STUDIES ON WATER TABLE MANAGEMENT SYSTEM IN THE WATERLOGGED AREA OF LOWER BHAVANI IRRIGATION PROJECT

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COIMBATORE – 641 003

2013

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Thesis submitted in part fulfillment of the requirements

for the award of the degree of

DOCTOR OF PHILOSOPHY IN SOIL &

WATER CONSERVATION ENGINEERING

to the Tamil Nadu Agricultural University, Coimbatore

by

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2013

CERTIFICATE

This is to certify that the thesis entitled **'STUDIES ON WATERTABLE MANAGEMENT SYSTEM IN THE WATERLOGGED AREA OF LOWER BHAVANI PROJECT'** submitted in part fulfillment of the requirements for the award of the degree in **DOCTOR OF PHILOSOPHY IN SOIL AND WATER CONSERVATION ENGINEERING** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Er. H.V.HEMA KUMAR** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes. However, part of the thesis work has been published in peer reviewed scientific journal of national/ international repute (Copy enclosed).

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Acknowledgement

ACKNOWLEDGEMENT

The author wishes to express his heartfelt gratitude to Prof. ***Dr.K.Ramaswamy,*** *Chairman, Dean, Agricultural Engineering College & Research Institute, Kumulur, TNAU, for his constant supervision, valuable suggestion, scholastic guidance, continuous inspiration, constructive comments, timely cautions, and immense help during the research work as well for this manuscript from its embryonic stage. The author also sincerely express his heartfelt gratitude to the members of the advisory committee,* ***Dr.S.Santhana Bosu****, Professor, Dept. of SWCE.,* ***Dr.S. Mahimairaja****, Dean, Agriculture, Dr.* ***R.Palanisami****, Professor & Head, Dept. of Physical Sciences & Information Systems, TNAU for their valuable timely advices to complete the thesis. The author would like to express special profound thanks to* ***Dr. I.Muthuchamy****, Prof.& Head, Dept. of SWCE for extending all the facilities for the successful completion apart from counseling at times of shortfalls.*

The author would like to express his deepest respect to all the respected teachers of the Department of SWCE., ***Prof. Dr. Senthilvel, Prof. Dr. Rangasawamy, Prof. Dr. Shanmukha Sundaram, Prof. Dr. Raviraj*** *for the valuable teaching, co-operation and inspirations throughout the course of this study and research work. The author had experienced the hospitality of* ***all the faculty and staff of AEC & RI, Kumulur, Trichy*** *during his last stages of Thesis making. The elated and emulated sense of decorum and kind gestures received from* ***Er. Parthipan Mylswamy****, Assistant Professor (Computer Science) in all respects, particularly extending the full time computer lab along with internet connection facilities are unforgettable life memories making the author totally a nostalgic free academic and learning environment.*

The author places a special record for ***Er. P.Praveen's*** *valuable services during system installation, data observations in the field. The author wishes to express his elated grateful feelings to* ***Thiru Dhanaseelan,*** *Progressive farmer, Kattadipalayam, Gopichettipalayam and his beloved son* ***Er. Thiruselvan****, for sparing their land for research and their timely services despite their hectic work. The author would never forget in his life* ***Er. Ganeshan****, Assistant Engineer, Agricultural Engineering Department, Gobichettipalem for his help during critical times of the Project. The author wish to express his cordial thanks to departmental and field staffs for their active help during the* *experimental period. The author is highly grateful to the* ***PWD*** *authorities and* ***MYRADA KVK s****taff for their kind gesture in providing data and lab facilities during the research work at Gopichettipalem. The author feels unwise to mention names, though the author spaces much in heart for his, profound thanks to all his* ***Kongunadu friends, all his classmates, juniors and seniors, Soil & Water Workstaff, Driver Vijayan****,* ***Thiru Veeraswamy*** *etc., for their benedictions and timely assistance. Special thanks are due to* ***Er. K.V.S. Rami Reddy, Er.G.Muralee Krishna, Er.Mukesh Palsania, Er. Navaneeth Pandyan, Er. R. Nagarajan, Er. Ch. Balachand, Dr. Manikandan, Er. Vivek and all other friends who helped voluntarily in many works.***

The author places a great regard to his beloved Seniour colleagues ***Dr. D. Appa Rao, Dr. M.Raghu Babu*** *,* ***Dr. A.Srinivasulu, Dr. B.V.S. Prasad., Dr.D.D. Smith****,* ***Dr. G.Ravi Babu****,* ***Dr. B.S. Devi Dr. (Mrs) G.V. Lakshmi*** *and his classmates* ***Er. G.V.Ramana Reddy, Er. P.S. Babu. Er. Mr. Phuchung Bhutia and Er. (Mrs) Reep Rebecca*** *who were chronic well wishers throughout the career. The author pays a great gratitude sense for his* ***Colleagues of ANGRAU****, Administrative* ***staff*** *for arranging him the deputation. There is a great support for the author especially from his beloved students,* ***Er.Sai Gangadhar, Er. (Mrs) K.Krupavati, Er. Ch. Muralee Krishna, Er. A.Rama Rao, Er. N.Ashok, Er. Mohana Rao, Er. B.Raj Kiran****,* ***Er. M.Srinivasulu*** *in terms of their chronic co-operation for which the author places a special place of sense of acknowledgements to them.*

Overall, the author attributes great salutations to ***Dr. T. V. Satyanarayana, Dean of Agricultural Engineering & Technology (ANGRAU)*** *for his benefactions/dictions, for almost a decade of academic brought up. Lastly the author is gratefully expresses indebtedness to his beloved parents, his elder brother, spouse, son, parents-in-law relatives and all his well-wishers for their countless benevolence both directly and indirectly in completion of this work.*

Date ***(H.V.HEMA KUMAR)***

ABBREVIATIONS

ac	:	acre
%	:	Per cent
ASAE	:	American society of Agricultural Engineers
^{0}C	:	Degree centigrade
CaRD	:	Controlled and Reversible Drainage system
CD	:	Controlled Drainage
CD-SI	:	Controlled Drainage- Subirrigation
CV	:	Co-efficient of Variation
cm	:	centimeter
cumec	:	Cubic meter per second
cu.m	:	Cubic meter
Cm/day	:	Centimeters per day
CSSRI	:	Central Soil Salinity Research Institute
DAS	:	Days After Sowing
dia.	:	Diameter
DC	:	Drainage coefficient
D_s	:	Deep Seepage
DDR	:	Design Drainage Discharge
d_L	:	Diameter of lateral pipe
EC	:	Electrical conductivity
e.g	:	For example
ET	:	Evapotranspiration
et al	:	And others
e	:	evaporation rate
FAO	:	Food and Agricultural Organization
FD	:	Free tile Drainage
Fig.	:	figure
ha	:	hectare
ha-m	:	hectare meter
hp	:	horsepower
i.e.	:	That is
IDNP	:	Indo Dutch Network Project
ILRI	:	International Land Reclamation Institute
k_a	:	Saturated Hydraulic conductivity

		above root zone
k_b	:	Saturated hydraulic conductivity below the drains
K_s	:	Saturated hydraulic conductivity
K_c	:	Crop coefficient
Kg/ha	:	Kilogram per hectare
km	:	kilometer
LDPE	:	Low density poly ethylene
l/s	:	liter per second
Mg/L	:	Milligram per litre
m^3/day	:	Meter cubed per day
msl	:	Mean sea level
m	:	meter
M	:	Critical water table difference
M.Cu.m	:	Million Cubic meters
Mha	:	Million hectares
mm	:	millimeter
m/s	:	meter per second
N.C.	:	Northern Carolina
ppm	:	Parts per million
q	:	flux rate (cm/day)
Q	:	discharge rate (m^3/day)
PVC	:	Poly vinyl chloride
RH	:	Relative Humidity
SAR	:	Sodium Adsorption Ratio
SEW_{30}	:	Sum of Excess Water within 30 cm
SSD	:	Subsurface Drainage
sq.km		Square Kilometer
S.D.	:	Standard Deviation
SI	:	Subirrigation
sq.m	:	Squared meter
T	:	Trafficability index
t	:	Time
tons/ha	:	Tones per hectare
TMC	:	Thousand million cubic feet
USDA-SCS	:	United states Department of Agriculture Soil Conservation Service
WTM	:	Water table management system
WT	:	Water table

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Abstract

ABSTRACT

STUDIES ON WATER TABLE MANAGEMENT SYSTEM IN THE WATERLOGGED AREA OF LOWER BHAVANI IRRIGATION PROJECT

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The productivity in case of food grain crops increased from 0.5 t ha^{-1} in 1951 to more than 2.0 t ha^{-1} in 2012 in India. Waterlogging and soil salinity adversely affected agricultural lands questioning doubts about the sustainability of irrigated agriculture. Later on, it was recognized that negligence of drainage component in the irrigation project plans was one of the major mistakes in the earlier planning processes. It is felt that Water table management system synonymously, known as Control Drainage and Sub Irrigation (CD - SI) system; with little modification in the design, if tested in the farmers' fields would definitely attract the farmers and policy makers for the adaptability in Tamil Nadu, where seasonal waterlogging and realms of water scarcity both exist in the same fields. Hence a progressive farmer's field was chosen to conduct on-farm research on pilot scale lying in Lower Bhavani Project Command along Thadapalli channel $13/6^{th}$ mile for the proposed study.

Characterization of waterlogging problems in the present research was carried out in three ways namely by calculating SEW 30 index , proposing a new indicator, Trafficability Index and Yield comparison with well drained fields in the same command with normal conditions. The SEW_{30} index from 40m, 80m, 120 and 160m from the canal were calculated as 520, 320, 120 and 150 cm days respectively with an average value of 277.5 cm days. As these values are higher than the optimal value of 200cmdays for dry

climate conditions, it could be concluded that the experimental area is under the problem of chronic waterlogging condition which needs reclamation measures. The trafficability index value (T) varies from 0.2 to 51.2 ranging from 1 to 8 days of delayed harvesting. It could be recommended that tolerable yield loss of almost 500-600 kg/ha due to operational constraints of the farmer for which 4-5 days delay from optimum might be allowed. Hence the trafficability Index corresponding to this delay might be in the order of 0.2 to 15.

For the present study after thorough drainage investigations, a spacing of 20m under drainage mode and a spacing of 10m for subirrigation mode were worked out for shallow depth of drain placement under consideration. Hence keeping 10m, as the key design spacing, the layout of field experimentation was prepared with 6m, 9m, 12m and 15m spacings for further investigation under two depths of drain placements i.e 60cm. and one closure to the conventionally adopted spacing i.e 80cm. With the above design considerations, the water table management system was installed during May 2012 in the above mentioned farmer's field. Corrugated perforated UPVC pipes of 80mm dia. were used as drain pipe material. Rigid PVC pipes of 110mm diameter were used to construct the collector. The laterals were fitted with PVC ball valves for their individual operations based on the necessity.

The canal releases during Kharif 2012 started from 1st June onwards. Observation wells were installed midway between the laterals (6m, 9, 12m & 15m spacings) in both 60cm and 80cm depth of drains placements for monitoring the water table fluctuations. Continuous monitoring of outflows, canal flow levels, water table heights were taken up for two crop seasons, paddy (ADT 45) followed by fodder sorghum in the study area for arriving at some valid conclusions. The crop yields were also monitored. The system functioned very well under shallow drain depth placements i.e. 60cm and 80cm in maintaining water table during both the modes making the root zone below 30cm from ground level throughout the study period.

The subirrigation trials during summer were taken up during April 2013, for performance evaluation by reversibly pumping water into the system with the help of a 5 HP oil engine. The short duration canal release was utilized for this purpose by storing the water in the downstream. The moisture content, rise and falls with elapsed time were monitored in all the replications at three different depths namely 15cm, 30cm and 45 cm respectively.

Exponential equations were fitted for drain discharge (q)-depth to water table (d) with elapsed time for all the spacing and depth combinations under controlled drainage mode operation of water table management system which could be of very high use in preparing the operational schedule of the system for better water table management. The shallow depth of drain placement (60cm) gave better performance in terms of water table depletion under drainage mode and water table rise under subirrigaion mode as per DRAINMOD 6.1 model simulation runs carried out.

The farmers convinced with the improvement of the trafficability due to the system, besides satisfying with an additional increment of 1.2 tonnes/hectare (for ADT 45 paddy variety) in the first season itself (4.0 tons/ha to 5.2 tons/ ha) without any change in other cultivation practices. The increase could be solely attributable to this technological intervention because there was no change in the yield levels of control plot. With the benefits achieved from the system, first season, the Benefit-Cost ratio of the water table management system worked out to be 1.62. The trafficability improvement while harvesting the crop was witnessed by the adjoining farmers. The average paddy yields in the study area were in the tune of 4.0 tonnes/ha before the installation of water table management system and the yield improvement was seen in the order of 5.2 tonnes/ ha in the system area after the introduction of the water table management system.

Without detrimental to much yield paddy or dry crop, uniformity of soil moisture during subirrigation, desired water table from ground, workability under subirrigation mode and drainage mode; altogether leads to a recommendation of 9 m as the design spacing and 60cm as the drain depth for the clay loams of the region.

Introduction

Chapter I

INTRODUCTION

Water resources development for irrigation remained effective vehicle in ushering the green revolution that India witnessed in the post independence era. The role of irrigation can be judged from the fact that, except in rare and limited areas, there has been no green revolution in India on un-irrigated land. In a quest to ensure food security, clean water and healthy environment to its people, priority was accorded to investments on expansion of irrigation immediately after independence. As a result, area under major and minor irrigation increased from 9.70 million ha during pre-plan to 42.77 million ha at the end of ninth plan. Area under minor irrigation also increased from 12.90 million ha in pre-plan period to 67.32 million ha at the end of annual plan 2000-01. It makes about 78% of the ultimate irrigation potential of the country. Introduction of irrigation coupled with other management practices resulted in substantial increase in crop productivity.

The productivity in case of food grain crops increased from 0.5 t ha^{-1} in 1951 to more than 2.0 t ha^{-1} in 2012. While these developments paid rich dividends as far as food security and rural economy are concerned, inadequacy of drainage in the irrigation expansion plans made irrigation to be a mixed blessing. Waterlogging and soil salinity adversely affected agricultural lands creating doubts about the sustainability of irrigated agriculture. Later on, it was recognized that negligence of drainage component in the irrigation project plans was one of the major mistake in the earlier planning processes. Simultaneously, there was pressure for resource conservation in terms of land and water resources. Economic justification, need to sustain profitable crop production system, positive socio-economic impacts on rural masses and regional economy prompted the planners to think seriously about better drainage facilities in irrigation commands. Anticipating this change, drainage research continued to be one of the major thrust areas of the agricultural research organizations in the country.

A large number of small-scale research projects were initiated which were culminated into operational research projects in Rajasthan and Haryana (RAJAD, 1995, HOPP, 2004). Later on private investments in terms public-private partnership for planning, design and implementation of large-scale drainage projects started pouring in the states on

Maharashtra and Karnataka. Indo-Dutch operational network centres in Rajasthan, Gujarat, Karnataka and Andhra Pradesh produced promising results. There was a lot change in technological part of drainage also. The research experiments in different parts of India started with manual installation. Use of clay/ concrete drainpipes and gravel filter envelopes were more common during those days. Now days, most of the subsurface drainage project activities such as survey, design, layout and installation are mechanized. Use of corrugated perforated PVC drainpipes and woven/ non –woven envelope material has become accepted practice. In contrast to earlier projects of small areas, new projects are being planned for few thousand hectares. Besides, technological aspects of subsurface drainage, social engineering and environment issues (related to disposal of drainage effluent) require more attention.

Though there were some success stories in past indicating correct identification of drainage problem and technical competence to tackle it, major achievements were accomplished during the last thirty years when a subsurface drainage based reclamation package was developed and implemented to cover about 40000 ha of waterlogged saline lands.

Tamil Nadu, endowed with bountiful and benign nature, has a tradition of preserving the ponds and tanks, dating back to the 4th and 5th centuries. With its long coast lines, alluvial plains, and hill chain of the Western Ghats, the state offers a wide variety of habitats. Situated on the southeast of Indian Peninsula, Tamil Nadu can be phisiograhically divided into i) the eastern coastal plain ii) the hilly region along the north and the west. The coastal plain is further divided into a) Coromondel plain in the north b) the alluvial plain of the Cauvery delta and c) the dry southern plains. Along the whole length of the western part, at a distance from the sea varying from 80 to 150 km runs the range of Western Ghats, a steep and rugged landmass averaging 1, 220 m above the sea level and rising to 2,440 m at the highest point.

The wetlands in Tamil Nadu comprise lakes, ponds, reservoirs and seasonally waterlogged areas. Nine districts namely Vellore, Cuddalore, Pudukkottai, Thanjavur, Ramananthapuram, Tirunelveli, Kanyakumari, Erode and Chengalpat comprise mainly such waterlogged lands. During 2000-2001, the Central Ground Water Board took up special studies aimed at delineating waterlogged areas and feasibility studies for anti-waterlogging measures in 10 studies in different states. Bhavani Command area being one among the 10 study areas. The working group constituted by the Ministry of Water Resources estimated in 1991 that an area of 1.6 lakh hectare was suffering from the problem in Tamil Nadu State.

Many irrigation project command areas of Tamil Nadu lack adequate supply of water to agriculture in three to four months every year due to inadequate water resources. Inevitable water scarcity for a few months and also water logging problems due to excess water release from reservoirs during heavy rainy periods from inter-state rivers is the common problem in some low lying areas. Hence a dual system to tackle waterlogging in monsoon season and scarcity during summer is the need of the hour. Parts of some districts like Trichy, Tanjore, Nagapattinam, Tiruvarur, Erode (old ayacuts) are frequently under the problem of waterlogging during North-East monsoon heavy rainfall periods (October-December). At the same time, the above areas are under the realms of water scarcity for a few months (February-May) during canal non-supply periods.

The CD & SI system, synonymously termed as Water Table Management System (WTM) is mainly adapted in waterlogged areas where the water quality is of not a major problem. Controlled Drainage-Subirrigation (CD-SI) system operates as a traditional drainage system during wet periods; excess water is removed from the field through a system of underground drain tubes which conveys outlet to a main drain tube or open ditch. During times of water shortage, a structure (such as a flashboard riser) is used in the outlet ditch to regulate the drainage rate. The dual-purpose system would normally fluctuate between the drainage, controlled drainage and subirrigation modes several times during one cropping season. (Doty *et al.,* 1975). Though in many parts of the world, particularly North Carolina University of USA., the CD-SI systems were functioning for the control of Water Table., in India, no substantial research had been reported in this direction.

The effective agricultural water management requires control of how much water is added to the soil (irrigation) and how much water is removed (drainage). Agricultural water management interventions have, understandably, focussed on perfecting the control of irrigation water. The result, in general terms has been to ignore the importance of drainage. Drainage removes excess water from the soil profile and provides a tool to control soil salinity. Some soils drain naturally but in many excessive irrigated lands, drainage systems have to be installed and operated to maintain water tables at an acceptable level.

The report from Knowledge and Research (KaR) contact R 7133 (November 2002)-Integrated Irrigation and Drainage to save water- carried out by International Development Group of Water Research Institute, reveals that there is a tune of potential of more than 25 million hectares area in the world needs Water Table Management Systems (2002). The major countries requiring this system, they reported are Egypt, India, Iraq, Israel, Pakisthan, Syria, Uzbekisthan, Tajikistha, and Turkmenistan.

The system is preferred to fulfill the following advantages. i) To provide a system that satisfies both drainage and supplemental irrigation needs, ii) To reduce water related stress, and thus increase crop yields, iii) for operational cost savings, mainly in reduced energy consumption compared to conventional irrigation systems iii) to reduce the fertilizer costs, iv) to conserve water, the system takes advantages of rainfall events, v) to offer flexibility in managing in drainage water vi) to protect the environment.

Essentially drainage technology is vital to alleviate the waterlogging problem, but at the same time, the same system technically, if used for irrigation with some modified design values through conjunctive strategy of ground water in the above areas, the crop productivity and production could be increased all round the year (2 to 3 crops). To meet the food needs of growing population of Tamil Nadu, depleting water resources and to safeguard the interest of the rice growing farmers of the state where such waterlogging is encountered, the Control Drainage and Sub Irrigation (CD & SI) system, if developed and tested in the farmers' fields would definitely attract the farmers and policy makers for the adaptability.

The system has a potential scope for its adoption based upon the field requirement in one of the irrigation project areas nearby TNAU research station, Bhavani Sagar. Farmers of Lower Bhavani Sagar Canal near Gobichettipalayam during their training programme expressed their felt problem of reduced paddy yields due to the inundation of canal water through seepage along the unlined canal line in the tail ends for considerably a long distance and water scarcity during canal non-supply periods. Hence it is proposed to conduct research on a pilot basis in a progressive farmer's field by executing CD & SI system (with little design modifications to suit the system for Indian conditions), which is proven technology in the developed and developing countries.

The study area was selected such that it could be easily accessible for both execution and monitoring the field data and of experimental layout with sufficient accuracy by ensuring the farmers' co-operation duly believing that it would become a demonstration plot for many such farmers along the canal length. Hence, the present research had been proposed to fulfil the following objectives.

Objectives

(i) To characterize the waterlogging problem and assess the cropping constraints in the study area.

(ii) To design and install hydraulically efficient water table management system, (Controlled Drainage and Sub Irrigation (CD & SI) system), in a pilot experimental area.

iii) To evaluate the system for its hydraulic and functional performance.

iv) To conduct simulation studies to optimize the design spacing and depth.

Review of Literature

Chapter II

REVIEW OF LITERATURE

A comprehensive review on the proposed research was carried out in order to, design, and field execution and performance evaluation of the Water Table Management System (WTM). The review of literature collected is discussed in sequential subsections viz.,i) Prospects of drainage studies in India & other countries ii) Water table management Systems iii) Characterization of water logging problem and assessment of cropping constraints. iv) Design and execution of hydraulically efficient water table management system v) Performance evaluation of water table management systems vi) Simulation studies for deriving appropriate scenarios to optimize the design and cost. vii) Nutrient transport/ leachate analyses and viii) Cost analyses of water table management systems.

2.1 Prospects of Drainage Studies in India & Other Countries

As per documentary evidences, subsurface drainage has been experimented in India for the last 130 years or so. The first ever subsurface drainage experiment to reclaim salt affected land was conducted by Robertson in 1873 (Gupta, 2002). Stone drains and tile drains were laid out to reclaim the lands. In spite of the use of collars in laying these drains, silting problem was noticed. The recorded evidence of environmental degradation due to water logging was in the first decade of the last century. Increasing incidences of Malaria in the Amritsar city scared the people to migrate to safer areas. Subsurface drainage through tube wells was implemented to tackle the problem of waterlogging. Sixteen tube wells of 0.0425 cumecs capacity each were installed. The scheme, operated for 16-17 years, was reported to be successful.

Similarly, Manjari drainage scheme, located in Khadakwasala irrigation project near Pune, in the command of distributory No. 5 and 6 of old Mutha right bank canal in Maharashtra state could be mentioned. Irrigation in this area commenced in 1880. The land adjacent to the nalla was damaged due to water logging in 1920. Some portion of damaged land was also affected by salt. The scheme comprised of two main drains with 16 underground closed lateral drains, Comprising earthen pipes loosely shunted in sockets and filled with filter material in periphery. The drainage scheme was successful and almost all damaged area was reclaimed within the period of 5 years. Though there were some success stories in past indicating correctly identification of drainage problem and technical competence to tackle it, major achievements were accomplished during the last thirty years when a subsurface drainage based reclamation package was developed and implemented to cover about 40000 ha of waterlogged saline lands in India. (Gupta, 2002)

With the expansion of irrigation through inter-basin transfer of water, twin problems of water logging and soil salinity continued to expand. Presently the area affected by these problems in the irrigation commands alone was estimated to cover about 5.6 million ha. Experimental evidences led to the realization that subsurface drainage was an essential intervention to reclaim such lands. In order to develop a package of practices for reclamation of water logged saline soils, an attempt was made by Central Soil Salinity Research Institute, (CSSRI) Karnal at Sampla as early as in 1980. Both open and tile drains functioned well and reclaimed the water logged saline lands.

After 1980 several experimental pilot areas were established under All India Coordinated Research Project (AICRP) on Sub-surface drainage Research and Indo-Dutch Network Project. During the last decade of 20th century, the total area under subsurface drainage increased to 16745 ha in the country under different projects. (Gupta, 2002; Raghu Babu 2004).

Subsurface drainage system was installed using bell mouthed perforated stone ware pipes as drain pipes and coarse sand as the envelope material at Endakuduru village in Krishna Eastern Delta near Machilipatnam in coastal Andhra Pradesh. The system effectively reclaimed the water logged and salt affected soils (Annual reports of All India Coordinated Research Project on Agricultural Drainage, India AICRPAD 1986 – 1998). In the drained areas, soil conditions were improved significantly and yields of paddy, sugarcane, betel vine and turmeric were increased by 30, 19, 30 and 11 %, respectively as compared to the yield obtained from the same fields that were not provided with drainage system. Some of the areas which were reclaimed were found low lying farmers fields under paddy than mean sea level.

Anticipating this change, drainage research continued to be one of the major thrust areas of the agricultural research organizations in the country. A large number of small-scale research projects were initiated which were culminated into operational research projects in Rajasthan and Haryana (RAJAD, 1995,). Later on private investments in terms public-private partnership for planning, design and implementation of large-scale drainage projects started pouring in the states on Maharashtra and Karnataka. There was a lot change in technological part of drainage also. The research experiments in different parts of India started with manual installation. Use of clay/concrete drain pipes and gravel filter envelopes was more common during those days. Now a days, most of the subsurface drainage project activities such as survey, design, layout and installation are mechanized. Use of corrugated perforated PVC drainpipes and woven/ non –woven envelope material has become accepted practice. In contrast to earlier projects of small areas, new projects are being planned for few thousand hectares. Besides, technological aspects of subsurface drainage, social engineering and environment issues (related to disposal of drainage effluent) require more attention.

Based on the pilot area studies in some locations, the following conclusive recommendations for subsurface drainage (Indo-Dutch Network Project, India, IDNP, 2002) were made for the two-ecological sub-regions of Andhra Pradesh for efficient planning, execution and functioning of sub surface drainage systems. For areas with sandy loam to clay loam soils as in Nagarjuna Sagar Right canal command area (Annual rain fall: 800-900 mm) having salinity, sodicity and water logging problems, a pipe subsurface drainage with the following characteristics could be adopted. A drain spacing of 30-60m and a drain depth of 0.9-1.0 m with Geo-textile envelope were the recommendations of the project. The package proved to increase paddy yield by 50% in two years. In addition to the above, following supplementary measures were also adaptable. Growing green manure like Dhaincha in combination with application of organic manures @ 5 t/ha along with gypsum @ 50% of requirement could give the farmers an additional income despite enriching the soil health. A drain spacing of 30-60 m and a drain depth of 0.9 to 1.0m with either Geo-textile or Nylon mesh envelopes were the recommendations for the study area. In both the areas, as a low cost measure, open drains of 1.0- 1.1m deep spaced between 75-100m were also recommended, but they were found requiring more maintenance of loss of considerable productive area of their construction.

To summarize, the results of investigations done in many places in Gujarat, Haryana, Maharashtra, Rajasthan, Andhra Pradesh, Karnataka and few studies in Tamil Nadu revealed that the drainage was a proven technology when executed and maintained by research staff. All the experiences of the past, when the site was left by the scientist and field staff., farmers, in very few cases only maintained in the post project period scenario The assets created at Uppugunduru ORP site., because of Agam Cooperative Society, farmers could maintain the system hardly for 4 years after the scientists left the site for the farmers. Linking of drainage with development schemes and involvement of public-private partnership assure that technology is going to survive with time and would be modified /standardized in due course of time to meet farmers' requirements.

Hiller *et al*., (1971) through their lysimeter experiments, concluded that drastic reductions both in quantity and quality of grain sorghum yield occurred when water tables were maintained at 30 and 60 cm as compared to the 90- and 120 cm treatments. Reduced growth of grain sorghum as measured by crop height and leaf area index occurred in general with the shallower water tables.

Carter *et al.,* (1973) had concluded that sugarcane yields had gradually increased during the past 50 years in Louisiana from a low of 7 tons/acre (State average in 1922) to a maximum of 29 tons per acre in 1963(USDA 1919-1971).

Ritzema *et al.,* (2009) had compiled the works at global level works on drainage and reported that salinity affects 10 to 16% of all irrigated lands while the annual rate of land loss due to waterlogging and salinity was about 0.5 million hectares per year. In this dissertation, the role of subsurface drainage to reduce these problems in irrigated agriculture in arid and semi-arid regions has been analysed and challenges for improving subsurface drainage practices have been formulated. To reverse the negative trend in salt build-up and waterlogging in irrigated lands in semi-arid and arid regions, a number of challenges for enhancing the role of subsurface drainage have been formulated: balancing top-down against bottom-up, from standardization to flexibility and - focus on capacity development.

The literature pertaining to benefits of drainage systems for various crops in other countries were many, it is restricted with the few articles with more emphasis on Indian experiences on drainage benefits and need to realize the importance of single panacea of dual system i.e. water table management system to overcome the earlier failures in this direction. Though enough research experiences prove the adaptability of water table management systems in other countries, this research is first of its kind in India.

2.2. Water Table Management Systems

The terms, Controlled Drainage-Subirrigation (CD-SI) system, Controlled and Réversible Drainage System and Water Table Management Systems are synonymously used in différent countries. The Water Table Management strategies can be grouped in to 3 categories (Camp *et al.,* 1992) namely, i) Sub Surface Drainage (SSD) which mainly lowers the water table during wet periods until an equilibrium condition exists. ii) Controlled Drainage (CD) which is achieved by placing a control structure such as flash board riser, in the outlet ditch or subsurface drain outlet to control the rate of outflow.iii) Controlled Drainage/ Subirrigation (CD-SI).

Several advantages of CD-SI system have been reported by Skaggs *et al* 1972 They are: i) Low labour requirement. ii) Single system provides both drainage and irrigation.iii) Low maintenance requirements. iv) No delays in cultural practices because of irrigation. v) Little or no nutrient leaching from the root zone.

Controlled Drainage-Sub irrigation (CD-SI) system operates as a traditional drainage system during wet periods; excess water is removed from the field through a system of underground drain tubes which conveys outlet to a main drain tube or open ditch. During times of water shortage, a structure (such as a flashboard riser) is used in the outlet ditch to regulate the drainage rate. The dual-purpose system would normally fluctuate between the drainage, controlled drainage and subirrigation modes several times during one cropping season (Doty *et al.,* 1975).

Skaggs *et al* 1996 reported that when a structure (such as a flashboard riser) is used in the outlet ditch to regulate the drainage rate, the system may function in either the controlled drainage or subirrigation mode. The process called controlled drainage occurs when the structure is used to conserve water by reducing drainage outflows and when no additional water is pumped in. During dry periods, water may be pumped into the control outlet where it moves back through the drainage network, thus raising the water level in the field. In this mode the system is being used for subirrigation. The dual-purpose system will normally fluctuate between the drainage, controlled drainage and subirrigation modes several times during one cropping season. Because the role of the system often changes, intensive monitoring and management of the system is necessary for effective operation.

T.E. Brabben et al 2002 in Konwlege and Research Programme report concluded that on integrated irrigation and drainage to save water. The report briefly reviews the findings of the study, which incorporates the field experience from Egypt, the development of the predictive tools and practical guidelines for controlled drainage and the potential for controlled drainage in other countries. Four principal actions to encourage dissemination and uptake are recommended. i) Awareness creation among policy makers/decision makers ii) Study of farmer management of controlled drainage through pilot trials iii) Enhancing the skills and knowledge of front line staff iv) Simple guidance leaflets for farmers. The proposed programme could be aimed at Egypt and India in the first place taking advantage of Egyptian experience.

2.3 Characterization of waterlogging and assessment of cropping constraints.

"Waterlogging" is defined as the state of land in which the subsoil water table is located at or near the surface with the result that the yield of crops commonly grown on it is reduced well below for the land, or, if the land is not cultivated, it cannot be put to its normal use because of the high subsoil water table. "Salinity control" is defined as the physical control, management, and use of water and related land resources in such a way as to maintain or reduce salt loading and concentrations of salt in water supplies. Drainage of irrigated land is required to reduce waterlogging and soil salinization that inevitably accompanies waterlogging in arid zones. At present, about 20-30 million hectares of irrigated land are seriously affected by salinity. (http://www.fao.org/nr/water/topics_qual_waterlogging.html

McFarlane et *al.,* (1989) classified common methods of assessing waterlogging are briefly described because the estimation of the extent of waterlogging depends on the methods used.

i) Air filled porosity: Wesseling and Van Wijk (2002) considered that soils were waterlogged if they had less than 10% air-filled porosity due to the presence of water.

However, under this definition severely compacted soils would be classified as waterlogged even with little water present.

ii) SEW_{30}: After a review of drainage experiments in The Netherlands, Sieben considered that crop yields were adversely affected when the water table was within 30 cm of the soil surface. He introduced the term SEW30 (i.e. the sum of excess water table rise above 30 cm) as a measure of waterlogging intensity. The SEW30 is the sum of all daily values (in cm) by which water tables are closer than 30 cm to the soil surface. Hence if the water table was 20 cm below the soil surface for 7 days, then at the soil surface for 2 days and afterwards more than 30 cm from the soil surface:
$SEW_{30} = (10 \times 7) + (30 \times 2) = 130$ cm d (units of cm days).

iii) Remote sensing: Waterlogged cereals are usually yellow or brown which suggests that coloured aerial photographs could be used to map the extent of the problem. However, there are many other crop conditions which produce the same colours. An examination of the spectra of waterlogged and non waterlogged wheat and oat crops (using a portable field spectroradiometer) showed that there is poor discrimination in the visible part of the spectrum but very good discrimination in the near infrared. The best discrimination using airborne multispectral scanning and Landsat TM was in the near and thermal infrared.

Tabuchi, 1987 had worked on the characterization of trafficability of machinery in paddy fields of Japan. It was found that trafficability in the marine alluvium and organic clay muck areas were hindered by shallow and weak plow soles. Areas with good plow soles at 20cm to 30cm depth and a peak CI of above 4.0 kg/cm^2 as in the riverine alluvium soil areas have better mechanization practices with tractor cultivation and combine harvester. The timing of the planting season to dry weather at these stages of activities is critical. The fields should be leveled and the drainage system improved to lower the ground water table especially for the marine alluvium and organic clay muck areas.

Brabben and Abbott (2002) presented a way for dissemination and uptake of controlled drainage methods with the intention of increasing the adoption of this technique. Four principal actions to encourage dissemination and uptake are recommended: i) Awareness creation among policy makers/decision makers ii) Study of farmer management of controlled drainage through pilot trials iii) Enhancing the skills and knowledge of front line staff iv) Simple guidance leaflets for farmers.

Studies by Symposium on Applied Computing SAC(1998) showed that the wetland area of the state was 1.24% of the total area in 1991. The total number of wetlands of the size 56.25 ha and above for the whole state was estimated at 1, 175 covering an area of 1,615.12 sq.km. The number and area of wetlands of the size 2 ha and above in eight districts in 2001 were 4,779 and 731.72 sq km respectively.

The wetlands in Tamil Nadu comprises lakes, ponds, reservoirs and seasonally waterlogged areas. Nine districts namely Vellore, Cuddalore, Pudukkottai, Tanjore, Ramananthapuram, Tirunelveli, Kanyakumari, Erode and Chengalpat mainly comprises majorly such waterlogged lands. During 2000-2001, the Central Ground Water Board took up special studies aimed at delineating waterlogged areas and feasibility studies for anti-waterlogging measures in 10 studies in different states. Bhavani Command area was being one among the 10 study areas. The working group constituted by the Ministry of Water Resources estimated in 1991 that an area of 1.6 lakh hectare is suffering from the problem in Tamil Nadu State.

2.4 Design and execution of hydraulically efficient water table management system

Fox *et al.,* (1956) had reported the procedure of sub irrigation systems design and requirements. They have evolved criteria for sub irrigation, the design dimensions of feeder ditch. They pointed out that in order for a subirrigation to be practical either an impermeable layer or a permanent water table should exist at a rather shallow depth to prevent excessive seepage losses.

Skaggs *et al* (1972) conducted an experiment to determine the feasibility of subirrigation on a Lumbee sandy loam soil. The results showed that water could be supplied to the root zone at a rate more than sufficient to satisfy plant needs for 7.5m and 15m tile spacings; however their response was too low for the 30m tile lines. The theoretical calculations showed that the suggested water table depth range of 60-90cm for potatoes could be maintained in this soil with a tile spacing of 19.2m.

Skaggs(1973) reported that the movement of the water table for subirrigation conditions was characterized by numerically solving a non- linear differential equation describing unsteady flow above a horizontal impermeable layer. The effect of water loss by evapotranspiration and deep seepage on the water table rise during subirrigation was also determined by numerical methods. It was concluded that an approximate solution derived could not be used to predict reliably the movement of the water table midway between drains when either D or R (two dimensionless parameters), was greater than 0.5. Solutions for smaller R and D values can be obtained from numerical solutions plotted. The test results with Hele-Shaw model showed that for subirrigation from open ditches the D-F assumptions were valid for L/d values, the numerical solutions given, will provide a reliable prediction of the water table movement.

Doty *et al.,* (1975) conducted a field study of water table control through subsurface conduits in sandy soils. They found that the water table must be kept at 105 cm or less from the soil surface. Silage yields from a field under controlled drainage were greater than those from a non drained field, and each additional day between 25 and 55 days that the water table was 105 cms or less from the surface, Silage yield increased from 0.3-0.6 ton per acre. They reported satisfactory results from drain line spacing of 40 m or more in sandy soils.

Doty and Parsons (1979) conducted an experiment to determine the water requirements and water table variations for a Controlled and Reversible Drainage (CaRD) System, with drain spacing of 8, 16 and 32 m. They found that the highest yields were produced between tile lines spaced 32m apart on both sandy loam and sandy clay soils.

Yau and Skaggs. (1980), reported that the Richards Equation for transient, two dimensional saturated –unsaturated flow in a two-layered soil was solved for subirrigation boundary conditions using a finite difference method. Solutions were obtained for a Panoche soil as the surface layer over Sarpy loam and Lumbee sandy loam as the high hydraulic conductivity bottom layer. The study resulted in the following conclusions., 1)The effect of increasing the drain depth so that it approaches or penetrates a high conductivity bottom layer is to reduce head loss due to convergence near the drain. The effect of deeper drains also increases with the hydraulic conductivity and thickness of the bottom layer. 2) As far as possible drains should be placed at the interface in the top of the high conductivity layer. Further increases in the depth of drain will not result in significant increases in subirrigation rate.

The most critical part in the design of subirrigation system is the determination of the drain spacing and drain depth necessary to supply water during dry periods and remove excess water during wet periods. According to Skaggs (1981), the required drain spacing depends on the soil properties such as hydraulic conductivity and profile depth. The optimum water table depth again depends on the soil properties, the crop to be grown and climatological factors of a given site.

Skaggs (1981) had summarized the factors affecting water movement in subirrigation drainage systems and discussed, as they relate to the design of such systems. The importance of analyzing operation of a subirrigation system under changing weather conditions was emphasized and the use of DRAINMOD, for that purpose was discussed. The results showed that both subirrigation and drainage requirements could be satisfied with 18-m drain spacing. While a 25 m drain spacing would be satisfactory for conventional drainage alone.

Carlos *et al.,* (1982) proposed an approach for incorporating crop drainage requirements into drainage design procedures. The overall methodology linked crop drainage requirements, climatological data and drainage theory into a workable design method through incorporation of the stress-day index concept into a water management model.

Doty *et al.,* (1986) reported the steps required to design Controlled Drainage-Subirrigation system for several soils in humid areas. They produced a nomogram of soils that could be used as a design guide. The nomogram uses soil hydraulic conductivity, approximate drain spacing, and ratio of a controlled Drainage -Subirrigation system spacings to subsurface drainage spacings.

Skaggs and Tabrizi (1986) had simulated Corn yields for a range of drainage system designs on 12 North Carolina soils. The spacings were used in Hooghoudt's equation to determine a design drainage rate (DDR) for eastern North Carolina. The average DDR values obtained were 1.1 cm/day for good surface drainage and 1.3 cm/day for poor surface drainage. Use of those DDR values would result in profits greater than 90% of the cases analyzed. Profits greater than 95% of the optimum were predicted in 51, of 72, or 70% of the soils considered.

