out around the Gulf of Mexico and, even during the colonial period, extensive areas of tidal marsh were reclaimed for rice production in the Carolinas and Georgia. Much reclamation for agriculture has been carried out in the Nile Delta where there are rich alluvial and marine deposits. Most of the reclamation in temperate latitudes has been for pasture, arable farming or horticulture. Many marshlands in tropical and equatorial regions are formed in brackish water and are often very high in sulphides. These sulphides are stable until the soil is drained and the improvements in soil aeration bring about oxidation to sulphates. If the soil is low in basic constituents such as lime, free sulphuric acid is produced and this renders the soil too acidic for crop production. Such soils are sometimes found in Europe and are termed 'cat clays' by the Dutch. In Britain most reclamation for agriculture has occurred on the eastern coast around the Wash and in similar areas, encouraged by the formation of tidal marshes and their rich alluvial soils. In SouthEast Asia and India, however, rice can be grown economically on such soils using planting and harvesting methods that do not entail draining the land. While such methods preclude the use of machinery, there is usually an abundance of labour in relation to the supply of land to counterbalance this. Reclamation of the acid sulphate soils of Pulau Petak in the delta of Barito river, South Kalimantan, Indonesia, started some 80 years ago (AARD & LAWOO, 1992 a & b).

The reclamation of Kuttanad was done by making ring bunds in low-lying lands around a convenient boundary. It all started nearly 100 years ago when shallow parts of the lake were bunded with the sole intention of raising the crop between November and March. The season was so carefully selected that it falls between the end of the flood season and the beginning of the dry season when the water become quite saline for agriculture. Flood protection was not a primary concern for the bunding. The bunded areas, which belonged to a group of farmers, are called *padasekharams*. The concept became very successful and in due course of time, the padasekharam area has spread to attain the present level of 55,000 ha. Simultaneously, people moved into these areas and settled on higher parts of land and on the bunds.

2.2 ACID SULPHATE SOILS

Acid sulphate soils are problem soils, which however, are suitable for various crops under controlled water management that keeps the sulphidic horizon reduced, preventing oxidation of pyrite (Dent 1986). Potential acid sulphate soils are rich in pyrite (FeS_2), which upon drainage and subsequent exposure to air oxidizes to sulphuric acid (H_2SO_4) and creates actual acid sulphate soils. Resulting from oxidation of reduced sulphur compounds in pyritic mud, these soils are also characterized by low pH, and high aluminium, iron and sulphate concentrations (Breemen and Pons, 1978). Of the estimated twelve million ha of potential and actual acid sulphate soils in the world, about six million ha is found in South East Asia (Langenhoff, 1986). These soils are mostly located in swampy coastal plains. The process of reclaiming pyritic swampy coastal plains has a large impact on the soil conditions. Soils that are drained over longer periods develop into actual acid sulphate soils, while areas that remain waterlogged or that are flooded daily remain potential acid sulphate soils. Under some favourable hydrologic conditions it may be possible to prevent oxidation of pyrite near the surface (Dent, 1992) but, in other areas, traditional methods of rice cultivation have been developed that have adapted to acid sulphate soil conditions. Farmers in South East Asia construct raised beds, that is, piling up of soil materials excavated from adjacent lateral ditches to form ridges 0.3 to 0.6 m higher than the original ground surface to avoid flooding in the rainy season so that upland crops can be grown on acid sulphate soils. Raised bed also enhance the drainage and leaching of toxic elements from the root zone (Dent, 1986; Sarwani *et al.*, 1993; Tri *et al.*, 1993; Xuan, 1993).

Hanhart *et al.* (1997), from his experiments, reported that the general drainage condition of an acid sulphate soil plays a decisive role in determining the occurrence of nutritional disorders and subsequently vegetative and reproductive growth and yield. By carrying oxygen-rich water into the root zone, the percolation rate appears to control the redox status in the root zone, thereby controlling the pH. In its redox controlling capacity, the percolation rate also controls the formation of respiration inhibitors such as H_2S, thereby controlling the oxidative power of the roots and sensitivity of the plant to high Fe concentrations. By its leaching capacity, the percolation rate controls the concentration of ferrous iron in the root zone.

Hanhart et *al.* (1997) further recommended proper water management on badly drained acid sulphate soils that have a heavy soil texture and a high organic matter content. The primary aim should be for maintaining a delicate balance between reductive and oxidative conditions in the root zone. During the vegetative stage, reduced conditions should be maintained, to prevent lowering of the pH and subsequent increase of the Al concentration above the critical level of 30 ppm for non-acid resistant resistant varieties. The iron concentration should be kept below the critical level of 300 ppm by maintaining a sufficiently high percolation rate during one week before heading and throughout the reproductive stage. Moderately oxidized conditions should be maintained, to prevent the formation of respiration inhibitors such as H_2S, thereby maintaining the oxidative power of the roots and enabling them to withstand relatively high Fe concentrations for one week before heading and throughout the reproductive stage.

Oxidation of pyrite results in a dramatic drop of the pH together with an increase in the concentration of ferrous iron and sulphate in the soil solution.

Under strongly oxidised conditions, ferrous iron is further oxidized to ferric iron, releasing an additional H^+

$$Fe^{2+} + \frac{1}{4}O_2 + \frac{5}{2}H_2O \rightarrow^{ox} Fe(OH)_3 + 2H^+$$

$$Fe^{2+} + \frac{1}{4}O_2 + \frac{5}{2}H_2O \rightarrow^{ox} Fe(OH)_3 + 2H^+$$

As a result of the low pH, clay minerals are hydrolysed, releasing a substantial amount of soluble aluminium into the soil solution. Under the oxidized conditions during the dry season, crops suffer from severe Al toxicity. The soil which is rich in organic matter and easily reducible ferric iron, produces quantitatively the most important reaction on flooding (Ponnamperuma, 1972):

$$Fe(OH)_3 + \frac{1}{4}CH_2O + 2H^+ \rightarrow^{RED} Fe^{2+} + \frac{1}{4}CO_2 + \frac{11}{4}H_2O$$

This process consumes acidity, resulting in an increase of the pH, often to near-neutral values (Van Breemen, 1993; Hanhart and Ni, 1991). The increase of the pH results in a sharp drop of the Al concentration, as the concentration of Al_{sol} appears to decrease ten-fold per unit increase of pH (Van Breemen, 1976). Flooding the soil initially increases the Fe concentration to a peak followed by gradual decrease (Nhung and Ponnamperuma, 1966; Ponnamperuma, 1972). After several weeks of flooding and soil reduction, sulphate reduction takes place, especially in pockets of easily decomposable organic matter. Sulphate is reduced to sulphide, which is largely precipitated as FeS, a process partly responsible for the drop in Fe^{2+}_{sol}. Small amounts of H_2S, which can be toxic to rice in very low concentrations, can be found in soil solution (Yoshida, 1981; Van Breemen, 1993). Prolonged submergence and soil reduction probably diminishes the H_2S concentration, by depletion of most of the easily decomposable organic matter.

Oxidation of pyrite produces sulphuric acid, which causes low pH values and high levels of soluble Fe^{2+} in soil waters when insufficient quick-acting neutralizing substances are present. Dissolved sulphate may turn into toxic H_2S under reduced conditions and, if present in excess of 200 to 500 mg/l, can even damage cement concrete by formation of highly hydrated sulphates (van Holst and Westerveld, 1973). Detrimental effects of pyrite oxidation by lowering the water table in coastal potential acid sulphate soils on crop yields were reported by Beye (1973), Kanapathy (1973), and Yin and Chin (1982). Such studies led to one of the general recommendations of potential acid sulphate soils: controlled high water table to keep the sulphidic subsoil waterlogged (Dent, 1986) and hence, prevent acid formation. This recommendation puts the emphasis on controlling the chemical processes in acid sulphate soils.

Many problems that arise from the development of potential acid sulphate soils can now be solved by using brackish or saline water to remove soil acidity or suppress acidification. Work in Vietnam on the use of salt and brackish water on rice fields (Van Mensvoort *et al.*, 1991and Seiler, 1989) has shown that a controlled high water table or the accelerated oxidation of pyrite by shallow drainage and subsequent leaching of acidity by salt or brackish water, can overcome the farmers' problems.

Production of rice critically depends on the lowering of acidity and salinity by natural flooding and leaching during the rainy season. When salinity and acidity are high, amendments (lime, phosphate) and extra water management measures are needed. However, most farmers cannot afford amendments. They depend on selecting a period in the rice growing season during which soil limitations (salinity and acidity) are minimal. Research into variations of salinity and acidity with time can help to recommend optimum transplanting dates, and appropriate cropping techniques and varieties.

Ritzema *et al.* (1991) reported that there is no spectacular change in pH in the case of actual acid sulphate soils during prolonged submergence. The magnitude of the pH decrease by pyrite oxidation mainly depends on (i) the quantity of pyrite, (ii) its oxidation rate, (iii) the rate of removal of soluble oxidation products, and (iv) the neutralising capacity.

2.2.1 Iron toxicity

Free carbon dioxide (CO_2) present in water can dissolve iron in soils, which otherwise, is mostly insoluble. Under anaerobic conditions it can be reduced easily and become soluble. Lack of oxygen is the prime reason for high amount of iron associated with anaerobic conditions.

Hanhart *et al.* (1997) conducted experiments to evaluate the effects of repeated removal of surface water under varying drainage conditions, with the aim of alleviating suspected Fe toxicity aggravated by H_2S together with Al toxicity on an acid sulphate soil of low permeability in the Mekong Delta, Vietnam. The results of the experiments indicated that surface water management could alleviate nutritional disorders and increase yield.

Under strongly reduced conditions, the oxidative power of the roots may be insufficient to oxidise ferrous iron at the root surface. The oxidative power of the roots may be affected by the presence of H_2S (Tadano and Yoshida, 1978; Yoshida, 1981). H_2S can be toxic to rice at the very low concentration of 1 ppm (Mitsui, 1955).

According to Subramoney and Kurup (1961), the high soluble iron content in the submerged rice soils of Kuttanad indicated by the red scum in paddy fields produces a physiological disorder to rice plants. Tanka *et* *al.* (1968) reported that the excess iron more readily entered the shoot of rice plant causing iron toxicity. Saerayossakul (1968) concluded that rice plants grown in solution containing more than 200 ppm of iron showed iron toxicity symptoms resulting in the reduction of yield and decreased uptake of other essential elements. Kuruvilla and Patnaik (1973) indicated that both aluminium toxicity and ferrous iron toxicity could limit rice growth. Ferrous iron is developed due to reduction of iron under continuous flooding in the presence of organic matter contained in these soils. Mortality of rice plants due to severe iron toxicity in an acid sulphate soil from Philippines has been reported by Ponnamperuma *et al.* (1973). Datta and Surajit (1981) found occurrence of iron toxicity in soils with low pH and high organic matter content. Money (1961) reported that the chief sources of toxicity in Kuttanad are extreme acidity, solubility of iron chlorides and sulphates.

The problem due to continuous submergence such as ferrous iron accumulations and hydrogen sulphide production in Kuttanad soils could be reduced according to Aiyer and Krishnaswamy (1971) by establishing blue green algae in the rice fields. According to them, aeration of the rice rhizosphere and soils by the blue green algae decreased the hydrogen sulphide production. Ottow *et al.* (1991) have pointed out the additional beneficial effect of organic matter in alleviating iron toxicity. The use of old seedling rice plants to alleviate primary iron toxicity has been recommended in a number of studies (Noorsyamsi and Hidayat, 1974; Van Breemen and Moorman, 1978; Prade *et al.*, 1988).

Raw salt (NaCl) is sometimes applied to the rice fields at the beginning of the rainy season. Applications of 100-200 kg/ha are recommended when farmers feel that rice yields are declining. The practice is then repeated every 2 to 3 years. Raw salt replaces Al from the adsorption complex (Van Mensvoort *et al.*, 1991) and it also alleviates iron toxicity problems in the same way as leaching with brackish water.

2.2.2 Aluminium toxicity

Acid soils are toxic to many plants largely because they contain easily soluble aluminium salts (Hartwell and Pember, 1918; Corner and Sears, 1922). Schofield (1949), Karthikakutty *et al.* (1977) and Alice (1984) reported aluminium as the main toxic constituent of soil acidity. Pons and Calve (1969) reported that rice crops grown in acid sulphate soils showed symptoms of aluminium toxicity and phosphorous deficiency. The Al concentration of 30 ppm and 3 ppm were found to be toxic for acid resistant and non-acid-resistant varieties of rice respectively (IRRI, 1978).

Boer (1976) found that exchangeable aluminium was present in tropical soils in substantial quantities when the pH dropped below 6.0, but toxicity usually developed below a pH of 5.0. The mechanism of toxicity was often indirect via inhibition of phosphorous, calcium and copper uptake and stimulation of manganese uptake. At lower pH values, solubility of aluminium rapidly increases (Magistad, 1925). The toxicity of acid sulphate soils to rice was attributed to excess aluminium in the soil solution (Moorman, 1963). Kuruvilla and Patnaik (1973) reported that the acid sulphate soils of Kerala developed aluminium toxicity due to high acidity which limited rice growth. Aluminium toxicity retarded root growth, thereby decreasing nutrient uptake as well as drought tolerance (Data and Surajit, 1981). Yogodin (1984) concluded that aluminium reduced total root length but did not affect the water uptake per unit root length.

2.2.3 Leaching of acid sulphate soils

Minh et al., (1997) found leaching toxic substances out of root zone as an effective measure for improving soil quality and crop yield in acid sulphate soils. Importance of leaching toxic substances out of the root zone for improving soil quality and crop yield were reported by many authors (Van Mensvoort *et al.*, 1991; Xuan, 1993; Tuong *et al.*, 1993). Soluble and exchangeable acidity should be removed as much as possible by leaching before applying amendments. In principle, leaching with fresh water is efficient in removing free H_2SO_4, and efflorescence of soluble Fe and Al salts from the soil. Kuruvilla and Patnaik (1973) suggested that acid sulphate soils of Kerala could be ameliorated for growing a good rice crop by leaching of salts followed by application of lime and continuous flooding. Earlier studies (Nhung and Ponnamperuma, 1966, Dent, 1986) indicated that the soil must be improved first by leaching of water-soluble acid and, then by liming and fertilization. Application of lime after preliminary leaching raises soil pH and leads to decreased concentration of iron and aluminium in the soil solution. There is a clear response of rice to nitrogen and phosphate in combination with lime. Once the pyrite layer of potential acid sulphate soil is oxidised, it produces high degree of acidity that inhibits plant growth. Before any other amendments can be applied, toxicities have to be removed from the root zone, usually by leaching with water (Brinkman, 1982).

Mann *et al.* (1982), from experiments in a poorly drained, saline clay soil of marine origin in Portugal, found that the leaching efficiency is decreased with time, indicating that the removal of salt is a slow process in fine-textured soil.

Van Mensvoort *et al.* (1991) suggested that continuous leaching with fresh water removes Al but does not affect exchangeable Al. By leaching with brackish water, exchangeable Al can be replaced by Na, Ca and Mg from the water added. Leaching with brackish water is efficient in removing exchangeable Al if done under oxidized conditions, but less so in reduced conditions.

2.2.4 Liming in acid sulphate soils

Kari soils of Kuttanad are deficient in lime and phosphate, but have abnormally high soluble salt concentration (Subramoney, 1949; Subramoney, 1956; Prabha *et al.*, 1975 and Aiyer and Sundaresan, 1979).

The amount of base to neutralize the acidity produced by oxidation of one per cent of oxidizable sulphur is in the order of 30 tons per ha of $CaCO_3$ per 10 cm of soil of bulk density 10^3 kg m^{-3}. Exchangeable cations provide a neutralizing capacity equivalent to between 3 and 30 tons of $CaCO_3$ on the same basis, depending on clay content and mineralogy (Dent, 1986). Any oxidizable sulphur in excess of that can be removed only by leaching or liming. In practice, liming is efficient only after most of the water-soluble acidity has been leached. At least in case of lowland rice, applications of 2 to 10 ton of $CaCO_3$ per ha on leached acid sulphate soils often have a distinct beneficial effect, while large doses are rarely economical.

2.2.5 Crop performance in acid sulphate soils

Kames (1973) reported that the yield of rice grown in acid sulphate soils is low to very low, between 500-1500 kg/ha. In a review on soil chemistry, in relation to the growth of rice in acid sulphate soils, Satawathanant (1986) listed adverse effects of H^+, Al toxicity, Fe toxicity, sulphide toxicity, electrolyte stress, adverse effects of CO_2 and inorganic acids, P deficiency, low base status and impaired microbial activities as the problems associated with decreased crop yields.

Rock phosphate has been successfully introduced in acid sulphate soils of the Mekong Delta paddy lands (Le Van Can, 1982). According to Chien *et al.* (1990) the agronomic effectiveness of rock phosphate is high on acid sulphate soils due to the low pH, high organic matter content and high phosphorus fixing capacity of these soils.

Agronomical and fertilizer experiments on rice production in acid sulphate soils (Deturck *et al.*, 1992) suggest that transplanting of three-week old healthy rice seedlings was superior to direct seeding in the acid sulphate soils of South-West Sri Lanka. NPK fertilization increased the grain yield significantly. The response of rice, however, decreased with increasing fertilizer rate. At low fertilization, an acceptable yield was obtained by increasing the plant density.

Hanhart and Ni (1991) found that rice grown under intermittent drainage had healthier root systems, less empty grains, heavier weight per panicle. Rice in continuous submergence showed strong bronzing symptoms but had more tillers.

Truong Thi Nga *et al.* (1993) found that, although both sugarcane and pineapple can tolerate acid sulphate soil pH from 3 to 5, it is essential that these crops be supplied with adequate water, K and Ca.

Mathew et al (2001) have found that subsurface drain spacing up to 30m can significantly improve the rice yield and remove the chemical heterogeneity of the soil which is the root cause for patchy crop growth and uneven ripening of rice crop in the low-lying acid sulphate soils of Kuttanad region in Kerala, India.

2.2.6 Salt tolerance of rice

Experiments on the salt tolerance of rice indicated that it is more tolerant to saline conditions at one stage of development than at other. Under field conditions, Kapp (1947) observed that soil salinity at the time of planting resulted in a greater decrease in grain yield than a comparable level of salinity induced when the plants were six weeks old. This reduction in yield by salinity present at the time of planting was attributed to a decrease in the per cent germination. He also observed that rice at critical salinity levels developed normal straw yield but with little or no grain. Ota *et al.* (1955) found grain formation to be related to the length of the growing period under saline conditions. Shimoyama and Ogo (1956) reported that rice plants were most sensitive to salinity during the early growing period and again during panicle formation. With respect to the effect of salinity during panicle formation, Ota *et al.* (1956) observed that germination of pollen was adversely affected by salinity and this resulted in a lower per centage fertilization of the florets in the panicle. Using a sand-culture technique, Iwaki (1956) studied the effect of salinity initiated at various stages of development from germination to grain formation. The effect of salinity was found to be greater after 2 to 3 leaf stage than before this stage. According to Ehrler (1958) vegetative growth was less severely affected than grain production by salinity.

Reports on tolerance of rice to salt during the flowering stage have been controversial. According to Pearson and Ayers (1960), rice is very tolerant to salt during germination, but very sensitive during the early seedling stages, gains tolerance progressively during the tillering stage, again becomes sensitive during flowering, and is tolerant during grain maturation. In contrast, Akihama (1960), Kaddah and Fakhry (1961), and Kaddah (1963) found no evidence that rice has higher sensitivity to salt at the flowering.

Bernstein (1961) and Kaddah (1961) reported that germination of the seed was delayed by increase in salinity. Bernstein (1961) showed rice to be more tolerant to salinity at germination than at seedling stage. Kaddah *et al.* (1973) reported that rice is not sensitive to salt after boot stage.

2.2.7 Environmental problems of drainage

Drainage of coastal areas for a variety of land uses has been undertaken in ignorance of the hazards posed by pyrite oxidation and acute degradation of estuarine ecosystems. The buffering capacity of waters is generally low and toxic threshold concentrations are often lower for aquatic organisms than for plant roots. Due consideration is therefore to be given while leaching severe acid sulphate soils so that it does not cause hazard to fish and the aquatic chain. It seems judicious to limit leaching, as much as possible, to periods with high surface water runoff, so that acid and often toxic products are diluted as much as possible.

Leaching of acid sulphate soil transfers acidity to the surroundings and may result in pollution of the surrounding water and land. Severe acidification of the surface water has been reported for many reclaimed acid sulphate soils (Dent, 1986). Polluted water may also harm aquatic organisms and crops in the surrounding and downstream areas, where the contaminated water is used for irrigation (Moormann and Van Breemen, 1978; Dent, 1986; Dat, 1991; Dent, 1992). Wendelaar Bonga and Dederen (1986) found that a low pH, below 3-4, is directly lethal to most fish species.

Veness (1990) had reported on the major environmental damage caused by drainage of acid sulphate soils typified by massive fish kills in rivers, a decline in coastal fishery resources, degradation of estuarine ecosystems and a decrease in the productivity of agricultural land. Smith (1990) reported 'acid shock' during the early part of the rainy season in drainage water from acid sulphate soils of the Plain of Reeds when almost all invertebrates of the entire area were wiped out. Willett *et al.* (1992) have reported on the fish kills that have occurred in the estuary of Tweed River. Drainage of acid sulphate soils of the floodplain of this river to improve sugarcane production was reported to be responsible for these fish kills.

Grismer (1993) found that under steady and transient conditions, drainage water salinity and cumulative salt load increases with increasing drain depth and spacing. His results suggest that water quality factors may be as important as other drainage system design parameters when considering construction of new drainage facilities.

While reporting on the effectiveness of leaching for improving the soil quality, Minh *et al.* (1997) pointed out its hazardous effect of polluting the environment. They quantified the concentration and amount of pollution from leaching of acid sulphate soils for rice, pineapple and yam cultivation in the Mekong River Delta and stressed the need to consider the environmental hazards while planning for reclamation of acid sulphate soils.

2.3 SUBSURFACE DRAINAGE

The purpose of subsurface drainage is to lower excessively high water tables close to the soil surface to prevent crop damage. Some subsurface drainage systems are designed to intercept the excess water before it creates problem. Others are designed either to relieve the root zone off excess water or to prevent its accumulation or to leach the salt accumulation from the root zone area. The high water table level will obstruct the exchange of oxygen and carbon dioxide between the atmosphere and the plant root system and will also decrease the beneficial leaching of soluble salts within and above the root zone.

2.3.1 Drainage criteria

When drainage theories are applied in practice, one faces a number of limitations. These limitations are the consequence of the wide variability in soil and plant properties. Although excellent progress has been made in recent years in developing drainage criteria and investigational tools, it still takes good judgement, local experience, and trial and error along with a thorough understanding of the basic principles to design a successful drainage system.

The proper functioning of a drainage system depends on the followings.

1. Establishment of the drainage requirements of the crop to be grown
2. Characterization of soil properties affecting drainage, and
3. Determination of the design system that will satisfy crop drainage requirements based on soil properties.

The static water table criterion for subsurface drainage design is the simplest and is widely used in drainage design. It is also the criterion for which most information is available. Considerable research has been done in The Netherlands with regard to optimum water table height (Luthin, 1957).

Designs based on falling water table criterion seems to be more realistic than static water level, because it represents the actual situation occurring during drainage. Several nonsteady-state drainage design equations have been presented in past years. Kraijenhoff van de Leur (1958, 1962) and van Schilfgaarde (1965, 1966) have developed methods for utilizing the fluctuating water table approach. However, much more research is needed for various crops and soil conditions taking the crop parameter into account in the design equations using the fluctuating water-table approach. Knowledge of the inputs concerning drainage requirements of crops is seriously lacking. Whatever these desired crop-drainage-requirement criteria might be, the specification of these criteria must be based on knowledge of the plant's interaction with its environment. Also, these criteria must be expressed in quantitative form to be useful to the drainage-design engineer.

In irrigated areas, salinity level in conjunction with the static or falling water table approach is often utilized as a basis for drainage design. The salt tolerance of the crop to be grown is the crop parameter governing the design in this case. A desired drainage rate is calculated then, based on the maximum permissible salt concentration in the soil.

Fipps *et al.* (1986) used a finite element solution to the Richards equation to simulate the effect of seepage to and from a field drained by parallel tubes. The drainage tubes were assumed to run parallel to an adjacent canal. Solutions were obtained for canal water levels both higher and lower than the water table in the field. Two 135 m wide regions with depths to the impervious layer of 3 m and 7 m were analyzed; each had four parallel drain tubes at a depth of 1 m. Solutions for both steady state and transient drainage events were obtained for two separate soils. Seepage to and from the canal had the maximum effect on the water table between the canal and the first drain. It had minimal effect on the water table heights between the first two drains and on the flow rate into the first drain. The effects of the canal water level on the rest of the field were negligible.

2.3.2 Steady-state drainage theory

Kirkham (1966) and Lovell and Youngs (1984) gave extensive reviews on various steady-state subsurface drainage theories. Prominent among those who investigated on the steady-state drainage problems for homogenous isotropic soils were Hooghoudt [as reported in van Schilfgaarde (1957) pages 85-91], Kirkham (1958), Toksoz and Kirkham (1961), Childs (1960), Hammad (1962), Ernst (1962), Dagan (1964), List (1964), and Hinesly and Kirkham (1966). Investigations on water-table heights in drained lands have been concerned particularly with two-dimensional steady-state problem of drainage by parallel equidistant sinks (Luthin, 1957; Kirkham, 1966). In theoretical studies, the uniform rainfall incident on the surface is assumed to percolate vertically through the unsaturated soil until it reaches the water table or the top of the capillary fringe. The problem then reduces to finding the equipotentials and streamlines with given boundary conditions in the saturated groundwater zone, the upper boundary of which emerges as part of the solution. Analytical solutions, (Engelund, 1951; Childs, 1969) may be found for a uniform soil for particular drainage situations when the soil extends to infinite depth and also when an impermeable barrier is at drain level. When the soil is bounded by an impermeable barrier at some finite depth, solutions in terms of Fourier series may be found (Kirkham, 1966). Analytical solutions of drainage problems in non-uniform soils are not usually possible. However, for soils whose conductivity varies only with depth or only with horizontal position, upper and lower estimates of water table heights in lands drained by ditches, which extend in depth to an impermeable floor were given by Youngs (1965, 1966). Estimates were also given for a special class of spatial variation of hydraulic conductivity. Youngs (1975), using theoretical considerations provided upper and lower limits within which the true water table must lie for a given rainfall rate and depth of impervious layer. The most critical limitation of these solutions is that they have been derived by assuming that the water percolates vertically from the soil surface through the unsaturated soil water zone to the water table at a rate equal to the precipitation rate.

In a steady-state situation, the recharge equals the discharge and there is no change in storage. Steady-state equations, however, are also applicable to unsteady-state situations, provided that the change in storage is small compared with the volume of recharge and discharge Oosterbaan (1988).

2.3.3 Non-steady state drainage theory

In situations like low-lying acid sulphate soils, particularly when the crop grown is paddy, the design criteria is to contain the acidity and salinity for a sustainable crop growth. This could be achieved by providing a salt free situation within the root zone by leaching with fresh water and by preventing the upward flux which causes salinisation. Transient drainage equations play a vital role in designing drainage systems in these areas. The normal problem encountered in the design of tile drainage systems is therefore to determine the maximum spacing between drains, which will enable the water table to fall to a predetermined height above the drains, in a given time, under given conditions of hydraulic conductivity, drainable porosity, and depth of aquifer.

Transient drain spacing equations describe the relationship among soil physical characteristics, depth and spacing of parallel subsurface drains and the fall of the water table at the midspacing between the drains. The accuracy of prediction of a given equation, all things being equal, depends upon how closely the assumptions and boundary conditions used to derive the theoretical equation approximate field conditions. Therefore, drainage equations are frequently tested against experimental field data.

Drainage problems may be approached in two ways. The classical potential (Laplace) formulation is the more general of the two, but leads, in nonsteady cases, to serious mathematical difficulties. The alternate approach is based on the Dupuit-Forchheimer idealization, which applies to water tables with small slope. The simplest mathematical treatment, both for steady state and for transient conditions, is based on Dupuit-Forchheimer assumptions. These assumptions ignore the effect of convergence of flow lines in the neighbourhood of the drains and consequently result in an overestimate of the rate of drainage. This overestimate is negligible only when an impervious barrier exists at a shallow depth below the drains.

Solution of Richards equation for combined saturated-unsaturated transient flow is required for an exact theoretical characterization of water table drawdown and associated water movement above the water table. Because it has not been possible to obtain a general solution to this non-linear equation, drain spacing equations have been derived by neglecting flow in the unsaturated zone above the water table and defining a soil property, drainable porosity, which represents the total fraction of the soil volume drained as the water table recedes. Although the concept of a constant drainable porosity can lead to significant errors, the concept can be effectively used for predicting water table drawdown with an accuracy sufficient for design purposes.

Kirkham and Gaskell (1951) proposed an equation for the rate of fall of water table in terms of hydraulic head function, the slope of the water table, the soil permeability, and drainable porosity. They analysed the problem by solving Laplace's equation for a series of steady states. Relaxation procedures were used to solve Laplace's equation. The assumption that a constant fixed drainable porosity is a major lacuna in the approach used by Kirkham and Gaskell since the drainable porosity actually depends on the soil moisture tension.

Glover, an engineer in The Bureau of Reclamation, U. S. Department of Interior had developed an equation (Dumm, 1954) for drain spacing based on the Dupuit-Forchheimer assumption, with the additional simplification that the thickness of the water bearing aquifer can be approximated as a constant. Thus, it neglects the effect of convergence of flow towards drains. This would lead its predictions to be increasingly less accurate as the depth to impervious layer increases. Furthermore, at small values of depth to impervious layer, the assumption of a time-constant thickness of the aquifer is not even met approximately.

Luthin and Worstell (1959) also developed an equation for falling water table. The main assumption in its derivation is that the discharge rate is proportional to the height of the water table. In addition, this equation does not take into account the depth of an impervious layer. Rapp (1962) reported that the Modified Glover equation for spacing of drains placed above an impermeable layer predicted existing drain spacings more accurately in a shallow soil in southern Alberta than did the Glover equation for drains placed on an impervious layer.

Hammad (1962) used potential theory and the assumption that the receding water table between drain tubes is nearly flat to derive equations for water table drawdown in both shallow and deep soils. Van Schilfgaarde (1963) proposed a rational procedure for the determination of the proper depth and spacing of tile drains. Although based on the Dupuit-Forchheimer theory, the procedure adequately accounts for the effect of convergence of flow towards the drains and it avoids the common simplifying assumption of a water-bearing stratum of constant thickness. Bouwer and van Schilfgaarde (1963) presented a simplified procedure for predicting rate of fall of water table in tile-drained soil. The procedure is based on steady-state theory and abrupt drainage of pore space which relates to the fall of the water table midway between drains, where the water table recession is the slowest and, therefore, the most critical.

Tapp and Moody (Dumm, 1964) modified the Glover's equation to consider fourth degree parabola as the initial water table shape. The resulting equation differed from the earlier only in that the numerical constant was replaced by approximately 3.7 (van Schilfgaarde, 1970). Dumm (1964) used preliminary field data and found Glover equation to provide accurate predictions for drains placed on a barrier.

Johnston *et al.* (1965) found that van Schilfgaarde equation predicted more accurately than Bouwer and van Schilfgaarde, Integrated Toksoz and Kirkham, and Luthin and Worstell equations. French and O'Callaghan (1966) found that the order of preference of drainage equations in terms of prediction was van Schilfgaarde > Hammad (thick layers) > Bouwer and van Schilfgaarde > Modified Glover in a silty clay soil. Skaggs *et al.* (1973) found in a sandy loam soil in North Carolina, when hydraulic conductivity was determined using soil cores, that the order of preference of equations was van Schilfgaarde > Bouwer and van Schilfgaarde > Glover > Hammad (thin layers). A study conducted in two clay soils in Egypt by Abdel-Dayem (1984) found that van Schilfgaarde and Modified Glover equations yielded essentially equal and reliable results during the latter stages of water table recession but for early stages van Schilfgaarde equation was more reliable. Buckland *et al.* (1987) compared predictions of water table positions and drain spacings computed using theoretical transient drain spacing equations with the measured performance of subsurface drains installed in a relatively shallow lacustrine soil in southern Alberta, Canada. The Bouwer and van Schilfgaarde equation, using a *C* factor of 1.0, most closely predicted the measured performance of the existing drains under all conditions.

2.3.4 Hydraulic conductivity

Hydraulic conductivity is one of the most important factors influencing spacing between lateral drains for subsurface drainage systems. While methods for determining hydraulic conductivity and drainable porosity have been rigorously developed and thoroughly tested, the properties often vary widely from point to point in the field and usually require numerous measurements to obtain field effective values. At the conference held in 1965 on Drainage for Efficient Crop Production, Kirkham (1966) summarized work on saturated hydraulic conductivity as a characteriser of soil for drainage design.

Isherwood *et al.* (1958) found that the soils they tested were not sufficiently uniform to define the field hydraulic conductivity by point measurements. It is apparent from the literature that in using point measurements to define the hydraulic properties of field size units we are confronted with the inevitable mismatch of reality.

Hydraulic conductivity from field investigations in alluvial soils shows a high spatial variability. French and O'Callaghan (1966) reported a discrepancy of 157 times between field value and laboratory measurements of hydraulic conductivity and attributed this to the lack of soil homogeneity. Bouwer (1969) has shown that the effective hydraulic conductivity can be estimated by the geometric mean of point hydraulic conductivities within the flow domain. Skaggs (1976) has presented a method of determining the effective hydraulic conductivity based on water table measurements where lateral drains were already installed in the field.

Bouma *et al.*, (1979) found that improvement of drainage conditions and lowering of the groundwater leads to a long-term increase of the hydraulic conductivity of heavy soils in The Netherlands.

Hydraulic conductivity determined by the auger-hole method (van Beers 1983) samples a relatively small volume of soil compared with the soil volume between two lateral drains. This, and the very high spatial variability of many of the soil physical properties make the use of *in-situ* augur hole estimated hydraulic conductivity values questionable for subsurface drainage design.

Literature on how to incorporate soil spatial variability into subsurface drainage design is scarce. The United Nations Food and Agriculture Organisation ("Drainage", 1986) suggested that lateral spacing be calculated at each hydraulic conductivity measurement site, and that areas with the same spacing be determined such that individual spacing within each area did not differ by more than 50% from the average spacing. Prasher *et al.* (1984), and Strzepek and Gracia (1987) have proposed delineation of areas of homogeneous hydraulic conductivity based on the probability distribution of the water table depth. Rogers and Carter (1987) have reported that in layered soils, such as the alluvial soils in the Lower Mississippi Valley, hydraulic conductivity measured in auger holes varied considerably. This variation presented problems in deciding which values to use in designing subsurface drainage systems. They discussed a systematic procedure of measuring hydraulic conductivity and determining it from field data and a finite element model to predict flow to an auger hole.

LeSaffre (1990) has used G. Guyon's pumping test to measure *in situ* values of two soil hydraulic parameters used for drainage design purposes, the horizontal component of saturated hydraulic conductivity, and the drainable porosity. He found this method to be more precise than the auger-hole method.

Kriging (a statistical method, based on the theory of regionalized variables and developed by D. G. Krige, for local estimation of soil properties) of log-transform hydraulic conductivity can be used to obtain estimates of the effective hydraulic conductivity ("Review" 1990; Ahmed and De Marsily 1987). Moreover, kriging provides the variance of estimation that indicates the level of uncertainty associated with estimation. Gallichand *et al.* (1991) through their study have shown how kriging, a linear unbiased estimator, can improve the representation of hydraulic conductivity for subsurface drainage design. Gallichand *et al.* (1992) have presented a procedure to take into account uncertainty in hydraulic conductivity and water table depth while delineating areas to which a single lateral drain spacing can be assigned. They used simple block kriging of log-transform hydraulic conductivity data to estimate the effective hydraulic conductivity of square blocks with sides equal to lateral drain spacing.

With the existing core or field methods for measuring the soil hydraulic conductivity, tile depths and spacing can seldom be predicted accurately. Hydraulic conductivity found by using tile-flow measurements provide more reliable values as they can account for the soil variability of the large sample size. Determination of drain spacings based on the mean value of measured hydraulic conductivity within the area to be drained does not take into account spatial variability of the hydraulic conductivity, and may result in large areas where the water table is shallower or deeper than the design water-table depth. Areas with shallow water table will reduce crop yield, while deeper than required water tables will result in unnecessarily expensive drainage systems.

The areas with a uniform lateral spacing should be as small as possible to control, with small variations of water tables at desired level. Conversely, practical considerations require that frequent changes in lateral spacing be avoided in order to maintain construction costs as low as possible. Consequently, a trade-off must be achieved between large areas with uniform lateral spacings, and small areas with low variability in hydraulic conductivity, which provide better water control.

2.3.5 Drainable porosity

Drainable porosity or specific yield is one of the basic input parameters in conventional methods for predicting water table drawdown. Drainable porosity is usually defined as the volume of water per unit area released when the water table falls by a unit distance. In drainage design it is conventionally assumed to be constant and treated as a soil property.

Childs (1960) and Taylor (1960) have shown that drainable porosity is not a constant but depends on water table depth as well as other factors. An equivalent drainable porosity can be obtained by continuous measurement of water table depth as suggested by Taylor (1960). Hoffman and Schwab (1964) presented a method of predicting drain spacings based on measured drain outflow. Although adaptable to any of the drain spacing solutions, they used van Schilfgaarde's (1963) equations to calculate hydraulic conductivity and drainable porosity from the outflow and drawdown measurements. While this method provides one of the most reliable means available for measuring field effective values of the soil properties, it is often difficult to measure drain outflow from an area; consequently the method has not been widely used in practice.

Methods were presented (Skaggs, 1976) for determining the hydraulic conductivity-drainable porosity ratio from water table drawdown measurements. However, outflow measurements needed for an independent determination of drainable porosity are relatively difficult and it is usually more convenient to calculate this property from the soil water characteristic by methods such as those used by French and O'Callaghan (1966) and Duke (1972).

Bhattacharya and Broughton (1979 a) had developed drainable porosity – water table depth functions based on laboratory and field experiments on a sandy and a clayey soil. They had demonstrated the use of such relations in subsurface drainage design through a water balance approach, leading to quantification of certain design parameters that would ensure maximum average annual revenue increase due to subsurface drainage (Bhattacharya and Broughton, 1979 b).

Variability of drainable porosity on water table depth was considered by Pandey et al (1992) in predicting hydraulic heads under a falling water table situation in a sand tank model. They developed and used a continuous function between drainable porosity and water table depth but used this function outside the differential sign of the governing differential equation (the Boussinesque equation) of saturated subsurface flow. Using their approach, the differences between the observed and the predicted hydraulic heads in space and time after the start of drainage were considerably reduced as compared to when drainable porosity was taken as a constant, as is the usual case in subsurface drainage design methods.

Subsequently, Gupta et al (1994) advanced the above concept further by solving the Boussinesque equation numerically, keeping the drainable porosity-water table depth function within the differential sign. By doing so, they could achieve a 71 per cent reduction in the average absolute deviation between the space–time distribution of water table depth when drainable porosity was taken as a continuous function of water table depth, from the case when it was taken as a constant.

2.4 ECONOMICS OF SUBSURFACE DRAINAGE

Designing a drainage system using any drainage equation requires a drainage criterion to be chosen, that is, a selection of the required drawdown and a recharge to achieve efficient drainage. Generally wider drain spacing can be adopted when the drains are installed at a greater depth below the soil surface. The deeper installation will increase the unit construction costs of the drainage system, while a wider spacing has the opposite effect. A combination of depth and spacing therefore, needs to be determined at which the construction costs per unit area attain a minimum. The designer, hence, is required to make a compromise between these interacting factors and provide a design that will produce a maximum increase in revenue to the farmer for a given soil condition and type of crop.

Wiser *et al.* (1974) have presented an approach for an optimum design of a subsurface drainage system based on the concept of interaction between cost associated with the spacing and water table relations. The balancing of drain depth against drain spacing has been investigated by Christopher and Winger (1975) on the basis of USBR bid contracts, but only a limited analysis was made for the influencing factors.

Gittinger (1976) has given a detailed analysis of various discounting measures commonly applied for agricultural projects, namely, benefit-cost ratio, net present worth, and internal rate of return.

Bhattacharya (1977) used the water balance approach in which the system installation cost and the market value of the harvested crop were compared for drainage systems designed with different drainage rates. Bhattacharya and Broughton (1979) found that the spacing required to obtain maximum revenue increases was sensitive to soil hydraulic conductivity, but insensitive to interest rate, amortization period and installation cost.

Skaggs and Tabrizi (1986) simulated corn yields for a large number of drainage system designs on twelve North Carolina soils that require improved drainage for efficient crop production. Simulations were conducted for three drain depths, ten drain spacings and two surface drainage treatments for each of the 12 soils. Economic analyses were done to determine the drain spacing that would give maximum return to land and management for each drain depth and surface drainage treatment. Those spacings were then used in Hooghoudt's equation to determine the steady drainage rate that would result when the water table midway between the drains is at the surface.

Gates and Grismer (1989) developed a simulation model which accounts for the major processes governing shallow saline water table behaviour in salinity-affected irrigated regions. Designed for feasibility stage project planning, the model may be used to develop economically optimal irrigation and drainage strategies for long-term regional management.

3. DESCRIPTION OF THE STUDY AREA

Kerala State, lying between 8°18' to 12°48' N latitude and 74°25' to 77°22' E longitude, is one of the small but beautiful narrow strip of land in the south-western corner of the Indian Peninsula (Figure 3.1).

Kerala may be divided into three geographical regions: (1) Highlands, (2) Midlands and (3) Lowlands. The Highlands slope down from the Western Ghats which rise to an average height of 900m, with a number of peaks well over 1800m in height. This is the area of major plantations like tea, coffee, rubber, cardamom and other spices. The Midlands, lying between the mountains and the lowlands, is made up of hills and valleys. This is an area of intensive cultivation. Cashew, Coconut, Arecanut, Cassava (Tapioca), Banana, Rice, Ginger, Pepper are grown here. The Lowlands or the coastal area, which is made up of the river deltas, backwaters and the shore of the Arabian Sea, is essentially a land of coconut and rice. Fisheries and Coir industry constitute the major industries of this area.

Figure 3.1 Map showing location of Kuttanad

Kerala is a land of rivers and backwaters. Forty-four rivers (41 west-flowing and 3 east-flowing) cut across Kerala with their innumerable tributaries and branches. These rivers are comparatively small and being entirely monsoon-fed, practically turn into rivulets in summer, especially in the upper areas. Backwaters form a specially attractive and economically valuable feature of Kerala. They include lakes and ocean inlets, which stretch irregularly along the coast. The largest backwater body is the Vembanad Lake.

Kerala is again divided into five agro-climatic zones taking into consideration of its physiography, climate, soil characteristics, sea water intrusion, land use pattern, vegetation etc as per the recommendations of the "Committee on agro-climatic regions and cropping patterns" constituted by Government of Kerala in 1973. The zones are:

- Southern zone
- Central zone
- Northern zone
- High Altitude zone
- Special zone for problem areas

The area of study is in the Kuttanad tract of Special zone for problem areas.

3.1 THE SPECIAL ZONE FOR PROBLEM AREAS

The Special Zone for Problem Areas lies on the coastal line of Kerala State. This zone is further divided into four physiographical tracts (Table 3.1).

Table 3.1 Special zone divided into different physiographical tracts

Physiographical Tracts	Taluks	Districts
Onattukara	Karthikappally, Mavelikara and Karunagappally.	Alappuzha, Kollam
Kuttanad	Kuttanad, Ambalappuzha, Cherthala, Vaikom, Changanacherry, Kottayam	Alappuzha, Kottayam, Pathanamthitta
Pokali	Paravoor and Kunnathunad	Ernakulam
Kole	Thalappilly, Mukundapuram, Thrissurr, Chavakkadu and Ponnani	Thrissur, Malappuram

The total area of the problem zone comes to 4,28,540 ha, which accounts for 11.02% of the total area of the state. The maximum area of 1,36,058 ha (31.75%) comes under Alappuzha district followed by 1,10,126 ha (25.75%) in Kottayam district. No forest area comes within the zone. The net rice sown area is 3,04,504 ha which accounts for 13.54% of total area sown in the state. Gross cropped area comes to 4,30,051 ha (14.12% of the total area of the state). The region extends from 9°17'N to 9°40'N and 76°19'E to 76°33'E. Most of the vast expanse of this region is lying below mean sea level; waterlogged throughout the year, subjected to continued flood submergence during the monsoons and saline water ingress during the summer months.

3.1.1 Kuttanad tract

Kuttanad region consists of 54 revenue villages spread over 10 Taluks in Alappuzha, Kottayam and Pathanamthitta Districts. It stretches for 75 km sandwiched between the sea and the hills. The bewildering labyrinth of waterways composed of lakes, canals, rivers and rivulets, is lined with dense tropical greenery. This region (Figure 3.2) of Kerala is an interface of marine, estuarine and fluvial systems representing a highly complex eco-system in India. The human interference in developing the landmass by reclamation has added a new dimension to this complex eco-system. The interrelationship of these different systems is so intricate that tampering of anyone will disturb the balance of the whole eco-system beyond redem- ption. The total area of Kuttanad tract is about 1100 km².

Figure 3.2 The Kuttanad region

3.1.2 History of Kuttanad

The early Cheras had their home in Kuttanad and they were called 'Kuttuvans', named after this place. During 9th to 12th century A.D, the district flourished in the field of religion and culture under the second Chera Empire. In early Tamil literature like 'Venpai' and *Tholkappiyam*, Kuttanad is mentioned as one of the 12 *Nadus* (Principalities) where people spoke *Kodumthamil*. There are references to Kuttanad in the great Tamil work *Thiruvaymozhi* written in the 8th century AD by the renowned Vaishnavite Saint Nammalvar and in *Periyapuranom* of the 11th century AD. Apart from these historical records, there are also certain legends connected with Kuttanad. It is said that the *Khandava Vana* mentioned in the epic Mahabharatha was situated in Kuttanad and that the remnants of the burnt forest still lie deep under the fields. It is said that the place was originally known as *Chuttanadu* (meaning burnt place), which later on became Kuttanad.

3.1.3 Population

The total population of Kuttanad is 1.4 million. The rural population alone constitutes one million with a population density of 800 persons per km². Forty per cent of the population is engaged in agriculture, the major economic activity in the area. Fishery is another important primary activity in the area.

3.1.4 Land holding

The total number of operational holdings in the zone is 8.88 lakhs, which accounts for 16.57 per cent of the total households in the state. Around 94.45 per cent of the total operational holdings are marginal in size (less than 1.0 ha.) against the State's figure of 92.5%. Small holdings (1.0 to 2.0 ha.) constitute 3.94% of the region. Only 0.04 per cent holdings in the zone are large (above 10 ha). From the survey conducted at this station and from the records available with the Revenue Department, it is found that altogether 125 cultivators are there in the project area, farming 75.238 ha of paddy fields. When the tenureship of the land is classified based on the extent of holding, it is seen that 88% of holdings falls below 1.00 ha and only 12 % are above 1.00 ha. The average size of holding is 0.601 ha.

3.1.5 Soils

The texture of the soil in the zone can be mainly classified as sand, sandy loam and clay. About 65% of the area has moderately well drained to well drained soils. The data on some of the physico-chemical properties are given in Table 3.2.

3.1.6 Agro-ecological situation

Although there is substantial homogeneity in physical features in Kuttanad, there exists considerable heterogeneity within the region with

Table 3.2 Physico-chemical properties of the kari soils

Physical-Chemical Properties	Single cropped area	Double cropped area
Apparent density, kg/m3	768-1082	671-1000
Absolute specific gravity	1.59-2.85	1.288-1.824
Pore space, %	25.94-64.9	25.3-72.57
Maximum water holding capacity, %	31.4-53.5	11.25-29.3
Volume of expansion, (%)	0.55-3.52	0.45-2.71
Total Nitrogen, (%)	0.021-0.032	0.024-0.043
Total Potassium, ppm	1.76-2.3	2.34-05.29
Total K_2O, ppm	20-34.8	20-40

respect to agro-ecological conditions, which is reflected in the potentials, constraints and possibilities for the resource use. The geological evolution of the land mass and the omnipresence of water and that too in dynamic flux in quantity as well as quality, lead to the evolution of different configurations of agro-ecological factors in various parts of the region.

Based on three criteria viz., flood submergence, vulnerability to saline intrusion and soil acidity, six agro–ecological zones have been identified in Kuttanad region (see Figure 3.2). They are:

- Upper Kuttanad
- Lower Kuttanad
- Kayal lands
- North Kuttanad
- Purakkad Kari
- Vaikom Kari

The two deltaic formations of the three river systems, namely Achencovil, Pamba and Manimala and the other of the Meenachil River constitute the core area of Kuttanad region. The deltaic formation of these river systems in the basin gradually slopes down to the Vembanad Lake and merges with it. The flood submergence therefore affects variously the different parts of the delta formation. Maximum impact is found in the areas close to the uplands identified as *Upper Kuttanad* because the availability of land to spread out the floodwater is minimum. The least is experienced in the areas adjoining the lake and backwaters since a vast expanse of land is available to contain and spread out the flow waters and is distinguished as *Kayal Land*. The areas in between is subjected to flood impact moderately and identified as *Lower Kuttanad*. Upper Kuttanad area, being away from the lake and back water systems, is least affected by salinity while Kayal Land, being closer, is more vulnerable to saline intrusions. The deltaic formation of the Meenachil River, which is separated by Kayal Lands from the former area and is subjected to both flood submergence and saline intrusion, has been identified as *North Kuttanad*. In both the deltaic formations, the soil is formed out of the alluvial deposits carried by the river systems. The core area is flanked by soils formed of undecomposed organic matter having high levels of acidity on either side, in the south and in the north. This area, being closer to the sea, is subjected to salinity intrusion. They are commonly called *Kari Lands*, in the north as *Vaikom Kari*, and in the south as *Purakad Kari*.

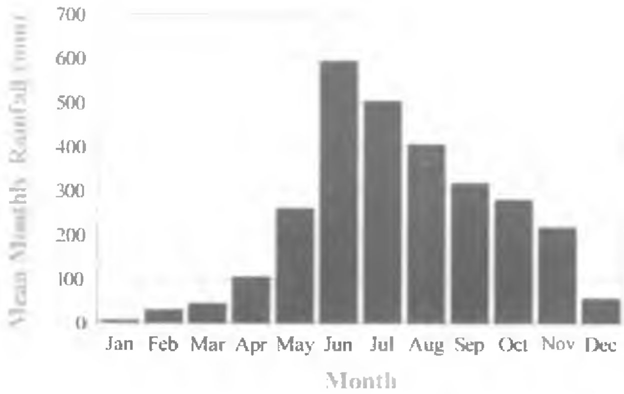


Figure 3.3 Mean monthly rainfall of the region (10 years)

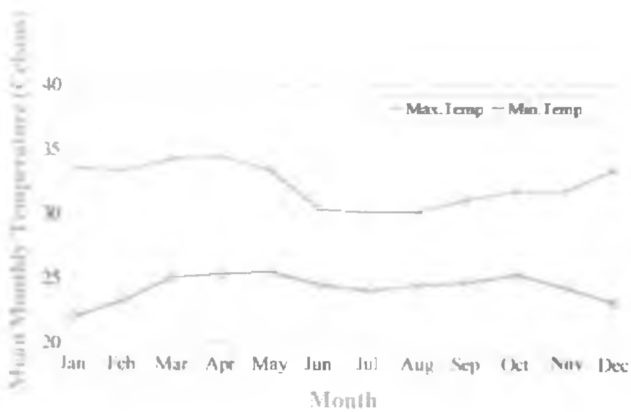


Figure 3.4 Mean monthly temperature of region (10 years)

3.1.7 Climate and season

Kuttanad is a warm humid region with fairly uniform temperature throughout the year ranging from 22°C to 35°C. The area experiences a typical tropical climate. The annual average rainfall is 300 cm of which about 83% are received during the monsoon months. Two distinct rainy periods, from June to August (during South-West monsoon) and from October to November (during North-East monsoon), are experienced. Practically very little rain is received in the months of January to February. The summer months, March to May, is endowed with occasional rains. The mean daily rate of evaporation is 4.37 mm. The mean monthly rainfall and mean monthly temperature over a period of 10 years for the region are given in Figure 3.3 and 3.4, respectively. There are two cropping seasons namely, *puncha* (November-March) and *virippu* (June-September). The *virippu* crop is also known as additional crop. In between the seasons the lands are kept under water fallow. The *puncha* crop is sown after the flood season is over while *virippu* crop is taken with the risk of floods during the Southwest monsoon.

3.1.8 Topography

There are three identifiable topographic delineations (Figure 3.5) in Kuttanad landmass, namely, the Dry lands (Garden Lands), the Wetlands and the Water bodies (Water Spread). The Dry Lands, where Kuttanad population inhabits, are 0.50-2.50m above Mean Sea Level (MSL). They cover an area of 31,000 ha. Except for the Coastal Kuttanad, there is a fair amount of uniformity in the characteristics in the Dry Lands found in the various agro-ecological zones. The Dry Lands have been formed by the deposition of alluvium brought down by the river systems. Apart from this, during the last hundred years, Dry Lands were made in the Kayal Lands, Kari Lands and Lower Kuttanad zones by depositing clay, silt and sand collected by manual dredging of water ways and the Lake area. On the other hand, in the Coastal Kuttanad, the Dry Lands have been formed by wave action in the sea by the deposit of sand dunes over the alluvial deposit of silt and clay. The Wetlands (66,000 ha) include low-lying areas (11,000 ha) of slightly above MSL, and areas below MSL (55,000 ha) reclaimed from the backwaters. The Water bodies constitute the remaining 13,000 ha along with the Vembanad Lake. The whole Kuttanad is criss-crossed by rivers, channels, canals, and other waterways.