To design a successful water table management system, five tasks must be performed (Evans and Skaggs, 1989). They are: 1) Preliminary evaluation and feasibility of the site. 2) Detailed field investigations. 3) Design computations.4) System layout and installation and 5) Operation and management. Detailed field investigation would enable to compute proper drain depth, drain spacing, drain grades, number and size of control structures needed to maintain a uniform water table and a proper pump capacity required for both water supply and the drainage outlet. Soil horizon, arrangement data, topography and crop rooting characteristics would help to determine drain depth, which generally ranged from 3-5 feet, depending on the site conditions (Evans and Skaggs, 1989).

Anonymous (1998). A good gravity or pumped drain outlet is needed to provide adequate flow capacity for expected peak discharges. For gravity flow systems, the drainage outlet should be at least 1.20 m below the average land surface (Evans and Skaggs, 1989). Carter *et al* .(1983) developed controls for a CD-SI system installed in a silt clay and silt loam soil. Electrical float switches were used to activate the pump for water removal and a solenoid valve for the addition of water to the system.

Pandey and Tyagi (2003) described four methods for deciding the land suitability for installation of sub-surface drainage system with their limitations in terms of time, cost and technical feasibility. Experimentation method required application of amendments and installation of tube wells which were essential under such situation. The outcome of the experimentation was generally known only after 2 or 3 years. If there was re-sodification, it indicated that the leaching amount was less than the leaching requirement and sub-surface drainage was needed.

2.5 Performance evaluation of water table management systems

G.O. Schwab *et al.,* (1956) had conducted experiments at Sandusky, Ohio on poorly drained Toledop silty clay soil. The field installation consisted of surface drained and combination tile and surface drained 0.5acre plots each replicated four times. Corn with conventional tillage and with no tillage was compared for the period 1968-71. Yields of all crops by drainage treatment (all years) increased in the following order: surface drainage only, tile drainage only, and the combination of surface and tile drainage systems.

Hiler *et al.,* (1971*)* reported that in considering the necessary steps for proper agricultural drainage design, the logical step is the determination of the drainage requirements of crops. The static water tables were maintained at 30,60,90 and 120 cm below the soil surface during the entire growing season. They found drastic reductions both in quantity and quality of grain sorghum yield occurred when water tables were maintained at 30 and 60 cm as compared to the 90 and 120 cm treatments. Considerable crop oxygen stress occurred in the 30-cm treatment fin ODR- is less than 20×10^{-8} $g/cm^2/min$ in the root zone) and in the 60-cm treatment Oxygen Diffusion Rate (ODR)) ranged from 40 to $90x\ 10^{-8}$ $g/cm^2/min$. during the following season.

Skaggs *et al* (1972) conducted field experiments at H.C.Austin farm near Aurora, North Carolina to determine the feasibility of the irrigation through subsurface drains and to study the water movement under subirrigated conditions in Lumbee sandy soil. The results showed that water could be supplied to the root zone at a rate more than sufficient to satisfy the plant needs for 7.5m and 15-m tile spacings. However, the response was too slow for the 30-m spacing tile lines. Theoretical calculations showed that the suggested water table depth range of 60 cm to 90 cm for potatoes could be maintained in the soil with a tile spacing of 19.2 m. An equation also was derived for the upward movement of the water table during subirrigation.

Hermsmeier (1973) conducted experiments with 7 drain lines ranging in depth from 135 cm to 90 cm at the lower and upper ends respectively by installing in the test site at a spacing of 60m. The drains are each 735 m. in length and were installed on a grade of

0.1 per cent. He concluded that shallow drains installed at a 120 cm depth and 60 m spacing in a clay and loamy clay soil removed only from 12 percent to 7.2 percent of the salt added by the irrigation water during four cropping seasons over a 2 ½ year period.

Doty *et al.,* (1975) reported that the Southern Coastal Plains contains millions of acres of a sandy soils with low water holding capacity. Controlled drainage alone should increase yields in the Southern Coastal Plains, but if the water level in the outlet ditch were controlled by pumping water from a well or lake into it during the extended drought, substantial increases in yields might be possible. The estimates of silage yields calculated, that can be produced with sunshine energy available at this location, without other limitations, was about 40 tons per acre., The highest yield in the study was 29.1 tons per acre.

Skaggs (1977) reported that the conventional methods of predicting water table drawdown due to drainage usually assume that the drain tube is completely permeable and offers no resistance to the entry of water. However, the reduction of inflow due to finite openings in drains all along has been recognized. He analyzed the effect of drain tube openings on drainage from a ponded surface. They concluded that drain spacings could be increased by more than two fold by placing a thin layer of gravel around the tube to reduce the hydraulic resistance near the drain.

Doty *et al* (1978)a had designed, instrumented, and operated a controlled and reversible drainage system for 2 years. Rainfall was below normal in 1975 and above normal in 1976. A positive head was required to produce the water mound. The highest yields (3- year average) were produced between tile lines spaced 32 m apart on both sandy loam and sandy clay loam soils; however difference in yield for the 8m, 16m and 32 m spacings were significant only at 85 per cent . The data indicated that controlled and reversible drainage could be accomplished with drain lines spaced 32 m apart for sandy clay loam soil, if drainage is provided during excessive rainfall. In sandy loam soils, 32m or wider spacings could be used in sandy loam or more permeable soils.

Skaggs (1978)b developed DRAINMOD as a field-scale, hydrologic model for design and evaluation of agricultural drainage and related water management systems.

Gilliam and Skaggs. (1979) reported that **c**learing and draining of unmanaged forest land for agricultural production had little effect upon quantity of drainage water, but peak runoff rates from the developed land were about three times higher than those from undeveloped sites. Development also resulted in a very significant increase in nitrogen and phosphorous afflux in the drainage water. Controlled drainage utilizing flashboard risers can be utilized to change both the hydrologic characteristics and the nutrient efflux by as much as 34% but the reduction varied with soil and management conditions.

Mohammad and Skaggs (1983) conducted a laboratory experiment to determine the effect of the drain tube openings on transient drainage and subirrigation process. They found that there was an increase in drain flow, draw down and subirrigation rates with increase in total perforated area up to 38.5 cm^2/m. By doubling the perforated area to 79 cm^2/m further increased the draw down rate with the use of 5cm thick gravel envelope. The locations of drain tube perforations had only a small effect on draw down, drainage outflow and subirrigation rates.

Mohammad and Skaggs (1984) used a laboratory soil tank to determine the effect of drain tube perforations on transient drainage and subirrigation processes. They concluded that 1) There was an increase in drain flow, drawdown and subirrigation rates with increase in total perforation area up to an area of 38.5 cm^2/m. Doubling the perforation area to 79 cm^2/m further increased the drawdown rate and about the same effect as the use of a 5 cm gravel envelope for the cases tested. 2) Tubes with smaller perforation areas had a greater proportion of the total hydraulic head loss occurring near the drain for both drainage and subirrigation.

Doty *et al* (1985) conducted a study in 800 ha (2000 acres) of land near Tarboro, North Carolina study to assess water table management effects on water saving and crop yields. Computer simulation showed that in 1982, without water level control, only 7% of the area could be irrigated with water pumped from Mitchell Creek. Crop yields in 1982 increased 20% and 16% for corn and soybeans, respectively, in the areas with water table control.

Smith *et al* (1985) had conducted a field experiment and a computer simulation analysis to evaluate the water requirements of subirrigation under three methods of system control. First year results from the field experiments indicated that irrigation water requirements could be reduced by controlling the system such that the midpoint water table depth was allowed to fluctuate within certain limits.

Focus *et al.* (1987) stated that one of the major operational-management problems of CD-SI system was deciding when to rise or reset the outlet water level to prevent over drainage. An automatic control system could alleviate this problem.

Davenport and Skaggs (1990) had conducted an experiment to determine the effect of fabric wrap envelope and drain slope on the performance of a combination of drainage and subirrigation system. The experiment consisted of 32 and 102 mm diameter drain tubes in two replications of four treatments of 0 and 0.2% slope, with and without fabric envelopes in a Portsmouth sandy loam soil. The fabric wrap envelope was effective in increasing the subirrigation rates, but effectiveness decreased with time. The entry resistance was less for drains that had both envelope and slope than any other treatment.

Borin *et al.,*(2003) studied the feasibility and performance of water table management, an experimental facility that reproduced a hypothetical agricultural basin on a 6 ha area was laid out in North East Italy in 1996. Maximum drainage volume was measured in the conventional pipe system that discharged, on average more than 50% of annual rainfall. With the surface system about 60% less water was discharged and 73-76% less with the controlled drainage systems, with slight differences between pipe and surface systems.

Prasad (2007) installed modified CD-SI system, the perforated pipes were placed at shallow depths of 40-45 cm having a closer spacing of laterals at 2.0 m at Soil and Water Conservation Field Laboratory In Tamil Nadu Agricultural University. The growth components like plant height, Leaf Area Index (LAI), Dry Matter Production (DMP) were significantly influenced by the method of irrigation. The maximum plant height was recorded in case of modified CD-SI system with treated wastewater (181.3 cm) when compared with other treatments, viz., furrow irrigation with treated wastewater (159.3cm), furrow irrigation with bore well water (150.6cm) and Drip irrigation with available bore well water (116.8cm) at 120 DAS.

2.6 Simulation studies for deriving appropriate scenarios to optimize the design and cost

Herman and Schilfgaarde (1963) presented a simplified procedure for predicting rate of fall of water table in tile drained or ditch-drained land. The procedure was based on steady state theory and abrupt drainage of pore space. In this respect, it lacks the theoretical sophistication of certain other treatments. Its simplicity, general however, favor of use of the proposed procedure in routine drainage design.

A useful tool for evaluating the hydrologic interaction between subsurface drainage system design parameters and wastewater irrigation applications is the agricultural water management computer model DRAINMOD (Skaggs, 1980)

Skaggs *et al.,*(1981) reported that the water management model DRAINMOD was evaluated for North Central Ohio Conditions by comparing predicted with measured drainage volumes for 8 years of record. Comparisons were made on four replications of subsurface drainage alone, surface drainage alone and combination plots having both surface and subsurface drainage. Inputs to the model were climatological crop and soil property data and drainage system parameters for each treatment. Comparison were made for the months of April through September; corn was grown on the experimental plots for all years considered.

Skaggs and Nassehzadeh (1982) had developed simulation methods for design and evaluation of drainage systems designs for waste water land treatment sites. The methods described were based on DRAINMOD, which may be used simulate the day to day performance of an artificially drained land treatment system over a long period of climatological record. Use of the model was demonstrated by considering an example of waste water application on a poorly drained sandy loam soil near Wilmington. N.C. Decreasing the drain spacing from 100 to 30m allowed a four-fold increase in the volume of water that could be applied in the example considered. Surface drainage has a much smaller effect on the amount of waste water that could be applied. Drainage outflows are also predicted by the model and may be used to help assess the pollutant load leaving the site.

Skaggs *et al.,* (1982) modified the DRAINMOD model to quantify stresses on corn caused by both excessive and deficient soil water conditions and to weigh those stresses according to the stage of the growing season and crop susceptibility at the time they occur. Methods were added to predict the planting date and thus determine any delays in planting that might occur due to the drainage system design. An approximate crop response model was used to predict annual crop yields in terms of stress-day indices for deficient and excessive soil water conditions and the delay in planting date.

Chang *et al.,* (1983) studied comprehensive analysis of soil water transformation on a field scale where most water management facilities were designed and installed as a single unit. The basis of DRAINMOD was a water balance at midpoint between two parallel drains. Using the approach of successive steady state equilibrium, the transient water movement in a tile-drained field was analyzed as steady state flow at sufficient small time increments. The reliability of the model for irrigated cropland in semiarid climate of California was tested with field data. The water table elevations were predicted by DRAINMOD agreed reasonably well with measurements for five experimental locations differing in soil texture in the San Joaquin Valley and the Imperial Valley. When the water table draw down exceeds 150 cm, the model over estimated the depth to the water table.

Fouss *et al.,* (1987) used the DRAINMOD model for simulating subsurface drainage in the lower Mississippi Valley. Predicted and measured surface runoff, subsurface drain flow, and water table depth were compared for 3 years, 1981, 1982, and 1983 which were, respectively, normal-to-wet, drier than normal, and very wet in growing season soil water conditions. Model predicted runoff, drain flow, and water table depth compared more closely with the field measured values during the wettest year, 1983. For the drier-than-normal year, 1982, runoff and drain flow were significantly over predicted because evapo-transpiration (ET) was underestimated by the model. Assumed deeper rooting for corn in 1982 increased soil water withdrawal by ET and significantly improved predictions of water table depth.

Workman and Skaggs (1989) compared a finite difference model SWATREN and DRAINMOD for North Carolina using a 15-years data set. Three drain spacing of 7.5 m, 15 m and 30 m were used to drain a sandy loam soil. The standard error of estimate for water table depth was ranged from 8.9 to 29.0 cm for SWATREN and 7.5 to 19.0 cm for DRAINMOD. The average absolute deviation for water table depth for the period of 4600 days was 13.4 cm for SWATREN and 11.4 cm for DRAINMOD. The results indicated that SWATREN required more parameters on soil properties and crops as well as more computing time than DRAINMOD.

Carthy and Skaggs (1990) developed a simple model for predicting drainage rates (flux) for changing boundary conditions, based on a water balance for the area between parallel drains. Drainage flux relationships were developed from numerical solutions to the non-linear Boussinesq-Equation. ***Drainmod*** was used to modify the curves which are obtained from solutions to the Boussinesq-Equation to predict drainage flux. Standard version DRAINMOD-5.1 used Hooghoudt's and Kirkham's equations to predict drainage flux for Elliptic and ponded water tables at the surface respectively.

Parsons *et al.,*(1990) developed a water management model, WATRCOM, (Water Management Model) for watershed scale drainage systems were developed. The model is based on water balances in sub regions of the watershed. Components of the model consist of a finite element solution of the Bousinesq equation to characterize the water movement in the saturated zone, a one dimensional analysis in the unsaturated zone at each node in the finite runoff. The model simulation procedures were tested using published solutions for parallel drainage to open ditches. WATRCOM predictions of water table height were within 1 % of the published finite difference solution for all cases considered. Differences in discharge rates over the simulation were less than 4%. Finer finite element grid spacings tended to increase predicted discharge rates.

Skaggs *et al.,* (1991) arrived at a conventional theory for predicting water table response to drainage and subirrigation. They assumed that the water table elevation directly over the drain is equal to the pressure head in the drain. This is contrary to field measurements which show head losses near the drain may be significant. Numerical methods were used to solve the Bousinesq equation subject to the radial flow condition near the drain. Solutions were obtained for both drainage and subirrigation. Solutions showed that head losses near the drain make up a relatively large percentage of the total head loss for subirrigation with narrow drain spacings.

Borah and Haan (1991) stated that errors could be introduced into model during the calibration process due to model structure, data used for estimation, objective function chosen, fitting criterion, and interaction of parameters

Chescheir *et al.,* (1992) developed a computer method for predicting nutrient and sediment removal from agricultural drainage water pumped on to wetland areas. The method utilized a model for simulating drainage from agricultural land and a model for simulating overland flow and nutrient and sediment removal on wetlands. Both simulation models were calibrated using data collected in field experiments. The simulation models were then coupled to predict the percent removal of sediment, total phosphorus (p), total Kjeldahl nitrogen (TKN), and nitrate nitrogen (NO_3-N) from drainage water for a 20 year period of climatological data. This method predicted that the 240 ha wetland buffer at the field research site could be expected to remove over 79% of the TKN, NO_3-N, P, and sediment in drainage water from a 1250 ha agricultural watershed. The method was used to evaluate the effects of buffer size and shape on the nutrient and sediment removal effectiveness of the wetland.

Seymour *et al.,*(1992) predicted the corn yield response to delayed planting. A two year field study was conducted to determine the effect of delay in planting on corn yield in eastern North Carolina. The relationship between yield and planting date was needed in order to quantify the effects of traffic ability, as influenced by drainage system design, on yield. Corn was planted on drained and sub- irrigated plots at planting dates ranging from mid-March to early June. Results indicated that yield decreased with planting date delay after 10 April. Results were in general agreement with those in earlier un irrigated experiments. The relationship between relative yield, Y, and planting date delay, D (days), beyond 10 April could be described by a piecewise linear relationship; $Y = 1.0 – 0.0088$ d, for $D < 40$; and $Y = 1.3 – 0.0162 D$, for $40< D < 80$. These relationships were used in the water management simulation model, DRAINMOD, to predict the effect of drainage design on planting delay and relative yield.

Wright *et al.,* (1992) studied the impacts of water table management (WTM) practices on water quality were modeled using a linked version of (Parsons and Skaggs, 1988). The *denitrification* component and the linked DRAINMOD - CREAMS model were modified to simulate daily hydrology (runoff, infiltration, evaporation, and soil moisture content), erosion, and nutrient processes for different WTM conditions. Measured data from Baton Rouge, Louisiana, were used to validate the linked model, and then controlled drainage- sub irrigation (CD-SI) was simulated to investigate the effects of different WTM systems on runoff, erosion, and nitrogen losses.

Johnson, *et al.,*(1991) developed an automated computer based system to control field scale controlled drainage subirrigation (CD-SI). The system successfully monitored the soil water potential-based control of CD-SI could be accomplished with automatic computer controls. Predicted surface runoff and subsurface drainage volumes were in good agreement with measurement with measured values for all three drainage treatments. Comparison of measured and predicted relationships showed that the time of occurrence of surface runoff and subsurface drainage events were predicted accurately in almost all cases and the deviations were found very small.

Bengtson *et al.,*(1993) had developed a model (FWTMOD) as a simplified method to predict daily changes in water table depth for a controlled drainage and subirriation system. The model was based upon a fluctuating water table equation derived by de-Zeeuw and Hellinga of the Netherlands. The model was calibrated and tested to evaluate its application in simulation of a subsurface drainage system. Monthly averages of the daily reaction factor of water table fluctuations and daily recharge –coefficient of soil moisture were determined from three years of data from field experiment. Recharge coefficients were multiplied by a correction factor to account for antecedent soil moisture conditions prior to the onset of rainfall events. The reciprocal of moisture deficit in the soil profile was used to estimate the correction factor. In general, the simple model, FWTMOD predicted daily water table fluctuations nearly as well as DRAINMOD for conventional subsurface drainage in a Commerce silt loam soil.

Gupta *et al.,* (1993) evaluated the model, DRAINMOD, for possible applications under semi-arid climatic conditions by comparing the predicted mid-span water table heights with the measured ones in four subsurface-drained test plots in Kota, India under the RAJAD (Rajasthan Agricultural Drainage) Research project. In general, a good agreement was observed between the measured data and the predicted values. The average absolute deviations between the measured and predicted mid-span water table heights ranged from 14 to 24 cm for the four test plots. The corresponding standard errors of estimate ranged from 15 to 30 cm. Based on these investigations, it was concluded that DRAINMOD could be used to design or evaluate subsurface drainage systems under the semi-arid climatic conditions.

Lorre *et al.,* (1994) studied the comparison of models for subsurface drainage in flat and slope lands. *Sidra* and *Slop* models were utilized for comparison. The two models were in excellent agreement for steady-state and transient drainage on flat lands. Differences in shape factors calculated from the two models were always <4%. The implicit solutions in *Sidra* were also in good agreement with *Slop* for slopping lands. The numerical solutions in *Slop* were reliable for low slopes but were unstable for conditions in which the streamlines could not be considered as horizontal.

Kandil e*t al.,* (1995) modified the water management model DRAINMOD to predict soil salinity as affected by irrigation water quality and drainage system design. The objectives of this study were to incorporate an algorithm to quantify the effects of stresses due to soft salinity on crop yields and to demonstrate the applications of the model. DRAINMOD -S was capable of predicting the long-term effects of different irrigation and drainage practices on crop yields. The overall crop function in the model included the effects of stresses caused by excessive soil water conditions (water logging), soil water deficits, salinity, and planting delays. The objective function for these simulations was crop yield. Soil water conditions and soil salinity were continuously simulated for a crop rotation of bean, cotton, maize, soybean, and wheat over a 19 years period. Yields of individual crops were predicted for each growing season. Results were also presented on the effects of drain depth and spacing on yields. It was concluded that DRAINMOD-S was a useful tool for design and evaluation of irrigation and drainage systems in irrigated arid lands.

Breve *et al.,* (1997) described the movement and fate of nitrogen in shallow water table soils with artificial drainage by utilizing the model DRAINMOD- N. The nitrogen transport component was used on an explicit solution to the advective-dispersive-reactive (ADR) equation. Nitrate-nitrogen was the main N pool considered. Functional relationships were used to quantify rainfall deposition, fertilizer dissolution, net mineralization, denitrification, plant uptake, surface runoff and subsurface drainage losses.

Luo *et al*., (2000) modified the original version of the DRAINMOD, which included freezing, thawing and snowmelt components. It numerically solved the heat flow equation to predict soil temperature. The modified DRAINMOD predictions of soil temperature agreed well with field observations. Luo *et al.,* (2001) predicted the field hydrology in cold conditions with modified DRAINMOD. The modified DRAINMOD correctly predicted the timing and magnitude of drainage events resulting from snow accumulation and subsequent snowmelt. Continuous long-term model simulations were generally in good agreement with drainage measurements.

Amatya and Skaggs (2002) tested the reliability of DRAINMOD for predicting water table elevations and subsurface drain flow under for different soils, crops and climates conditions.

Vepraskas (2002) determined whether DRAINMOD could predict water table in soils with and without a perimeter ditch. DRAINMOD was calibrated for each soil plot using measurement of *in situ* saturated hydraulic conductivity, soil water characteristic, depth to impermeable layer, depth of rooting and rainfall. Adjustments were made by iteration to minimize the absolute deviation were generally less than 20cm for periods ranging from 1 to 3 years. The DRAINMOD showed that it could be adopted to simulate water table levels in landscapes that do not contain a network of parallel drains.

Sammons *et al., (*2002) simulated the hydrology of tile drained watershed using a GIS-integrated DRAINMOD. As per sensitivity analysis, the most effective parameter in changing the model output were drain depth, drain spacing and saturated hydraulic conductivity. DRAINMOD was able to simulate with reasonable accuracy when tile drainage system design was based on the Indiana Drainage Guidelines.

Skaggs *et al.,* (2005) developed a method to determine lateral effect of drain-ditch on wetland hydrology. This method calculated the distances of influence of a single ditch constructed through a wetland DRAINMOD was used to predict water table fluctuations between parallel ditches for 50 years climatological record. Analyses were conducted for climatological conditions for three locations in Eastern North Carolina. Results showed that the threshold drainage intensities would result in water table drawdown for an initially ponded surface to a depth of 25cm in approximately 6 days (threshold time).

Sinai and Jain (2005) evaluated the water management model DRAINMOD for Jordan valley. Five identical drainage plots were selected, out of 10 existing, as replicated for this study. Deviation in a range of 0.3-1.7m between observed water table depth and that simulated by DRAINMOD was found in 4 out of 5 replicates. A reasonable agreement was found only in one drainage plot out of the five tested. These findings contradicted the world wide conviction that DRAINMOD simulation was in good agreement with observed field data. It was therefore recommended not to use DRAINMOD or similar vertical flow models for simulation of water table depth in irrigated fields with subsurface drainage system in Jorden Valley.

Wang *et al.,* (2005) studied DRAINMOD to predict and compare drain flow for three drain spacing and crop yield at the Southeastern Purdue Agricultural Centre (SEPAC). The daily efficiency for model testing ranged from 0.66-0.81, with the average deviation of 0.01 to 0.07cm/day and standard errors of 0.03-0.17cm/day. On monthly basis, 91% of plot years had efficiency values over 0.5 and 76% over 0.6 for years with on site rainfall data. The relative corn and soybean yields were well predicted on average, with percent error ranging from 1.3 to 9.7% for corn and from -3.3 to 10.3% for soybean.

Singh *et al.,* (2007) calibrated and validated DRAINMOD for two soils: Webster soil cultivated with continuous corn (WEBS_CC) and Canisteo soil cultivated with corn-soybean rotation (CANI_CS). The overall values of index of agreement index of agreement and model efficiency EF were higher than 0.85 for both WEBS_CC and CANI_CS, and showed a close agreement between the predicted and observed subsurface drainage. Then DRAINMOD was further used to simulate impacts of varying designs of subsurface drainage system for WEBS_CC over the 14 years of weather record in Iowa's tile landscapes. Simulation results suggested that a drainage system designed for a drainage intensity of 0.46 cm/day with a drain depth of 1.05m and drain spacing of 25m was sufficient enough to maximize crop production while minimizing subsurface drainage and its associated nitrate-nitrogen loss.

Wahba and Christen (2006) modeled subsurface drainage for salt load management in southeastern Australia. The value of the DRAINMOD -S model described various drainage design and management strategies under the semi-arid conditions of South-eastern Australia. The model could now be used to investigate design and management options in detail for different site conditions. This would assist decision makers in providing appropriate subsurface drainage management policies to meet drainage disposal constraints within integrated water resources management planning.

Singh *et al.,* (2007) evaluated drainage design and management modification against conventional drainage system installed at a drain depth of 1.20 m with free drainage at outlet. The simulation results indicated the potential of a tradeoff between subsurface drainage and surface runoff as a pathway to remove excess water from the system. While a reduction of subsurface drainage might occur through the use of shallow and controlled drainage, these practices might increase surface runoff in Iowa's subsurface drained landscapes. The simulation also indicated that shallow and controlled drainage might increase the excess water stress on crop production, and thereby resulted in slightly lower relative yields.

Srinivasulu *et al.,*(2008) simulated the hypothetical effects of Drainage Water Management (DWM) operational strategy on hydrology and crop yield using DRAINMOD**.** The potential effects of selected operational strategy on hydrology and corn yield were simulated over a period of 15 years. On an average, the predicted annual drain flows were reduced by 60%. DWM increased the average surface runoff by about 85% and slightly decreased the relative yield of corn crop by 0.5%. With simulated DWM, the water table rose above the conventional drainage level during both the winter and the crop periods.

Srinivasulu *et al*., (2009) calibrated and validated the DRAINMOD Model for the Water Quality Field Station (WQFS) based on observed drain flow data from the four replicates of continuous corn treatment plots, with 10 m drain spacing, for the period from 1995 to 2005. It was found that DRAINMOD predicted the drain flows reasonably well with good monthly Statistics: Nash-Sutcliff efficiency of 0.70 and 0.85; Index of agreement of 0.91 and 0.96; and Percent Error (PE) of 5.6 and 0% for the calibration and validation periods respectively.

Srinivasulu *et al*., (2010) studied the effects of climatic variability, drain spacing and growing season operational strategy on annual drain flow and crop yield, for a hypothetical Drainage Water Management (DWM) system using the DRAINMOD model. DWM showed potential for reducing annual average drain flow from all drain spacing's (10-35m) regardless of the growing season operational strategy with reductions varying between 52 & 55% for the drain spacing considered. Approximately 81 to 99% of annual drain flow reduction occurred during the non-growing seasons. Fixed DWM operational strategies led to an increase in mean predicted yield for narrow spacing's compared with conventional drainage systems. On average with the best-case operation selected for annual weather conditions, DWM increased relative yield by approximately 0.8, 0.4 and 0.2% for the 10, 20 and 30m drain spacing respectively.

2.7 Nutrient transport/ Leachate Analyses

i)Nitrogen removal

Biological nitrification followed by de-nitrification was believed to be the major pathway for ammonia removal in both types of constructed wetlands (Copper *et al.,* 1990; Gersberg *et al*., 1985). Nitrogen could be removed in pond systems by plant or algal uptake, nitrification and de-nitrification and loss of ammonia gas to the atmosphere (evaporative stripping = volatilization).

Kikuth (1977) found that the nitrogen removal in aquatic plant systems was 26-96 per cent, primarily due to nitrification or de-nitrification. In reed bed, nitrogen removal ranged from 25-85 percent by the same mechanism. Plant tissue analysis at several locations indicated that a single annual harvest of the plant material might account for ten percent or less of the nitrogen- removed by the system (Reed *et al*., 1988). A more frequent harvesting program might increase this potential, but it would also increase the costs for operation of the system.

ii)Phosphorus removal

The principal mechanisms for phosphorus removal are plant uptake or retention in the soil. Some experimental and developmental work had been undertaken using expanded clay aggregates and the addition of iron and aluminum oxides; some of these treatments might have promise but the long-term expectations had not been defined. Phosphorus removal of 28-57 percent in the National Space Technology Lab studies with water hyacinths was reported.

iii) Heavy metal removal

The heavy metal removal in the constructed wetlands was attributed to precipitation-adsorption phenomena. Heavy metals are retained by soils in three ways: by adsorption on to the surfaces of mineral particles, complexation by humic substances in organic particles, and precipitation reactions (Walton *et al.,* 1994).

Prasad (2007) et.al installed modified CD-SI system, the perforated pipes were placed at shallow depths of 40-45 cm having a closer spacing of laterals at 2.0 m at Soil and Water Conservation Field Laboratory In Tamil Nadu Agricultural University. It was found that the soil before applying treated wastewater as a source of irrigation had EC 0.27 and 0.29 dS/m in modified CD-SI system and furrow treatments. At the end of the crop season, it had shown that 0.36 and 034 dS/m at top soil (15 cm) with a slight decline at 30 cm. Similarly, there was no much variation in soil pH (a range of 7.71 to 7.66 before wastewater applied and 7.78 and 7.69 after the application of treated wastewater). The more nitrogen balance was observed in modified CD-SI system with treated wastewater (31.71 Kg/ha), Potassium balance was more in the case of CD-SI system with treated wastewater (47.87 Kg/ha), but phosphorus balance was observed more in the case of treatment of furrow irrigation with bore well water (6.69 Kg/ha). The nitrogen removal efficiency of soil was noticed high in furrow irrigation with treated wastewater (44.45%), phosphorus removal efficiency was more in drip irrigation with bore well water (14.94%) and the potassium removal efficiency was more in furrow irrigation with treated wastewater (30.34%). The modified CD-SI system appeared to be practical from the point of treated wastewater application in the system and also it is a cost effective proposition for maintaining soil health.

Srinivasulu *et al.,*(2012) had developed a GIS based distributed modeling methodology to use the field scale DRINMOD model for predicting drain flow on a watershed scale. The nitrate loss through subsurface drainage was estimated from the DRAINMOD predicted drain flow and observed average annual nitrate concentrations.

The model predictions of stream flow, drain flow and crop yield were reasonable in comparison to observed data. After evaluation of the methodology, the impact of DWM on the nitrite load from the subsurface drainage systems in the Hoagland Ditch in West Central Indiana watershed was assessed.

2.8 Cost analyses of water table management systems

Hiller *et al.,*(1971) in "Economics of controlled drainage and subirrigation systems" reported that, on poorly drained soils these systems could be very cost effective when compared to the combination of a conventional drainage system and an overhead sprinkler irrigation system. However, their cost effectiveness varies considerably from one location to another and depends on the crop, soil, topography, climate, water supply, and degree of management. The costs can be divided into System Costs, Water Supply Costs, Underground Tubing Costs, Land grading costs, Control Structure Costs, Field Border Costs, and Miscellaneous Costs like labour costs.

Wayne Skaggs *et a*l 1996 reported the cost economics with fixed and variable costs for the water table management system to reduce water-related stress on their crops, many farmers in North Carolina's lower coastal plain are considering the installation of a dual-purpose system of underground tubing that can be used for both subsurface drainage and sub irrigation.

In summary, the studies on drainage both surface and sub-surface and their impacts on soil health, crop growth, hydrology, effluent and its fate several in number. However, the CD-SI research on controlled drainage cum subirrigation is far lacking behind and the adoption at field scale is very meager at global level. Though the technology of dual purpose system has a large potential in areas suffering with water scarcity in one season and waterlogging in another part of the year, the research and adoption of CD-SI system completely lacking in India. Except few studies in Tamil Nadu Agricultural University, the author finds no research reported in India on Water Table Management Systems. Hence this study is proposed to investigate the application of the CD-SI system in Tamil Nadu state to conduct it as on farm research directly in the farmer's field where exactly the problems as explained earlier exist.

Materials & Methods

Chapter III
MATERIALS AND METHODS

As per the proposed objectives of the research, the data collected, materials used and methodology adopted are discussed under the following five sections i) Description of study area & characterization of waterlogging problems in the experimental area ii) Methodology followed in designing and execution of water table managment systems, iii) Hydraulic functional performance of the installed system iv) Simulation runs with DRAINMOD software and v) Cost analysis.

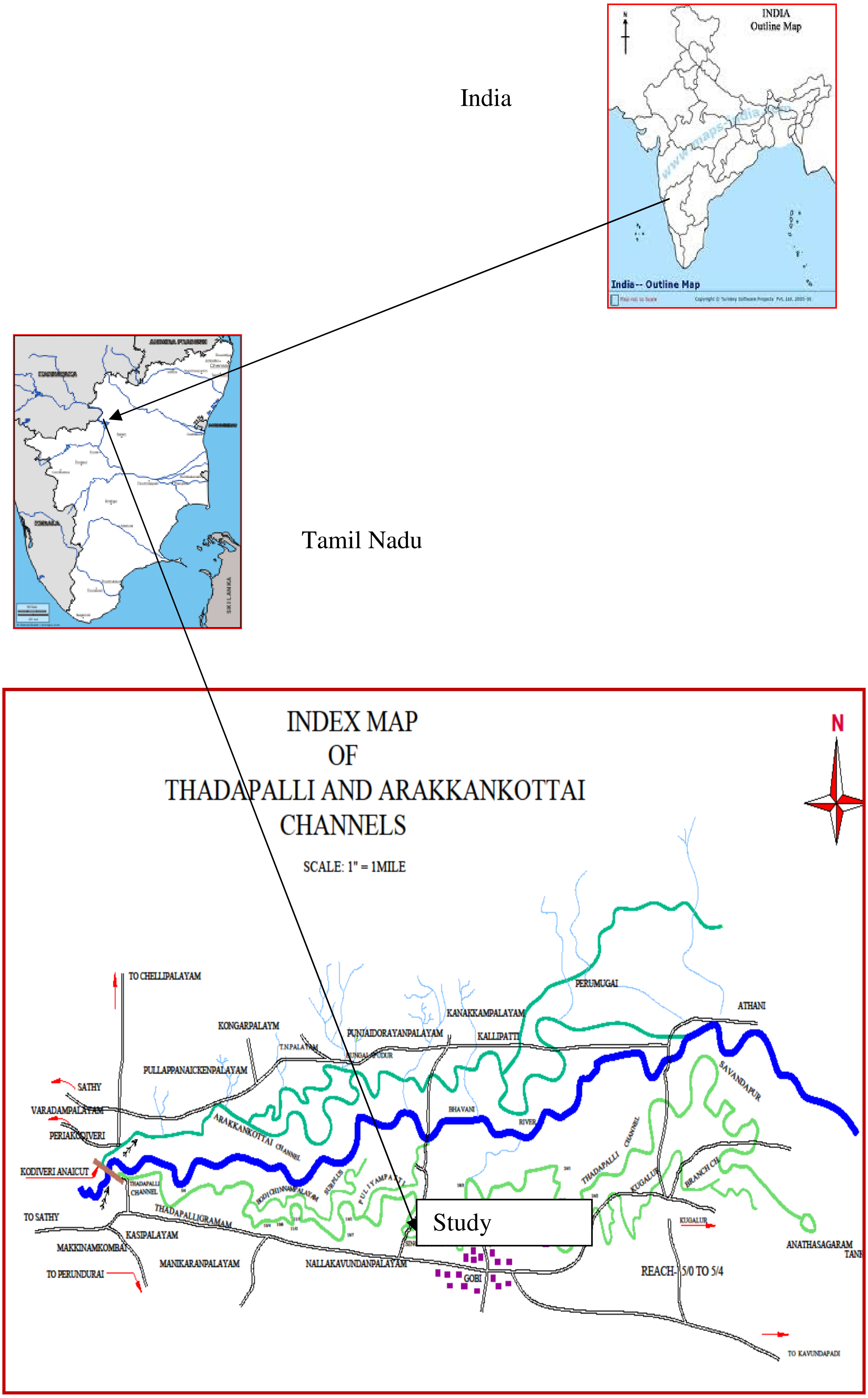
3.1. Description of study area

A brief description of the study area, with its topography and soil types, water resources, cropping pattern including rainfall analysis is presented in this sub-section.

3.1.1. Location of study area

The project site is located in Lower Bhavani Irrigation Project (LBP) of north western part of Tamil Nadu state in India (Fig.3.1) The study area for conducting experiment for the proposed research is selected in one of the farmer's fields near 13/6th mile at Gopichettipalayam (Gobi), 11.454°N 77.438°E, 35 km from Erode, District Head Quarters) Thadapalli channel (one of the channels from Kodiveri) command of Lower Bhavani Project (LBP).

The seasonal waterlogging problems of the area have been addressed on a pilot scale experiment and thereby, results could be extended to large scale adoption. The catchment area of Kodiveri (3 km away from the experimental site) anicut is 253.35 sq. km, mostly comprises of Western Ghats range. Average temperature ranges from 38^{0}C - 18^{0}C. Average relative humidity ranges from 64% -79%. The wind velocity is found to be in the range of 3.0-6.5 kmph. The mean pan evaporation is 150 mm per month. The mean sunshine hours /day recorded is 6. The runoff water from the southern slope of Western Ghats drains into the river Kodiveri Anicut. There are two canals below the reservoir system. They are from river sluice and canal sluice. Thadapalli main canal and Arakkankottai main canal commands 7,144 ha and 2,772 ha respectively totalling to 9,916 ha.



3.1 Experimental field site in Thadapalli channel command area.

3.1.2. Soils and topography

Almost 60% command area lies under slopy terrain and 40% under flat topography. The soil is generally made of red loam and mixed soil with clay content. The top soil depth varies from 0.3m to 0.1 m. The command's sloping pattern ranges from 1 in 100 to 1 in 2000. There are no. of wells in the command which usually recharges after completion of canal irrigation season, helps to rabi rainfed crops in the command like sorghum. The bed fall of the feeding canals is 1 in 1000 to 1in 2000 resulting the silting up of canal bed and the desilting have to be taken up to carry the designed discharge. The control structures need to be rehabilitated due to deteriorated condition. The canals of the area are also unlined and the canal seepage raises the water table encroaching the root zone during cropping season.

3.1.3. Available surface and ground water resources at project head

The design yield (calculated) based on 75% dependable rainfall of the catchment is 612 million cubic meters (MCM). The present yield is only 459 MCM. In the present cropping pattern of the ayacut, at least 612 MCM is required to take one successful crop. So, there is nearly 153 MCM shortfall in the surface water potential. It can be best overcome by adopting efficient water management methods. The command has very poor ground water storage, as the entire area lies in a confined aquifer zone which permits limited storage. The impervious layer lies at almost 1.0 to 1.5 m from the surface. All along the channels, the paddy fields suffer with waterlogging and harvesting problems because of seepage (Plate 3.1).

3.1.4. Crops and cropping pattern

The farm holdings of the individual farmers vary from 0.25 to 2 ha. only. Most of the farmers are small farmers. They take up the cultivation by themselves. As the basin is very much closed to Gobi town, the literacy rate is high. Rice is the main crop cultivated in the project area of all irrigation systems. Paddy is only crop grown in both the crop periods. The crop rotation followed in the command is i) Paddy-Paddy-fallow-1 year rotation, ii) Paddy-Paddy-Pulses 1 year rotation. Most of the tail end areas were kept without any cultivation due to inadequacy of water. The gap area was developed in the command area due to improper water management.

3.1.5. Experiment Site

An interaction was initially made with Tamil Nadu State Agricultural Engineering Department Engineers. The field of a Progressive Farmer and Water Users' Association President by name Thiru Dhanaseelan was identified for conducting the on farm research, keeping the post maintenance and extension activities into account by the farmer himself.

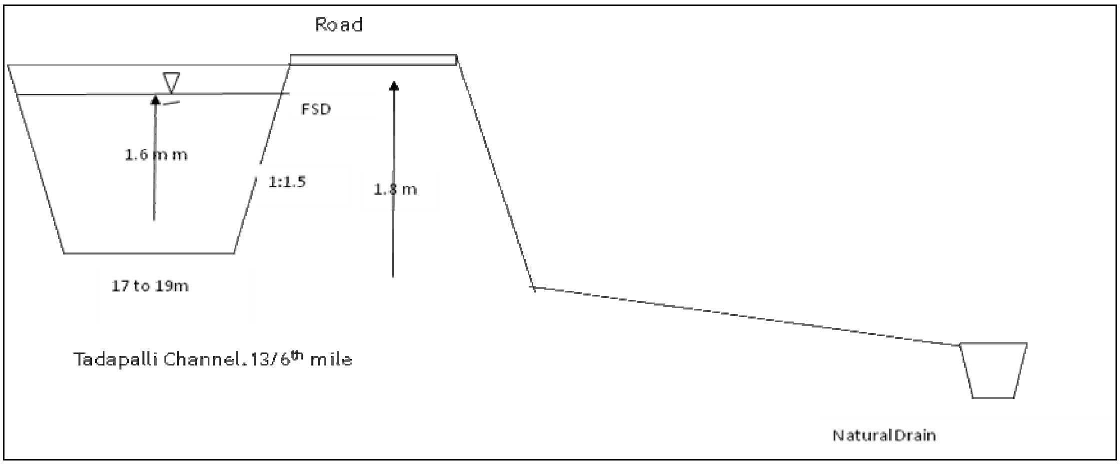


Fig. 3.2. Hydraulic details of Thadapalli channel at 13/6th mile.

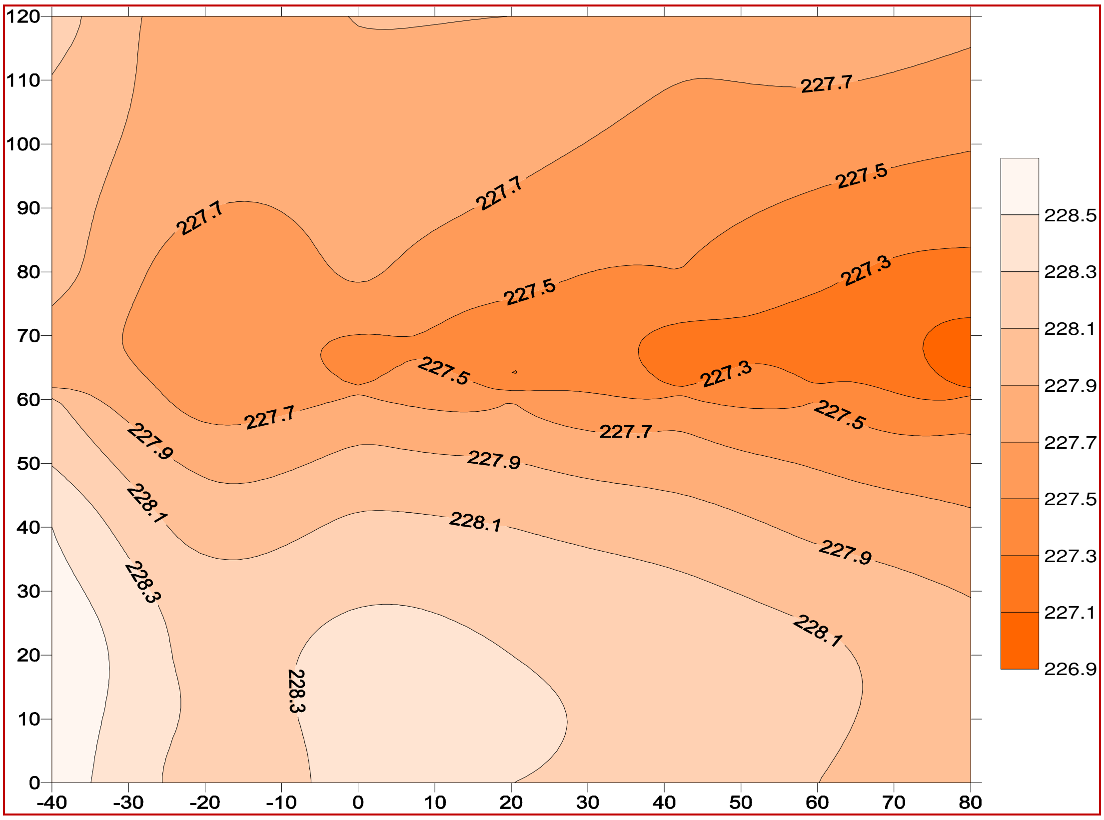


Fig.3.3 Contour map of study area in Kattadipalayam near Gobi

The location falls exactly besides 13/6th mile of Thadapalli Channel. The channel dimensions are given in Fig.3.2. The contour map of the selected experimental plot is drawn after taking levels at a grid spacing (40m x 40m) with manual levelling work (Fig.3.3). It could be seen that the valley portion in the centre of the field which is natural drain towards main drain. The collector pipe line was placed along with that natural drain and the laterals were joined perpendicular to it. (E-W). Based on this map, the lateral slope and collector profile was created and accordingly the installation process was completed using dumpy level to ensure proper functioning of the drainage system.

3.1.6. Annual and seasonal average rainfall analysis

Rainfall analysis were performed for Gopichettipalem for the rainfall data collected from PWD office seasonally and annually using "Easy Fit' Software. The software tries more than 55 probability distributions and gives the rank accroding to the goodness of fit. The analyis was carried out to have overall understanding about the rainfall pattern and its distribution over annually and seasonally in the study area. This would be highly useful for crop selection and planning for irrigation when subirrigation system is used.

Gamma, Frechet, Beta and Beta probability distributions were the best fits for the annual rainfall, south-west, north-east and summer rainfall data of Gopichettipalem respectively. The probability density functions for these data sets analyzed through the above software are given in Fig. 3.4. The statistical parameters like mean, variation, standard deviation, kurtosis, skewness coefficient along with scale and shape parameters of various distributions are tabulated in Table 3.1. Using the scale, shape and other parameters, one can easily find out the occurrence of rainfall at certain level of probability. This analysis would be useful for planning purposes to take certain risk levels and proceed further with irrigation or soil water conservation structures. In the present study, the analysis was carried out to know whether any rainfall contribution is needed into a small secondary storage especially at the times of subirrigation to be given for third crop and some times even to second crop.

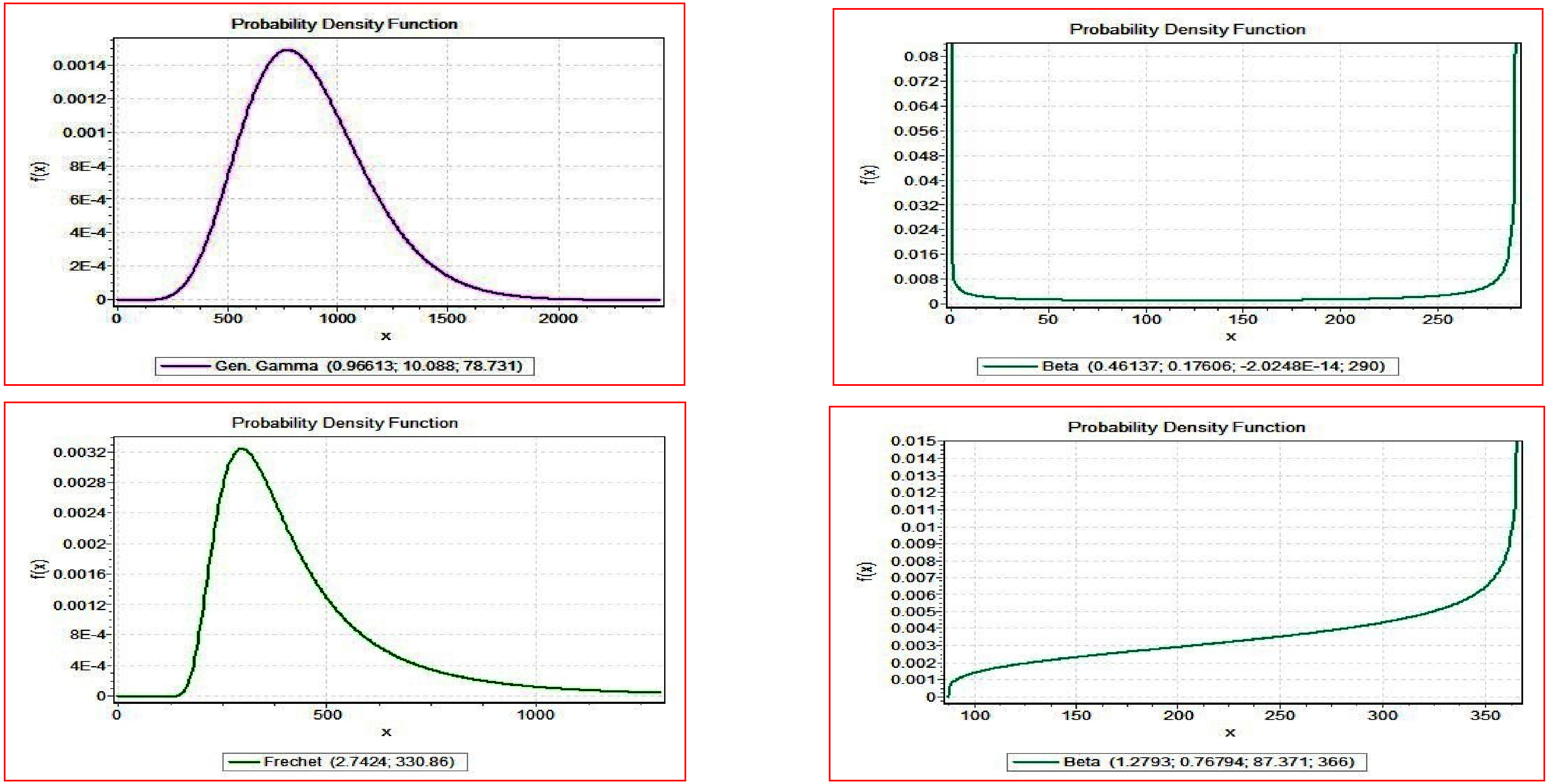


Fig. 3.4 Probability density functions for annual rainfall, north-east, south-west and summer monsoon rainfall data of Gopi

Table 3.1. Descriptive statistics of average annual rainfall analysis

Sl. No.	Statistic	Annual rainfall	South west monsoon	North east monsoon	Summer
1	Sample Size	10	10	10	10
2	Range (mm)	924.9	629	290	265
3	Mean (mm)	863.46	404.99	230.94	267.59
4	Variance	67980.0	32244.0	4222.8	5403.2
5	Std. Deviation	260.73	179.57	64.983	73.507
5	Coef. of Variation	0.30196	0.44339	0.28139	0.2747
7	Std. Error	82.45	56.784	20.549	23.245
8	Skewness	-0.18928	-0.1925	-1.1302	-0.28401
9	Excess Kurtosis	-0.64058	-0.65142	1.4474	-1.1768
10.	Distribution & parameters associated.	Gen. Gamma k=0.96613 α=10.088 β=78.73	Frechet α =2.7424, β =330.86	Βετα α_1=0.46137 α_2=0.17606 a=2.0248E14 b=290.0	Beta α_1=1.2793 α_2=0.7679 a=87.371 b=366.0

The probability density function of 4-P Generalized Gamma Distribution is given as,

$$f(x) = \frac{k(x-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} \exp(-((x-\gamma)/\beta)^k) \text{ with domain } \gamma \le x < +\propto$$

k is continuous hape parameter (>0), α = continuous shape parameter(>0), β = continuous shape parameters. γ = 0 yields to 3-P Gamma distribution.

The probability density function of Frechet Distribution is given as,

$$f(x) = \frac{\alpha}{\beta}(\frac{\beta}{x-\lambda})^{\alpha-1} \exp(-(\frac{\beta}{x-\lambda})^{\alpha}) \text{ with domain } \gamma \le x < +\propto$$

α = continuous shape parameter(>0), β = continuous shape parameters. γ = 0 yields to 2-P Frechet distribution.

The probability density function of Beta Distribution is given as,

$$f(x) = \frac{1}{B(\alpha_{1,}\alpha_2)} \frac{(x-a)^{\alpha_1-1}(b-x)^{\alpha_2-1}}{(b-a)^{\alpha_1+\alpha_2-1}} \text{ with domain } a \le x \le b$$

α_1 = continuous shape parameter(>0), α_2= continuous shape parameters.a and b are continuous boudnary parameters (a>b)

3.1.7. Characterization of waterlogging and drainage investigations

After a review of drainage experiments in The Netherlands, Sieben considered that crop yields were adversely affected when the water table was within 30 cm of the soil surface. He introduced the term SEW_{30} Index (i.e. the sum of excess water table encroaches above 30 cm) as a measure of waterlogging intensity. The SEW_{30} is the sum of all daily values (in cm) by which water tables are closer than 30 cm to the soil surface. Hence if the water table was 20 cm below the soil surface for 7 days, then at the soil surface for 2 days and afterwards more than 30 cm from the soil surface:

SEW_{30} = (10 x 7) + (30 x 2) = 130 cm days.

The SEW30 index assumes that the waterlogging intensity increases linearly with water table rise above 30 cm. There may not be a constant relationship between air-filled porosity and SEW_{30}. In loamy soils with a structure which inhibits gas movement (e.g. an absence of long and continuous pores), it is possible to get different air-filled porosities for the same perched water levels in the profile. The similar procedure was adopted to quantify the waterlogging problems in the experimental study area.

Before design and execution of the CD-SI system, the two study locations were selected just adjacent to the Thadapalli canal (14/6 & 13/6th miles) in the same area for quantifying the characterization of waterlogging problems faced by farmers along the canal seepage induced due to of nonlining. The SEW_{30} index was calculated for both the investigation areas similar to the procedure discussed above.

Tabuchi (1987) had worked on the characterization of trafficability of machinery in paddy fields of Japan. The soil strength profile of each soil type in relation to the mechanization practices was investigated to assess the problems associated with trafficability.

In the study area, trafficability of combine harvester was found to be a major problem in terms of soil moisture content present in the soil at the time of harvest. In view of residual canal flows and slow reduction of water table causing harvesting delay in many paddy fields accounting for considerable shattering losses of harvesting. Hence a concept of trafficability index was worked out relating to paddy grain moisture content and harvesting delay causing variation in the paddy yield and was discussed here under.

The farmers of the study area also expressed the trafficability problems of combine harvester during harvest of paddy crop. In first location, the terraced field with a pond at the bottom point caused less ability to intercept of field moisture, trafficability problems persisted. A delay of about ten days or more even for harvesting with combine harvester was the serious concern in the fields adjoining the canal.

Paddy is usually harvested at moisture content of about 20-25 percent (wet basis), during the rainy season and lower moisture during the dry season. At this moisture content at harvest, paddy has a high respiration rate and is very susceptible to attack by micro-organisms, insects and pests. Harvesting early when paddy is still at high moisture content will minimize shattering losses in the field.

Correct timing of harvest is crucial to crop loss prevention. Grain losses may occur caused by rats, birds, lodging, insects, and shattering. Timely harvesting ensures good grain quality and high market value. Harvesting too early would result in a larger percentage of unfilled or immature grains, which would lower yield and in cause higher grain breakage during milling. Harvesting too early would lead to excessive losses and increased breakage in rice. Harvest time also affects the germination potential of rice seed.

To characterize the effect of waterlogging in the area, an index, namely Trafficability Index was proposed, taking the harvesting delay in days than normal and grain moisture content was proposed as mentioned below. The paddy yield (Y) is a function of harvesting delay (D) in days and difference in grain moisture content with optimum moisture (%) for harvesting with combine, (dθ) in fraction.

Assuming 'dY' difference between normal paddy yield and reduced yield because of harvesting delay (shattering losses) i.e. then, 'dY' value varies indirectly with 'D' and also with 'dθ'.

Mathematically,

$$dY \propto \frac{1}{D(d\theta)}$$

Incorporating a proportionality constant, T

$$dY = T\frac{1}{D(d\theta)}$$

$T = (dY)D(d\theta)$ Tons. days/ha.

Threshold value for harvesting delays, (≥0), D could range from 1-15 days or even more. Similarly 'dθ' (≥0) up to a threshold difference (say 10%) moisture or even more than that. The severity of trafficability problem occurs either due to harvesting delay or due to more reduction of grain moisture content than the optimum value. The relationship between delay in harvesting, grain moisture content and grain yield for a variety is known, the trafficability index could be easily worked out. Based on a study at IRRI, Philippines, the generalized data of above parameters were collected and presented in Table 3.2. (Anonymous 2003)

Table 3.2. Reduction in paddy (ADT45) yield due to harvesting delays and reduction in grain moisture (%).

Sl. No.	Days after heading (Days)	Grain Moisture Reduction (%)	Paddy Grain Yield (Tons/ha)
1	34	20%	6.1
2	36	19%	6.0
3	38	18%	5.8
4	40	17%	5.5
5	42	15%	5.0

From Table 3.2, it could be clearly understood that the delay in harvesting due to excessive soil moisture makes the reduction of grain moisture leading to more shattering losses which is a major impact of waterlogging. The trafficability of heavy machinery for other agricultural operations like transplanting were worked out in the earlier research investigations. But trafficability related to paddy harvesting with combine harvester is the need of the hour because of the major breakthrough happening in this direction for the farming community. The developed Index was used for assessing the impact of waterlogging in the study location. In the study area, six farmers were surveyed for assessing the reduction of paddy yield due to delay in harvesting and the same is reported in Chapter IV.

3.1.8 Seepage losses to nearby drains or canals

Methods for quantifying steady seepage losses in the lateral direction could be developed by considering three cases shown in Fig. 3.5 (a to c).

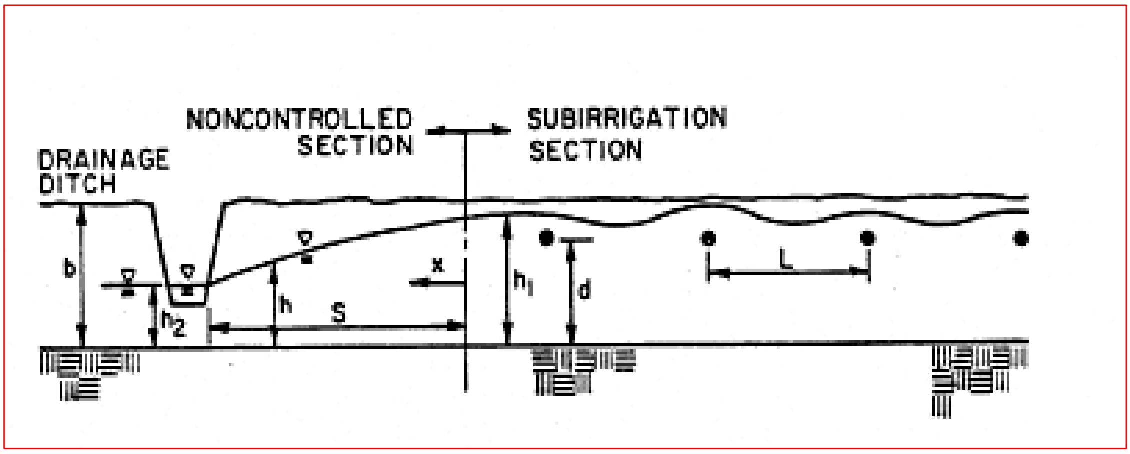


Fig.3.5(a) Water table profile for seepage from a subirrigated field to a drainage ditch

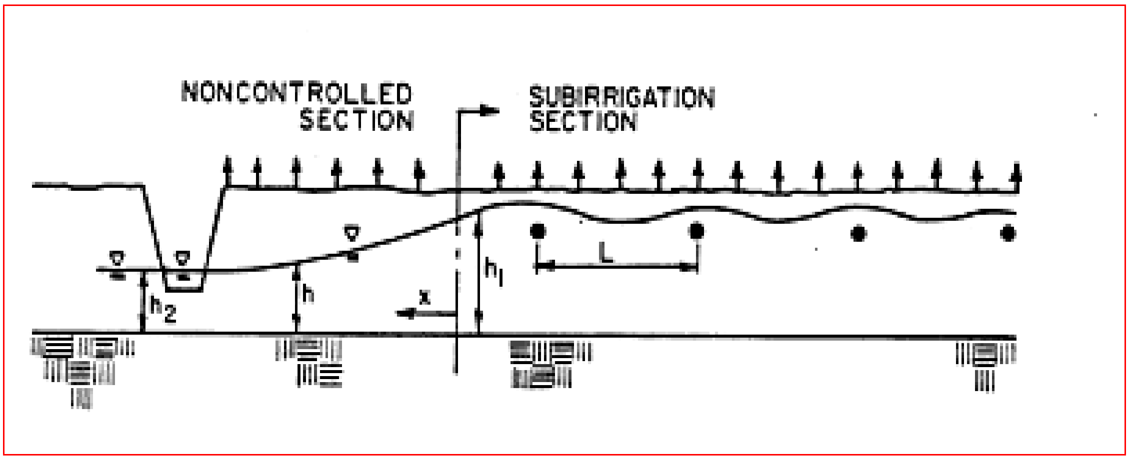


Fig.3.5(b) Water table profile for seepage from a subirrigated field to a drainage ditch-Evaporation losses considered

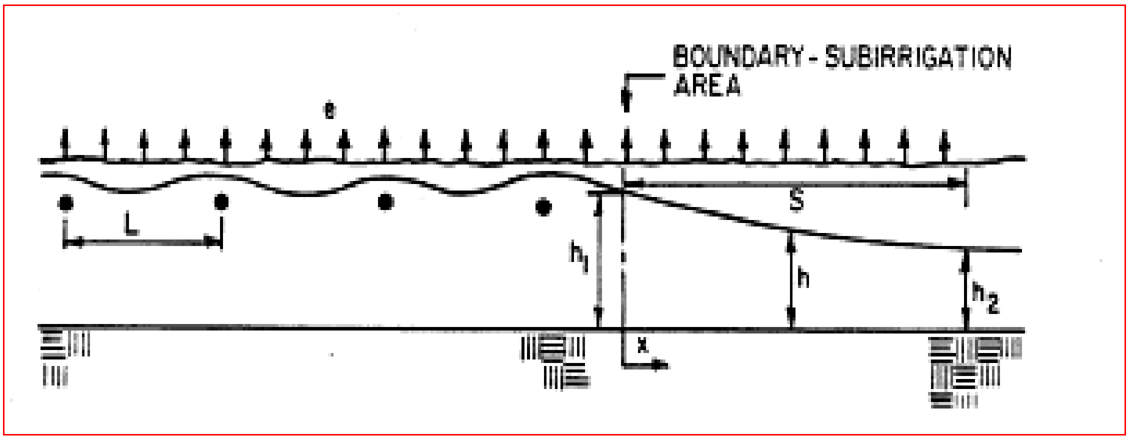


Fig.3.5(c) Water table profile for seepage from a subirrigagted field to a drainage ditch considering vertical or deep seepage

Using the D-F assumptions, the seepage rate may be expressed as,

$$q = -kh\frac{dh}{dx}, \qquad \text{....... Eq. 3.1.}$$

Where q is the seepage rate per unit length of the drainage ditch (or) per unit thickness into the paper (cm^3/cm hr or ft^3/ft hr). 'k' is the effective lateral hydraulic conductivity (cm/hr). h is the water table elevation above the impermeable layer (cm or ft), which is a function of the horizontal position, x. If Evapotranspiration from the surface is assumed negligible, q is constant for all x and Eq. 3.1 could be solved, subject to the boundary conditions

H = h_1 at x = 0, H = h_2 at x =s , The solution for 'h' may be written as,

$$h^2 = -\frac{h_1^{\,2} - h_2^{\,2}}{S}x + h_1^{\,2} \qquad \text{........ Eq. 3.2.}$$

Differentiating Eq. 3.2., and substituting back into Eq.3.1,

$$q = \frac{k}{2s}(h_1^{\,2} - h_2^{\,2}) \qquad \text{...... Eq.3.3.}$$

Then, if the length of the field is unity, the seepage loss from the side of the field may be calculated by using the following relationship.

$$Q = ql = \frac{kl}{2s}\left(h_1^{\,2} - h_2^{\,2}\right) \qquad \text{...... Eq.3.4.}$$

Where l = width of the field entering seepage flow

Vertical water losses due to ET along the field boundaries increase the hydraulic gradients in the horizontal direction and, thus, seepage losses (Figure 3.6). In this case, the flux, q may still be expressed by Eq.3.1, but rather than the flux being constant, the equation could be written according to Harr (1962).

$\frac{dq}{dx} = -e$, Where e is the ET rate. Then substituting Eq.3.1.for q

$$\frac{d}{dx}\left[h\frac{dh}{dx}\right] = \frac{e}{k} \qquad \text{....... Eq.3.5.}$$

3.1.9 Seepage losses to adjacent undrained lands

Subirrigation systems are often located next to forest or cropland that is not drained. However, seepage losses may still occur along these boundaries because of low water tables in the undrained areas. The subirrigation is used during dry period and hence water tables would be drawn down due to ET. Such a situation is shown schematically in Fig. (3.5c). The problem here, as opposed to the cases above is that neither h_2 nor S is known. For purposes of this problem, it was assumed that water could move to the surface or to the root surface (or to the root zone) at a rate sufficient to support an ET rate of 'e' for water table elevations less than h_2. Then, from principles of conservation of mass, one could write for any point, x,

q(x) = (S-x) e

Where q(x) is the flow rate per unit length of the field (into the paper) expressed as a function of x, e is the steady ET rate, S is the limiting distance where $h = h_2$ the limiting water table elevation that will allow upward water movement to the surface at rate e. Substituting in Eq.3.1. for q gives

$$-Kh\frac{dh}{dx} = (S-x)e \qquad \text{................Eq.3.6.}$$

Separating variables and integrating subject to the condition $h = h_1$ at $x= 0$ yields the following expression for h,

$$q = \sqrt{(h_1^2 - h_2^2)Ke} \qquad \text{............Eq.3.7.}$$

Normally, seepage losses to surrounding undrained areas would be highest during peak consumptive use periods. The value of h_1 would depend on the water level held in the subirirgation system. The value of h_2 would depend on the soil profile and could be chosen form relationships for maximum upward flux versus water table depth (Fig. 3.5a). To be on the safe side h_2 should be chosen so that the depth of the water table was at least 1.0 m at x = S.

3.1.10. Vertical or deep seepage

Subirrigation and water table control systems are usually located on soils with tight underlying layers and/ or high natural water tables so that vertical losses are not excessive. When evaluating a potential site for a subirrigation system, vertical seepage losses under raised water table known to exist. These losses should be added to lateral seepage estimates to determine the water supply capacity needed in addition to that required to meet ET demands. Referring to Fig. 3.6c, the vertical seepage flux may be estimated as,

$$q_v = k_v(\frac{h_1 - h_2}{D}) \quad \text{................Eq.3.8}$$

Where q_v is the flux (m/day), k_v is the effective vertical hydraulic conductivity of the restricting later, h_1 is the average distance from the bottom of the restricting layer to the water table, h_2 is the hydraulic head in the ground water aquifer referenced to the bottom of the restricting layer and D is the thickness of the restricting layer., This analysis was used to quantify the seepage losses through Thadapalli Channel 13/6th mile which in turn was used to arrive at the drainage coefficient of the CD-SI system.

Before taking up the design and installation work, drainage investigations were carried out at two locations at 1 kilometre interval. The observation wells were installed in 40m x 40m grid network and the water table levels were recorded at fortnightly intervals (Plate 3.2.) The characterization of waterlogging and cropping constraints were recorded as mentioned in the above procedure.

The specifications of observation wells were followed as per CSSRI, Karnal guidelines (Table 3.3). Seeing the fineness through mechanical analysis of soil, the slope of the lateral pipes could be fixed to increase the velocity of flow for easy flush out. The slope of the lateral pipes was fixed to increase the velocity of flow for easy flush out. The rise of water table in the observation well was recorded with the help of an auger provided by Hydraulic Conductivity test kit., was recorded at a single location for 5 times during full supply level of the canal with a ponding depth of 10 cm depth in the paddy field (Plate 3.3). The data on of soil, water quality and mechanical analysis of soil and water are furnished in Tables 3.4, 3.5 & 3.6 respectively.

Table 3.3. Specifications of installed observation wells.

Sl. No	Item	Specification
1	Grid size	40m x 40m
2	Diameter	32 mm
3	Material	PVC
4	Length	1.8-2.0m
5	Depth	0.9- 1.5 m
6	Envelope	Coconut coir
7	Method of Installation	labour
8	% open area	10
9	Size of perforations	10mm

To know the status of the soil in terms of pH, EC and its textural classification, 4 no. of soil samples (2 samples each on either side of the field collector drain) were collected from the experimental study site and the results of report is given in Table 3.4.

Table 3.4 Soil sample analysis for the waterlogged area near 13/6th mile of Thadapalli channel.

Sl.No.	Sl. No.	Parameter	Value	Unit	Comments
1	Sample 1 (O11)	pH	7.8	-	1.Neutral Soil 2.Non-Saline 3. Clay loam (black) 4.Noncalcareous
		EC	0.1	dS m^{-1}	
2	Sample 2 (O14)	pH	7.4	-	1.Neutral Soil 2.Non-Saline 3. Clay loam(Reddish brown) 4.Noncalcareous
		EC	0.2	dS m^{-1}	
3	Sample 3 (O21)	pH	5.6	-	1. Acid Soil 2. Non-Saline 3. Clay loam(Black) 4. No-calcareous
		EC	0.1	dS m^{-1}	
4	Sample 4 (O24)	pH	6.0	-	1. Neutral Soil 2. Non-Saline 3. Clay loam (black) 4. Non-calcareous
		EC	0.1	dS m^{-1}	

From the Table3.4, it was observed that the soil is mostly neutral and with localized parts of acidity. The texture of the soil was found as clay loam. The soil was non-saline. But through detailed mechanical analysis, it was found that the textural class of sandy clay loam patches were also present in the study area.

Table 3.5 Mechanical analysis-soil samples analysis report

Sl. No.	Parameters (%)	Sample –I (Near road)	Sample –II (Near drain)
1	Total Sand	55.2	50.4
2	Coarse Sand	11.8	6.2
3	Fine Sand	43.4	44.2
4	Silt	10.5	12.4
5	Clay	33.8	36.4
6	Textural Class	Sandy Clay Loam	Sandy Clay

The water quality of the samples collected from surface ponding of standing paddy crop showed for its neutrality and salinity free status. Thus it was ensured that no induction of salinity through surface irrigation.

Table 3.6. Water quality from ponded surface at two locations of the study area

Sl.No.	Parameter	Value	Unit	Comments
Sample 1	pH	7.82	-	Neutral Water
	EC	0.48	$dS\ m^{-1}$	Non-Saline
Sample 2	pH	7.33	-	Neutral Water
	EC	0.53	$dS\ m^{-1}$	Non-Saline

3.1.11. Measurement of in-situ saturated hydraulic conductivity

In 14/6th mile, for finding out in-situ saturated lateral hydraulic conductivity, Hydraulic Conductivity test kit was used to conduct auger hole experiment at two locations i.e. near to the road, where representative soil samples were taken. Hooghoudt's formula was used for finding out the hydraulic conductivity.

In this experiment (Fig. 3.6), the water in the auger hole was bailed out with a bailer and the rise of water level within one minute was recorded and the average of 5 readings was taken as the measure The average water table values over the depth from below ground levels were plotted. The values on x- axis denote the time taken to the rise of water level (Fig.3.7). This analysis was used to arrive at hydraulic conductivity parameter which was very much essential for the design of water table management systems. From standard Hooghoudht's equation,

$$K_s = \frac{2.3aS}{(2d+a)\Delta t}\log_{10}\frac{y_o}{y_1}$$

Where, K_s = saturated hydraulic conductivity

'a' = radius of the auger hole

'd'=depth of the hole below ground level

S is defined by 'ad'/0.19

'y_0 & y_1 over a particular time interval the initial and final water levels

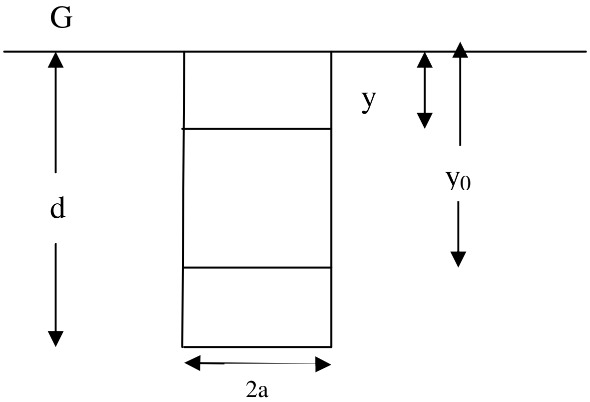


Fig. 3.6 Auger hole method for finding out saturated hydraulic conductivity

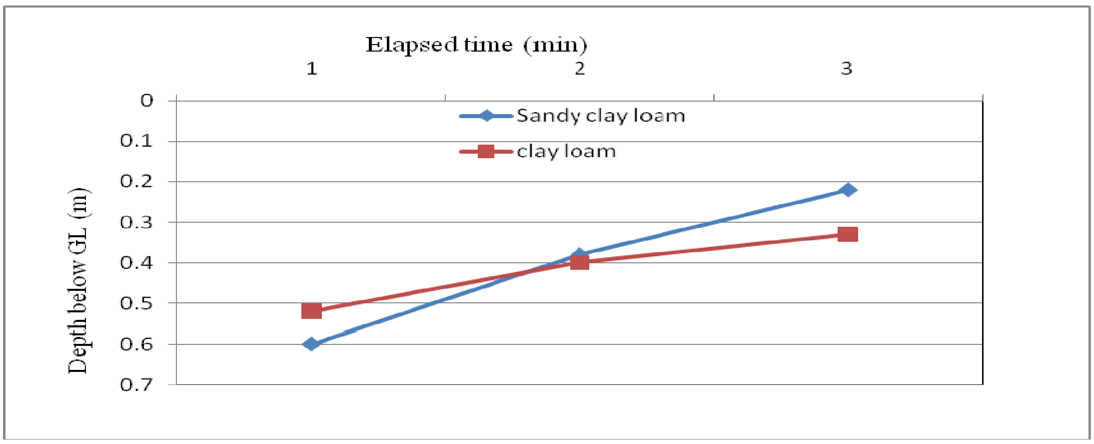


Fig. 3.7. Average rise of water level in auger holes in sandy clay loam and clay loam soils at experimental site.

As per the auger hole dimensions and the experiment, it was found that

a = 0.02m,

d = 0.9 m,

y_0 & y_1 are 0.6m and 0.22m respectively.

Time interval = 120 seconds.

S= 0.0947.

K_s works out to be 0.75 m/day.

Similarly in the other location, i.e. representing sandy clay, the values were found

a = 0.02m

d= 0.9m

y_0 & y_1 are 0.52m and 0.33m respectively,

Time interval = 120 seconds.

S = 0.0947,

K_s works out to be 0.35/day.

The value of hydraulic conductivity as per standard literature was found as clay loam (0.6m/day) and Sandy clay loam (1.876 m/day) as per the standard literature which are comparable with the above two locations. As per the soil sampling, majority of the soil is of sandy clay loam, to represent the average value, a hydraulic conductivity of 1.5 m/day was taken as a design value for all calculations.

3.2. Design and execution of water table management systems

The main criteria in designing the water table management system is that it should function efficiently both under subirrigation and drainage modes fulfilling both the needs. Under drainage mode., it should remove the excess waterlogging and keep the crop in congenial condition. Under subirrigation mode, the upward flux and the discharge rate must satisfy the plant's life saving irrigation needs. Inevitably, if the system is efficient in subirrigation mode., it will satisfy the needs of the controlled drainage also since the spacing requirement is less for subirrigation mode.

3.2.1 Design considerations of water table management systems

The main items to be considered for the design of Sub surface drainage system are i)Layout of the system, ii) Spacing and Depth of lateral drains, iii) Collector diameter and slope iv) Inspection chamber/sump v) Outlets/out fall of main drain. The same items holds good for the design of subirrigation systems too, but with some additional parameters like seepage considerations, crop water requirements, upward flux etc.,

3.2.2. Layout of subsurface drainage system

Significant points to be considered in a layout are i) The existing irrigation and drainage facilities. ii) Outlet conditions by pumping or gravity and pollution problems emanating from the drainage effluent. iii) Long term maintenance cost. iv) The available slope on flat. In the present study at Gopichettipalayam farm, Grid iron type of layout (Fig.3.10) was selected to suit the topography. The already existing natural field drain was identified for collector pipe location. Care was taken in the installation to have little outfall of 20 cm at the end of the collector.

3.2.3 Spacing calculations under drainage system mode operation

Factors considered in computation of the closed sub-surface drainage spacing are i) Desirable water table depth for crop production ii) Drain depth iii) Water table height above the drains iv) Depth of impermeable layer v) Effective flow depth.vi) Type of drainpipe. Vii) Hydraulic conductivity of the soil.

Many equations, which were developed, inter relating the above factors based on the following assumptions are considered: i) Two-dimensional flow i.e., the flow is identical in any cross section perpendicular to the drain. ii) Uniform distributions of the recharge, steady or non-steady over the area. The equations were developed using Darcy's Law and the equation of continuity. (Most drainage equations are based on the Dupuit-Forchheimer assumptions. These allow us to reduce the two dimensional flow to a one dimensional flow by assuming parallel and horizontal stream lines.) Commonly used steady state, Hooghoudt equation was used to design the lateral drain spacing. The equation used is as follows (Ritzema H.P.ed. 1994).

$$R = q = \frac{8k_b Dh + 4k_a h^2}{L^2} \qquad \text{------------------------------(1)}$$

Where,

R = Recharge rate per unit surface area m/d
q = Drain discharge rate per unit surface area.
k_a = Hydraulic conductivity of the layer above the drain level (m/day)
k_b = Hydraulic conductivity of the layer below the drain level (m/day)
h = Water table height above drains at mid point between drain(m)
D = Height of the water level in the drains above the impervious layer (m)
L = drain spacing (m)

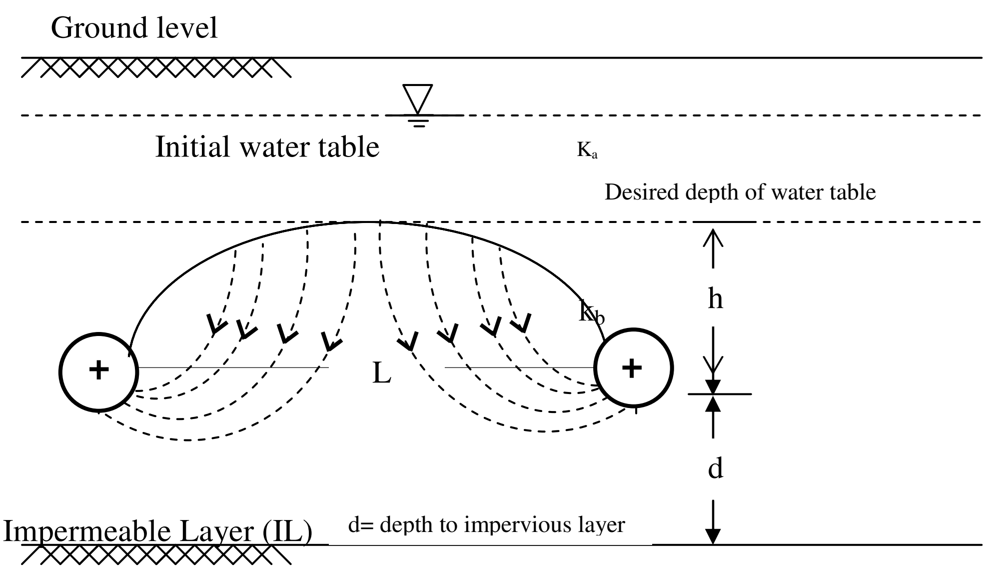


Fig.3.8 Possible pattern of flow into closed sub-surface drains

Schematic view of the spacing of the drains is shown in Fig.3.9. Incorporating various parameters from the Table 3.5, the drain spacing was determined.

$$L^2 = \frac{4KH(2d_e + H)}{R} \qquad \text{……..Eq.3.9}$$

As explained in the previous section, the approximate seepage analysis was estimated and thereby recharge rate was calculated to use in the above design equation under drainage mode. The hydraulic conductivity 'K' was found out experimentally with auger hole. The calculations performed were given in the previous subsection for both the soil types present in the experimental site. Based on the data collected on water table fluctuations, soil water quality and hydraulic conductivity in the project site, the design parameters were worked out for the subsurface drainage systems and were presented in Table 3.7

Table 3.7. Design parameters of water table management systems at Gobi under controlled drainage mode

S.No	Design Parameters	Specification
1.	Saturated hydraulic conductivity	0.75m/day
2.	Drainage coefficient	1 cm/day
3.	Hydraulic head above the drains	0.4-0.25
4.	Depth to impervious layer below drains	0.3-0.5 m
5.	Equivalent depth	1.05 m
6.	Design diameter of pipe	30 mm

3.2.4. Design of subirrigation systems (SI)

The spacing, depth of placement of drains and diameter of the drain pipes and length of drains constitute the core of the design of Controlled Drainage and Sub-Irrigation (CD & SI) system. Water table movement between parallel drains can be predicted by solving Boussinesq equation for the appropriate initial and boundary conditions. The Boussinesq equation neglects flow in the unsaturated zone and is based on continuity, Darcy's law and the Dupuit Forchheimer (D-F) assumptions.