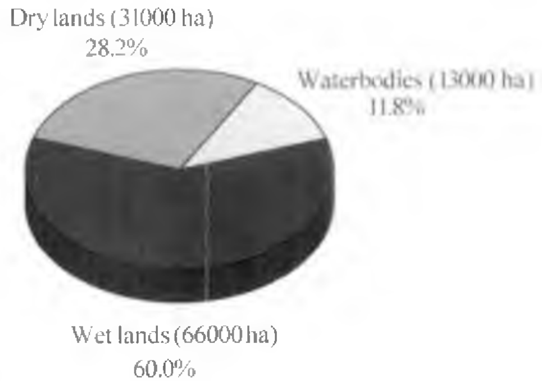


Figure 3.5 Topographical delineations of Kuttanad landmass

3.2 PUNCHA LANDS

The present paddy fields of Kuttanad, also known as *Puncha lands*, were formerly vast stretches of water. These were slowly reclaimed for rice cultivation. The process of reclamation was initiated during the later half of 18th century. The earlier reclamations were confined to water logged areas of comparatively shallow depth in upper reaches of Kuttanad. The increasing pressure of population on land during the last century and the exhaustion of shallow backwaters for reclamation purpose compelled the people to venture into deeper waters of Vembanad Lake and a sizable area has been reclaimed for paddy cultivation. A contiguous stretch of Wetlands, bound by waterway or other natural features, reclaimed for rice cultivation by constructing ring bunds (earthen) is called a '*Padasekharam*' (polder), which is a homogeneous physical entity. The typical sketch of a *padasekharam* is shown in Figure 3.6. The size of a *padasekharam* varies from 5 ha to nearly a 1000 ha. The total area of *Puncha lands* is 55,000 ha. The lands are mostly waterlogged with an elevation of 0.50 to 2.00m below MSL. Agricultural practices in *Puncha Lands* vary greatly depending on the flood risk, soil fertility and risk of saline water intrusion. The three-pronged problems of flooding, lack of fresh water and salinity intrusion are almost inherent features of this area. The *Puncha Lands* of Kuttanad are again classified under three categories viz., *Karappadam, Kayal lands* and *Kari lands* with reference to elevation, geographical formation and soil characteristics. The special feature of *Puncha* cultivation is the construction of outer ring bunds and pumping out of water before the fields are prepared for cultivation. Generally one crop of paddy is grown in the *Puncha lands* but of late one additional crop of paddy is also grown sometimes.

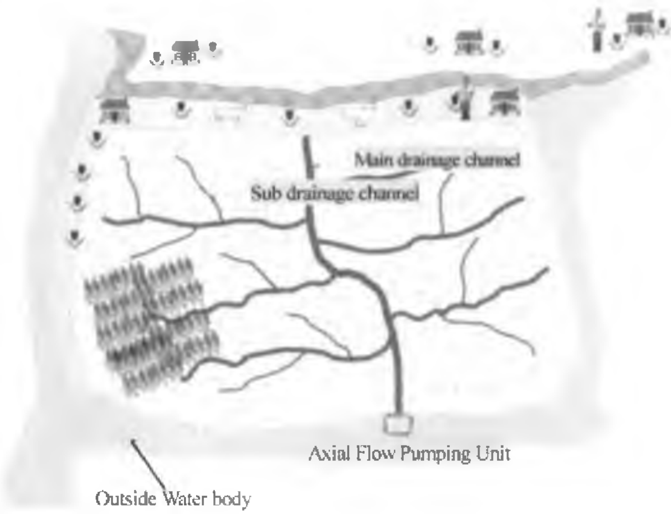


Figure 3.6 Skematic sketch of a Padasekharam

3.2.1 Karappadam lands

The *Karappadam lands* are alluvial soils generally situated along with the waterways and constitute the lower reaches of the eastern and southern periphery of Kuttanad with an area of about 33,000ha. It contains fair amount of acidity, high salt content and appreciable amount of organic matter.

3.2.2 Kayal Lands

They represent the recently reclaimed beds of Vembanad Lake, found 1.5 to 2.5 m below MSL covering 13,000 ha. These soils are mostly under flood fallowing for a minimum period of six months in a year. Salinity is the major problem though the intrusion of seawater is prevented by the existing hydraulic structures.

3.2.3 Kari lands

Kari lands are the black peaty acid sulphate soils at or below MSL in the north, east and southwest of the Kuttanad covering 9,000 ha. They are located in the Taluks of Shertallai and Ambalapuzha of Alappuzha district and Vaikom and Kottayam of Kottayam district in two distinct names, *Purakad Kari* and *Vaikom Kari*. The location of *Kari lands* in the Ambalapuzha taluk of Alappuzha district is shown in Figure 3.7. These lands are similar to that of the rest of Kuttanad with respect to topography, formation, climate and vegetation but for high organic matter content of the soil and its acidic nature. They are categorised under clayey and fine loamy sulfaquents. It is believed that they were formed and developed in the distant geologic past when the area was covered by dense forest. In the succeeding geological ages, sea advanced and engulfed many places. After thousands of years, the sea receded exposing the coastal region and part of the present midlands. During these geological upheavals, the entire forest area was submerged far below the ground and thereafter silted up to varying levels. The topsoil is admixed with well-decomposed organic matter to the tune of 10-30%. But underneath the top layer, is the partially decomposed, fibrous plant residue containing less than 50% mineral matter. Hence, these soils are both mucky and peaty in

Figure 3.7 Location of *Kari lands* in Ambalapuzha Taluk

nature. In some places, large logs of wood locally known as *Kandamaram* occur embedded in the sub-soil (Figures 3.8 & 3.9). The soil profile up to a depth of 1 m is clay. A mixture of clay, sand and organic matter is found from 1 m to 1.5 m, beyond which the formation is almost sandy.

Figure 3.8 Large logs of wood are found in the soil proving the presence of forest in the past

Figure 3.9 Embedded wood in the subsurface layer-another view

3.3 HYDRAULIC STRUCTURES IN KUTTANAD

In order to avoid the natural risk to the *puncha* crop (November-March) and for taking two crops in Kuttanad, various developmental activities by constructing certain hydraulic structures were taken up in Kuttanad for the past. This has helped in taking up an additional crop in Kuttanad during the *virippu* season (June-September).

3.3.1 Major structures

Thottappally spillway

Figure 3.10 Thottappally Spillway, an important flood relief structure

Since the primary aim of earthen bunds around the *padasekharam* was to make the land suitable for paddy cultivation and not to prevent the floods, it became necessary to limit the flood levels to a level below these bund levels so as to enable cropping in the wet season. Thottappally spillway (Figures 3.10

& 3.11 and marked in Figure 3.2), an important flood protection structure, was thus constructed in 1955 in south to divert flood waters of Pamba, Manimala and Achencovil rivers to the sea. The spillway turned out to be inefficient due to the inadequate carrying capacity of the main canal leading to the spillway.

Figure 3.11 Thottappally spillway with its shutters closed

Thanneermukkom Barrier

Salinity intrusion was one of the major problems of Kuttanad during the dry season. Thanneermukkom barrier (Figure 3.12), marked in Figure 3.2, was constructed during 1975 across the lagoon to create the freshwater lake in the south (Vembanad Lake). It was successful in preventing salinity intrusion in the dry season and retaining the fresh water from the rivers flowing into the Vembanad Lake. However, the barrier has created various adverse effects. The reduction in fisheries and an increase in aquatic weed growth are prominent among them. It has transformed the southern part of the lagoon into an area where salinities are too low for the prawns and fish that constitute the major resource for the estuarine fishery. The barrier interrupts the migration routes of marine fish and prawns as its gates are closed during pre-monsoon period when maximum upstream migration takes place. *Macro brachium rosenbergii*, the giant fresh water prawn and a native species of Kuttanad, is almost on the verge of extinction due to the absence of the required salinity during the breeding season. Decline of clam species of Vembanad Lake for the want of sufficient salinity levels during breeding time is a major concern to the lime-shell industry in Kuttanad. The prevention of saline water entry into Vembanad Lake is adversely affecting the mangrove habitat, a unique blend of land and aquatic ecosystem of Kuttanad. The effect of the elimination of tidal flushing on pollution levels

Figure 3.12 Thannermukham Barrier for preventing salinity intrusion.

cannot be underestimated. The situation has been aggravated in recent years by the introduction of high yielding paddy varieties, which require heavy doses of fertilizer and pesticides.

3.3.2 Minor structures

Ring bunds

The backbone of cultivation in Kuttanad is ring bunds, constructed mainly with the locally available soil, around each *padasekharam*. It all started nearly 100 years ago when shallow parts of the lagoon were bunded with the sole intention of raising the *puncha* crop between November and March. The season was so carefully selected that it fell between the end of the flood season and the beginning of the dry season before the water becomes too saline for crop production. Flood protection was not a primary concern for the bunding. The concept became very successful and in due course of time the *padasekharam* area has spread to attain the present level of 55,000 ha. Simultaneously, people moved into these areas and settled on higher parts of land and on the bunds.

KLDC bunds

The structural soundness of earthen ring bunds is generally poor throughout the area. Their deterioration has been accelerated by the wave action due to the introduction of motorized navigation. Bunds frequently collapsed even when there was no flood. In the 1970's, the Kerala Land Development Corporation (KLDC) started a bund repair and improvement scheme. This work has only been half completed and has been ceased for various reasons, mainly the high cost involved. Many of the rebuilt bunds have been damaged again in the meantime, mainly by wave action.

3.4 AGRICULTURE

3.4.1 Crops grown

Paddy is the only crop grown extensively. Inadequate drainage conditions make most of the land in the *padasekharams* unsuitable for other crops. Coconut is grown on the bunds and on elevated areas and they are not normally subjected to floods or salinity intrusion. Cocoa, banana, cassava, and pepper are also grown in elevated areas to a limited extent. The present cropping pattern of the various agronomic zones is shown in Figure 3.13. The Kayal areas, which are 1.5-2.5 m below sea level, are kept under water for six months due to salinity problems. Farmers go for double cropping in lower and upper Kuttanad and in Purakad where the soils are acid sulphate. The main crop is paddy while Vaikom areas cultivate cassava and in Upper Kuttanad pulses are grown for green manure.

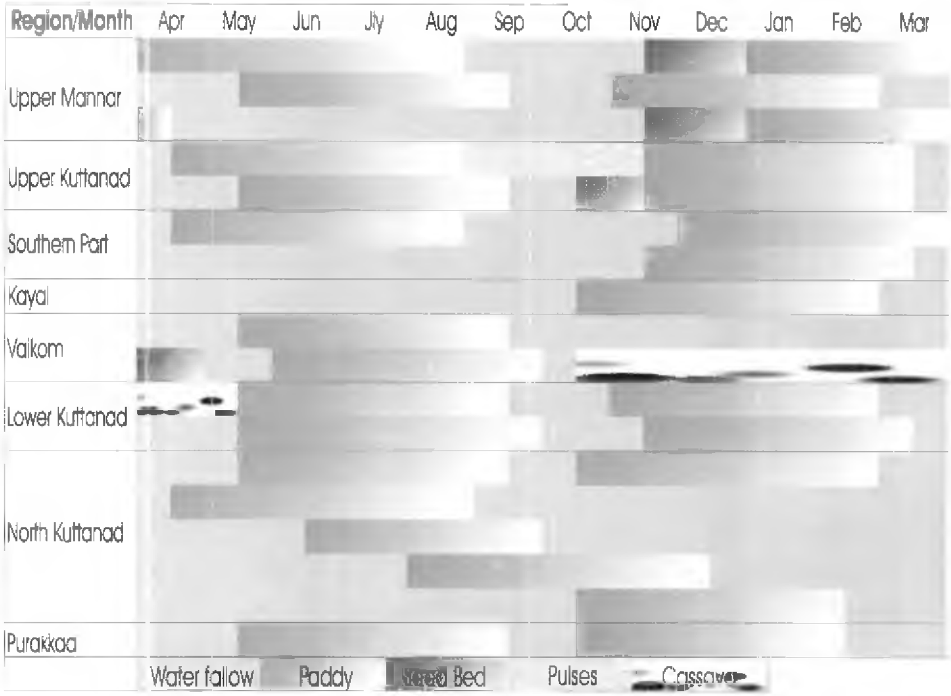


Figure 3.13 Cropping pattern in various agronomic zones.

3.4.2 Traditional rice cultivation

Cultivation operations begin with two rounds of ploughing. Then water is let in. The land gets flooded with the outbreak of Southwest monsoon. The level of water may rise to 3m or even more, submerging the bunds. The whole area then looks like a sheet of water. In July, when the water level falls to about one metre, one or two more ploughing is done. This helps to stir up the soil and to allow fresh water to percolate down. In September, when the water level goes down to a manageable level, the outer bunds are constructed with clay stakes, reeds and bushes. The field bunds are also repaired and renovated after which drainage pumping is continued till the field is completely drained. The soil is then raked by passing a harrow, locally called *palli*. The undecomposed organic matter and weeds are then removed and the soil is brought to a soft puddle. Fresh water is let in to a depth varying from a few centimetres to 0.50 m according to the topography of the land. Sprouted seeds are generally broadcast in standing water. Transplanting of seedlings is rarely done. After two or three days, water is drained by pumping and the fields are allowed to dry for about 10 days more till soil develops cow's foot wrinkles on the surface. Lime is applied at this stage on the soil surface after which water is left in and maintained to a depth of five to eight centimetres. Fertilizer application is done at the tillering and the panicle initiation stages of growth of rice after draining water from the fields. The fields are flooded one or two days after the application of fertilizers. The letting in and draining out of water and weeding are done as and when required. The fields are completely drained 10 days before crop maturity to facilitate harvesting operations.

Table 3.3 Cost of cultivation of rice in Kari lands

Sl No	Item	Cost/ha (Rs)	Category of Expenditure	Farmer's share of labour/ha (Rs)
1	Initial pumping & outer bund consolidation	500	LP	-
2	Ploughing - Power tiller	1250	LP	-
3	Land Levelling	938	LP	150
4	Making interior bunds (@ Rs.150/- for man labourer)	750	LP	750
5	Seed (@ 50kg/acre)	1500	SD	-
6	Sowing	250	OT	250
7	Dewatering during cultivation	375	OT	375
8	Weedicide (2-4 D) (@ 1kg/ha)	160	WD	-
9	Weedicide -Application charge	250	WD	250
10	Quick Lime (@ 250kg/ha)	825	FT	-
11	Quick Lime - Application charge	150	FT	150
12	Fertilizer (90:45:45 N:P:K) kg/ha	1900	FT	-
13	Fertilizer - Application charge	200	FT	200
14	Hand weeding & Gap filling	1125	OT	150
15	Threshing charge	875	HT	-
16	Labour charge during harvest	750	HT	375
17	Insecticide (if necessary)	400	PP	-
18	Insecticide - Application charge	500	PP	500
19	TOTAL	12698	-	3150

LP: Land Preparation; WD: Weed Control: SD: Seed; OT: Other Charges; FT: Fertilizer;
HT: Harvest PP: Plant Protection

3.4.3 Cost of cultivation

The major items of expenditure required for the cultivation of rice for one hectare is given in Table 3.3 and the abstract of the cost is given in Table 3.4. On an average the rice cultivation in the Kari lands are not profitable as seen from the tables. There is no other option except to cultivate, as the farmers are fully dependent on the produce from their small farms. The

Table 3.4 Abstract of cost of cultivation of paddy

Item	Expenditure/ha (Rs)
Land Preparation	3438
Seed	1500
Fertilizer	3075
Weed Control	410
Insecticide	900
Other operations	1750
Harvest	1625
Total Expenditure	12698
Income (from I ha)	
Rice @ Rs.6000/t for 2 t, Rs	12000
Straw @ Rs.50/qtl for 10 q, Rs	500
Total Income, Rs	12500
Farmer's Share of labour, Rs	3150
Apparent expenditure, Rs	9548

physical labour that the farmers put into cultivation (shown as farmer's share in the form of job opportunity and security) is considered the major income for the cultivation and is the solitary benefit they get through farming. Introduction of technologies not only for improving the productivity of the soil but also to decrease the cost of production is highly warranted in this situation.

3.4.4 Present cultivation scenario

High yielding varieties of paddy are cultivated throughout the Kari lands. The crop has to overcome the adverse effects of acidity and salinity. The farmers, after every harvest, flood the fields (Figure 3.14) from the water bodies to contain the acidity, which would other wise, occur consequent to drying of the fields. The standing water

Figure 3.14 Field is flooded by farmers after harvest to avoid acidity formation.

in the field is frequently pumped out during cultivation by using axial flow pumps, giving a leaching effect. However, this is not found to be successful enough to boost the yield, primarily because the washing effect hardly penetrates beyond a few centimetres from the soil surface. The high water table condition in the field inhibits the downward percolation of the standing water to create the desired leaching effect. As a result, symptoms of iron toxicity on the paddy leaves are predominant. The roots are also found to decay due to sulphide injury. All these factors result in a patchy growth of crop and a poor yield of 1 to 2 tonnes per hectare, even after 100 % adoption of high yielding varieties and modern technologies with respect to the application of fertilizers, pesticides etc. During extreme summers, when the water level in the surrounding water bodies goes below the field level, the farmers are unable to use the water for inundation of their fields, resulting in soil cracking and salt encrustation of the land surface, followed by an extremely acidic profile after the rains.

3.4.5 Cropping intensity

The present infrastructure in the area supports a cropping intensity of about 120%. The main crop is still the *puncha* crop (November-March) grown on about 80% of the land. The scope for developing more land by reclamations in the lake is virtually exhausted. Therefore, the increased crop production will have to come from higher cropping intensities and yields. This calls for flood protection measures and sub-surface drainage so that an overall increase in production can be obtained.

3.4.6 Seeds

The area experiences a high demand for quality seeds. This problem is found to be more prominent during the *puncha* crop season (November-March). About 62% of seeds are procured from outside Kuttanad- from extension or agricultural service agencies. Seed supplied through the National Seed Corporation (NSC) covers only 2.5% of the total demand. The main reason for this low procurement percentage is the high cost of the NSC seeds. High yielding varieties are being used throughout the area. There is an affinity towards short duration and red kernelled types. A popular variety of paddy cultivated is Pattambi-39, called Jyothi by the farmers. This is found to have very high seedling vigour, consistent high yields, resistant to blast and tolerant to the brown plant hopper. It has duration of 105-115 days, with high milling quality but is fairly long grained contrary to the like of local people and has an inherent high risk of shedding and sprouting.

3.4.7 Co-operative farming

Since the area is below MSL, the impounded water has to be drained from the entire area to make it suitable for cultivation. Individual farming concept would not be feasible in this peculiar hydrologic condition. A group of farmers, depending on the number of farm holdings in the area, forms a co-operative society. The society elects a Convenor and an Executive Committee every year for the farming activities. The group of farms mainly confines to a *padasekharam* and, therefore, the committee is known as the *Padasekhara* Committee.

3.4.8 *Puncha* special office

In order to encourage paddy cultivation in the *puncha* areas, the Government of Kerala had established a special office known as *Puncha* Special Office in 1942. *Puncha* Special Office is an administrative set-up and helps to arrange and subsidize dewatering expenses of the cultivators in Kuttanad.

Whenever a *padasekharam* is ready for cultivation, the *Padasekhara* Committee, through their representative, applies to the *Puncha* Special Officer for dewatering the *padasekharam*. The *puncha* special officer in turn advertises for a contractor for the purpose in local dailies. The lowest bidder becomes the contractor who has to satisfy the conditions laid down by the *Padasekhara* Committee and the *Puncha* Special Office. It is the contractor's duty to find and arrange suitable pumpsets including its prime mover. He is also responsible for making necessary arrangements for pumping in time so that the cultivation can be done at the right time. The contractor is also responsible for paying rent for the pump and its prime mover, rent for the space in which it is installed, the pump operators salary, etc. At present, the rate at which the pumping contract given by the *Puncha* Special Office ranges from Rs 350/- to Rs 850/- per ha per season. The auction for drainage pumping contract is usually conducted from mid July to September or from February to April depending on the cropping season. An incentive of Rs 250/ha/season is also given by the *Puncha* Special Office as production bonus to reduce the cost of production to the farmers who cultivate and belong to the *padasekharam*. The amount is given through the *Padasekhara* Committee.

3.4.9 Labour problems

Lack of labourers is becoming a serious problem for the cultivation of paddy in Kuttanad. The problem gets aggravated during the peak periods. Labour costs are also very high compared to the corresponding rates in other states. The male labourer has to be paid Rs 150/- per day whereas for a female labourer, it is Rs 75/-. The working hours are also the lowest here, six hours a day.

3.5 ECOLOGY OF KUTTANAD

The ecology of Kuttanad with respect to the ability to sustain life, both on land and in water, is influenced by the combination of floodwater and seawater entering Vembanad Lake. The wide spectrum of divergence in salinity from sweet water to seawater enable sustenance of a wider range of aquatic life both plant and animal. An ecological balance has been struck over the period of its evolution with combination of plant and animal life both on the land and in the waters of Kuttanad. The extensive water surface provides rich favourable environment for the brackish water fish. The paddy lands merging with Kayal are subjected to saline water intrusion and provide rich grounds for breeding and culturing of prawns. The eastern shores of the Vembanad Lake sustain rich crops of lime shells both live and dead, based on which the lime shell industry and a cement plant are thriving.

The developmental activities in Kuttanad viz., the Thottappally spillway, the Alappuzha-Changanacherry road cum channel, saltwater barrier at Thanneermukkom and the improvements of *padasekharam* bunds under KLDC scheme has wide long effects on the rice cultivation and the Kuttanad ecosystem. The most significant influence was noticed in the rice cultivation. These developmental activities have reduced the risks of natural hazards like flood and saline water intrusion for *Puncha* crop (November-March) and helped in the extension of the area under an additional crop. Now the entire Kuttanad area is under high yielding varieties of rice. However, due to the elimination of the risks from natural hazards, the discipline to cultivate rice in the most favoured season has disappeared. The use of high yielding varieties with low resistance to pests and diseases along with the wayward selection of season has resulted in repeated crop loss.

The total prevention of saline water and the large-scale adoption of additional crop of rice have affected Kuttanad ecosystem to a large extent. One of the major effects is the proliferation of water weeds especially Salvenia. The complete prevention of saline water ingress had caused unhampered and rapid growth of Salvenia causing problems in paddy cultivation and inland navigation in Kuttanad. However, this problem has been redeemed to a large extent with the help of a tiny weevil Cyrtobagus salveniae, which is a classic achievement in the annals of biological control of weeds in Kerala. The prevention of salt-water intrusion and continuous cultivation without flood fallow has caused the appearance of new weed flora like Echiumum, Lymnea, Marcelia, etc., which are not native of Kuttanad. These weeds have begun causing serious problems in rice cultivation, besides affecting the soil health of Kuttanad. The adoption of additional crop in large areas continuously has resulted in depletion of organic matter content soil fertility and micronutrient status of the soil causing yield reduction in several parts.

The prevention of ingression of the saline water into Kuttanad for protecting the paddy crop has adversely affected the growth of several estuarine organisms. The giant water prawn (Macrobrachium rosenbergii), a native species of Kuttanad, is almost on the verge of extinction due to the absence of the required salinity during its breeding season. Another casualty of the prevention of saline water ingress is the clam species of Vembanad Lake. There are about six species of calms in the area, the major one being Villoritta cyprinoids, the breeding of which is hampered due to the absence of salinity during its breeding season from February to April. The decline in the multiplication of clams in Vembanad Lake will adversely affect the lime-shell industry in Kuttanad.

The prevention of saline water ingress into Vembanad Lake is adversely affecting the mangroves on the bank of the lake. The mangroves are an intrinsic part of the sheltered tropical coastal and estuarine environment and serves as nursery and feeding ground for a variety of aquatic organisms. It also forms a sanctuary for many native water birds and also a number of migratory birds. Mangrove habitat is a unique blend of land and aquatic ecosystem. It has very good land-building characteristics and prevents soil erosion in the lake banks. The absence of salinity and indiscriminate felling for firewood pose a great threat to Mangroves

The most important problem of pollution caused by Thanneermukkom barrage is that the entire Kuttanad forms a static pool after the closure of the barrage. The periodic tidal flow, which used to flush the water body, is completely prevented with the result that the drained water from the paddy fields with a heavy load of pesticide and fertilizer residues remains stagnant in the water body. Added to these pollutants are the human, animal, agricultural and industrial wastes that are emptied into the Kuttanad water system which virtually turn Kuttanad, the rice bowl of Kerala into a poison bowl.

3.6 DRAINAGE

It is a normal practice in the area to keep the *padasekharam* under flooded conditions during off-season. This is to avoid the formation of acidity on drying which is a common feature of acid sulphate soils. During the flooded season, the depth of water in the field will be about 1-1.5 m. The entire water has to be drained off before cultivation. It requires about 10-15 days to drain the field depending on the carrying capacity of the drainage channels. It is also essential to keep the water levels to an optimum during cultivation. Water level in the field increases due to lateral seepage from main water bodies and also due to frequent washing of the field carried out by the farmers. Thus drainage forms an integral part of farming operations.

3.6.1 Network of open drains

Every *padasekharam* has got a network of open drains. It consists of at least one main open drain and a series of secondary open drains. The secondary open drains are connected to a main open drain. Water collected by the secondary open drains is carried to the main open drain by gravity. The density of open drains varies from *padasekharam* to *padasekharam*. The main open drains have an average width of 2-3 m with a maximum width of about 6.0 m at the outlet. The width of secondary open drains varies considerably and ranges from 0.6 m to 2 m. The depth of main open drains is about 1.5 m with a gentle slope towards the pumping bays while the depth of the secondary open drain varies from 0.6 m to 1.2 m. The main open drains are connected to a pumping bay from where the water is pumped out to the adjoining outside water body. Every *padasekharam* has a minimum of one pumping bay. There could be pumping bays located on both sides of the main open drain depending on the size of the *padasekharam*. The silting up of these drains with the passage of time and thereby reducing it carrying capacity is a major problem in the area. Adequate funds for the widening and deepening of these drains are hardly available. A typical field drain is shown in Figure 3.15.

Figure 3.15 A typical field drain used for surface drainage

3.6.2 Drainage pumps

Drainage pumping is an indispensable part of cropping activity in Kuttanad. In the olden days dewatering the fields was done with the age-old water wheel (*chakram*) consuming considerable time and labour. The dewatering could be commenced only when the floodwater receded to manageable level from October-November onwards. The introduction of drainage pumpsets (*Petty and Para*) changed the entire face of Kuttanad cultivation.

3.6.3 *Petty and Para*

Petty and Para, a crude adaptation of axial flow pump with its casings and delivery made of wood to avoid corrosion, is the main pumping system used. George Brendon, a British engineer, introduced it in Kuttanad during 1918. The typical installation of the system is shown in Figure 3.16. Figures 3.17 and 3.18 show the close-up view of the working model of a Petty and Para. Though the efficiency is very low to the tune of 20%, it is extensively used for drainage pumping in Kuttanad and is very popular (Thomas, 1992). The impeller is made of mild steel, which is replaced almost every year. The water sucked is discharged at right angles through a rectangular wooden trough into the main water body. The discharge trough is equipped with a flap door, which automatically shut off entry of water into the pumping bay when the pump is idle. While pumping, the flap door gets opened by the pressure of outgoing water. The pumping bay consists of a concrete bed and brick masonry sidewalls. The pump is installed on this bay by means of wooden beams and is driven by a belt driven electric motor. Thomas (1992) gave a good account of the Petty and Para specifications used in Kuttanad. Pumps are commercially available in seven sizes such as: 50 hp. 30 hp, 25 hp, 20 hp, 15 hp, 10 hp, and 5 hp. The allowable maximum rpm of the pump increases with the decrease in the size of unit. The maximum rpm of a 50 hp unit is only 312 whereas that of a 10 hp unit is 360. The number of vanes in the pump impeller varies from 4 to 6. The number of vanes is 6 for 50 hp, 40 hp, 30 hp units and 4 for 10 hp. For others there are five vanes. The size of the shaft depends on the power to be transmitted and ranges from 4.5 cm to 7.5 cm. The cross sectional area of *Petty* is always less than that of *Para*. The ratio varies from 0.55 to 0.88 for 50 hp to 10 hp units. The pulley on the motor side varies from 18 to 24 cm and that on pump side varies from 48 to 71 cm.

Figure 3.16 Typical field installation of *Petty and Para* (locally made axial-flow pump)

Figure 3.17 Working model of *Petty and Para*

Figure 3.18 Close-up view of the impeller used in *Petty and Para*

4. DESIGN AND MONITORING OF EXPERIMENTS

The *padasekharam* selected for studying the drainage problems was "Kavil Thekkumpuram *Padasekharam*" in Karumady village of Ambalapuzha Taluk, Alappuzha District, Kerala. The location of the *padasekharam* is given in Figure 3.7. The map of the *padasekharam* with all the necessary details is shown in Figure 4.1. The area is a typical and representative tract of acid sulphate soil with a definite boundary and found to be very severely affected by the drainage problems. The total cropping area is 75 ha. It lies 4 km east of Ambalapuzha junction and is bounded by Ambalapuzha-Thakazhy road in the north, Kalathil Thodu (Thodu means a watercourse) in the east, Kari Thodu in the south and Karumady Thodu in the west. Kalathil Thodu, Kari Thodu, and Karumady Thodu mentioned above are canals that are connected to the extensive backwater system in Kuttanad and ultimately drain into sea.

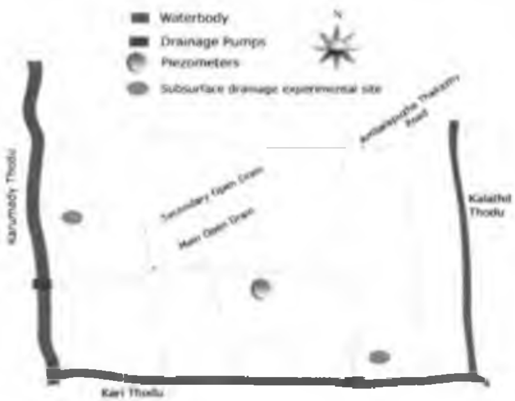


Figure 4.1 "Kavil Thekkumpuram Padasekharam" in Karumady village where drainage experiments were conducted

The area is 1-1.5 m below Mean Sea Level (MSL). It has strong earthen bunds along the boundary to protect from floods during cultivation. Axial flow pumps are used to drain the impounded water collected during off-season. There are two pumping outlets, one with a 30 hp axial flow pump at the western boundary and another with a 20 hp axial flow pump at the southern boundary. Two main open drains, which are interconnected, lead water to the pumping bays. A number of secondary open drains join the main open drains from different parts of the field. Presently, the experiment area has 1163 m of main open drains with a mean width of 2.5 m and a maximum width of 6.0 m at the outlet end. The secondary open drains cover a length of 4844 m over the entire area with widths ranging from 0.6 m to 2 m. The average depth of main open drains is 1.5 m with a gentle slope towards the pumping bays while the depth of the secondary open drain vary from 0.6 m to 1.2 m. With the total farming area of 75 ha, the average length of main open drain and secondary drains are 15.5 m/ha and 64.6 m/ha respectively.

4.1 SOIL CHEMICAL PROPERTIES

Chemical analysis of the Kari lands revealed that they are extremely acidic with pH ranging from 3.0 to 4.5 and Electrical Conductivity (EC) as high as

6.0 dSm^{-1} during the summer season. The ionic concentration of Fe, SO_4, Ca, Mg and Cl were found to be present in toxic concentrations for paddy, rendering the soil poor in productivity. The salt accumulation during summer is shown in Figure 4.2. The soil cracks during the summer season on drying (Figure 4.3). This makes the subsoil more acidic due to the oxidation of sulphur compounds and later with inundation forming free sulphuric acid. The intrusion of saline water in the summer season in the surrounding water bodies not only brings down the quality of irrigation water but can also have devastating effect on crops. The soil profile contains a lot of sulphur and iron deposits (Figure 4.4). Symptoms of iron toxicity on the leaves are predominant (Figure 4.5). The roots are also found to decay due to the sulphide injury (Figure 4.6). All these factors result in patchy crop growth and poor grain yield approximately 1.5 tons/ha even after 100% adoption of high yielding

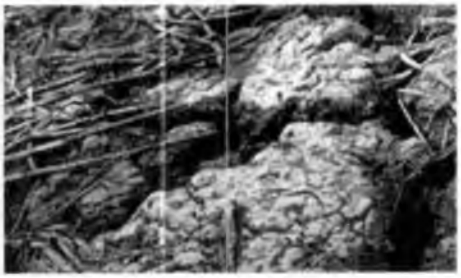


Figure 4.2 Salt accumulation during summer

Figure 4.3 Soil cracks during summer and enhances acidity formation

Figure 4.4 Soil profile showing accumulation of sulphur and iron deposits

Figure 4.5 Symtoms of iron toxicity on the leaves

Figure 4.6 Root decay due to sulphide injury

paddy varieties. The inability to leach the salts is the main reason for poor productivity. The typical hydrological situation prevailing in the area, where the field level is always lower than the outside water bodies does not permit the desired leaching. Moreover, the upward flux carries a lot of sub-soil toxicity to the root zone.

4.2 ASSESSMENT OF PRE-PROJECT YIELD POTENTIAL OF PADDY CROP WITH RESPECT TO PROXIMITY TO OPEN DRAINS AND NITROGEN APPLICATION

A crop cutting survey and crop yield recording survey on the rice crop of the project area was conducted to

- Assess the pre-project yield potential of the rice crop
- To identify the fertility level of the different spots in the area
- To understand the influence of existing open drainage channels on the yield of rice crop

The yield assessment of paddy crop in the project area was done by crop cutting at different locations. Crop yield survey was also conducted simultaneously by contacting each farmer. Fifty-three farmers were grouped into three zones according to the location of their fields under 4 categories based on the level of their nitrogen application. In 1981-82 *rabi* season, the paddy yield with respect to N application (Kg/ha) and location of drainage channel with respect to the field was assessed.

The three zones were:

Zone A : Field with channel in the mid field-9 farmers

Zone B : Field with channel on the sides of the field-38 farmers

Zone C : Field without channel in the immediate vicinity-6 farmers

The four categories were:

< 40 Kg/ha (Nitrogen Application)			: 12 farmers
41-70	"	"	: 11 farmers
71-100	"	"	: 16 farmers
Above 100	"	"	: 14 farmers

4.3 SURVEY AND CHARACTERIZATION OF PHYSICO-CHEMICAL PROPERTIES OF THE SOIL

It has been observed that the crops nearer to the open drains performed consistently well because of the marginal drainage in that area. Hence, a study was conducted from soil samples collected from 72 locations at three depths such as: 0-30 cm (D_1), 31-60 cm (D_2), and 61-90 cm (D_3) to determine the influence of open drains in improving the soil quality. These samples were collected from fields nearest to the main open drains (S_1), from fields nearest to the secondary open drains (S_2), and from fields with no drainage channels (S_3). The drained areas were again divided into border areas (L_1) and centre of the field (L_2). The samples were analysed for determining the chemical properties of the soil with respect to their proximity to open drainage channels. The main chemical properties analysed were variations in acidity, total soluble salts, total organic carbon, total nitrogen and total potassium. The data will serve as the pre-project information on the quality of the soil and will help to compare the changes brought about in soil with the layout of the drainage system.

4.4 SEASONAL CHANGES IN GROUNDWATER

In order to find the seasonal changes in the groundwater flow and its effect of leaching in the polder, 24 observation wells were installed in the area. The observation wells were made of 50 mm PVC pipes and were spaced at 100 m apart. The pipes were perforated with 6 mm holes and were wound all around with coir to prevent clogging. The locations of the observation wells are shown in Figure 4.7. The locations were so selected that the effect of fluctuations due to surface drainage and surrounding high water bodies could be studied. Water levels in these observation wells were recorded at weekly intervals except during flood fallowing.

4.5 IRRIGATION WATER QUALITY

The experimental area is surrounded from three sides by canals, which form a part of the main canal network in Kuttanad. The quality of irrigation water in these canals varies considerably depending on the season. Irrigation water sample data collected at fortnightly intervals for five years were analysed to find out the best period of cultivation in terms of acidity and salinity.

4.6 ARTESIAN PRESSURE

Knowledge of the presence of artesian aquifer is important for the design of subsurface drainage system. A battery of piezometers was installed in the experimental polder for the purpose. Their locations are shown in Figure 4.7.

They were installed at depths of 0.75 m, 1.5 m, 3.0 m, and 4.5 m. The data collected from them were analysed to find out whether any hydrostatic pressure existed underneath.

4.7 ENERGY CONSUMPTION FOR DRAINAGE PUMPING

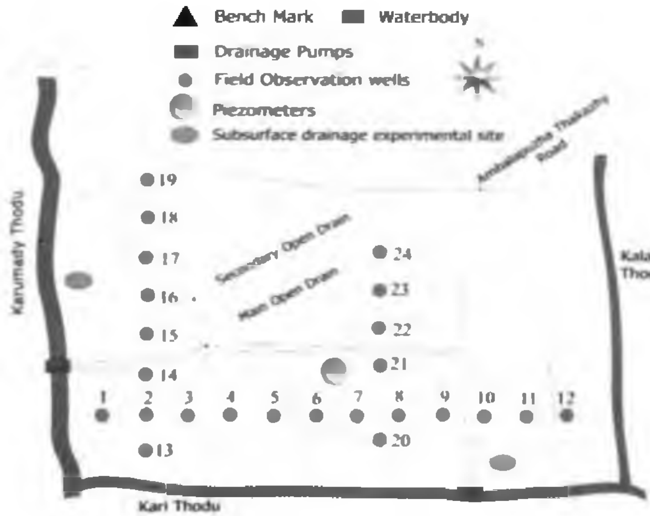


Figure 4.7 Location of observation wells and piezometers

Severe acidity is developed if fields are left dry during off-season. Therefore, the polders are flooded with water to a depth of 0.5 to 1 m during that period. Dewatering of these fields before cultivation forms an integral part of cropping activity and drainage pumps become indispensable in Kuttanad. A major problem faced by the farmers is the non-availability of low cost and efficient water lifting devices for drainage. The effect of corrosion due acidity on metallic parts of the pumpsets is another concern. Pumping is done using axial flow pumps of varying sizes. *Petty* and *Para*, as they are known locally, a crude adaptation of axial flow pump with its casing and delivery made out of wood to avoid corrosion, was introduced in Kuttanad for drainage pumping in 1918 by George Brendon, a British engineer. Though the efficiency is very low to the tune of 20% (Thomas, 1992), these pumpsets are extensively used for drainage pumping in Kuttanad and are very popular. One or more of such pumps cater to the need of a *padasekharam* and they are connected to the main open drain. There are a number of secondary open drains, which are connected to the main drain, the density of which is often not adequate to drain the area within the stipulated time. Once the initial impounded water in these polders are pumped out, which takes about 3-4 weeks, the water level in the polder has to be kept to an optimum level throughout the cultivation season by continuous pumping. The maintenance of drainage channels is very poor and they get silted up with the passage of time. Thus the carrying capacity of the channels reduces substantially and consequently the flow towards the pumping system reduces. This makes the pumpset to work overtime and a lot of energy is consumed. These pumpsets are selected based on the local thumb rules, without any scientific basis.

Drainage pumping thus becomes a major consumer of electrical energy in agricultural sector in Kuttanad. The efficient use of pumpsets is very important considering the alarming power situation in Kerala. A study was therefore conducted on the present set-up by taking 74 polders of different sizes.

4.8 PILOT STUDIES

The following pilot studies were conducted to ascertain the feasibility of drainage as a measure to address the problems faced in the Kari land region for crop production.

4.8.1 Determination of suitable drain materials

A study was conducted for understanding the efficacy of subsurface drainage materials like PVC and baked clay pipe in the acid-saline soils. Single-line drain testing, using the above two materials, were conducted for the purpose. PVC drains used were of 100-mm diameter and were slotted at its $1/3^{rd}$ circumferential area in two bands. The slot size was 0.1 x 5 cm and the mean slot area was 162.5 cm^2/m. Tile drains used were baked clay pipes of 60 cm length of 125 mm outer diameter and 100 mm inner diameter with bell mouth at one end. The annular spacing at the joints was the only port of entry for water in this case and the mean port area was 89.95 cm^2/m. The functioning of both the drains was assessed in identical situations.

Trenches having a top width of 75 cm and bottom width of 30 cm for a length of 30 m were excavated. River sand was used as envelope material and was spread all along the trench to a thickness of 10 cm. The drains were laid into these trenches at a gradient of 0.2% and were then covered with the envelope material to a 10 cm thickness over it. Finally the trenches were back-filled with the excavated earth.

For the purpose of testing the performance of single drain lines, the entrance component constitute an important parameter, both as a single value and as a fraction of the total head loss. Describing the flow resistance as the head loss per unit rate of flow, we have, for the entrance component:

$$r_e = \frac{h_e}{q} \qquad (4.01)$$

or

$$r_e = \frac{h_e L}{Q} \qquad (4.02)$$

where

r_e = entrance resistance, days/m

h_e = entrance head loss, m

L = length of the drain, m

q = flow rate m^3 /day/m length of drain

Q = (qL), the total drain discharge over the length L

The out flow, (Q), was measured at the end of drain line. The head loss (h_e) was measured as the vertical difference between the centre of the drainpipe and the water level in a piezometer at a distance of 40 cm away i.e., just beyond the trench wall. The schematic drawing showing the details are given in Figure 4.8

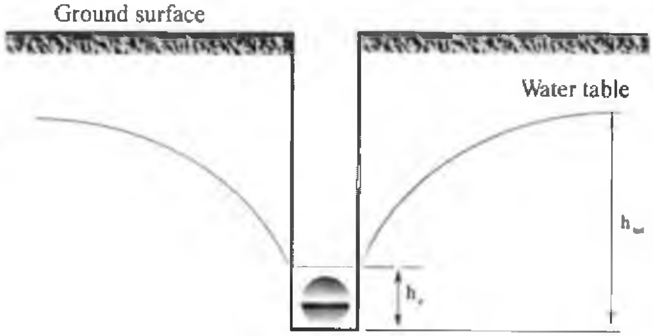


Figure 4.8 Schematic diagram showing head loss parameters

Criteria for entrance resistance depend on such factors as normal discharge rates under the prevailing hydrologic and cropping conditions, depth of drains and the desirable water table depths or fluctuations. Expressing the entrance head loss as a fraction of the total head is therefore preferable. The general criteria recommended for assessing the drain line performance based on head loss fraction is given in Table 4.1.

4.8.2 Pilot study on drain performance

An observational trial on subsurface drainage was conducted using clay tile drains with and without holes (6 mm) and PVC drainpipes with slots. The study was intended to develop a technology for the layout of subsurface drainage suitable for the project area. The study also aimed at providing information on the performance of rice crop under subsurface drainage.

Table 4.1 Drain performance criteria based on head loss fraction

Head loss fraction h_e/h_{tot}	Drain line performance
Smaller than 0.20	Good
0.20 - 0.40	Moderate
0.40 - 0.60	Poor
Larger than 0.60	Very poor

(Drainage testing FAO, Rome, 1976)

The types of the drains used were:

Baked clay tiles (10 cm) with holes

Baked clay tiles (10 cm) without holes

PVC pipes (10 cm) with slots around

The slot specifications of the PVC pipe were:

No of slots	:	70 (in 2 bands of 35 each)
Slot length	:	5 cm
Slot width	:	1 mm
Slot area	:	35 cm^2/m

Effective length of each drain line was 30 m. Graded river sand was used as filter material all around the drains at 10-cm thickness. The drains were installed at an average depth of 90 cm at a slope of 0.2%. The drains terminated in a collection pit. Pumping out water using a diesel engine pumpset facilitated the required drainage.

Four observation wells were installed at:

1. Close to the drain line
2. 2.5 m away from the drain line
3. 5.0 m away and
4. 7.5 m away

The observations recorded were:

a. Drain discharge at different time intervals

b. Subsidence of water table at different time intervals

c. Zone of influence of drainage

4.8.3 Pilot study on crop performance

A crop performance study was conducted during the *puncha* season (November-March) in 1983-84 intending to find out whether there is any measurable variation in yield of paddy under the influence of subsurface drainage. The trial was undertaken by raising a paddy crop as per the package of recommendations of the Kerala Agricultural University in the observational area where PVC and tile drains were installed. Pre-planting and post-harvest soil samples were collected to assess the variations in chemical properties due to subsurface drainage. The yield of paddy was collected both from the observational area and from the control plots that lie beyond the zone of influence of drainage.

4.9 SUBSURFACE DRAINAGE

4.9.1 Subsurface drainage design layout

The layout of the drainage system is given in Figure 4.9. Considering the geometry of the field and availability of farmers' field for *in situ* experimentation, nine lines of parallel lateral drains were installed. The first six lines close to the main collection sump were at 15 m spacing and the remaining at 30m spacing. These spacings were selected based on the results of a pilot study conducted earlier using a single drain line in which its influence was found to reach 7.5 m on either side. The length of first five lines was 75 m and the remaining was of 100 m. In order to offset the hydrologic interference between adjacent plots as much as possible, buffer lines were introduced between test spacings and at boundaries. Thus the first line, designated as $1B_{15}$, is a buffer line and so are the 6[th] and the 9[th] designated as $6B_{15/30}$ and $9B_{30}$ respectively. The lines $2E_{15}$, $3E_{15}$, $4E_{15}$, and $5E_{15}$ are experimental lines of 15 m spacing and the lines $7E_{30}$, and $8E_{30}$ are experimental lines of 30 m spacing. Further replication for 30 m spacing or some other spacing was not possible because of the geometry of the field.

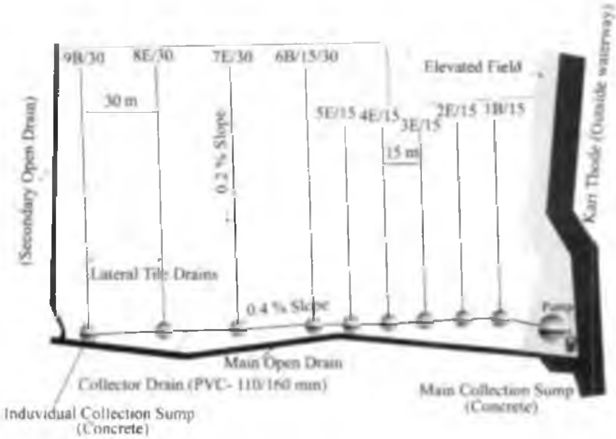


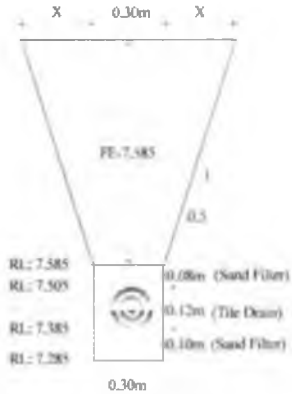
Figure 4.9 Layout of the subsurface drainage experiment

4.9.2 Drainpipes and their laying

Baked clay pipes were used as drains. These drain pipes were of 60 cm length with an outside diameter of 125 mm and inside diameter of 100 mm, having bell mouth at one end (Figure 4.10). They were provided with 15 numbers of 6 mm holes on 1/3[rd] of its peripheral area. These holes were arranged in three bands of 5 holes each. Excavation for installing the drainpipes was done as per the trench cross

Figure 4.10 Baked clay pipes used for subsurface drains

section shown in Figure 4.11. All lateral lines were given a slope of 0.2%. Reduced levels (RL) were taken at frequent intervals to maintain the correct slope throughout. After giving precise slope to the trench, river sand was spread to a thickness of 10 cm. This was followed by laying of tiles. The open end of the first drainpipe was covered with a gunny bag to prevent soil entry. The tiles were placed at an average depth of 0.875 m. The tail end of each pipe was connected to the bell mouth of the other. In order to minimize sand entry into the drains during high flow, the tiles were laid with their bell mouth pointing towards the downstream end. The tiles were placed with the holes facing the trench bottom. The main water entry is through the annular space at the joints between the bell mouth and tail end of the pipes. The average total annular space was 53 cm² per metre length of the drain line. After laying the drains, river sand filter was spread again over the drains to a thickness of 8 cm. The trench was then backfilled. The laid out drain is shown in Figure 4.12.



X=(FE-7.735) x 0.5 where FE= field elevation

Note: RL is with respect to the bench mark elevation of 10.00

Figure 4.11 Trench for laying drains, with its dimensions

Figure 4.12 Laid out drain in the field

4.9.3 Collector drains

Rigid PVC pipes were used as collector drains to carry the drainage water into the main sump. The collector pipes were laid at 0.4% slope. Based on the design calculations and the availability of pipes in the market, 110 mm pipes were used to connect the 30 m spaced drains and 160 mm pipes were used for the 15 m spaced drains.

4.9.4 Collection sumps

Pre-fabricated concrete (Figure 4.13) rings with 60 cm outside diameter, 50 cm inside diameter and 50 cm height were used for the construction of discharge measurement sumps . These sumps were placed at the discharge end of each drain line. They were provided with holes for the entry of drainpipe and collector pipes.

Figure 4.13 Pre-fabricated concrete rings for collection sumps

Adequate spacing between the drain entry and collector entry was provided for facilitating the measurement of discharges at each collection sump. All the tile drains entered into their respective collection sumps at the same elevation. A 110 mm PVC pipe of 60 cm length was used as the connecting piece between the drain line and discharge measurement sump. This provided a clean free-fall of drainage water into the sump making the discharge measurements easy and accurate. Pre-fabricated concrete rings with 110 cm outside diameter, 100 cm inside diameter, and 50 cm height were used to construct the main sump. The sump was designed subject to the space limitations at the site. The bottom most ring acted as a stilling basin.

4.9.5 Filter materials

River sand was used as a filter material around the drains with the purpose of preventing the fine particles of soil entering the drains and for minimising the entrance resistance. On an average 20 cm thick layer of river sand was used all around the tile drains.

Sieve analysis of the filter material (river sand) and the base material (soil) was done to determine the suitability of the filter. Spalding (1970) suggested that the most reliable criteria for the design of filter are those prescribed by the United States Waterways Experimental Station.

The design criteria are:

$D_{15}\ F \;<=\; 5\ D_{85}\ S$

$D_{15}\ F \;<=\; 20\ D_{15}\ S$

$D_{50}\ F \;<=\; 25\ D_{50}\ S$

$D_{50}\ F \;>=\; 5\ D_{15}\ S$

where D_{15} F is the size of particle in filter, 15% passing through the sieve and D_{85} S is the size of particle in soil, 85% passing through the sieve. The first three criteria represent the filtration quality and the last one represents the adequacy of the hydraulic conductivity.

4.9.6 Drainage pump

Two 5-hp electric motor pumpsets, one to be used for emergency, were used to dispose off the drain water from the main sump to the outside canals.

4.9.7 Outlet conditions

The water collected at the main sump is drained at present to the outside water body. The same water is used for irrigation purpose. Since these water bodies belong to an extensive network of backwaters, canals and rivers, the quality of irrigation water is not affected seriously because of the diluting effect. But, an extensive project on subsurface drainage in the area may affect

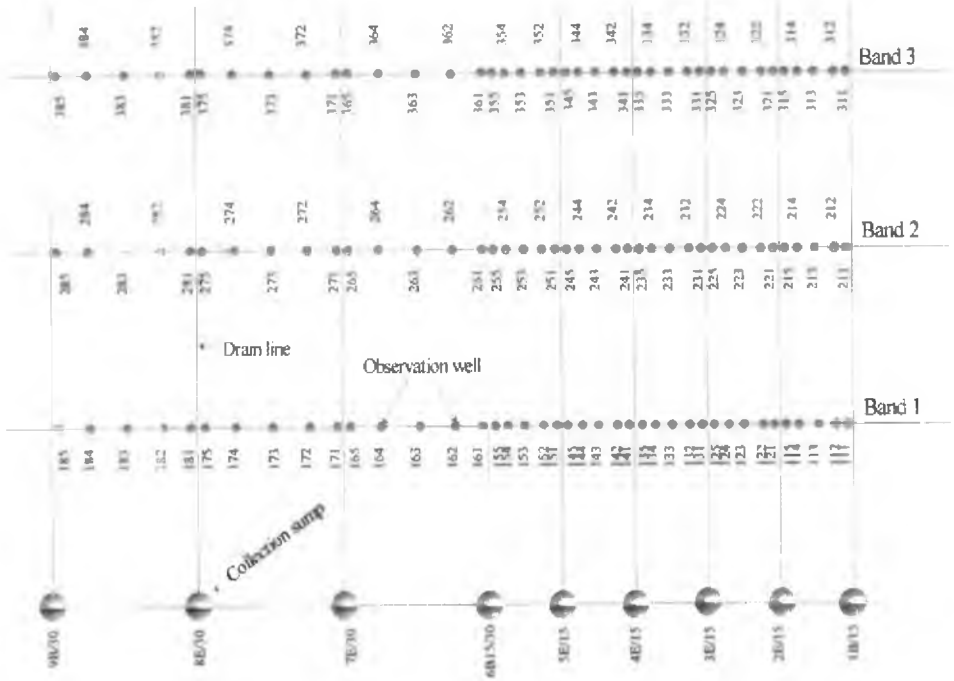


Figure 4.14 Placement of observation wells in the drained area

the quality of the irrigation water, which needs to be studied. Separate disposal canals may be required towards the sea in that case. However, once the monsoon is set, all these waters drain into the sea and quality improves.

4.9.8 Observation wells

A series of observation wells were installed in the subsurface-drained area to record the fluctuations in the water table elevations during drainage. They were made with 40-mm PVC pipes, each with a length of 1.5 m. Five millimetre holes with a spacing of 10 cm were drilled in six bands at the bottom 50-cm length and coir was wound around it. The bottom end of the tube was covered with polythene to prevent soil entry. The placement of observation wells in the tile-drained experimental area is shown in Figure 4.14. They were installed in three bands, each band perpendicular to the drain lines at L/4, L/2, and 3L/4 distances from the discharge end where L is the length of the drain in metre. For a 75-m long drain these bands of observation wells were at 18.75 m, 37.5 m, and 56.25 m from the collection sump and for a 100-m long drain they were at 25 m, 50 m, and 75 m. The observation wells were placed on these bands at 0.40 m, at S/8 and S/2 from the drains where S is the spacing in metre. The nomenclature of observation wells was based on the location of each drain. The first digit represented the band number, the second digit, the drain number and the third, the serial number towards the western side of the drain line. Thus, all observation wells ending with the digit 3 represented the mid-spacing observation wells. There were altogether 120 observation wells installed in the experimental area.

4.10 DETERMINATION OF SOIL HYDROLOGICAL CONSTANTS FROM FIELD DATA

Drainage planning is generally done after gathering information by surveying the area and collecting data from auger holes, piezometers, soil samples etc. The parameters obtained from the data thus collected are fed into groundwater flow or drainage equations to arrive at the drain spacings and drain depths. Such a procedure has drawbacks due to the following reasons.

- The drainage equations are often over simplified models of a very complex reality.
- The aquifer through which the groundwater-flow taking place is not at all homogeneous.
- Soils, particularly in alluvial plains, are layered and the permeability varies considerably in both horizontal and vertical directions
- It is not unusual for the permeability measured in auger holes which are located in adjacent plots to differ by several hundred per cent
- The infiltration rate and drainable pore space differ with changes in soil texture and structure, even within one field, and so will soil water storage and recharge to the groundwater reservoir from irrigation losses and rain
- The inadequacy of information obtained on field conditions, both in terms of quantity and quality.

Since hydraulic conductivity is one of the most important parameters used in calculating spacing between lateral drains for subsurface drainage systems, lateral drain spacings should be determined based on the mean value of hydraulic conductivity measurements within the area to be drained. Point measurements of hydraulic conductivity, however, does not take into account its spatial variability and may result in erroneous designs resulting in unnecessarily expensive drainage systems.

Drainable porosity is another basic input parameters in conventional methods for predicting water table drawdown. Drainable porosity is usually defined as the volume of water released per unit area when the water table falls by a unit distance. In drainage design it is conventionally assumed to be constant and treated as a soil property. Point measurements of drainable porosity can affect the drainage designs in a big way. The effective drainage porosity determined from drain outflow measurements can offset all field heterogeneities and would be a reliable parameter in proper design.

Considering the aforesaid reasons, drainage designs are to be tested in field conditions to collect data on soil hydrological properties such as hydraulic conductivity, drainable porosity, thickness of phreatic aquifer etc. This, and related information thus arrived will represent the average values over the drained area.

4.10.1 Hydraulic conductivity

The field data collected from experimental area were used to determine the soil hydrological constants. It was assumed that the hydrologic, soil, and topographic conditions in the experimental area were representative of those prevailing in the entire area under investigation. The field was initially flooded with water to bring the water table nearer to the surface. Once the water table was stabilized, initial readings from all the observation wells were taken. Thereafter, drawdown from observation wells and drain-discharge from collection sumps were taken at varying intervals during drainage. Initially, readings were taken at short intervals. An electrical continuity probe was used to measure the water levels in the observation wells. The drawdown observations were then converted to their respective hydraulic heads. The best-fit curves were drawn by plotting hydraulic heads at mid-spacing versus time and drain discharge versus time

These best-fit curves were then used to interpolate hydraulic heads and discharges at fixed intervals of five hours. The mid-spacing hydraulic heads adjacent to each drain was averaged for further analysis. The drain line and its respective adjacent observation well numbers are given in Table 4.2.

Table 4.2 Observation wells influencing drains

Drain No	Adjacent Observation Well No					
2E15	113	213	313	123	223	323
3E15	123	223	323	133	233	333
4E15	133	233	333	143	243	343
5E15	143	243	343	153	253	353
7E30	163	263	363	173	273	373
8E30	173	273	373	183	283	383

Drain outflow method

The van Schilfgaarde equation (1963) given below was used for finding hydraulic conductivity values from the field data.

$$S = 3A\left[\frac{K\,t\,(d_e + h)(d_e + h_0)}{2f\,(h_0 - h)}\right]^{1/2} \qquad (4.03)$$

where

S = drain spacing, m;

A = a constant;

K = effective hydraulic conductivity, m/day;

t = time, days;

d_e = equivalent depth as defined by Hooghoudt, m;

h = mid-spacing water table height, m at time, t;

h_o = initial mid-spacing water table height, m;

f = porosity.

The term A is defined as

$$A = \left[1 - \left(\frac{d_e}{d_e + h_0}\right)^2\right]^{1/2} \qquad (4.04)$$

It was assumed that the water table is essentially flat and, therefore,

$$f = \frac{q\,t}{h_0 - h} \qquad (4.05)$$

where

q = average drain outflow during time t, m/day;

The equivalent depth, d_e, is calculated from the expression after Hooghoudt (1940)

$$d_e = \frac{D}{\frac{8D}{\pi L}\ln\left(\frac{D}{u}\right) + 1} \qquad (4.06)$$

where

u = πr, r, being the radius of the drain, m;

D = depth to impermeable layer, m;

L = drain spacing, m.

Investigations had shown that the impervious layer is far below the soil and always exceeded more than half the spacing and hence D was taken as $L/2$.

Substituting Equation (4.05) into (4.03) and solving for K, yields

$$K = \frac{2\, q\, S^2}{9\, A^2\, (d_e + h)(d_e + h_0)} \qquad (4.07)$$

The effective hydraulic conductivity was computed for the entire profile using Equation (4.07) for varying water table height (h) of 1-cm interval starting from the initial water table height (h_o). The drain discharge for corresponding head was calculated first by computing the time required for the water table to drop to that head using the time-hydraulic head relationship developed from field data and then calculating the discharge rate for that time from the time-discharge relationship, also developed from field data. The equivalent hydraulic conductivity for each drain for the soil profile tested was found taking the weighted average using Equation- 4.08.

$$K_{eq} = \frac{1}{h_i - h} \int K(h)\, dh \qquad (4.08)$$

where K(h) is the hydraulic conductivity as a function of mid-spacing water table height.

Auger-hole method

Auger-hole method (van Beers, 1958) was used to find the hydraulic conductivity below the water table as a point measurement to see how the point measurement value of hydraulic conductivity differed from that of drain outflow measurements. This method is rapid and simple and gives the average permeability of the soil layers extending from the water table to a small distance below the bottom of the hole. The general principle is that a hole is bored into the soil to a certain depth below the water table and when equilibrium is reached with the surrounding groundwater, a part of the water in the hole is removed. The water seeps into the hole again, and the rate at which the water rises in the hole is measured and then by using suitable formula, the hydraulic conductivity is computed.

Equation 4.09 (Ernst, 1950) was used to find the hydraulic conductivity assuming the soil to be homogenous and $D_a >= 1/2 H_a$.

$$K = \frac{4000}{\left(\frac{H_a}{r} + 20\right)\left(2 - \frac{y}{H_a}\right)} \frac{r}{y} \frac{\Delta y}{\Delta t} \qquad (4.09)$$

where

K = hydraulic conductivity, m/day;

H_a = depth of hole below the groundwater table, cm;

Y = distance between groundwater level and the average level of the water in the hole for the time interval Δt, cm;

r = radius of auger hole, cm;

D_a = depth of the impermeable layer below the bottom of the hole, which has a permeability of about one tenth or less of the permeability of the layer above, cm.

The experimental set-up is depicted in Figure 4.15. The test was conducted at two locations in the experimental area, 40 m from the main water body and 90 m away from the main water body. The auger holes extended to a depth (H_a) of 0.5 m below ground surface. Four sets of observations were taken from each location.

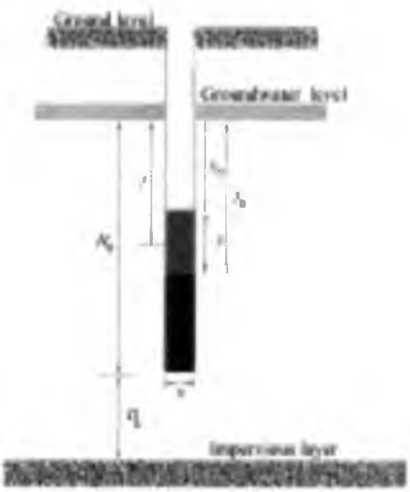


Figure 4.15 Experimental set-up for auger hole method

4.10.2 Drainable porosity

The equivalent drainable porosity at any profile can be determined by Equation-4.10 proposed by Taylor (1960).

$$f_n(Z) = \frac{V_n - V_{n-1}}{A(Z_n - Z_{n-1})} \quad (4.10)$$

where

f = equivalent drainable porosity;

Z = water table depth, m

V = cumulative outflow volumes, m^3

A = area through water falls, m^2 and

n = subscript showing the position of water table depth

The entire profile was divided into slabs of 1 cm thick. The time required to lower the water table from initial depth (h_o) to 1 cm below was obtained from the corresponding equation developed for time-hydraulic head relationship. The total volume of water drained during that period is the area below the drain outflow hydrograph for the same period. This was obtained by integrating the equation developed for time-drain discharge relationship for the same time period. The drainable porosity of the slab in the profile was obtained by dividing the total volume drained by the slab thickness. The drainable porosities for successive slabs of 1 cm thickness were found out for the entire range of water table drawdown for all the drains. Equations were then developed for drainable porosity with respect to the mid-spacing water table. The average equivalent drainable porosity for each drain for the soil profile tested was found out by taking the weighted average using the following equation.

$$f_{eq} = \frac{1}{h_0 - h_t} \int f(h)\, dh \qquad (4.11)$$

where

$f(h)$ = the drainable porosity as a function of water table height.

4.11 TESTING OF TRANSIENT DRAINAGE EQUATIONS

The following equations were evaluated to test their accuracy in predicting water table drawdown.

Modified Glover Equation (Dumm,1964)

$$L^2 = \frac{\pi^2 K D t}{f \ln\left(\frac{3.7 h_0}{\pi h_t}\right)} \qquad (4.12)$$

van Schilfgaarde Equation (van Schilfgaarde, 1963)

$$L^2 = \frac{9K d_e t}{f \ln\left(\frac{h_0(2 d_e + h_t)}{h_t(2 d_e + h_0)}\right)} \qquad (4.13)$$

Bouwer and van Schilfgaarde (Integrated Hooghoudt) Equation (Bouwer and van Schilfgaarde, 1963)

$$L^2 = \frac{8K d_e t}{C f \ln\left(\frac{h_0(2 d_e + h_t)}{h_t(2 d_e + h_0)}\right)} \qquad (4.14)$$

Hammad Equation for Thick Layers (Hammad, 1962)

$$L^2 = \frac{2\pi K t}{f \ln \frac{h_0}{h_t} \ln \frac{2L}{2\pi r}} \qquad (4.15)$$

where

L = Drain spacing, m

K = Hydraulic conductivity, m/day

D = Depth to impervious layer from drain, m

f = Drainable porosity

d_e = Equivalent depth, m

r = Radius of drain, m

h_o = Initial water table height above drain, m

h_t = Water table height at time,t, m

t = time elapsed, sec

The *C*-factor in Equation- 4.14, used to account for the changing water table shape during recession (Bower and van Schilfgaarde, 1963), is the ratio of the average flux between the drains to the flux midway between the drains.

The symbols used in the equations are explained schematically in Figure 4.16. It was assumed that the water table recedes uniformly between the drains and retains its shape and therefore, the value of *C* is taken as one. It was also assumed that the soil is homogenous with respect to hydraulic conductivity and drainable porosity. Flow in the unsaturated zone was neglected. Equations- 4.12, 4.13 and 4.14 are based on Dupuit-Forchheimer assumptions and assumes an initial parabolic water table shape while Equation- 4.15 is based on potential theory and considers an elliptical initial water table shape.

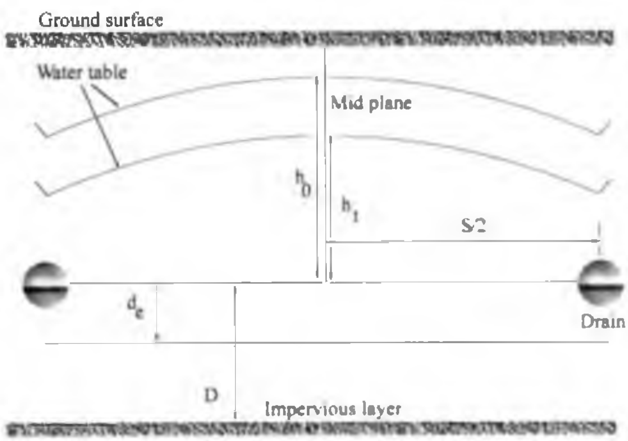


Figure 4.16 Schematic diagram explaining symbols in the transient drainage equations

The average hydraulic conductivity and drainable porosity values found by drain outflow measurements were used in the drainage equations for comparing them with the observed values.

4.12 CROP PERFORMANCE UNDER DRAINAGE

Paddy crop was grown in the subsurface-drained area to evaluate the effect of subsurface drainage on the crop performance. The effect of drainage at any point was considered to depend on the perpendicular distance of that point from the drain. Randomized Complete Block Design (RCBD) was used to find the effect of drainage on crop in relation to the proximity to drains. The layout of the treatments is given in Figure 4.17.

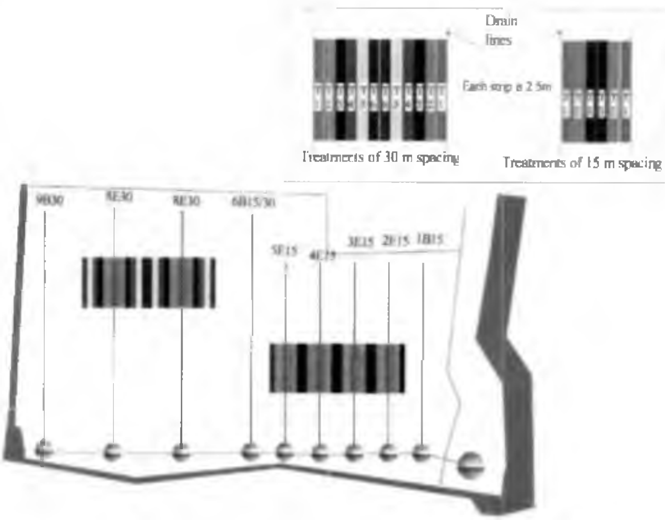


Figure 4.17 Layout of various treatments for crop performance experiments

The standing crop was divided into strips of 2.5 m width parallel to the tile lines. Thus, within the area of influence of a 15 m spaced drain lines (7.5 m on either side), there were three strips each on either side. These strips were named T_1 (0-2.5 m), T_2 (2.5 m-5.0 m), and T_3 (5.0 m- 7.5 m). There were 4 experimental lines in 15 m spacing and the total number of replications was eight. In order to compare the crop performance for each replication, eight control plots were also taken from areas where there was no influence of subsurface drainage, i.e. normal farmers' practice. Thus for a 15 m drain line, there were four treatments [T_1, T_2, T_3 and T_4 (control)] and eight replications. Similarly, the 30 m drain line was also divided into strips of 2.5 m within its area of drainage influence (15 m on either side). There were six strips on either side of the 30 m spaced drain. These strips were named T_1 (0-2.5 m), T_2 (2.5-5.0 m), T_3 (5.0- 7.5 m), T_4 (7.5-10 m), T_5 (10.0-12.5 m), and T_6 (12.5-15.0 m). There were two experimental lines for 30 m spacing and the total number of replications was four. Control plots (T_7) were taken in a similar way as for the 15 m spaced drains. Thus for a 30 m drain line, there were 7 treatments [T_1, T_2, T_3, T_4, T_5, T_6, and T_7 (control)] and four replications.

The treatment and control plots were influenced uniformly by the usual surface drainage practiced by the farmers. The treatment plots were drained (through the subsurface drainage system) every day for eight hours throughout the cropping period except for a few days during which the fertilizers were applied. All non-labour inputs were supplied to the farmers so as to obtain a similar package of practice. The observations on growth parameters like height at maturity, number of plants/m^2, number of panicles/m^2, number of grains per panicle, grain yield, 100-grain weight, straw yield and chaff percentage were recorded.

4.13 CHEMICAL CHANGES DUE TO DRAINAGE

Drain out-flow from each drain was collected during cropping season for the first two years after the installation of the system to study the effect of drainage on improving the general soil condition. The parameters monitored were pH and EC of the leachate samples.

In order to assess the variation brought out by the drainage on soil chemical properties, another experiment with three treatments, namely, 15 m and 30 m spaced subsurface drainage and control with no subsurface drainage, were considered. In all the treatments, four locations were fixed for soil sampling. Wet soil samples at a depth of 0.5 m were drawn at four critical stages of crop growth, namely, germination, active tillering, panicle initiation, and after harvest, to assess the effect of drainage on the different soil chemical parameters. The sampling locations were kept the same throughout the cropping season. The chemical parameters monitored were pH and EC of wet soil samples and Fe, SO_4, Ca, Mg, Na, K, and Cl concentrations after drying the same samples. Standard chemical analysis procedures were followed for estimating different ionic concentrations. The concentrations of different elements/radicle were worked out in ppm. Leachate samples were also collected during the same time from the drains. Mean values for each treatment were used to interpret the changes taking place in the field due to drainage and its resulting effect on crop growth.

4.13.1 Soil sample analysis

Dry soil and distilled water were taken in 1:5 ratio for doing the dry soil analysis. Twenty-five grams of dry soil was mixed with 125 ml of distilled water and the mixture was shaken for 30 minutes and then filtered and the filtrate was used for the analysis. In the case of wet soil analysis, wet soil and distilled water were taken at 1:1 ratio. Forty grams of wet soil was mixed with 40 ml of distilled water for the purpose.

pH

Acidity was measured by a pH meter. Soil samples prepared for wet soil analysis were used for determining the pH.

Electrical Conductivity (EC)

Electrical conductivity of soil samples was measured by a conductivity bridge. Soil samples prepared for wet soil analysis was used for this purpose too.

Iron (Fe)

Iron was measured by a colorimeter using an appropriate filter. The extract prepared for dry soil analysis was used for making the sample to be fed to the colorimeter. The sample was prepared by adding 2.2 ml of distilled water along with 1 ml of hydrochloric acid, 0.8 ml of potassium thiocynate, and one drop of hydrogen peroxide to 6 ml of soil sample extract.

Sulphate (SO_4)

2 ml of distilled water was added to 8 ml of extract prepared for dry soil analysis. The solution was shaken thoroughly after adding 1 mg of barium chloride and the colorimeter reading was taken using the appropriate filter.

Chloride (Cl)

Chloride was also found out using soil extract prepared for dry soil analysis. 5 ml extract was mixed with 1 ml of potassium chromate and titrated with 0.02 normal silver nitrate solution till the solution turned reddish brown in colour.

Calcium (Ca)

1 ml of 50% potassium hydroxide and 0.1 g of Patton Readers Reagent was added to 5 ml of extract and titrated with Ethylene Diamine Tetra-Acetic Acid (EDTA) till a bluish colour is obtained.

Magnesium (Mg)

Magnesium was also determined by titration. 1 ml of Ammonia Buffer solution and two drops of Erichrome Black was added to 2.5 ml of extract and titrated with EDTA solution until a bluish colour is obtained.

Sodium (Na)

0.1 ml of extract was mixed with 9.9 ml of distilled water. The resulting solution was mixed thoroughly and Flame Photometer reading was taken.

Potassium (K)

Potassium was found out by taking direct reading from Flame Photometer.

4.13.2 Water sample analysis

The methodology used for determining pH, EC, Fe, SO_4, Na, and K was the same as for.the soil analysis except for the water sample taken instead of soil extract. The water sample collected is directly used here for the analysis.

Calcium (Ca)

2 ml of potassium hydroxide and Patton Readers Reagent was mixed with 10 ml of water sample and titrated with EDTA until a bluish colour is obtained.

Magnesium (Mg)

Magnesium was also determined by titrating 2.5 ml of water sample with EDTA solution until a bluish colour is obtained. The sample was mixed with 1.5 ml of Ammonia Buffer solution and two drops of Erichrome Black before titration.

Chloride (Cl)

2.5 ml of water sample was mixed with 0.5 ml of potassium chromate and titrated with silver nitrate till the solution turned to reddish brown colour.

4.14 VARIETAL RESPONSE IN ACID SALINE FIELDS OF KUTTANAD

Paddy varieties released by the Kerala Agricultural University are most popular in Kuttanad. These varieties are cultivated in the *Kari* land region also. However, after the introduction of subsurface drainage, it was felt necessary to study the varietal response of different paddy varieties under drained condition to exploit the full potential of yield. To achieve this goal, a study was conducted to find the best-suited varieties; their optimum population density; fertilizer requirement and other agro-techniques. Three varieties selected for the purpose are K_{16}, K_{18}, and Jyothi. The first two varieties are pre-release cultures for Kari soils evolved at the Rice Research Station, Moncompu of the Kerala Agricultural University, and the third, a popular variety of the area used as control. The fertilizer doses tested were 60:30:30, 90:40:45 and 120:60:60 (N: P: K, Kg/ha). The seed rates were 75, 100 and 125 (Kg/ha). Thus there were 27 treatment combinations in two replications. The crop performance in this experiment was compared with the crop where farmers' practices of surface drainage only were adopted.

4.15 EVALUATION OF DIFFERENT DRAIN TUBE FILTERS

The envelope materials or the filter materials used around the drainpipes normally perform the following main functions

- Prevent soil particles from entering the pipe, which may in the long run clog the drain
- To act as a more permeable medium than the parent soil and thereby reduce the entrance resistance
- To give a firmer support to the laid drain pipes (quite relevant in peaty soils where the soils subside due to drainage)

One of the main factors that increased the cost per hectare of the subsurface drainage system is the filter material used around the drains. The study can throw light into the effectiveness of the filter materials used and can suggest an economically viable filter material.

There were 21 drain lines in 3 blocks, surrounded by 7 types of filter materials. Thus, there were 7 treatments in 3 replications. Each tile line was 40 m long and was spaced 15 m apart. The filter materials were selected according to the local availability. The drain discharge and the subsidence of water table were studied from each treatment. The crop performance also was studied. The effectiveness of the filter materials was statistically tested by the Randomised Block Design technique using data on hydraulic head and the corresponding drain discharge.

The treatments were:

- Sea sand all around the drain
- Sea sand around the joints only
- River sand all around the drain
- River sand around the joints only
- Coir fibre around the joints only
- Paddy straw around the joints only
- No filter materials

Layout of the experiment is given in Figure 4.18.

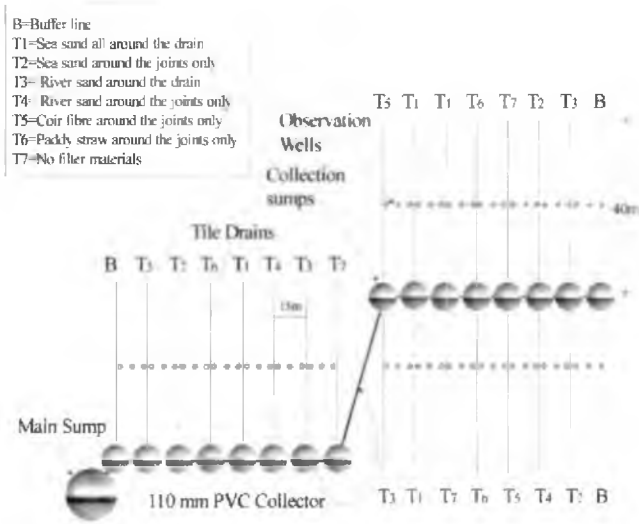


Figure 4.18 Layout of experiment for testing different drain tube filters

Figures 4.19 to 4.21 show the use of coir fibre, river sand and paddy straw used as filter materials.

Figure 4.19 Coir fibre as filter material

Figure 4.20 River sand as filter material

Figure 4.21 Paddy straw as filter material

4.16 ECONOMICS

Based on the prevailing material and labour cost, the capital investment of a hypothetical subsurface drainage system suitable for a *padasekharam* (100 ha) was worked out. The benefits were worked in terms of additional yield actually obtained during the experiment of paddy crop under subsurface drainage system. Baked clay pipes of 110 mm diameter and 60 cm length were considered as drain pipes and river sand as filter material. The drains were to be installed at an average depth of 1 m with 30 m spacing.

The system consisted of parallel subsurface drains of 100 m length each discharging into a secondary open drain. All secondary open drains were to be connected to a main open drain, which had their outlets at the periphery of the field and adjacent to the main water body outside. The drained water would be pumped into these main water bodies with the help of two suitable pumping units located at the outlets of the main open drain. It was assumed that when the system is working properly, farmers could go for double cropping. The life expectancy of the system was taken as 20 years.

The economic analysis was done using discounting measures commonly applied to agricultural projects, namely, benefit-cost ratio, net present worth, and internal rate of return. The process of finding the present worth of a future income is called "discounting". The procedures given by Gittinger (1976) were used for the purpose.

4.16.1 Benefit-cost ratio (B-C Ratio)

The benefit-cost ratio is used almost exclusively as a measure of social benefit and most commonly for water resource projects. The most important assumption to be made in computing the benefit-cost ratio is the discounting rate. The most appropriate rate is the opportunity cost of capital- the rate that will yield the most if all the capital were invested in all the possible projects. In most developing countries it is assumed to be between 8 and 15 per cent (Gittinger, 1976). In the present case, an opportunity cost of 12% was taken as the discounting rate. When the benefit-cost ratio is used to evaluate projects, the formal decision criterion is to accept all projects with a ratio of one or greater.

4.16.2 Net present worth (NPW)

Another way to estimate the worth of a project is to subtract the costs from the benefits on a year-to-year basis to arrive at the incremental net benefit and then to discount that. The net present worth can be determined by adding up the discounted incremental net benefit for the life span of the project. The same problem of choice of discount rate mentioned in connection with the B-C ratio arises also in connection with the NPW criterion. The formal selection criterion for the net present worth measure of project worth is to accept all projects with a positive net present worth when discounted at the opportunity cost of capital.

4.16.3 Internal rate of return (IRR)

Another way of measuring the worth of a project is to find the discount rate that makes the NPW equal to zero and the BC-ratio equal to one. This discount rate is termed the IRR and represents the average earning power of the money used in the project over the project life. Internal rate of return turns out to be a very useful measure of project worth. It is the measure, which the World Bank uses for practically in all its economic and financial analyses of projects, as do most other international financing agencies (Gittinger, 1976). The formal selection criteria for the internal rate of return measure of project worth are to accept all projects having an IRR above the opportunity cost of capital.

5. RESULTS AND DISCUSSION

This chapter deals with the results of the study carried out at the All India Coordinated Research Project on Agricultural Drainage, Karumady, Alappuzha, Kerala based on the methodologies presented in the preceding chapter.

5.1 ASSESSMENT OF PRE-PROJECT YIELD POTENTIAL OF PADDY CROP WITH RESPECT TO PROXIMITY TO OPEN DRAINS AND NITROGEN APPLICATION

Fifty-three farmers were grouped into three zones according to the location of their fields under 4 categories based on the level of their nitrogen application. In 1981-82 rabi season, the paddy yield with respect to N application (Kg/ha) and location of drainage channel with respect the field was assessed. The data is presented in Table 5.1. It is seen from the table that the grain yield was the highest where the drainage channel was in the middle of the field (Zone A) and the least where there was no drainage channel in the vicinity (Zone C). Thus there was an increase of 369Kg/ha (13%) when the drainage channel was in the middle of the field and only 164 Kg/ha (5.80%) where the drainage channel was on one side of the field. The yield became more prominent where there was a higher level of N application (> 100Kg/ha). Hence it could be inferred that the paddy yield could substantially be increased in *Kari* soil when better drainage facilities were provided in conjunction with high level of N application. This indicated that the full potential of N application could be realized only when sufficient drainage was provided in acid saline soils of Kuttanad.

Table 5.1 Mean table of paddy yields (*Puncha* crop)

Rate of N application (kg/ha)	Paddy yields, kg		
	Zone A	Zone B	Zone C
<40	3210	3208	2190
41-70	3210	3022	2880
71-100	2627	3023	-
Above 100	3708	2863	3390
Mean	3189	2984	2820

5.2 SURVEY AND CHARACTERIZATION OF PHYSICO-CHEMICAL PROPERTIES OF THE SOIL

This experiment was conducted to assess the physical, chemical and hydrological properties of the soil at varying depths and also to identify the influence of proximity of drainage channel on the quality of soil. Seventy-two samples were collected from the project area, such that 18 numbers of treatment combinations are replicated four times. Soil samples were collected during 1982 and were analysed on the basis of 1:5 soil water ratio. The results of the analysis are given in Tables 5.2 to 5.6.

Table 5.2 Soil pH (mean values)

	S1	S2	S3	L1	L2	Mean
D1	3.46	3.48	3.54	3.51	3.46	3.49
D2	3.24	2.98	3.11	3.15	3.07	3.11
D3	2.94	3.06	3.16	3.02	3.08	3.05
L1	3.30	3.15	3.22	0.00	0.00	3.22
L2	3.11	3.19	3.32	0.00	0.00	3.21
Mean	3.21	3.17	3.27	3.23	3.20	

CD between D level=0.2

Table 5.3 Total Soluble Salts (EC, dSm-1)

	S1	S2	S3	L1	L2	Mean
D1	1.50	2.00	1.30	1.90	1.30	1.60
D2	1.90	2.30	2.70	1.90	2.70	2.30
D3	2.50	1.80	2.00	2.20	2.00	2.10
L1	1.90	2.30	1.80	0.00	0.00	2.00
L2	2.10	1.70	2.30	0.00	0.00	2.03
Mean	1.98	2.02	2.02	2.00	2.00	

CD between D level= 0.43
CD between DxS combination = 0.74
CD between DxL combination = 0.61
CD between SxL combination = 0.61

Table 5.4 Organic Carbon, % (Walkley and Black Value)

	S1	S2	S3	L1	L2	Mean
D1	4.47	3.79	3.41	3.88	3.90	3.89
D2	4.47	3.75	3.29	3.89	3.78	3.84
D3	3.78	3.33	2.35	3.14	3.17	3.15
L1	4.49	3.60	2.83	0.00	0.00	3.64
L2	3.99	3.65	3.21	0.00	0.00	3.62
Mean	4.24	3.62	3.02	3.64	3.62	

Non Significant

Table 5.5 Total Nitrogen (%)

	S1	S2	S3	L1	L2	Mean
D1	0.43	0.28	0.27	0.36	0.29	0.32
D2	0.33	0.24	0.26	0.28	0.26	0.27
D3	0.25	0.21	0.18	0.22	0.21	0.21
L1	0.38	0.24	0.24	0.00	0.00	0.28
L2	0.29	0.24	0.24	0.00	0.00	0.26
Mean	0.33	0.24	0.24	0.28	0.26	

CD between DxS combination = 0.28

Table 5.6 Total Potassium, %

	S1	S2	S3	L1	L2	Mean
D1	0.29	0.24	0.20	0.21	0.27	0.24
D2	0.30	0.24	0.22	0.25	0.25	0.25
D3	0.21	0.20	0.11	0.16	0.18	0.17
L1	0.24	0.20	0.18	0.00	0.00	0.12
L2	0.29	0.25	0.17	0.00	0.00	0.24
Mean	0.27	0.22	0.18	0.21	0.24	

Non Significant

It was found that, as the depth increased, the soil pH reduced. This might be because of the organic acids released by the anaerobic reduction of organic matter present in the sub soil. The sub soil contained higher quantities of soluble salts than the surface soil. The presence of drainage channel (S) and location of the plot (L had no independent influence on the Total Soluble Salts (TSS). But the two-level interactions of depth x proximity of drainage channel (DxS), depth x location of the field (DxL), and location x proximity of drainage channel (LxS) were found to be significant. In general, it was found that when fields were provided with sufficient open drains, the TSS of the topsoil was minimum and increased with depth of the soil profile.

The organic carbon content of the soil was almost uniform throughout the profile up to 1-m depth. The content ranged between 3.0% and 4.23%. Total nitrogen content of the soil decreased with depth. The top plough layer contained highest content of N. In the fields where field drainage channels were present (S), the content of N was significantly higher than the fields without good drainage (S_2 and S_3).

Total potassium (K) content of the soil was unaffected with depth of soil. The first one metre soil profile contained almost uniform content of K. Towards deeper layer and in the fields without sufficient field drainage channels, the K content was lower.

5.3 SEASONAL CHANGES IN GROUNDWATER

The layout of observation wells in the field to monitor the fluctuation of groundwater table is shown in Figure 4.7. Fluctuation of water level in the observation wells (No 15, 16, 17, 18, and 19) installed towards the western boundary of the polder is shown in Figure 5.1. Observation well 19 recorded the highest water level and water level in the remaining wells showed a progressively decreasing trend as their distance from the main open drain increased. The total decrease in water level was 0.5 m between the nearest (OBW 15) and the fartherest (OBW 19) wells over a distance of 500 m, which amounted to a water table gradient of 0.1%. The effect of the main open drain up to a distance of 100 m was very prominent, giving a 0.25% slope of water table.

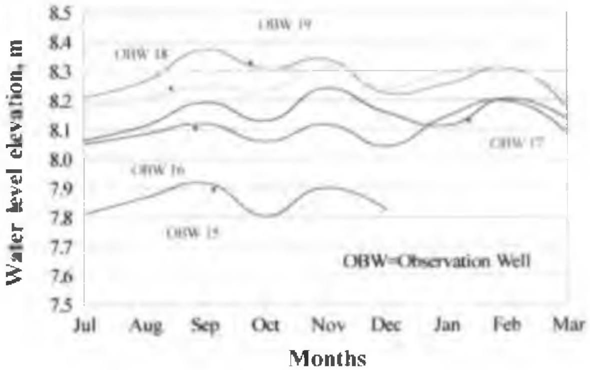


Figure 5.1 Seasonal fluctuation of water level in the experimental area

This study showed that open drains could play a major role in leaching of toxic salts from the area. The experimental *padasekharam* has a main open drain of 1163 m long with a mean width of 2.5 m and a maximum width of 6.0 m at the outlet end. The total length of secondary open drains is 4844 m over the entire area with a width ranging from 0.6 m to 2 m. The average depth of main open drains is 1.5 m with a gentle slope towards the pumping bays while the depth of the secondary open drain varied from 0.6 m to 1.2 m. With the total farming area of 75 ha, the average length of main open drain and secondary open drains were 15.5 m/ha and 64.6 m/ha, respectively. Thus the need of more open drains is felt for improving crop productivity in the area. However, increasing the density of open drains can lead to area loss and inconvenience to cultivation. The farmers also resist parting with land from their small holdings for more open drains. Introduction of subsurface drainage for improving the crop productivity, thus, is an alternate solution.

5.3.1 Artesian pressure

Knowledge of the presence of artesian aquifer is important for the design of subsurface drainage system. A battery of piezometers was installed in the experimental polder for the purpose. The location of these piezometers is shown in Figure 4.7. They were installed at depths of 0.75 m, 1.5 m, 3.0 m, and 4.5 m. Data collected from these piezometers at fortnightly intervals for 5 years during 1983-88 were analysed to find out whether any hydrostatic pressure existed underneath. A close examination of the graphical presentation of the data (Figure 5.2) indicated no artesian pressure in the project area. Water level in piezometer-4, which was installed at a depth of 0.75 m, was always at a higher elevation than that in other piezometers. This means that the downward movement of water from 0.75 m was impeded because of the low permeable clay layer below which a more permeable sandy layer is present.

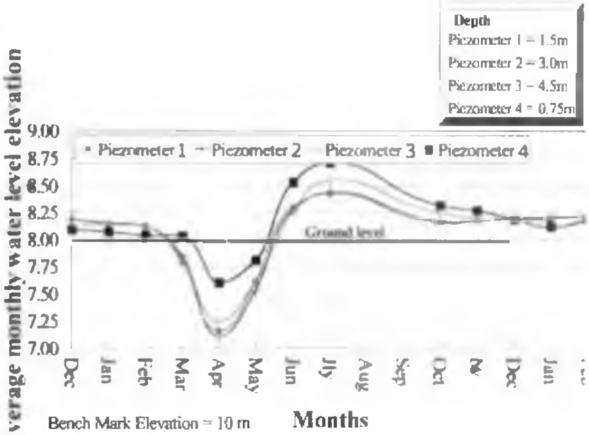


Figure 5.2 Seasonal fluctuation of water level in the piezometers

5.4 IRRIGATION WATER QUALITY

The farming activities generally start as soon as the *Padasekhara* Committee gets formal sanction to drain the polder from the *Puncha* Special Office. This process consists of advertising in local newspapers for the pumping contract, selection of the contractor, execution of necessary documents for pumping, getting electricity connection etc. Normally it is a routine process and takes its own time. The best cropping period may have passed in the meantime and the crop suffers. The best cropping period differs from place to place based on the advance front of the salinity intrusion depending upon its proximity to sea.

An experiment was conducted to assess the periodic changes in the quality of flooding water, drainage water and ground water and to identify the fluctuation in the quality of water during the periods of fallowing and cultivation. This would provide sufficient information to study the impact of quality of water on the ecology of the area.

Table 5.7 Monthly variation of pH of irrigation water in the project area from 1983-84 to 1987-88

Month	1983-84	1984-85	1985-86	1986-87	1987-88	Mean
April	5.41	5.25	5.20	5.73	5.28	5.374
May	-	5.57	5.86	5.90	5.01	5.585
June	2.84	5.26	5.26	4.52	4.20	4.416
July	2.91	6.30	7.06	5.83	3.81	5.182
August	3.98	5.92	6.58	6.12	3.63	5.246
September	4.28	5.95	6.11	6.38	3.80	5.304
October	4.48	5.85	6.39	6.37	3.86	5.390
November	3.75	5.07	7.36	6.01	3.74	5.186
December	3.30	4.72	7.08	6.48	4.79	5.274
January	3.16	4.61	6.54	6.91	4.65	5.174
February	5.66	3.21	6.04	6.85	5.23	5.400
March	5.32	6.14	6.53	6.36	6.30	6.130

Water sample data collected at fortnightly intervals for a period of five years from the surrounding water bodies (Table 5.7 and 5.8), which were used for irrigation, were analysed (pH and EC) to find out the best period of cultivation in the experimental area. These samples were collected from the surrounding water bodies from where the irrigation water was also drawn. The best cropping period was determined based on acidity and salinity of the irrigation water.

Table 5.8 Monthly variation of EC of irrigation water in the project area from 1983-84 to 1987-88 (dSm-1)

Month	1983-84	1984-85	1985-86	1986-87	1987-88	Mean
April	-	0.61	2.69	3.81	3.87	2.748
May	-	0.58	1.66	2.27	5.61	2.530
June	2.03	0.44	1.71	2.94	3.89	2.202
July	1.97	0.16	1.03	1.13	1.63	1.184
August	1.45	0.40	0.87	0.44	0.94	0.820
September	0.96	1.03	0.98	1.00	1.22	1.038
October	0.59	1.21	1.38	0.77	1.01	0.992
November	0.68	2.01	0.53	0.70	0.50	0.884
December	0.77	2.63	1.73	1.92	0.51	1.332
January	0.99	1.95	0.86	0.38	0.74	0.984
February	1.23	0.81	0.38	0.64	0.72	0.756
March	0.31	1.69	0.86	1.36	0.48	0.940

The results are presented in Figure 5.3. A perusal of the figure showed that the irrigation water was not highly acidic throughout the year except during the middle of May when hot climate prevailed. However, the acidic conditions were not so severe for crop production. The salinity levels of irrigation water were higher during the summer months of March to May till the arrival of southwest monsoon in June. The pH range of 5.25 to 5.40 and EC range of 0.80-1.4 dSm^{-1} during the period July to mid-February were found to be favourable for paddy. The summer months of March to May should be avoided for cultivation. However, the best period for growing single crop could be considered from August to November as seen from Figure 5.3. Farmers who are opting for single crop should be advised to complete the pumping contract formalities in advance so that they can take the advantage of this favourable period.

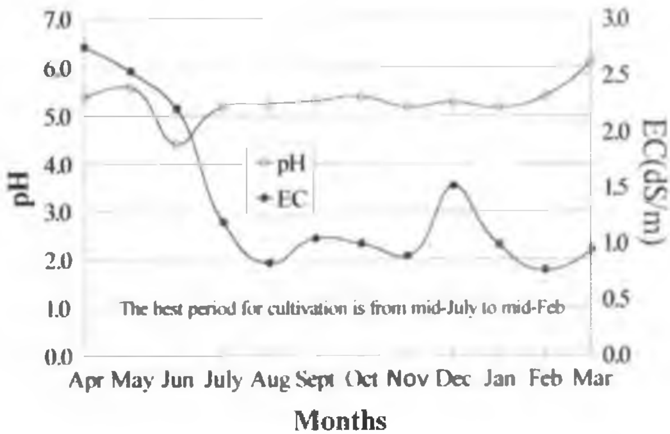


Figure 5.3 Seasonal fluctuation in irrigatoin water quality

5.5 ENERGY CONSUMPTION FOR DRAINAGE PUMPING

Drainage pumping consumes a lot of electrical energy in agricultural sector in Kuttanad. The efficient use of pumpsets is very important considering the alarming power situation in Kerala. A study was conducted on the present set-up by taking 74 polders of different sizes. The area covered by these polders is 12.4% of the total area of Kuttanad and is considered to be representative. The data collected from these polders are given in Table 5.9. These polders

Table 5.9 Energy consumption for drainage pumping from selected padasekharams

Sl. No	Padasekharam (Farm)	Area, ha	Pumpset		hp/ha	Energy, kwh/ha	
			No	Hp		Puncha	Additional
1	Alappathadi Vakkapadam	26.91	1	25	0.93	346	419
2	Aranoottil	10.06	1	10	0.99	111	213
3	Arrupanku Kayal	34.72	1	25	0.72	262	162
4	Ayyankadu	11.13	1	10	0.90	490	127
5	Chagankari	33.08	1	20	0.60	0	160
6	Chaladi Mannamkuzhi	22.88	1	15	0.66	243	304
7	Chennankari East	19.20	1	15	0.78	280	312
8	Chennankari Pullattu	12.20	1	10	0.82	110	134
9	Cheppilakka Sankara Mangalam	35.74	1	25	0.70	134	128
10	Cherukali Kayal	32.99	1	15	0.45	109	204
11	Chirakkupuram	34.73	2	30	0.86	566	382
12	East Veype, West Veype	23.99	1	30	1.25	439	498
13	Edachery North	26.69	1	30	1.12	560	467
14	Edampady	31.30	1	25	0.80	0	264
15	Edappally Somathuram	11.04	1	15	1.36	384	331
16	Enpathum	10.34	1	10	0.97	193	220
17	Ezhappadi	8.62	1	10	1.16	390	490
18	Ezhumankari Munnooti Nalpathu	12.55	1	15	1.20	172	232
19	Ezhupathyanchilaya Manikkamangalam	31.81	2	30	0.94	471	310
20	Irumpanam	8.26	1	10	1.21	249	137
21	Irupatthirandum	8.83	1	10	1.13	148	76
22	Kadanthankadu	9.61	1	10	1.04	335	517
23	Kadaval Onar	7.22	1	10	1.39	473	290
24	Kakkanadu Kari	12.29	1	15	1.22	353	290
25	Kanakasseri	5.75	1	10	1.74	384	304
26	Kaniyarkkadu	6.31	1	10	1.58	303	150
27	Kannadisserikka	7.42	1	10	1.35	505	365
28	Karukodi	4.02	1	10	2.49	341	418
29	Kattakuzhi	2.27	1	10	4.40	437	299
30	Kavalam East	2.04	1	5	2.45	533	466
31	Kayal thuruth	4.32	1	10	2.31	496	241
32	Kayalppuram Pawathkadu	4.95	1	10	2.02	181	456

Table continued...

Table 5.9 Energy consumption for drainage pumping from selected padasekharams							
Sl. No	Padasekharam (Farm)	Area, ha	Pumpset		hp/ha	Energy, kwh/ha	
			No	Hp		Puncha	Additional
33	Kozhichal North	7.69	1	15	1.95	273	343
34	Kozhichal South	4.76	1	10	2.10	267	145
35	Kuppapuram	7.69	1	15	1.95	472	259
36	Madathikandam	420.00	11	255	0.61	325	0
37	Madathil Kayal Pokka Tazcha West	88.92	3	48	0.53	117	268
38	Mangalam, Manikka mangalam kayal	167.00	3	80	0.48	147	218
39	Maniyankari	143.47	4	85	0.59	223	0
40	Mathoor South Edasseri	104.92	2	65	0.62	301	112
41	Mecheri Vakka	239.10	2	100	0.42	637	602
42	Meenappally	50.53	1	25	0.49	306	341
43	Menakothakari	105.65	2	60	0.57	264	353
44	Moola Ponghampra	106.31	2	60	0.56	99	166
45	Moolamangalam Kayal	307.20	5	210	0.68	213	319
46	Muttucha Onar	103.54	3	70	0.68	246	361
47	Nellikkathuruth	56.93	2	40	0.70	185	418
48	Nenmalasseril Poonjhi Thuruth	106.86	2	70	0.66	361	348
49	Nootunazhi	196.34	3	130	0.66	379	0
50	North Mathi Kayal	305.74	5	190	0.62	375	429
51	Paruthivalavu	100.95	3	70	0.69	302	455
52	Pathadi Manalerikkal	95.16	2	60	0.63	445	527
53	Perumanikkari North Thollayiram	44.82	1	30	0.67	253	258
54	Pongapooppally Kayal	196.69	4	160	0.81	661	635
55	Ponmeli Vakkal	198.08	7	145	0.73	223	313
56	Puthanthuram	75.75	2	55	0.73	220	415
57	Puthiyattil	49.85	2	40	0.80	130	417
58	Rajaramapuram Kayal	155.01	4	120	0.77	413	528
59	Shankara Mangalam New Block	407.14	7	320	0.79	638	851
60	South Mathi Kayal	145.03	2	120	0.83	124	0
61	Tachattu Varampinakom	133.73	2	100	0.75	399	0
62	Thadathil	155.82	4	130	0.83	478	500
63	Thekkemanappally	66.69	1	50	0.75	249	488
64	Thekkethadam	122.01	4	95	0.78	286	320
65	Umpukattu Varampinakom	101.80	2	100	0.98	707	758
66	Umpukattu Varampinakom	138.64	3	130	0.94	368	419
67	Umpukattusseri	176.36	4	160	0.91	298	321
68	Uthimada Punnapuram	61.62	3	60	0.97	172	394
69	Vadakkekari, Madathanikari	136.30	3	150	1.10	427	775
70	Valiyathuruthu	59.68	2	60	1.01	412	332
71	Valluvankadu	149.97	3	130	0.87	512	512
72	Vavakadu South	161.86	4	190	1.17	511	0
73	Vavakkattu	309.67	10	480	1.55	1075	948
74	West Vellisrakka	154.84	4	150	0.97	482	0

were categorized based on the capacity of the pumpsets installed (hp/ha). The selected categories were less than 0.5, 0.5-0.75, 0.75-1.0, 1.0-1.25, 1.25-1.5, 1.5-2.0 and 2.0-2.5 hp/ha. The relative area covered and energy consumption for the two main cropping seasons for these categories are shown in Table 5.10.

A perusal of the data of Table 5.9 reveals that the *Additional (*locally known as *virippu)* season (June-September) consumed comparatively more energy than the *puncha* season (November-March). This is obvious because the *Additional* season is preceded by the southwest monsoon and requires more initial pumping than in the *puncha* season.

On an average, the energy consumption for *puncha* and *Additional* crop are 331 Kwh/ha and 462 Kwh/ha, respectively (Table 5.10). It is interesting to note that the category where the installed capacity was 0.50-0.75 hp/ha consumed the lowest energy of 246 kwh/ha in *puncha* season (November-March) while the lowest energy consumption of 311 kwh/ha was obtained in case of *Additional* season (June-September) for an installed capacity of less than 0.5 hp/ha. Based on these results, it could be inferred that, in the present set-up, the pumping capacity requirement is only 0.50-0.75 hp/ha, the higher between the two being taken since the same pumping installation is used for both the seasons.

Table 5.10 Area covered and energy consumption for drainage pumping in selected polders

Installed hp/ha	Area Covered, ha	% Area Covered, ha	Average Energy consumption, kwh/ha	
			Puncha crop	*Additional* crop
<0.50	489.62	7.61	338	311
0.50-0.75	2887.47	44.90	246	342
0.75-1.00	2202.46	34.25	358	480
1.00-1.25	468.68	7.29	307	511
1.25-1.50	25.68	0.40	275	582
1.50-2.00	337.11	5.24	467	509
2.00-2.50	20.08	0.31	328	501
Average			331	462

Considering the installed capacity of 0.50-0.75 hp/ha as the optimum, the excess energy consumption at present was calculated and the results of analysis are given in Table 5.11.

It was found that an additional energy of 0.829 million kwh is used by the selected polders in a year due to the improper selection of pump. The data projected for the whole Kuttanad is given in Table 5.12 and the corresponding excess energy consumption was found to be 6.7 million kwh which is nearly 22% of the actual requirement.

Table 5.11. Excess Energy Consumed in Selected Polders

Installed hp/ha	Actual Area Covered, ha	Average energy consumed, kwh/ha			Total energy Consumed, kwh	Energy Required for 0.5-0.75 hp/ha, kwh	Additional Energy Consumed, kwh
		Puncha	*Additional*	Total			
<0.5	489.62	338	311	649	317,779	288,038	29,741
0.50-0.75	2 887.47	246	342	588	1,698,670	1,698,670	0
0.75-1.00	2 202.46	358	480	838	1,845,274	1,295,682	549,593
1.00-1.25	468.68	307	511	818	383,173	275,722	107,451
1.25-1.50	25.68	275	582	858	22,021	15,106	6.915
1.50-2.00	337.11	467	509	976	328,924	198,316	130,608
2.00-2.50	20.08	328	501	828	16,632	11,813	4.818
Total	**6 431.10**				**4,612,474**	**3.783,348**	**829,126**

Table 5.12. Excess Energy Consumed in whole Kuttanad (projected)

Installed hp/ha	% Area covered	Area covered in Kuttanad (Projected), ha	Average energy consumed,kwh/ha			Total energy Consumed (Projected), kwh	Energy required for 0.5-0.75 hp/ha (Projected), kwh	Additional energy consumed Projected, kwh
			Puncha	*Additional*	Total			
<0.5	7.61	3958.9	338	311	649	2,569,470	2,328,991	240,479
0.50-0.75	44.90	23347.3	246	342	588	13,734,952	13,734,952	0
0.75-1.00	34.25	17808.4	358	480	838	14,920,348	10,476,502	4,443,846
1.00-1.25	7.29	3789.6	307	511	818	3,098,228	2,229,409	868,818
1.25-1.50	0.40	207.6	275	582	858	178,054	122,143	55,911
1.50-2.00	5.24	2725.7	467	509	976	2,659,586	1,603,526	1,056,060
2.00-2.50	0.31	162.4	328	501	828	134,479	95,520	38,959
Total	**100.00**	**52000.0**				**37,295,116**	**30,591,043**	**6,704,073**

There is still further scope for improvement if the drainage channels are properly designed and maintained. The total length of the main and lateral open drains should be in proportion to the total area to be drained and in conformity to the geometric shape of the field. The design of these open drains should be based on the number of days within which the volume of water from the entire area is to be drained during the critical *Additional* season (June-September). Depending on this discharge and the time factor, proper width, depth, side slope and bed slope of the drain have to be determined. The carrying capacity of the drain so designed is the main factor, which is often neglected in selecting the suitable pump size in the area. Besides conserving energy, a properly designed open drain also enhances the internal flow of water through the soil system. This helps in partially washing the toxic salts from the root zone area, which in turn can increase the productivity.

The main problem inhibiting crop production in the *Kari* lands, therefore, is the inability to leach acidity and salts because of the low-lying nature of the area. The existing surface drains, though efficient in controlling adverse chemical problems in its vicinity, are inefficient in preventing the sub-soil salinity and its upward movement. The density and size of open drains are not adequate to improve crop production over the entire area. Salinity intrusion from Arabian Sea in the waterways surrounding the *padasekharam* is a major concern. Administrative delays in getting sanction for electrical connection for drainage pumping often delays the cropping beyond the best period. The best period for cultivation depends on the advance front of the salinity intrusion and lack of sufficient data in this regard often make it difficult to recommend the best period for crop production at different locations. Efficient and suitable drainage pumps for the region are not available. The metallic parts of the existing pumps get corroded every season due to acidity in the drained water. The selection of the existing pumps are not done scientifically and the drainage channels are silted up to varying levels resulting in consumption of a lot of additional energy. Acid resistant paddy varieties suitable for the region are scarce. Labour costs are very high and the unavailability of labourers is very serious during peaks periods of cultivation. All the above-mentioned problems contribute to the uneconomical paddy cultivation in the *Kari* lands of Kuttanad.