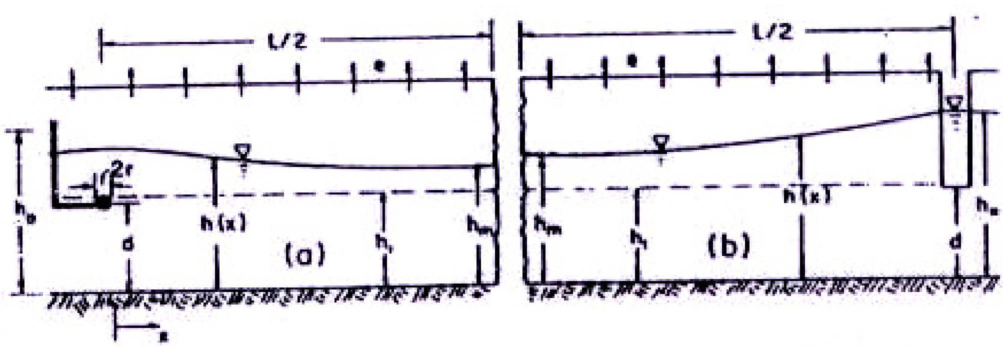


Fig. 3.9 Water table response to subirrigation through a) drain tubes and b) open ditches

Referring to Fig. 3.9, It may be written as

$$f\frac{\partial h}{\partial t} = K\frac{\partial}{\partial x}\left[h\frac{\partial h}{\partial x}\right] + e \qquad \text{.......Eq.3.10}$$

Where ,

h= elevation of water table above the impermeable layer,

t = time,

x= the horizontal position

e= the rate of vertical infiltration into the saturated zone ('e' is negative for Evapotranspiration or vertical seepage)

K = lateral saturated hydraulic conductivity

f = drainable porosity.

Design methods for drain spacing and depth consider three operational modes in case of a subirrigation system, viz i) Steady State ii) Transient State and iii) Subirrigation under changing weather conditions. SI systems must be designed to satisfy both irrigation and drainage requirements.

Steady State operation: The position and shape of the water table during steady state subirrigation can be approximated by making the Dupuit-Foreheimer (D-F) assumptions using the approach of Fox *et al* (1956)., If water movement in the unsaturated zone is neglected, the horizontal flow rate per unit length of the drain may be expressed as

$$Q_X = -K_S h\frac{dh}{dx} \qquad \text{......Eq.3.11}$$

K_s is the effective saturated conductivity in the horizontal direction.

Referring to Fig. 3.9,

H is the height of the water table above the impermeable layer and is function of the horizontal position, x

At any position x, Q_x must be equal to the rate that water leaves the profile by ET from Z to L/2 i.e

$$Q_X = e\left(\frac{L}{2} - x\right) \qquad \text{....Eq.3.12}$$

Where 'e' is the ET rate.

Substituting Eq.3.11 for q_x is

$$-K_S h \frac{dh}{dx} = e\left(\frac{L}{2} - x\right)$$ …..Eq.3.13

Separating variables and integrating subject to a boundary condition of h = h_u(at x=0)

Yields an expression for the water table elevation in terms of x

$$h^2 = \frac{e}{K_S} X^2 - \frac{eL}{K_S} X + h_0{}^2$$ …..Eq.3.14

Thus if the D-F assumptions hold the water table would assume an elliptical shape for steady ET conditions. The drains should be placed close enough to maintain a minimum standard WT elevation at mid position, x = L/2

During a period of high ET demands, as discussed previously, the design, WT elevation at the midpoint H1 as well as over the drain, H_0 would depend on the crop and the rate that water can be transferred upward through the profile. The design WT elevations can be chosen from relationships when they are already available. The relationship between the steady upward flux drains spacing and midpoint water table elevation can be calculated from Eq.3.14.

By substituting h_1 at x= L/2 and solving for e.

$$e = \frac{4K_S\left(h_0{}^2 - h_1{}^2\right)}{L^2}$$ ……Eq.3.15

Defining the difference between the water level at the drains and that midway between the drains as M= h_0-h_1, Eq.3.11 may be written as

$$e = \frac{4K_S M\left(2h_0 - M\right)}{L^2}$$ ……Eq.3.16

Then the spacing necessary to maintain in a specified 'e' at a given h, is

$$L = \left(4K_S M \,\frac{(2H_0 - M)}{e} \right)^{\frac{1}{2}} \text{ or} \qquad \text{....Eq.3.17}$$

$$L = \left[\frac{4K_S \left(h_0^{\,2} - h_1^{\,2}\right)}{e} \right]^{\frac{1}{2}} \qquad \text{....Eq.3.18}$$

Equations 3.16 to 3.18 should be reliable for open ditches that penetrate close to the impermeable layer where the ratio L/h_o is large so that D-F assumptions hold. However, these equations do not account for convergence losses near drain tubes or open ditches that do not reach the impermeable layer. An approximate method of correcting for these convergence losses is to use the Hooghoudt equivalent depth concept. The equivalent depth from the drain to the impermeable layer, 'd_e' can be calculated from equations presented by Moody (1966) and substituted for the actual depth to the impermeable layer d in Fig. 3.9, The h values are adjusted accordingly. Moody's equation for $d/L < 0.3$ can be written as follows

$$d_e = \frac{d}{\left[1 + \frac{d}{l} \left(\frac{8}{\pi} \ln \frac{d}{r_e} - 3.4 \right) \right]} \qquad \text{......Eq.3.19}$$

Where r, is the effective drain tube radius (Skaggs 1978 a) which is smaller than the actual radius because the tube wall is not permeable but has only a small percentage of open area. The equivalent water table elevations at the drain 'h_e' = y_0+ d_e and midway between the drains h_1' = y_1+ d_e., are substituted for h_0 and h_1 respectively, in Equations 3.16 to 3.18., that is

$$e = \frac{4K_S M(2h_0 - M)}{L^2} \qquad \text{........Eq.3.20}$$

$$L = \left(\frac{4K_S M\left(2h_0 - M\right)}{e} \right)^{\frac{1}{2}} \qquad \text{..........Eq.3.21}$$

Where $M = h_0 - h_1 = h_o' - h_1'$,

A problem arises when Eq. 3.20 and 3.21 are applied for deep midpoint water table depths. The magnitude of e as predicted by Eq. 3.16, increases with M, until the water table at the midpoint reaches the equivalent depth of the impermeable layer, 'h_i' = 0 for deeper midpoint water table depths (which can occur because the actual depth to the impermeable layer is greater than the equivalent depth), Eq.3.16 predicts a decrease in q with increasing M. Ernst (1975) observed that this was inconsistent with the physics of flow since the maximum subirrigation rate should occur when the water table at the midpoint is deepest. He derived an equation similar to Eq. 3.16 to correct these deficiencies. Ernst's equation may be written in the present notation as

$$e = \frac{4K_S M\left(2h_0' - \frac{h_0'}{h_0}M\right)}{L^2} \qquad \text{.......Eq.3.22}$$

The required drain spacings to maintain a given' e' is obtained by re-writing Eq.3.22., as

$$L = \left(\frac{4K_S M\left(2h_0' - \frac{h_0'}{h_0}M\right)}{e}\right)^{\frac{1}{2}} \qquad \text{.......Eq.3.23}$$

Because d, depends on the drain spacing, L, an iteration process is required computed L from either Eq. 3.18 or 3.22, one iteration is usually sufficient for convergence. For sub irrigation trials, the design spacing must be smaller than for drainage spacing, which was computed from the following equation,

$$L = \sqrt{4K_s M(2h_o' - \frac{h_o'}{h_o}M)/e} \qquad \text{.......Eq.3.24}$$

The calculations performed to compute the spacing under subirrigation mode with (Table 3.8) were furnished in Chapter IV. Subirrigation in the transient state-water table rise was not analyzed in view of cumbersome involved in acquiring the accuracy in parameter estimation for Indian conditions.

Based on the spacing arrived under both drainage and subirrigation modes, and on the optimum parameters chosen, experimental layout for suiting to the field's natural conditions, following the lines of experimental design, the layout of the water table management system was prepared (Fig. 3.10).

3.2.5. Design diameter of drain pipes

A drainage pipe has to perform two distinct roles 1) it must accept the water moving from the soil and allow it to enter the pipe with the minimum of resistance. 2) It must transport all the water flowing into it while still accepting water along its whole length.

In general, for clay and cement concrete tiles, the minimum diameter prescribed is 100 mm, while for the PVC and PE pipes, it is 75 mm. Wessling's equation for uniform flow in smooth pipes and corrugated pipes derived from Manning's equation will be used to calculate the size of the lateral drain pipes. (Anonymous, 2000 IDNP, Karnal Report). Size of the lateral pipe required to carry the design flow rate is given by

$$'Q' = 80\,(d_L)^{2.714}\, i^{-0.572} \qquad \ldots\ldots\ldots\ldots\ldots(i)$$

d_L = Diameter of the lateral pipe(m)
Q = Discharge m^3/day
L = Spacing of drain(m)
i = slope lateral pipe(fraction)

Table 3.8.Design parameters of estimated for spacing under subirrigation mode for water table management systems at Gobi

S.No	Design Parameters	Specification
1.	Average hydraulic conductivity	0.75m/day
2.	Evaporation rate	0.0055m/day
3.	Actual and critical water table difference (M)	0.10m
4.	Effective radius r_e	0.036 m
5.	Equivalent depth	0.69 m
6.	Design diameter of pipe	55 mm

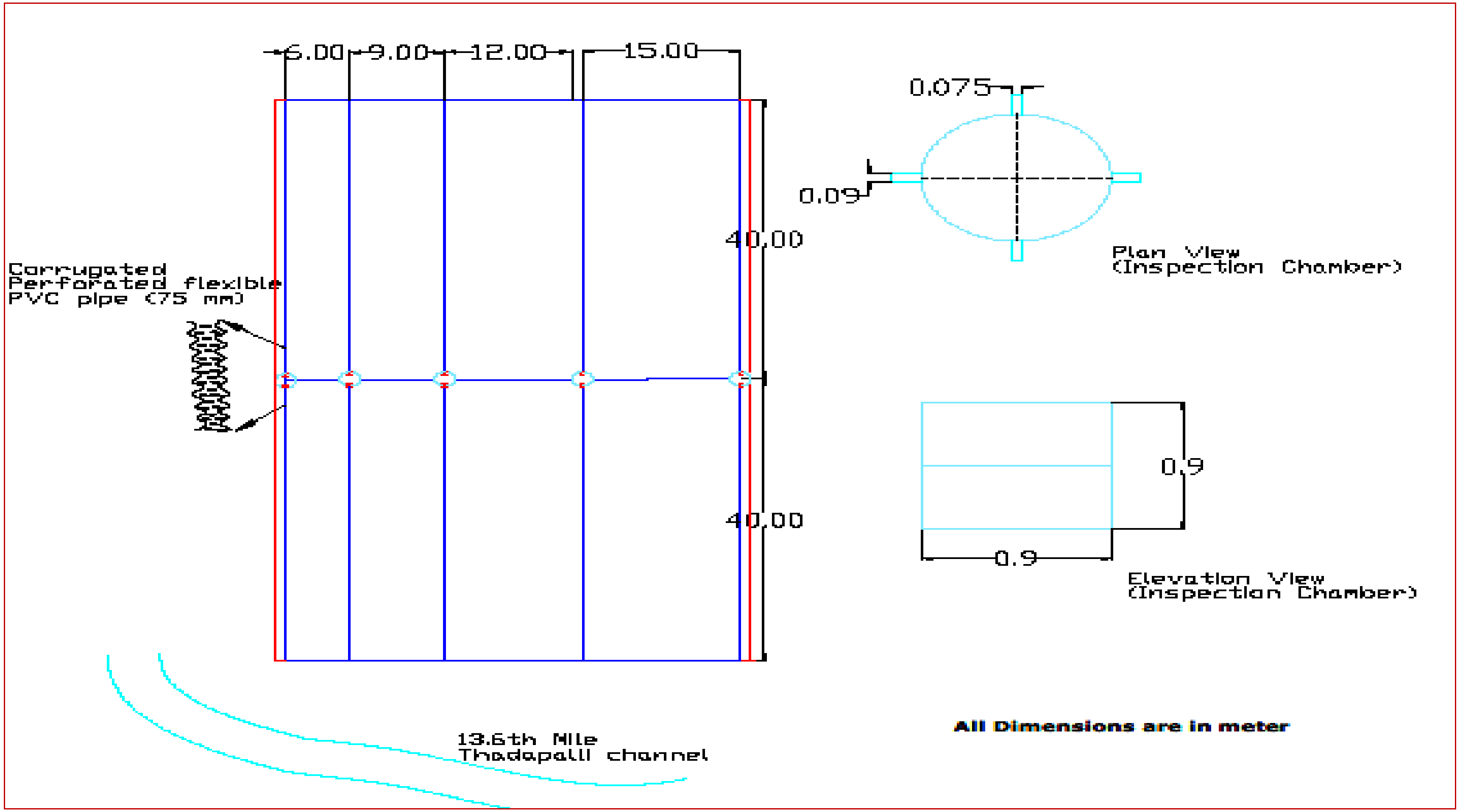


Fig. 3.10 Experimental layout of water table management systems at Gobi

Following values were adopted for various parameters of the study area,

$L \quad = 9m$

Maximum drain length = 40 m,

Hence for q= 16cm/day ,

From Eq.ii), Q = 57.6 m^3/day

‘d_L’ = 55mm.

As subirrigation requires higher diameter than in drainage mode to carry more discharge rate and the next commercially available diameter is 80 mm, hence 80 mm diameter was selected. In the present study, corrugated perforated UPVC pipes of 80 mm have been used for laterals and PVC pipe of 110 mm has been used for the collector line to match the requirements of drain discharge as well as subirrigation inflow rate. Specifications of field corrugated perforated flexible PVC pipes are given in Table 3.9.

The depth of drain placement was done on the basis of i) Crop characteristics ii) Soil depth and texture iii) Cost of the system iv) Capillary rise. As per the literature, as the system has to work on subirrigation mode., two depths were selected for the study i.e 60cm., and 80 cm. for field testing and accordingly the layout was prepared.

3.2.7 Grade of the pipes

A gradient was provided to the drain pipes to meet the following requirements. i) Less risk of water remaining stagnant in some parts of the pipeline. ii) Less risk of counter slopes in some parts of the pipe line. iii) To follow the slope of the land and keep the depth of the drain below the land surfaces more or less the same along the drain. Common drain slopes in flat areas are 0.001 for field drains and 0.0003 to 0.001 for collectors. In the present study, a gradient of 0.1 to 0.2 % for the lateral pipes and 0.6 % for collector pipe has been provided to maintain a desirable minimum velocity of 45 cm/sec for the flow in the pipes.

Table 3.9 Specification of field adopted corrugated perforated flexible PVC pipes

Sl. No	Technical Parameter	Specification
1	Nominal Diameter	80 mm
2	Pipe material	Hard PVC
3	Depth of pipe corrugations	4.2 mm
4	Pipe coil length	100
5	Pipe coil width	54 cm
6	No. of infiltration openings per m.	120
7	No. of infiltration opening in cross sect.	3
7	Angular distribution –Interval of openings	60^0
8	Width of infiltration openings	1.3 mm
9	Length of infiltration openings	8.5 to 15 mm
10	Water inlet area in cm^2/m	18.4 to 32.4
12	Bending radius at 0^0 C	240 mm
13	Nature of the pipe	Flexible corrugated perforated PVC pipe

3.2.8. Drain envelope materials

The functions of envelope materials are i) Filter function to restrict soil particles. ii) Hydraulic function to constitute a medium of good permeability. iii) Bedding function to support the pipe from soil load. According to the literature, envelop material is required in case the clay content is less than 30%, S A R > 13, (RAJAD 1995). However, with the increasing use of plastic pipes and considering the cost of transport of gravel material, synthetic materials are commonly used. But, in the present study, to avoid more synthetic material in the soil, and earlier experience in Tamil Nadu research, as the locally available coconut coir was wrapped around the pipes which was found more durable when placed in soil-water system.

3.2.9 Construction of water table management systems

At both the sites, semi-mechanical construction was done. Laying of drain pipes and back filings were done manually. After marking and staking of the proposed layout, trenches were dug with a poclain having bucket width of 40 cm (Plate 3.4 &3.5) With the help of staff gauges and dumpy level the depth of cut was monitored throughout the digging operation to ensure proper gradient in the laterals and collector lines. Trench digging for collector line was completed before taking up digging for the lateral lines. Cleaning and smoothening was done manually along the bottom of the lateral and collector lines to attain proper surface conditions for laying the pipes.

Before placing the lateral pipes on the trenches, zero sized chips (Plate 3.8) are placed along the bed to act as filter to a thickness of 2.5 cm. Lateral pipes were wrapped firmly with two coconut coir fiber envelope material manually (Plate 3.6 & 3.7). One end of the lateral was closed with an end plug and other end was fixed with rigid PVC pipe and connected to the inspection chamber. The pipes were lowered smoothly and were placed in the trenches. Above the laterals also, 1" thick zero sized metal chips were placed (Plate 3.9). Care was taken to see that no damage was caused to the pipes while back filling was done with minimum soil disturbance compared to before trenching (Plate 3.12). Rigid PVC pipes of 110mm diameter and 6 m length were used to construct the collector. Required numbers of pipes were joined together with PVC solvent cement to make water tight and placed between the inspection chambers (Plate 3.11) with 10 no. of ball valves for all laterals for controlling the flow. Installation of collector pipe was started from the outlet and moved towards upstream end.

3.2.10. Construction of inspection chambers

Totally five Inspection chambers were constructed at each junction point where the lateral met the collector line. RCC rings of 0.90 m diameter and 0.30 m height were used for constructing the inspection chambers. Care was taken to maintain an elevation difference of 0.15 m between the lateral pipe and collector pipe in all the chambers, the lateral pipe being at higher elevation. These inspection chambers were used to measure the discharge from laterals and convey the effluent to the outlet.

3.3 Evaluation for hydraulic and functional performance of water table management system

The canal releases water during 2012 Kharif started from 1st June onwards. Utmost care was taken in finishing the execution of water table management system by 30th May 2012. As the research is a direct on-farm trial, immediately after transplantation of paddy ADT 45 variety by the farmer *i.e*. on 6th June 2012., observation wells were again installed midway between the laterals (6m, 9, 12m & 15m spacings) in both 60cm and 80cm depth of drains.

Continuous evaluation of drain outflows, canal flow levels, water table heights (Plate 3.14) were taken up for two crop seasons, rice followed by fodder sorghum in the study area for arriving at some initial valid conclusions.

3.3.1. Performance evaluation of water table management system under controlled drainage mode.

For evaluating the hydraulic and functional performance of Water Table management system, during the month of June, 2012, immediately after transplantation, the drain discharge (q), depth to water table (d) along with elapsed time were recorded for every 6 hours leaving the midnight observation continuously for four days.

To know the recession of controlled flow and decline of observation well reading i.e fall in water table height/ rise in water table with the decreased flow were recorded and were plotted for both the drain depth and for all spacing combinations. During these experiments, the water table steadily declined and attained the value below drains and similarly draiange coeffcient was also reduced after few hours of operation. The drain discharge was controlled by 50% of valve opening fitted at the eand of lateral (q). For knowing the trend of the decline of both drain discharge (q) and depth to water table (d), over some elapsed time (t), q-d-t plots were drawn for all the replications. The trend line was observed to be exponential rise and fall for h and q respectively. The trendline equations were fitted using MS excel and were represented directly in the graph. These are unsteady state curves which needs further detailed analysis. The analysis could evolve a package of controlled operation of the draiange system for efficient water table managment.

The crop establishment and yield parameters were monitored and compared with the control plots adjoining to the experimental layout both in the fields of lower elevation than the site and also on the fields with similar inundated conditions.

3.3.2. Performance evaluation of water table management system under subirrigation mode

In the whole study area, because of dry year, no canal release was foreseen for the second season paddy. Almost all the farmers kept their land fallow. The farmer has taken up fodder sorghum as the summer crop on the advice to suit to subirrigation experiment trial. The initial moisture at different depths, in near, middle and end reach mid way between the laterals were observed. After pumping the water through the system, continuously for 5 days, the moisture content rise and fall were recorded in all the trials at different depths namely 15cm, 30cm and 45 cm respectively.

Similarly the subirrigation treatments during summer (Plate 3.15 to 3.19) were taken up for performance evaluation by reversibly pumping water into the system. The occurrence of dry year made the farmers to realize about the subirrigation system for dry crop i.e. fodder sorghum for supporting it for life saving. The subirrigation trials were accomplished with the one week canal water release given for standing crop on the farmers' demand. The results obtained were given in Chapter IV.

3.4 Simulation studies using DRAINMOD

By considering different possible real field parameters, simulation studies were conducted for various soil types and water table conditions using DRAINMOD for further recommendations.

3.4.1. Principle of DRAINMOD

DRAINMOD was developed at North Carolina State University in the mid 1970's (Skaggs, 1978, 1980). It is based on a water balance in the soil profile and uses climatological records to simulate the performance of drainage and water table control systems. The model was developed specifically for shallow water table soils. DRAINMOD simulates the performance of a given system for a long period of weather record. It predicts water table depth, drainage rates, surface runoff, ET, etc. on a continuous basis. Alternative system designs could be simulated to select the one that best satisfies the system design objectives.

Several drainage and associated water management practices could be analyzed with DRAINMOD simulation like i) Conventional Drainage ii) Controlled Drainage iii) Subirrigation iv) Surface (sprinkler) Irrigation (Wastewater irrigation) v) Hydrologic Analysis of Wetlands vi) calculate the runoff volume from vii) Analysis for Nitrogen Movement and Loss viii) Analysis for Soil Salinity

3.4.2. Objective functions of DRAINMOD

Several objective functions are calculated in DRAINMOD to quantify the performance of the system that is simulated. Annual values of these functions are summarized and ranked. Monthly and daily summaries are also available at the option of the user. The model determines the number of days during two specified intervals when soil water conditions are suitable for field work such as tillage, harvesting, etc

Stress due to high water tables (excessive soil water conditions) is quantified by the SEW value, which stands for "Sum of Excess Water". Normally SEW_{30} is calculated as follows:

$$SEW_{30} = \sum_{i=1}^{N} (30 - X_i)$$

Where, X_i is the water table depth in cm on day i and N is the number of days in the growing season. Negative terms in the summation are ignored; i.e. no stress is calculated for water table depths greater than 30 cm. While the SEW_{30} values seem to be appropriate for corn, it should be emphasized that the SEW concept is approximate. Conversely crops with deeper rooting systems may be stressed by water tables 45 or 60 cm deep. The SEW value was calculated for each growing season from planting to crop maturity. However paddy rice being shallow rooted crop, SEW_{30} index would be applicable.

The software is user friendly and the manual provided gives the details of inputting the data in to the model.

3.4.2.1 Input requirements and data used in DRAINMOD

The following input files are required to run the model and detailed project window site with specific input window. i) General information ii) Weather information iii) Drainage design. iv) Soil v) irrigation vi) Crops and v) Salinity.

Approximate methods are used to quantify the hydrologic components: subsurface drainage, subirrigation, infiltration, evapotranspiration (ET) and surface runoff. For example, equations developed by Hooghoudt (Luthin, 1978), Kirkham (1957) and Ernst (1975) were used to calculate drainage and subirrigation rates, and infiltration rates are predicted by the Green Ampt equation. Soil property inputs include the saturated hydraulic conductivity (by layers), the relationships between drainage volume and water table depth, and information concerning upward flux from the water table. The effective root zone depth as a function of time is also an input.

Hourly precipitation and daily maximum and minimum temperatures are read from weather records and the water balance is conducted on an hour by hour basis. Summaries of the model predictions for hydrologic components such as rainfall, infiltration, drainage, ET, etc., are available on a daily, monthly or annual bases. The performance of a given system design or management alternative may be simulated for a long period of climatological record, say 20 to 40 years to consider the effects of the year by year and seasonal variability. The effects of water management system design on yields may also be evaluated.

3.4.2.2. DRAINMOD output parameters

Simulation of the variables like depth to water table, drain flow, relative yields, soil salinity and drain water salinity under current as well as different hypothetical scenarios were conducted. The output of the software is in the form of tables and graphs for various scenarios.

3.4.2.3 DRAINMOD modules

The model was run for two modules namely i) Controlled drainage (CD) ii) Subirrigation (SI). The analysis window of the model is presented in Fig.3.11. Scenario formulation and evaluation studies were conducted through i) Variation of Drain volume ii) Prediction/Fluctuations of Water table depth as model output for each module for every one combination of the following two scenarios.

i) Scenario I (Different drain spacings)

This situation was obtained by introducing the values of spacing between the drains as 6m, 9m, 12m & 15m and 20m. The model predicted outputs at different levels of drain spacing's were compared with the results obtained in actual drainage situation.

ii) Scenario II (Different levels of drain depths)

This scenario was obtained by selecting three values of drain depths namely 60cm, 80cm and 100 cm. The model predicted outputs at different levels of drain depths were compared with the results obtained in actual drainage situation.

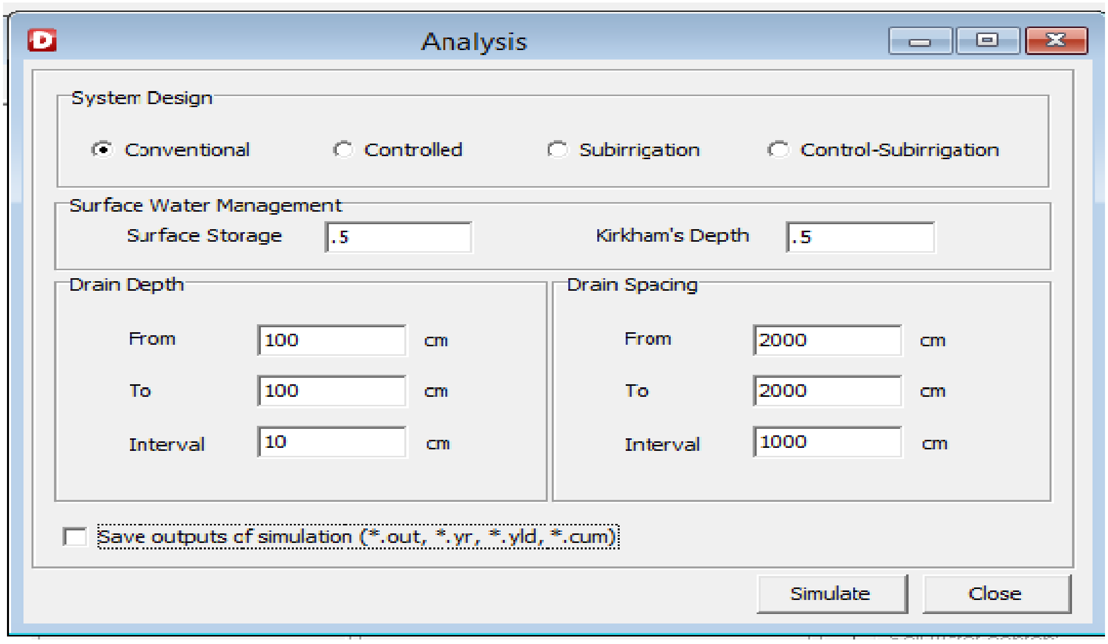


Fig. 3. 11 Different module possibilities in DRAINMOD operation

3.4.2.4. DRAINMOD operational procedure

The Menu Buttons are available at any time DRAINMOD is open. The main menu and submenu components are enlisted below. The various buttons provided for the operation of DRAINMOD are shown in **Fig.3.12.**

Project- i) Open Project : Opens window to allow user to open a project file.

ii) Copy Project Files: Opens window to allow user to open a project file.

iii) Save as Save the current project with a different name. Automatically saves the GEN file and nitrogen file if applicable.

iv) Print User can print an input or output file.

v) Settings Set the default directories for accessing inputs files.

vi) Exit DRAINMOD **without** option of saving or discarding changes to open projects

Utilities

This menu houses the DRAINMOD utilities such as create soil or weather file

i) Create Weather File : Allows user to generate DRAINMOD formatted rainfall, PET, or temperature files.

ii) Create Soil File : Generate DRAINMOD formatted soil files.

iii) Create contributing area input file: Contributing Area Runoff

Iv) Batch Run

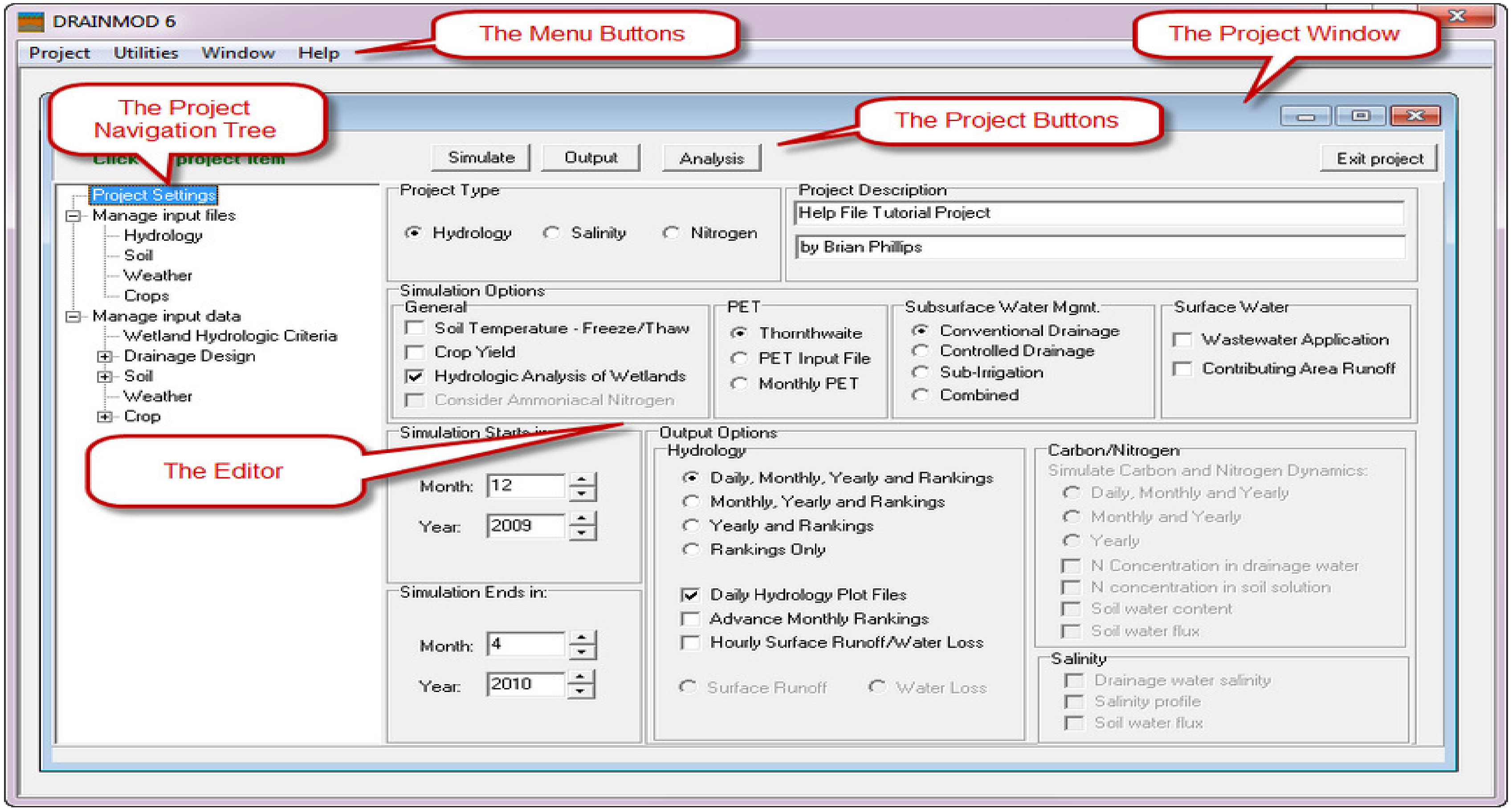


Fig. 3.12. Main menu window (project setting windows) various buttons for inputting the data

3.4.2.5. Selecting the Best Alternative

Knowing the cost of a drainage or irrigation system provides only part of the picture. To determine whether installing a system is a wise investment, the potential benefits in terms of increased yield must also be known. Because a large number of factors are involved and calculations can become complex, a computer-based water management model entitled DRAINMOD has been used to help in comparing alternative systems. The predicted net return for each of the options is compared to that for the present situation.

3.4.3. Testing of DRAINMOD 6.1 with field data

The predicted values of drain discharge (q), depth to water table (d) with duration (days) during for the month of June 2013 for Controlled drainage and April 2013 for Subirrigation were chosen for Testing of the Model DRAINMOD 6.1 for its validity. As the design spacing arrived is 10m., the testing was done for this spacing under both the drain depths namely 60cm and 80cm respectively. Chi squared Test was applied for finding out whether the values are significant or not.

3.5. Economics of water table management systems

Estimates of cost of the system were necessary to compare the relative cost of the water table management system installations and evaluate the economics of the system. A simple methodology followed for agricultural machinery and irrigation pump sets was followed. Cost of the system includes fixed costs and operating costs.

Fixed costs: include i) Interest on investment and ii) Depreciation

i) Interest: Interest was calculated on the average value of the installation at the prevailing rate.

$$\text{Annual Interest Cost} = \frac{(\text{Value of installation-Salvage value}) \times \text{Interest rate}}{2}$$

ii) Depreciation: Depreciation is the loss in the value of the pumping plant due to the operation or age.

$$\text{Annual depreciation} = \frac{(\text{original costs} - \text{salvage value})}{\text{Useful life in years}}$$

Operating costs

The subirrigation system mode requires either electrical motor driven pump set or oil engine driven pump set for pumping water reversibly into the water table management systems.

i) Fuel Energy consumption

$$\text{Energy consumption} = \frac{\text{Brake horse power}}{\text{Motor efficiency}} \times 0.746 \text{ kilowatt-hours (units)}$$

Engine: an estimate of the rate of fuel consumption for a given engine can most accurately be made if the manufacturers' fuel consumption curve for that engine is available.

Cost per hour of operation = BHP x Fuel consumed in liters/hr x cost of fuel per litre

2. Lubricating oil and grease: negligible for electric driven plants
For diesel and petrol engines, 4.5 litres per 1000 hp-hours.

3. Pump maintenance and repairs

$$\text{Centrifugal pump: yearly cost} = \frac{\text{Total Cost}}{\text{Estimated life in years}}$$

$$\text{Turbine pump: yearly cost} = \frac{\text{Total Cost}}{\text{Estimated life in years}}$$

4. Engine maintenance and repairs

5. Operator's wages: At prevailing rates.
Total annual cost of operation = Fixed cost + operating cost.
The B-C ratio was calculated by using the formula,

B-C ratio = Gross Returns/Total cost of cultivation. The detailed calculations performed were discussed in Chapter IV.

Plate 3.1 Water logging due to seepage just beside Thadapalli channel 13/6th mile.

Plate 3.2 Installation of observation wells for drainage investigations

Plate 3.3Inserting 2m deep auger for hydraulic conductivity measurement

Plate 3.4 Trench making to required depth with JCB (15.014.2012)

Plate 3.5 Trenches dug for laterals and collector with inspection chamber rings (Sumps) placed in the field.

Plate 3.6 Wrapping coconut coir on corrugated flexible perforated PVC pipes (Gwalior)

Plate 3.7 Coconut coir wrapped drain pipes of required length

Plate 3.8 Zero chips for bedding material kept ready for placement

Plate 3.9 & 3.10 Placing 2.5 cm thick bedding material (zero chips) below and above the drain pipes (coconut coir enveloped)

Plate 3.11 Water table management system in operation during first crop season

Plate 3.12 Taking observations of water table from observation wells

Plate 3.13 Interconnection of collector and laterals for subirrigation

Plate 3.14 Subirrigation through diesel engine and hired water for two replications during February 2013.

Plate 3.15 Subirrigation through diesel engine pumpset during February 2013

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Plate 3.16 Subirrigation with 5HP diesel engine pumpset during canal release (April 2013).

Plate 3.17 Subirrigation through 5 HP diesel engine pumpset during canal release (April 2013) with water source

Plate 3.18 Soil samples collection for soil moisture studies.

Results & Discussion

Chapter IV

RESULTS AND DISCUSSION

The results obtained from the present research investigations with discussions are reported here under. In this chapter, various sections cover discussions on waterlogging, cropping constraints, design and installation of water table management systems, evaluation of hydraulic performance and simulation studies with DRAINMOD 6.1 software.

4.1. Characterization of waterlogging and cropping constraints

As the channel is unlined, seepage losses were more all along the channel, toe drains were constructed by Agricultural Engineering Department to control the seepage losses in the paddy fields all along Thadapalli Channel. Like in other canal commands, drainage measures were not planned properly either to control waterlogging or to maintain equitable supply to the tail end areas in the canal command. In most of the areas, only canal water is used for irrigation. Except in few areas, where sugarcane and turmeric are grown, farmers are using ground water as irrigation source when the canal supplies are stopped.

The summer crop was not found and the land was kept fallow. The farmers had to depend on canal supplies for two paddy crops. But sometimes, during scanty rainfall years, farmers get canal supplies for one season only. Some progressive farmers are cultivating banana in the upper reaches and avail the canal supplies for recharging their open wells.

The drainage investigations were carried out in two sites initally 1 km apart along the Thadapalli Channel 14/6th and 13/4th mile to characterize the waterlogging problems. At 14/6 th mile, the study region was found totally terraced and there was a natural pond causing surrounding lands too waterlogged. There was certain land experiencing very poor yield and certain land not fit for cultivation. At little upstream of this natural small water body, there was all along a natural drain flowing ¾ th full throughout the cropping season.

The grid network of observation wells along with canal is shown in Fig. 4.1. for carrying out drainage investigations at this location. 20 observaton wells were installed at 40 x 40 m grid spacing and fortnightly observations were taken and presented in Table 4.1 in an area of 2ha. of field. The average of row wise observation wells in different dates were calculated and tabulated in Table 4.2 and also plotted in Fig. 4.2.