5.6 PILOT STUDIES

5.6.1 Determination of suitable drain materials

The entrance resistance and head loss fraction for tile drains and PVC pipe drains are given in Table 5.13. By comparing the head loss fraction for both these drains, it can be seen that the fraction, (h_e/h_{tot}), is lower in the case of tile drain as per the criteria given in Table 4.01. As read from Table 5.13, the head loss fraction for the tile drain is very low and i.e., below 0.30 where as in case of the PVC drains, it is around 0.80, for the period of 72 hours of continuous drainage. Hence it is inferred from the general criteria that the

Table 5.13 Entrance resistance and head loss fraction of different drain pipes						
Hours after drainage	PVC drain			Tile drain		
	h_e (cm)	h_{tot} (cm)	h_e / h_{tot}	h_e (cm)	h_{tot} (cm)	h_e / h_{tot}
1	20.10	23.2	0.87	4.60	18.00	0.255
6	18.10	22.6	0.80	4.60	17.00	0.270
12	18.10	22.6	0.80	4.50	17.00	0.265
24	17.10	20.7	0.83	4.00	16.00	0.250
48	16.10	18.1	0.88	3.50	14.00	0.250
72	16.10	17.2	0.94	3.50	14.00	0.250

performance of clay tile drain are good in the project area whereas the performance of PVC drain is very poor even when the mean port opening area is more in the PVC drains.

The poor performance of the PVC drains may be because of the small slot width (1-mm) where the slots are clogged due to iron precipitation (ochre formation). Increasing the present slot width may favour entry of soil particles and thereby silting the drains. Finding out a proper slot size for the PVC pipes in these situations is a suggested future work in these situations.

5.6.2 Pilot study on drain performance

The data on discharge and subsidence of water table due to continuous drainage by pumping for 6 hours from the PVC and tile drains installed are shown in Table 5.14

Table 5.14 Mean discharge and mean water table drawdown after 6 hours of drainage					
Type of drain	Discharge (lit/min)	Water table drawdown at different lateral distances from drain, cm			
		0.0 m	*2.5 m*	*5.0 m*	*7.5*
PVC	17.15	52.01	10.13	3.26	2.08
Baked Clay	26.98	90.48	17.48	7.63	2.09

The values in Table 5.14 show that the zone of influence of tile drain (Baked Clay) is almost up to 7.5 m on either side of the drain line. In the case of PVC drains, this distance is up to 5 m. Moreover, the PVC drain was not functioning properly as indicated by the water table drawdown recorded at 0 m point.

5.6.3 Pilot study on crop performance

The data on yield and soil chemical properties are given in Tables 5.15 and 5.16. The observational study indicated that the yield of paddy could be considerably increased if a suitable system of subsurface drainage is practiced in the project area.

Table 5.15 Paddy yield in the subsurface drained observational area

Treatment	Grain Yield (kg/ha)	
	PVC Drain	*Tile Drain*
Drained	2888	3115
Control	2435	2410
Increase in yield	453	705
% Increase over Control	18.60	29.25

Before planting, the pH was 2.85 and salinity level of the surface soil was 3.13 dSm^{-1}. Considerable reduction in acidity and salinity could be achieved when subsurface drainage was practiced in the observational area. Though a slight reduction in soil acidity level has been recorded in the control plot in Zone I, the control field maintained the high acidity level and salinity level during the cropping season. Hence, subsurface drainage can be an effective measure to improve the soil and thereby to increase the yield of paddy in the project area.

Table 5.16 Soil sample data after harvest of crop

Zone	Depth of sampling, cm	Location of soil samples					
		PVC drain		Tile drain		Control	
		pH	EC (dSm^{-1})	pH	EC (dSm^{-1})	pH	EC (dSm^{-1})
I	0-20	3.70	1.63	4.30	1.35	4.14	3.30
	40-60	3.58	3.95	4.22	2.98	2.93	7.90
	80-100	3.70	2.35	2.43	8.30	2.51	7.50
II	0-20	3.51	2.75	4.78	0.95	2.41	1.20
	40-60	3.32	5.88	3.34	4.65	3.28	3.70
	80-100	3.14	4.65	2.96	5.35	2.96	2.10

Zone I: 0.5 m from the drain line; Zone II: 5.0 m from the drain line

5.7 EVALUATION OF THE INSTALLED SUBSURFACE DRAINAGE SYSTEM

The detailed description on the installed subsurface drainage system is given in section 4.9. The layout of the system is shown in Figure 4.9. The performance of the subsurface drainage system in the low-lying acid sulphate soil was studied based on the drain out-flow, crop performance, changes in soil and leachate chemical properties.

5.7.1 Particle size of the filter and base material

The results of the sieve analysis are given in Tables 5.17 and 5.18. The different particle sizes obtained from Figure 5.4, as per the criteria given in section 4.9.5, are given below.

$D_{15}F$ = 0.25 mm $D_{15}S$ = 0.125 mm

$D_{50}F$ = 1.05 mm $D_{50}S$ = 0.250 mm

$D_{85}F$ = 2.75 mm $D_{85}S$ = 0.400 mm

(F: Filter; S: Soil)

From the above, it can be seen that all the above criteria have been satisfied in terms of filtration quality and adequacy of hydraulic conductivity.

Table 5.17 Sieve analysis of river sand filter

Sample	Mass retained in sieves, g							Total mass
	Sieve size, mm			Sieve size, micron				
	5.6	2	1	500	106	45	<45	
1	121.00	207.50	380.50	245.50	458.00	4.25	13.50	1430.25
2	72.50	214.50	357.00	199.00	295.50	2.42	10.58	1151.50
3	99.00	229.00	412.50	265.50	413.50	3.83	18.17	1441.50
4	69.50	209.75	380.50	231.50	377.50	2.92	12.83	1284.50
Total	362.00	860.75	1530.50	941.50	1544.50	13.42	55.08	5307.70
% Retained	6.82	16.22	28.84	17.74	29.10	0.25	1.00	
Cumulative %	6.82	23.04	51.87	69.61	98.71	98.96	100.0	

5.7.2 Drain outflow

The field was initially flooded with water to bring the water table nearer to the surface. Once the water table was stabilised, initial reading from all the observation wells (see Figure 4.14 for the location of observation wells) was taken. Continuous drainage pumping followed this. Thereafter, drawdown in observation wells and drain discharge from collection sumps were taken at varying time intervals during drainage. Initially, readings were taken at short intervals. The drawdown observations were converted to their respective hydraulic heads and best-fit curves were obtained by plotting hydraulic heads at mid-spacing versus time and drain discharge versus time. The observed data collected at various time intervals for discharge and hydraulic head at mid-spacing are given in Appendix A. The best-fit curves thus obtained for drain discharges and mid-spacing hydraulic heads are given in Appendix B. These curves were then used to interpolate hydraulic heads and discharges at fixed time intervals of five hours. The mid-spacing hydraulic heads adjacent to each drain was averaged to represent a single average hydraulic head. The average hydraulic heads thus obtained were used for further analysis. The average hydraulic heads for each drain at fixed time intervals of five hours are given in Appendix C.

Table 5.18 Sieve analysis of base material

Sample	Mass retained in sieves, g							Total mass
	Sieve size, mm			Sieve size, micro				
	5.6	2	1	500	106	45	<45	
1	0.00	0.00	0.05	1.88	18.12	0.60	1.68	22.3
2	0.00	0.00	0.07	1.65	19.77	1.52	1.67	24.6
3	0.00	0.00	0.06	1.41	18.87	1.54	1.72	23.6
Total	0.00	0.00	0.17	4.94	56.76	3.66	5.07	70.5
% Retained	0.00	0.00	0.24	7.00	80.40	5.18	7.1	
Cumulative %	0.00	0.00	0.24	7.23	87.63	92.81	100.0	

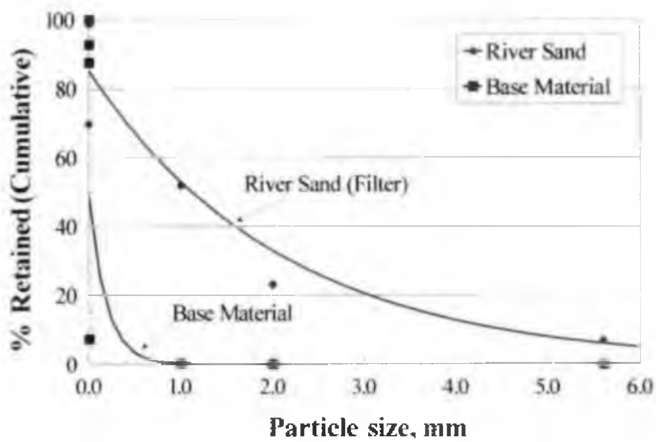


Figure 5.4 Particle size distribution of base material and filter material (River sand)

An abstract of the computed average values of hydraulic heads at mid-spacing at fixed intervals of five hours for all the drains are given in Table 5.19 and the corresponding drain discharges in Table 5.20. Figures 5.5 and 5.6 show the comparative discharges and drawdowns for all the drains. The regression equations to predict the hydraulic head and drain discharges at various times are given in Table 5.21. Looking at Figures 5.5 & 5.6 for discharge and hydraulic head at mid-spacing respectively, it is observed that a progressive decline occurs in the discharge rates and hydraulic heads at identical times for different drain lines. This decline depends on the distance

Table 5.19 Average hydraulic head (m) at mid-spacing

Time, hours	Drain No					
	$2E_{15}$	$3E_{15}$	$4E_{15}$	$5E_{15}$	$7E_{30}$	$8E_{30}$
0	0.69	0.69	0.66	0.66	0.51	0.44
5	0.68	0.69	0.63	0.61	0.49	0.44
10	0.64	0.64	0.59	0.59	0.48	0.43
15	0.62	0.62	0.57	0.58	0.47	0.42
20	0.60	0.60	0.56	0.57	0.46	0.41
25	0.59	0.58	0.54	0.56	0.45	0.40
30	0.58	0.57	0.53	0.55	0.44	0.39
35	0.57	0.56	0.52	0.55	0.43	0.38
40	0.56	0.55	0.51	0.54	0.43	0.37
45	0.55	0.54	0.50	0.53	0.42	0.36
50	0.54	0.53	0.50	0.52	0.41	0.36
55	0.54	0.53	0.49	0.52	0.41	0.35
60	0.53	0.52	0.48	0.51	0.40	0.34
65	0.53	0.51	0.48	0.50	0.39	0.33
70	0.52	0.51	0.47	0.49	0.38	0.32
75	0.52	0.50	0.46	0.49	0.37	0.32
80	0.51	0.49	0.46	0.48	0.37	0.31
85	0.51	0.49	0.45	0.47	0.36	0.30
90	0.50	0.48	0.45	0.47	0.35	0.30
95	0.50	0.48	0.44	0.46	0.34	0.29
100	0.49	0.47	0.43	0.45	0.34	0.28
105	0.49	0.47	0.43	0.45	0.33	0.28
110	0.48	0.46	0.42	0.44	0.32	0.27
115	0.48	0.46	0.42	0.44	0.32	0.26
120	0.48	0.45	0.42	0.43	0.31	0.26

Table 5.20 Average discharge, q (mm/day)

Time, hours	Drain No					
	$2E_{15}$	$3E_{15}$	$4E_{15}$	$5E_{15}$	$7E_{30}$	$8E_{30}$
5	10.28	10.45	8.20	7.40	2.85	2.34
10	9.39	8.93	6.78	5.91	1.95	1.73
15	8.90	8.14	6.07	5.18	1.56	1.45
20	8.57	7.63	5.61	4.72	1.34	1.27
25	8.33	7.25	5.28	4.39	1.18	1.16
30	8.13	6.96	5.02	4.14	1.07	1.07
35	7.97	6.72	4.82	3.94	0.98	1.00
40	7.83	6.52	4.64	3.77	0.92	0.94
45	7.71	6.35	4.50	3.63	0.86	0.89
50	7.60	6.20	4.37	3.51	0.81	0.85
55	7.51	6.06	4.26	3.40	0.77	0.82
60	7.43	5.95	4.16	3.31	0.73	0.79
65	7.35	5.84	4.07	3.22	0.70	0.76
70	7.28	5.74	3.99	3.15	0.67	0.74
75	7.21	5.65	3.91	3.08	0.65	0.71
80	7.15	5.57	3.84	3.01	0.63	0.69
85	7.09	5.49	3.78	2.95	0.61	0.68
90	7.04	5.42	3.72	2.90	0.59	0.66
95	6.99	5.36	3.67	2.85	0.57	0.64
100	6.94	5.29	3.61	2.80	0.56	0.63
105	6.90	5.24	3.57	2.76	0.54	0.62
110	6.86	5.18	3.52	2.72	0.53	0.60
115	6.82	5.13	3.48	2.68	0.51	0.59
120	6.78	5.08	3.44	2.64	0.50	0.58

of these drains from the adjacent water body (see Figure 4.9 for location of drains from water body). This is caused by the specific feature of the polders in the area that are surrounded by water bodies, the water level in which are always higher than that in the field and thereby contributes a substantial lateral seepage. The influence of the water bodies was visible up to a distance of 60 m though it decreased with distance. As the drainage continued, the drop in discharge rate and hydraulic head stabilized and became almost steady later on. Since the soil of the experimental area is acid sulphate, prolonged subsurface drainage is not advisable as it can make the soil severely acidic. Hence, the purpose of the subsurface drainage is controlled leaching by keeping the water table within the root zone. Transient drainage theories are, therefore, to be used in suitably designing the subsurface drainage systems in this area.

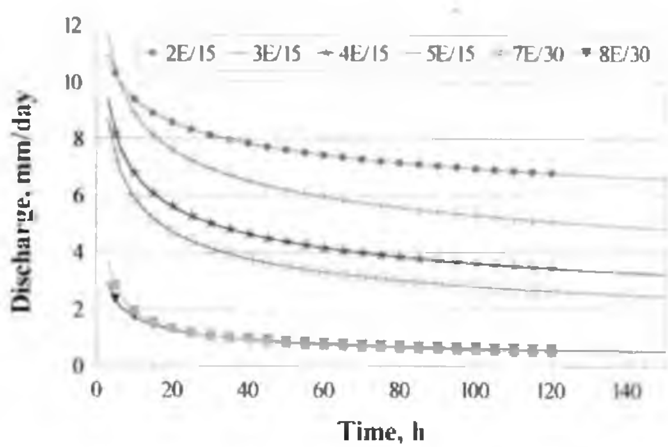


Figure 5.5 Drain discharge with respect to time

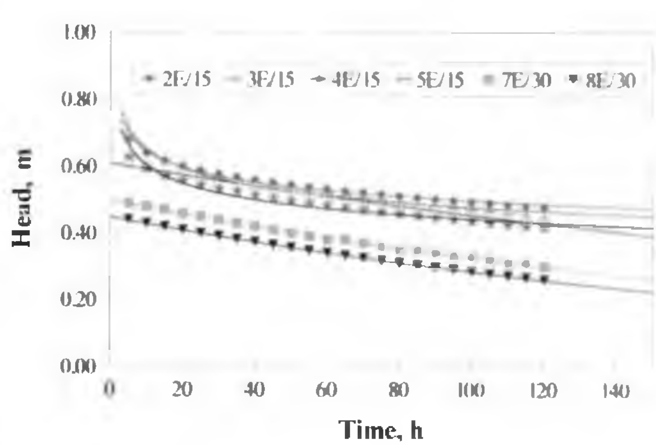


Figure 5.6 Water table drawdown with respect to time

5.7.3 Soil hydrological constants

Hydraulic conductivity

Drain outflow method

The methodology described in section 4.10.1 was used to find the hydraulic conductivity using drain outflow measurements at various mid-spacing hydraulic heads near the drains. Figure 5.7 shows the variation of hydraulic conductivity within the flow domain at different water table heights.

Table 5.21 Regression equations to predict hydraulic head and drain discharge from field observations

Drain No	Initial water table height, h_0, (m)	Equations developed from field data	
		h (m) vs t (hrs)	q (mm/day) vs t (hrs)
2E15	0.69	$h=0.835\ t^{-0.113}$	$q=12.69\ t^{-0.13}$
3E15	0.68	$h=0.889\ t^{-0.135}$	$q=15.06\ t^{-0.287}$
4E15	0.66	$h=0.821\ t^{-0.135}$	$q=12.73\ t^{-0.273}$
5E15	0.66	$h=0.608\ e^{-0.0029t}$	$q=12.47\ t^{-0.324}$
7E30	0.51	$h=0.499\ e^{-0.0043t}$	$q=6.85\ t^{-0.546}$
8E30	0.44	$h=0.447\ e^{-0.0046t}$	$q=4.74\ t^{-0.438}$

The values were higher for the topsoil layer. It varied directly with the mid-spacing water table height for drains close to the outside water body ($2E_{15}$, $3E_{15}$ and $4E_{15}$) and exponentially for drains away from the outside water body ($5E_{15}$, $7E_{30}$ and $8E_{30}$). The transition in the mode of variation took place at a distance of 60 m from the water body. The values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights.

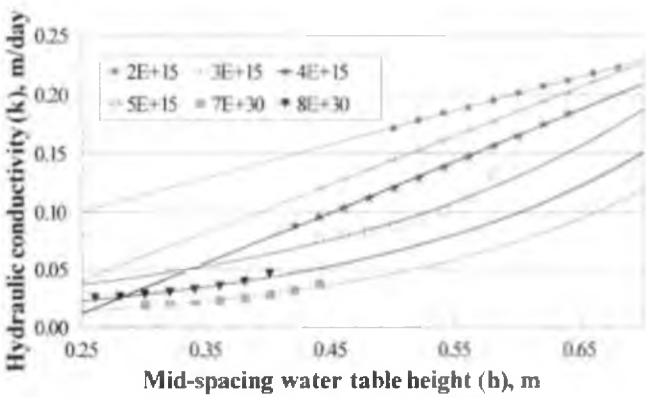


Figure 5.7 Variation in hydraulic conductivity within the flow domain at different mid-spacing water table

The regression equations developed for hydraulic conductivity (K) for each drain as a function of mid-spacing water table height (h) at time, t, along with its equivalent values (K_{eq}) for the entire flow domain is given in Table 5.22. The equivalent hydraulic conductivity for the flow domain was found by taking the weighted average using Equation-4.08.

The initial and final mid-spacing water table heights used in the above equation were taken from Table 5.19. The average K_{eq} computed was 0.167 m/day (between $2E_{15}$, $3E_{15}$ and $4E_{15}$) and 0.055 m/day (between $5E_{15}$, $7E_{30}$ and $8E_{30}$) respectively for the two distinct regions (up to 60 m from the water body and beyond that).

Table 5.22 Regression equations for the variation of hydraulic conductivity within the flow domain in relation to mid-spacing water table heights

Drain No	Equations developed for effective hydraulic conductivity near the vicinity of the drains	Equivalent hydraulic conductivity, Keq (m/day)
2E15	$K=0.028+0.287\ h$	0.194
3E15	$K=-0.063+0.414\ h$	0.173
4E15	$K=-0.096+0.438\ h$	0.134
5E15	$K=0.0148+e^{3.62\ h}$	0.100
7E30	$K=0.028+ e^{4.74h}$	0.030
8E30	$K=0.028+ e^{4.184\ h}$	0.036

Auger hole method

The auger hole test was conducted at two locations in the experimental area, 90m from the water body and 40m away from the water body to find the hydraulic conductivity. The methodology used is given in section 4.10.1. The data collected are given in Tables 5.23 and 5.24. The average hydraulic conductivity found out by the method was 0.063 m/day and 0.107 m/day, respectively, for the distances mentioned above. The hydraulic conductivity values obtained by the drain outflow method and auger hole method were almost same for areas located away from the water body. Therefore, auger hole method can be adopted without losing much accuracy in such areas where drain outflow data are difficult to obtain.

Drainable porosity

Drainable porosity (f), defined as the ratio of the drained voids volume to the total volume of the voids plus the volume of the soil particles, is a necessary parameter in all equations that predict drawdown. During drainage it is not normally a constant, but is related, among other things, to the water table depth. Both the time of drawdown and the shape of the water table depend on the particular way in which drainable porosity is related to water table depth. The drainable porosity is not used as such in the drawdown equations. The average porosity value for a drawdown depth is used for calculations. This average value is called the equivalent drainable porosity (f_{eq}). Drainable porosity at any point in the soil is not solely a function of water table depth but is also determined by the time during which the drainage is permitted before the water table falls to a new position. The time required for a prescribed drawdown is affected by the size, depth, and spacing of the drains. The importance of drainable porosity lies in the fact that all drawdown equations use this term to be multiplied with the drawdown to find the total volume of drainable water.

Table 5.23 Auger hole observations taken at 90 m away from main water body

Sl No	Time,t (sec)	y at time	
SET I			
1	0	33	H_a = 38 cm r = 5.8 cm D t = 2073-338 = 1735 sec D y = 32-28 = 4 cm y = 32-4/2 = 30 cm k = 0.056 m/day (using equation 4.09)
2	338	32	
3	750	31	
4	1137	30	
5	1628	29	
6	2073	28	
Set II			
1	0	34.5	H_a = 38 cm r = 5.8 cm D t = 1895-190 = 1705 sec D y = 33.5-28.5 = 5 cm y = 33.5-5/2 = 31 cm k = 0.07 m/day (using equation 4.09)
2	190	33.5	
3	435	32.5	
4	753	31.5	
5	1115	30.5	
6	1520	29.5	
7	1895	28.5	
Set III			
1	0	34.5	H_a = 38 cm r = 5.8 cm D t = 2084-264 = 1820 sec D y = 33.5-28.5 = 5 cm y = 33.5-5/2 = 31 cm k = 0.065 m/day (using equation 4.09)
2	264	33.5	
3	602	32.5	
4	915	31.5	
5	1290	30.5	
6	1702	29.5	
7	2084	28.5	

Note: For [illegible]ns. see Figure 4.15

The drainable porosity was calculated using the drain outflow observations. The entire profile was divided into layers of 1 cm thickness and the time required to lower the water table from initial depth by 1 cm was obtained from the corresponding regression equation developed for time-hydraulic head relationships as given in Table 5.21. The total volume of water drained during that period is the area below the drain outflow hydrograph for the same period. This was obtained by integrating the equation developed for time-drain discharge relationship (Table 5.21) for the same time period. The

Table 5.24 Auger hole observations taken at 40 m away from main water body

Sl No	Time, t (sec)	y at time	
Set I			
1	0	32	H_a = 37.7 cm
2	145	31	r = 5.8 cm
3	300	30	D t = 885-145 = 740 sec
4	495	29	D y = 31-27 = 4 cm
5	695	28	y = 31-4/2 = 29 cm
6	885	27	k = 0.133 m/day (using equation 4.09)
Set II			
1	0	34	
2	160	33	H_a = 37.7 cm
3	345	32	r = 5.8 cm
4	565	31	D t = 1750-160 = 740 sec
5	775	30	D y = 33-26 = 7 cm
6	1020	29	y = 33-7/2 = 29.5 cm
7	1255	28	k = 0.107 m/day (using equation 4.09)
8	1490	27	
9	1750	26	
Set III			
1	0	34	
2	215	33	
3	440	32	H_a = 37.7 cm
4	680	31	r = 5.8 cm
5	920	30	D t = 1995-215 = 740 sec
6	1160	29	D y = 33-26 = 7 cm
7	1430	28	y = 33-7/2 = 29.5 cm
8	1750	27	k = 0.095 m/day (using equation 4.09)
9	1995	26	
Set IV			
1	0	34	
2	235	33	
3	470	32	H_a = 37.7 cm
4	745	31	r = 5.8 cm
5	995	30	D t = 2075-235 = 1840 sec
6	1245	29	D y = 33-26 = 7 cm
7	1530	28	y = 33-7/2 = 29.5 cm
8	1790	27	k = 0.093 m/day (using equation 4.09)
9	2075	26	

Note: For notations, see Figure 4.15

drainable porosity of a layer in the profile is obtained by dividing the total volume drained by the layer thickness. The drainable porosities for successive layers of 1 cm thickness was similarly found out for the entire range of water table drawdown for all the drains and is graphically shown in Figure 5.8.

For areas near drains $2E_{15}$, $3E_{15}$, and $4E_{15}$, the drainable porosity increased as the mid-spacing water table height decreased. These drains were located nearer to the outside water bodies (see Figure 4.9 for their locations) and a significant amount of recharge entered the field due to their proximity to the outside water bodies. During drainage, the water table fell at a faster rate and almost became steady at later stages (see Figure 5.6) because of the recharge from the adjoining water bodies. Thus, the total volume of water drained was comparatively more attributing to higher drainable porosities at lower water table heights. This recharge effect continued and was found to be prominent up to the drain $4E_{15}$, which was located at a distance of 60 m away from the water body. The drainable porosity found out by this method for areas near drains $2E_{15}$, $3E_{15}$, and $4E_{15}$ did not represent the true values and would be considerably in error because of this recharge effect. This is true for the cases if an appreciable quantity of artesian water are entering the drained area or if deep seepage losses are great (Taylor, 1960). Hence drainable porosity values calculated near these drains ($2E_{15}$, $3E_{15}$, and $4E_{15}$) were not used for further analysis. For areas near drains $5E_{15}$, $7E_{30}$, and $8E_{30}$, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. This showed that this region was away from the recharge influence and the drainable porosity values calculated represented the real values. The constant region of the graph for drains $5E_{15}$, $7E_{30}$, and $8E_{30}$, implied a fairly homogenous soil. The slight initial decrease in drainable porosity in case of $5E_{15}$, $7E_{30}$, and $8E_{30}$, with declining water table might be due to a compact soil layer immediately below the surface. Hence, drainage designs are to be made separately for areas up to 60m away from water bodies and for distances beyond that. When drainage designs are made for areas nearer to water bodies, the recharge component should be incorporated for arriving at a proper design. The regression equations developed for drainable porosity, *f*, with respect to the mid-spacing water table height (h) at time, t, for the flow domain along with the equivalent drainable porosity values are given in Table 5.25. The equivalent drainable porosity for each drain catchments for the flow domain was found by taking the weighted average using Equation-4.11.

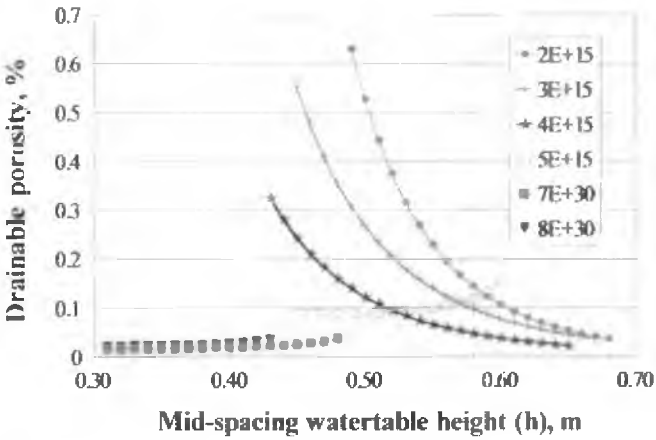


Figure 5.8 Variation in drainable porosity within the flow domain at different mid-spacing water table heights

Table 5.25 Regression equations for the variation of drainable porosity within the flow domain in relation to mid-spacing water table heights

Drain No	Equations developed for drainable porosity near the vicinity of the drains	Equivalent drainable porosity, fe
5E15	$f = 0.0198\ e^{3.086 h}$	0.10
7E30	$f = 0.0038\ e^{4.257 h}$	0.02
8E30	$f = 0.0050\ e^{4.204 h}$	0.02

The initial and final mid-spacing water table heights used in the above equation were taken from Table 5.19. The average equivalent drainable porosity for the flow domain for areas near drains $5E_{15}$, $7E_{30}$, and $8E_{30}$, is 0.04.

5.7.4 Testing of transient drainage equations

Transient drainage equations are generally used to predict the water table drawdown at mid-spacing. These equations relate the soil physical properties to the depth and spacing of parallel drains and the water table at the mid-spacing between the drains. The accuracy with which these equations predict the water table drawdown depends primarily on how closely the assumptions and boundary conditions used to derive them approximate the field conditions.

The following equations were tested for their accuracy in prediction of water table drawdown.

- Modified Glover Equation (Dumm, 1964)
- Bouwer and van Schilfgaarde (Integrated Hooghoudt) Equation (Bouwer and van Schilfgaarde, 1963)
- Hammad Equation for Thick Layers (Hammad, 1962)

The equations are given in section 4.11 (Equations 4.12, 4.14 and 4.15) and the symbols used in the equations are explained schematically in Figure 4.16. The equivalent hydraulic conductivity and equivalent porosity values given in Table 5.22 and Table 5.25 were used in these drainage equations for predicting the drawdown at different time for comparing them with the observed values. The predicted and observed drawdown curves are shown in Figures 5.9 to 5.11.

As seen from Figure 5.9, all the equations overestimated the drawdown for 15-m spacing. Equation-4.12 (Modified Glover Equation) deviated the most out of all. Equation-4.14 (Integrated Hooghoudt) and Equation-4.15 (Hammad Equation), though overestimated, were almost at par in predicting the drawdown. In the case of 30 m spacing (Figure 5.10 & 5.11), equation 4.14 (Integrated Hooghoudt) underestimated the drawdown throughout the recession and it became progressively more towards the later stages. However, Equation-4.15 (Hammad Equation) closely approximated the observed drawdown for 30 m spacing. Equation-4.12 (Modified Glover Equation) overestimated during the initial period and then slightly underestimated towards the later stages.

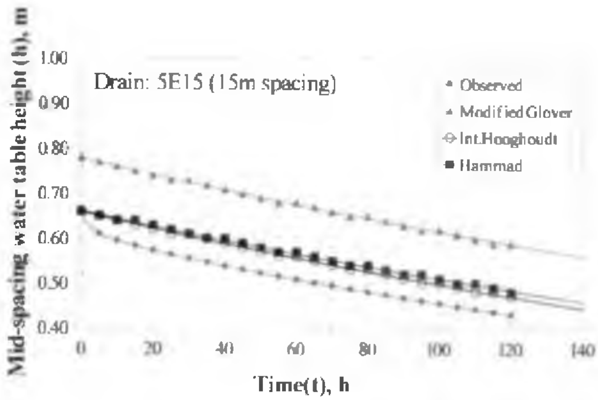


Figure 5.9 Observed and predicted drawdown in 15 m spacing (Drain 5E15)

It could be concluded that both Integrated Hooghoudt equation and Hammad equation for thick layers could be used in case of closer spacings and Hammad equation for thick layers in case of wider spacings. However, if any one equation is to be recommended for general use, Hammad equation for thick layers was found to be better taking both the spacings into consideration.

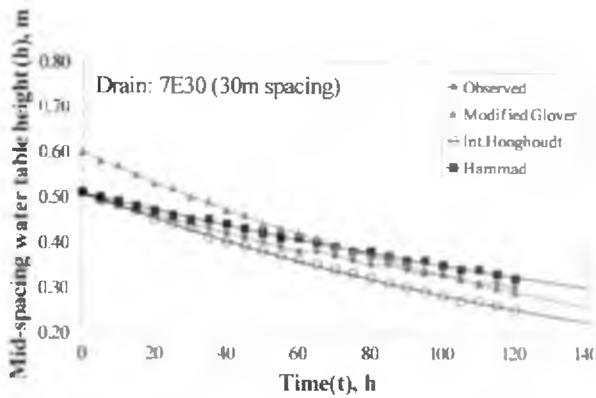


Figure 5.10 Observed and predicted drawdown in 30 m spacing (Drain 7E30)

5.7.5 Crop performance under subsurface drainage

Paddy crop (variety: Pattambi-39) was taken in the subsurface drained experimental area to evaluate the effect of drainage on crop performance. The layout of the experiment is shown in

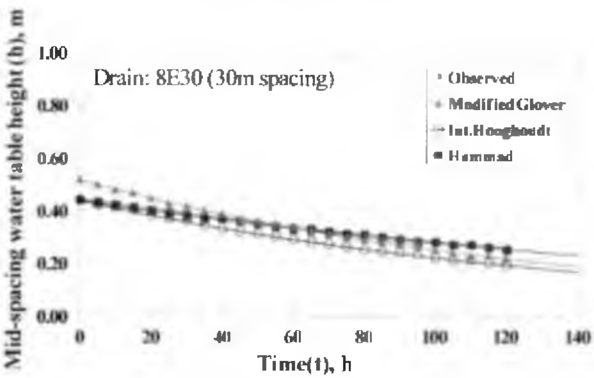


Figure 5.11 Observed and predicted drawdown in 30 m spacing (Drain 8E30)

Figure 4.17 and details of the experiment are explained in section 4.12. All the treatment plots (T_1 through T_6) were under subsurface drainage. The treatment plots mainly indicated the distance of different experimental plots from the drain line. These plots also had the influence of the usual surface drainage practised by the farmers. The control plots were away from the subsurface drained area such that there was no influence of the subsurface drainage on them. The control plots also had the influence of the regular surface drainage. The treatment plots were drained every day for eight hours throughout the cropping period except for a few days during which the fertilizers were applied. The observations taken, mainly crop growth parameters, were analysed under Randomized Complete Block Design (RCBD) and the results are summarized in Table 5.26.

Table 5.26 Growth parameters of paddy crop raised in the experimental area

Treatments	Height at maturity, cm	Plants/-m2	Panicles/-m2	Grains/P-anicle	Grain yield, t/ha	100-Grain weight, g	Straw yield, t/ha	Chaff
15 m Spacing								
T1	97.7	90.0	465	41.5	3.72	20.43	4.46	29.5
T2	98.3	90.0	437	38.7	3.58	20.45	4.00	33.4
T3	97.6	95.0	512	39.2	3.65	20.05	4.25	33.0
T4	79.0	72.5	476	35.7	2.24	18.53	5.71	35.0
CD*	2.7	16.5	NS	NS	0.33	0.52	NS	NS
30 m Spacing								
T1	97.60	85.00	415	38.00	3.87	19.96	4.42	27.70
T2	96.50	85.00	347	46.25	3.74	20.08	3.90	38.20
T3	97.38	82.50	440	33.50	3.48	19.52	3.77	33.70
T4	96.70	102.50	515	33.00	3.49	19.15	4.65	35.80
T5	96.23	97.50	540	35.50	3.54	19.25	5.15	31.70
T6	98.00	90.00	540	33.00	3.22	19.57	5.05	31.70
T7	76.68	70.00	490	30.00	2.21	19.03	4.90	37.50
CD*	6.49	NS	121	9.24	0.30	0.58	NS	NS

* at 95% confidence

Height at maturity

Height of plants at maturity in case of all the treatments having 15 m and 30 m drain spacing was found to be significantly superior to control (Figure 5.12 & 5.13). However, the variation among the treatments was non-significant.

Plants per unit surface area

There was significant difference in plant population (plants per m^2) between the treatments and the control in case of 15 m spacing (Figure 5.14). The values were higher in case of the treatment plots. The difference was statistically non-significant for 30 m spacing though the control plot recorded the lowest value (Figure 5.15). Even though all the non-labour inputs like seeds, fertilizers etc were provided to the farmers to obtain a uniform package of practice in the experimental area, the increased germination per centage due to better drainage in closer spacing possibly contributed to the significant difference in plants per m^2 in case of 15 m spacing. The comparatively higher values of plants per m^2 in both spacings suggest that providing controlled subsurface drainage can increase germination per centage.

Panicles per m^2

Difference between the treatments in the number of panicles in one square metre in the 15 m spacing (Figure 5.16) was non-significant. It was, however, significant in the case of 30 m spacing (Figure 5.17) due to the lower values recorded in the vicinity of the drains. The treatments away from the drains recorded the highest values indicating the importance of better water management through proper scheduling of drainage. The nutrient loss near the vicinity of the drains due to enhanced drainage conditions could have contributed to the lower values of panicles per m^2 in that area. Even the control plots recorded higher values than that near the vicinity of the drains. The study shows that excess drainage can adversely affect panicle formation.

Grains per panicle

The variation in grains per panicle in 15 m spacing (Figure 5.18) was non-significant. But in 30 m spacing (Figure 5.19), except T_2, all the treatments including the control were at par. However, in both the spacings, control plot recorded the lowest value.

Grain yield

In all treatments pertaining to 15 m and 30 m drain spacing (Figure 5.20 & 5.21), the grain yield was statistically superior to control. In the case of 15 m, T_1, T_2, and T_3 were at par as the difference among them was lower than the critical value of 0.33 t/ha. In 30 m spacing, T_1 was superior to all other treatments except T_2. However, treatments T_2 to T_5 were at par as the difference among them was less than the critical difference value of 0.30 t/ha. T_6 was the lowest with a grain yield of 3.2 t/ha. In spite of the low yield, T_6 was statistically superior to control. All these indicate that the adoption of subsurface drainage with 30-m spacing can produce significant higher yields over control, which is the farmers' practice of open surface drainage only. In control plot, germination of pollen must have been adversely affected by salinity resulting in lower per centage of fertilization of the florets in the panicle (Ota et al., 1956). The average grain yield during the season was 1.36 t/ha higher than that of control, which was equivalent to 61% increase in yield due to drainage.

100-Grain weight

The 100-grain weight parameter of all treatments in 15 m spacing (Figure 5.22) was statistically superior to that of control. In 30-m spacing (Figure 5.23), though the control plot recorded the lowest value, only T_1 and T_2, which were in the vicinity of the drain, were found significantly superior.

Straw yield

The variation in straw yield (Figure 5.24 & 5.25) was statistically non-significant. This indicates that adoption of subsurface drainage has little effect on straw yield. However, it slightly increased with the distance, though the increase was not statistically significant.

Chaff percentage

The difference in chaff percentage (Figure 5.26 & 5.27) was also found to be non-significant for both the spacings.

Many of the crop growth parameters in the experimental area, particularly the grain yield and 100-grain weight was significantly superior to that of the control plot when subsurface drainage was provided. From t he above findings, it could be inferred that spacing up to 30 m could significantly improve the productivity of the area. Wider spacing than 30 m may have to be explored by conducting further experiments.

5.7.6 Yield Consistency

Though all the crop growth parameters are equally important in assessing the efficiency of a subsurface drainage system, yield becomes the most important parameter when one is to assess the financial feasibility of the system. The yield data collected for 14 years after the installation of the system is shown in Figure 5.28. The average increase in yield was 1.10 t/ha equivalent to 42.52% over control.

5.7.7 Effect of drainage on soil heterogeneity

Leachate collected from tile drains during cropping season for the first two years after the installation of the drains were analysed to determine the effect drainage on alleviating the soil heterogeneity with regard to acidity and salinity. The results pertaining to temporal variations of pH and EC during both the years are presented in Figure 5.29 to 5.32. The acidic conditions (pH) during both the years were not detrimental. They were controlled by the farmers's practice of keeping the soil under standing water and thereby preventing oxidation and formation of acidity. However, it was seen that, during the first cropping season after the installation of drains, the acidity varied in the area in a non-uniform manner and it was very detrimental in the area near to drain $7E_{30}$ (Figure 5.29). During the second year of drainage, the non-uniformity of acidic levels was completely controlled and the severely affected area near drain $7E_{30}$ was fully improved (Figure 5.30). The magnitude and trend in variation of EC in areas near to different drains were also quite erratic during the first year (Figure 5.31) and became uniform by the second season (Figure 5.32). Figure 5.32 for EC for the second year shows that as the distance of the drain from the water body increases (see Figure 4.9 for location of drains from water body), the amount of salts leached also increases. This indicated that the higher water level outside the farming area created a hydraulic gradient causing an internal drainage, which washed the salts around that area even before the introduction of the tile drainage. This observation substantiates the comparatively higher yields at places where there is a nearby waterway or drainage channel. The Figure 5.32 also clearly indicated a substantial reduction of salt content of the area controlled by $7E_{30}$. Hence, installation of subsurface drainage in Kari soils can remove the soil heterogeneity, which is the root cause of patchy crop growth observed in the area. However, a period of minimum two years is required to make the soil stable with respect to pH and EC. The effect of drainage on other soil chemical properties might be similar which could be concluded only on further investigation.

5.7.8 Chemical changes due to drainage

The results on the chemical changes of soil and leachate for the different subsurface drain spacings at different stages of crop growth are graphically represented in Figures 5.33 to 5.50.

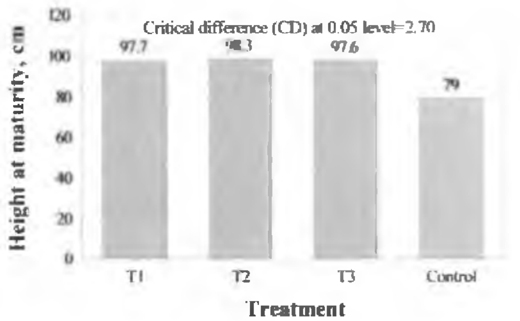


Figure 5.12
Height at maturity (15 m spacing)

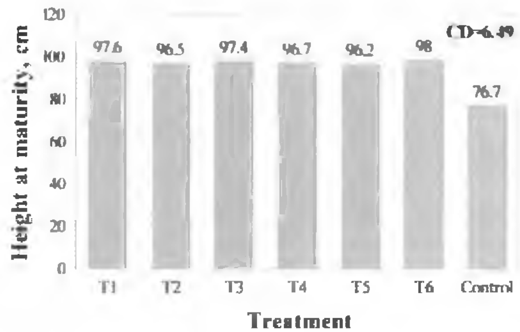


Figure 5.13
Height at maturity (30 m spacing)

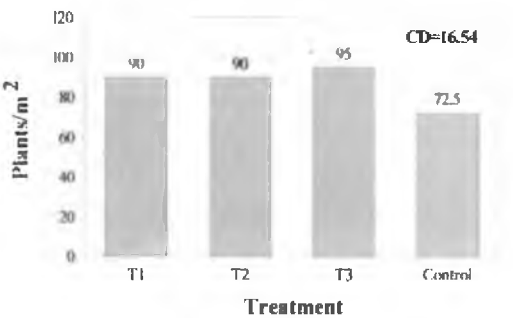


Figure 5.14
Plants/m^2 (15 m spacing)

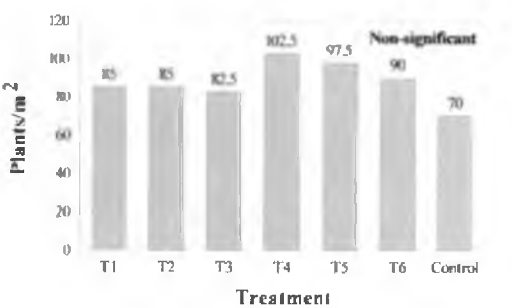


Figure 5.15
Plants/m^2 (30 m spacing)

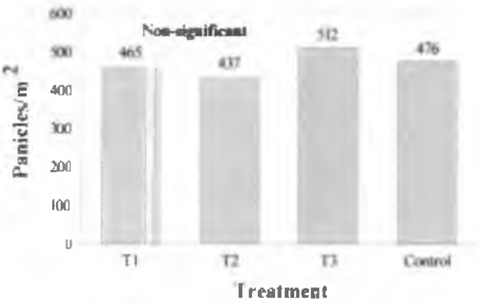


Figure 5.16
Panicles/m² (15 m spacing)

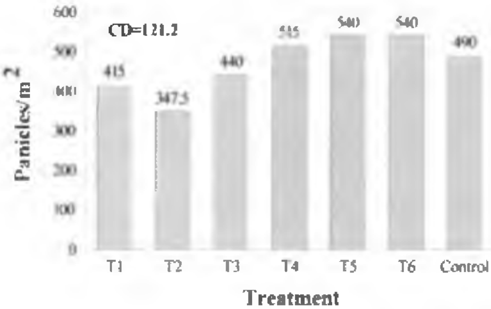


Figure 5.17
Panicles/m² (30 m spacing)

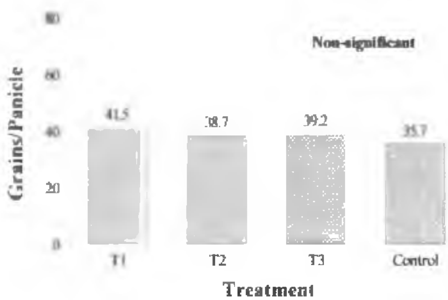


Figure 5.18
Grains per panicle (15 m spacing)

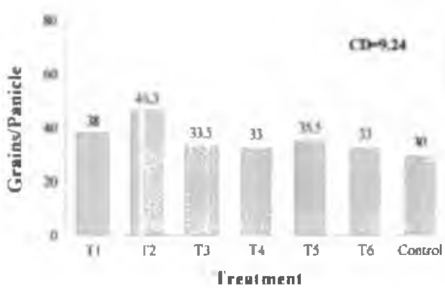


Figure 5.19
Grains per panicle (30 m spacing)

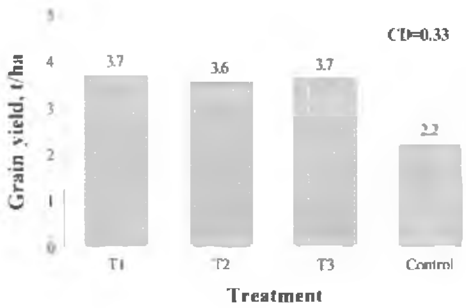


Figure 5.20
Grain yield (15 m spacing)

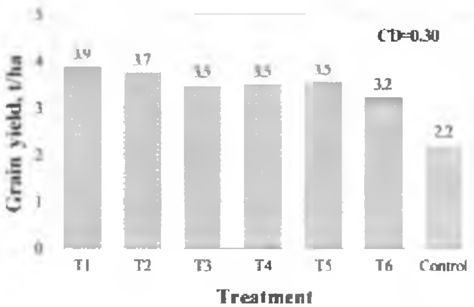


Figure 5.21
Grain yield (30 m spacing)

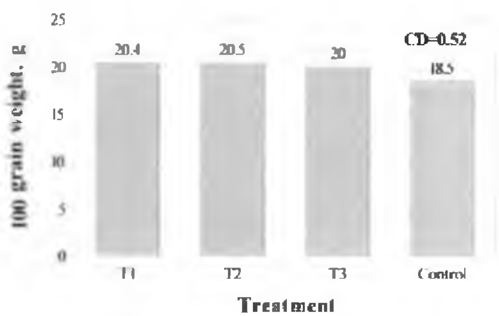


Figure 5.22
100-Grain weight (15 m)

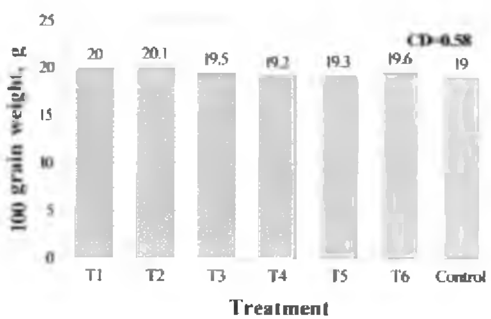


Figure 5.23
100-Grain weight (30 m)

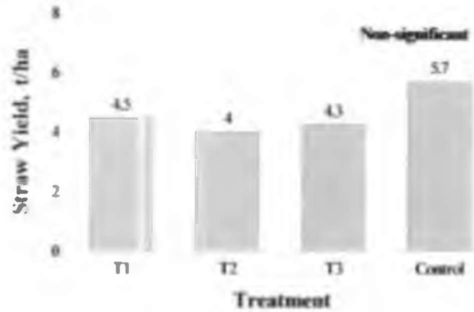


Figure 5.24
Straw yield (15 m spacing)

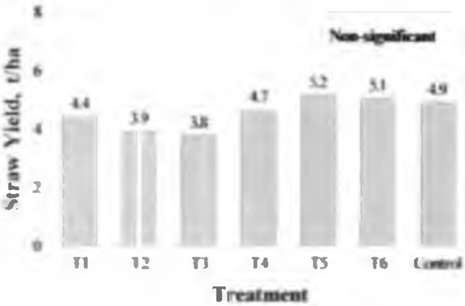


Figure 5.25
Straw yield (30 m spacing)

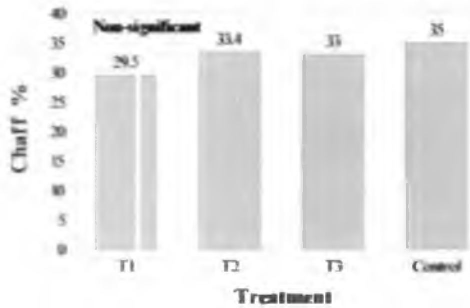


Figure 5.26
Chaff% (15 m spacing)

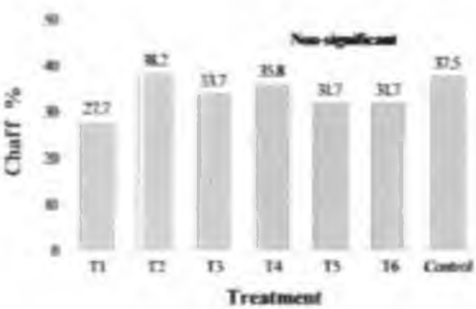


Figure 5.27
Chaff% (30 m spacing)

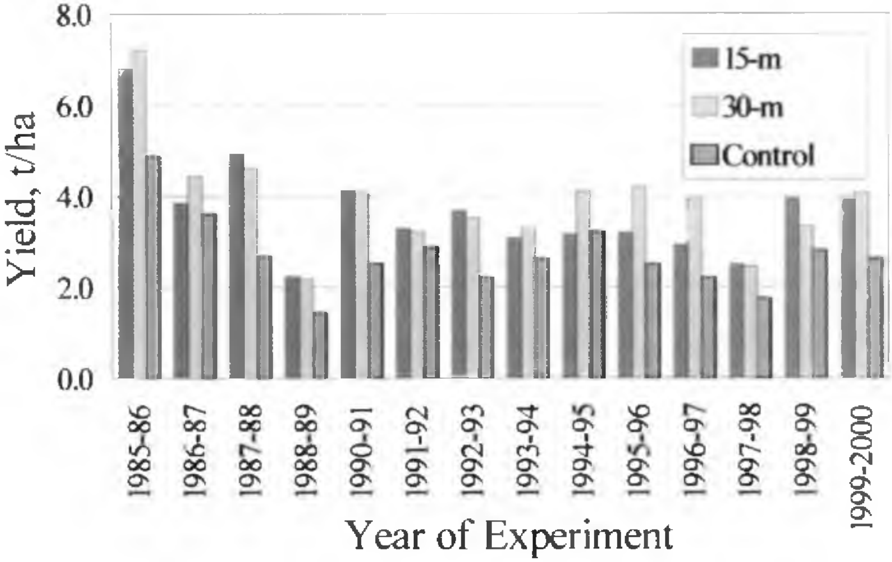


Figure 5.28 Consistently higher paddy yield due to subsurface drainage

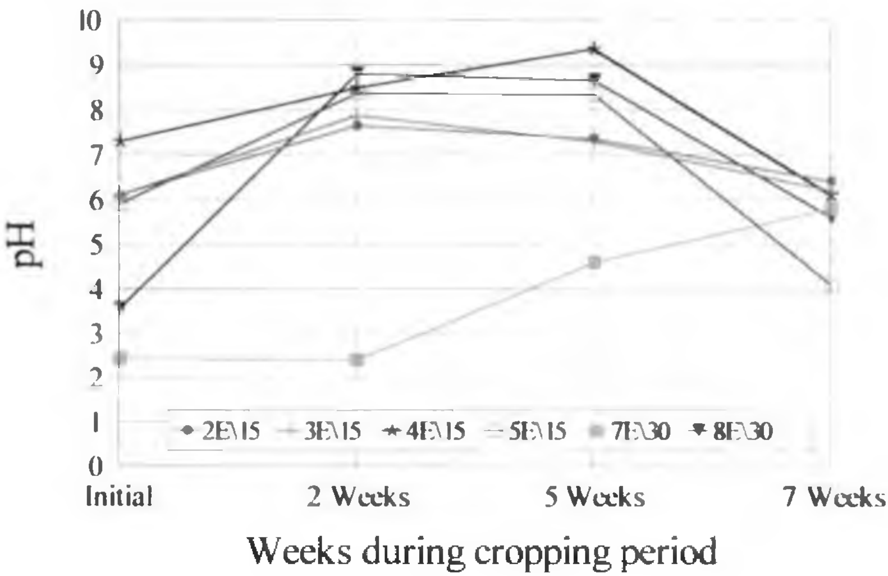


Figure 5.29 Temporal variation in acidity-first year after installation

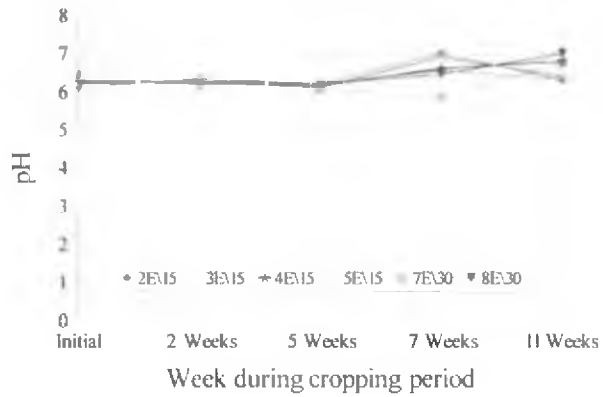


Figure 5.30
Temporal variation in acidity-Second year after installation

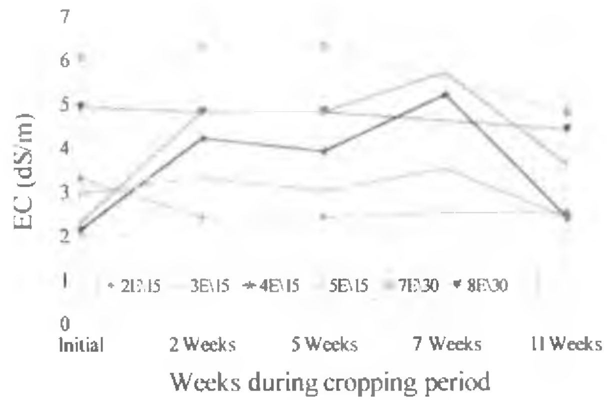


Figure 5.31
Temporal variation in salinity-First year after installation

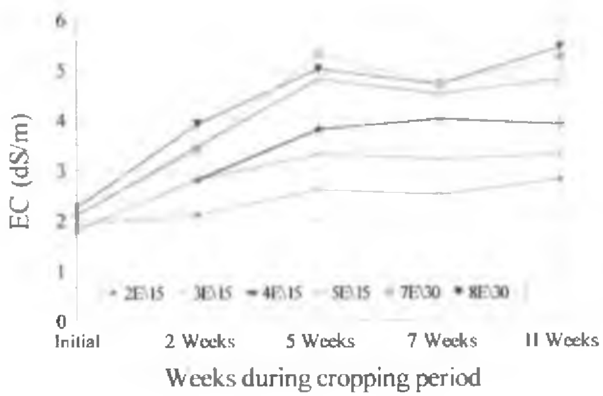


Figure 5.32
Temporal variation in salinity-Second year after installation

The soil pH showed only moderate variation due to drainage (Figure 5.33. It was higher than the control throughout the cropping season for the drained soils, though the difference was marginal. The acidity level was comparatively higher during the germination period, which decreased during active tillering and then slightly increased up to panicle initiation. It then increased rapidly towards the harvest. Prior to germination and towards the harvest period, when the field was drained completely for enabling the crop to establish and for convenience in harvest, respectively, oxidation of the pyrites (FeS_2) took place thereby enhancing the acidity level. The crop was grown in standing water during the period between active tillering and panicle initiation with the regular controlled subsurface drainage and hence that period had a relatively less acidity due to submerged conditions and leaching. Since the soil is rich in organic matter and easily reducible ferric iron, the reduction process due to submergence consumes acidity (Ponnamperuma, 1972), resulting in an increase of the pH, often to near-neutral values as reported by Hanhart and Ni (1991) and Van Breemen (1993). The observed high values of acidity in the leachate of 30 m spaced drains (Figure 5.34 may be attributed to the large area being drained and the corresponding high H^+ ion content in the drainage water. Since the irrigation water was not acidic, it could be inferred that subsurface drains can improve the soil acidity during the cropping season substantially. The higher levels of acidity in the leachate was not serious enough to cause concern for the fish species since the pH level lethal to fish is below 3-4 (Wendelaar Bonga and Dederen, 1986).

A close scrutiny of Figure 5.35 & 5.36 shows that salinity of the soil could be controlled considerably in the drained area. The topsoil never contained detrimental levels of EC because of the farmers' practice of frequent surface drainage. However, the substantial replenishment from the subsoil could be controlled by the drains, as revealed from the data for the leachate, which sometimes had conductivity as high as 5.75 dSm^{-1}. The additional salinity in leachate was caused by sub-soil salinity since the irrigation water was relatively non-saline. It was noted that the soil EC values were comparatively high during the onset and stoppage of drainage *ie* at the time of germination and harvest period, respectively. This is an indication of sub-soil salinity being brought towards the root zone as soon as the drainage is stopped or its intensity is reduced. This observation indicates that the salt concentration in the soil is influenced by drainage and the hydrological situations of the locality controlling the flux of salinization-desalinization processes.

Iron concentration of soil decreased substantially when drained by subsurface drains of 30 m spacing (Figure 5.37). This is further substantiated by the high concentration of water soluble iron obtained in the leachate of drains spaced at 30 m during the cropping season (Figure 5.38). In case of 15 m spacing, however, this trend could not be established. The iron content in leachate was always higher than that of irrigation water indicating that soluble iron is being leached from the soil. However, the overall low concentration (<9 ppm) of iron was mainly due to the aerobicity created by drainage whereby the ferrous forms were converted to ferric forms. It was almost nil for drained plots during germination, the reason being that good subsurface drainage prevailed at that period and the farmers' practice of draining the field completely for the crop to establish at that time. However, the comparative values for control plot was the highest during germination. But in all the cases the values were not higher enough to cause iron toxicity to rice crop, the toxicity level being 200 ppm which could result in the reduction of yield and decreased uptake of other essential elements (Saerayossakul, 1968). Thus iron transformations were not serious enough to cause concern for rice culture in the acid sulphate soils of Kuttanad under proper drainage conditions. However, the role of iron in alleviating the toxic effects of sulphur needs further investigation. It could be presumed that a larger portion of reduced iron under anaerobic condition was converted to insoluble iron sulphide by chemical reaction thus preventing the hydrogen sulphide injury to plants.

Control plots registered higher values of sulphate concentration. Though the sulphate concentration was comparatively less in the drained soils than that in the control, it increased due to drainage as seen in Figure 5.39. The oxidation of pyrite has resulted in the increase of concentration of sulphate. The aerobicity created during drainage played a definite role in alleviating the harmful effects of anaerobic conditions leading to sulphate reduction. Concentration of SO_4 (Figure 5.40) was very low in the leachate compared to that in the soil, indicating that accumulation of sulphate was chiefly in insoluble forms.

Calcium and Magnesium content of soil were lower for treatments receiving drainage in all the stages of crop growth than the control (Figure 5.41 & 5.43). The leachate samples also contained substantial amount of these ions in comparison to the irrigation and surface drained water showing the effect of subsurface drainage in controlling the total soluble salts (Figure 5.42 & 5.44).

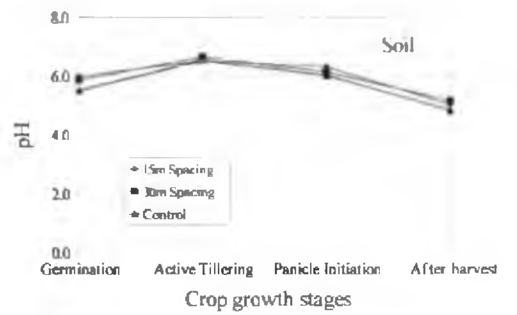


Figure 5.33
Chemical changes in soil on drainage: pH

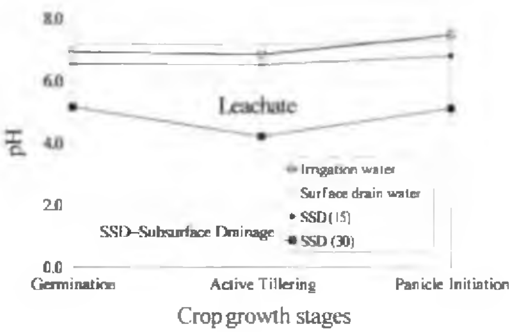


Figure 5.34
Chemical changes in leachate on drainage: pH

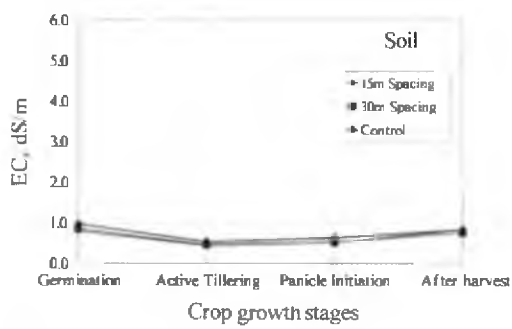


Figure 5.35
Chemical changes in soil on drainage: EC

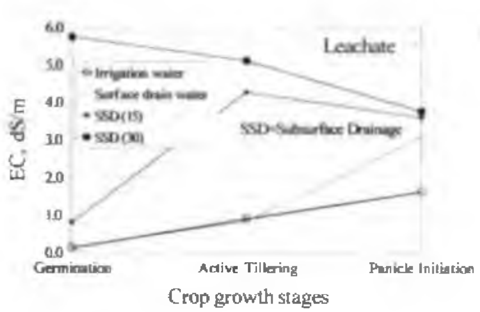


Figure 5.36
Chemical changes in leachate on drainage: EC

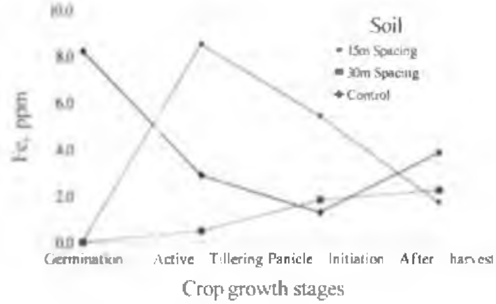


Figure 5.37 Chemical changes in soil on drainage: Fe

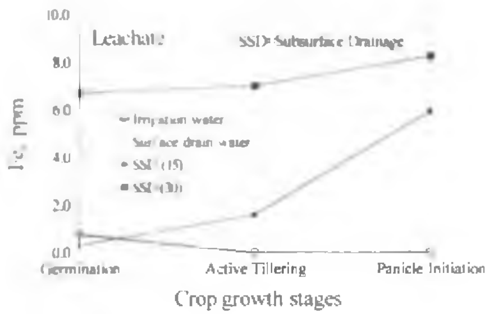


Figure 5.38 Chemical changes in leachate on drainage: Fe

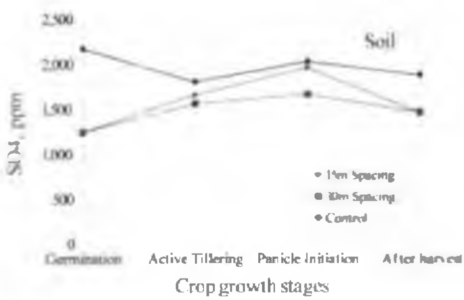


Figure 5.39 Chemical changes in soil on drainage: SO_4

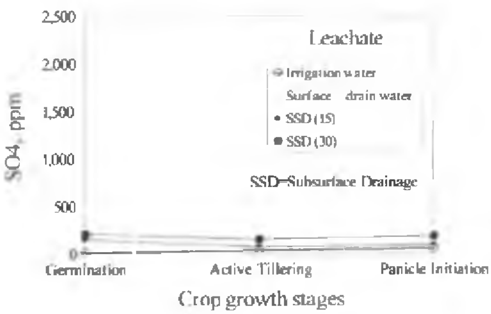


Figure 5.40 Chemical changes in leachate on drainage: SO_4

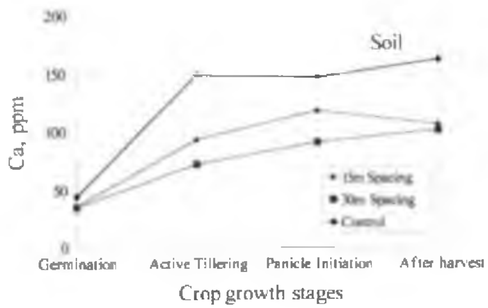


Figure 5.41
Chemical changes
in soil on drainage: Ca

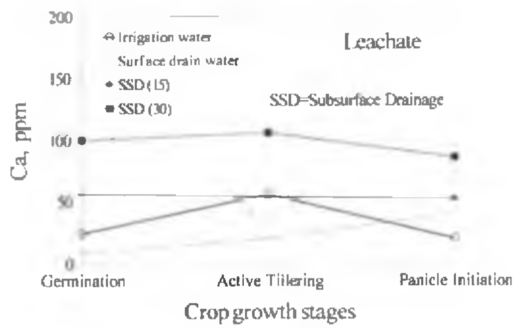


Figure 5.42
Chemical changes
in leachate on drainage: Ca

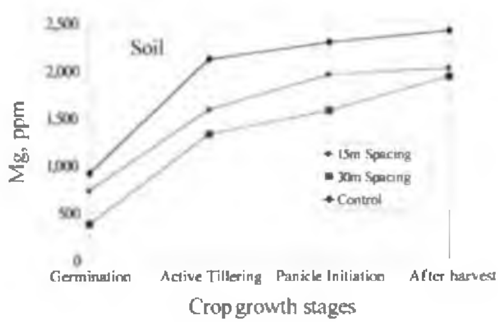


Figure 5.43
Chemical changes
in soil on drainage: Mg

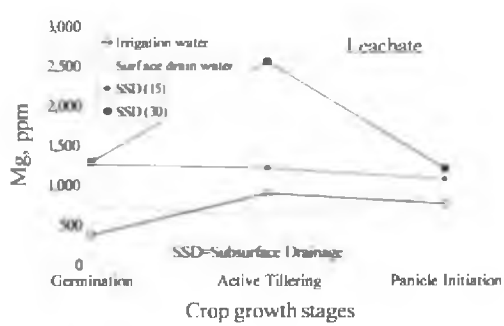


Figure 5.44
Chemical changes
in leachate on drainage: Mg

Chloride content in soil decreased drastically due to subsurface drainage. The control plot which is surface drained also has shown lower values (Figure 5.45). The decrease in concentration of chloride due to drainage is attributed to the preferential removal of chloride ions from the soil matrix, being the chief anion highly soluble in water. After drainage, when pumping was stopped, the trend reversed quickly with the accumulation of chloride in soil. The leachate concentration (Figure 5.46) clearly showed higher chloride content in subsurface drained water at all stages of crop growth.

Potassium content of the soil samples showed lower values and it was significantly lower for subsurface drained plots (Figure 5.47). Leachate showed

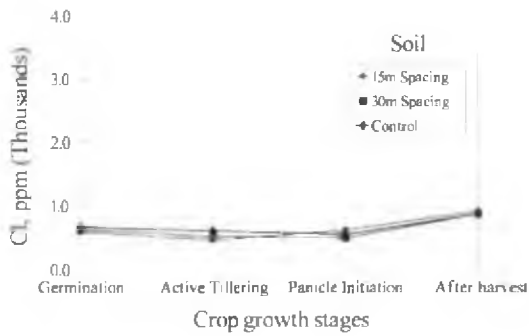


Figure 5.45 Chemical changes in soil on drainage: Cl

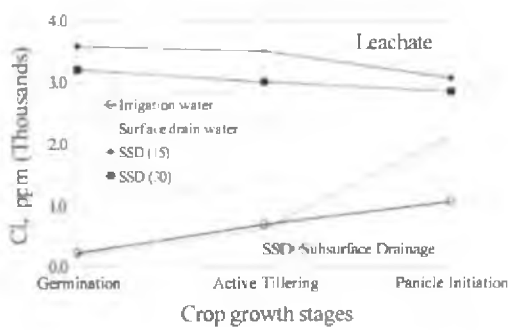


Figure 5.46 Chemical changes in leachate on drainage: Cl

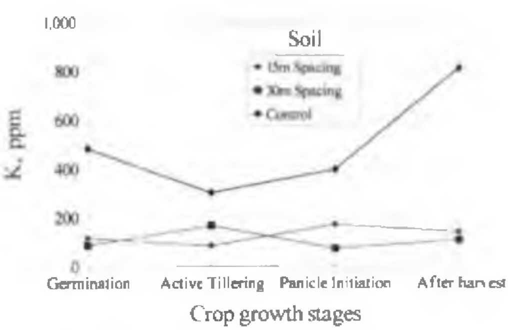


Figure 5.47 Chemical changes in soil on drainage: K

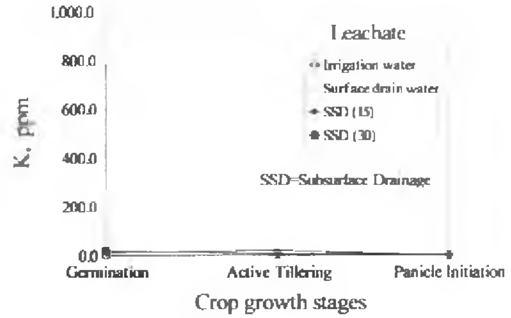


Figure 5.48
Chemical changes in leachate on drainage: K

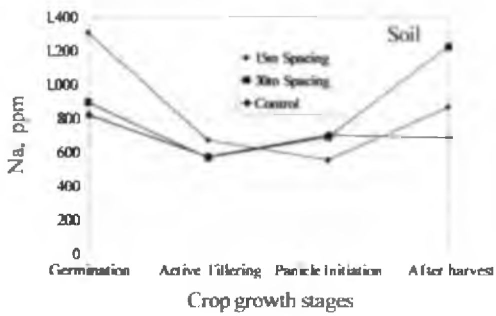


Figure 5.49
Chemical changes in soil on drainage: Na

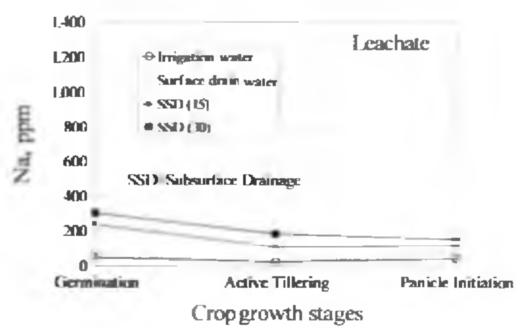


Figure 5.50
Chemical changes in leachate on drainage: Na

very low concentration of K during the cropping period mainly due to crop uptake (Figure 5.48).

During drainage, the Na content decreased significantly to lower values and picked up towards harvest when there was no drainage pumping (Figure 5.49). During drainage, a substantial amount of sodium was removed from the soil through leachate, chiefly as chlorides, as is evident from the leachate data (Figure 5.50). Sodium, being the chief cation in the soil, registered high values in the soil.

5.8 VARIETAL RESPONSE IN ACID SALINE FIELDS OF KUTTANAD

Introduction of subsurface drainage in the paddy fields of acid saline soils conclusively proved that rice yield could be increased significantly by its proper adoption. As a further step for exploiting the full potential of yield, it was felt necessary to prepare a package of practices for rice cultivation in these soils. To achieve this goal, it was felt necessary to find the best-suited varieties; its optimum population density; fertilizer requirement and other agro-techniques. Trials were initiated during 1996-99 with three varieties,

K_{16}, K_{18}, and *Jyothi*. The first two varieties were pre-release cultures for *Kari* soils evolved at the Rice Research Station, Moncompu of the Kerala Agricultural University, and the third, a popular variety of the area used as control. The fertilizer doses tested were 60:30:30, 90:40:45 and 120:60:60 (N: P: K, Kg/ha). The seed rates were 75, 100 and 125 (Kg/ha). Thus there were 27 treatment combinations tried in two replications. This experiment was compared with the crop where farmers' practices of open drainage only were adopted. The results are presented in the Table 5.27 and 5.28.

A critical review of the data in Table 5.27 reveals that the pre-release cultures, K_{16} and K_{18}, were superior to *Jyothi*, the local check. The K_{18} culture was found to be the most suitable of the varieties tested in *Kari* soils with a maximum yield of 3.16 t/ha. The crop performance with respect to yield attributing factors clearly indicates the superiority of the cultures over *Jyothi*. It was observed that the dose of 120:60:60 of N: P: K per ha could produce 2.79 t/ha of rice in *Kari* lands. Among the seed rates, 100Kg/ha was found to achieve the highest yield of 2.85t/ha.

Table 5.27 Effect of Individual treatments on grain yield and yield attributing factors (1996-99)

Treatm-ents	Grain Yield t/ha	Straw yield, t/ha	Plants/ m2	Height at maturity, cm	Panicles /m2	Panicle length, cm	Grains/ panicle	Chaff %	100 grain wt,
V1	2.79	5.69	79.47	95.91	323	22.67	154	33.82	2.55
V2	3.16	6.38	84.02	92.01	344	21.78	140	29.58	2.48
V3	2.17	5.53	95.55	79.86	353	22.98	93	34.53	2.80
S1	2.62	5.91	85.97	87.70	332	24.56	129	31.10	2.61
S2	2.85	5.99	84.33	90.57	338	21.68	130	31.36	2.51
S3	2.66	5.69	88.75	89.51	350	21.20	127	28.54	2.72
F1	2.74	5.83	91.41	89.97	344	21.24	119	28.80	2.52
F2	2.60	5.60	79.44	88.54	323	21.49	132	33.00	2.66
F3	2.79	6.16	88.19	89.27	354	21.64	125	32.75	2.65

VARIETIES	SEED RATE	FERTILIZER DOSE
V1: K16	S1 = 75 kg/ha	F1 = 60:30:30 (N:P:K)
V2: K18	S2 = 100 kg/ha	F2 = 90:45:45 (N:P:K)
V3: Jyothi	S3 = 125 kg/ha	F3 = 120:60:60 (N:P:K)

A review of the data in Table 5.28 clearly indicates the supremacy of the *Kari* cultures, K_{16} and K_{18} over the control variety, *Jyothi*. K_{16} recorded the highest grain yield, 3.63 t/ha, at a seed rate of 100 Kg/ha and at the highest fertilizer dose, 120:60:60. So far as K_{18} is concerned, the highest seed rate of 125 Kg/ha with a fertilizer dose of 60:30:30 also produced 3.63 t/ha. The highest grain yield recorded by *Jyothi* was only 2.61 t/ha with a combination of lesser seed rate of 75 Kg/ha and with a fertilizer dose of 120:60:60. Hence it may be inferred that the Kari culture K_{16} and K_{18} can produce an incremental yield of 1 t/ha over the commonly adopted variety *Jyothi*.

Table 5.28 Effect of treatment combinations on grain yield and yield attributing characters (1996 - 1999)

Sl No	Treatment Combinations	Grain yield, t/ha	Straw yield, t/ha	Plants/-m2	Height cm	Panicl-es/m2	Panicle length, cm	Grains/-panicle	Chaff %	100 grain wt.
1	V1S1F1	2.93	6.21	81.25	100.38	415.00	22.84	151.16	33.63	2.53
2	V1S1F2	2.67	5.96	75.00	75.69	285.00	22.15	140.89	30.00	2.47
3	V1S1 F3	2.49	5.59	76.25	94.49	287.00	22.85	150.48	32.38	2.74
4	V1S2F1	2.49	6.08	92.75	96.90	333.75	22.57	152.00	36.13	2.10
5	V1S2F2	2.74	5.55	75.00	100.16	342.50	23.25	157.52	37.25	2.37
6	V1S2 F3	3.63	5.73	70.00	97.38	340.00	23.10	160.05	34.38	2.25
7	V1S3F1	2.88	5.34	97.50	99.81	317.50	22.49	168.94	28.63	2.58
8	V1S3F2	2.67	5.10	77.50	100.78	300.00	22.21	152.44	35.88	2.71
9	V1S3F3	2.65	5.70	70.00	97.68	290.00	22.64	151.00	36.13	2.84
10	V2S1F1	2.80	6.08	70.00	92.81	302.50	21.43	154.33	32.63	2.54
11	V2S1F2	3.06	6.10	72.50	92.70	286.25	21.00	144.00	28.75	2.48
12	V2S1F3	2.66	7.05	91.25	92.68	342.50	24.27	150.74	26.38	2.16
13	V2 S2 F1	3.51	6.30	82.50	92.00	306.25	21.67	135.49	32.88	2.33
14	V2 S2F2	3.07	6.18	78.75	93.43	301.25	21.52	150.50	31.38	2.49
15	V2 S2 F3	3.54	7.10	83.75	92.78	388.75	21.61	140.90	32.00	2.48
16	V2 S3F1	3.63	6.35	111.25	89.08	385.00	20.50	125.34	26.75	2.52
17	V2 S3 F2	3.40	5.61	70.00	91.41	381.25	21.13	149.83	27.50	2.85
18	V2 S3 F3	2.85	6.65	96.25	91.24	402.50	22.96	111.28	28.00	2.49
19	V3 S1F1	2.30	5.31	98.75	80.49	366.25	19.56	89.38	31.75	2.83
20	V3 S1F2	2.06	5.41	95.00	79.40	330.00	19.73	89.26	33.63	2.76
21	V3 S1F3	2.61	5.54	113.75	80.70	375.00	19.77	91.99	30.75	2.98
22	V3 S2 F1	2.25	4.95	92.50	80.18	325.00	20.37	94.96	34.88	2.59
23	V3 S2 F2	2.07	5.51	83.75	82.36	325.00	22.51	103.96	28.25	2.96
24	V3 S2 F3	2.41	6.56	100.00	76.96	387.00	18.53	79.06	33.13	2.80
25	V3 S3 F1	1.92	5.93	96.25	78.14	341.00	19.79	95.53	36.88	2.72
26	V3 S3 F2	1.66	5.03	87.50	80.96	357.50	20. 00	101.18	44.38	2.90
27	V3 S3F3	2.31	5.54	92.50	76.55	373.75	19.11	87.36	37.13	2.91

VARIETIES	SEED RATE	FERTILIZER DOSE
V1: K16	S1 = 75 kg/ha	F1 = 60:30:30 (N:P:K)
V2: K18	S2 = 100 kg/ha	F2 = 90:45:45 (N:P:K)F
V3: Jyothi	S3 = 125 kg/ha	3 = 120:60:60 (N:P:K)

5.9 EVALUATION OF DIFFERENT DRAIN TUBE FILTERS

The installation of the system was carried out in the year 1988. The observations with respect to this experiment were noted just after the crop. Observations like hydraulic head (cm) and drain discharge (mm/day) during drainage were taken independently with respect to time for a period of 770 hours continuously. The above two data were then related through the common field of time. The drain discharge from drains with different filter materials at identical values of head for 3 replications and its mean values are given in Table 5.29-5.32. The graphical representation of the data (Figure 5.51-5.54) clearly indicates that there is a distinct difference in the drain performance among the replications. However, when the discharge rates at identical heads for all the filter treatments including that of control were subjected to statistical analysis, no significant difference was found between the treatments. A similar trend was also noticed after a lapse of 6 years (1995) as seen from Table 5.33.

The analysis of the yield and yield attributing characters for the crop raised during 1995 and 1996 are given in tables 5.34 and 5.35. The analysis of the data clearly shows that there is no significant yield difference among the treatments. This conclusively proves that all the treatments were equally effective. Hence it may be inferred that no filter materials are required for subsurface drainage in heavy clay soil of Kuttanad.

Table 5.29 Drain discharge versus time: Replication I

Head cm	Discharge, mm/day						
	Drain 1	Drain 2	Drain 3	Drain 4	Drain 5	Drain 6	Drain 7
65	-	-	-	-	-	-	-
60	8.8	-	13.6	13.2	-	15.6	-
55	7.2	16.0	11.6	11.2	-	12.0	-
50	6.0	12.4	10.0	10.0	-	10.0	-
45	5.2	9.6	8.8	8.8	7.2	8.0	-
40	4.4	8.4	8.0	8.0	6.1	6.4	-
35	3.6	7.2	6.8	6.4	5.4	5.2	-
30	2.4	6.0	6.0	6.0	4.6	4.4	-
25	2.0	4.8	4.8	4.8	3.8	3.2	-
20	1.2	4.0	4.0	4.0	2.9	2.8	-
15	0.8	2.8	2.8	2.8	2.2	2.0	-
10	0.4	2.0	2.0	2.0	1.5	1.2	-
5	0.4	1.2	0.8	1.2	1.5	0.8	-
0	0.0	0.0	0.0	0.0	0.0	0.0	-

Drain 1: Sea sand around drain, Drain 2 : Sea sand around joints, Drain 3: River sand around drain, Drain 4: River sand around joints, Drain 5: Coir fibre around joints, Drain 6: Paddy straw around joints, Drain 7: No filter (Control)

The literature related with textural group says that soil which contains less than 15% silt and clay form relatively simple capillary system with a large volume of non-capillary pore space, which ensures good drainage and aeration. The textural analyses of the Kari soil reveal that the mean value of silt and clay is marginally over 15%. This also has contributed to increasing the efficiency of the system without envelope material.

5.10 ECONOMICS OF SUBSURFACE DRAINAGE

The study on the crop performance under subsurface drainage in the acid sulphate soils of Kuttanad revealed that a drain spacing of up to 30 m could significantly increase the yield. The yield increase due to drainage was to the tune of 42.5% (1.10 t/ha) over control. The influence of a wider spacing greater than 30 m can be studied by conducting further experiments. On the basis of results of the study, an economic analysis was done for an assumed subsurface drainage system for a 100 ha rectangular area. The layout of the proposed drainage system is given in

Table 5.30 Drain discharge versus time: Replication II

Head, cm	Discharge, mm/day						
	Drain 1	Drain 2	Drain 3	Drain 4	Drain 5	Drain 6	Drain 7
65	-	-	30.8	-	44.0	-	32.0
60	30.8	49.2	28.0	24.8	40.4	-	29.2
55	28.4	45.6	26.0	22.4	37.6	-	26.8
50	26.0	42.0	23.6	20.4	34.4	-	24.0
45	23.6	36.8	21.2	18.4	31.6	56.8	22.0
40	20.8	35.2	18.8	16.4	28.8	51.6	19.6
35	18.4	32.0	16.8	14.4	26.0	45.6	17.6
30	16.4	28.0	14.8	12.4	22.8	39.6	15.2
25	14.0	24.0	12.8	10.4	20.0	33.6	13.2
20	12.0	20.4	10.4	8.8	16.0	27.2	10.8
15	9.6	16.0	8.4	6.4	13.2	21.6	8.0
10	6.8	12.0	6.4	4.8	9.6	15.2	5.6
5	3.6	3.2	3.6	2.8	5.6	7.2	2.8
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Drain 1: Sea sand around drain, Drain 2: Sea sand around joints, Drain 3: River sand around drain, Drain 4: River sand around joints, Drain 5: Coir fibre around joints, Drain 6: Paddy straw around joints. Drain 7: No filter (Control)

Table 5.31 Drain discharge versus time: Replication III

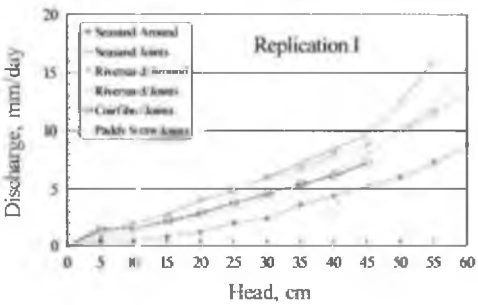
Head, cm	Discharge, mm/day						
	Drain 1	Drain 2	Drain 3	Drain 4	Drain 5	Drain 6	Drain 7
65	-	-	-	-	-	-	-
60	29.6	38.8	-	34.8	28.0	35.2	38.4
55	27.2	35.6	-	32.0	26.0	32.0	34.8
50	25.2	33.2	26.4	28.8	24.0	29.6	33.2
45	23.6	30.4	23.6	26.8	21.6	26.8	30.4
40	20.8	28.0	20.8	23.2	18.8	24.0	27.6
35	18.8	25.2	18.0	21.6	17.2	21.6	24.8
30	16.4	22.4	15.6	18.8	15.2	19.2	21.6
25	11.2	19.2	13.2	16.0	12.8	16.0	18.8
20	8.8	16.0	10.8	13.6	10.4	13.2	15.2
15	6.4	12.8	8.0	10.4	8.0	10.4	11.6
10	3.6	9.2	5.6	8.0	5.6	7.2	8.0
5	0.0	4.8	3.2	4.0	3.2	4.0	4.4
0	-	0.0	0.0	0.0	0.0	0.0	0.0

Drain 1: Sea sand around drain. Drain 2: Sea sand around joints. Drain 3: River sand around drain, Drain 4: River sand around joints, Drain 5: Coir fibre around joints, Drain 6: Paddy straw around joints, Drain 7: No filter (Control)

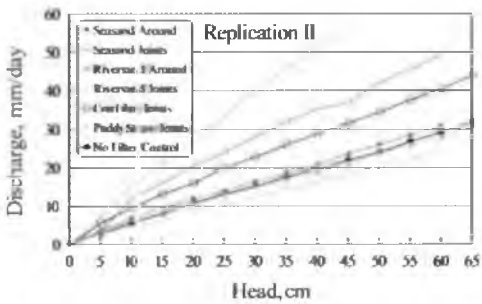
Figure 5.55 The system consists of parallel subsurface drains of 100 m length each. discharging into a secondary open drain. All secondary open drains are connected to a main open drain, which have their outlets at the periphery of the field and adjacent to the water body outside. The drained water is pumped into these main water bodies with the help of two suitable pumping units located at the outlets of the main open drain. The estimate of the cost of the system is given in Appendix- D.

Table 5.32 Mean drain discharge at different hydraulic heads for different treatments in mm/day, 1989

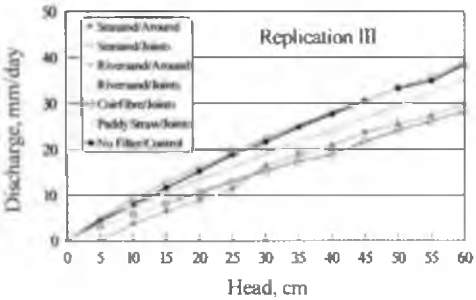
Sl No	Treatments	Hydraulic head, cm				
		45	40	30	20	10
1	Sea sand all around the drain, T1	17.5	15.3	11.7	8.1	4.5
2	Sea sand around joints only, T2	25.6	23.9	18.8	13.5	7.7
3	River sand all around the drain, T3	17.9	15.9	12.1	8.4	4.7
4	River sand around joints only, T4	18.0	15.9	12.4	8.0	4.9
5	Coir fibre around joints only, T5	20.1	17.9	14.2	9.9	5.6
6	Paddy straw around joints only, T6	30.5	27.3	21.1	14.1	7.9
7	No filter material, T7	22.0	19.9	15.3	10.7	5.6
	CD (0.05)	NS	NS	NS	NS	NS



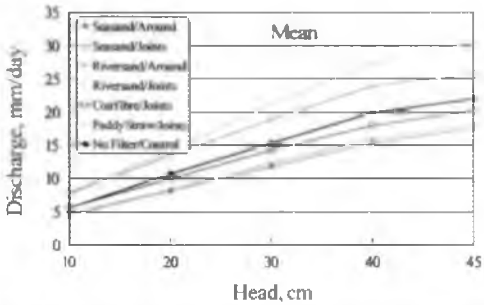
Fifure 5.51
Drain discharge at various heads for drains laid with different filter materials (Replication I)



Fifure 5.52
Drain discharge at various heads for drains laid with different filter materials (Replication II)



Fifure 5.53
Drain discharge at various heads for drains laid with different filter materials (Replication III)



Fifure 5.54
Drain discharge at various heads for drains laid with different filter materials (Mean)

Table 5.33 Mean drain discharge at different hydraulic heads for different treatments in mm/day, 1995

Sl No	Treatments	Hydraulic head, cm					
		50	45	40	30	20	10
1	Sea sand all around the drain, T1	17.2	15.5	13.1	10.6	8.1	4.5
2	Sea sand around joints only, T2	20.0	18.0	16.0	12.0	8.2	7.7
3	River sand all around the drain, T3	18.7	16.4	14.7	11.5	7.5	4.7
4	River sand around joints only, T4	17.6	15.9	13.9	10.6	6.9	4.9
5	Coir fibre around joints only, T5	25.0	22.7	20.3	15.0	10.1	5.6
6	Paddy straw around joints only, T6	18.5	16.9	15.0	11.4	7.6	7.9
7	No filter material, T7	15.6	13.8	12.2	9.1	6.0	5.6
	CD (0.05)	NS	NS	NS	NS	NS	NS

A minimum increase in yield of 1 t/ha was expected when the crop is grown under subsurface drainage system. This assumption is based on the experimental results where an average increase in yield of 1.1 t/ha (based on 14 years data) was obtained when paddy crop was taken in farmers' field with the additional input of subsurface drainage. It is assumed that the area can go for double cropping after the introduction of subsurface drainage system

Table 5.34 Yield and yield attributing characters under filter study, 1995

Treat-ments	Grain Yield t/ha	Straw yield. t/ha	Plants/-m2	Ht at Maturity. cm	Panicles/-m2	Length of panicle cm	Grains/-panicle	Chaff %	100 grain weight
T1	3.0	3.43	166.8	85.2	260.0	21.0	101.8	17.67	2.88
T2	2.9	3.10	110.0	80.5	256.7	21.7	104.3	17.67	2.77
T3	2.6	3.30	136.8	82.0	216.7	21.8	97.8	16.00	2.80
T4	2.9	3.37	123.3	81.5	214.0	21.2	104.5	14.67	3.05
T5	2.9	3.67	110.0	85.2	303.3	21.7	111.5	13.00	2.90
T6	3.1	2.77	86.8	80.3	220.0	21.3	69.3	19.67	2.86
T7	2.9	2.73	140.0	85.9	280.0	23.0	104.3	22.67	2.64
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5.35 Yield and yield attributing characters under filter study, 1996

Treat-ments	Grain Yield t/ha	Straw yield, t/ha	Plants/-m2	Ht at Maturity. cm	Panicles/-m2	Length of panicle. cm	Grains/-panicle	Chaff %	100 grain weight
T1	3.13	4.20	73.33	86.87	223.3	21.30	122.73	29.67	2.83
T2	3.25	3.57	76.57	83.60	203.3	21.77	117.60	22.67	2.86
T3	2.99	4.67	73.33	87.53	216.7	21.87	113.93	35.33	2.78
T4	3.17	4.03	70.00	87.67	220.0	21.17	113.73	29.33	2.80
T5	3.01	5.10	80.00	85.20	220.0	21.87	118.80	35.33	2.70
T6	3.07	4.17	73.33	86.07	206.7	21.07	109.00	35.67	2.87
T7	2.43	3.63	73.33	90.80	220.0	22.03	140.07	34.00	2.74
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

since each *padasekharam* can be better managed through the proper network of drainage systems. Based on the estimated cost and benefit of the system as given in Appendix-D, an economic analysis was made to assess its financial viability. The analysis was done using the discounting measures commonly applied to agricultural projects, namely, benefit-cost ratio, net present worth, and internal rate of return. The procedures given by Gittinger (1976) were used for the purpose. An expected life of 20 years was assumed for the system with no salvage value. Since the labour is costly in Kerala, the annual growth rate of cost was taken as 5 per cent while that of benefit was 2 per cent. All the costs and benefits were discounted at 12% to the present worth for each year

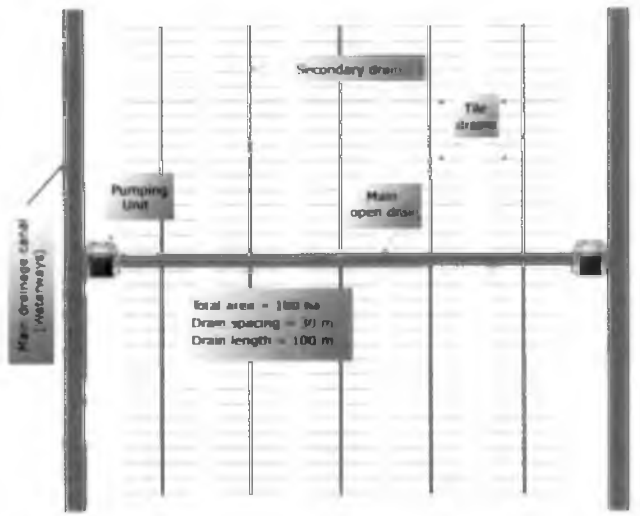


Figure 5.55 Layout of the hypothetical drainage system in a 100 ha area

during the life span of the project. An abstract of the analysis is given in Table 5.36. The B-C ratio was calculated by dividing the sum of the discounted benefits of each year during the life span of the project by the sum of the discounted costs for each year during the corresponding period. The NPW was calculated by adding the discounted net benefits for each year during the project period. Trial and error method was used to find IRR, the discount rate that makes the NPW equal to zero. Figure 5.56 shows the break up of the different discounted cost of the system.

The analysis showed that the project is economically viable because a B-C ratio of 2.45 was obtained. Since the NPW is positive, Rs 5.17 million in this case, the project is acceptable on that measure too. Similarly, the IRR, which is 47%, is far beyond the opportunity cost and hence the project is economically viable. Though all the discounting measures have been used, any one of these would suffice in decision-making.

There is a tendency in agricultural projects to be optimistic about potential yields especially when the information is based mainly on experimental trials. A test to determine how sensitive the project's internal economic and financial returns are to lower yields may not only provide information useful in deciding whether to implement the project, but may also emphasize the need to assure proper extension services if the project is to yield as high a return as could reasonably be expected. Hence a sensitivity analysis was done to see how the B-C ratio, NPW and IRR varies with the errors in yield-estimates. All the three discounting criteria were calculated for incremental yield increases of 0.1 t/ha starting from 0 to 1.4 t/ha (1.36 t/ha, being the maximum obtained during experiment). The expected variations are depicted in Figure 4.57 to 4.59.

Table 5.36 Abstract of the economic analysis of a subsurface drainage system in 100 ha for Kari lands

Year	Capital cost, Rs	O & M cost, Rs	Total cost, Rs	Benefits, Rs	Discount factor	Present worth of costs, Rs	Present worth of benefits, Rs	Cash flow, Rs	Net present worth, Rs
1	2250000	-	2250000	-	0.893	2008929	-	-2250000	-2008929
2	-	180000	180000	1200000	0.797	143495	956633	1020000	813138
3	-	189000	189000	1224000	0.712	134526	871219	1035000	736693
4	-	198450	198450	1248480	0.636	126119	793432	1050030	667313
5	-	208373	208373	1273450	0.567	118236	722590	1065077	604353
6	-	218791	218791	1298919	0.507	110846	658073	1080127	547226
7	-	229731	229731	1324897	0.452	103918	599316	1095166	495398
8	-	241217	241217	1351395	0.404	97424	545806	1110178	448382
9	-	253278	253278	1378423	0.361	91335	497073	1125145	405738
10	-	265942	265942	1405991	0.322	85626	452692	1140049	367065
11	-	279239	279239	1434111	0.287	80275	412273	1154872	331998
12	-	293201	293201	1462793	0.257	75257	375463	1169592	300205
13	-	307861	307861	1492049	0.229	70554	341939	1184188	271385
14	-	323254	323254	1521890	0.205	66144	311409	1198636	245265
15	-	339417	339417	1552328	0.183	62010	283605	1212911	221594
16	-	356388	356388	1583375	0.163	58135	258283	1226987	200148
17	-	374207	374207	1615042	0.146	54501	235222	1240835	180721
18	-	392917	392917	1647343	0.130	51095	214220	1254425	163125
19	-	412563	412563	1680290	0.116	47901	195093	1267726	147192
20	-	433191	433191	1713895	0.104	44908	177674	1280704	132766
TOTAL	2250000	5497021	5497021	27408670	7.00	3631234	8902011	19661650	5270777
Discount Rate				0.12					
Benefit Cost Ratio				2.45					
Net Present Worth				Rs 5,270,777/-					
Internal Rate of Return				47%					

The relationship established between the three discounting measures and the variations in the yield are:

$$b = 2.45\ x \qquad (5.1)$$

where b = B-C ratio;
x = yield increase, t/ha.

$$n = -3.63 + 8.9\ x \qquad (5.2)$$

where n = NPW, Rs (Million); and

$$i = -12.13 + 58.39\ x \qquad (5.3)$$

where I = IRR, (%)

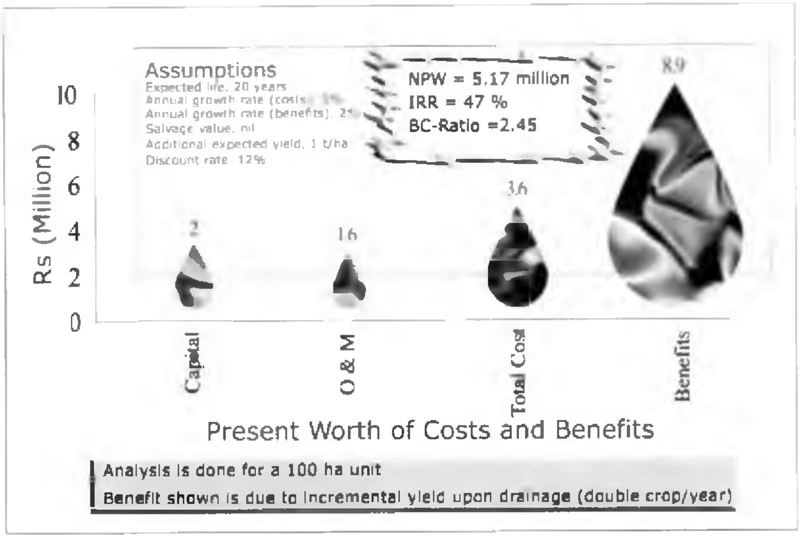


Figure 5.56 Break-up of the discounted cost and benefits of subsurface drainage in a hypothetical 100 ha area

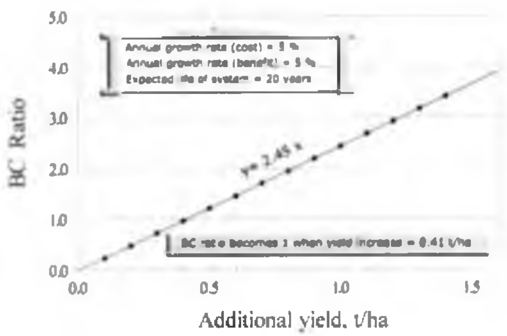


Figure 5.57
Variation in BC Ratio with incremental yield

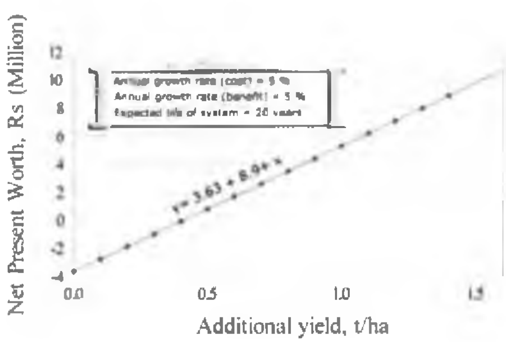


Figure 5.58
Variation in NPW with incremental yield

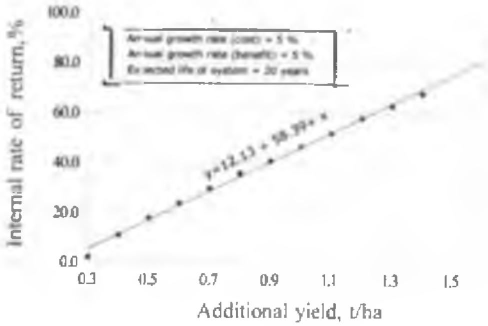


Figure 5.59
Variation in IRR with incremental yield

It could be seen that the B-C ratio becomes one (Figure 5.57) or the NPW becomes zero (Figure 5.58) when the yield increase due to drainage falls to 0.41 t/ha. This is the critical yield when the IRR becomes the opportunity cost (Figure 5.59). It could be concluded that the subsurface drainage system is economically feasible in Kari lands if it can increase the yield by 0.41 t/ha from the present level. The analysis could also be sensitive to the price variations of rice, delay in implementation of the project and subsequent cost overrun. Since the prevailing market rates are used in evaluating costs and benefits and the annual growth rates (2%) of benefits is kept less than the annual growth rate (5%) of costs, the analysis presented above is reasonable and could be used by policy makers, entrepreneurs, and private and public sector financial entities as a stepping stone for further critical consideration of subsurface drainage projects in Kuttanad.

6. SUMMARY AND CONCLUSIONS

Research efforts on soil drainage to improve and sustain rice yields in the *Kari* soils of Kuttanad were started at Karumady, Alappuzha by the Kerala Agricultural University in collaboration and with financial and technical assistance from the Indian Council of Agricultural Research in 1981. A large volume of research data has been generated and analyzed in this cooperating centre pertaining to agricultural land drainage and associated activities during 1981-2002. A summary of the work and pertinent conclusions are given below.

6.1 RESEARCH BACKGROUND

With a meagre geographical spread of less than 1.18% of the country, the state of Kerala supports over 3.43% of her population. With the increased population pressure and consequent fragmentation of the land holdings, farming in the State is characterized by predominance of tiny holdings that are incapable of sustaining farming communities, especially in the coastal tracts of Kerala. Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts. The high rainfall coupled with undulating topography subject the low land rice fields to environmental vagaries of flash floods in the monsoon and tidal saline incursions during the summer. Impeded by poor drainage, excess water and poor water management, the potential of high yielding rice varieties is hardly realized in this region. The situation is further aggravated in acid saline soils owing to high acidity, salinity and accumulation of toxic salts in these soils.

With the aforementioned problems in mind, the area selected for the drainage studies was the most vulnerable part of Kuttanad, the *Karilands*. Various experiments were conducted in the study area, which was a part of a 75 ha rice co-operative farm. *Kariland* soils are acid-sulphate in nature, contain high amounts of clay fraction and organic matter and are frequently subjected to saline water inundation, as the cultivated lands are situated below the mean sea level. The cultivated lands are protected by strong bunds from the flowing water bodies all around. Presently in the *Kari lands* of Kuttanad, paddy is the only crop grown extensively. High yielding varieties of paddy are being used throughout the area. The crop has to overcome the adverse effects of acidity and salinity to register an average yield. Symptoms of iron toxicity on the leaves are predominant. The roots are also found to decay due to the sulphide injury. All these factors result in patchy crop growth and a poor grain yield of approximately 1.5 tons/ha, even after 100% adoption of high yielding paddy varieties. The idea behind the selection of this site was to introduce subsurface drainage to bring about substantial washing of the soil profile and to increase the productivity of these soils.

6.2 PILOT STUDIES

6.2.1 Role of surface drains in improving productivity

The farmers of the *kariland* rice fields practice surface drainage to control the problems arising out of salinity, acidity and waterlogging. Pilot studies conducted in the farmers' fields on the role of surface drains in improving the rice productivity have shown that grain yield was the highest in the vicinity of the drainage channels and the lowest where there was no drainage channel. Chemical analysis of the soil samples indicated increase in acidity with the depth of the soil. The sub soil also contained higher quantities of soluble salts than the surface soil. In general, it was found that, when fields were provided with sufficient open drains, the Total Soluble Salts (TSS) of the topsoil was minimum and increased with depth of the soil profile. The organic carbon content of the soil was found to be almost uniform throughout the profile up to 1 m depth and it ranged between 3.0% and 4.23%. Total nitrogen content of the soil was found to decrease with depth of soil. The top plough layer contained the highest content of N. In the fields where drainage channels were present, the content of N was found to be significantly higher than the fields without good drainage. Total potassium (K) content of the soil was found unaffected with depth of soil. The first one metre soil profile contained almost uniform content of K. But towards deeper layer and in the fields without sufficient field drainage channels, the K content was found to be lower.

Using a well-distributed network of observation wells, a study was conducted on the influence of open drains on the water table movement. The study revealed that open drains could play a major role in leaching of toxic salts from the area. With the total farming area of 75 ha, the average length of main open drain and secondary open drains were 15.5 m/ha and 64.6 m/ha, respectively. For adequate improvement of the root zone environment and to ensure higher rice productivity, more open drains are needed in the area. However, increasing the density of open drains leads to loss of cultivable area and inconvenience to cultivation. The farmers also resist parting with land from their small holdings for constructing more open drains. Introduction of subsurface drainage for improving the crop productivity, thus, is an alternate solution.

6.2.2 Selection of cropping season based on the quality of irrigation water

Studies on the quality of irrigation water, based on the analysis of water samples collected at weekly intervals for five years, indicated that irrigation water was slightly acidic throughout the year. However, the acidity was not too severe to adversely affect rice production if proper management practices were adopted. The salinity levels of irrigation water were higher during the summer months of March to May till the arrival of southwest monsoon in June. The summer months of March to May should be avoided for cultivation. The best period for growing single crop can be considered from August to November. Presently farmers seldom get this optimum period for cultivation. The fields are to be drained off the impounded water in time. This is often found difficult because of the poor financial status of the cooperatives and the delay in getting subsidized electric connection for drainage pumping.

6.2.3 Present set-up of drainage pumping and its limitations

Cultivated lands are below the mean sea level and drainage of excess water from the fields is necessarily to be done by pumping out the water. Even when crops are not cultivated, the land is not allowed to dry and crack for the fear of developing high acidity due to oxidation of the sulphur compounds in the soil. Fields are flooded with water to a depth of 0.5 to 1 m after the harvest in order to avoid severe acidity on drying. Therefore, dewatering of the fields before cultivation is an integral part of cropping activity in the region. A major problem faced by the farmers is the non-availability of low cost and efficient water lifting devices for dewatering. The commercial pumping units with metallic casings are corroded under the acidic water environment. Hence drainage pumping is done using axial flow pumps of indigenous make of varying sizes. These pumps have wooden casing and cast iron impeller. The efficiency of these pumpsets is very low to the tune of 20%. From a study conducted on the present set-up of pumping system, it was found that pumping units with a capacity of 0.50-0.75 hp/ha is the optimum. A sample survey and analysis of the pump performance of the rice co-operatives has revealed that an additional energy of 0.829 million kwh is used by them in a year due to the improper selection of pumps. The corresponding excess energy consumption for the entire Kuttanad was found to be 6.7 million kwh, which is nearly 22% more than the actual requirement.

6.2.4 Comparative studies on the performance of PVC pipe and Clay tile drains

The entrance resistance and head loss fraction are two parameters that can predict the performance of drains. Experiments revealed that the head loss fraction was lower in the case of clay tile drains than for the PVC pipe drains. The head loss fraction for the clay tile drains was below 0.30 whereas in case of the PVC drains, it was around 0.80. Hence it is inferred that the performance of clay tile drain would be better in the project area as compered to the PVC pipe drain despite the fact that the per cent open area is more in the PVC pipe drains. The poor performance of the PVC drains may be due to the blocking of the small width (1 mm) slots on account of iron precipitation (ochre formation) Increasing the slot width might favour entry of soil particles and thereby cause silting of the drains. Finding out a proper slot size for the PVC pipes in these situations is a suggested future work.

Studies on discharge and subsidence of water table due to continuous drainage has shown that the zone of influence of tile drain (Baked Clay) is almost up to 7.5 m on either side of the drain line. In the case of PVC drains, this distance was only up to 5 m.

6.2.5 Studies on crop performance under subsurface drainage

Pilot studies conducted using single subsurface drain line indicated that the yield of paddy could be considerably increased (29.25%) when subsurface drainage was provided. Subsurface drainage also could reduce acidity and salinity. The control field maintained a high acidity level and salinity level during the cropping season.