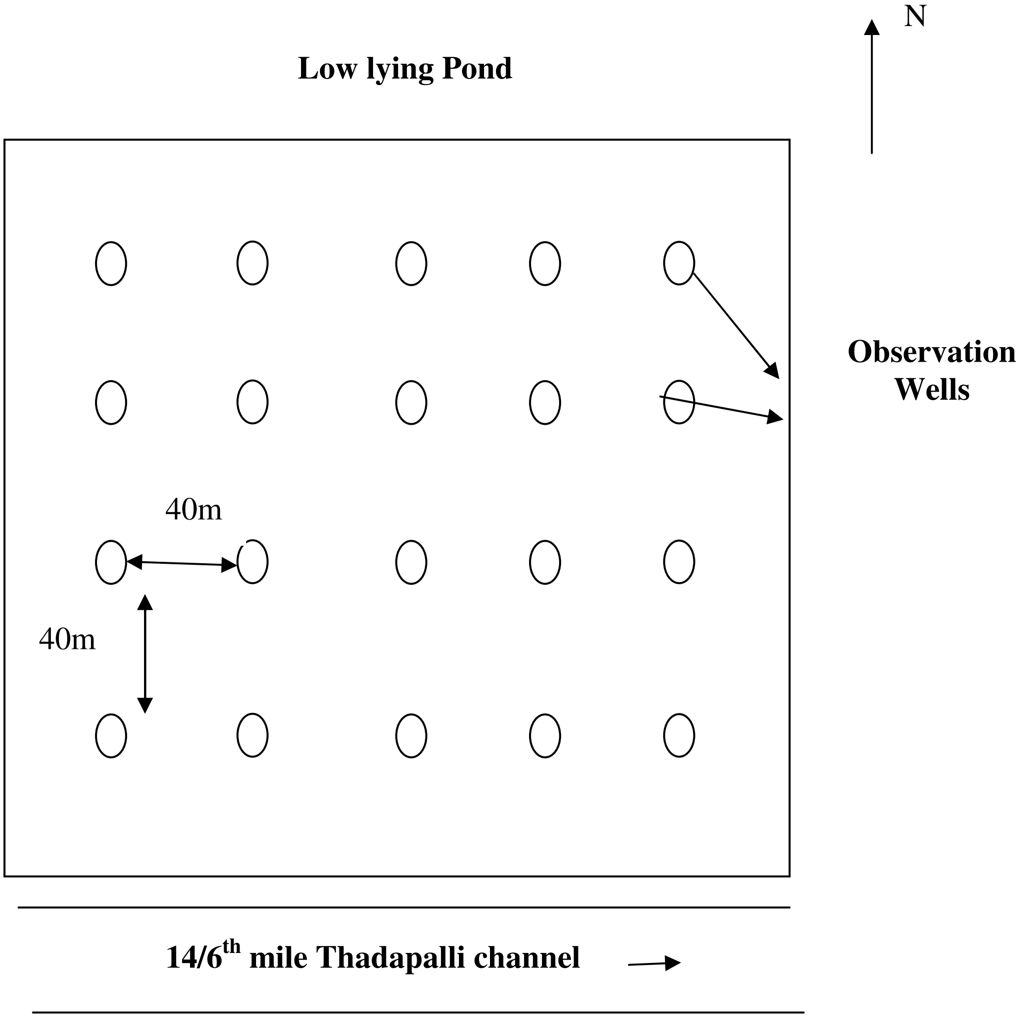

Fig. 4.1 Observation wells grid network for monitoring water table fluctuations at 14/6th mile, Thadapalli channel

Table 4.1. Water table elevations above mean sea level at 14/6th mile of Thadapalli channel

Sl. No	OW No.	MSL of Ground (m)	Date of observation 9 (m)			
			23.12.2011	03.01.2012	18.01.2012	02.02.2012
1	O11	212	211.8	211.8	211.75	211.54
2	O12*	211.805	211.605	211.605	211.565	211.365
3	O13	211.545	211.345	211.345	211.315	211.105
4	O44	211.19	211.01	211.01	210.92	210.73
5	O55	210.615	210.395	210.395	210.355	210.165
6	O21	212.12	211.88	211.87	211.86	211.58
7	O22	212.385	212.145	212.145	212.145	211.905
8	O23	211.84	211.64	211.61	211.61	211.35
9	O24	210.955	210.735	210.685	210.685	210.455
10	O25	210.51	210.31	210.25	210.26	210.02
11	O31	212.59	212.31	212.3	212.19	211.99
12	O32	212.31	212.03	212	211.91	211.73
13	O33	211.695	211.395	211.405	211.315	211.075
14	O34	211.21	210.95	210.9	210.79	210.61
15	O35	210.655	210.375	210.365	210.255	210.055
16	O41	212.53	212.07	211.99	211.98	211.82
17	O42	212.19	211.75	211.71	211.63	211.49
18	O43	211.09	210.65	210.6	210.54	210.41
19	O44	210.59	210.13	210.09	210.05	209.87
20	O45	210.21	209.76	209.72	209.66	209.52

*In O12 '1' stands for row no.1(distance from canal),' 2' stands for the observation well no. 2 within the row.)

Table 4.2. Average water table fluctuations (m) in the investigation site above MSL

Sl. No.	Distance from canal (m)	GL(m)	Date			
			23.12.2011	03.01.2012	18.01.2012	02.02.2012
1	40	212.2	212	212	211.95	211.7
2	80	212	211.78	211.75	211.75	211.6
3	120	211.5	211.1	211.2	211.1	210.9
4	160	211.2	210.75	210.7	210.65	210.5

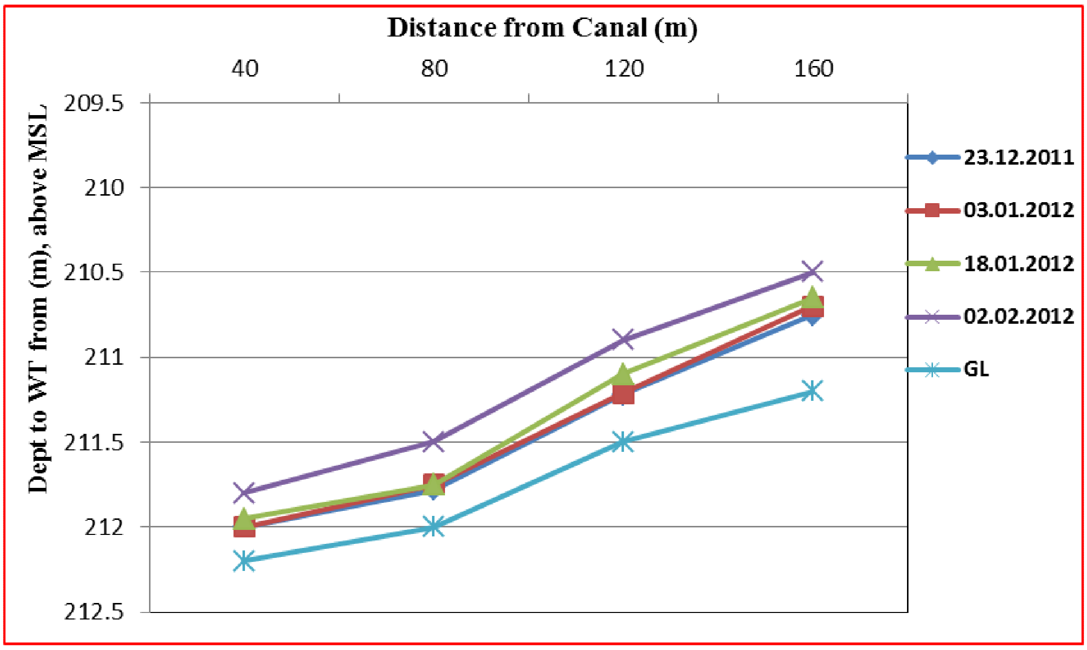

Fig. 4.2. Water level fluctuations near 14/6th mile of Thadapalli channel.

Further by careful examination of the water table (WT) data from Table 4.1, Table 4.2 and Fig. 4.2, the following information could be drawn.

- As the field was found terraced, the water table depth towards downfield from canal was found decreasing.
- There exists an elevation difference of 1m within 160m distance.
- The water table gradient prevailed from the canal to the tail reach where natural drain was present.
- Before the release of the canal, the WT was the lowest in all the observation wells.
- Depth to watertable was found very close to the ground level in the immediate vicinity of the canal ranged from 0.2m to 0.25m with a mean of 0.23m, and it went up to 0.5m during I week of February 2012, i.e. early harvesting stage of paddy stage.
- Observation wells installed beyond 80m showed deeper water tables ranging from 0.3m - 0.7 m with a mean value of 0.49 m and it went up to 0.7m during I week of February i.e. early harvesting stage of paddy.
- As the time progressed during the crop season, the WT was declining from December to February month due to less irrigation during early maturity and maturity periods of the crop.

4.1.1. Calculation of SEW_{30} index for the location near 14/6th mile of Thadapalli channel

The value of SEW_{30} index (as centimeter days) combines all the days in a growing season when excess water was present in some or all of the top 30 cm of the soil profiles(i.e. the zone in which most roots are usually to be found). Values of more than 200 cm days are often sufficient to depress crop growth in temperate growing conditions (Setter and Grower, 2003). The no. of days of encroachment of the water table (WT) within the root zone were worked out based on the WT status at different depths and days during the crop season were arrived and tabulated in Table 4.3.

Table 4.3 Calculation of SEW_{30} index for the location near 14/6th mile of Thadapalli channel

Sl. No.	Distance from canal (m)	WT falling within the root zone (30 cm), days			SEW30 Index (cm days)
		20-30	10-20cm	0-10cm	
1	40	22	15	0	520
2	80	16	8	0	320
3	120	15	0	0	150
4	160	12	0	0	120
Overall average					**277.5**

In Table 4.3., SEW 30 index was worked out as explained in the previous chapter subsection 3.1. Near to the canal SEW30 index was found to be high compared to the fields far away from the canals. From the above table, the SEW_{30} index from 40m, 80m, 120 and 160m from the canal were calculated as 520, 320, 150 and 120 cm days respectively with an average value of 277.5 cm days. As these values are higher than the optimal value of 200cmdays for dry climate conditions, it could be concluded that the experimental area is under the problem of chronic waterlogging condition which needs reclamation measures. A single SEW 30 index could represent for the entire 2 ha land. But for greater accuracy for larger areas, for characterizing the localized problematic lands, it is very much essential to divide the land in to sub units and mapping of SEW_{30} index for the entire area for better planning of drainage measures.

The identified farmer in 14/6th mile was reluctant in taking up and installing CD-SI systems in his field, another nearby farmers field in 13/6th mile in the same problem area was chosen for installing the system and field investigations were carried out. At 13/6th mile., before drainage system installation, 10 no. of observation wells were installed and two sets of readings once in fortnight were collected before the system installation. The same were utilized in designing the water table management system. At the time of installation of observation wells at both the locations, it was found that there was an impeding impervious soil below 1-1.2 m depth making the water difficult for deep percolations. As the farmers irrigate the water from field to field, farmers were maintaining the ponding depth more than 15 to 20cm water to ensure the constant ponding as their regular practice.

4.1.2. Trafficability Index for paddy crop

Owing to the waterlogging conditions, the trafficability problem was posed by the higher moisture and loss of yield due to shattering losses arising out of non-timely/delayed harvest of crop. The impact of waterlogging could be measured in terms of developed Trafficability Index (T).

T = dy D (dθ), where,

T = Trafficability Index in tons days/ha

dY = decreased yield (tons/ha)

D = delay in harvesting (days)

dθ = difference in grain moisture (fraction) with optimum level

Threshold value for harvesting delays, (>0), D could range from 1-15 days or even more. Similarly 'dθ' (>0) up to a threshold difference (say 10%) moisture or even more than that. The severity of trafficability problem occurs either due to harvesting delay or due to more reduction of grain moisture content than the optimum value. Hence the range of Trafficability Index could be calculated based on the already available research data. With the available field data collected, the following calculations were performed to arrive the Trafficability index and is given in Table 4.4.

Table 4.4. Calculation of Trafficability Index(T)

Sl. No.	Days after heading, D(days)	Grain Moisture Reduction, dθ, (%)	Reduction in Paddy Grain Yield dY, tons/ha	T (Tons. days/ha)
1	1	1	0.2	0.2
2	2	2	0.3	1.2
3	3	3	0.4	3.6
4	4	4	0.5	8.0
5	5	5	0.6	15.0
6	7	7	0.7	34.3
7	8	8	0.8	51.2

The trafficability index value (T) varies from 0.2 to 51.2 ranging from 1 to 8 days. It could be recommended that tolerable yield loss of almost 500-600 kg/ha due to operational constraints of the farmer for which 4-5 days delay from optimum might be allowed. Hence the Trafficability Index corresponding to this delay might be in the order of 0.2 to 15 as deduced from Table 4.4.

4.1.3 Crop yield status under waterlogged conditions (pre-project)

In general, both the locations, the farmers were experiencing lower paddy yields than average yield of 5.2 tons/ha. On interaction with 15 farmers, the paddy yield data per ha. in the fields adjoining was collected and presented in Table 4.5..

Table 4.5. Conventional paddy yields in the study area

Sl. No.	Farmer	Yield (tons/ha)
1	F1	4.32
2	F2	4.08
3	F3	3.21
4	F4	4.45
5	F5	4.82
6	F6	4.20
7	F7	4.32
8	F8	4.57
9	F9	4.20
10	F10	3.95
11	F11	5.43
12	F12	5.19
13	F13	5.68
14	F14	4.69
15	F15	4.45
Average Yield (tons/ha)		**4.00**

From the above Table 4.5, it could be observed that the paddy yield per hectare varied between 3.21 to 5.43, average yield being 4.00 tons/ha. On further interaction, it was found that the paddy yield in the fields free from water logging problems were in the tune of as high as 5.2 tons/ha.

4.2. Design and execution of water table management systems

The hydraulic head causing the seepage flow nearby the canal to the field were collected from Public Works Department (PWD), Gopichettipalayam for four years i.e. 2009-2012 and the same were presented Fig. 4.3.

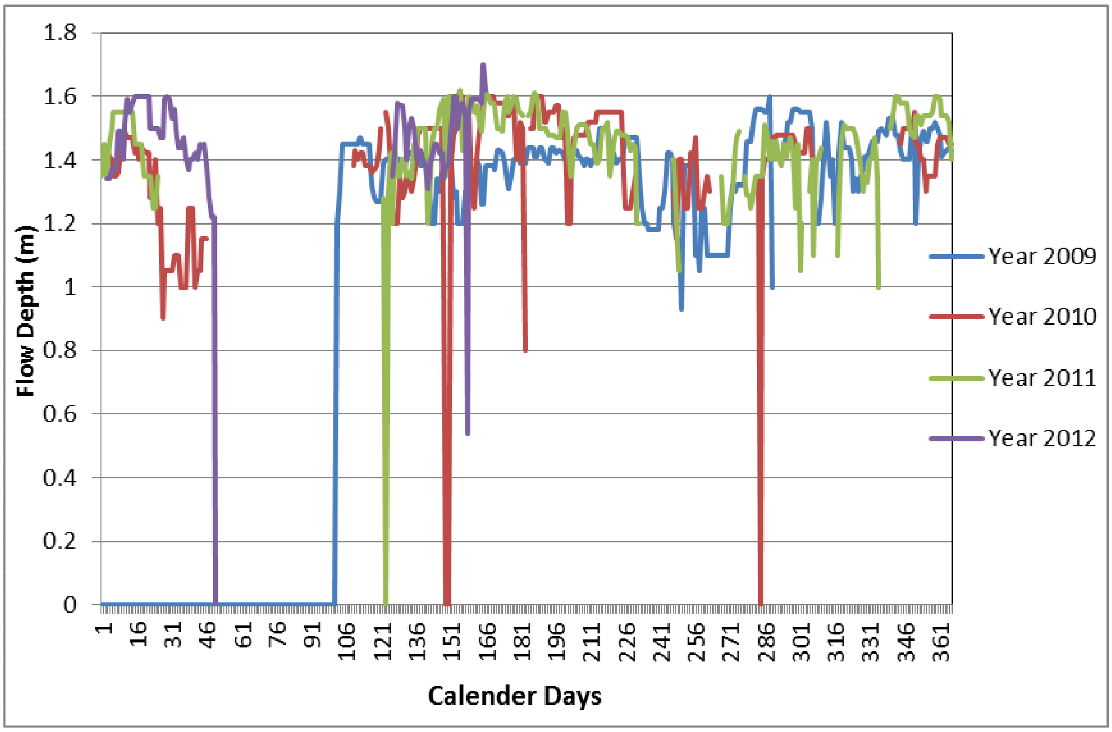

Fig. 4.3 Flow depths during canal flows at Thadapalli channel 13/6th mile during 2009-2012.

The following inferences could be drawn from Fig. 4.3

1) There was an average canal flow of 1.5m depth throughout the year except during February to April (46th to 100th day)
2) There was a mild fluctuation of flow depth across the years.
3) Within each year, seepage causing flow depth is predominating during the month of June moth in all most all the years.

This might be due to the higher inflow from the reservoir coupled with more rainfall in some years of the study. This data was being used as an input both for the design of drainage coefficient as well as for simulation which will be discussed in the section 4.4.

The water table management system was designed considering two modes of operations viz., subsurface drainage and subirrigation into consideration. Under drainage mode, steady state Hooghoudt's equation was considered. For subirrigation, the procedure explained by Skaggs and Doty (1995) was followed.

4.2.1 Steady state spacing under drainage mode for the water table management system (WTM) in the study area.

The generally used Hooghoudt equation for subsurface drainage spacing is given below.

…..Eq. 4.1

The values of parameters of the above equation are given below.
K = 0.75 m/day
Hydraulic gradient i= Hydraulic Head/Length of canal seepage
= (Flow depth in canal + level difference from canal bed level CBL to the field)/ Length of canal seepage

= (1.5+0.5)/160m = 2/160

Hydraulic gradient of 2 m head of water acts at 160m as seepage

As per Darcy's law, V= Ki,

K is taken as 0.75 m/day.

Hence V= 0.75 x 2/160 = 1 cm/day

Taking 5% as deep seepage, D_s= 0.05 cm/day

On an average, the recharge R would be (0.05+1.00)/2= 0.75 cm/day

Therefore drainage coefficient was rounded and taken as 1cm/day or 0.01 m/day.

H= Hydraulic head above the drains = 0.3m

Substituting the above values in Eq. 4.1., the drain spacing 'L' was arrived as 20m.

4.2.2 Design spacing under subirrigation mode for the WTM in the study area.

The hydraulic conductivity appears to decrease with depth so that it is restrictive to water movement below a depth of about 1.-1.5 m. A water table management system is to be designed for the productions of a third crop during summer either growing for less water requiring pulse crop or any other fodder crops remunerative to the farmers of the region.

In Gopichettipalayam area, the ET rate during summer usually did not exceed 5.5mm/day as per the previous weather records and was taken as design value for ‘e’ in Moody’s equation as explained in the Section 3.2. For using this equation applicable to the filed situation, the water table should be maintained at depths within 0.4 m taking a conservative estimate of the average root zone depth of 0.25m, the midpoint water table should be held at a depth, no greater than 0.5m from the surface.

Referring to the Fig. 3.10 of previous chapter, this would give a value (h_1= 1.5-0.5) = 1m, at mid point i.e. at x= L/2. The water table depth to be maintained at the above drain points depends on the root zone depth and crop tolerance for wet conditions. Generally the study location, for the summer crop, the water table must be raised for few life saving irrigations. Hence the effective root zone depth was assumed to be limited to 0.3m for this soil and a water table depth at the drains of 0.45m was taken based upon the field observations of water table data. Based on the methodology discussed, the subirrigation spacing L was calculated by analyzing the flow through the drains and rising the water table with the following basic equation.

$$L = \left[\frac{4K_S\left(h_0^{\,2} - h_1^{\,2}\right)}{e} \right]^{\frac{1}{2}} \qquad \text{….Eq. 4.2}$$

h_0= 1.5-0.30 = 1.2

h_1= 1.0 m

Substituting the above values in Eq.4.2, preliminary L works out to be 10.77m.

$$d_e = \frac{d}{\left[1 + \frac{d}{l}\left(\frac{8}{\pi}\ln\frac{d}{r_e} - 3.4\right)\right]} \qquad \text{…Eq.4.3}$$

Substituting this L value by considering r_e effective radius of drains as 0.036m, for 80mm corrugated perforated UPVC pipes (design diameter explained in section 3.2), by Eq. 4.3, the d_e value was worked out as 0.8m.

h_o’= 0.8+0.5= 1.3m

$$L = \sqrt{4KsM\ (2ho' - \frac{ho'}{ho}M\ )\,/\,e} \qquad \text{…Eq. 4.4}$$

Adopting M= 0.15m and using Eq.4.4, L works out to be 9.96m say 10 m.

The design parameters under both drainage and sub irrigation mode are presented in Table 4.6

Table 4.6. Design parameters of water table management systems

S. No	Design Parameters	Specification	
		Controlled Drainage	Subirrigation
1.	Average Hydraulic Conductivity	0.75m/day	0.75 m/day
2	Drainage Coefficient	1 cm/day	0 cm/day
3	Hydraulic head above the drains	0.4-0.25 m	0.3-0.45m
4	Equivalent depth	1.05m	0.8m
5.	Evaporation rate	0.0055m/day	0.0055m/day
6	Difference between actual and Design watertable (M)	0.3m	0.15 m
7	Effective radius r_e	0.036m	0.036 m
8	Drainable pore space	10%	10%
9.	Drain spacing	20m	10m

4.3. Hydraulic and functional performance of water table management system

The hydraulic and functional performance of the water table management was studied in this investigation under three divisions namely 1) A detailed investigation leading to drain discharge (q)-depth to water table (d) –elapsed time (t) relationships through the form of exponential equations for ready prediction of both the parameters under controlled drainage operation 2) Monitoring of data on depth to water table and drain discharge for one entire crop season. 3) Variation of soil moisture content at different depths of soil profile in lower, middle and last reaches midway between the laterals of all the spacings and depths under subirrigation. The results are reported here under and discussed.

4.3.1. Hydraulic performance studies of controlled drainage

Immediately after transplation of paddy nursery continuously for three days for every 6hours, the observations of both drain discharge and depth to water table mid way between the drains were recorded. The midnight observations were skipped in view of operational difficulty. The readings are presented in Table 4.7.

To know the recession of controlled flow and decline of observation well reading i.e fall in water table height/ rise in water table with the decreased flow were recorded and were plotted for both the drain depth and for all spacing combinations in Fig. 4.4 to 4.11.

During these experiments, the water table steadily declined and attained the value below drains and similarly draiange coeffcient was also reduced after few hours of operation. The drain discharge was controlled by 50% of valve opening fitted at the each end of lateral (q). For knowing the trend of the decline of both drain discharge (q) and depth to water table (d), over some elapsed time (t), q-d-t plots were drawn for all the drain spacing and depth combinations for different elapsed times.

Table 4.7 Performance monitoring of water table management system for drain discharge- depth to water table with elapsed time.

Sl. No.	Elapsed Time(hrs)	6m spacing		9m spacing		12 m spacing		15m spacing	
60cm drain depth		**q cm/d**	**d cm**	**q cm/d**	**d cm**	**q cm/d**	**d cm**	**q cm/d**	**d cm**
1	0	1.16	58.84	0.98	41	1.02	39	0.8	38
2	6	1.0	59	0.84	43	0.96	43	0.94	42
3	12	0.8	59.2	0.8	46	0.8	46	0.78	45
4	24	0.64	59.36	0.65	50	0.65	50	0.62	48
5	30	0.59	59.41	0.58	53	0.58	53	0.57	50
6	36	0.5	59.5	0.49	55	0.48	55	0.48	51
7	48	0.38	59.62	0.37	57	0.37	57	0.37	53
8	54	0.34	59.66	0.32	58.5	0.3	58	0.35	54
9	60	0.28	59.72	0.25	59	0.26	59	0.29	55.5
10	72	0.18	59.82	0.18	60	0.18	60	0.2	58
80cm drain depth									
1	0	1.2	40	1.2	41.5	1	42	1.15	39
2	6	1.16	45	1.12	46	0.99	43	1.12	45
3	12	1.07	50	1	51	0.98	52	1.105	48
4	24	0.88	58	0.89	58	0.97	55	0.82	54
5	30	0.83	59	0.82	59	0.85	56	0.78	58
6	36	0.77	62	0.77	61	0.75	56.5	0.72	61
7	48	0.6	67	0.58	64	0.72	58	0.58	66
8	54	0.56	70	0.56	67	0.71	58.5	0.53	68
9	60	0.52	71	0.52	68	0.7	60	0.49	69
10	72	0.5	74	0.45	70	0.63	61	0.43	72

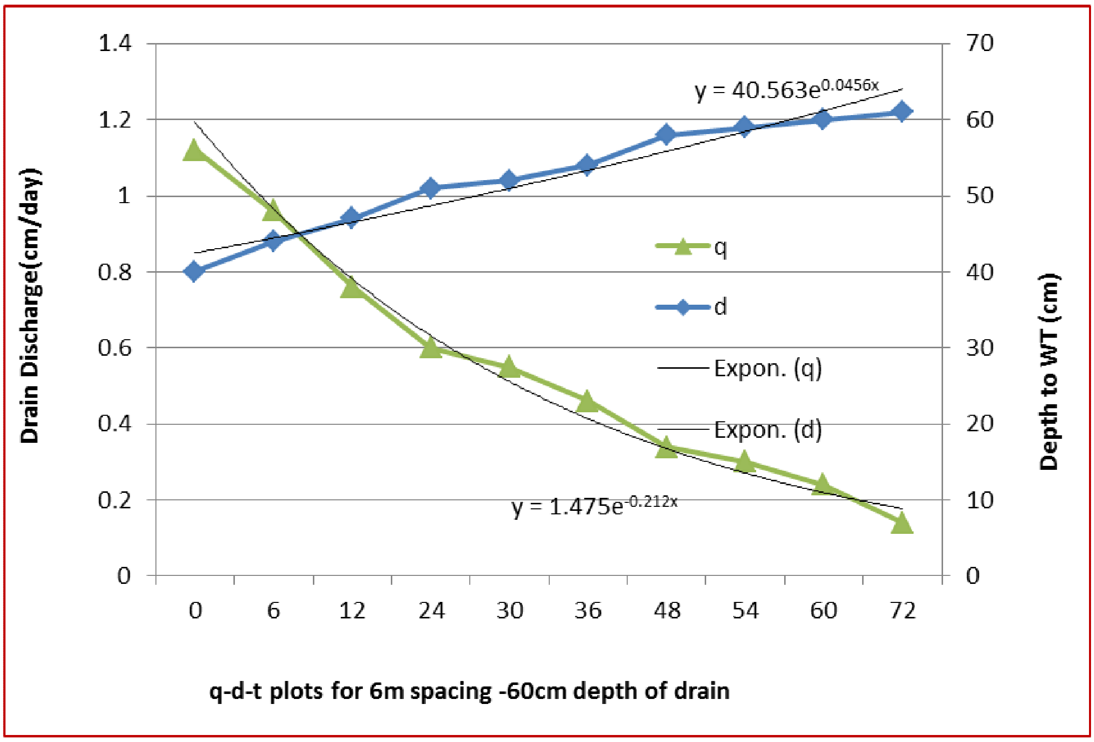

Fig. 4.4. Plots of q-d-t for 6m spacing-60cm drain depth replication

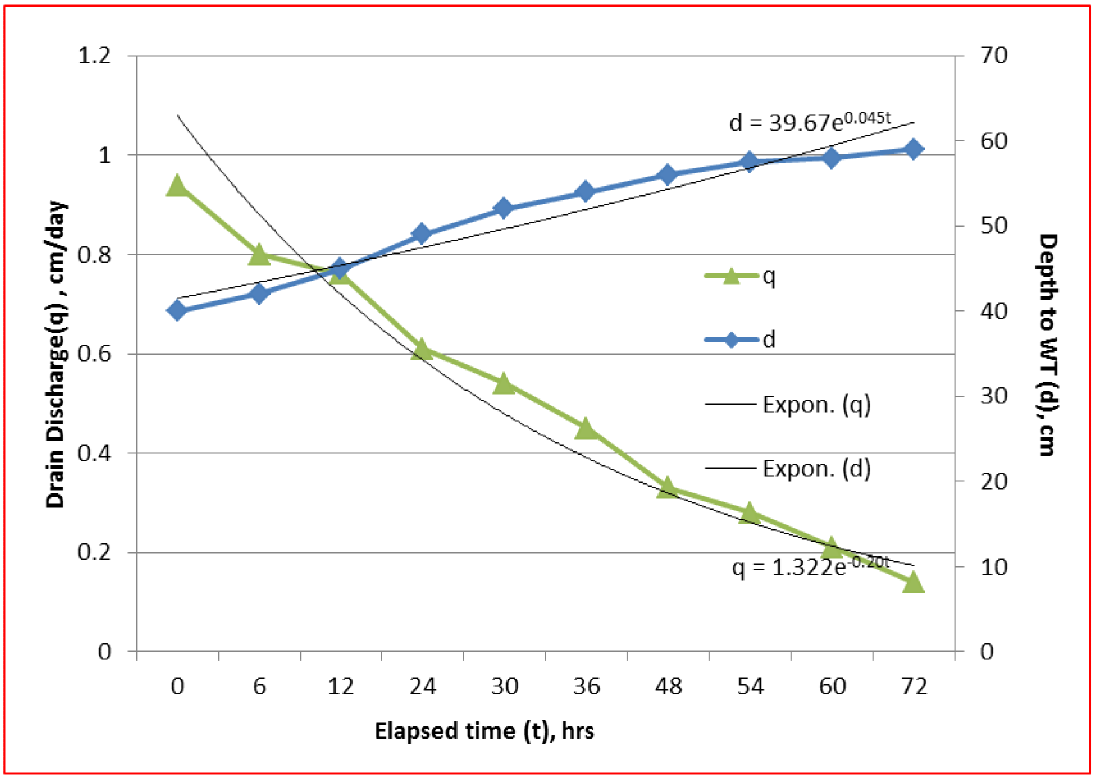

Fig. 4.5. Plots of q-d-t for 9 m spacing-60cm drain depth replication

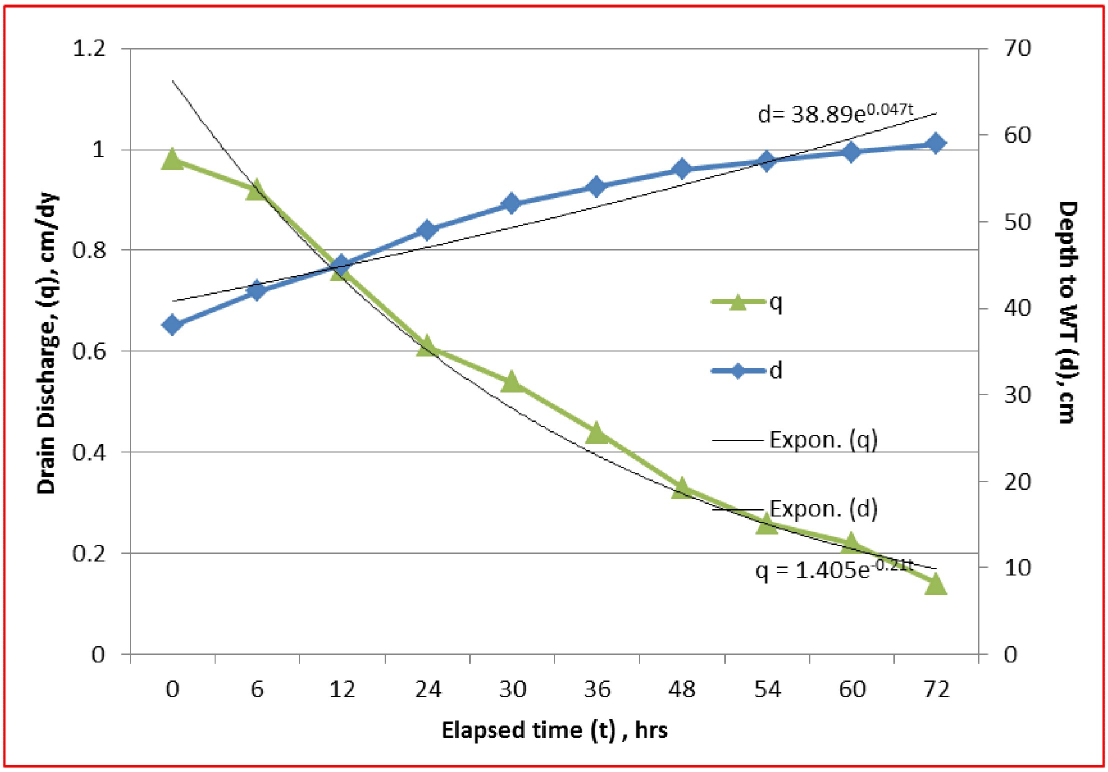

Fig. 4.6 Plots of q-h-t for 12m spacing- 60cm drain depth replication

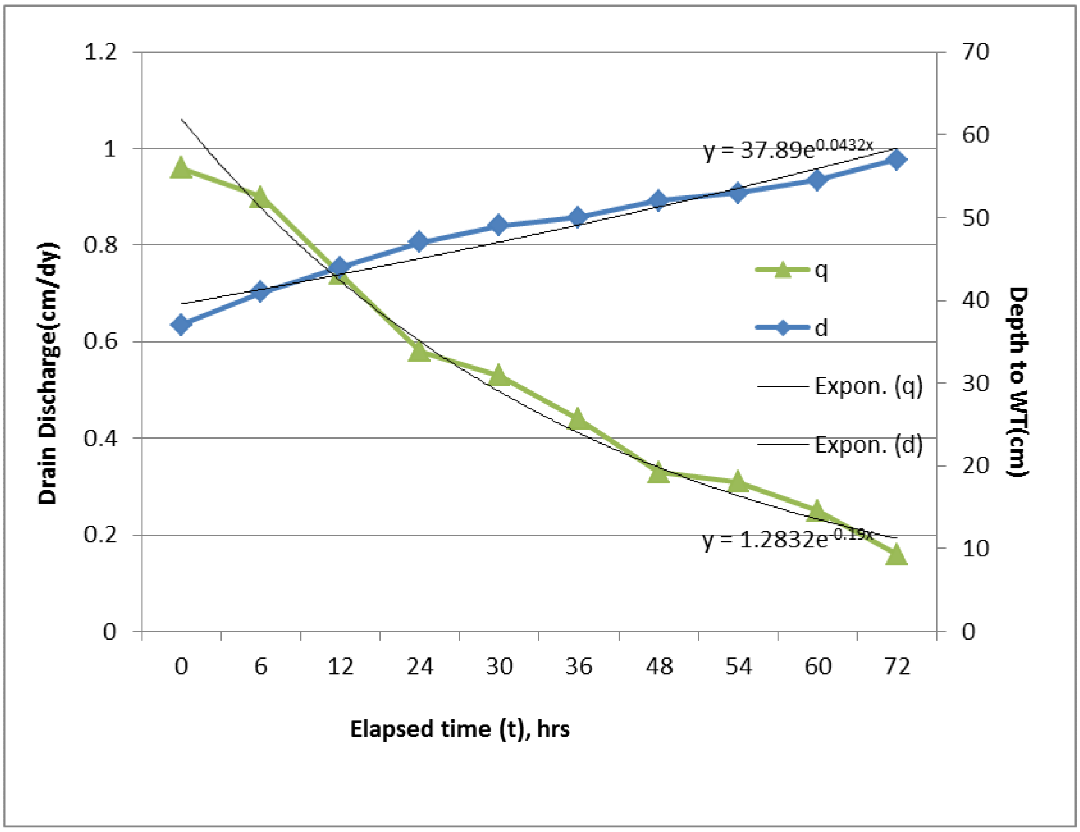

Fig. 4.7 Plots of q-h-t for 15m spacing -60cm drain depth replication

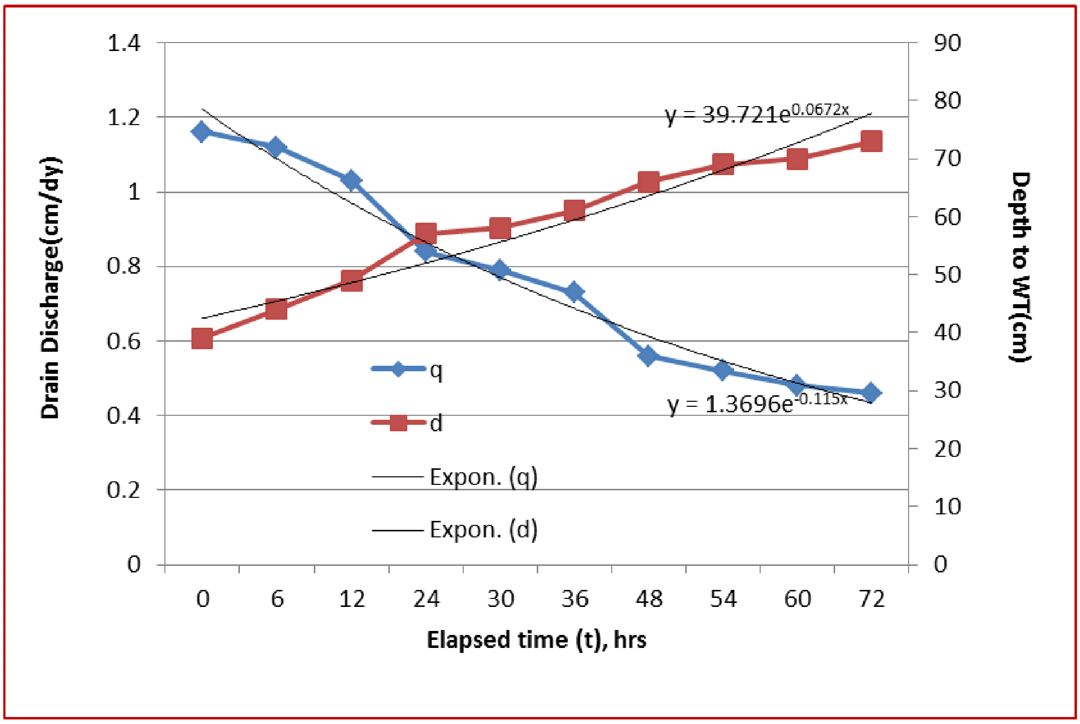

Fig. 4.8 Plots of q-h-t for 6m spacing-80cm drain depth replication

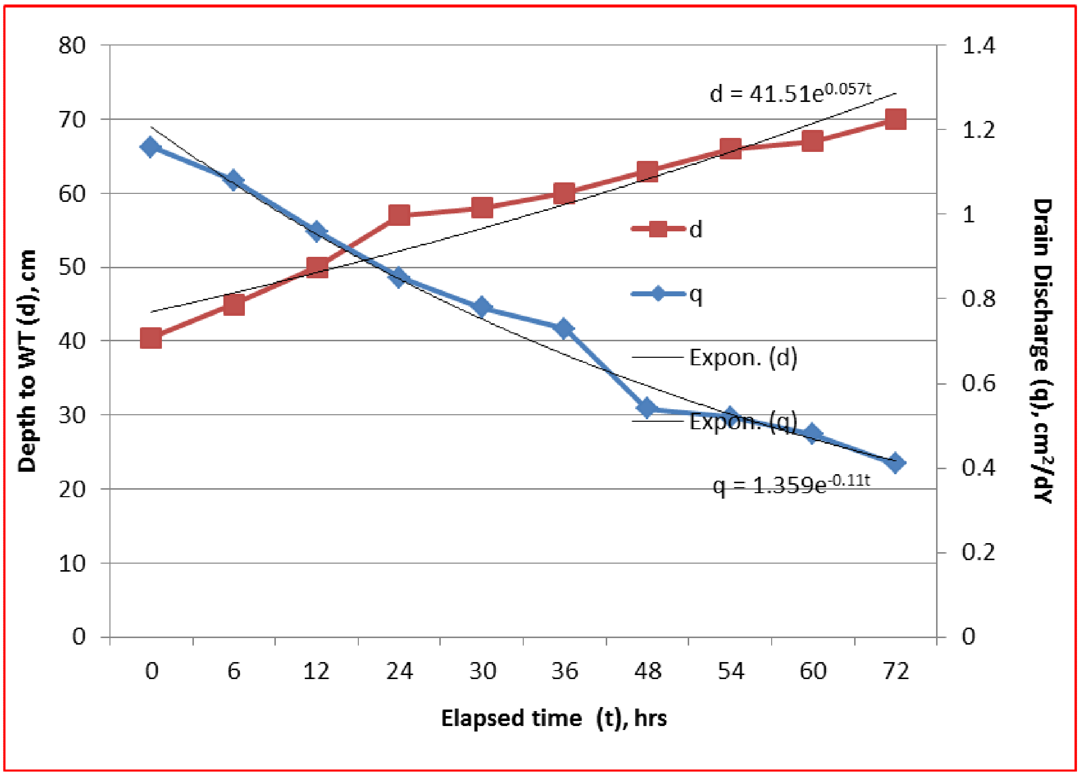

Fig. 4.9 Plots of q-h-t for 9m spacing -80cm drain depth replication

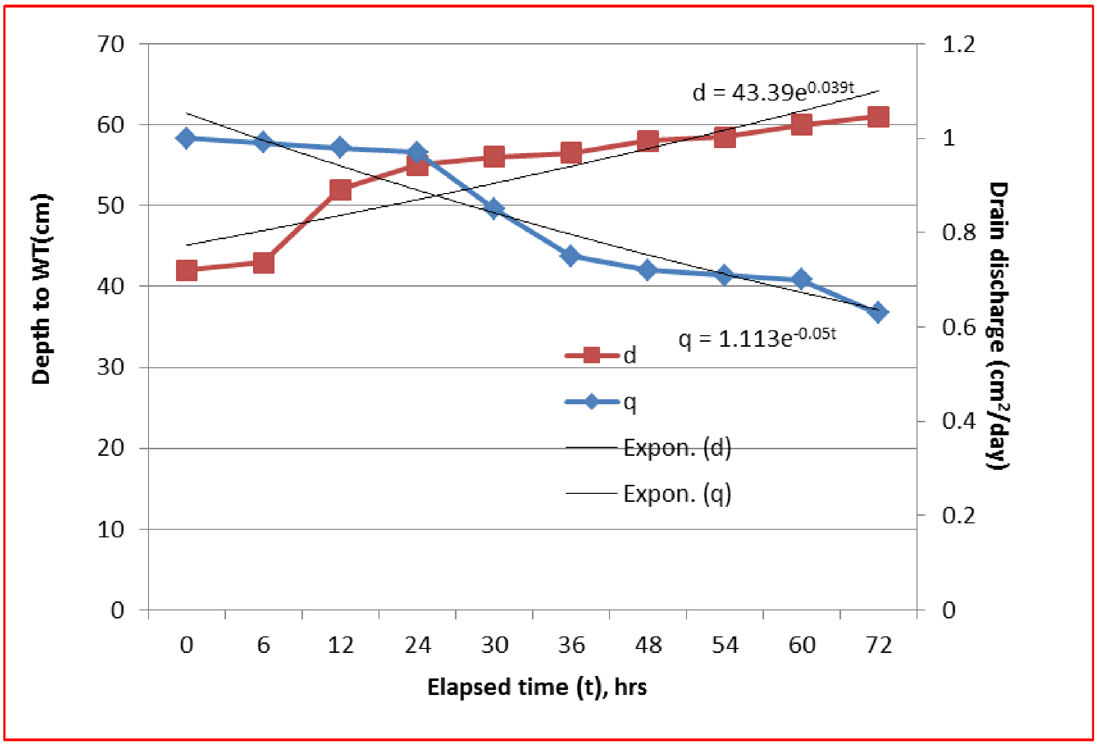

Fig. 4.10 Plots of q-h-t for 12m-spacing -80cm drain depth replication

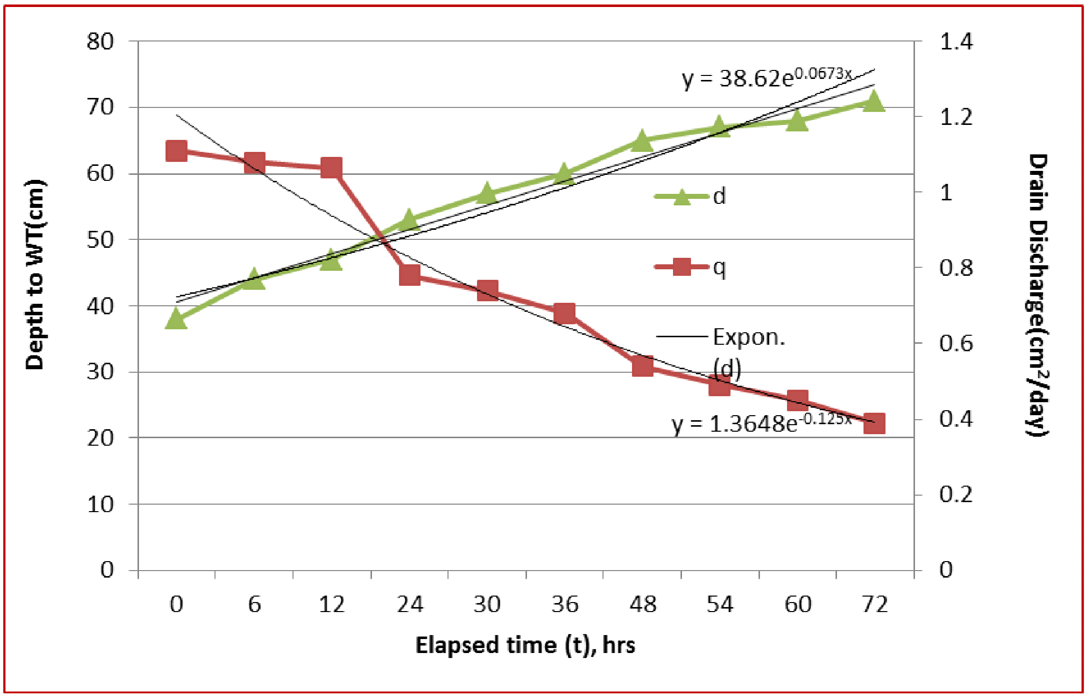

Fig. 4.11 Plots of q-h-t for 15m spacing -80cm drain depth replication

From Fig. 4.4 to Fig. 4.11, it could be observed that the depth to water table and drainage discharges varied with time exponentially. The equations were fit based on the trend of the variation of the above parameters in un-steady state conditions. The trend line was observed to be exponential rise and fall for d and q respectively. The trendline equations were fitted using MS excel and are represented directly in the graph. The equations for all the trials are enlisted in Table 4.8 and 4.9. The analysis could evolve a package of controlled operation of the draiange system for efficient water table managment.

Table 4.8 Prediction equations for drain discharge with elapsed time (t) for different drain depths

Sl. No.	Spacing (m)	q-t relationship	
		60 cm drain depth	80 cm drain depth
1	6m	$d = 1.475e^{-0.21t}$	$d = 1.359e^{-0.11t}$
2	9m	$d = 1.322e^{-0.20t}$	$d = 1.359e^{-0.11tx}$
3	12m	$d = 1.405e^{-0.021t}$	$d = 1.113e^{-0.05t}$
4	15m	$d = 1.283e^{-0.19t}$	$d = 1.364e^{-0.12t}$

From Table 4.8, it could be inferred that, the decay constant 'α' varied from -0.19 to -0.21 for 60m spacing and similarly -0.05 to -0.12. The coefficient varied between 1.283 to 1.475 with an increasing trend with spacing.

Table 4.9 Prediction equations for drain discharge with elapsed time (t) for different drain depths

Sl. No.	Spacing (m)	q-t relationship	
		60 cm drain depth	80 cm drain depth
1	6m	$q = 40.5e^{0.045t}$	$q = 39.72e^{0.067t}$
2	9m	$q = 39.67e^{0.045t}$	$q = 41.51e^{0.057t}$
3	12m		$q = 43.39e^{0.057t}$
4	15m	$q = 37.89e^{0.043t}$	$q = 38.62e^{0.067t}$

From Table 4.9, it could be observed that the constant 'α' varied from 0.043 to 0.045 for 60m spacing and similarly 0.057 to 0.067. The coefficient varied between 37.89 to 43.39 with a decreasing trend with spacing. From the above equations, the prediction of depth to water table and drain discharge could be easily carried out. This type of analysis when used properly, the operation of controlled drainage could be effciently done.

4.3.2. Performance evaluation of water table management system under controlled draiange mode.

The volumetric discharges from all the laterals were collected with a measuring jar and stop watch. The controlled drainage option let the farmer an opportunity of either closure or opening of the valves as and when there was excess irrigation water. The data on observation wells and lateral discharges once in the fortnight during the growing season were monitored. Farmer and the operating worker were under the opinion that if the water was let out from the field through the laterals, they might get water shortage because of the sudden closure of the canal. Initially the valves were kept for individual laterals. Five laterals with 80cm depth on one side with 6m, 9m, 12m, & 15m spacing and five more laterals on another side, with 60cm depth of placement of drains with the above spacing intervals were installed. The laterals were designated as L11, L12, L13, L14 , L15 and L21, L22, L23, L24, L25 for 80cm and 60cm drain depths respectively.

The fortnightly discharge (lps) collected from the pilot area is given in Table 4.10

Table 4.10 Discharge fluctuations of laterals from water table management systems

Sl.No.	Laterals	Discharge(lps)					
		6.6.12	21.6.12	6.7.12	21.7.12	5.8.12	20.8.12
1	L11	1.05	1.10	1.00	1.05	0.95	0.85
2	L12	1.10	1.09	1.05	1.10	1.00	0.95
3	L13	1.65	1.50	1.20	1.35	1.15	1.00
4	L14	1.65	1.55	1.45	1.40	1.20	1.10
5	L15	1.95	1.80	1.60	1.65	1.25	1.25
6	L21	1.20	1.12	1.05	1.10	0.80	0.95
7	L22	1.35	1.28	1.10	1.25	0.95	0.90
8	L23	1.80	1.65	1.55	1.50	1.25	1.10
9	L24	2.00	1.90	1.60	1.55	1.35	1.20
10	L25	2.10	2.05	1.85	1.65	1.50	1.35

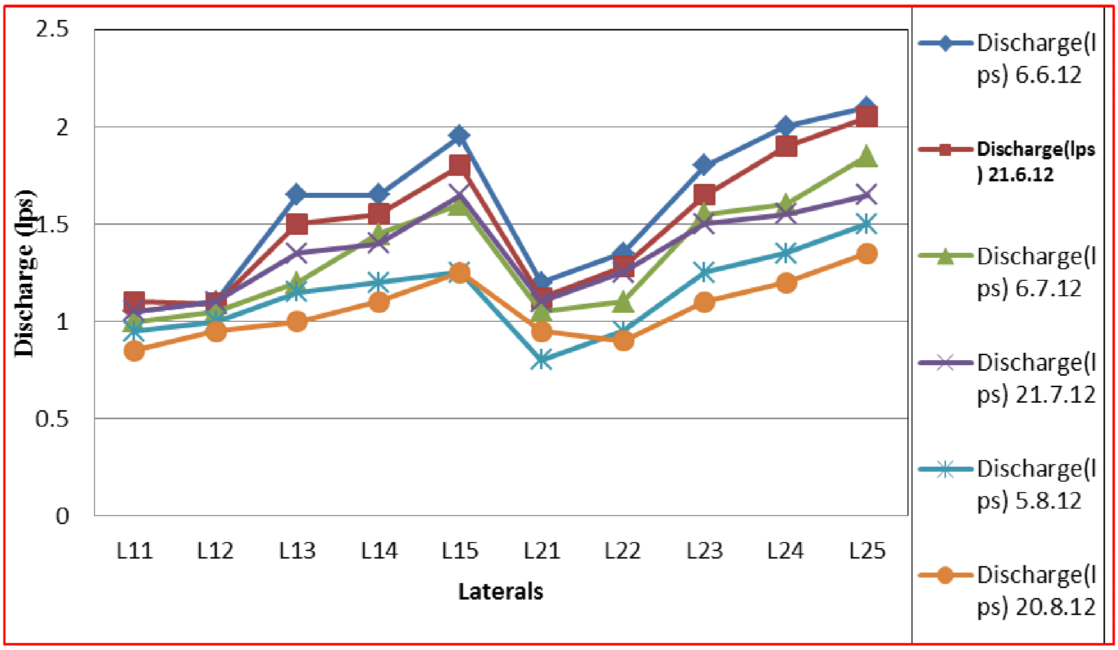

Fig.4.12 Discharge fluctuations during the study period (paddy-kharif) in all the laterals during the study period

From Fig. 4.12 and Table 4.10 the following highlights are enlisted:

- The drain discharges were more in higher spacings than in lower spacings.
- The drain discharges reduced over the season proceeded towards harvesting
- More reduction of water table depths were found during early harvest and harvesting stages
- The discharge values were considered as unsteady state discharges, might behave differently if the valves are operated and continuously opened. The valves were opened intermittently depending upon the field submergence in the present investigation for rice crop.

The observations on depth to water table are presented in Table 4.11 and graphically represented in Fig. 4.13.

Table 4.11 Water level elevations in the 13/6th mile drainage investigation site

OW	Ground	15.05.12	02.06.12	15.06.12	30.06.12	30.07.12	30.08.12
Control-I	228.4	227.5	228.1	228.0	228.0	227.9	227.7
*OW11	228.2	227.3	227.9	227.8	227.7	227.7	227.5
OW12	228.1	227.2	227.8	227.7	227.7	227.6	227.4
OW13	228.0	227.1	227.7	227.6	227.5	227.5	227.3
OW 14	227.9	227.0	227.5	227.5	227.5	227.4	227.3
OW 21	227.8	226.9	227.5	227.4	227.3	227.3	227.1

OW 22	227.7	226.8	227.4	227.4	227.3	227.2	227.0
OW 23	227.7	226.8	227.3	227.3	227.2	227.2	227.0
OW 24	227.6	226.7	227.3	227.2	227.2	227.1	226.9
Control-II	227.5	226.6	227.2	227.2	227.1	227.0	226.8

*** OW11-24 stands for the midway observation well in between 6m-15m spacings under 80cm and 60cm drain depths respectively**

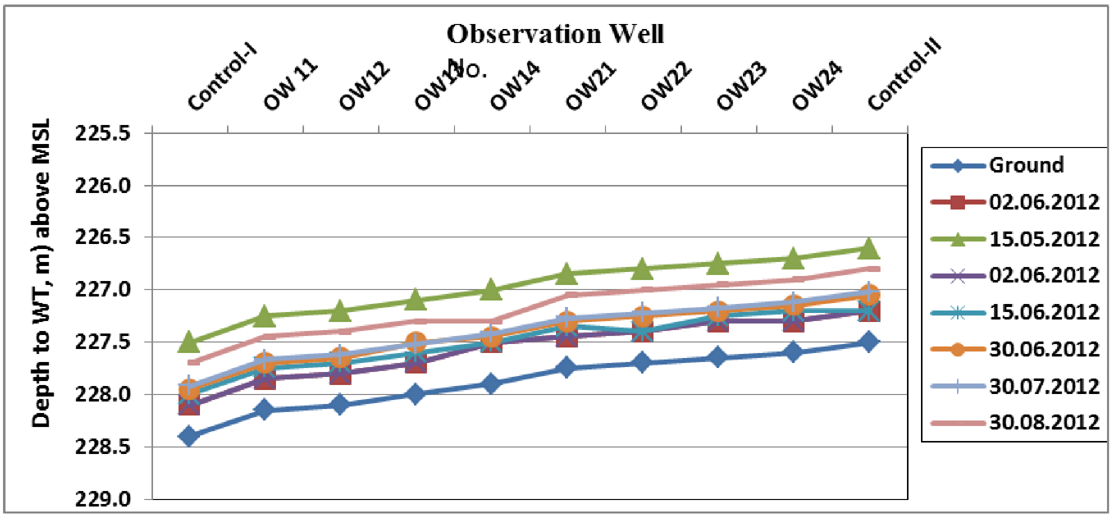

Fig. 4.13. Water level fluctuations in the near 13/6th mile of Thadapalli channel

From Fig. 4.13 and Tble 4.8, the following salient findings were highlighted.

- ➢ The treatments OW11 to OW14 were under 80cm of drain depth areas showing more depth to water table in all the days of observations. The elevation above MSL was alslo low in the above area. Hence the magnitude was differed with that of the other side of the collector drain., i.e. 60cm drain depths.
- ➢ Before the installation of the water table management system, the depth to water table was high.
- ➢ The water table gradient also closely followed the ground surface elevations.

4.3.3. Performance evaluation of WTM under subirrigation mode

After one crop season, because of the operational difficulty involved in operating 10 valves, the laterals and collector pipes were interconnected and at the end of the collector pipe one PVC ball valve were fitted. This was very much essential for conducting the subirrigation trails.

During the study period i.e. from 2012-13, the water was not allowed for the second season starting from September 2012 because of insufficient storage in Bhavani Sagar Reservoir. Hence there was only one crop grown in the entire command. During the year 2013 also till March month end, canal release did not take place. But during the year, 2013, 30th March to 4th April, there was a canal release for a short period. During 1st and 2nd April, Subirrigation experiment was conducted in the study area where fodder sorghum crop was standing on one side of the collector i.e. 80cm drain depth.

Water from the canal which is 160m away to the lower end of the water table management system was diverted to a surface depression in the main drain where the collector pipe was installed. The pump set' discharge was measured volumetrically. The average discharge was calculated as 25,000 liters per hour. The system was operated for 8 hours daily; two laterals were open at a time to ensure for pressure build up. The depth of water application was 8cm/day for all the lateral spacings. The valves of pair of laterals were let open accordingly.

Before starting the experiment, the initial soil samples were taken representing 15cm, 30cm and 45cm depths from all the replications chosen for the study. The soil moisture content was arrived gravimetrically by keeping the soil samples in oven for 105^{0}C. After the pumping operation for two days.., the soil moisture content depletion from saturation were recorded successively for 4 days i.e. 3rd,4th, 5th and 6th April midway between the laterals at lower, middle and farther ends at three different depths as mentioned above. The samples were initially weighed immediately and were kept simultaneously in the oven for 24 hours at 105^{0}C. The soil moisture observations of this investigation under two major trials i.e. 60cm and 80cm drain depth for 8 spacings totally were arrived and were presented in Table 4.12 and 4.13 respectively. Here A1, A2 and A3 represents lower reach for three soil depths (15cm, 30cm & 45cm) near to the collector pipe. Similarly, B1, B2 & B3 represents mid spacing and C1, C2 and C3 represents farther end from the collector pipe line at depths 15cm, 30cm and 45cm respectively. R_1, R_2, R_3 and R_4 are effective mid way areas for 6m, 9m, 12m and 15m spacings on one side of the collector (80cm drain depth) and similarly R5, R6, R7 and R8 represents for the other side of the Collector (60cm drain depth) as shown in Fig. 4.14 Referring to the figure, immediately above the channel is the 80 cm drain depth observations, and further down after the collector are the 60cm drain depth observations for all the spacings.

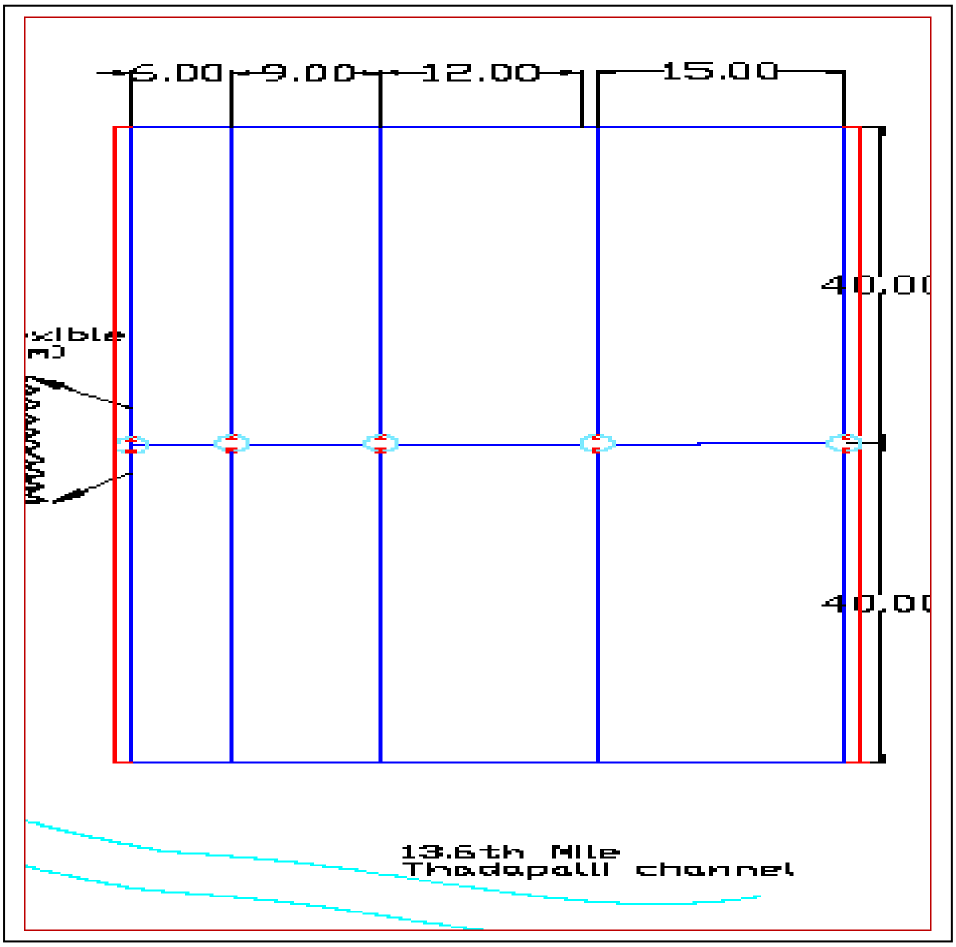

Fig. 4.14 layout of subirrigation trials

Table 4.12 Observation of moisture (%) readings taken after subirrigation (80 cm drain depth)

Sl.No.	Location	Before Trial	Dates			
		1.5.2013	3.5.13	4.5.13	5.5.13	6.5.13
1	R1A1	2.73	44.67	44.53	43.09	41.75
2	R1A2	2.80	50.32	50.70	48.83	45.34
3	R1A3	2.89	51.67	51.75	50.17	46.74
4	R1B1	2.62	39.11	39.92	39.27	34.53
5	R1B2	2.66	39.77	40.56	39.80	36.04
6	R1B3	2.80	43.09	43.89	43.26	40.24
7	R1C1	2.71	34.83	35.54	30.24	28.70
8	R1C2	2.74	40.48	41.11	38.18	34.76
9	R1C3	3.00	40.94	42.31	39.13	35.88
10	R2A1	2.55	46.21	44.59	41.99	38.96
11	R2A2	2.84	48.24	46.59	43.89	42.40
12	R2A3	3.01	48.02	48.49	45.97	43.02
13	R2B1	2.54	31.81	32.63	30.46	29.76
14	R2B2	2.61	35.87	37.14	35.93	34.69
15	R2B3	3.13	42.94	43.49	41.66	39.59
16	R2C1	2.31	21.51	22.70	21.90	20.93
17	R2C2	2.78	24.86	25.00	23.01	22.47
18	R2C3	2.85	28.70	30.31	28.43	26.88
19	R3A1	2.68	30.16	31.04	30.16	28.71
20	R3A2	2.76	32.62	32.62	32.86	30.56
21	R3A3	3.01	37.23	38.26	38.74	36.29
22	R3B1	2.62	23.89	15.99	15.91	15.64
23	R3B2	2.66	23.02	17.13	16.83	17.32
24	R3B3	2.80	27.66	18.34	19.13	19.01
25	R3c1	2.69	17.54	15.93	16.75	16.66
26	R3c2	2.83	19.11	17.54	16.99	18.26
27	R3c3	3.11	22.31	19.13	19.37	19.54
28	R4A1	2.46	28.81	31.79	31.67	23.30
29	R4A2	2.85	36.59	37.36	37.62	32.39
30	R4A3	2.94	53.85	54.14	53.79	40.16
31	R4B1	2.56	9.81	10.46	10.16	9.46
32	R4B2	2.61	11.21	12.37	11.61	10.57
33	R4B3	3.29	14.37	14.92	14.59	13.02
34	R4c1	2.71	8.56	9.54	9.57	8.57
35	R4c2	2.84	9.57	10.36	11.16	9.50
36	R4c3	3.26	8.73	9.74	9.38	8.86

Table 4.13 Observation of moisture (%) readings taken after subirrigation (60cm drain depth)

Sl.No.	Trial	Before trial	Dates			
		1.5.13	3.5.13	4.5.13	5.5.13	6.5.13
1	R5A1	2.69	45.94	45.54	44.60	43.03
2	R5A2	2.73	48.02	48.49	47.34	45.21
3	R5A3	2.75	52.94	52.23	50.49	46.71
4	R5B1	2.54	44.83	44.05	41.97	38.02
5	R5B2	2.60	49.27	45.61	44.37	43.17
6	R5B3	2.66	50.16	51.11	45.92	43.71
7	R5C1	2.29	34.04	31.94	29.91	28.01
8	R5C2	2.54	38.80	39.14	36.69	31.59
9	R5C3	2.69	39.29	39.49	37.14	33.26
10	R6A1	2.46	47.70	46.59	43.80	40.23
11	R6A2	2.63	51.67	49.76	45.86	43.57
12	R6A3	2.67	53.14	50.28	46.66	44.98
13	R6B1	2.54	33.02	34.11	30.92	28.00
14	R6B2	2.78	37.30	38.97	36.71	32.69
15	R6B3	2.83	40.21	39.29	37.41	33.80
16	R6C1	2.45	23.02	23.43	22.34	20.50
17	R6C2	2.62	24.69	25.48	23.10	18.09
18	R6C3	2.81	25.88	25.80	23.02	20.16
19	R7A1	2.38	30.16	31.04	30.16	28.71
20	R7A2	2.76	32.62	32.62	32.86	30.56
21	R7A3	2.91	37.23	38.26	38.74	36.29
22	R7B1	2.54	17.06	15.99	15.91	15.64
23	R7B2	2.61	15.86	17.13	16.83	17.32
24	R7B3	2.69	18.57	18.34	19.13	19.01
25	R7c1	2.46	15.96	15.93	16.75	16.66
26	R7c2	2.73	18.19	17.54	16.99	18.26
27	R7c3	2.77	18.49	19.13	19.37	19.54
28	R8A1	2.33	29.77	31.16	28.66	26.27
29	R8A2	2.53	38.29	40.16	40.17	36.59
30	R8A3	2.70	55.76	55.00	54.37	42.94
31	R8B1	2.66	10.96	11.94	13.24	10.17
32	R8B2	2.76	12.72	14.37	15.89	15.23
33	R8B3	3.21	15.96	21.60	22.31	18.74
34	R8c1	2.47	9.61	10.31	10.80	8.93
35	R8c2	2.69	13.51	9.43	9.86	8.56
36	R8c3	3.06	12.39	10.39	10.57	9.14

From the Table 4.12 and Table 4.13, the following inferences could be drawn.

- There was a gradual decline in the moisture contents towards farther ends within the effective area mid way between the drains
- There was an increase in the moisture content within the profile i.e. through 15, 30 and 45 cm depths.
- More moisture content readings were noticed in 60cm drain depth replications
- As the season was summer and there was no rainfall in the area for a period more than 3 months, and the soil was dry, the moisture contents declined drastically within 4 days after the experiment.

The variation of soil moisture with elapsed days was graphically represented from Fig 4.15 to 4.22.

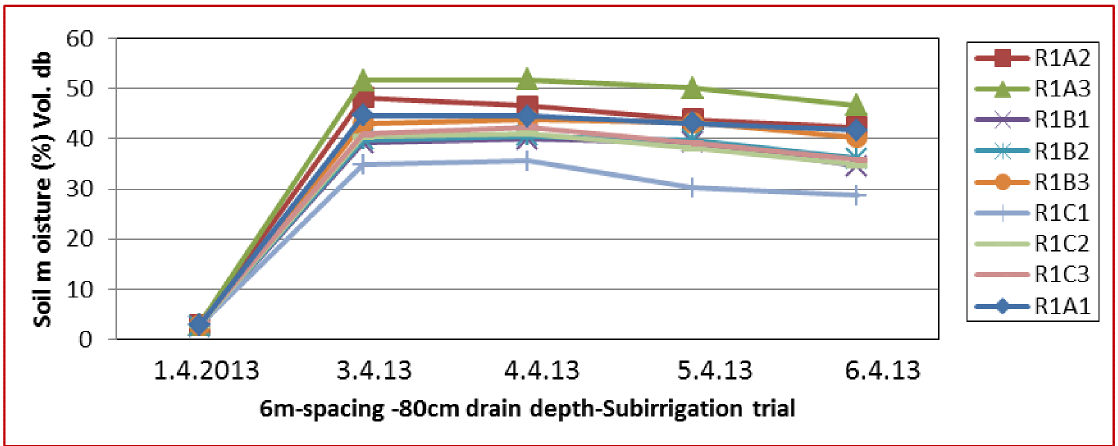

Fig.4.15 Subirrigation trial(1st April 2013) moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 6m spacing-80cm drain depth

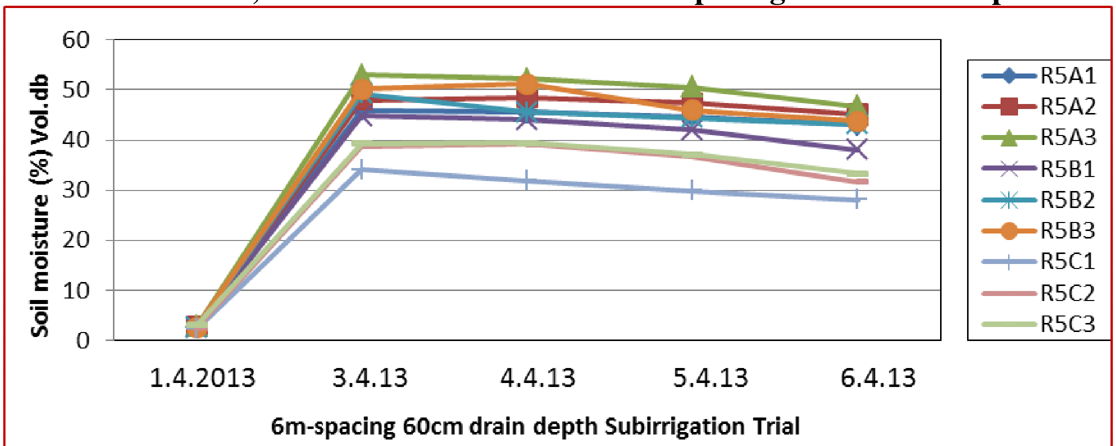

Fig.4.16 Subirrigation trial (1st April 2013 moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 6m spacing-60 cm drain depth

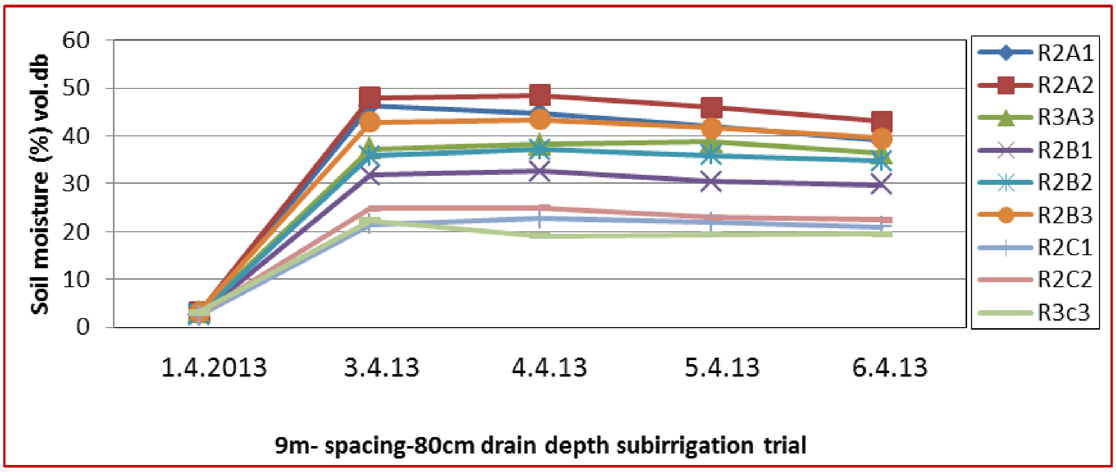

Fig.4.17 Subirrigation trial (1st April 2013) moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 9m spaicing-80cm drain depth

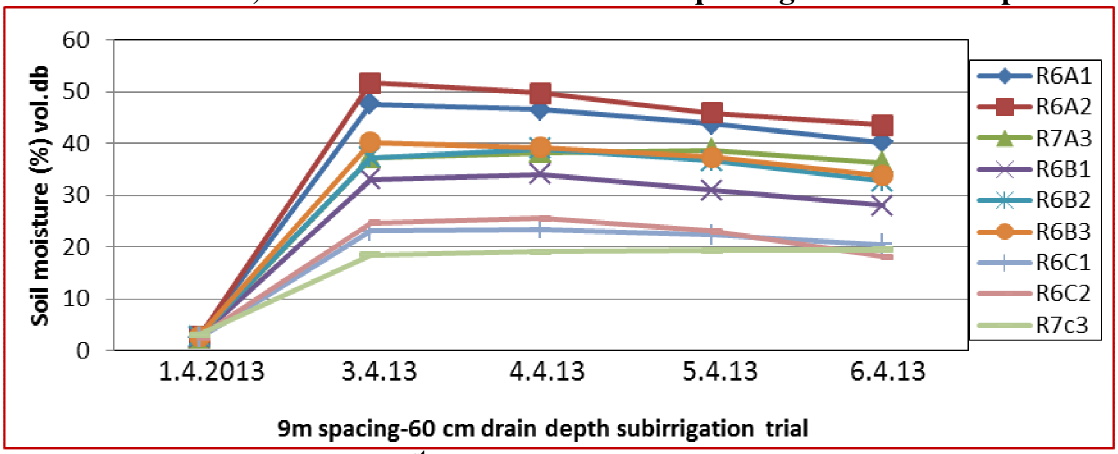

Fig.4.18 Subirrigation trial (1st April 2013) moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 9m spacing-60cm drain depth.

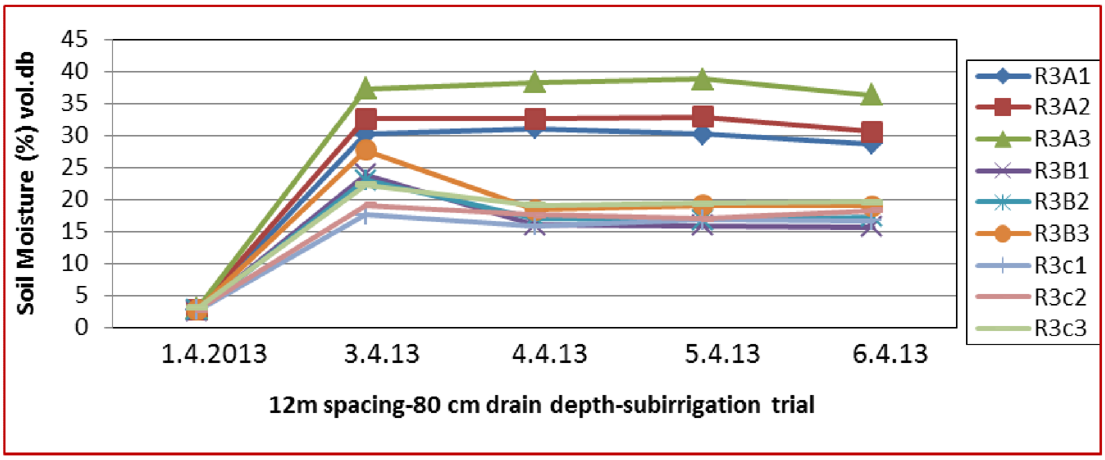

Fig.4.19 Subirrigation trial (1st -6th April 2013) moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 12m spacing-80 cm drain depth

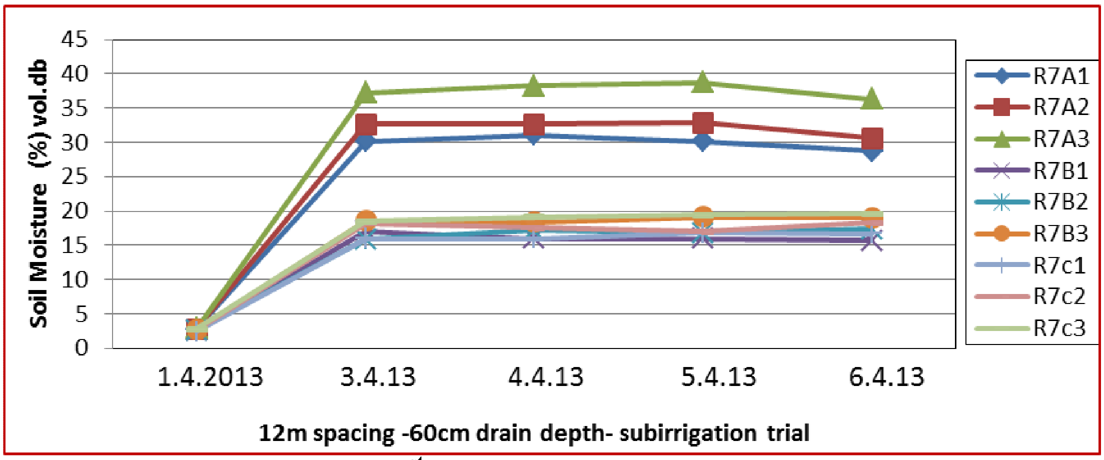

Fig.4.20 Subirrigation trial 1st April 2013 moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 12m spacing-60 cm drain depth

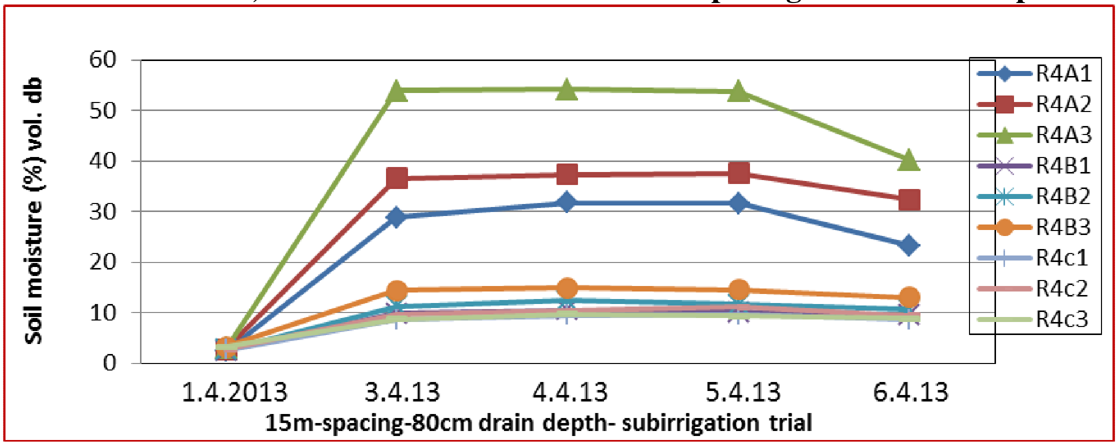

Fig.4.21 Subirrigation trial 1stApril 2013 moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 15m spacing-80cm drain depth

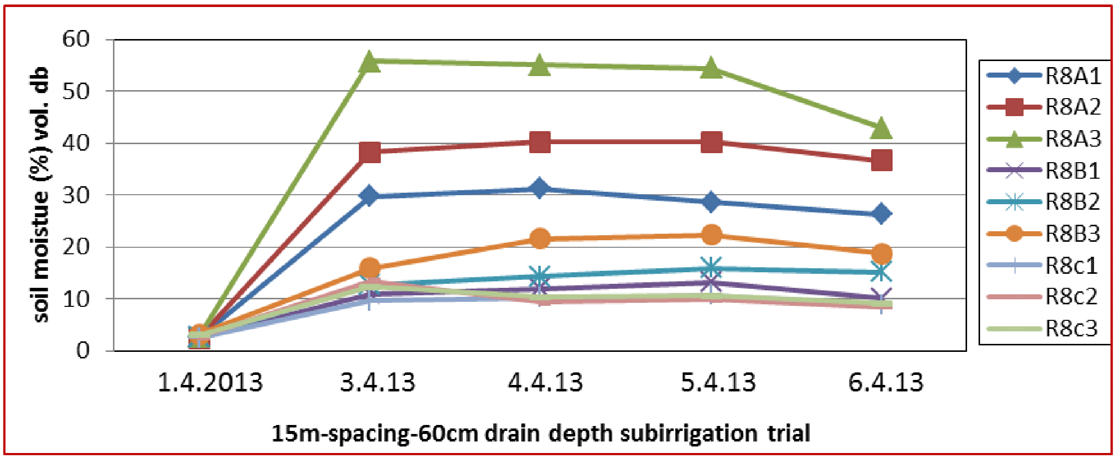

Fig. 4.22 Subirrigation trial 1st April 2013 moisture contents (%) at 15cm, 30cm & 45cm at lower, middle and last reaches in 15m spacing- 60 cm drain depth

The trend of moisture content decline over the time and also over the depth for all locations were shown from Fig.4.15 to 4.22. From the above figures, it was observed that the drain depth 60cm treatments were observed to have more soil moisture content than 80cm replications. This was because of the less opportunity time and limited capillary rise for the water for the water to rise from drain level.

It was observed that near to the collector, i.e. lower reaches, the higher soil moisture content was found because of the pressure build up near to the valves made the water raise up and oozing to the surface and causing surface inundation. (Plates 4.1 to Plates 4.2). Hence the soil moisture contents in the lower reaches were found to be in the tune of 40- 50% in all the replications. There was uniformity of soil moisture contents in lower spacings of 6m and 9m than in 12 and 15m. The decline of the moisture contents at these spacings were also found more. At the end of 4th day after the experiment, the soil moisture content fell down to below 20% in all the replications. The above moisture content (%) values were arrived after calculating the dry weight basis values to volume basis.

4.3.4. Performance study of the water table management system in terms of paddy crop yields under controlled drainage mode.