6.3 DETAILED STUDIES ON SUBSURFACE DRAINAGE

Many of the observations at the pilot stage of the study clearly indicated that subsurface drainage could increase the rice productivity and improve the soil conditions to a large extent. The zone of influence of a clay tile drain line was found to extend to 7.5 m on its either side. Hence, subsurface drains were installed at 15m (replicated 4 times) and also at 30m (replicated twice) spacings, with buffer drain lines to offset boundary conditions, for detailed studies on various aspects. The 30 m spacing was adopted as a trial to investigate the possibility of economising the drainage system cost and also to investigate the long-term reclamation effect. The major studies conducted were on determining soil hydrological constants, the most important input parameters to all drainage equations, from drain outflow data; testing of different transient drainage equations suitable for the area; and crop performance under subsurface drainage.

6.3.1 Determination of soil hydrological constants

Hydraulic conductivity

Hydraulic conductivity is one of the most important factors influencing spacing between lateral drains in subsurface drainage systems. While methods for determining hydraulic conductivity and drainable porosity have been rigorously developed and thoroughly tested, the properties often vary widely from point to point in the field and usually require numerous measurements to obtain field-effective values. Accurate measurement of these two input parameters in drain spacing equations is important in the successful technical and economical design of any drainage system.

A detailed study conducted in subsurface drained field has shown that the hydraulic conductivity (K) values were comparatively higher for the topsoil layer in the experimental area. It varied directly with the mid-spacing water table height for drains close to the outside water body and exponentially for drains away from the outside water body. The transition in the mode of variation took place at a distance of 60 m from the water body. The K values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights. The computed average equivalent K was 0.167 m/day for regions up to 60m from the water body and 0.055 m/day for regions beyond that.

The auger hole test was conducted at two locations in the experimental area, 40 m and 90 m away from the water body to find the hydraulic conductivity. The average K was 0.107 m/day and 0.063 m/day, respectively, for the distances from the water body mentioned above. The K values obtained by the drain outflow method and auger hole method were almost same for areas located away from the water body. Therefore, auger hole method can be adopted without losing much accuracy in such areas where drain outflow data are not available, such as in an undrained area.

Drainable porosity

Drainable porosity, defined as the ratio of the drained voids volume to the total volume of the voids plus the volume of the soil particles, is a necessary parameter in all drain spacing equations that predict drawdown. During drainage it is not normally a constant, but is related, among other things, to the water table depth. Both the time of drawdown and the shape of the water table depend on the particular way in which drainable porosity is related to water table depth. The drainable porosity is not used as such in the drawdown equations. The average porosity value for a drawdown depth is used for calculations. This average value is called the equivalent drainable porosity. Drainable porosity at any point in the soil is not solely a function of water table depth but is also determined by the time during which the drainage is permitted before the water table falls to a new position. The time required for a prescribed drawdown is affected by the size, depth, and spacing of the drains. The importance of drainable porosity lies in the fact that all drawdown equations use this term to be multiplied with the drawdown to find the total volume of water drained.

For areas near to outside water bodies, the drainable porosity increased as the mid-spacing water table height decreased. Being nearer to the outside water bodies, a significant amount of recharge entered the field and was intercepted by the subsurface drain. During drainage, the water table fell at a faster rate and almost became steady at later stages because of the recharge from the adjoining water bodies. Thus the total volume of water drained was comparatively more attributing to higher drainable porosities at shallow water table heights. This recharge effect continued and was found to be prominent up to a distance of 60 m away from the water body. The drainable porosity found out by this method for areas nearer to the adjoining water bodies did not represent the true values and would be considerably in error because of this recharge effect. This is more related to the horizontal water transmission property of the soil than the drainable porosity. This is also true when an appreciable quantity of artesian water is entering the drained area or if deep seepage losses are great (Taylor, 1960). Hence drainable porosity values calculated near the drains under external influence were not used for further analysis. For the drains that were away from the water bodies, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. This showed that the drained region was away from the recharge influence and the drainable porosity values calculated represented the real values. Hence, drainage designs are to be made separately for areas away from water bodies and for areas nearer to water bodies if these water bodies have definite influence (like recharge) on the adjoining areas. When drainage designs are made for areas nearer to water bodies. the recharge component should be incorporated for arriving at a proper design. The average equivalent drainable porosity arrived at from the experiments for the flow domain of the drains that were away from the water bodies was 0.04.

Testing of transient drainage equations

Transient drainage equations are generally used to predict the water table drawdown at mid-spacing. These equations relate the soil physical properties to the depth and spacing of parallel subsurface drains and the water table at the mid-spacing between the drains. The accuracy of water table prediction by these equations depends primarily on how closely the assumptions and boundary conditions used to derive them approximate the field conditions. In a study conducted using the field data consequent to drainage, some of the drainage equations were tested for their accuracy in predicting the water table drawdown. The equivalent hydraulic conductivity and equivalent porosity values already found out were used in these drainage equations for predicting the drawdown at different time for comparing them with the observed values. It was found that both Integrated Hooghoudt equation and Hammad equation for thick layers could be used for drainage system design in case of closer spacings and Hammad equation for thick layers in case of wider spacings in *Kari* land situations. However, if any one equation is to be recommended for general use, Hammad equation for thick layers was found to be better taking both the spacings into consideration.

6.3.2 Crop performance under drainage

Crop performance (paddy) studies were conducted under drained conditions and ill-drained conditions (control). An ill-drained condition refers to the farmers' practice of adopting shallow surface drainage only. A drained condition refers to the intervention of subsurface drainage, in addition to the farmers' practice of surface drainage. All the non-labour inputs like seeds, fertilizers etc were provided to the farmers to obtain a uniform package of practice in the experimental area, which comprises the drained area as well as the control area.

Height of plants at maturity in case of 15-m and 30-m drain spacing was higher and found to be significantly superior to the control area. No significant spatial variation was found in these spacings. There was significant difference in plant population (plants per m^2) between the 15-m spacing and the control. The difference was statistically non-significant for 30-m spacing though the control plot recorded the lowest value. The increased germination percentage due to better drainage in closer spacing contributed to the significant difference in plants per m^2 in case of 15-m spacing. The comparatively higher values of plants per m^2 in both the spacings suggest that providing controlled subsurface drainage can increase germination percentage. Difference between the treatments (areas at different lateral distances from the drain) in the number of panicles in one square metre in the 15-m spacing was non-significant. It was, however, significant in the case of 30-m spacing due to the lower values recorded in the vicinity of the drains. The areas away from the drains recorded the highest values indicating the importance of better water management through proper scheduling of drainage. The nutrient loss near the vicinity of the drains due to enhanced drainage conditions could have contributed to the lower values of panicles per m^2 in that area. Even the control plots recorded higher values than that near the vicinity of the drains. The study shows that excess drainage can adversely affect panicle formation.

The variation between the treatments (areas at different lateral distances from the drain) in grains per panicle in 15-m spacing was non-significant. There was also no remarkable variation among the treatments in 30-m spacing.

However, for both the spacings, the corresponding control plots recorded the lowest value. In areas covered under 15-m and 30-m drain spacing, the grain yield was statistically superior to control. In the case of 15-m spacing, there was no spatial variation for this parameter. However, in 30-m spacing, there was spatial variation in this parameter, with areas nearer to the drains recording higher values than those from areas away from the drain. All these indicated that the adoption of subsurface drainage with 30-m spacing could produce significant higher yields over control. In control plot, germination of pollen must have been adversely affected by salinity resulting in lower percentage of fertilization of the florets in the panicle (Ota et al., 1956). The average increase in grain yield under subsurface drainage was 1.36 t/ha higher than that of control, which was equivalent to 61%. The 100-grain weight parameter in 15-m spacing was statistically superior to that of control. In this case too, there was no spatial variation. In 30-m spacing, though the control plot recorded the lowest value, only areas that were in the vicinity of the drain were found significantly superior.

The variation in straw yield was statistically non-significant indicating that adoption of subsurface drainage has little effect on the vegetative growth of rice plants. However, it slightly increased with the distance, though the increase was not statistically significant. The difference in chaff percentage was also found to be non-significant for both the spacings.

Many of the crop growth parameters in the experimental area, particularly the grain yield and 100-grain weight was significantly superior to that of the control plot when subsurface drainage was provided. From the above findings, it could be inferred that spacing up to 30 m could significantly improve the productivity of the area. Effect of drain spacing wider than 30 m may have to be explored by conducting further experiments.

6.3.3 Soil chemical changes due to drainage

Studies conducted using the leachate samples collected from the drainage effluent have clearly shown that the soil heterogeneity with regard to acidity and salinity could be alleviated after the introduction of subsurface drainage. The spatial variation in acidity before the introduction of subsurface drainage, though not detrimental because of the better water management practices adopted by farmers, was not uniform. Acidity was controlled by the farmers' practice of keeping the soil under standing water. The introduction of subsurface drainage has removed erratic spatial variation in acidity. The magnitude and trend in spatial variation of EC in areas near to different drains were also quite erratic before the introduction of subsurface drainage, which became uniform after its introduction. Hence, installation of subsurface drainage in *Kari* soils can remove the soil heterogeneity, which is the root cause of patchy crop growth observed in the area. However, a period of minimum two years is required to make the soil uniform with respect to pH and EC. The effect of drainage on other soil chemical properties might be similar which could be concluded only on further investigation.

The soil pH showed only moderate variation in their absolute values due to drainage. It was higher than the control throughout the cropping season for the drained soils, though the difference was only marginal. Acidity level was comparatively higher during the germination period, which decreased during active tillering and then slightly increased up to panicle initiation. It then increased rapidly towards the harvest. Prior to germination and towards the harvest period, when the field was drained completely for enabling the crop to establish and for convenience in harvest respectively, oxidation of the pyrites took place thereby enhancing the acidity level. The crop was grown in standing water during the period between active tillering and panicle initiation with the regular controlled subsurface drainage and hence that period had a relatively less acidity due to submerged conditions. Since the soil is rich in organic matter and easily reducible ferric iron, the reduction process due to submergence consumes acidity (Ponnamperuma, 1972), resulting in an increase of the pH, often to near-neutral values as reported by Hanhart and Ni (1991) and Van Breemen (1993). Observed high values of acidity in the leachate of 30 m spaced drains may be attributed to the large area being drained and the corresponding high H^+ ion content in the drainage water. Since the irrigation water was not acidic, it could be inferred that subsurface drains could improve the soil acidity during the cropping season substantially. Higher levels of acidity in the leachate were not serious enough to cause concern for the fish species since the pH level lethal to fish is below 3-4 (Wendelaar Bonga and Dederen, 1986).

Studies have shown that salinity of the soil could be controlled considerably by subsurface drainage in the area. The topsoil never contained detrimental values of EC because of the farmers' practice of frequent surface drainage. However, substantial upward salt influx was found coming from the subsoil and the subsurface drains controlled this influx. Substantial amount of salinity was found in the leachate, which was caused by sub-soil salinity since the irrigation water never contained salts in detrimental proportions. It was also noted that the soil EC values were comparatively high during the onset and stoppage of drainage *ie* at the time of germination and harvest period respectively. This is an indication of sub-soil salinity being brought towards the root zone as soon as the drainage is stopped or its intensity is reduced. This observation indicated that drainage and the hydrological situations prevailing in the locality influence the salt concentration in the soil.

Iron concentration of soil decreased substantially in case of soils drained by subsurface drains of 30-m spacing. This is further substantiated by the high concentration of water-soluble iron obtained in the leachate of drains spaced at 30 m during the cropping season. In case of 15-m spacing, however, this trend could not be established. The iron content in leachate was always higher than that of irrigation water indicating that soluble iron is being leached from the soil. However, the overall low concentration (< 9 ppm) of iron was mainly due to the aerobicity created by drainage whereby the ferrous forms were converted to ferric forms. It was almost negligible for drained plots during germination, the reason being that good subsurface drainage prevailed at that period and the farmers' practice of draining the field completely for the crop to establish at that time. However, the comparative values for control plot was the highest during germination. But in all the cases the values were not higher enough to cause iron toxicity to rice crop, the toxicity level being 200 ppm which could result in the reduction of yield and decreased uptake of other essential elements (Saerayossakul, 1968). Thus iron transformations were not serious enough to cause concern for rice culture in the acid sulphate soils of Kuttanad under proper drainage conditions. However, the role of iron in alleviating the toxic effects of sulphur needs further investigation. It could be presumed that a larger portion of reduced iron under anaerobic condition was converted to insoluble iron sulphide by chemical reaction thus preventing the hydrogen sulphide injury to plants.

Sulphate concentration of soil increased drastically due to drainage. As already stated, this is because of the oxidation of pyrite resulting in the increase of concentration of sulphate. This is supposedly due to the conversion of the reduced forms of sulphur already present in the soil before drainage to oxidized forms, mainly SO_4^{-2}. Control plots registered still higher values. It appears that accumulation of sulphates occurred during drainage in the soil. The aerobicity created during drainage must have played a definite role in alleviating the harmful effects of anaerobic conditions leading to sulphate reduction. Concentration of SO_4 was very low in the leachate compared to that in the soil, indicating that accumulation of sulphate was chiefly in insoluble forms.

Calcium and Magnesium content of soil were lower in drained area during all the stages of crop growth than in the control area. The leachate samples also contained substantial amount of these ions in comparison to the irrigation and surface drained water showing the effect of subsurface drainage in controlling the total soluble salts.

Chloride content in soil decreased drastically due to subsurface drainage. The control plot which is surface drained also has shown lower values. The decrease in concentration of chloride due to drainage is attributed to the preferential removal of chloride ions from the soil matrix, being the chief anion highly soluble in water. After drainage, when pumping was stopped, the trend reversed quickly with the accumulation of chloride in soil. The leachate concentration clearly showed higher chloride content in subsurface drained water during crop growth.

Potassium content of the soil samples showed lower values and it was significantly lower for subsurface drained plots. Leachate showed very low concentration of K during the cropping period mainly due to crop uptake.

During drainage, the Na content decreased significantly to lower values and picked up towards harvest when there was no drainage pumping. During drainage, a substantial amount of sodium was removed from the soil through leachate, chiefly as chlorides.

6.3.4 Varietal studies under drainage

Introduction of subsurface drainage in the paddy fields of acid saline soils conclusively proved that rice yield could be increased significantly by proper adoption of the subsurface drainage technology. As a further step for exploiting the full potential of yield, it was felt necessary to prepare a package of practices for rice cultivation in these soils. To achieve this goal, it was required to find the best-suited varieties; their optimum population density; fertilizer requirement and other agro-techniques. The K_{18} culture was found to be the most suitable of the varieties tested in *Kari* soils with a maximum yield of 3.16 t/ha. It was observed that the fertilizer dose of 120:60:60 of N: P: K per ha and a seed rate of100Kg/ha was found to achieve the highest yield with subsurface drainage.

6.3.5 Studies on envelope materials for drains

Filter/Envelope materials are generally provided around the drains for minimizing the entrance resistance, filtering out the finer soil particles in the water flowing into drains and to provide a cushioning effect to the drains. A separate study was conducted to find the efficacy of different locally available filter/envelope materials by using them in a subsurface drainage system. Analysis of the drain outflow data and crop growth parameters revealed no significant difference in terms of reduction of the entrance resistance among the different filters (sea sand, river sand, paddy straw and coir fibre). All the filter materials used were found equally effective and even the drains laid without filter worked effectively.

Hence it may be inferred that no filter materials are required for subsurface in heavy clay soil of Kuttanad. The literature related with textural group indicate that soil which contains less than 15% silt and clay form relatively simple capillary system with a large volume of non-capillary pore space, which ensures good drainage and aeration. The textural analyses of the Kari soil reveal that the mean value of silt and clay is marginally over 15% attributing to the increased efficiency of the system without envelope material.

6.3.6 Economics of drainage in *karilands*

The study on the crop performance under subsurface drainage in the acid sulphate soils of Kuttanad revealed that a drain spacing of up to 30 m could significantly increase the yield. A minimum increase in yield of 1 t/ha was expected when the crop is grown under subsurface drainage system. This assertion is based on the experimental results where an increase in yield of 1.1 t/ha (based on 14 years data) was obtained when paddy crop was taken in farmers' field with the additional intervention of subsurface drainage. It is assumed that the area can go for double cropping after the introduction of subsurface drainage system since each of the farmers' cooperatives (*padasekharam)* can be better managed through the proper network of drainage systems. Based on the estimated cost of the system, an economic analysis was made to assess the financial viability of a subsurface drainage system in the *Kari* lands of Kuttanad. The analysis was done for a 100 ha area using the discounting measures commonly applied to agricultural projects, namely, benefit-cost ratio, net present worth, and internal rate of return. An expected life of 20 years was assumed for the system with no salvage value. Since the labour is costly in Kerala, the annual growth rate of cost was taken as 5 per cent and that of benefit was 2 per cent. All the costs and benefits were discounted at 12% to the present worth for each year during the life span of the project.

The analysis showed that the project is economically feasible because a B-C ratio of 2.45 was obtained. Since the NPW is positive, Rs 5.17 million in this case, the project is acceptable on that measure too. Similarly, the IRR, which is 47%, is far beyond the opportunity cost and hence the project is economically feasible. It could be concluded that the subsurface drainage system is economically feasible in *Kari* lands if it can increase the yield by 0.41 t/ha from the present level.

6.4 MAJOR CONCLUSIONS

The following conclusions are made based on the studies conducted at Karumady:

- Inability to leach the soil profile due to inherent high water table conditions is the main cause for poor productivity of the *kari* soils.

- Full potential of N efficiency can be realized only in conjunction with drainage.
- The density of open drains is not adequate to get the desired sub soil leaching. The open drainage density cannot be increased due to consequent loss of cultivable area and maintenance problem.
- The best cropping season depends on the quality of irrigation water, the salinity levels of which are determined by the movement of saline waterfront from the Arabian Sea. August-November is considered to be the best season for paddy cultivation.
- The efficiency of indigenous drainage pumpsets presently used is very low to the tune of 20%. The excess energy consumed for drainage pumping using the present set-up is 6.7 million kwh, which is nearly 22% more than the actual requirement.
- The performance of clay tile drains are better than PVC drains even though mean port opening area is more in PVC drains. The reason is thin slot width of the PVC drains that are clogged due to iron sludge deposition.
- The equivalent hydraulic conductivity was 0.167 m/day in the region under influence of the outside water bodies and 0.055 m/day in the regions beyond the influence of the outside water bodies.
- The drainable porosity decreased with mid-spacing water table heights and became almost constant at lower water table heights. The equivalent drainable porosity was 0.04.
- Hammad equation for thick layers was found to be the best suited for drainage system design for the area.
- Many of the crop growth parameters in the experimental area, particularly the grain yield and 100-grain weight was significantly superior to that of the control plot when subsurface drainage was provided.
- Drain spacing up to 30 m could significantly improve the productivity of the area.
- The overall increase in rice yield due to subsurface drainage is 1.1 t/ha over ill-drained areas.
- Subsurface drainage could remove the heterogeneity in the soil chemical properties, which is the root cause for patchy crop growth and uneven ripening of rice crop in the area.

- The salinity in the soil could be controlled considerably by subsurface drainage.
- Subsurface drainage was also very efficient in leaching iron, sulphate, chloride, sodium, potassium, calcium and magnesium.
- The filter/envelope materials around the drains were not found to be an absolute requirement in these types of soils.
- The K_{18} culture was found to be the most suitable of the varieties tested in *Kari* soils under subsurface drainage with a maximum yield of 3.16 t/ha. It was observed that the fertilizer dose of 120:60:60 of N: P: K per ha and a seed rate of100Kg/ha was found to achieve the highest yield.
- Economic analysis for a 100 ha farm revealed that subsurface drainage system in the region is economically feasible with a B-C ratio of 2.45, NPW of Rs 5.17 million and IRR of 47%. The system can economically support if it can realize an additional yield of 0.41-t/ha from the present level.

7. IMPACT OF DRAINAGE AND RECOMMENDATIONS

7.1 IMPACT OF DRAINAGE IN THE *KARI* LANDS KUTTANAD

Rice is the staple food in Kerala. Its production has experienced continuous decline over the last two decades, particularly under tremendous pressure from more remunerative, high-value crops like coconut, banana, and pineapple. The area under paddy has shrunk from a peak of 0.881 million ha (production: 1.4 million tonnes) in the mid-1970s to 0.45 million ha (production: 0.77 million tonnes) presently. The average current productivity of rice is 2,203 kg/ha. The current annual requirement of rice in Kerala is estimated to be 4.0 million tonnes.

7.1.1 Paddy cultivation scenario

Individual farming concept does not hold in the *Kari* lands (acid sulphate soils) for paddy cultivation as the cultivated lands lie below the mean sea level and more than 90% of the holdings are marginal in size (<1.0 ha). Cooperative farming is the only option for sustainable crop production. Even then, paddy cultivation in the present set up is a gambling. The fact that most of the farmers cultivate paddy is because they do not have any alternative means of livelihood. Under the adverse cropping environment of the region, crop failure is common. The cooperative set up is almost bankrupt and often fails to raise the minimum funds required for the infrastructure development for cultivation. The farmers are economically poor to contribute to the common pool of funds of the cooperative to enable it to arrange for the necessary inputs for cultivation in time. Migration of labour into urban areas and to Gulf countries for better prospects is seriously affecting the farm labour availability in the area. Labour hiring costs are high compared to the other states. Organized marketing facilities are lacking and the monopoly of modern rice mills is a hindrance to the farmers in getting a fair price for their produce.

7.1.2 Adaptability of subsurface drainage

Financial insolvency of the farmers is the main constraint for large-scale adoption of the capital-intensive subsurface drainage technology in the *Kari* lands of Kerala. Where more than 90% of farm holding is marginal (<1.0 ha), the question of individual farmers adopting subsurface drainage does not arise. The benefits of drainage in terms of improvement of soil and parameters of crop growth mostly remain obscure to the farmers. The increase in grain yield is seldom realized to be an outcome of drainage, as the total yield even after drainage lags far behind those obtained from elsewhere in Kuttanad where the acidity and salinity problems are absent. Moreover, drainage is not considered as an essential input comparable to irrigation. The benefits of drainage often remain unquantified. Despite the above constraints with the farmers, there is a dire need to introduce suitable technologies for rice cultivation with a view to increasing its productivity and production. Field experiments in the *karilands* have established the techno-economic viability of subsurface drainage in substantially increasing the rice production from the present level. Looking into the financial constraints of the farmers for making one time large investment, governmental and financial institutions can play a major role in providing the technological infrastructure for the development of this region. A polder-wise demonstration of the benefits of subsurface drainage system could be a prerequisite in the right direction.

7.1.3 Impact of drainage

The increase in paddy yield obtained due to subsurface drainage in the *Kari* lands is on an average 1.0 t/ha over the present yield. If the whole *Kari* lands (9000 ha) is brought under subsurface drainage, the rice production can be increased to 9000 tones in one season. The system is expected to increase the cropping intensity by an additional rice crop in approximately 2000 ha, which will produce an extra yield of 6000 tones (@ 3 t/ha). Thus the total rice production in *Kari* lands could be increased to an extent of 15000 tones annually. Looking at the presently bleak rice production status, the importance of preserving the rice fields by improving its productivity is of great importance to the state. The present trend of conversion of low productive land for alternate enterprises could also be put to a halt and protect these lands from serious environmental consequences. Another important factor is the employment generation for the farmers and labourers who are in the verge of total despair and poverty.

7.2 RECOMMENDATIONS

Based on the experience of introducing subsurface drainage in the *Kari* lands of Kuttanad, the following recommendations are made:

- A polder wise demonstration of the subsurface drainage technology in rice fields is recommended to convince the farmers, planners and funding agencies about its benefits. Governmental or financial institutions would have to arrange requisite fund for this.
- Complimentary to rice culture, introducing fresh water fish cultivation during water fallow situation would increase the total productivity and the economic status of the farmers of the region.

- In view of the low efficiency of the indigenous pumping systems (*petty and para*) and also in view of their essentiality for drainage water pumping, appropriate industry for manufacturing more efficient pumps may be established.
- On the present level of knowledge, a subsurface lateral drain spacing of 30 m at an average depth of 1 m is recommended as a design practice. Any further increase in spacing would make the system more economical. However, suitability of increased spacing needs to be investigated through field experiments.
- Due to ease in handling and installation, the commercially available corrugated PVC drainpipes may be tested for its performance in the heavy clay soils of Kuttanad.
- Institutional structure of the polders (*Padasekhara* Committee) needs to be strengthened. Presently the financial status of almost all such Committees is very poor to support the minimum infrastructure development activities.
- Development and adoption of salt and acid-resistant rice varieties, in conjunction with sub-surface drainage is recommended.
- Many of the rice growing co-operatives farms (*padasekharams*) are directly connected to the vast backwaters of the Kuttanad region. The occasional high salinity build up in these backwaters often makes them unsuitable for irrigation and drainage in any form will not be able to cope with such an emergency. Alternate source of irrigation facilities available should be developed to counter these emergency situations so that the risk of cultivation can be minimized.
- Ensuring the selection of the best period for cultivation based on the advance front of salinity from the sea appropriate to the area of cultivation is of prime importance.
- The density of open drains is seldom sufficient in all padasekharams and need to be increased. The existing opens drains are to be renovated periodically to ensure maximum leaching of salts.

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APPENDIX - A

Fileld data on water table draw down consequent to drainage

Observation Well No 113			Observation Well No 123		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.64	1	0.00	0.62
2	2.02	0.63	2	2.10	0.62
3	3.52	0.63	3	3.60	0.62
4	5.08	0.63	4	5.18	0.62
5	6.25	0.62	5	6.33	0.61
6	8.05	0.61	6	8.27	0.60
7	9.83	0.60	7	10.00	0.59
8	12.00	0.59	8	12.13	0.57
9	14.07	0.59	9	14.22	0.56
10	16.00	0.56	10	16.38	0.54
11	17.95	0.54	11	18.02	0.54
12	20.08	0.52	12	20.32	0.53
13	22.00	0.52	13	22.10	0.52
14	24.03	0.52	14	24.15	0.51
15	25.50	0.52	15	25.62	0.51
16	27.00	0.51	16	27.12	0.50
17	28.80	0.51	17	28.93	0.50
18	30.00	0.50	18	30.12	0.49
19	32.03	0.49	19	32.12	0.46
20	33.60	0.49	20	33.70	0.46
21	35.12	0.49	21	35.20	0.47
22	36.92	0.48	22	37.00	0.47
23	38.25	0.47	23	38.32	0.46
24	40.00	0.46	24	40.25	0.46
25	41.83	0.46	25	42.08	0.46
26	44.42	0.47	26	44.60	0.46
27	45.88	0.47	27	46.00	0.46
28	48.17	0.47	28	48.27	0.45
29	49.50	0.46	29	49.58	0.45
30	51.00	0.46	30	51.08	0.45
31	52.75	0.46	31	52.85	0.45
32	55.55	0.46	32	55.63	0.44
33	56.92	0.45	33	57.00	0.43
34	59.53	0.45	34	59.63	0.43
35	61.75	0.45	35	61.82	0.43
36	64.08	0.45	36	64.27	0.43
37	66.00	0.43	37	66.18	0.43
38	68.00	0.44	38	68.17	0.43
39	69.92	0.44	39	70.05	0.43
40	71.83	0.45	40	71.95	0.42
41	74.00	0.45	41	74.12	0.42
42	76.50	0.44	42	76.60	0.42
43	78.58	0.44	43	78.70	0.42
44	80.67	0.44	44	80.73	0.41
45	82.52	0.44	45	82.58	0.41
46	84.33	0.44	46	84.42	0.41
47	85.57	0.44	47	85.78	0.41
48	88.00	0.43	48	88.20	0.41
49	90.00	0.43	49	90.22	0.41
50	92.00	0.43	50	92.18	0.41
51	94.00	0.43	51	94.20	0.41
52	96.25	0.44	52	96.37	0.41
53	98.08	0.44	53	98.20	0.41
54	99.58	0.44	54	99.70	0.41
55	101.50	0.44	55	101.62	0.41
56	104.05	0.43	56	104.12	0.41
57	106.02	0.43	57	106.10	0.41
58	107.73	0.43	58	107.80	0.41
59	109.67	0.43	59	109.73	0.41

Table continued...

Observation Well No 133			Observation Well No 143		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.61	1	0.00	0.58
2	2.20	0.60	2	2.25	0.58
3	3.63	0.60	3	3.68	0.56
4	5.25	0.60	4	5.30	0.54
5	6.38	0.60	5	6.43	0.52
6	8.38	0.58	6	8.48	0.50
7	10.10	0.58	7	10.22	0.48
8	12.22	0.56	8	12.30	0.45
9	14.28	0.56	9	14.35	0.43
10	16.52	0.53	10	16.65	0.43
11	18.13	0.52	11	18.25	0.42
12	20.45	0.53	12	20.60	0.41
13	22.20	0.51	13	22.32	0.40
14	24.23	0.51	14	24.32	0.40
15	25.70	0.51	15	25.80	0.40
16	27.22	0.49	16	27.32	0.39
17	28.98	0.48	17	29.07	0.39
18	30.22	0.48	18	30.30	0.39
19	32.17	0.48	19	32.23	0.38
20	33.75	0.46	20	33.82	0.38
21	35.27	0.46	21	35.35	0.38
22	37.07	0.46	22	37.17	0.38
23	38.38	0.46	23	38.43	0.38
24	40.33	0.46	24	40.45	0.38
25	42.12	0.45	25	42.23	0.38
26	44.72	0.44	26	44.50	0.38
27	46.08	0.44	27	46.15	0.38
28	48.30	0.44	28	48.35	0.38
29	49.65	0.43	29	49.70	0.37

Table continued...

Observation Well No 133			Observation Well No 143		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	51.13	0.43	30	51.20	0.37
31	52.90	0.43	31	52.95	0.37
32	55.68	0.41	32	53.78	0.37
33	57.07	0.41	33	57.15	0.37
34	59.70	0.41	34	59.75	0.36
35	61.85	0.41	35	61.92	0.36
36	64.33	0.41	36	64.40	0.36
37	66.25	0.41	37	66.30	0.36
38	68.23	0.41	38	68.30	0.36
39	70.10	0.41	39	70.17	0.36
40	72.03	0.40	40	72.18	0.36
41	74.20	0.40	41	74.27	0.36
42	76.65	0.40	42	76.72	0.36
43	78.78	0.40	43	78.83	0.36
44	80.78	0.40	44	80.83	0.36
45	82.63	0.39	45	82.70	0.36
46	84.47	0.39	46	84.50	0.36
47	85.85	0.39	47	85.90	0.36
48	88.30	0.39	48	88.37	0.36
49	90.28	0.39	49	90.35	0.35
50	92.30	0.39	50	92.45	0.35
51	94.28	0.39	51	94.37	0.35
52	96.45	0.39	52	96.53	0.35
53	98.28	0.39	53	98.37	0.35
54	99.78	0.39	54	99.85	0.35
55	101.70	0.38	55	101.75	0.35
56	104.15	0.38	56	104.28	0.35
57	106.15	0.37	57	106.22	0.35
58	107.85	0.37	58	107.90	0.35
59	109.78	0.37	59	109.83	0.35

Observation Well No : 153			Observation Well No : 163		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.63	1	0.00	0.56
2	2.37	0.62	2	2.47	0.56
3	3.75	0.62	3	3.80	0.56
4	5.38	0.61	4	5.43	0.56
5	6.50	0.61	5	6.57	0.56
6	8.60	0.61	6	8.75	0.56
7	10.35	0.61	7	10.48	0.55
8	12.35	0.61	8	12.50	0.55
9	14.45	0.60	9	14.53	0.55
10	16.77	0.59	10	16.92	0.55
11	18.37	0.59	11	18.55	0.55
12	20.75	0.59	12	20.92	0.54
13	22.40	0.59	13	22.52	0.54
14	24.37	0.59	14	24.43	0.54
15	25.88	0.59	15	25.98	0.54
16	27.40	0.58	16	27.50	0.53
17	29.13	0.58	17	29.25	0.52
18	30.33	0.57	18	30.43	0.52
19	32.27	0.57	19	32.33	0.52
20	33.88	0.56	20	33.95	0.52
21	35.40	0.56	21	35.47	0.51
22	37.25	0.56	22	37.32	0.50
23	38.48	0.54	23	38.57	0.50
24	40.55	0.54	24	40.67	0.50
25	42.37	0.54	25	42.53	0.50
26	44.93	0.54	26	45.10	0.50
27	46.23	0.54	27	46.33	0.50
28	48.38	0.54	28	48.43	0.49
29	49.77	0.53	29	49.83	0.49
30	51.27	0.53	30	51.35	0.49
31	53.00	0.53	31	53.07	0.48
32	55.80	0.51	32	55.87	0.47
33	57.20	0.51	33	57.27	0.46
34	59.78	0.51	34	59.85	0.46
35	61.97	0.51	35	62.03	0.46
36	64.48	0.50	36	64.57	0.46
37	66.38	0.51	37	66.47	0.46
38	68.38	0.51	38	68.50	0.46
39	70.23	0.51	39	70.32	0.46
40	72.22	0.50	40	72.28	0.45
41	74.32	0.50	41	74.40	0.45
42	76.75	0.50	42	76.82	0.44
43	78.87	0.49	43	78.97	0.44
44	80.88	0.48	44	80.93	0.43
45	82.75	0.48	45	82.80	0.43
46	84.55	0.48	46	84.60	0.43
47	85.97	0.48	47	86.03	0.42
48	88.43	0.48	48	88.55	0.42
49	90.42	0.48	49	90.50	0.42
50	92.58	0.47	50	92.70	0.41
51	94.47	0.47	51	94.52	0.41
52	96.60	0.47	52	96.68	0.41
53	98.45	0.47	53	98.52	0.41
54	99.88	0.47	54	99.95	0.41
55	101.85	0.47	55	101.92	0.41
56	104.25	0.46	56	104.30	0.39
57	106.25	0.46	57	106.33	0.39
58	107.95	0.46	58	108.00	0.38
59	109.88	0.46	59	109.97	0.38

Table continued...

Observation Well No 173			Observation Well No : 183		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.44	1	0.00	0.42
2	2.50	0.44	2	2.53	0.41
3	3.85	0.44	3	3.92	0.41
4	5.47	0.44	4	5.52	0.41
5	6.63	0.44	5	6.68	0.41
6	8.83	0.44	6	8.95	0.41
7	10.62	0.43	7	10.70	0.41
8	12.60	0.42	8	12.75	0.41
9	14.62	0.41	9	14.68	0.40
10	17.10	0.39	10	17.20	0.39
11	18.68	0.39	11	18.83	0.39
12	21.08	0.39	12	21.23	0.37
13	22.60	0.39	13	22.67	0.37
14	24.48	0.39	14	24.53	0.38
15	26.15	0.37	15	26.23	0.38
16	27.58	0.37	16	27.63	0.38
17	29.38	0.36	17	29.43	0.37
18	30.63	0.35	18	30.70	0.37
19	32.40	0.35	19	32.47	0.36
20	34.00	0.35	20	34.08	0.35
21	35.53	0.35	21	35.63	0.35
22	37.55	0.33	22	37.47	0.35
23	38.62	0.33	23	38.68	0.35
24	40.78	0.33	24	40.88	0.35
25	42.67	0.33	25	42.78	0.35
26	45.20	0.31	26	45.30	0.35
27	46.40	0.31	27	46.45	0.34
28	48.48	0.31	28	48.53	0.34
29	49.88	0.31	29	49.97	0.34

Table continued...

Observation Well No : 173			Observation Well No 183		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	51.40	0.30	30	51.48	0.33
31	53.12	0.30	31	53.18	0.33
32	55.93	0.29	32	55.98	0.32
33	57.32	0.28	33	57.38	0.32
34	59.92	0.28	34	60.10	0.32
35	62.12	0.28	35	62.17	0.31
36	64.65	0.27	36	64.70	0.31
37	66.55	0.27	37	66.63	0.31
38	68.60	0.27	38	68.67	0.31
39	70.38	0.27	39	70.43	0.30
40	72.32	0.26	40	72.37	0.29
41	74.45	0.26	41	74.53	0.29
42	76.88	0.25	42	76.95	0.29
43	79.03	0.24	43	79.07	0.29
44	80.98	0.24	44	81.03	0.28
45	82.87	0.23	45	82.90	0.28
46	84.68	0.23	46	84.77	0.27
47	86.10	0.23	47	86.15	0.27
48	88.63	0.23	48	88.70	0.27
49	90.58	0.23	49	90.65	0.27
50	92.75	0.23	50	92.80	0.26
51	94.58	0.22	51	94.63	0.26
52	96.73	0.22	52	96.78	0.26
53	98.57	0.22	53	98.60	0.26
54	100.02	0.22	54	100.07	0.25
55	101.97	0.22	55	102.03	0.25
56	104.35	0.21	56	104.40	0.25
57	106.40	0.21	57	106.45	0.25
58	108.05	0.20	58	108.10	0.24
59	110.03	0.20	59	110.12	0.24

Observation Well No : 213			Observation Well No : 223		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.69	1	0.00	0.69
2	2.03	0.68	2	2.08	0.69
3	3.53	0.68	3	3.62	0.69
4	5.13	0.67	4	5.20	0.68
5	6.27	0.67	5	6.33	0.68
6	8.17	0.68	6	8.33	0.65
7	9.90	0.63	7	10.02	0.64
8	11.12	0.63	8	13.27	0.62
9	13.20	0.63	9	14.98	0.62
10	16.10	0.61	10	16.20	0.60
11	17.93	0.60	11	18.03	0.59
12	20.12	0.60	12	20.22	0.57
13	21.15	0.59	13	22.03	0.57
14	24.03	0.58	14	24.12	0.56
15	25.55	0.57	15	25.65	0.55
16	27.05	0.56	16	27.15	0.54
17	28.80	0.56	17	28.93	0.54
18	30.03	0.56	18	30.07	0.53
19	30.38	0.55	19	32.63	0.53
20	33.78	0.55	20	33.93	0.52
21	35.52	0.54	21	35.63	0.52
22	37.08	0.54	22	37.25	0.52
23	40.02	0.53	23	40.08	0.50
24	41.85	0.53	24	41.95	0.50
25	44.43	0.52	25	44.50	0.50
26	45.87	0.52	26	45.90	0.50
27	47.53	0.52	27	47.63	0.50
28	49.53	0.52	28	49.58	0.49
29	51.03	0.51	29	51.12	0.49

Table continued...

Observation Well No : 213			Observation Well No : 223		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	52.78	0.51	30	52.83	0.49
31	54.02	0.51	31	53.08	0.49
32	55.62	0.51	32	55.90	0.49
33	57.48	0.51	33	57.58	0.49
34	59.58	0.51	34	59.67	0.49
35	61.80	0.50	35	61.90	0.49
36	64.12	0.50	36	64.22	0.48
37	66.10	0.50	37	66.17	0.48
38	68.02	0.50	38	68.08	0.48
39	69.93	0.49	39	70.00	0.48
40	71.92	0.49	40	72.00	0.47
41	74.05	0.49	41	74.12	0.47
42	76.53	0.48	42	76.63	0.47
43	78.53	0.48	43	78.60	0.47
44	80.75	0.49	44	80.83	0.47
45	82.53	0.49	45	82.62	0.47
46	84.37	0.49	46	84.40	0.47
47	85.85	0.49	47	85.93	0.47
48	88.02	0.49	48	88.07	0.47
49	90.02	0.48	49	90.08	0.47
50	92.02	0.48	50	92.07	0.47
51	94.02	0.48	51	94.07	0.47
52	96.28	0.48	52	96.38	0.47
53	98.12	0.48	53	98.17	0.47
54	99.60	0.48	54	99.67	0.47
55	101.53	0.49	55	101.62	0.47
56	104.12	0.49	56	104.22	0.47
57	106.08	0.48	57	106.17	0.47
58	107.75	0.48	58	108.80	0.47
59	109.68	0.48	59	109.73	0.47

Observation Well No : 233			Observation Well No : 243		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.68	1	0.00	0.65
2	2.17	0.68	2	2.20	0.64
3	3.72	0.68	3	3.78	0.64
4	5.25	0.68	4	5.30	0.64
5	6.45	0.68	5	6.53	0.64
6	8.45	0.66	6	8.55	0.63
7	10.17	0.65	7	10.32	0.63
8	11.35	0.63	8	13.40	0.63
9	13.38	0.64	9	15.28	0.63
10	16.32	0.64	10	16.42	0.63
11	18.13	0.62	11	18.25	0.62
12	20.32	0.62	12	20.42	0.62
13	22.08	0.62	13	22.15	0.62
14	24.17	0.61	14	24.23	0.62
15	25.72	0.60	15	25.80	0.62
16	27.23	0.60	16	27.30	0.62
17	29.00	0.60	17	29.10	0.61
18	30.12	0.59	18	30.18	0.61
19	32.75	0.59	19	32.83	0.61
20	34.18	0.58	20	34.40	0.61
21	35.75	0.58	21	35.87	0.61
22	37.33	0.58	22	37.45	0.61
23	40.30	0.56	23	40.25	0.60
24	42.02	0.55	24	42.65	0.60
25	44.43	0.55	25	44.67	0.60
26	46.00	0.54	26	46.05	0.60
27	47.75	0.54	27	47.83	0.60
28	49.50	0.53	28	49.70	0.59
29	51.20	0.53	29	51.22	0.59

Table continued...

Observation Well No : 233			Observation Well No : 243		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	52.88	0.53	30	52.95	0.58
31	54.15	0.52	31	54.20	0.58
32	55.83	0.52	32	55.95	0.58
33	57.65	0.52	33	57.73	0.58
34	59.75	0.51	34	59.83	0.57
35	62.00	0.50	35	62.08	0.57
36	64.27	0.50	36	64.32	0.57
37	66.22	0.50	37	66.27	0.57
38	68.13	0.50	38	68.20	0.56
39	70.03	0.49	39	70.08	0.55
40	72.05	0.49	40	72.12	0.55
41	74.18	0.48	41	74.23	0.55
42	76.70	0.48	42	76.77	0.55
43	78.63	0.48	43	78.68	0.54
44	80.92	0.47	44	81.00	0.54
45	82.70	0.47	45	82.77	0.54
46	84.58	0.47	46	84.63	0.54
47	86.00	0.47	47	86.08	0.54
48	88.13	0.46	48	88.22	0.53
49	90.13	0.46	49	90.18	0.53
50	92.13	0.46	50	92.20	0.53
51	94.02	0.45	51	94.17	0.52
52	96.43	0.45	52	96.58	0.52
53	98.25	0.45	53	98.30	0.52
54	99.73	0.44	54	99.82	0.51
55	101.67	0.44	55	101.73	0.51
56	104.28	0.44	56	104.37	0.51
57	106.27	0.44	57	106.32	0.51
58	107.88	0.44	58	107.93	0.51
59	109.80	0.44	59	109.87	0.50

Observation Well No 253			Observation Well No 263		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.65	1	0.00	0.56
2	2.23	0.65	2	2.30	0.55
3	3.85	0.65	3	3.97	0.55
4	5.35	0.65	4	5.47	0.55
5	6.60	0.65	5	6.70	0.55
6	8.72	0.65	6	8.80	0.54
7	10.50	0.64	7	11.47	0.53
8	13.47	0.63	8	13.53	0.53
9	15.35	0.63	9	15.42	0.53
10	16.52	0.63	10	16.65	0.53
11	18.35	0.63	11	18.48	0.53
12	20.52	0.63	12	20.63	0.52
13	22.27	0.63	13	22.32	0.52
14	24.30	0.63	14	24.38	0.52
15	25.90	0.62	15	26.05	0.51
16	27.35	0.62	16	27.45	0.51
17	29.17	0.62	17	29.23	0.51
18	30.20	0.62	18	30.30	0.50
19	32.95	0.62	19	33.05	0.50
20	34.53	0.62	20	34.68	0.50
21	35.97	0.62	21	36.08	0.50
22	37.88	0.61	22	37.78	0.50
23	40.32	0.61	23	40.38	0.50
24	42.12	0.60	24	42.22	0.50
25	44.72	0.60	25	44.83	0.49
26	46.15	0.60	26	46.22	0.49
27	47.97	0.59	27	48.00	0.48
28	49.68	0.59	28	49.85	0.48
29	51.27	0.58	29	51.37	0.48

Table continued...

Observation Well No : 253			Observation Well No : 263		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	52.98	0.58	30	53.05	0.47
31	54.27	0.58	31	54.33	0.47
32	56.05	0.58	32	56.20	0.47
33	57.80	0.58	33	57.90	0.47
34	59.92	0.58	34	60.03	0.47
35	62.17	0.57	35	62.25	0.46
36	64.38	0.57	36	64.48	0.46
37	66.33	0.56	37	66.33	0.45
38	68.27	0.56	38	68.35	0.45
39	70.15	0.56	39	70.22	0.45
40	72.15	0.56	40	72.22	0.45
41	74.30	0.55	41	74.38	0.44
42	76.83	0.55	42	76.90	0.44
43	78.72	0.54	43	78.78	0.43
44	81.07	0.54	44	81.18	0.43
45	82.83	0.54	45	82.93	0.43
46	84.72	0.54	46	84.80	0.42
47	86.15	0.54	47	86.23	0.42
48	88.28	0.53	48	88.37	0.42
49	90.23	0.53	49	90.32	0.42
50	92.25	0.52	50	92.32	0.41
51	94.22	0.52	51	94.32	0.41
52	96.65	0.52	52	96.72	0.40
53	98.38	0.51	53	98.43	0.40
54	99.90	0.51	54	100.00	0.39
55	101.80	0.50	55	101.87	0.39
56	104.43	0.50	56	104.52	0.39
57	106.40	0.50	57	106.47	0.39
58	107.98	0.50	58	108.05	0.39
59	109.93	0.50	59	110.02	0.38

Observation Well No : 273			Observation Well No 283		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.38	1	0.00	0.44
2	2.37	0.38	2	2.43	0.42
3	4.07	0.38	3	4.17	0.42
4	5.52	0.38	4	5.55	0.42
5	6.75	0.37	5	6.78	0.42
6	8.85	0.36	6	8.93	0.42
7	10.72	0.35	7	10.82	0.42
8	13.62	0.34	8	13.68	0.42
9	15.48	0.34	9	15.53	0.42
10	16.78	0.34	10	16.90	0.41
11	18.70	0.34	11	18.82	0.41
12	20.70	0.34	12	20.80	0.41
13	22.37	0.33	13	22.42	0.41
14	24.42	0.33	14	24.50	0.40
15	26.13	0.32	15	26.20	0.40
16	27.50	0.32	16	27.58	0.39
17	29.30	0.31	17	29.35	0.39
18	30.37	0.31	18	30.42	0.38
19	33.12	0.30	19	33.18	0.38
20	34.78	0.30	20	34.92	0.38
21	36.23	0.29	21	36.30	0.38
22	37.78	0.29	22	37.90	0.38
23	40.53	0.29	23	40.63	0.37
24	42.30	0.29	24	42.38	0.37
25	44.95	0.28	25	45.00	0.36
26	46.27	0.28	26	46.32	0.36
27	48.07	0.28	27	48.10	0.36
28	49.90	0.28	28	49.95	0.35
29	51.42	0.27	29	51.47	0.35

Table continued...

Observation Well No 273			Observation Well No 283		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	53.13	0.27	30	53.17	0.35
31	54.37	0.26	31	54.43	0.35
32	56.32	0.26	32	56.40	0.35
33	58.00	0.26	33	58.08	0.34
34	60.13	0.25	34	60.23	0.34
35	62.35	0.25	35	62.42	0.33
36	64.53	0.25	36	64.60	0.32
37	66.53	0.25	37	66.60	0.32
38	68.43	0.24	38	68.50	0.32
39	70.27	0.24	39	70.32	0.31
40	72.28	0.24	40	72.37	0.31
41	74.43	0.23	41	74.52	0.31
42	76.97	0.23	42	77.02	0.30
43	78.83	0.22	43	78.87	0.30
44	81.25	0.22	44	81.32	0.30
45	83.02	0.22	45	83.10	0.29
46	84.90	0.21	46	84.95	0.29
47	86.33	0.21	47	86.40	0.29
48	88.58	0.21	48	88.48	0.29
49	90.37	0.21	49	90.45	0.28
50	92.40	0.21	50	92.47	0.28
51	94.38	0.21	51	94.43	0.28
52	96.77	0.21	52	96.83	0.28
53	98.48	0.21	53	98.55	0.27
54	100.05	0.20	54	100.12	0.27
55	101.93	0.20	55	102.00	0.27
56	104.58	0.19	56	104.65	0.27
57	106.55	0.19	57	106.62	0.26
58	108.12	0.18	58	108.15	0.26
59	110.08	0.18	59	110.15	0.26

Observation Well No : 313			Observation Well No : 323		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.74	1	0.00	0.76
2	2.10	0.74	2	2.13	0.75
3	3.55	0.64	3	3.60	0.75
4	5.13	0.73	4	5.18	0.75
5	6.27	0.74	5	6.33	0.75
6	8.12	0.74	6	8.22	0.75
7	9.83	0.73	7	9.93	0.75
8	12.02	0.73	8	12.08	0.75
9	14.03	0.73	9	14.12	0.75
10	16.13	0.73	10	16.20	0.74
11	17.78	0.72	11	17.85	0.73
12	20.13	0.71	12	20.22	0.73
13	22.00	0.71	13	22.05	0.72
14	24.05	0.71	14	24.12	0.72
15	25.58	0.70	15	25.63	0.71
16	27.05	0.70	16	27.12	0.71
17	28.80	0.70	17	28.87	0.71
18	30.03	0.69	18	30.08	0.71
19	32.12	0.69	19	32.18	0.71
20	33.63	0.69	20	33.67	0.71
21	35.17	0.63	21	35.22	0.70
22	36.92	0.68	22	36.97	0.70
23	38.28	0.68	23	38.50	0.70
24	40.05	0.68	24	40.13	0.69
25	41.88	0.67	25	41.93	0.68
26	44.40	0.66	26	44.47	0.69
27	45.88	0.67	27	45.93	0.68
28	47.58	0.66	28	47.67	0.68
29	49.53	0.66	29	49.60	0.67
30	51.03	0.65	30	51.10	0.66
31	52.80	0.65	31	52.87	0.66
32	54.03	0.62	32	54.10	0.66
33	55.57	0.65	33	55.62	0.66
34	57.48	0.65	34	57.52	0.65
35	59.58	0.65	35	59.62	0.65
36	61.77	0.64	36	61.85	0.65
37	64.13	0.64	37	64.20	0.64
38	66.05	0.64	38	66.12	0.64
39	68.05	0.64	39	68.12	0.64
40	69.97	0.63	40	70.03	0.63
41	71.92	0.62	41	71.98	0.62
42	74.10	0.62	42	74.17	0.62
43	76.67	0.61	43	76.73	0.60
44	78.63	0.60	44	78.70	0.60
45	80.70	0.62	45	80.77	0.61
46	82.52	0.61	46	82.57	0.60
47	84.35	0.61	47	84.42	0.60
48	85.83	0.61	48	85.88	0.60
49	88.05	0.61	49	88.12	0.60
50	90.05	0.61	50	90.12	0.60
51	92.05	0.61	51	92.12	0.60
52	94.05	0.62	52	94.15	0.60
53	96.28	0.60	53	96.32	0.60
54	98.25	0.59	54	98.28	0.60
55	99.70	0.59	55	99.75	0.60
56	101.53	0.59	56	101.57	0.60
57	104.08	0.60	57	104.15	0.60
58	106.03	0.60	58	106.08	0.59
59	107.70	0.60	59	107.77	0.58

Table continued...

Observation Well No 333			Observation Well No 343		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.73	1	0.00	0.74
2	2.17	0.74	2	2.23	0.74
3	3.67	0.74	3	3.73	0.74
4	5.23	0.74	4	5.28	0.73
5	6.40	0.74	5	6.47	0.74
6	8.33	0.74	6	8.52	0.68
7	10.08	0.73	7	10.20	0.73
8	12.17	0.72	8	12.25	0.73
9	14.18	0.75	9	14.25	0.72
10	16.28	0.71	10	16.33	0.72
11	18.08	0.71	11	18.17	0.71
12	20.33	0.70	12	20.42	0.70
13	22.13	0.71	13	22.22	0.72
14	24.17	0.70	14	24.25	0.70
15	25.72	0.70	15	25.78	0.69
16	27.18	0.69	16	27.27	0.69
17	28.90	0.69	17	28.95	0.68
18	30.13	0.66	18	30.20	0.68
19	32.28	0.68	19	32.38	0.68
20	33.75	0.67	20	33.82	0.67
21	35.28	0.67	21	35.37	0.67
22	37.03	0.66	22	37.12	0.67
23	38.55	0.66	23	38.60	0.66
24	40.23	0.65	24	40.30	0.66
25	42.02	0.64	25	42.10	0.64
26	44.55	0.65	26	44.63	0.66
27	46.02	0.64	27	46.08	0.65
28	47.72	0.63	28	47.78	0.65
29	49.67	0.63	29	49.75	0.64
30	51.20	0.62	30	51.27	0.64
31	52.93	0.62	31	52.97	0.64
32	54.15	0.61	32	54.20	0.63
33	55.75	0.61	33	55.83	0.63
34	57.58	0.60	34	57.62	0.63
35	59.68	0.60	35	59.77	0.63
36	61.92	0.59	36	62.00	0.62
37	64.27	0.59	37	64.33	0.61
38	66.20	0.59	38	66.28	0.61
39	68.18	0.58	39	68.25	0.60
40	70.13	0.57	40	70.20	0.59
41	72.05	0.56	41	72.07	0.58
42	74.22	0.55	42	74.25	0.58
43	76.78	0.55	43	76.85	0.57
44	78.77	0.54	44	78.83	0.57
45	80.85	0.55	45	80.93	0.56
46	82.62	0.54	46	82.68	0.55
47	84.47	0.54	47	84.53	0.54
48	85.93	0.54	48	86.00	0.53
49	88.18	0.54	49	88.27	0.55
50	90.18	0.54	50	90.27	0.55
51	92.18	0.54	51	92.27	0.55
52	94.22	0.53	52	94.30	0.54
53	96.58	0.53	53	96.65	0.55
54	98.33	0.53	54	98.40	0.55
55	99.83	0.52	55	99.92	0.55
56	101.67	0.51	56	101.72	0.55
57	104.25	0.52	57	104.37	0.55
58	106.13	0.52	58	106.17	0.55
59	107.80	0.52	59	107.87	0.55

Table continued...