The paddy crop in the experimental site was harvested during 1st week of September 2012. To know the performance of the water table management system in terms of crop yields, it was felt paramount importance along with hydraulic aspects. Hence the yield data at the time of harvesting were collected in the midways between all the spacing and depth combinations and were presented (Table 4.14).

Table 4.14 Paddy (ADT 45) yield in the experimental field of water table management system

Sl. No.	Drain depth	Drain spacing	Yield (t/ha)
1	60cm	6m	4.30
2		9m	5.35
3		12m	5.69
4		15m	5.72
5	80cm	6m	4.88
6		9m	5.25
7		12m	5.33
8		15m	5.38
9	Control		3.78

- From the Table 4.14, it was observed that, at lower most spacing chosen; the yield levels were less compared to larger spacings for both the drain depths.
- The average yield was found as 5.3 and 4.935 tons/ha under 60cm and 80cm drain depths respectively.
- The variation between the yield levels at higher spacings i.e 12m and 15m was found very less in both the drain depths.
- The average paddy yield in the system installed field was 5.22 tons/ha as against and 4.2 tons/ha being the conventional yield in the previous years and the control plot 3.78 tons/ha in the present year of investigation.
- The additional yield obtained in 12m and 15m spacings were found to be very less compared to the 9m spacing area.
- From the field data, the depth to water table depth and drain discharges were found to be more in 6m spacing compared to all the other three spacings under two depths. The variation of these two parameters was also found very less compared to 6m spacing. The less yields in the 6m spacing area might be probably due to loss of nutrients because of more drain outflow and more reduction in water table height beyond root zone.

4.3.4. Performance study of the water table management system in terms of paddy crop yields under subirrigation mode.

In the study area, the year 2012 was declared as dry year. Because of non-canal release, no second and third crops were raised in the entire study area. To test the performance of water table management system under subirrigation mode also, fodder sorghum was raised in the 80cm drain depth for all the spacings. Initially during early December 2012, the crop establishment was poor because of the residual moisture content which was present in the soil. During first week of April 2012, the crop was irrigated with supplemental irrigation through reversible pumping with the help of a 5 HP diesel engine. The surface inundations through subirrigaion trials were presented in Plates 4.1 to Plate 4.8. The yield data of fodder sorghum is given for both 60cm and 80cm drain depth fields are presented in Table 4.15.

Table 4.15 Fodder sorghum yield in the experimental field of water table management system

Sl. No.	Drain depth	Drain spacing	Yield (t/ha)
1	60 cm	6m	1.05
2		9m	1.1
3		12m	1
4		15m	0.9
5	80cm	6m	0.85
6		9m	0.90
7		12m	0.82
8		15m	0.80
9	Control		0.60

From Table 4.15, the following inferences could be drawn for the same depth of application of irrigation water i.e. 16 cm.

- The average fodder sorghum yield was found to be 0.94 tons/ ha in 80cm drain depth.
- More yield was observed in 6m, 9m spaced areas compared to 12m and 15m spacing areas.
- The lowest yield was observed in 15m spacing followed by 12m, 9m and 6m spacings.
- As observed from the data on moisture content after subirrigation trials, there was not only a drastic variation of moisture reduction in 12 and 15m spacing. but also the moisture content levels were less compared to lower spacings

The statistical analysis was carried out with the yield data of paddy under controlled drainage mode and yield data of fodder sorghum under subirrigation mode for standard error and critical difference parameters. The results are presented in Table 4.16.

Table 4.16 Statistical analysis of yield data under both controlled drainage and subirrigation modes for 60cm and 80cm drain depths

Sl. No	Statistical parameter	Drain Depth	Controlled drainage	Subirrigation
a)	Standard Error	60cm	0.4631	0.889
		80cm	0.31	0.066
b)	Critical difference	60cm	0.066	
		80cm	0.0035	

As was no much yield difference between 6m and 9m spacings under subirrigation mode, since there was little difference in yield levels in the paddy under 9m spacing with higher spacings., 9m spacing could be recommended for the water table management system for clay loam soils of lower Bhavani project. Similarly with in 60cm and 80cm depth replications, the based on the statistical analysis inferences, 60cm could be recommended for depth of placement of drain pipes for the water table management system for the clay loam soils of lower Bhavani project.

4.3. Simulation studies with DRAINMOD 6.1

The DRAINMOD 6.1 model was operated with three modules i.e. i) Conventional drainage ii) Controlled drainage (CD) and iii) Sub irrigation (SI). The following various input data (Table 4.17) was given for the operation of the software, DRAINMOD 6.1.

The input file windows were presented from Fig. 4.23 to 4.31. Main window of the software (Fig.4.23) gives the overall project file, wherein the module., and basic hydrologic concepts were incorporated like surface flow., water losses., requirement of simulation period based on input weather data etc., The key input parameters fed into the model is given in Table 4.17.

Table 4.17 Key input data given to the model

Sl. No.	Parameter	Value/Range along with Specification
1	Simulation Period	June-Sept. 2012 for Controlled Drainage
2	Simulation Period	April 2013 for SI
3	Maximum ponding depth	10cm
4	Critical water table depth	30cm
5	Drainage coefficient	1cm/day
6	Maximum subirrigation pump capacity	8cm/day
7	Field ratio for overland flow (area contributing runoff)	3.5
8	Seepage distance	160m
9	Head causing the seepage	2m
10.	Draiange coefficient(SI)	0cm/day
11.	Crops chosen: i) CD	Paddy
	ii) SI	Fodder Sorghum

Window shown in Fig. 4.23 shows the hydrologic data, surface runoff files. The soil related file which includes the upward flux and moisture content, saturated conductivity and profile details pertaining to Gopichettipalayam study area were fed in the DRAINMOD model. For the incorporation of weather files, the rainfall and temperature data of Bhavani Sagar were fed in row-wise format accepted by the software (Annexure I and II). Two crop files were given as input files which are the details related to fodder sorghum and paddy crop.

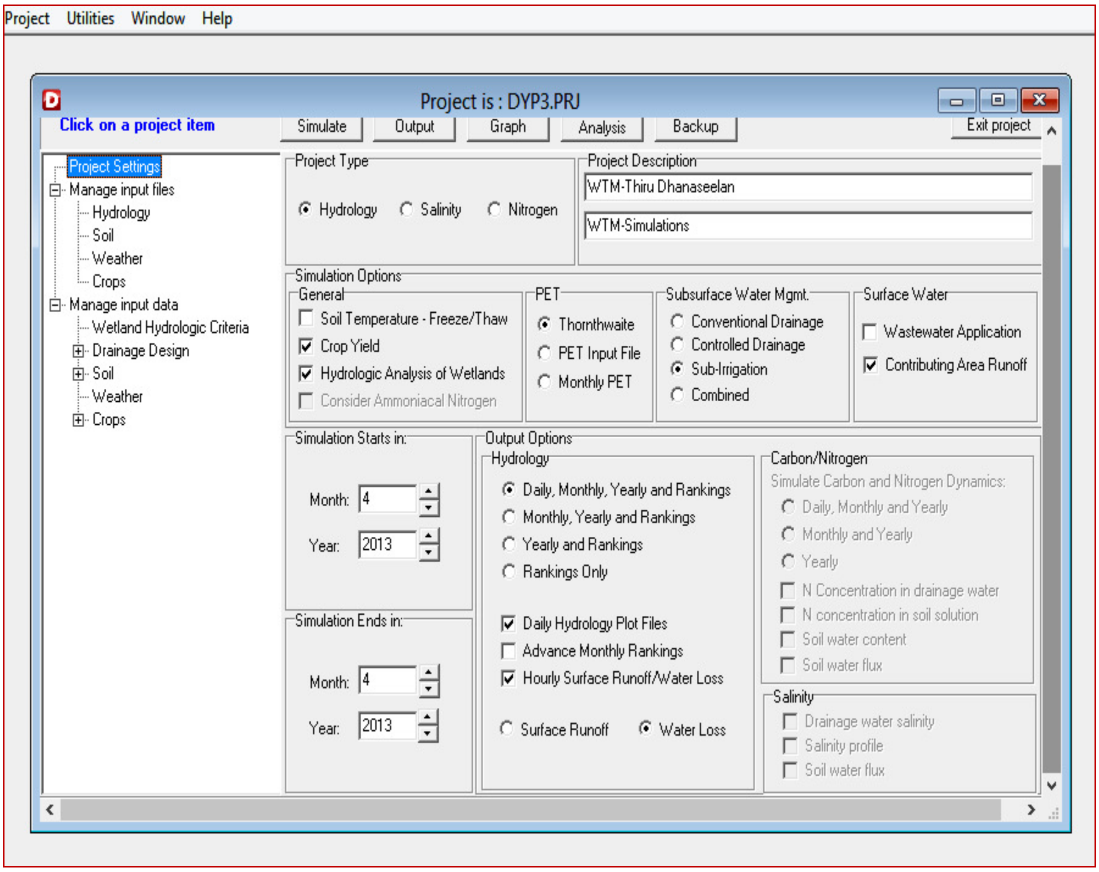

Fig. 4.23 Project setting window of DRAINMOD 6.1 model

Fig. 4.24 to 4.29 gives the input data files which can be changed for each scenario and modules. They are related to hydrology, weather, soil and crop. Fig. 24, 25, 26 and 27 represents the hydrology related files like, overland flow file etc., Fig. 4.28 and Fig. 4.29 window facilitates to change the input data pertaining to weir settings., and three possible seepage flows that would prevail namely., downs slope, lateral and vertical or downward directions. In Drainage design settings option, the changes were made for drainage and subirrigation modes by changing the critical depth to water table, drainage coefficient, spacing and depth of placement etc., under each module and each replication trial. The soil input data on upward flux, soil water characteristic were incorporated as observed from field.

Simulation runs were made for various spacings viz., 6m, 9m, 12m, 15m and 20m along with three depths (60cm, 80cm & 100cm) for each spacing for conventional and controlled drainage modes. The SI module was operated up to 15m spacing-depths combinations.

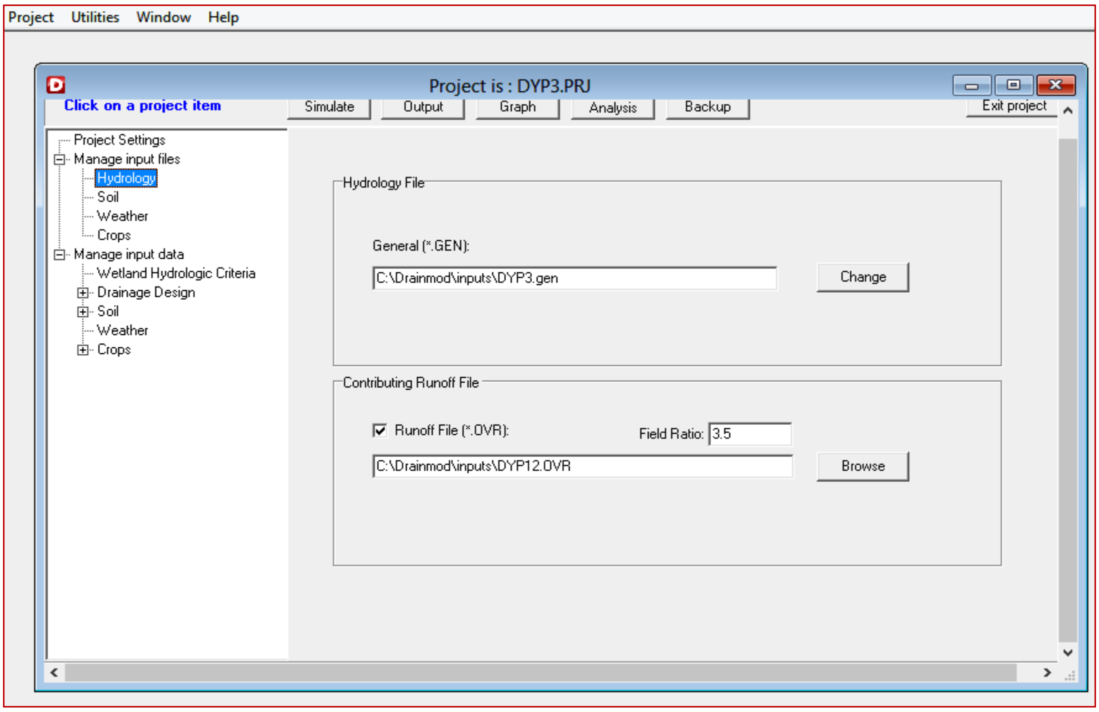

Fig. 4.24 Hydrology file option window of DRAINMOD 6.1 model

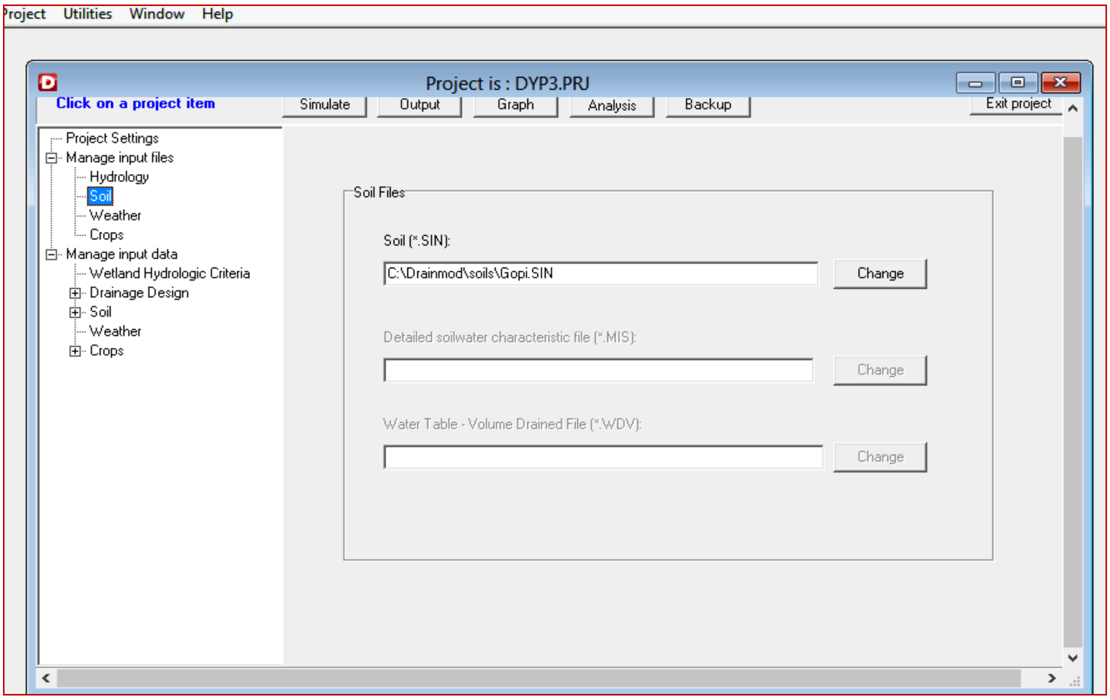

Fig. 4.25 Soil file window of DRAINMOD 6.1 model

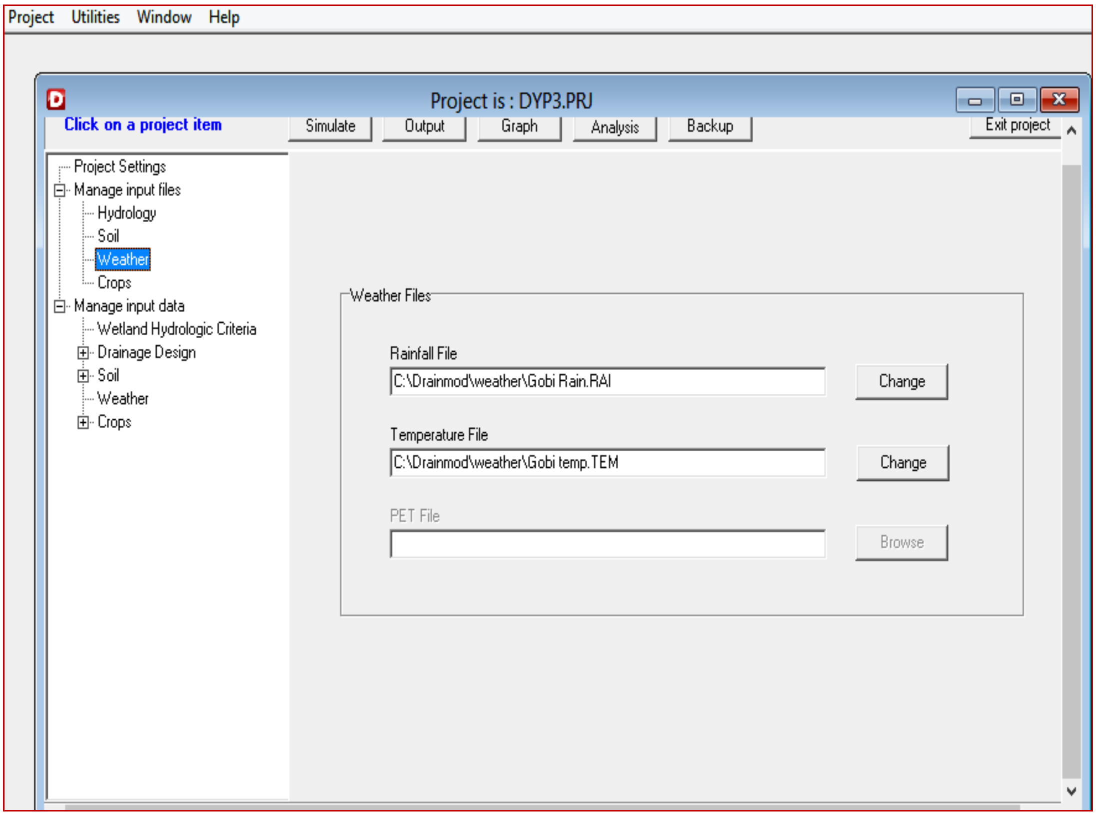

Fig. 4.26 Project setting window of DRAINMOD 6.1 model

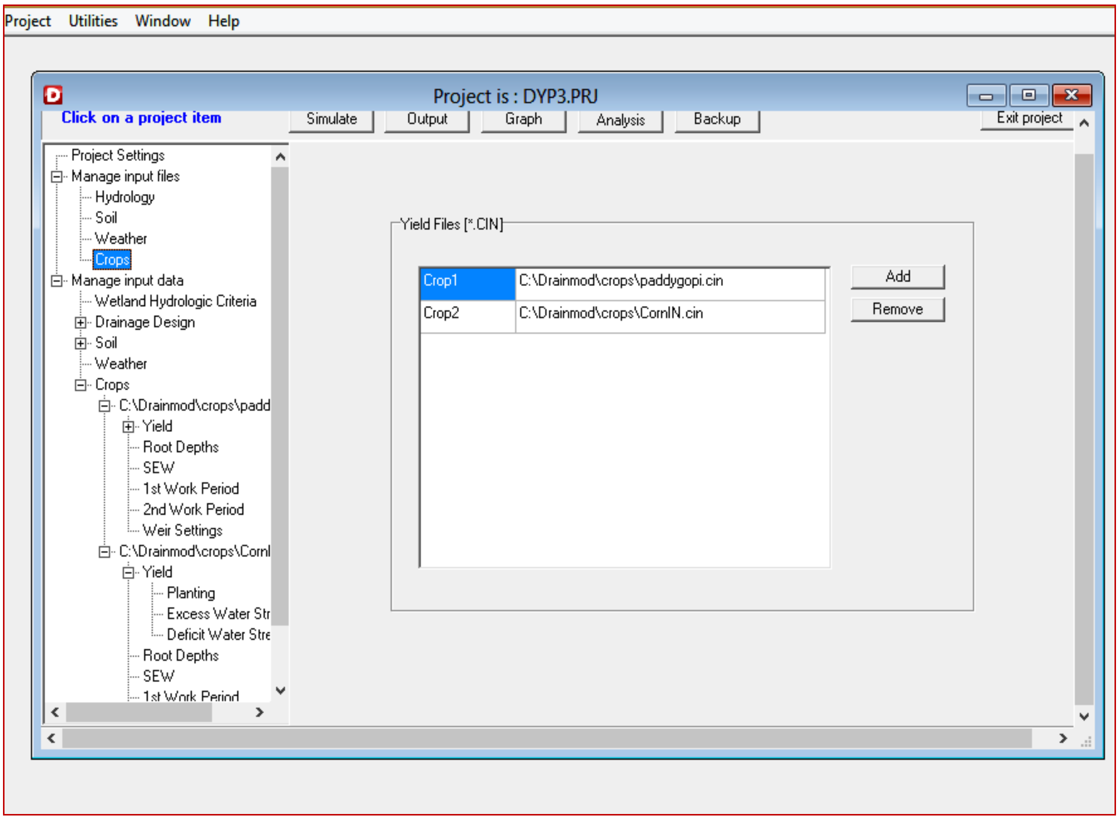

Fig. 4.27 Crop input file window of DRAINMOD 6.1 model

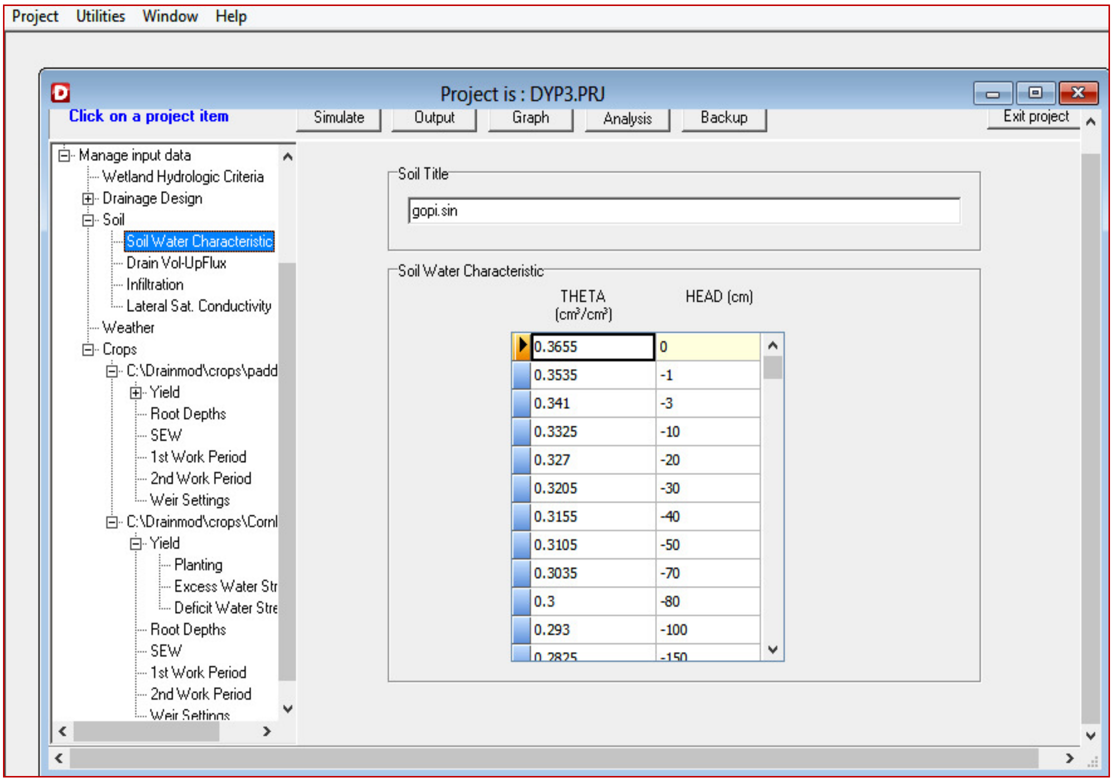

Fig.4.28 Soil input data window of DRAINMOD 6.1 model

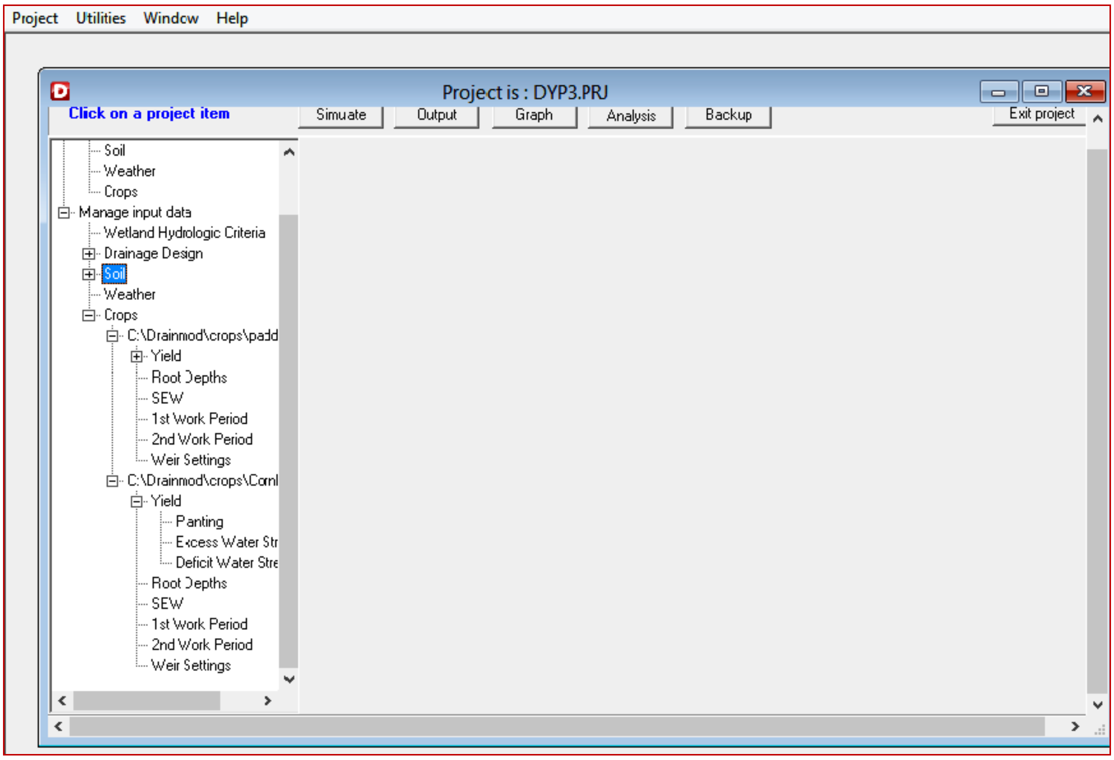

Fig. 4.29 Crop input data project setting window of DRAINMOD 6.1 model

4.4.1. Prediction of water table depths under controlled drainage with DRAINMOD 6.1.

The controlled drainage option in project settings was chosen. The input data pertaining to Area contributing runoff file (hydrology) file, saturated conductivity values, drainage coefficient (1cm/day) were given to the model. The weather data of rainfall and temperature, soil input file along with upward flux- moisture content details as per the input menu window were given pertaining to clay loam soils. The crop details of paddy crop with root establishment details, planting delays etc., were also fed in the model. The model was run for each time with 60cm as drain depth and 6m, 9m, 12m, and 15m respectively. Accordingly the output files generated were saved separately for each run. The notepad files were imported to MS excel and the depth to water table data were plotted for all the spacings and 60cm, 80m and 100cm drain depths respectively and were shown in Fig. 4.30, Fig. 4.31 and Fig. 4.32 respectively.

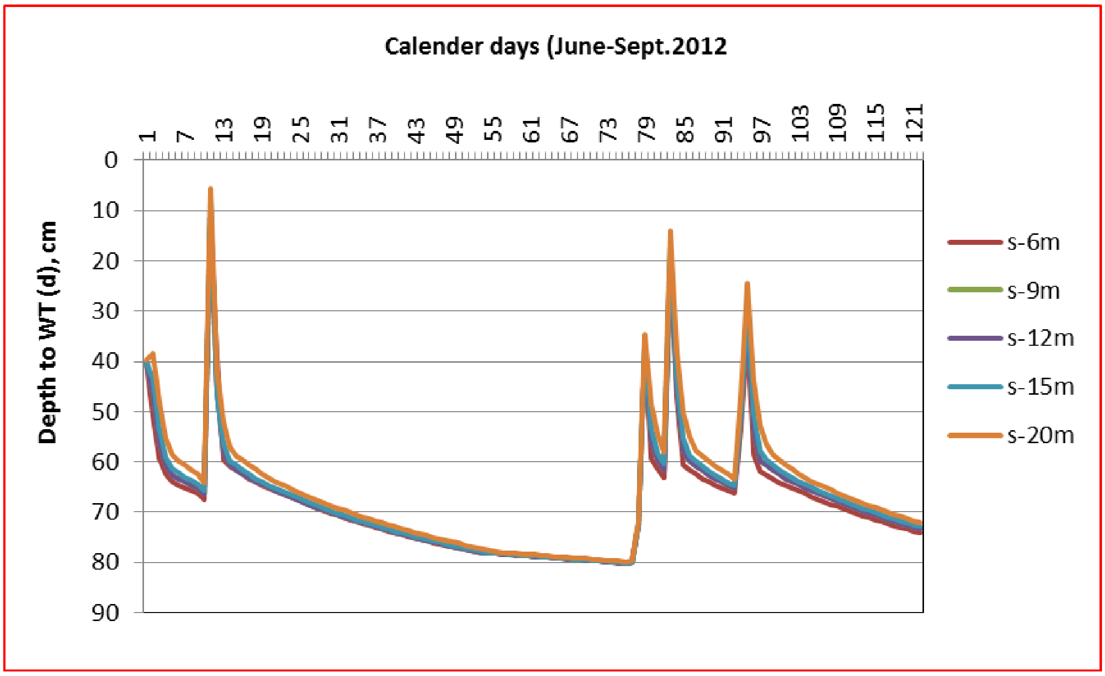

Fig. 4.30 Prediction of depth to water table in 60cm drain depth under controlled drainage module

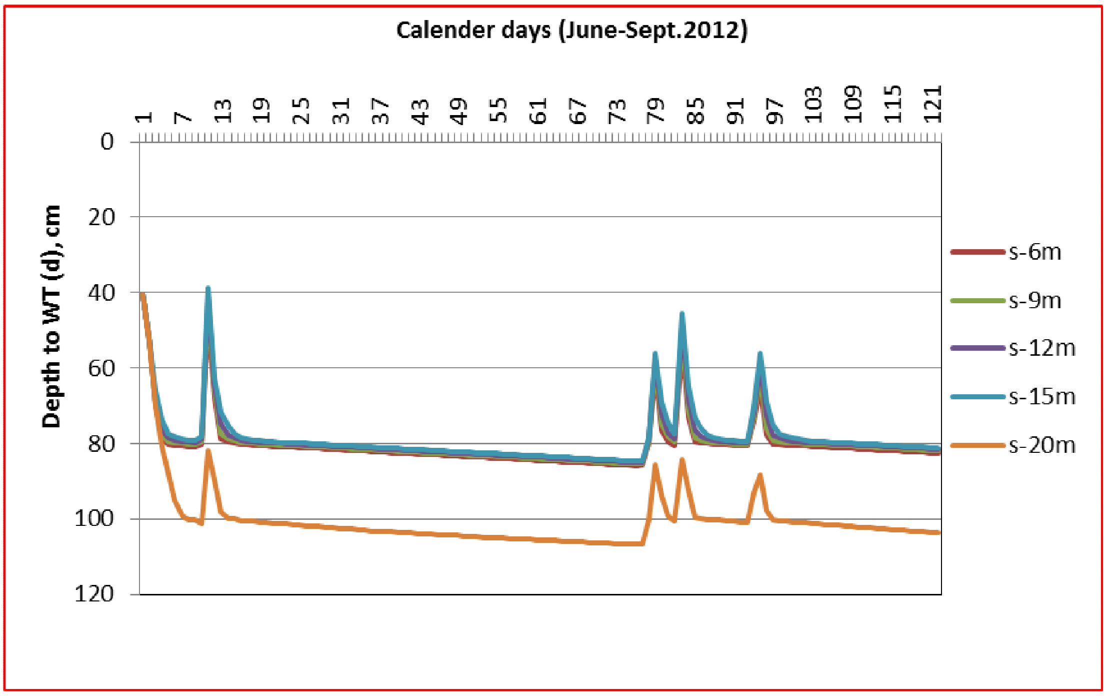

Fig. 4.31 Prediction of depth to water table in 80cm drain depth under controlled drainage module

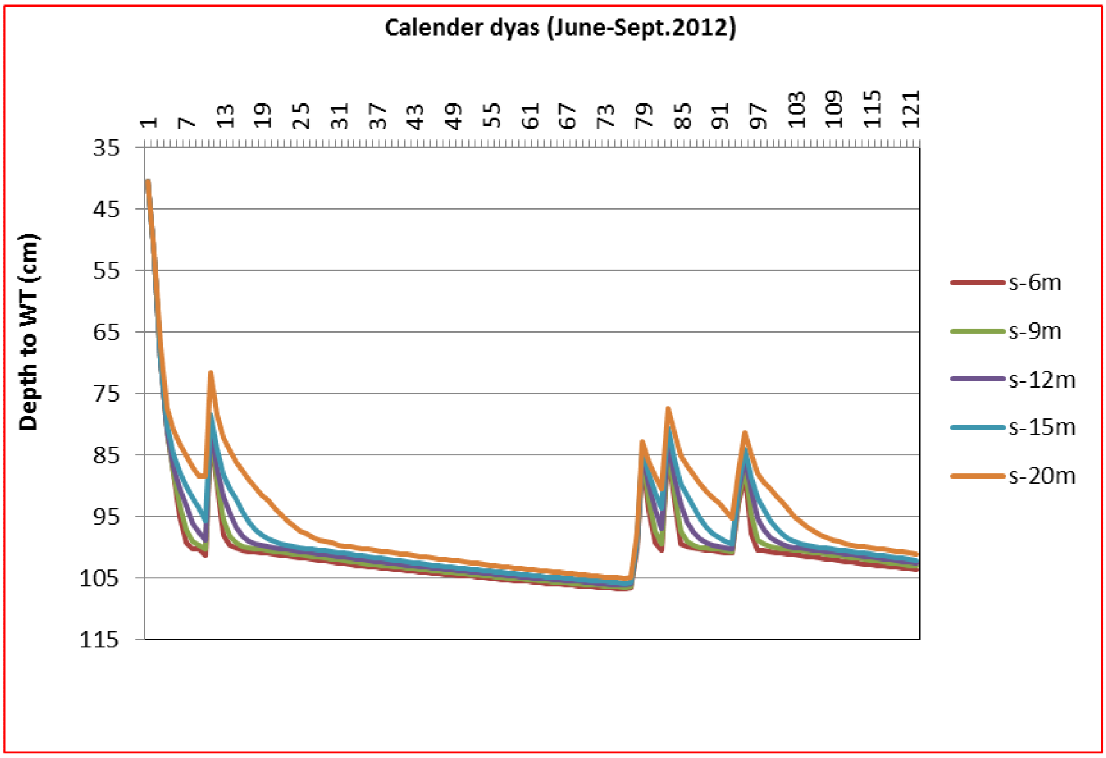

Fig. 4.32 Prediction of depth to water table in 100 cm drains depth under controlled drainage module.

From Fig. 4.30 to 4.32, the following inferences could be drawn:

- The depth to water table reductions was in the order of 6m, 9m, 12m, 15m and 20m respectively. More being in 20m spacing in all the depths.

- The water table most of the days were found at 80cm, 100cm and 105 cm in three different depth combinations i.e 60cm, 80cm and 100cm drain depths.

- This might be because of the more seepage flow in to 100cm depth of drain above it and due to more opportunity to dispose the outflow.

- The model predicted values were not differed by much variation except in 80cm drain depth plot.

- The entire seasonal monitoring shows that there was almost 5 times the water table close to the ground surface in a crop season of 110 days. This might be because of the controlled drainage operation, the model takes an option of maximum surface ponding depth a 10cm above ground. Hence to maintain that in appropriate times, and the controlled drainage operation was automatically programmed in the model.

- Though the model predictions are nearby in terms of depth to water table predictions, the controlled drainage valve operation for the water table management needs to be trained based on the fluctuations of watertable from the simulated values.

4.4.3. Prediction of draiange coefficient/ drain discharge using DRAINMOD 6.1 under controlled drainage mode

The input files and input data were same for this simulation as in the case of 4.4.3. The output files in note pads contain the drainage discharge values for the simulation period in cm/day units along with depth to water table data. The saved notepad files were imported to MS excel and the drainage discharge data were plotted against calendar days for all the spacings and 60cm, 80m and 100cm drain depths respectively and were shown in Fig. 4.30, Fig. 4.33 and Fig. 4.35 respectively.

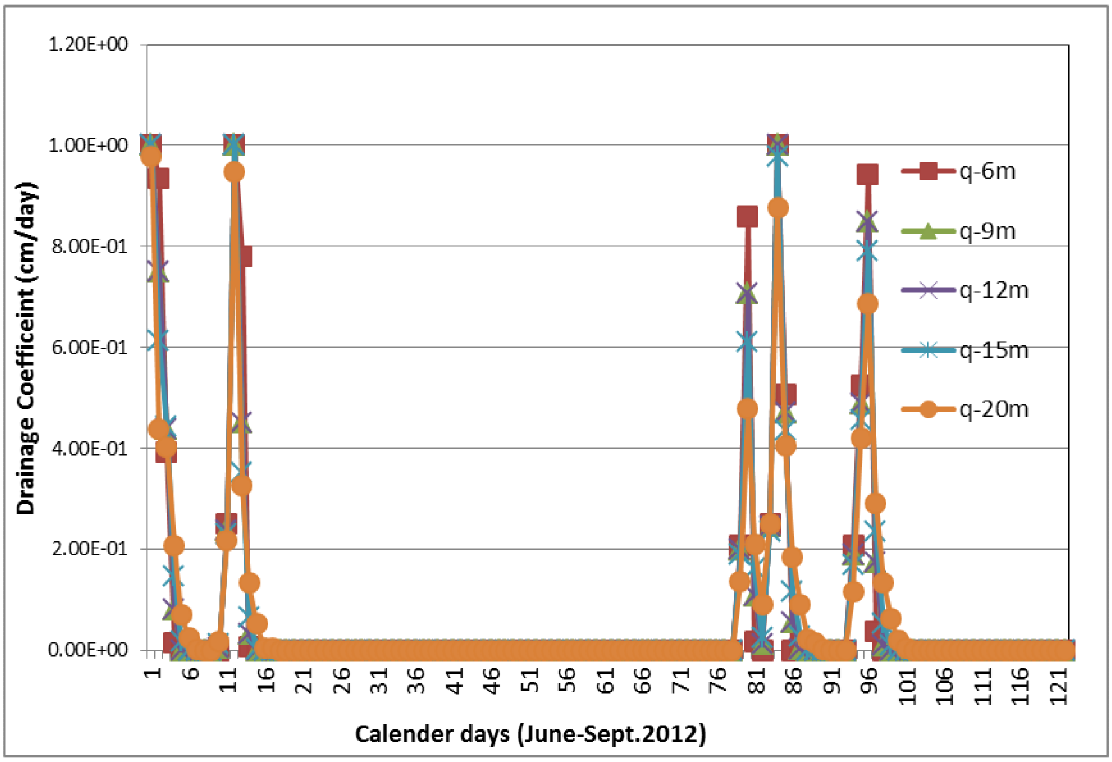

Fig. 4.33 Prediction of drainage coefficient (cm/day) in 60 cm drains depth under controlled drainage module.