Observation Well No : 353			Observation Well No : 363		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.72	1	0.00	0.61
2	2.27	0.71	2	2.32	0.61
3	3.80	0.72	3	3.88	0.61
4	5.32	0.71	4	5.38	0.61
5	6.50	0.70	5	6.65	0.61
6	8.62	0.71	6	8.77	0.60
7	10.27	0.72	7	10.47	0.61
8	12.32	0.70	8	12.43	0.61
9	14.33	0.69	9	14.48	0.61
10	16.50	0.70	10	16.60	0.61
11	18.27	0.68	11	18.58	0.60
12	20.50	0.69	12	20.58	0.59
13	22.27	0.70	13	22.35	0.61
14	24.33	0.69	14	24.43	0.61
15	25.83	0.67	15	25.90	0.61
16	27.32	0.69	16	27.42	0.61
17	29.00	0.68	17	29.08	0.61
18	30.25	0.68	18	30.30	0.62
19	32.47	0.68	19	32.53	0.61
20	33.88	0.67	20	34.00	0.61
21	35.43	0.66	21	35.50	0.61
22	37.18	0.66	22	37.28	0.61
23	38.65	0.66	23	38.73	0.61
24	40.38	0.66	24	40.47	0.61
25	42.17	0.66	25	42.25	0.60
26	44.72	0.65	26	44.80	0.61
27	46.17	0.68	27	46.25	0.61
28	47.83	0.64	28	47.92	0.61
29	49.80	0.63	29	49.82	0.61
30	51.30	0.63	30	51.37	0.61
31	53.00	0.63	31	53.07	0.61
32	54.60	0.62	32	54.70	0.60
33	55.90	0.63	33	56.02	0.61
34	57.68	0.62	34	57.75	0.61
35	59.82	0.62	35	59.90	0.61
36	62.07	0.61	36	62.13	0.61
37	64.40	0.61	37	64.50	0.61
38	66.35	0.60	38	66.50	0.61
39	68.32	0.60	39	68.45	0.61
40	70.27	0.59	40	70.35	0.61
41	72.15	0.59	41	72.27	0.60
42	74.33	0.57	42	74.40	0.59
43	76.92	0.56	43	76.97	0.59
44	78.87	0.56	44	78.90	0.59
45	81.02	0.57	45	81.12	0.61
46	82.73	0.56	46	82.80	0.61
47	84.60	0.56	47	84.67	0.61
48	86.05	0.56	48	86.12	0.60
49	88.35	0.55	49	88.43	0.60
50	90.33	0.55	50	90.42	0.60
51	92.37	0.54	51	92.47	0.60
52	94.38	0.53	52	94.47	0.59
53	96.75	0.52	53	96.82	0.59
54	98.47	0.52	54	98.57	0.59
55	99.93	0.52	55	99.97	0.59
56	101.75	0.52	56	101.83	0.59
57	104.43	0.49	57	104.50	0.58
58	106.25	0.52	58	106.30	0.59
59	107.92	0.52	59	107.98	0.58

Table continued...

Observation Well No 373			Observation Well No 383		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
1	0.00	0.52	1	0.00	0.45
2	2.38	0.51	2	2.45	0.45
3	3.95	0.52	3	4.03	0.45
4	5.45	0.52	4	5.50	0.45
5	6.70	0.52	5	6.77	0.45
6	8.87	0.52	6	8.98	0.45
7	10.67	0.51	7	10.77	0.44
8	12.57	0.52	8	12.68	0.44
9	14.62	0.51	9	14.70	0.44
10	16.68	0.51	10	16.80	0.43
11	18.75	0.50	11	18.75	0.42
12	20.77	0.51	12	20.97	0.42
13	22.42	0.51	13	22.55	0.45
14	24.55	0.51	14	24.60	0.43
15	26.00	0.52	15	16.05	0.43
16	27.53	0.50	16	27.60	0.42
17	29.17	0.50	17	29.30	0.42
18	30.35	0.51	18	30.40	0.42
19	32.60	0.51	19	32.67	0.42
20	34.08	0.50	20	34.17	0.42
21	35.60	0.51	21	35.70	0.41
22	37.38	0.50	22	37.47	0.42
23	38.83	0.50	23	38.92	0.41
24	40.58	0.50	24	40.67	0.41
25	42.50	0.50	25	42.55	0.40
26	44.97	0.50	26	45.05	0.41
27	46.33	0.50	27	46.38	0.41
28	47.98	0.50	28	48.03	0.41
29	49.88	0.50	29	49.93	0.40

Table continued...

Observation Well No 373			Observation Well No 383		
Sl. No	Time (t), hrs	Head (h), m	Sl. No	Time (t), hrs	Head (h), m
30	51.40	0.49	30	51.45	0.40
31	53.13	0.49	31	53.20	0.40
32	54.78	0.49	32	54.85	0.39
33	56.20	0.48	33	56.35	0.39
34	57.82	0.48	34	57.90	0.39
35	59.98	0.48	35	60.03	0.39
36	62.22	0.48	36	62.30	0.39
37	64.57	0.48	37	64.63	0.38
38	66.57	0.48	38	66.63	0.38
39	68.50	0.48	39	68.58	0.38
40	70.40	0.48	40	70.47	0.38
41	72.33	0.46	41	72.38	0.37
42	74.48	0.45	42	74.55	0.37
43	77.00	0.44	43	77.03	0.36
44	79.00	0.46	44	79.08	0.37
45	81.18	0.46	45	81.25	0.36
46	82.87	0.46	46	82.93	0.36
47	84.72	0.46	47	84.78	0.36
48	86.33	0.46	48	86.48	0.36
49	88.50	0.00	49	88.58	0.36
50	90.48	0.46	50	90.55	0.35
51	92.55	0.45	51	92.62	0.35
52	94.53	0.45	52	94.65	0.35
53	96.97	0.44	53	97.02	0.35
54	98.58	0.29	54	98.62	0.35
55	100.02	0.42	55	100.07	0.32
56	101.88	0.42	56	101.93	0.35
57	104.58	0.42	57	104.63	0.38
58	106.37	0.42	58	106.43	0.33
59	108.03	0.42	59	108.10	0.33

Fileld data on drain discharge

Drain: 2E15			Drain : 3E15		
Sl. No	Time (t), hrs	Discharge (q), mm/day	Sl. No	Time (t), hrs	Discharge (q), mm/day
1	1.65	39.13	1	1.68	34.24
2	3.07	12.27	2	3.10	12.27
3	4.05	9.13	3	4.08	10.02
4	5.33	7.54	4	5.38	8.30
5	6.32	7.27	5	6.38	7.61
6	8.22	7.02	6	8.25	7.90
7	9.92	8.47	7	10.00	7.68
8	12.37	8.14	8	12.43	6.79
9	14.22	7.90	9	14.27	6.85
10	16.42	8.93	10	16.53	8.65
11	18.20	8.47	11	18.33	8.22
12	20.23	8.47	12	20.30	7.34
13	22.17	8.22	13	22.22	7.47
14	24.07	6.32	14	24.12	6.27
15	25.58	6.32	15	25.65	6.23
16	27.13	6.52	16	27.20	6.91
17	28.90	7.02	17	28.97	6.74
18	29.92	7.15	18	30.00	6.23
19	31.88	6.32	19	31.97	5.75
20	33.75	6.52	20	33.82	5.75
21	36.87	6.96	21	36.92	6.52
22	37.62	7.08	22	37.68	5.83
23	40.17	8.65	23	40.25	6.96
24	42.18	8.84	24	42.27	6.74
25	44.25	7.75	25	44.42	6.32
26	46.50	7.68	26	46.55	6.13
27	47.37	8.39	27	47.47	6.04
28	49.65	8.30	28	49.72	6.00
29	51.10	8.22	29	51.17	5.95

Table continued...

Drain: 2E15			Drain : 3E15		
Sl. No	Time (t), hrs	Discharge (q), mm/day	Sl. No	Time (t), hrs	Discharge (q), mm/day
30	52.68	8.14	30	52.77	5.91
31	53.80	8.14	31	53.88	5.87
32	55.90	6.96	32	55.97	6.04
33	58.18	7.61	33	58.25	5.95
34	60.08	6.96	34	60.15	6.04
35	61.87	6.52	35	61.92	5.87
36	-	-	36	-	-
37	64.23	8.47	37	64.35	6.57
38	66.28	8.39	38	66.35	6.57
39	68.18	8.30	39	68.25	6.09
40	70.08	8.14	40	70.13	6.09
41	71.90	8.06	41	71.98	6.04
42	74.02	7.90	42	74.08	5.79
43	76.28	7.75	43	76.35	5.75
44	77.20	7.75	44	77.25	5.75
45	80.13	7.61	45	80.20	5.87
46	82.17	7.40	46	82.25	5.83
47	84.15	7.08	47	84.18	5.63
48	85.60	7.02	48	85.67	5.59
49	88.08	6.85	49	88.17	5.75
50	91.25	7.75	50	91.38	5.95
51	93.67	7.40	51	93.80	5.67
52	96.17	7.40	52	96.30	5.71
53	98.23	7.61	53	98.30	5.71
54	101.13	7.61	54	101.20	5.67
55	103.70	7.54	55	103.77	5.34
56	106.20	7.34	56	106.25	5.44
57	109.08	7.15	57	109.13	5.52
58	113.25	6.96	58	113.33	5.48
59	117.08	6.96	59	117.17	5.30

Drain : 4E/15			Drain : 5E/15		
Sl. No	Time (t), hrs	Discharge (q), mm/day	Sl. No	Time (t), hrs	Discharge (q), mm/day
1	1.83	17.48	1	1.75	24.17
2	3.13	10.81	2	3.17	9.78
3	4.12	10.27	3	4.17	8.22
4	5.42	8.30	4	5.48	7.02
5	6.43	5.55	5	6.50	5.52
6	8.32	5.83	6	8.38	6.13
7	10.07	5.48	7	10.15	5.44
8	12.55	5.37	8	12.68	7.15
9	14.33	5.27	9	14.43	5.01
10	16.67	5.48	10	16.80	5.20
11	18.42	5.37	11	18.50	5.14
12	20.42	5.20	12	20.50	4.81
13	22.28	5.10	13	22.33	4.52
14	24.33	6.04	14	24.33	2.08
15	25.72	5.23	15	25.85	1.98
16	27.25	5.17	16	27.35	2.06
17	29.03	5.48	17	29.33	2.09
18	30.07	4.89	18	30.22	1.72
19	32.05	4.33	19	32.20	4.05
20	33.88	4.28	20	33.97	3.84
21	36.05	4.54	21	36.12	3.93
22	37.75	4.42	22	37.82	4.13
23	40.35	5.01	23	40.45	4.26
24	42.33	4.98	24	42.43	3.91
25	44.57	4.47	25	44.62	4.30
26	46.63	4.21	26	46.70	3.91
27	47.60	4.33	27	47.67	3.88
28	49.78	4.33	28	49.95	3.84
29	51.25	4.30	29	51.35	3.82

Table continued...

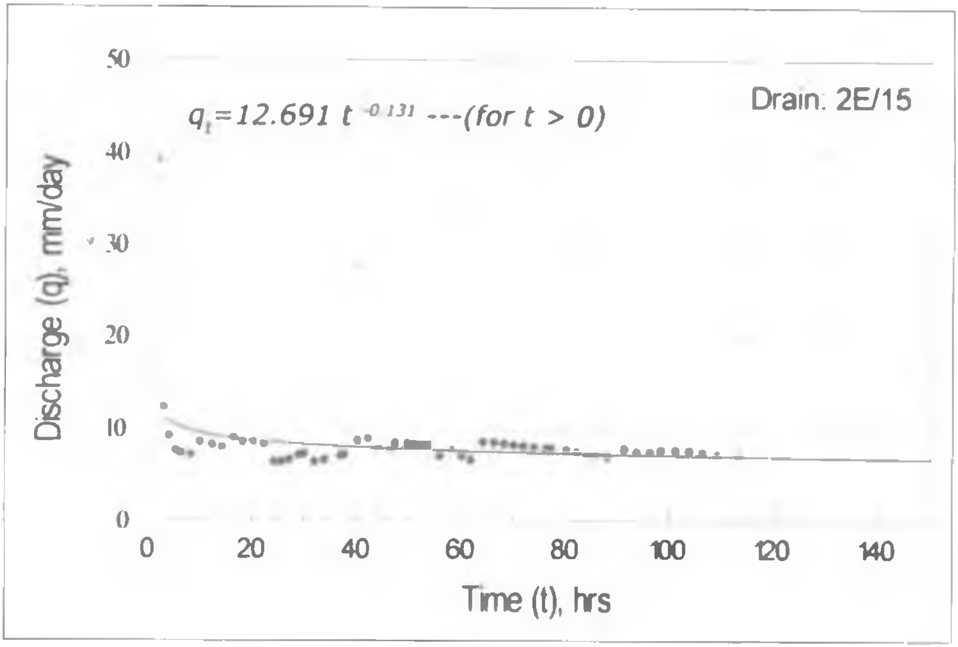
Drain : 4E/15			Drain : 5E/15		
Sl. No	Time (t), hrs	Discharge (q), mm/day	Sl. No	Time (t), hrs	Discharge (q), mm/day
30	52.93	4.30	30	53.05	3.80
31	53.97	4.28	31	54.03	3.80
32	56.03	4.13	32	56.12	3.54
33	58.33	4.15	33	58.45	3.67
34	60.25	4.17	34	60.33	3.69
35	62.00	3.93	35	62.10	3.42
36	64.45	4.26	36	64.55	3.95
37	64.45	4.26	37	66.55	3.59
38	66.43	4.19	38	68.48	3.51
39	68.33	4.15	39	70.33	3.45
40	70.25	4.11	40	72.17	3.42
41	72.07	3.95	41	74.28	3.38
42	74.18	3.89	42	76.52	3.33
43	76.43	3.84	43	77.42	3.33
44	77.33	3.84	44	80.42	3.29
45	80.33	3.77	45	82.42	3.17
46	82.32	3.72	46	84.37	3.14
47	84.27	3.69	47	85.85	3.14
48	85.75	3.75	48	88.42	3.02
49	88.25	3.69	49	91.58	2.57
50	91.50	3.77	50	94.08	2.16
51	93.92	3.86	51	96.50	3.15
52	96.38	4.86	52	98.50	3.08
53	98.38	3.74	53	101.40	3.10
54	101.30	3.77	54	103.93	3.11
55	103.83	3.77	55	106.43	3.07
56	106.33	3.70	56	109.33	2.78
57	109.22	3.69	57	113.62	3.00
58	113.42	3.65	58	117.60	2.98
59	117.25	3.77	59	117.17	5.30

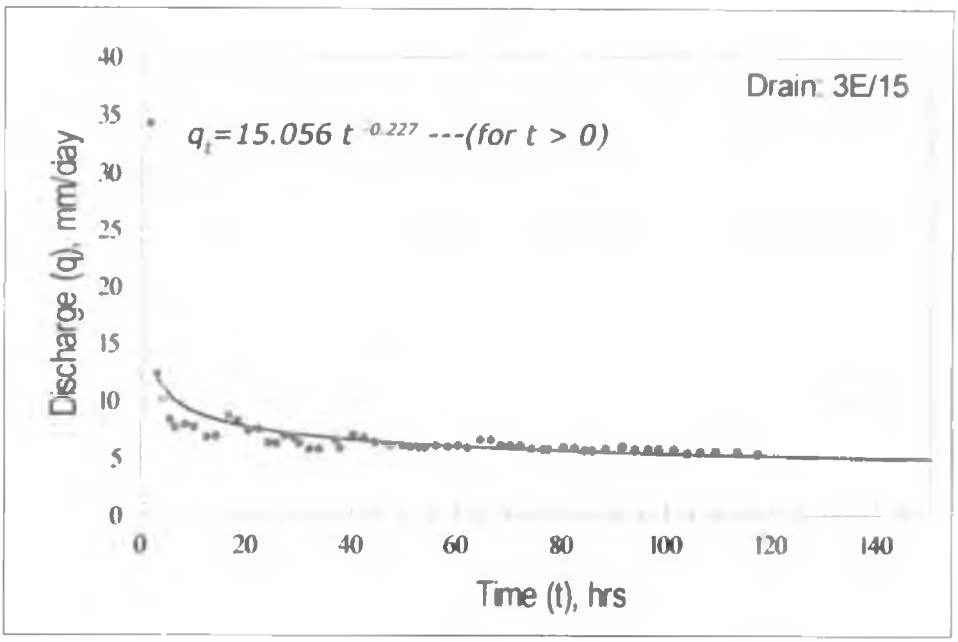
Drain : 7E/30			Drain : 8E/30		
Sl. No	Time (t), hrs	Discharge (q), mm/day	Sl. No	Time (t), hrs	Discharge (q), mm/day
1	1.82	7.34	1	1.85	11.01
2	3.25	4.05	2	3.30	2.33
3	4.28	2.66	3	4.37	1.99
4	5.63	1.87	4	5.70	1.63
5	6.65	1.58	5	6.75	1.43
6	8.58	1.56	6	8.67	1.52
7	10.33	1.51	7	10.42	1.41
8	12.90	1.45	8	13.00	1.24
9	14.60	1.61	9	14.68	1.27
10	17.00	1.75	10	17.08	1.38
11	18.75	1.47	11	18.83	1.28
12	20.68	1.29	12	20.78	1.31
13	22.58	1.62	13	22.68	1.13
14	24.57	1.37	14	24.67	1.19
15	26.08	1.29	15	26.17	1.09
16	27.75	1.10	16	27.87	1.12
17	29.50	1.10	17	29.58	1.10
18	30.50	1.13	18	30.63	1.06
19	32.42	0.90	19	32.55	0.89
20	34.20	1.04	20	34.30	0.93
21	36.53	0.87	21	36.65	0.89
22	38.05	0.92	22	38.18	0.95
23	40.70	1.27	23	40.83	1.04
24	42.75	1.00	24	42.88	0.99
25	44.83	0.95	25	45.00	0.94
26	46.83	0.91	26	47.00	0.84
27	47.93	0.93	27	48.12	0.96
28	50.20	0.92	28	50.32	0.95
29	51.53	0.91	29	51.75	0.93
30	53.22	0.88	30	53.33	0.92
31	54.33	0.83	31	54.43	0.86
32	56.48	0.76	32	56.72	0.81
33	58.72	0.77	33	58.85	0.80
34	60.60	0.76	34	60.72	0.82
35	62.33	0.73	35	62.52	0.78
36	62.33	0.73	36	-	-
37	64.90	0.88	37	65.00	0.93
38	66.83	0.78	38	66.98	0.81
39	68.83	0.74	39	69.08	0.80
40	70.58	0.73	40	70.67	0.78
41	72.48	0.73	41	72.58	0.77
42	74.60	0.73	42	74.75	0.74
43	76.85	0.73	43	77.02	0.73
44	77.70	0.72	44	77.83	0.71
45	80.73	0.59	45	80.87	0.59
46	82.75	0.58	46	82.90	0.58
47	84.70	0.55	47	84.87	0.64
48	86.18	0.54	48	86.33	0.64
49	88.78	0.56	49	89.00	0.82
50	91.92	0.54	50	92.08	0.74
51	94.35	0.47	51	94.50	0.64
52	96.83	0.50	52	97.02	0.63
53	98.85	0.49	53	99.02	0.61
54	101.77	0.49	54	101.97	0.60
55	104.25	0.47	55	104.42	0.59
56	106.78	0.47	56	106.97	0.58
57	109.67	0.47	57	109.83	0.57
58	114.12	0.45	58	114.17	0.59
59	118.00	0.42	59	119.25	0.62

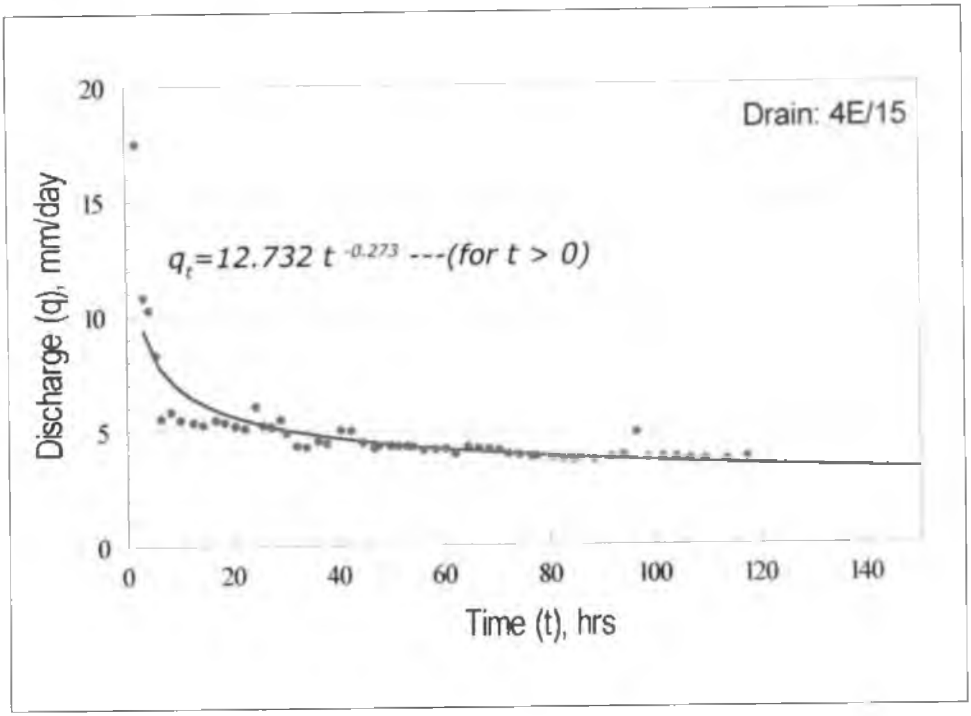
Table continued...

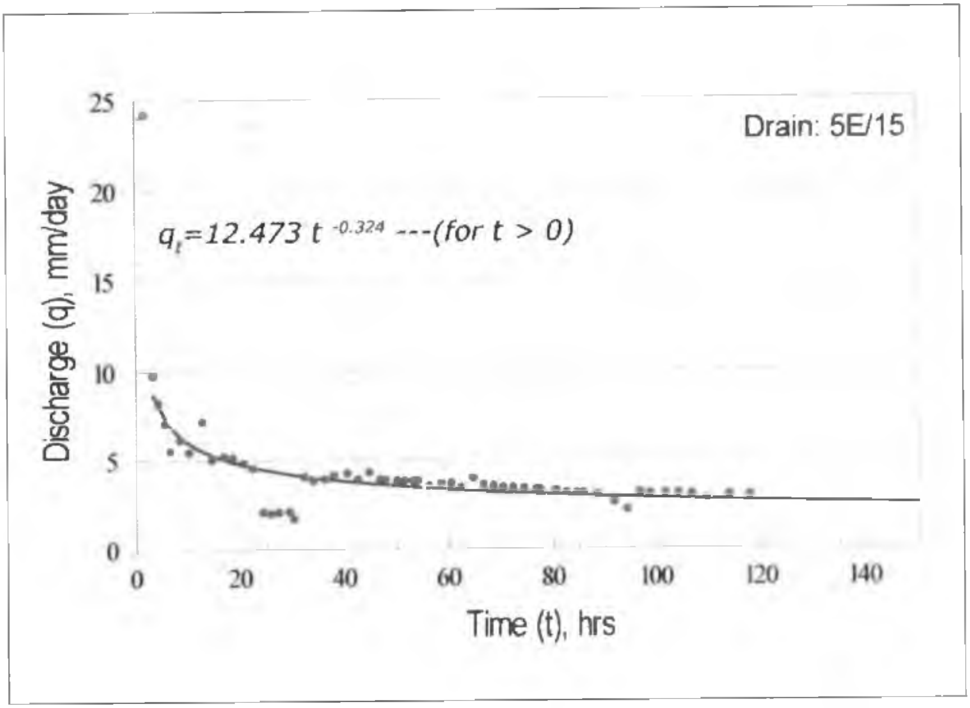
APPENDIX - B

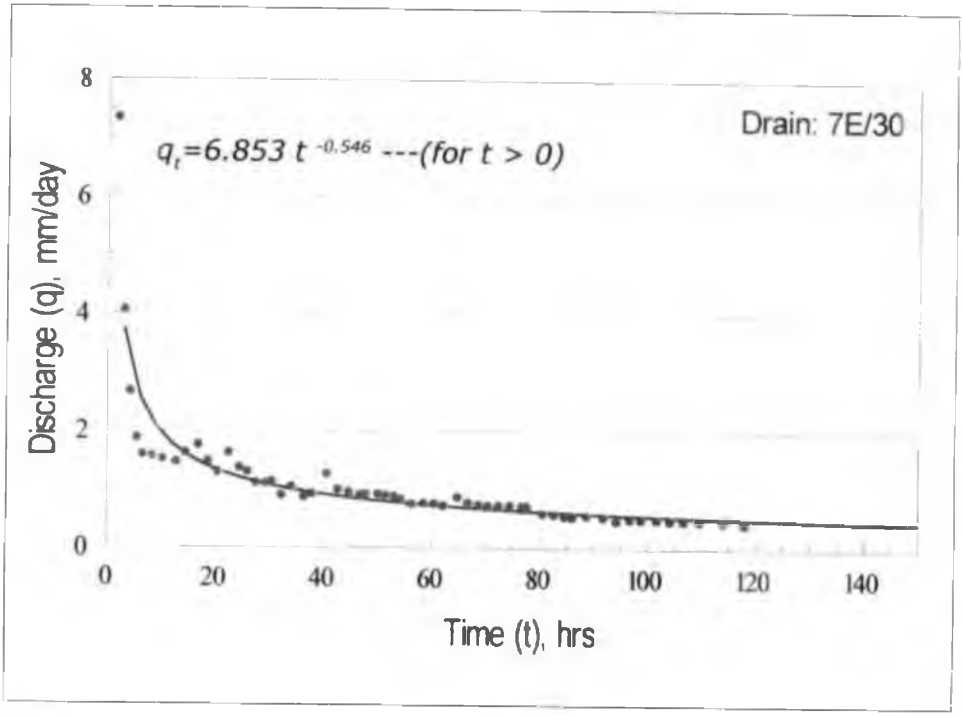
Best-fit curves for drain discharges.

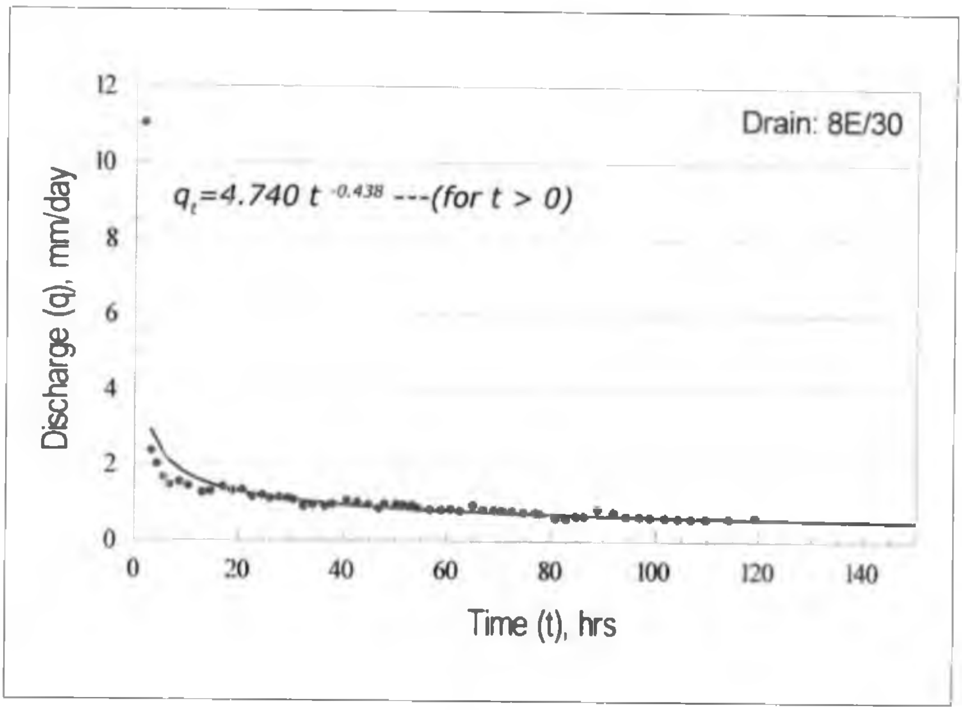




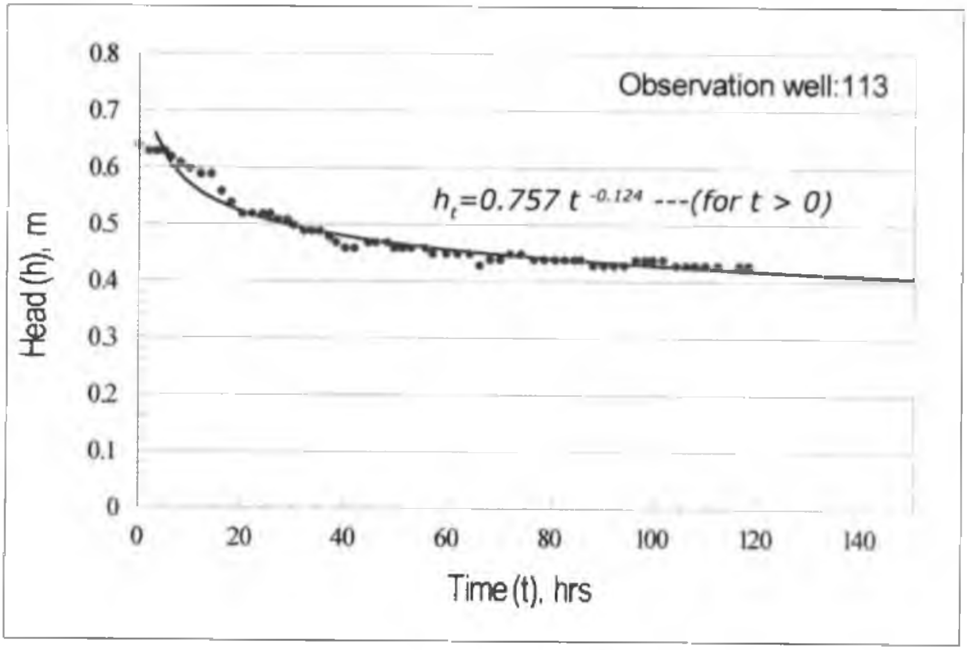

Drain: 4E/15
$q_t = 12.732\ t^{-0.273}$ ---(for t > 0)
Discharge (q), mm/day
0
5
10
15
20
0
20
40
60
80
100
120
140
Time (t), hrs

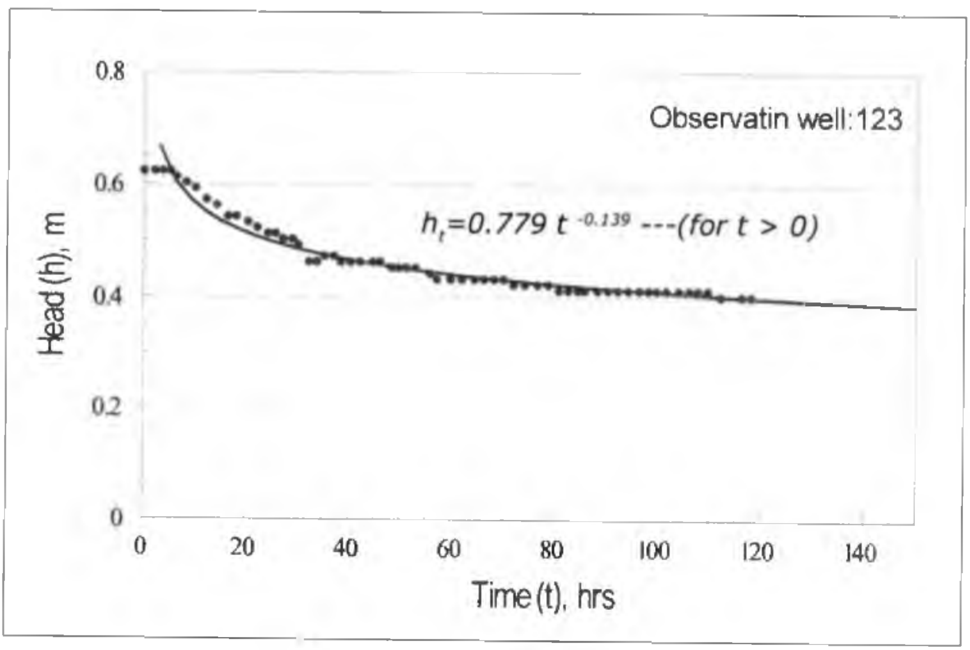

Drain: 5E/15
$q_t = 12.473\ t^{-0.324}$ ---(for t > 0)
Discharge (q), mm/day
0
5
10
15
20
25
0
20
40
60
80
100
120
140
Time (t), hrs

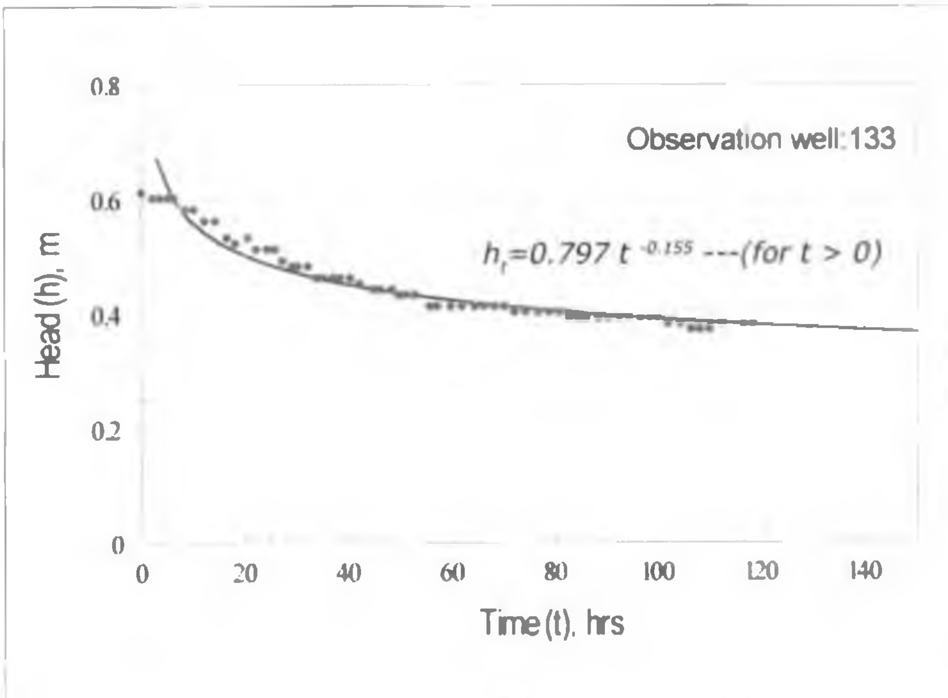

Drain: 7E/30
q_t=6.853 t^-0.546 ---(for t > 0)
Discharge (q), mm/day
8
6
4
2
0
0
20
40
60
80
100
120
140
Time (t), hrs

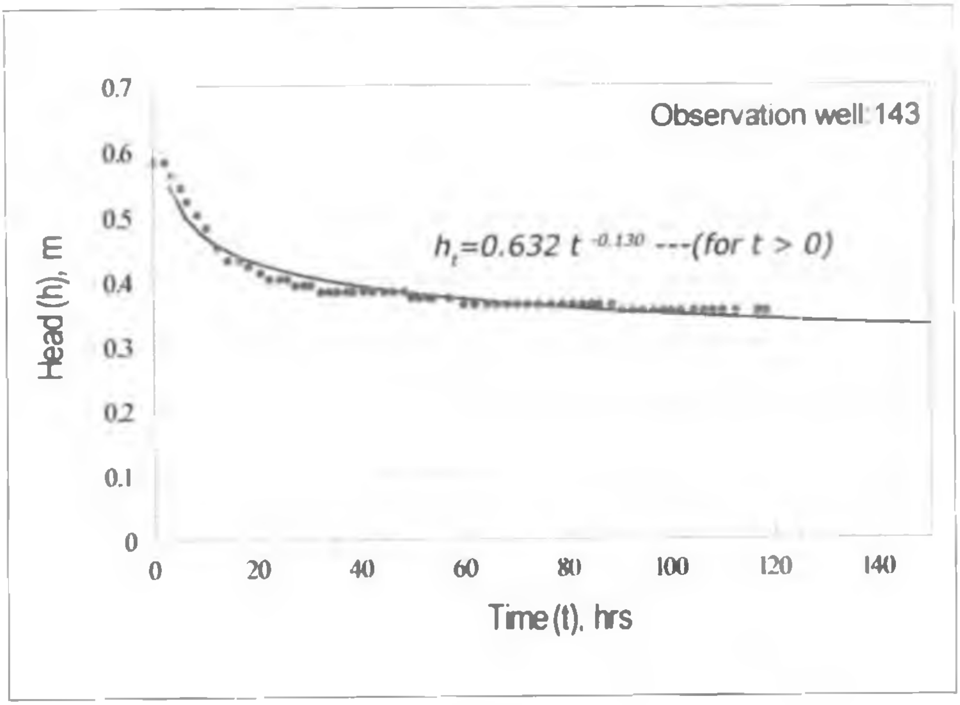

Drain: 8E/30
q_t=4.740 t^-0.438 ---(for t > 0)
Discharge (q), mm/day
12
10
8
6
4
2
0
0
20
40
60
80
100
120
140
Time (t), hrs

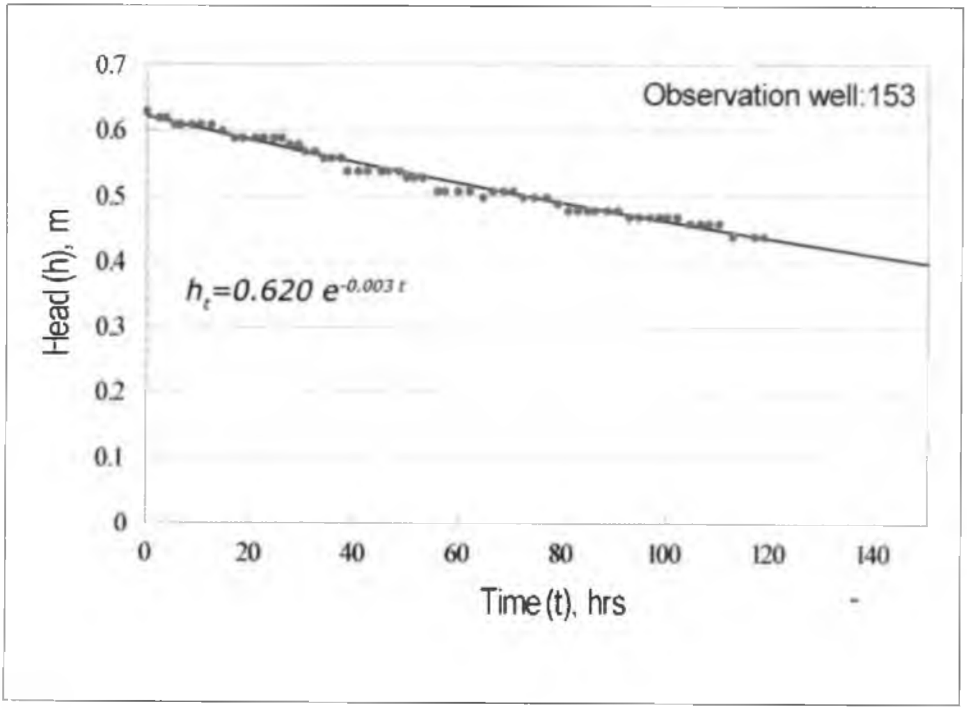
Best-fit curves for mid-spacing hydeaulic heads

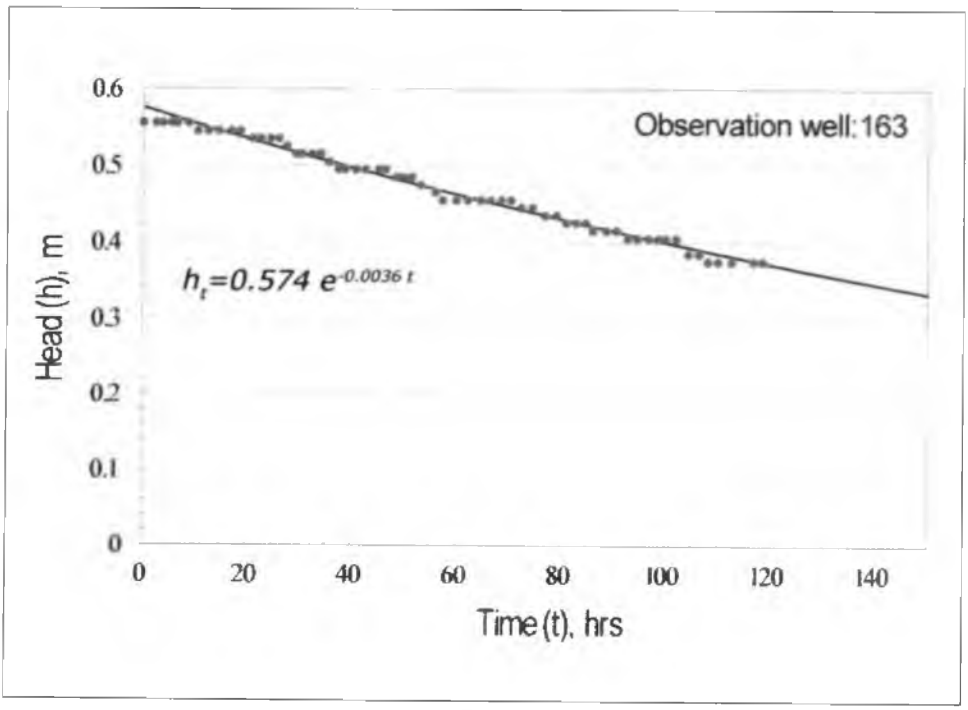


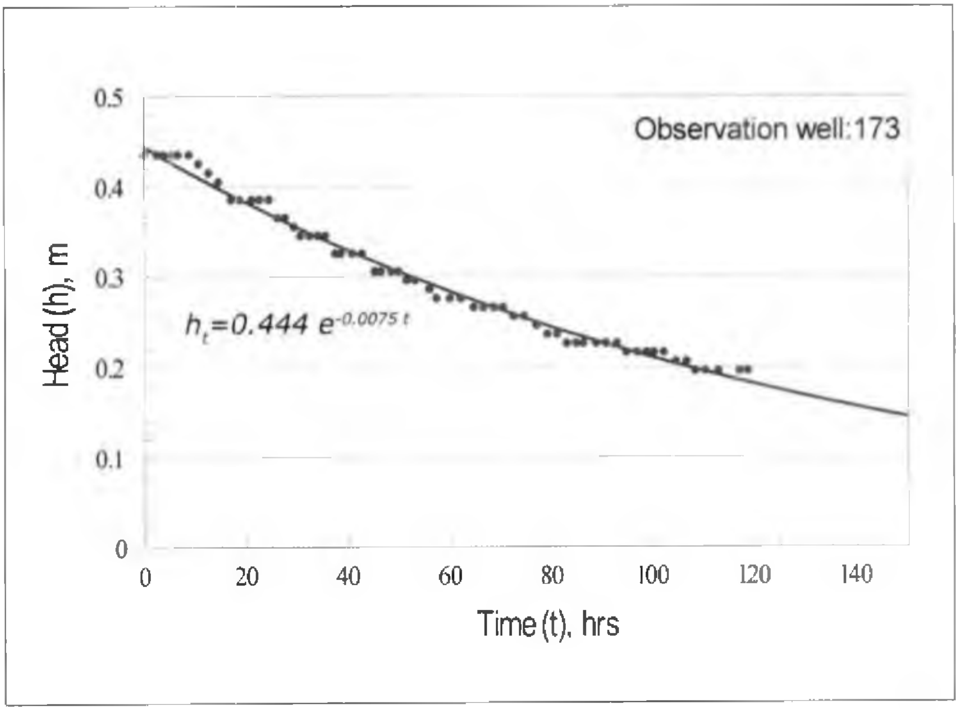


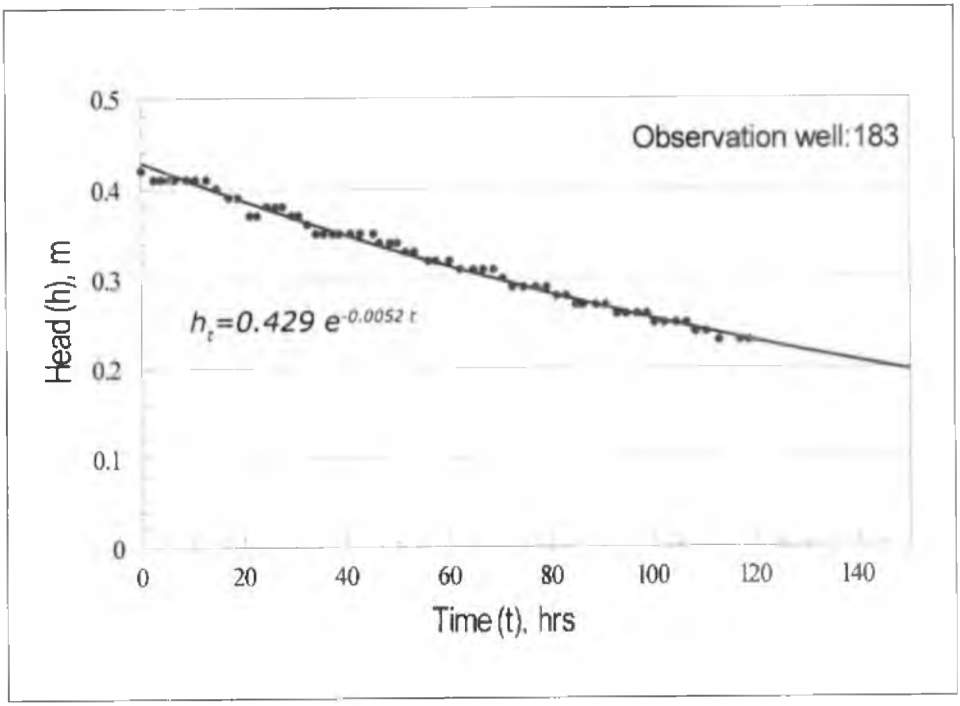

Observation well:133
$h_t=0.797\ t^{-0.155}$ ---(for t > 0)
Head (h), m
Time (t), hrs
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140

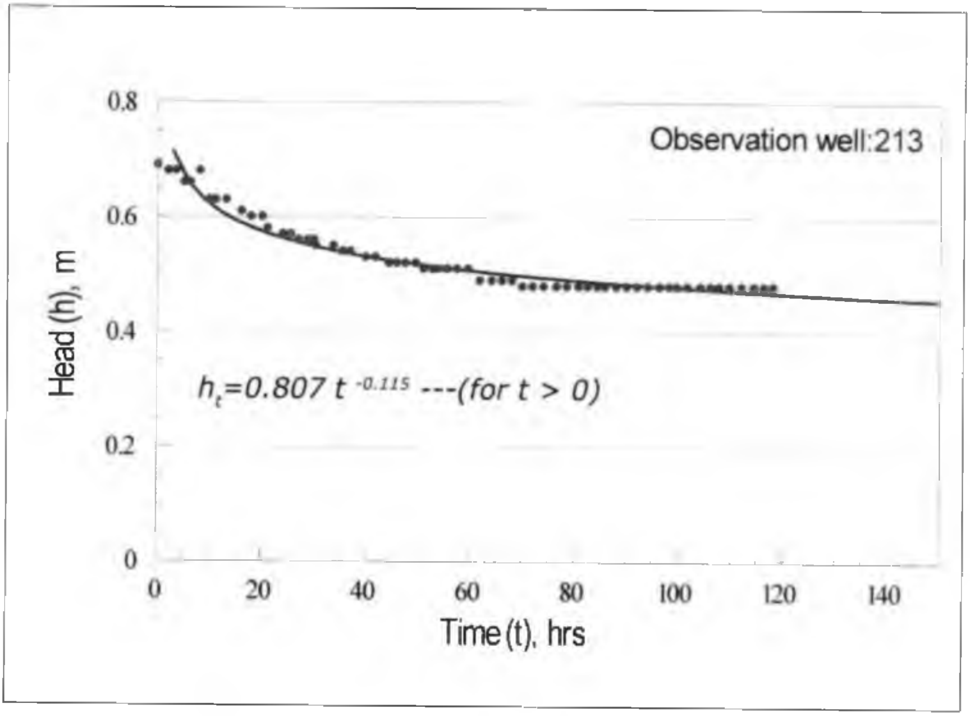

Observation well:143
$h_t=0.632\ t^{-0.130}$ ---(for t > 0)
Head (h), m
Time (t), hrs
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140

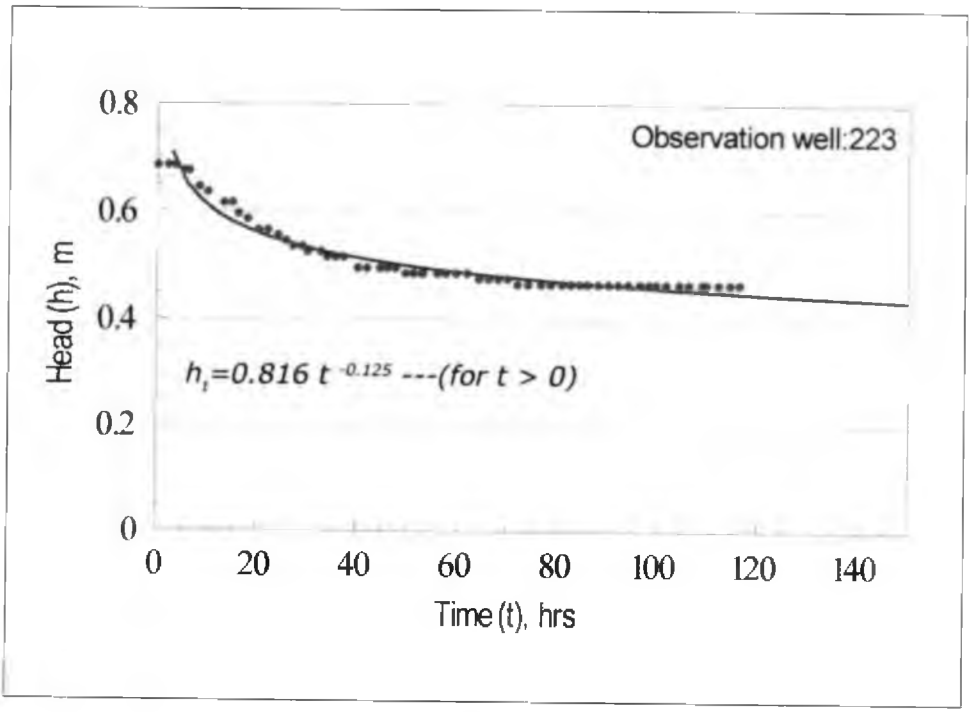

Observation well: 153
$h_t=0.620\ e^{-0.003\,t}$
Head (h), m
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Time (t), hrs

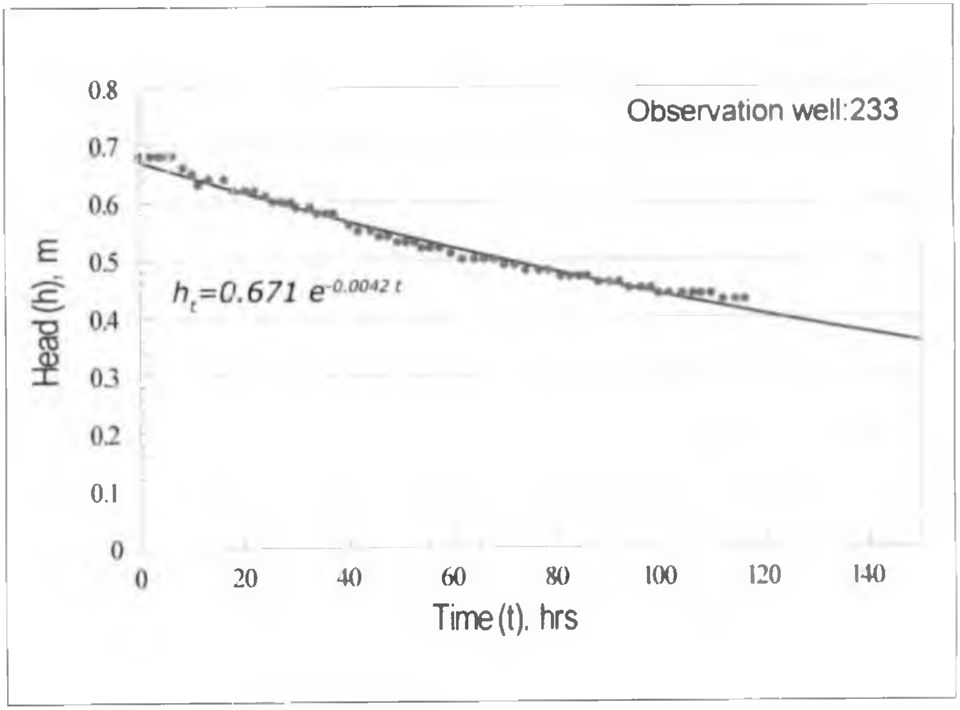

Observation well: 163
$h_t=0.574\ e^{-0.0036\,t}$
Head (h), m
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Time (t), hrs

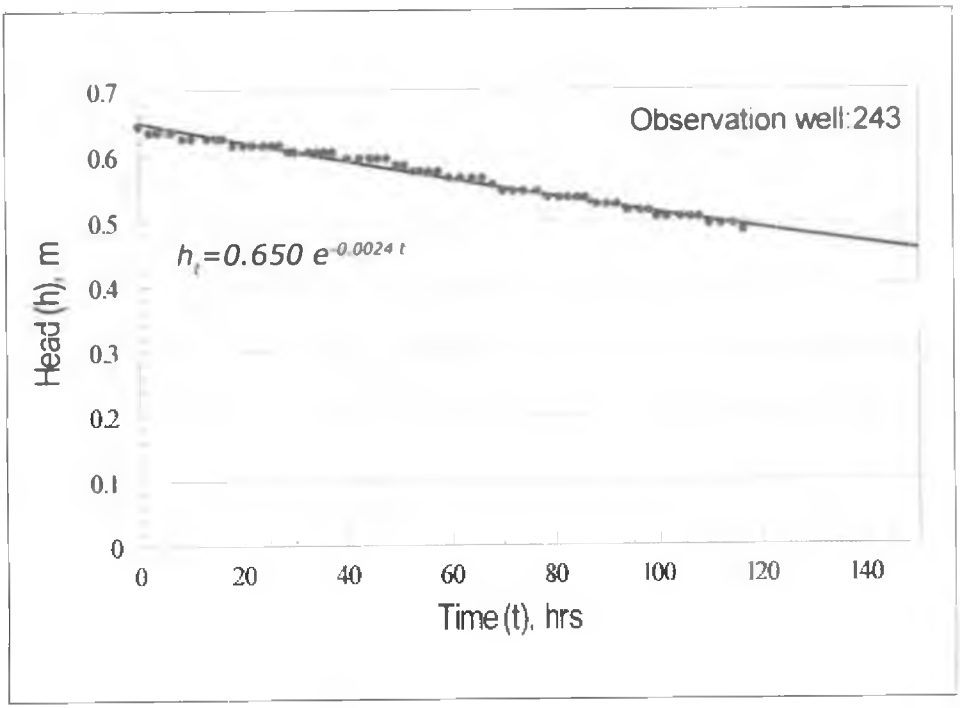

Observation well:173
$h_t=0.444\ e^{-0.0075\ t}$
Head (h), m
Time (t), hrs
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140

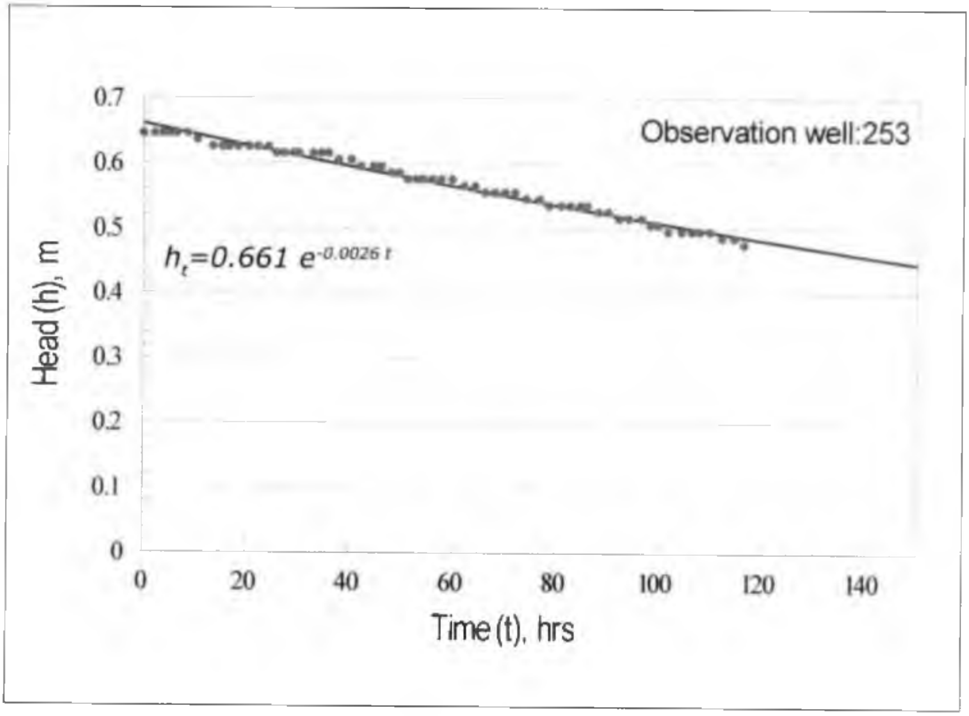

Observation well:183
$h_t=0.429\ e^{-0.0052\ t}$
Head (h), m
Time (t), hrs
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140

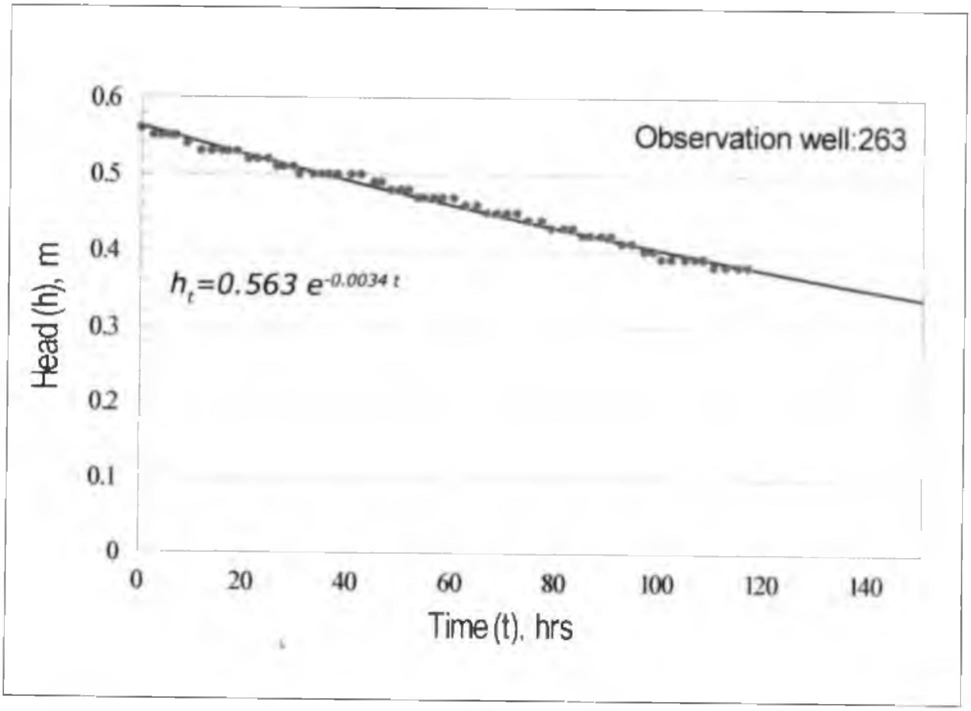

Observation well:213
h_t=0.807 t $^{-0.115}$ ---(for t > 0)
Head (h), m
0.8
0.6
0.4
0.2
0
0 20 40 60 80 100 120 140
Time (t), hrs

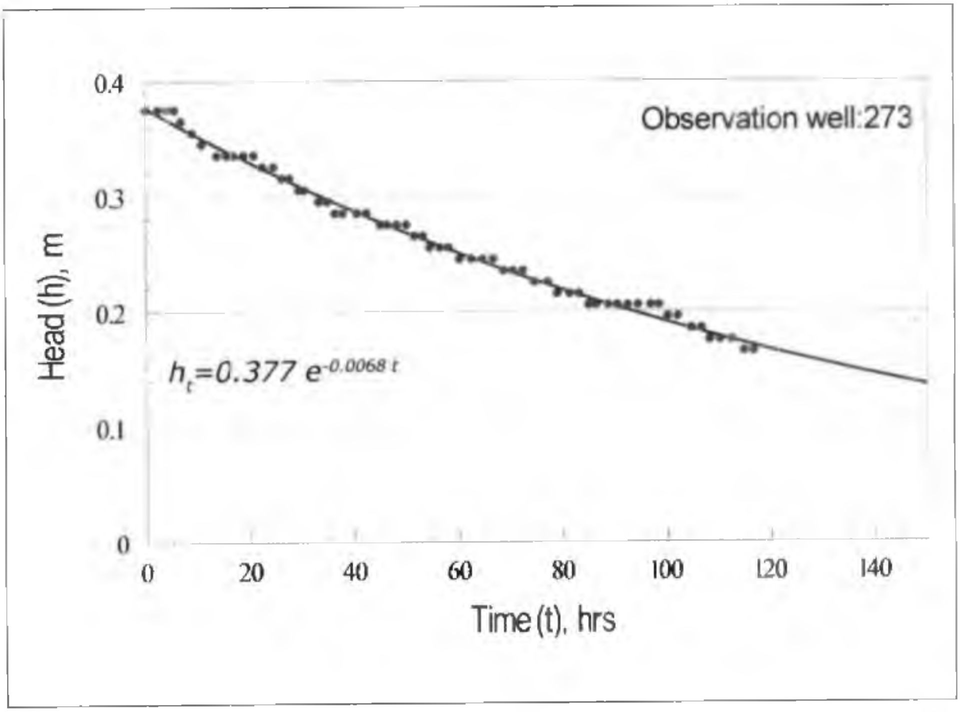

Observation well:223
h_t=0.816 t $^{-0.125}$ ---(for t > 0)
Head (h), m
0.8
0.6
0.4
0.2
0
0 20 40 60 80 100 120 140
Time (t), hrs

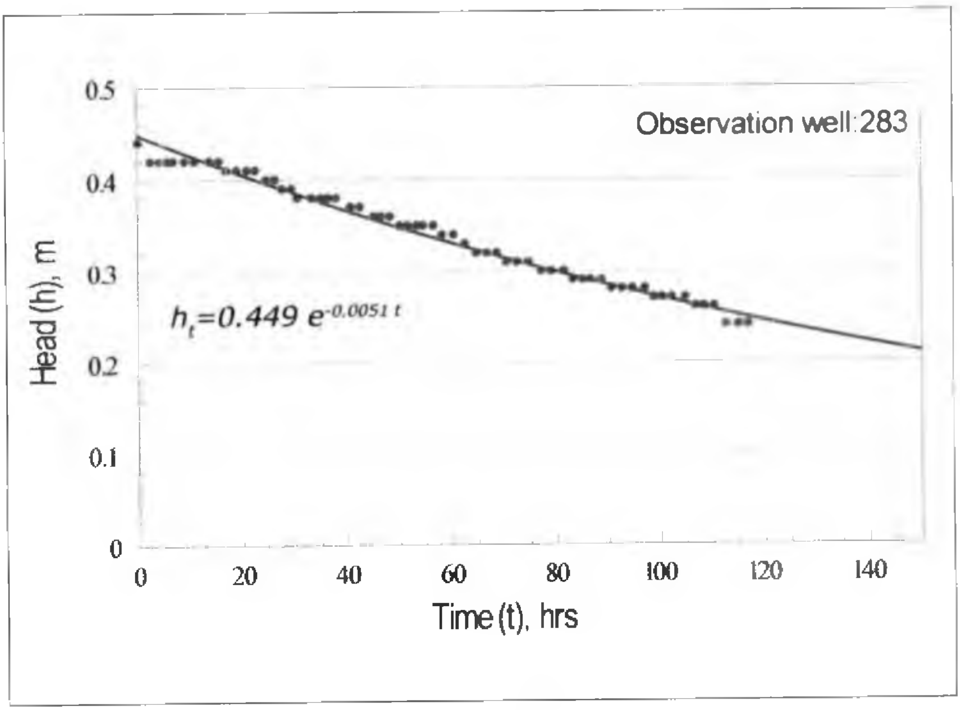

Observation well:233
h_t=0.671 $e^{-0.0042 t}$
Head (h), m
Time (t), hrs
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
20
40
60
80
100
120
140

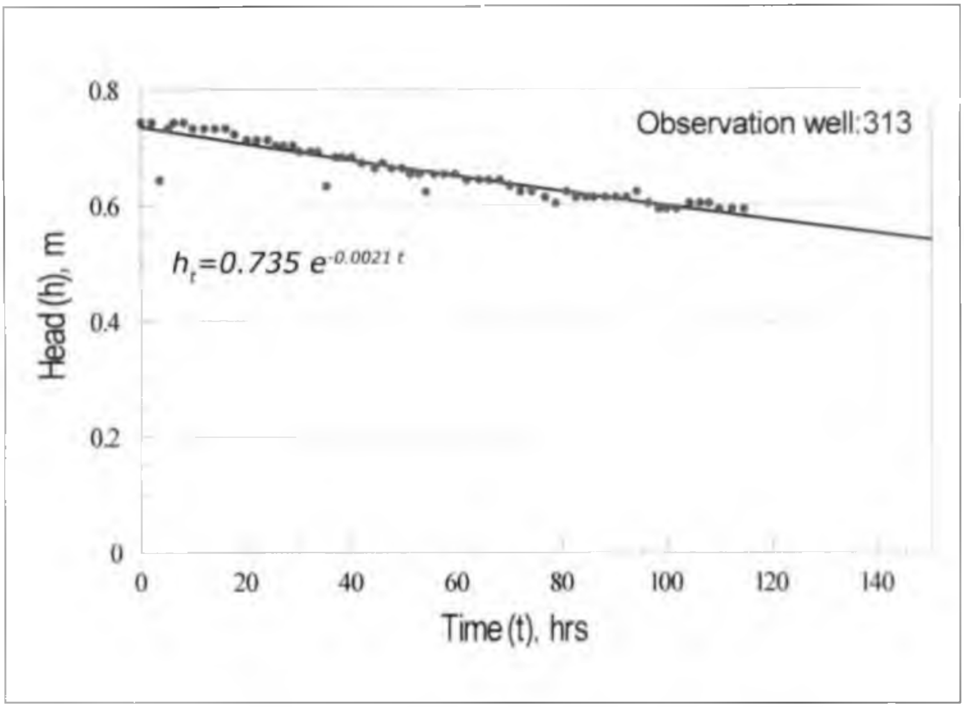

Observation well:243
h_t=0.650 $e^{-0.0024 t}$
Head (h), m
Time (t), hrs
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
20
40
60
80
100
120
140

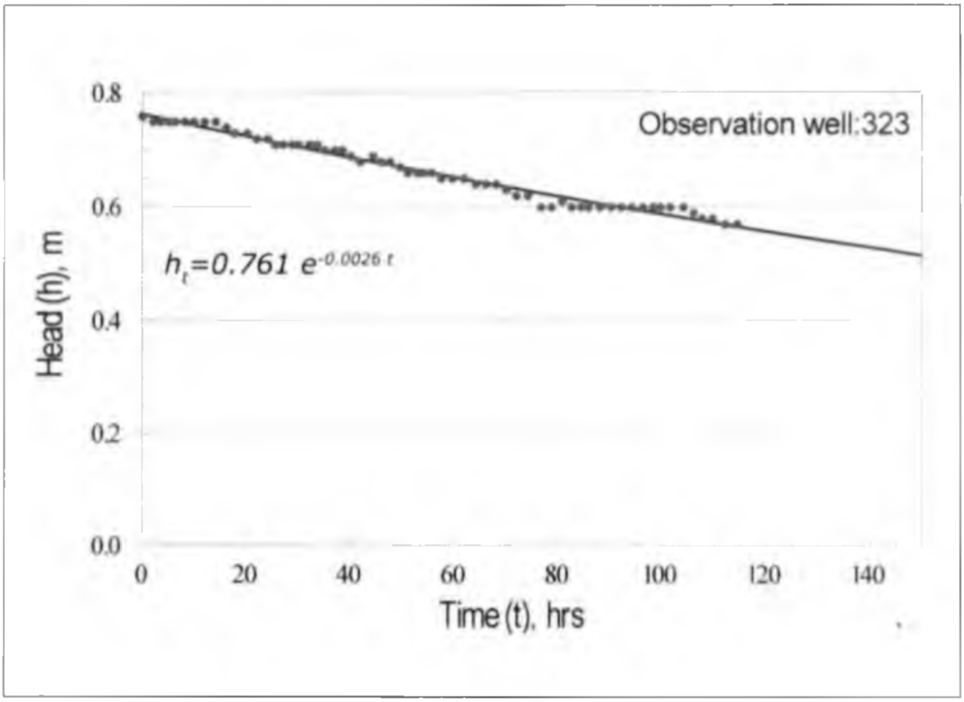

Observation well:253
$h_t=0.661\ e^{-0.0026\ t}$
Head (h), m
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Time (t), hrs

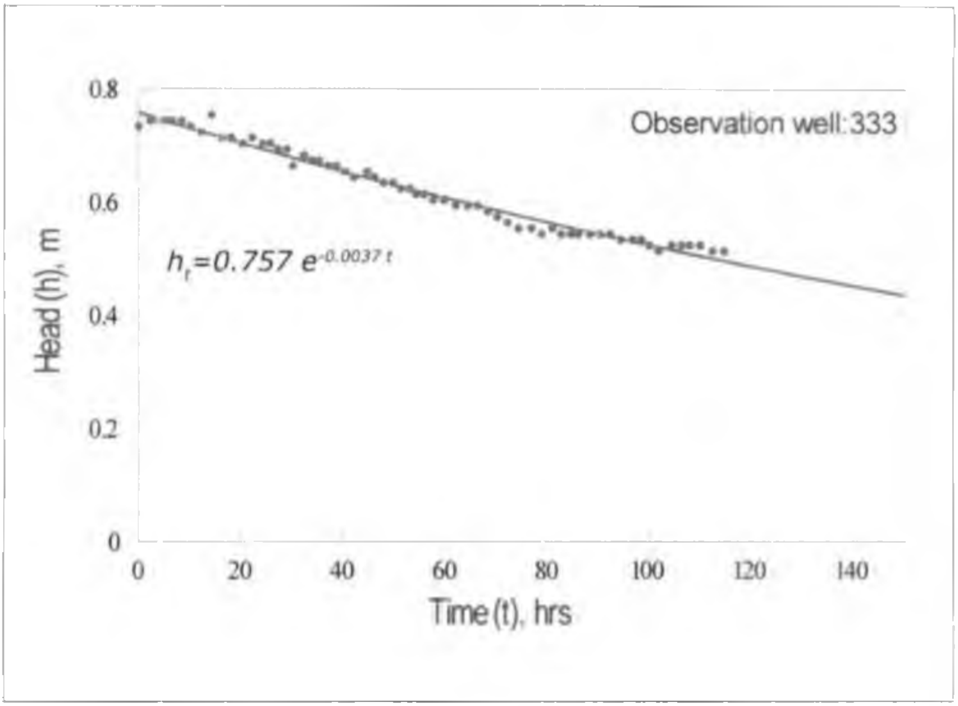

Observation well:263
$h_t=0.563\ e^{-0.0034\ t}$
Head (h), m
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Time (t), hrs

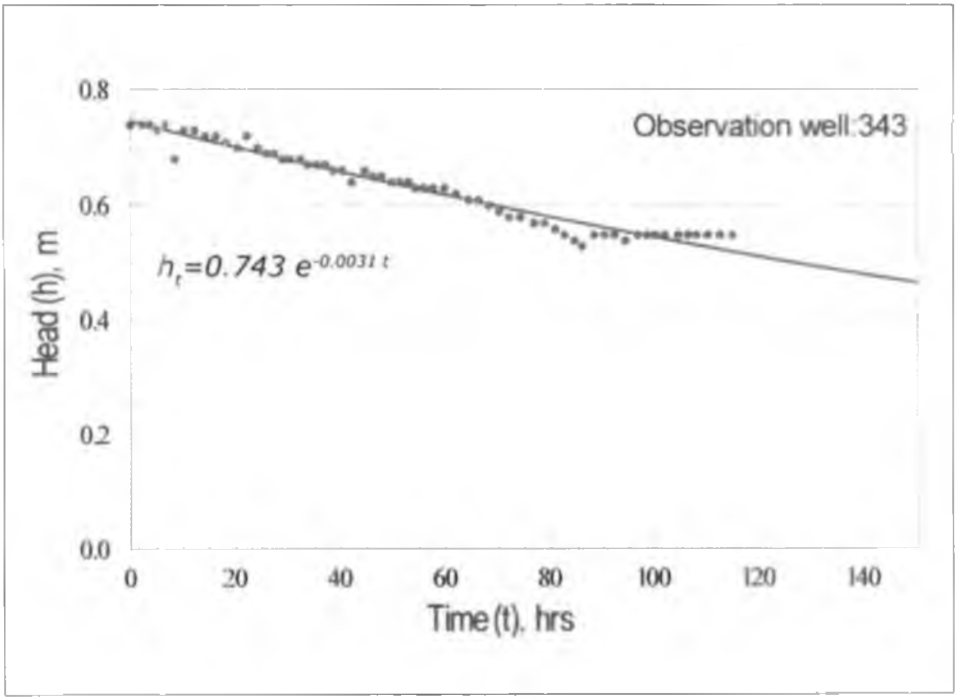

Observation well:273
$h_t=0.377\ e^{-0.0068\ t}$
Head (h), m
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Time (t), hrs

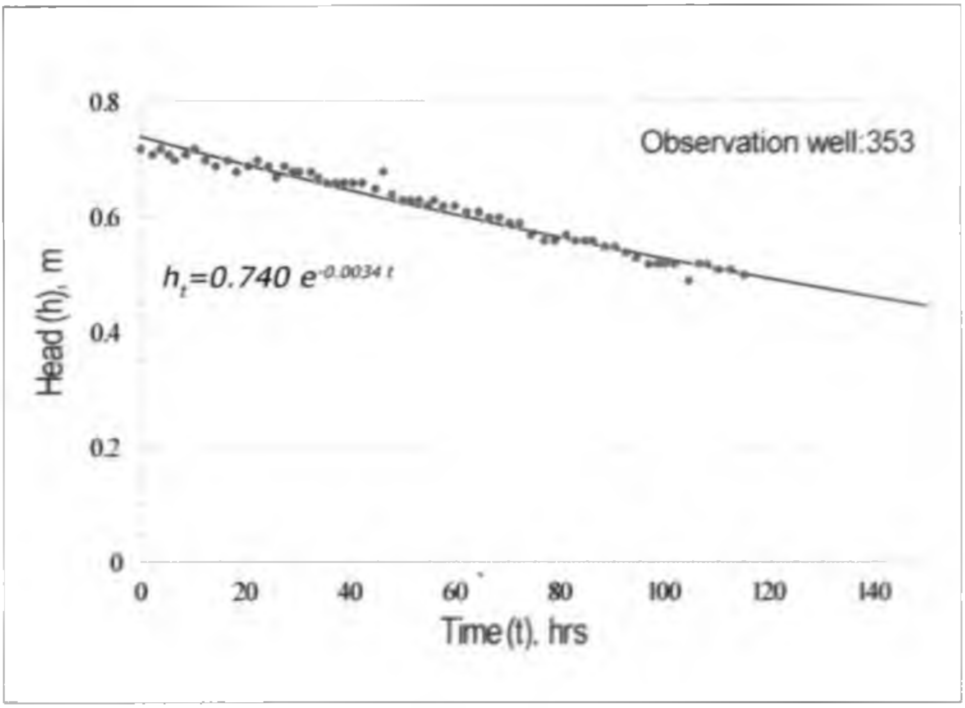

Observation well:283
$h_t=0.449\ e^{-0.0051\ t}$
Head (h), m
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
120
140
Time (t), hrs

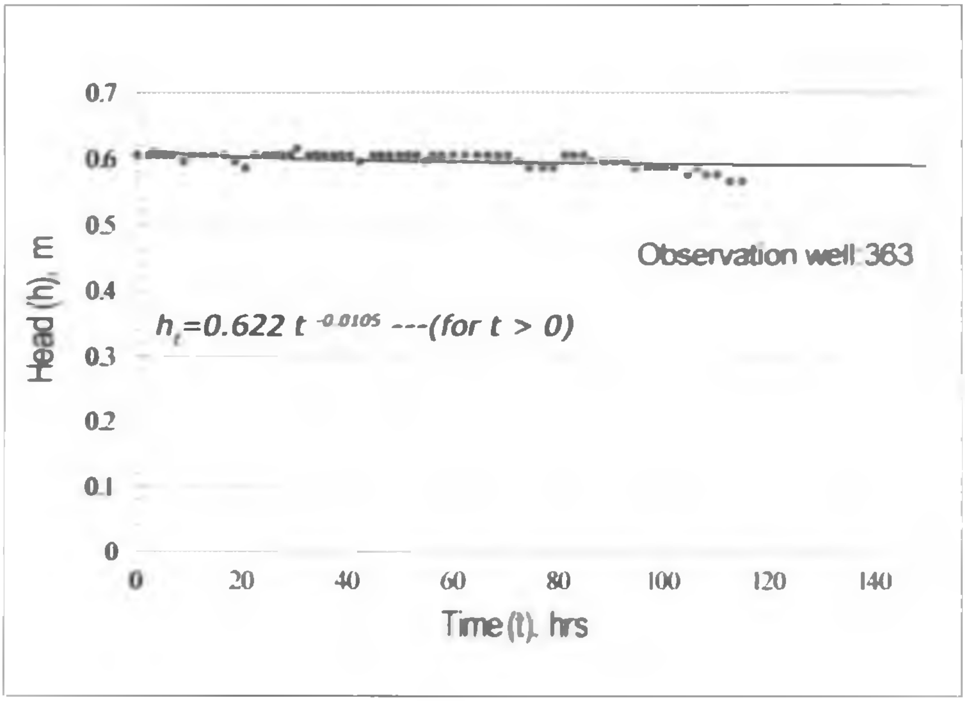

Observation well:313
h_t=0.735 $e^{-0.0021\,t}$
Head (h), m
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
120
140
Time (t), hrs

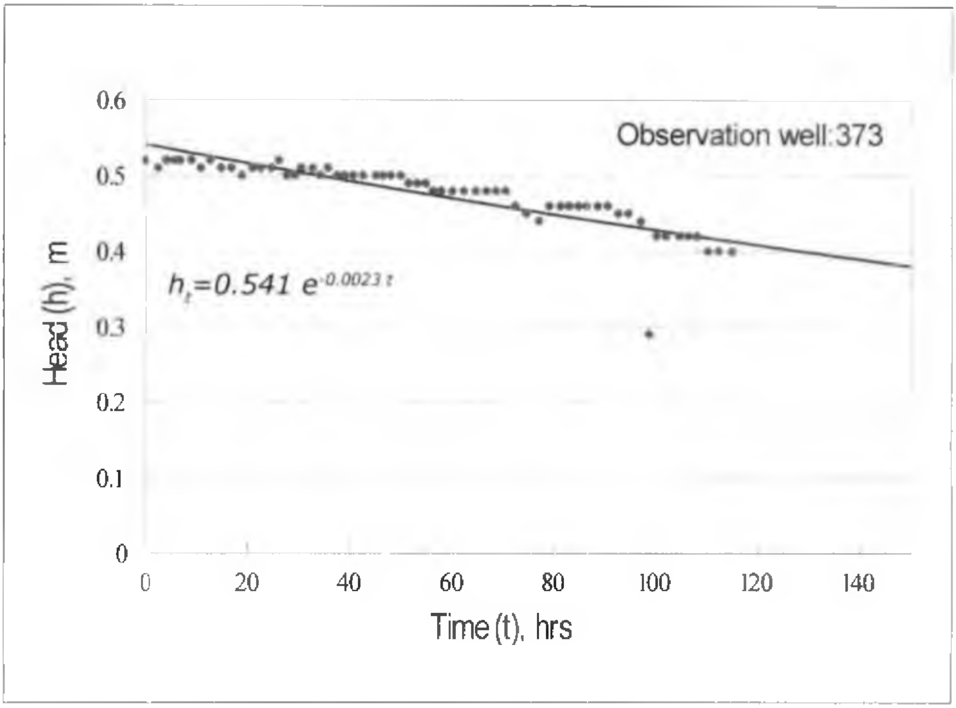

Observation well:323
h_t=0.761 $e^{-0.0026\,t}$
Head (h), m
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
Time (t), hrs

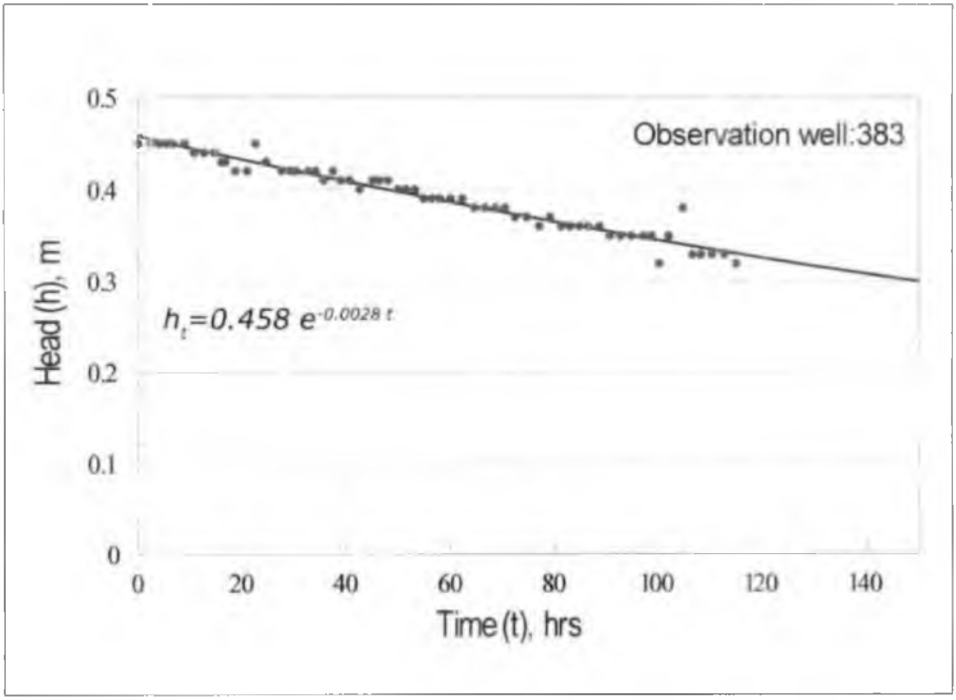

0.8
0.6
0.4
0.2
0
Head (h), m
Observation well:333
$h_t=0.757\ e^{-0.0037\ t}$
0
20
40
60
80
100
120
140
Time (t), hrs


0.8
0.6
0.4
0.2
0.0
Head (h), m
Observation well:343
$h_t=0.743\ e^{-0.0031\ t}$
0
20
40
60
80
100
120
140
Time (t), hrs


0.8
0.6
0.4
0.2
0
Head (h), m
Observation well:353
h_t=0.740 $e^{-0.0034\,t}$
0
20
40
60
80
100
120
140
Time (t), hrs


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Head (h), m
Observation well:363
h_t=0.622 $t^{-0.0105}$ ---(for t > 0)
0
20
40
60
80
100
120
140
Time (t), hrs


Observation well:373
h_t=0.541 $e^{-0.0023\,t}$
Head (h), m
Time (t), hrs
0
0.1
0.2
0.3
0.4
0.5
0.6
0
20
40
60
80
100
120
140


Observation well:383
h_t=0.458 $e^{-0.0028\,t}$
Head (h), m
Time (t), hrs
0
0.1
0.2
0.3
0.4
0.5
0
20
40
60
80
100
120
140

APPENDIX - C

Average Hydraulic heads at mid-spacings.

Average hydraulic head at mid-spacing for drain 2E15							
Time (t), hr	Hydraulic head (h) of observation wells at mid-spacing, m						Average head (h), m
	113	213	313	123	223	323	
5	0.62	0.67	0.73	0.62	0.67	0.75	0.68
10	0.57	0.62	0.72	0.57	0.61	0.74	0.64
15	0.54	0.59	0.71	0.53	0.58	0.73	0.62
20	0.52	0.57	0.71	0.51	0.56	0.72	0.60
25	0.51	0.56	0.70	0.50	0.54	0.71	0.59
30	0.50	0.55	0.69	0.49	0.53	0.70	0.58
35	0.49	0.54	0.68	0.48	0.52	0.69	0.57
40	0.48	0.53	0.68	0.47	0.51	0.69	0.56
45	0.47	0.52	0.67	0.46	0.51	0.68	0.55
50	0.47	0.52	0.66	0.45	0.50	0.67	0.54
55	0.46	0.51	0.66	0.45	0.49	0.66	0.54
60	0.46	0.50	0.65	0.44	0.49	0.65	0.53
65	0.45	0.50	0.64	0.44	0.48	0.64	0.53
70	0.45	0.50	0.64	0.43	0.48	0.63	0.52
75	0.44	0.49	0.63	0.43	0.47	0.63	0.52
80	0.44	0.49	0.62	0.42	0.47	0.62	0.51
85	0.44	0.48	0.62	0.42	0.47	0.61	0.51
90	0.43	0.48	0.61	0.42	0.46	0.60	0.50
95	0.43	0.48	0.60	0.41	0.46	0.59	0.50
100	0.43	0.48	0.60	0.41	0.46	0.59	0.49
105	0.42	0.47	0.59	0.41	0.46	0.58	0.49
110	0.42	0.47	0.59	0.41	0.45	0.57	0.48
115	0.42	0.47	0.58	0.40	0.45	0.56	0.48
120	0.42	0.47	0.57	0.40	0.45	0.56	0.48

Average hydraulic head at mid-spacing for drain 3E15							
Time (t), hr	Hydraulic head (h) of observation wells at mid-spacing, m						Average head (h), m
	123	223	323	133	233	333	
5	0.62	0.67	0.75	0.62	0.72	0.74	0.69
10	0.57	0.61	0.74	0.56	0.65	0.73	0.64
15	0.53	0.58	0.73	0.52	0.62	0.72	0.62
20	0.51	0.56	0.72	0.50	0.59	0.70	0.60
25	0.50	0.54	0.71	0.48	0.57	0.69	0.58
30	0.49	0.53	0.70	0.47	0.56	0.68	0.57
35	0.48	0.52	0.69	0.46	0.54	0.67	0.56
40	0.47	0.51	0.69	0.45	0.53	0.65	0.55
45	0.46	0.51	0.68	0.44	0.52	0.64	0.54
50	0.45	0.50	0.67	0.43	0.52	0.63	0.53
55	0.45	0.49	0.66	0.43	0.51	0.62	0.53
60	0.44	0.49	0.65	0.42	0.50	0.61	0.52
65	0.44	0.48	0.64	0.42	0.50	0.60	0.51
70	0.43	0.48	0.63	0.41	0.49	0.58	0.51
75	0.43	0.47	0.63	0.41	0.49	0.57	0.50
80	0.42	0.47	0.62	0.40	0.48	0.56	0.49
85	0.42	0.47	0.61	0.40	0.48	0.55	0.49
90	0.42	0.46	0.60	0.40	0.47	0.54	0.48
95	0.41	0.46	0.59	0.39	0.47	0.53	0.48
100	0.41	0.46	0.59	0.39	0.47	0.52	0.47
105	0.41	0.46	0.58	0.39	0.46	0.51	0.47
110	0.41	0.45	0.57	0.38	0.46	0.50	0.46
115	0.40	0.45	0.56	0.38	0.46	0.49	0.46
120	0.40	0.45	0.56	0.38	0.45	0.49	0.45

Average hydraulic head at mid-spacing for drain 4E15							
Time (t), hr	Hydraulic head (h) of observation wells at mid-spacing, m						Average head (h), m
	133	233	333	143	243	343	
5	0.62	0.72	0.74	0.51	0.43	0.73	0.63
10	0.56	0.65	0.73	0.47	0.42	0.72	0.59
15	0.52	0.62	0.72	0.44	0.42	0.71	0.57
20	0.50	0.59	0.70	0.43	0.41	0.70	0.56
25	0.48	0.57	0.69	0.42	0.41	0.69	0.54
30	0.47	0.56	0.68	0.41	0.40	0.68	0.53
35	0.46	0.54	0.67	0.40	0.40	0.67	0.52
40	0.45	0.53	0.65	0.39	0.39	0.66	0.51
45	0.44	0.52	0.64	0.38	0.39	0.65	0.50
50	0.43	0.52	0.63	0.38	0.38	0.64	0.50
55	0.43	0.51	0.62	0.37	0.38	0.63	0.49
60	0.42	0.50	0.61	0.37	0.37	0.62	0.48
65	0.42	0.50	0.60	0.37	0.37	0.61	0.48
70	0.41	0.49	0.58	0.36	0.36	0.60	0.47
75	0.41	0.49	0.57	0.36	0.36	0.59	0.46
80	0.40	0.48	0.56	0.36	0.36	0.58	0.46
85	0.40	0.48	0.55	0.35	0.35	0.57	0.45
90	0.40	0.47	0.54	0.35	0.35	0.56	0.45
95	0.39	0.47	0.53	0.35	0.34	0.55	0.44
100	0.39	0.47	0.52	0.35	0.34	0.54	0.43
105	0.39	0.46	0.51	0.34	0.34	0.53	0.43
110	0.38	0.46	0.50	0.34	0.33	0.53	0.42
115	0.38	0.46	0.49	0.34	0.33	0.52	0.42
120	0.38	0.45	0.49	0.34	0.32	0.51	0.42

	Average hydraulic head at mid-spacing for drain 5E15						
Time (t), hr	Hydraulic head (h) of observation wells at mid-spacing, m						Average head (h), m
	143	243	343	153	253	353	
5	0.51	0.43	0.73	0.61	0.65	0.73	0.61
10	0.47	0.42	0.72	0.60	0.64	0.72	0.59
15	0.44	0.42	0.71	0.59	0.64	0.70	0.58
20	0.43	0.41	0.70	0.58	0.63	0.69	0.57
25	0.42	0.41	0.69	0.58	0.62	0.68	0.56
30	0.41	0.40	0.68	0.57	0.61	0.67	0.55
35	0.40	0.40	0.67	0.56	0.60	0.66	0.55
40	0.39	0.39	0.66	0.55	0.60	0.65	0.54
45	0.38	0.39	0.65	0.54	0.59	0.64	0.53
50	0.38	0.38	0.64	0.53	0.58	0.62	0.52
55	0.37	0.38	0.63	0.53	0.57	0.61	0.52
60	0.37	0.37	0.62	0.52	0.56	0.60	0.51
65	0.37	0.37	0.61	0.51	0.56	0.59	0.50
70	0.36	0.36	0.60	0.50	0.55	0.58	0.49
75	0.36	0.36	0.59	0.50	0.54	0.57	0.49
80	0.36	0.36	0.58	0.49	0.54	0.56	0.48
85	0.35	0.35	0.57	0.48	0.53	0.55	0.47
90	0.35	0.35	0.56	0.47	0.52	0.55	0.47
95	0.35	0.34	0.55	0.47	0.52	0.54	0.46
100	0.35	0.34	0.54	0.46	0.51	0.53	0.45
105	0.34	0.34	0.53	0.45	0.50	0.52	0.45
110	0.34	0.33	0.53	0.45	0.50	0.51	0.44
115	0.34	0.33	0.52	0.44	0.49	0.50	0.44
120	0.34	0.32	0.51	0.43	0.48	0.49	0.43

Average hydraulic head at mid-spacing for drain 7E30						
Time (t), hr	Hydraulic head (h) of observation wells at mid-spacing, m					Average head (h), m
	163	263	173	273	373	
5	0.56	0.55	0.43	0.36	0.53	0.49
10	0.55	0.54	0.41	0.35	0.53	0.48
15	0.54	0.53	0.40	0.34	0.52	0.47
20	0.53	0.53	0.38	0.33	0.52	0.46
25	0.52	0.52	0.37	0.32	0.51	0.45
30	0.51	0.51	0.35	0.31	0.50	0.44
35	0.51	0.50	0.34	0.30	0.50	0.43
40	0.50	0.49	0.33	0.29	0.49	0.42
45	0.49	0.48	0.32	0.28	0.49	0.41
50	0.48	0.48	0.30	0.27	0.48	0.40
55	0.47	0.47	0.29	0.26	0.48	0.39
60	0.46	0.46	0.28	0.25	0.47	0.38
65	0.45	0.45	0.27	0.24	0.46	0.38
70	0.45	0.44	0.26	0.23	0.46	0.37
75	0.44	0.44	0.25	0.23	0.45	0.36
80	0.43	0.43	0.24	0.22	0.45	0.35
85	0.42	0.42	0.23	0.21	0.44	0.35
90	0.41	0.42	0.23	0.20	0.44	0.34
95	0.41	0.41	0.22	0.20	0.43	0.33
100	0.40	0.40	0.21	0.19	0.43	0.33
105	0.39	0.39	0.20	0.18	0.42	0.32
110	0.38	0.39	0.19	0.18	0.42	0.31
115	0.38	0.38	0.19	0.17	0.41	0.31
120	0.37	0.38	0.18	0.17	0.41	0.30

Average hydraulic head at mid-spacing for drain 8E30							
Time (t), hr	Hydraulic head (h) of observation wells at mid-spacing, m						Average head (h), m
	173	273	373	183	283	383	
5	0.43	0.36	0.53	0.42	0.44	0.45	0.44
10	0.41	0.35	0.53	0.41	0.43	0.44	0.43
15	0.40	0.34	0.52	0.40	0.42	0.44	0.42
20	0.38	0.33	0.52	0.39	0.41	0.43	0.41
25	0.37	0.32	0.51	0.38	0.40	0.43	0.40
30	0.35	0.31	0.50	0.37	0.39	0.42	0.39
35	0.34	0.30	0.50	0.36	0.38	0.41	0.38
40	0.33	0.29	0.49	0.35	0.37	0.41	0.37
45	0.32	0.28	0.49	0.34	0.36	0.40	0.36
50	0.30	0.27	0.48	0.33	0.35	0.40	0.36
55	0.29	0.26	0.48	0.32	0.34	0.39	0.35
60	0.28	0.25	0.47	0.31	0.33	0.39	0.34
65	0.27	0.24	0.46	0.31	0.32	0.38	0.33
70	0.26	0.23	0.46	0.30	0.31	0.38	0.32
75	0.25	0.23	0.45	0.29	0.31	0.37	0.32
80	0.24	0.22	0.45	0.28	0.30	0.37	0.31
85	0.23	0.21	0.44	0.28	0.29	0.36	0.30
90	0.23	0.20	0.44	0.27	0.28	0.35	0.30
95	0.22	0.20	0.43	0.26	0.28	0.35	0.29
100	0.21	0.19	0.43	0.25	0.27	0.34	0.28
105	0.20	0.18	0.42	0.25	0.26	0.34	0.28
110	0.19	0.18	0.42	0.24	0.26	0.34	0.27
115	0.19	0.17	0.41	0.24	0.25	0.33	0.26
120	0.18	0.17	0.41	0.23	0.24	0.33	0.26

APPENDIX-D

Estimate for installation of tile drainage for 100 ha area

(The cost/rates quoted are as per the then prevailing rates in 1998)

Total area	100 ha	
A. CAPITAL COST		
1. Cost of tile drains		
Spacing of drains	30 m	
Length of 1 line	100 m	
No of lines	320	
Total length	32000 m	
Length of one tile	0.6 m	
No of tiles required	53333	
Add 5% for breakage	2667	
Total tiles required	56000	
Cost of one tile	Rs 12	
Total cost of drains		Rs 6,72,000/-
2. Cost of excavation for tile drains		
Dimensions of trench		
Depth	1.0 m	
Bottom width	0.5 m	
Top width	1.5 m	
Side slope	0.5 : 1	
Cross-sectional area	1 m^2	
Volume of excavation	1 m^3/m	
Length of excavation	32000 m	
Total volume	32000 m^3	
Rate of excavation	Rs 14 /m^3	
Total cost of excavation for tile drains		Rs 4,48,000/-
3. Cost of laying drain and back filling		
Rate of laying drains and backfilling	Rs 4 /m	
Length of laying drains	32000 m	
Total cost of laying and back filling		Rs 1,28,000/-

4. Cost of river sand as filter materials		
Quantity required	0.1 m^3/m	
Total length	32000 m	
Total quantity required	3200 m^3	
Cost of river sand	Rs 90 /m^3	
Total cost of river sand as filter		Rs 2,88,000/-
5. Cost for covering with filter materials		
Rate of covering with filter materials	Rs 2 /m	
Total length	32000 m	
Total cost		Rs 64,000/-
6. Cost of excavation for secondary open drains		
Depth	1.5 m	
Bottom width	0.6 m	
Side slope	0.5 : 1	
Top width	2.1 m	
Cross sectional area	2.625 m^2	
Total length	10000 m	
Total volume of earth work	20250 m^3	
Rate of excavation	Rs 15 /m^3	
Total cost of excavation for secondary open drains	Rs 3,93,750/-	
7. Cost of excavation of main open drains		
Depth	2.0 m	
Bottom width	1.5 m	
Side slope	0.5 : 1	
Top width	3.5 m	
Cross sectional area	5.00 m^2	
Total length	1000 m	
Total volume of earth work	5000 m^2	
Rate of excavation	Rs 15 /m^3	
Total cost of excavating main open drains		Rs 75,000/-

8. Cost of pumping system		Rs 1,00,000/-
9. Cost of consultation		Rs 20,000/-
10.Cost for electrical connection		Rs 20,000/-
11. Overhead charges		Rs 41,250/-
Grand total of A		**Rs. 22,50,000/-**
B. OPERATION AND MAINTENANCE COST		
1. Periodical maintenance of open drains	Rs 50,000/-	
2. Maintenance of Pumping system		
3. Energy requirement		
Electrical energy required	400 kwh/ha	
Total area	100 ha	
Total energy erquirement	40000 kwh	
Cost per unit	Re 1.00 /kwh	
Total cost of electric energy		Rs 40,000/-
4. Salary of pump operators		
Salary of one operator per month	Rs 2500	
No. of operators	4	
No. of months/season	4	
No. of season/year	2	
Total salary for one year		Rs 80,000/-
Total of B		**Rs. 1,80,000/-**
C. BENEFITS		
Additional average yield expected per season on account of the introduction of sub-surface drainage system	1 ton/ha	
No. of seasons/year	2	
Total additional yield	200 tons/year	
Cost of paddy	Rs 6,000 /ton	
Total benefits		**Rs. 12,00,000/-**

APPENDIX - E
Important visitors and their comments

I was happy to see that the technical programme of the Agril Drainage project has been well started and some results have already been obtained. I hope that the work will acquire additional momentum with the filling of the existing vacancies.

Dr. A. M. Michael,

Project Director, WTC, New Delhi, 2 –6 – 83

Visited the centre on 16th June 1987. It is good that the experimental layout of filters could be completed before the rains. Lot of data has been collected which need to be analyzed systematically. The work has progressed extremely satisfactorily.

Dr. A. K. Bhattacharya,

Project Co-ordinator, WTC, New Delhi 16-7-87

It was my pleasure visiting the Drainage Project at Karumady and to see the very useful work of immense practical application in bringing to economical and efficient crop production on the extensive Kari lands of Kuttanad. The results of the study at the station could be applied to other similar situations. It is suggested that a suitable Technical bulletin be published shortly giving information in the technological development at the station. The study needs further strengthening by increasing additional objectives and providing facilities and additional staff. The area provides immense scope for establishing an ORP aimed at large scale reclamation of karilands using appropriate technology.

Dr. A. M. Michael,

Director, WTC, IARI, New Delhi, 10-1-89

Today we visited the Drainage Project site of the Agricultural University of Kerala. We have been received by Mr. Nair and Mr. Mathew who did give a very good briefing with slides of what is going on. The visit to the field completed the tour, which has been very instructive and has really been an eye-opener for us.

We wish the scientists all the success for their good programme.

Consulting Agronomist,

Water Balance Study Project, The Netherlands, 2/2/89

This was my first visit. Although I knew about this drainage project, the actual magnitude of the problem became clear to me only after my physical visit to the drainage site. The way the problem has been tackled is very commendable as it has been tested and executed directly in the farmer's field. I wish all success and co-operation from our end.

Dr. T. K. Sarkar,

Project Director, WTC, New Delhi, 23-10-89

It was very interesting to see that the research on drainage of potential acid clay soils is going on. It is very essential to maintain contacts with other similar research in India and elsewhere in the world.

May we meet somewhere (Wageningen)

Thanks

Jacob Vos,

ILRI, Wagenengin, 23-10-89

I visited the institute. This is the first time that I am seeing this type of experiment. I am fascinated. The results are encouraging. Dept has plans to have these things extended to the farmer's field as trial. Hence my visit and I am really happy to state that I am encouraged to do so.

M. Janardanan Pillai,

Director of Agriculture, Kerala, 16-3-91

I am very happy that Dr. Michael's desire for making a publication out of the drainage research work is going to be fulfilled. The centre has done extremely valuable work on drainage in farmer's field, which has been found to be very effective in improving paddy yields and improving the soil. I wish that the technology were adopted in a large scale with the assistance from the State Govt.

Dr. A. K. Bhattacharya,

Project Coordinator, WTC, New Delhi, 23-3-91

Visited the center during 21-22, February 1992, saw the entire field experiments under cropped condition. Visual difference in crop condition between drained and undrained situation were not very conspicuous. The real difference is expected to be seen in yield. The proposed publication was thoroughly discussed. I hope that it will be published soon. It has much valuable information. The new office building is good. Overall, the progress of work was extremely encouraging. The center and the University may initiate the contact with NABARD as they have shown interest in drainage developmental work. Similarly, the state Government may also be persuaded by the scheme staff / University and the farmers to take up large-scale drainage work.

Dr. A. K. Bhattacharya,

Project Coordinator, WTC, New Delhi, 22-2-92

I am overwhelmed to see the Kuttanad area of Kerala. The area possesses one of the most challenging problems of land and water management. The AICRP on Agril. Drainage, manned by three competent scientists, Mr.Mathew, Mr.Raju and Mr. Nair have started excellent experiments on farmer's fields to study the effect of drainage on rice yields. The experimental findings have potential of large-scale field adoption, as the technology developed by the team has increased the rice yield considerably. The team deserves special appreciation for their field oriented applied work.

I have enjoyed seeing the entire Kari area in a motorized boat. i have had the privilege of seeing several good parts of the world in many developed countries. I am pleased to write that the Kuttanad area is one of the best in the world for the development of the tourism, Fishery apart from rice farm.

S. R. Singh,

Project Director, WTC for Eastern Region, 23-6-95

This is for the first time that I had an opportunity to see the serious drainage site of this magnitude. I admire the work of the devoted scientists who are engaged in AICRP on Agril. Drainage under constrained conditions. I have been monitoring the work and knew the relevant and successful implementation of the programme. But after witnessing the work at the site I realize the seriousness of the drainage project.

I wish success of the project and prosperity to the staff associated with it.

Wish all of them a happy New Year.

G. Singh,

ADG(Engg.), ICAR, 1-11-95

The visit to the project is very useful, informative. An excellent research work is in progress for solution of Karilands. The interaction with WTC scientists will be a mutually beneficial programme. We are extremely grateful to the scientist of the center.

A. K. Singh,

Principal Scientist, WTC, New Delhi, 23-3-96

I am extremely happy to see the work on sub surface drainage for reclaiming acid sulphate soils in Kuttanad. The result seems to be promising and there is a need to extend this work to larger areas.

Dr. N. K. Tyagi,

Director CSSRI, Karnal, 20.4.96

I note with great sense of appreciation, the activities of this centre related to Agricultural Drainage. Further thrust in this area is being contemplated now to promote this technology on a larger scale, in order to benefit the farming community at large. I feel that full attention need to be paid to this area. I wish all success in the endeavors of this centre.

M. Selvarajan,

ISRO, Bangalore, 30.07.96

Visited the Drainage project site on 30.1.97. Installation of the left over portion of the wider spacing experiment is complete and the center's efforts are commendable in this regard. The new area needs more attention now than the earlier area in terms of monitoring. The final disposal section of the earlier experimental area may be modified as discussed so that the pump outlet may be converted to a gravity outlet system. A temporary pump and instrument shed may be made at the outlet point of new experimental area. A comprehensive report on the work done so far at the new area including all relevant construction details and sketch may be sent to me soon.

Dr. A. K. Bhattacharya,

Project Coordinator, WTC, 30.1.97

On behalf of the Indo-Dutch Network Operational Research Project on Land Reclamation we have come to study the possibility of including the sub surface activities of Kerala Agricultural University into the net work and give financial and other support. We found that the team has acquired wonderful experiences and all proposals are thought over very ably. We are convinced that they will become one of our best partners in India.

R.J. Oosterbaan,

Chief Technical Advisor, Indo dutch project, ILRI, 13.9.1997

Visited Karumady centre of AICRP on Agril. Drainage today and discussed all the technical programs. The various items of the technical programs give ample opportunity to deviate from various routine studies going on for some years. The fund and expenditure position is okay. The progress of work is satisfactory. In communication. the center has problem for both inward and outward communication. The telephone facility will be very useful for the centre. Many important and knowledgeable visitors have praised the research work and that is a great satisfaction to me. The recently published English and vernacular bulletins are excellent.

Dr. A. K. Bhattacharya,

Project Coordinator, WTC, 20.2.98

I am very impressed with the collective effort of AICRP on Agril. Drainage centre, Karumady, and the farmers participating, that have demonstrated how to take reliable crop of rice in Kari land. I complement and congratulate the individuals who have made it possible. I see prospect of further increase of productivity through soil, water and nutrient management. Also prospect exists for integrated fish farming in fallow fields. The results already achieved need to be replicated in entire Karilands. State Government should mobilize its funds in this direction. I wish continued success.

Dr. A. Alam,

DDG (Engineering) ICAR, 20.1.2000