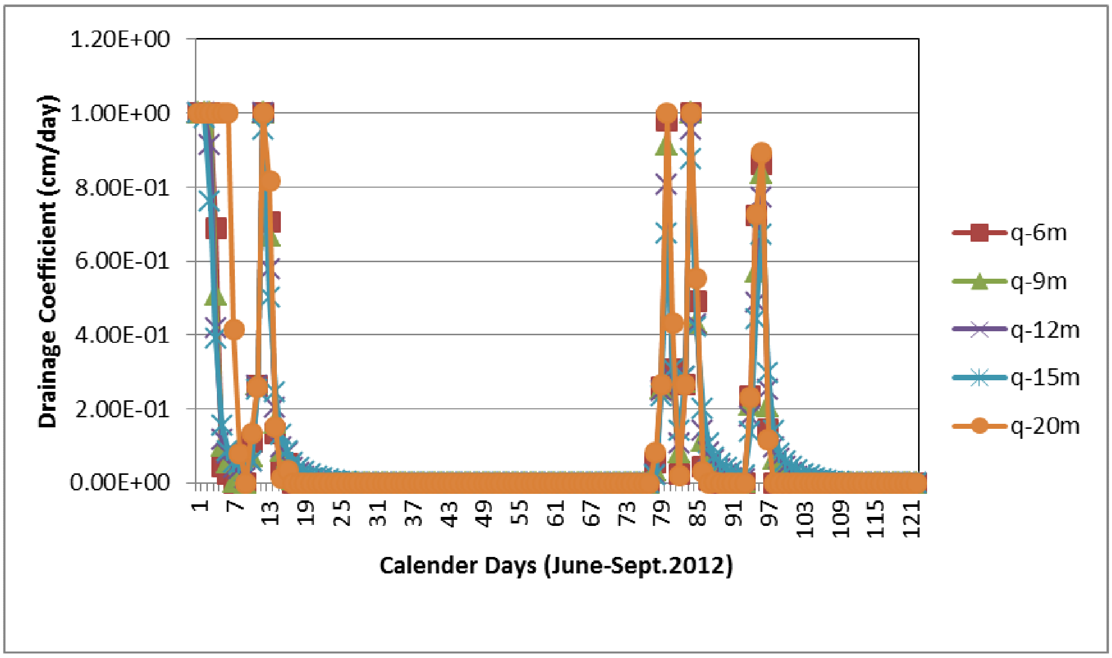

Fig. 4.34 Prediction of drainage coefficient (cm/day) in 80 cm drains depth under controlled drainage module.

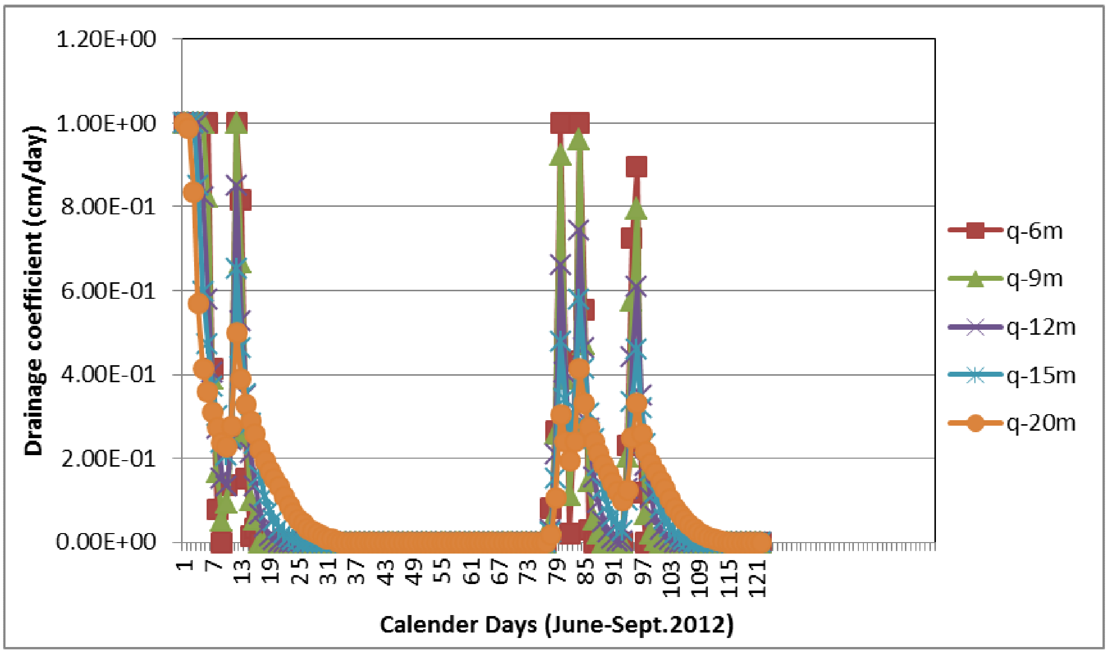

Fig. 4.35 Prediction of drainage coefficient (cm/day) in 100 cm drains depth under controlled drainage module.

Under Controlled drainage mode, the system ran with almost with 0.5cm/day and subsequently reduced when the canal flow was cut off during 1st September 2012. The drain discharges did not vary much with drain depths.

- There was a little increasing trend of drain discharge with increase in drain depth. This might be because of more accumulation of volume of water above the drains.
- Drain discharge under 6m spacing was more than the other spacings.
- Drain discharge under 9m spacing did not vary much with that of 6m spacing.
- For each drain depth, and each spacing, almost 5 times during the crop season, the drains performed fully with the drainage coefficient of 1cm/day.

Modeling studies carried out through DRAINMOD 6.1 model clearly indicates that the a depth of drain placement of 60cms along with a spacing of 9m would be of highly optimum in terms of the following valid reasons.

i) In terms of cost

ii) In terms of subirrigaion yields of fodder sorghum

iii) In terms of paddy yields

iv) Relatively very less yield loss in both the seasons without much compared to other combinations.

v) Better hydraulic performance during subirrigaion trials in terms of uniform spread, and moisture content over the elapsed days.

4.4.5 Simulation runs with Subirrigation module with DRAINMOD 6.1.

The drainage coefficient under subirrigation was taken as zero. Subirrigation was given through a pump at a discharge rate of 8cm/day. The model predicted values of depth to water table values with little or no deviation from other combination of trials. The predicted water table heights were plotted in Fig. 4.36. The less variation might be due to the fact that, the subirrigation pumps capacity was less than that was required for the supplemental irrigation for dry crops. Since after pumping, as the collector valve was closed, the performance in terms of water table reduction might be more or less uniform. But moisture content distribution and its depletion would certainly be different in individual case which in turn depends on the rise of moisture from drain pipes and as well closeness while pumping was going on. Hence there was a declining trend of water table though for two days, the water table was brought to 32cm from below ground level using the water table management systems. Further, the ET rates during summer, cracks developed in the surface and subsurface soil layers, make a drastic depletion of water table.

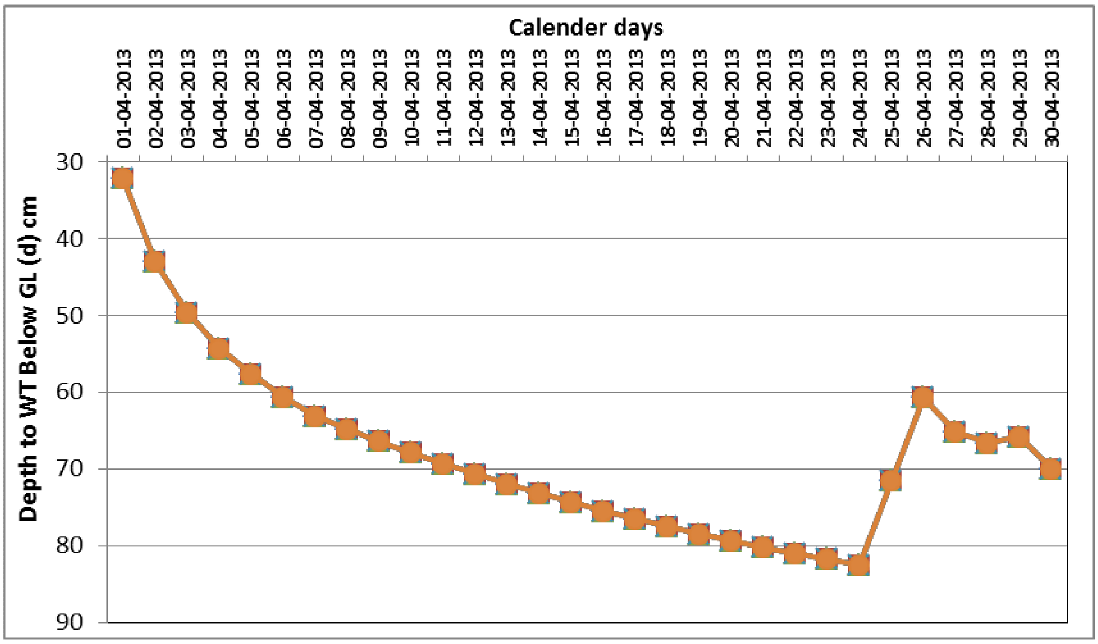

Fig. 4.36 Depth to water table in subirrigation module

4.1.3. Testing of DRAINMOD 6.1 with the field data of water table management system

Testing of DRAINMODE 6.1 with the field observed data was carried out to verify the predicted values whether representing the water table management functioning or not. For testing controlled drainage module, the data collected from 1st June to 5th June, 2012 were used for testing the model. Similarly for subirrigation mode, the field data collected after subirrigation trials i.e during 1-7th April 2013 were used for testing. Commonly adopted chi-squared test was used for model testing for all these three modules. The testing results were incorporated in Table 4.18 and Table 4.19 respectively separately for depth to water table and drain discharges of water table management system for 9m spacing respectively.

Table 4.18 Depth to water table under controlled drainage mode (9m spacing)-Chi-squared test

Sl No.	Date	Depth to WT (cm) 60cm drain depth			Depth to WT (cm) 80cm drain depth		
		Observed	Predicted	Chi-sq.	Obs.	Predicted	Chi-sq.
1	1.6.12	40.27	45.5	0.679	41.5	44	0.150
2	2.6.12	46.67	48.37	0.061	58	59	0.017
3	3.6.12	56.31	60	0.241	64	68	0.25
4	4.4.12	60.64	64	0.224	71	75	0.225
5	5.4.12	62.52	65.72	0.163	72	80	0.888
Total				**0.205**			**0.085**

Table 4.19 Drain discharge under controlled drainage mode (9m spacing)-chi squared test

Sl No.	Date	Drain discharge (cm/day) 60cm drain depth			Drain discharge (cm/day) 80cm drain depth		
		Observed	Predicted	Chi-sq,	Observed	Predicted	Chi-sq
1	1.6.12	0.98	1.2	0.049	1.2	1.5	0.075
2	2.6.12	0.65	0.9	0.096	0.89	0.92	0.001
3	3.6.12	0.37	0.45	0.017	0.58	0.62	0.002
4	4.4.12	0.18	0.22	0.008	0.45	0.5	0.005
5	5.4.12	0.15	0.22	0.032	0.4	0.42	0.001
				1.37			**1.53**

As the drainage coefficient is taken was zero for subirrigation mode, only water table depletion i.e depth to water table is only need to be tested. The results of Chi-squared test for the verification of water table management system performance under subirrigation mode is given in Table 4.20.

Table 4.20 Depth to water table under subirrigation mode (9m spacing)-chi squared test.

Sl No.	Date	Depth to water table (cm) 60 cm drain depth			Depth to water table (cm) 80cm drain depth		
		Observed	Predicted	Chi-sq,	Observed	Predicted	Chi-sq
1	3.4.12	49.67	52	0.109	50.97	54	0.180
2	4.4.12	54.28	55	0.009	55.48	58	0.114
3	5.4.12	57.69	59	0.0297	59.09	69	1.662
4	6.4.12	60.67	69	1.143	61.17	72	1.917
5	7.4.12	63.17	72	1.234	63.87	75	1.939
				4.19			**8.36**

For testing the model, 9m spacing was chosen because of closeness to the designed value (10m). From Table 4.18 and Table 4.19, from standard statistical tables, it is seen that the data on depth to water table showed significance. . But the drain discharges predicted by the model were found more than that of the field observed data for both the drain depths for 9m spacing. This might be due to the fact that, the valves operation makes the controlled drainage vary with that of the model as model chooses a value of 50% of valve operation showed non-significance.

Similarly the predicted values of depth to water table under subirrigation mode showed higher values than the observed data. The reason for this might be attributed that the soil at the time of subirrigation was very much dry. Also the model calculated the depth to water table based on the constant subirrigation pump discharge at particular scheduling interval i.e. for every 20 days in the present input file. But for the present investigation, it was highly difficult to pump a rate of 8cm/day for two days. The soil was under full of cracks during the month of April 2013. Hence there was heavy depletion of water table during the month making more difference than the values predicted by the model.

4.5 Cost analysis of water table management system

Taking optimal drain spacing and depth as 9m and 60cms for better performance of the water table management system in the present investigation, the system cost was worked out along with operation cost and B-C ratio. The break cost details of the various components of the system per hectare are given in Table 4.21

Table 4.21 Cost details of water table management systems

Sl No.	Item	Cost/ha (Rs.)
1	UPVC pipes	75000
2	Labour	10000
3	Trenching	10000
4	PVC pipes	3000
5	Cement rings*	6000*
6	Valves & fittings	2000
	Total	**1,06,000**

* Optional

For arriving at Benefit- Cost ratio on per ha basis, we have,

1. The Annual operations cost of the system is worked out as follows

i) Fixed cost = 1,00,000/- Assuming the life of the system as 10 years and the Salvage value as 1000/-

We have depreciation = (C-S)/L = 9, 900/-

ii) For Indian conditions, the operation and maintenance of the system by farmers is almost Rs 1000/-.

iii) Fuel Cost for diesel engine, hiring charges and operators costs was assumed as Rs. 5000/- per annum.

Now total cost of operation = Fixed costs + Variable costs

= 15,900- rounded to Rs.16,000/

The cost of cultivation of paddy per ha for two seasons

=Rs.75,000/-per ha.

Cost of cultivation of dry crop =Rs.10,000/- per ha

Total gross cost including the system annual cost = Rs.1,01,000/-

2. Gross Returns expected to foresee through this technological intervention

Paddy yield expected based on the field investigation = 10.4 tons/ha

(for two seasons)

Straw yield per ha for both the seasons(paddy) = Rs.3, 000/-

Straw yield for sorghum = Rs. 5,000/-

As per latest prevailing market rates,

Paddy yield (Gross) in Rs. @ Rs. 1500/- per quintal

=1, 56,000/-

Gross benefits =1, 64,000/-

Hence B-C ratio = Gross Benefits/Total costs = (2)/ (1)

= 1,61,000/95,000 = 1.62

If the water table management system is adopted in large scale, the execution cost would certainly come down and make the system still viable with more B-C ratio.

It was also observed that the trafficability was improved considerably and the tillage operation could be taken very efficiently with tractor ploughing without any time delay (for sorghum crop). It was also gathered from farmers that it took at least 20-25 days in system not installed area (nearby farmers' fields). It was observed that on an average, 0.30 to 0.4 m lowering of water table during subsurface drainage mode during waterlogging condition could be attained resulting in good aeration and rice yields increased to a tune of 25% increase from 4.1 tons/ha to 5.2 tons/ha compared to system non-installed areas and conventional yield of the farmer apart from foreseeing of ease in harvesting paddy with combine harvester without wheel sinkage problems.

The water table management system could be installed with the spacing of 9 m, which was functionally adaptable for subsurface drainage mode but at a relatively higher cost. It was successfully implemented in the study area (0.8 acres) in a farmer's field at Thadapalli channel ayacut of Lower Bhavani Project of Tamil Nadu. The system was efficiently functioning both under subsurface drainage systems for rice crop in one crop season in the year 2012 and subsequently for taking dry land fodder millet crop with subirrigation mode in the consecutive season (2012-13).

Plate 4.1. Subirrigation trial performance in 9m spacing-75 cm drain depth replication

Plate 4.2. Subirrigation trial performance in 9m spacing-60 cm drain depth

Summary & Conclusions

Chapter VI
SUMMARY AND CONCLUSIONS

The effective agricultural water management requires control of how much water is added to the soil (irrigation) and how much water is removed (drainage). The CD & SI system, synonymously termed as Water Table Management System (WTM) is mainly adapted in waterlogged areas where the water quality is of not a major problem. The dual-purpose system would normally fluctuate between the drainage, controlled drainage and subirrigation modes several times during one cropping season. (Doty *et al.,* 1975). Hence a dual system to tackle waterlogging in monsoon season and scarcity during summer was recognized as the need of the hour. The system has a potential scope for its adoption based upon the field requirement in one of the irrigation project areas nearby TNAU research station, Bhavani Sagar. Farmers of Lower Bhavani Sagar Canal near Gobichettipalayam during their training programme expressed their felt problem of reduced paddy yields due to the inundation of canal water through seepage along the unlined canal line in the tail ends.

Hence the present research was proposed to address the following issues.

- Characterization of waterlogging problem.
- To design and install hydraulically efficient water table management system in a pilot area in a farmer's field.
- Evaluation of the system for its hydraulic and functional performance
- Simulation studies for deriving appropriate scenarios to optimize the design spacings and depths.

Characterization of waterlogging problems in the present research was carried out in three ways namely by calculating SEW 30 index , proposing a new indicator, Trafficability Index and Yield comparison with well drained fields in the same command with normal conditions. The SEW_{30} index from 40m, 80m, 120 and 160m from the canal were calculated as 520, 320, 120 and 150 cm days respectively with an average value of 277.5 cm days. As these values are higher than the optimal value of 200cmdays for dry climate conditions, it could be concluded that the experimental area is under the problem of chronic waterlogging condition which needs reclamation measures.

The combine harvester operation in many fields was delayed because of soil moisture causing more wheel sinkage. Hence the reduction in grain moisture is accounting for a shattering loss. Hence an index for trafficability (TI) was proposed relating the delay in harvesting (D), difference in grain moisture than optimum, (dθ) and decrease in yields (dY) based on research and farmers' interaction. $T = (dY)D(d\theta)$ tons days/ha. The trafficability index value (T) varies from 0.2 to 51.2 ranging from 1 to 8 days of delayed harvesting. It could be recommended that tolerable yield loss of almost 500-600 kg/ha due to operational constraints of the farmer for which 4-5 days delay from optimum might be allowed. Hence the trafficability Index corresponding to this delay might be in the order of 0.2 to 15. The characterization for proper drainage measures in the field level is of paramount importance all along the adjoining fields of the command.

The water table management system was designed using Steady state Hooghoudt's equation under drainage mode and the procedure suggested by Skaggs and William (1981) for efficient functioning both under subirrigation and drainage modes fulfilling both the needs. Inevitably, if the system was efficient in subirrigation mode., it would satisfy the needs of the drainage also since the spacing requirement was less for subirrigation mode but with little additional cost of drain materials and installation charges. The design parameters under both drainage and sub irrigation mode were summarized and were presented in Table 5.1.

For the present study after thorough drainage investigations, a spacing of 20m under drainage mode and a spacing of 10m for subirrigation mode were worked out for shallow depth of drain placement under consideration. Hence keeping 10m, as the key design spacing, the layout of field experimentation was prepared with 6m, 9m, 12m and 15m spacings(in and around design spacings) for further investigation under two depths of drain placements i.e 60cm. and one closure to the conventionally adopted depth of i.e. 80cm.

Table 5.1. Design Parameters of estimated for spacing under subirrigation mode for water table management systems at Gopichettipalayam

S.No	Design Parameters	Specification	
		Drainage	Subirrigation
1.	Average Hydraulic Conductivity	0.75m/day	0.75 m/day
2	Drainage Coefficient	1 cm/day	0 cm/day
3	Hydraulic head above the drains	0.4-0.25 m	0.3-0.45m
4	Equivalent depth	1.05m	0.8m
5.	Evaporation rate	0.0055m/day	0.0055m/day
6	Design difference in WT	0.3m	0.15 m
7	Effective raidius r_e	0.036m	0.036 m
8	Drainable pore space	10%	10%
9.	Drain spacing	20m	10m

Corrugated perforated pipes of 80mm dia. were used as drain pipe material. Rigid PVC pipes of 110mm diameter and 6 m length were used to construct the collector. Locally available coconut coir was used as an envelope material ensuring long system life. Care was taken in the bedding and installation with proper gradients for laterals and collector.

Continuous evaluation of drain outflows, canal flow levels, water table heights were taken up for two crop seasons, paddy followed by fodder sorghum in the study area for arriving at some initial valid conclusions. Initially, the crop establishment and yield parameters were also monitored and compared with the control plots adjoining to the experimental layout both in the fields of lower elevation than the site and also on the fields with similar inundated conditions.

Since the system under drainage mode was designed with closer spacing, the system was found hydraulically performing very well during the study period in maintaining the water table at desired levels. The system functioned very well under shallow drain depth placements i.e. 60cm and 80cm in maintaining water table during both the modes. During controlled drainage mode, the WT varied from 30cm to 90cm making the root zone free from waterlogging over the entire season.

The system was operated fully by opening all the valves and the entire water was drained out one week before harvesting enabling the soil for better trafficability of combine harvester. There was a gathering of about 20 no. of adjoining farmers to witness the harvesting operation with combine harvester totally free from sinkage of wheels as felt by the adjoining farmers and the present farmer by himself in previous years. The farmers convinced with the improvement of the trafficability due to the system, besides satisfying with an additional increment of 1.2 tonnes/ha of Paddy (ADT 45) in the first season itself. (4.0 t/ha to 5.2 ha) without any change in all his other cultivation practices. This could be solely attributable to this technological intervention because there was no change in the yield levels of control farms.

Fodder sorghum was taken as the summer crop which enabled to conduct subirrigation trials for giving supplemental irrigation. The subirrigation trials during summer were taken up for performance evaluation by reversibly pumping water into the system with the help of a 5 HP oil engine, for two days by diverting the canal supply to the lower end of the Collector during 1^{st}-2^{nd} April 2013. The subirrigation trials could be accomplished with the one week short canal release given for standing crop on the farmers' demand. The moisture content rise and falls with elapsed time were monitored in all the replications at three different depths namely 15cm, 30cm and 45 cm respectively. The initial moisture at different depths in near, middle and end reach midway between the laterals were also observed for comparison of the systems for hydraulic performance under various drain depth and spacing combinations.

By considering different possible real field parameters, simulation studies were also conducted for various soil types and water table conditions using DRAINMOD for further recommendations

Based on these carried out as part of the doctoral research, the following major conclusions could be drawn.

1. The average SEW30
2. index was found to be 280 cm days in the study area within the 160m distance from the canal and 520 cmdays and 320 cmdays considering 40m and 80m distance from the canal necessitating reclamation measures of drainage nearby canal fields.
3. The trafficability index (T) varied between 0.2 to 51.2 tons days/ha in the study area in the adjoining farmers field which was considered as the impact of

waterlogging reducing the yield tremendously making the non-timely harvesting by combine due to the presence of more soil moisture. The optimal value of 0.2-15 could be suggested for the soil conditions of the region.

4. The average paddy yields in the study area were in the tune of 4.0 tonnes/ha before the installation of water table management system and the yield improvement was seen in the order of 5.2 tonnes/ ha in the system area.

5. Exponential equations were fitted for drain discharge (q)-depth to water table (d) with elapsed time for all the spacing and depth combinations under controlled drainage mode operation of water table management system which would be of useful in preparing the operational schedule of the system for better water table management.

6. The water table depletion was in the decreasing trend with increase in drain depth and with drain spacing. The drain discharges were also found in decreasing order with increase in spacing and increasing order trend with drain depths.

7. Shallow depth of drain placement (60cm) gave better performance in terms of water table depletion under drainage mode and water table rise under subirrigaion mode as per DRAINMOD 6.1 simulation runs carried out as part of this study.

8. Better water table control was ensured (almost below critical water table depth of 30cm.) throughout the season because of the control valves provided individually. Hitherto no research had been reported in this direction in India. Earlier studies revealed more drudgery involved in heavy drawdowns some times which was not acceptable by the farmers in certain situations.

9. There was a substantial yield increment to the tune of 1.2 tonnes/hectare over previous years which could be exclusively attributed to the technological intervention of water table management system as there was no difference found either in the prevailing weather and farmers' cultivation practices when compared to the previous years.

10. The benefit cost ratio worked out to be 1.62 for the installed water table management system considering two paddy crops and one dry land crops into consideration. Only the initial incremental yield was considered. There evidences with drainage system increasing the yields over the seasons to attain to the normal yields.

11. As there was much yield difference between 6m and 9m spacings under subirrigation mode, since there was little difference in yield levels in the paddy under 9m spacing and also with higher spacings., 9m spacing could be recommended for the water table management system for clay loam soils of Lower Bhavani project. From the field data, the depth to ground water and drain discharges were found to be more in 6m spacing, compared to all the other three spacings under two depths. The variation of these two parameters was also found very less compared to 6m spacing. The fewer yields in the 6m spacing area might be probably due to loss of nutrients because of more drain outflow and drastic reduction in water table height beyond root zone.

12. Without detrimental to much yield paddy or dry crop, uniformity of soil moisture during subirrigation, desired water table from ground, workability under subirrigation mode and drainage mode; altogether leads to a recommendation of 9 m as the design spacing and 60cm as the drain depth for the clay loams of the region.

Scope for future Study

1. Nutrient transport models could be better applied and the status of application of N, P, K could be analysed with models like DRAINMOD-N II etc.,

2. Automation of CD-SI system could be made for opening and closing up of the main valve for the watertable management.

3. The deposition of silt particles inside drain pipes over the time could be tested for clogging purposes.

4. Optimal pumping rates and duration along with scheduling for different soil conditions for using combined controlled subsurface drainage system under

reversible flow mode under subirrigation (CD-SI) system need to be studied in detail.

5. Recycling of excess drainage water in monsoon season based upon its quality of effluent, a storage option for using it in the subsequent crop season could be thought of, wherever feasible.

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Appendices

Appendix - I

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2002

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	-	-	-	-	-	33.0	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	21.0	-
11	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	47.0	-	-
14	-	-	-	-	21.0	-	-	-	-	-	-	-
15	-	-	-	-	4.0	-	-	-	-	7.0	18.0	-
16	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	5.0	-	-	-	-	-	-	-
18	-	-	46.0	-	-	-	-	-	-	-	-	-
19	-	-	35.0	-	10.0	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	50.4	-	-
21	-	-	2.0	7.0	-	-	-	-	-	6.0	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-
27	-	11.0	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-
29	-		-	39.0	-	-	-	-	-	-	-	-
30	-		-	-	-	-	-	-	-	-	-	-
31	-		-	-	-	-	-	-	-	-	-	-
Total	**0.0**	**11.0**	**83.0**	**46.0**	**40.0**	**0.0**	**0.0**	**0.0**	**0.0**	**143.4**	**39.0**	**0.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2003

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	-	-	-	-	-	33.0	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	21.0	-
11	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	47.0	-	-
14	-	-	-	-	21.0	-	-	-	-	-	-	-
15	-	-	-	-	4.0	-	-	-	-	7.0	18.0	-
16	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	5.0	-	-	-	-	-	-	-
18	-	-	46.0	-	-	-	-	-	-	-	-	-
19	-	-	35.0	-	10.0	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	50.4	-	-
21	-	-	2.0	7.0	-	-	-	-	-	6.0	-	-
22	-	-	-	-	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	-	-	-	-
27	-	11.0	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-
29	-		-	39.0	-	-	-	-	-	-	-	-
30	-		-	-	-	-	-	-	-	-	-	-
31	-		-	-	-	-	-	-	-	-	-	-
Total	**0.0**	**11.0**	**83.0**	**46.0**	**40.0**	**0.0**	**0.0**	**0.0**	**0.0**	**143.4**	**39.0**	**0.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2004

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	-	-	-	8.0	-	3.0	12.0	-
2	-	-	-	-	-	-	-	-	-	3.0	4.0	-
3	-	-	-	-	13.0	-	-	-	-	5.2	9.0	-
4	-	-	-	-	32.0	31.0	-	-	-	22.0	-	-
5	-	-	-	-	4.0	-	-	-	-	-	-	-
6	-	-	-	-	10.0	-	-	-	-	-	-	-
7	-	-	-	3.0	4.0	-	-	7.0	1.2	-	-	-
8	-	-	-	-	3.0	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	1.0	-	5.0	-
10	-	-	-	-	-	-	26.0	-	-	-	8.0	-
11	-	-	-	-	-	-	-	-	-	-	7.0	-
12	-	-	-	-	-	-	-	-	33.0	26.0	14.0	-
13	-	-	-	-	-	-	-	-	-	17.0	7.0	-
14	-	-	-	-	19.0	-	-	-	-	-	2.0	-
15	-	-	-	-	-	-	-	-	10.0	45.0	4.0	-
16	-	-	-	-	14.0	-	7.0	-	1.0	53.0	4.0	-
17	-	-	-	-	1.0	-	3.0	-	7.0	6.0	-	-
18	-	-	-	-	-	-	-	-	1.0	38.0	-	-
19	-	-	-	-	-	-	-	-	-	11.0	-	-
20	-	-	-	-	-	-	-	-	-	6.0	-	-
21	-	-	-	-	-	-	-	-	-	6.0	-	-
22	-	-	-	16.0	-	-	-	-	-	2.0	-	-
23	-	-	-	-	-	-	-	-	-	2.0	-	-
24	-	-	-	-	1.0	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	31.0	-	-	-
26	-	-	-	1.0	-	-	-	-	2.0	-	-	-
27	-	-	-	-	-	-	-	-	-	3.0	-	-
28	-	-	-	-	9.0	-	-	1.0	-	3.0	-	-
29	-	-	-	3.0	-	-	-	-	-	18.0	-	-
30	-	-	-	-	26.0	-	-	-	-	1.0	-	-
31	-	-	-	-	-	-	2.0	-	-	22.0	-	-
Total	**0.0**	**0.0**	**0.0**	**23.0**	**136.0**	**31.0**	**38.0**	**8.0**	**87.2**	**289.2**	**64.0**	**0.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2005

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	33.0	-	-	2	-	-	-	-	-	-	-
2	-	20.0	-	-	-	-	-	-	-	-	26.00	-
3	-	14.0	-	-	-	-	-	-	-	5.0	27.00	-
4	-	1.0	-	11.0	-	-	-	-	-	-	6.00	-
5	-	-	-	2.0	19	7.0	4.0	-	5.0	7.0	6.00	65.0
6	-	-	-	-	-	-	-	-	16.0	-	47.00	-
7	-	-	-	24.0	-	-	-	-	27.0	-	3.00	-
8	-	-	-	-	-	-	-	-	1.0	15.0	-	-
9	-	-	-	-	-	-	-	-	28.0	26.0	-	-
10	-	-	-	-	-	2.0	-	-	-	-	-	-
11	-	-	4.0	11.0	-	-	-	-	9.0	-	-	2.0
12	-	-	-	-	-	-	-	-	-	-	34.0	-
13	-	-	-	-	24	-	1.0	-	-	19.0	-	4.0
14	-	-	-	-	-	-	-	-	-	26.0	-	11.0
15	-	-	-	-	-	-	39.0	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	-	-	-	-	5.0	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-
19	-	-	-	-	-	-	10.0	-	-	38.0	-	-
20	-	-	-	-	-	-	27.0	-	-	2.0	-	-
21	-	-	-	2.0	-	-	4.0	-	-	7.0	-	-
22	-	-	-	-	-	-	-	-	-	31.0	-	-
23	-	-	-	-	-	-	-	-	-	51.0	12.0	-
24	-	-	-	-	-	-	-	58.0	-	15.0	76.0	-
25	-	-	-	-	-	-	3.0	-	-	29.0	19.0	-
26	-	-	-	-	5.0	-	-	6.0	-	1.0	-	-
27	-	-	-	-	4.0	-	-	26.0	-	6.0	3.0	-
28	-	-	-	-	-	-	2.0	6.0	-	1.0	-	-
29	-	-	-	-	38.0	-	-	-	-	-	-	-
30	-	-	-	4.0	94	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	4.0	-	9.0	-	-
Total	**0.0**	**68.0**	**4.0**	**54.0**	**186.0**	**9.0**	**95.0**	**100.0**	**86.0**	**288.0**	**259.0**	**82.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2006

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	-	-	-	3.0	-	-	-	-
2	-	-	-	-	-	-	-	6.0	-	-	51.0	-
3	-	-	-	-	-	-	-	3.0	7.0	-	7.0	-
4	-	-	1.0	-	-	-	-	-	-	-	2.0	-
5	-	-	-	-	-	14.0	-	-	1.0	-	16.0	-
6	1.0	-	-	-	1.0	18.0	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	1.0
8	-	-	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	5.0	11.0	-	-	-
10	-	-	-	-	-	-	-	-	29.0	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	24.0	-	-	17.0	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	3.0	-	-	-	-	-	3.0	-	-	-
16	-	-	-	-	-	-	-	-	1.0	2.0	-	-
17	-	-	-	38.0	-	-	-	-	9.0	-	1.0	-
18	-	-	-	-	-	-	-	-	-	1.0	-	-
19	-	-	-	51.0	-	-	-	-	36.0	1.0	-	96.0
20	-	-	-	-	-	-	8.0	-	-	76.00	-	61.0
21	-	-	-	-	-	-	-	-	-	18.00	-	38.0
22	-	-	-	-	-	-	7.0	9.0	-	8.00	-	-
23	-	-	-	-	-	4.0	-	-	-	10.00	-	-
24	-	-	-	-	10.0	1.0	-	6.0	-	8.00	-	-
25	-	-	-	-	6.0	-	-	26.0	-	4.00	-	-
26	-	-	-	10.0	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	2.0	-	13.0	-	-
28	-	-	-	-	12	-	2.0	-	45.0	33.0	-	-
29	-	-	-	2.0	-	-	-	23.0	-	-	-	-
30	-	-	-	-	-	-	-	6.0	-	3.0	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-
Total	**1.0**	**1.0**	**28.0**	**101.0**	**29.0**	**54.0**	**17.0**	**77.0**	**135.0**	**173.0**	**17.0**	**196.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2007

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	-	-	-	-	-	-	22.0	-
2	-	-	-	-	NIL	-	-	-	15.0	1.0	20.0	-
3	-	-	-	-	46.0	-	-	-	64.0	-	4.0	-
4	-	-	-	-	-	-	-	-	2.0	-	9.0	-
5	-	-	-	-	-	-	-	-	-	-	2.0	-
6	-	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	15.0	-
8	-	-	-	-	-	-	-	-	-	20.0	-	-
9	-	-	-	-	-	-	-	-	-	-	2.0	9.0
10	-	-	-	-	-	-	-	-	-	2.0	4.0	-
11	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	12.0	-	-	-	-	-	-	-
16	-	-	-	-	25.0	-	-	-	-	4.0	1.0	-
17	-	-	-	-	31.0	13.0	-	-	-	-	-	-
18	-	2.0	-	-	-	-	-	-	-	1.0	18.0	-
19	-	1.0	-	-	65.0	-	-	-	-	-	16.0	-
20	-	-	-	-	-	-	-	-	-	-	5.0	-
21	-	-	-	-	-	-	-	77.0	-	-	2.0	-
22	-	-	-	15.0	-	-	-	-	-	-	-	-
23	-	-	-	-	-	-	-	-	-	-	-	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	2.0	-	-
26	-	-	-	-	3.0	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-
28	1.0	-	-	-	-	-	-	-	3.0	-	-	-
29	-		-	-	-	-	-	-	2.0	39.0	-	-
30	-		-	-	-	-	-	-	12.0	47.0	-	-
31	-		-	-	-	-	-	-	-	58.0	-	-
Total	**1.0**	**3.0**	**0.0**	**15.0**	**182**	**13**	**0**	**77.0**	**98.0**	**174.0**	**120.0**	**9.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2008

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	24.0	-	-	-	-	4.0	-	-	-
2	-	-	-	-	-	-	-	-	-	-	-	-
3	-	-	-	21.0	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	39.0	14	-	-
5	1.0	-	-	-	-	-	-	-	-	17	-	-
6	-	-	-	-	-	-	-	-	-	1.0	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	3.0	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	4.0	18.0	-	1.0
10	-	-	10.0	-	-	-	-	-	1.0	-	-	1.0
11	-	11.0	49.0	-	27.0	-	-	5.0	4.0	-	-	-
12	-	-	6.0	-	-	-	-	-	-	10.0	-	-
13	-	-	2.0	-	-	-	-	6.0	-	2.0	-	-
14	-	-	21.0	-	-	-	-	-	-	1.0	-	1.0
15	-	-	3.0	-	-	-	15.0	-	-	38.0	-	-
16	-	12.0	-	-	-	-	-	-	-	52.0	-	1.0
17	-	-	-	-	-	-	-	5.0	-	1.0	-	-
18	-	-	-	-	-	-	-	1.0	-	1.0	-	-
19	-	-	-	-	-	-	11.0	-	-	-	-	-
20	-	-	-	-	1.0	-	-	34.0	-	2.0	-	-
21	-	-	-	-	20.0	-	-	25.0	1.0	6.0	-	-
22	-	-	-	-	26.0	-	-	-	-	44.0	-	-
23	-	-	-	-	-	1.0	-	1.0	-	2.0	1.0	-
24	-	-	-	-	-	-	-	-	-	2.0	11.0	-
25	-	-	-	-	-	-	-	-	-	1.0	2.0	-
26	-	-	-	-	-	-	-	9.0	-	6.0	1.0	-
27	-	-	-	-	26.0	-	-	2.0	-	1.0	1.0	-
28	-	-	-	-	-	-	-	14.0	-	-	33.0	-
29	-	-	-	-	-	-	-	10.0	-	-	5.0	-
30	-	-	-	1.0	-	-	-	4.0	-	-	9.0	-
31	-	-	-	15.0	2.0	-	-	11.0	-	-	-	-
Total	**1.0**	**23.0**	**91.0**	**61.0**	**105.0**	**1.0**	**26.0**	**127.0**	**53.0**	**219.0**	**63.0**	**4.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2009

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	-	-	2.0	1.0	-	-	4.0	-
2	-	-	-	-	-	-	-	-	-	-	-	1.0
3	-	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	-	-	-	-	15.0	-	-	-	2.0	-
6	-	-	-	-	-	-	-	-	-	-	7.0	-
7	-	-	-	-	-	-	3.0	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	-	18.0	-
9	-	-	-	-	-	-	-	-	-	-	43.0	-
10	-	-	-	-	-	-	-	-	-	-	48.0	-
11	-	-	-	-	13.0	-	-	-	-	-	4.0	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	178.0	-	-	-	-	1.0	-	80.0	-	-
14	-	-	-	-	-	-	-	-	20.0	16.0	1.0	-
15	-	-	-	-	-	-	-	14.0	5.0	5.0	13.0	-
16	-	-	-	-	12.0	-	7.0	-	-	-	2.0	3.0
17	-	-	-	1.0	-	-	2.0	24.0	3.0	-	2.0	-
18	-	-	-	4.0	15.0	-	4.0	-	-	-	-	-
19	-	-	-	-	3.0	-	-	-	-	-	-	-
20	-	-	-	-	69.0	1.0	-	-	24.0	-	2.0	-
21	-	-	-	-	-	-	-	-	7.0	-	-	-
22	-	-	-	-	2.0	-	-	-	-	-	-	-
23	-	-	6.0	1.0	2.0	-	-	-	-	-	4.0	-
24	-	-	-	-	-	-	-	-	-	-	-	-
25	-	-	-	-	-	-	-	-	-	-	-	-
26	-	-	-	-	-	-	-	-	30.0	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-	-
28	-	-	-	-	-	-	-	-	4.0	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	4.0	2.0	-	-	-	1	-	-
31	-	-	-	-	56.0	-	-	-	-	10	-	-
Total	**0.0**	**0.0**	**184.0**	**6.0**	**176.0**	**3.0**	**33.0**	**40.0**	**93.0**	**112.0**	**150.0**	**4.0**

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2010

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	44.2	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-	-	-	-	81.8	-
3	-	-	-	-	-	23.2	-	-	-	75.8	9.6	-
4	-	-	-	-	-	-	-	-	-	3.0	16.0	-
5	-	-	-	-	-	3.4	-	-	-	-	57.0	-
6	-	-	-	-	-	14.2	-	-	-	7.0	10.8	-
7	-	-	-	-	17.8	-	-	-	-	-	-	-
8	-	-	-	-	-	-	-	-	-	4.6	1.2	-
9	-	-	-	-	1.0	-	5.6	-	-	-	25.8	-
10	-	-	-	-	-	-	-	-	1.0	-	73.2	-
11	1.20	-	-	-	-	0.6	21.0	-	2.0	-	1.0	-
12	-	-	-	-	-	-	-	-	18.0	-	15.4	-
13	-	-	-	-	-	-	-	-	1.60	-	59.6	-
14	-	-	-	-	-	-	2.2	-	-	-	2.0	-
15	-	-	-	-	-	0.4	-	-	-	-	1.2	-
16	-	-	-	-	18.4	-	10.0	3.0	8.4	-	2.0	-
17	-	-	-	-	-	-	22.0	40	2.8	-	-	-
18	-	-	-	17.20	6.2	-	-	-	-	-	24.2	-
19	-	-	-	-	8.0	-	-	-	-	-	1.0	-
20	-	-	-	-	2.2	-	-	-	-	-	-	-
21	-	-	-	2.00	-	-	-	20	-	-	19.0	-
22	-	-	-	-	-	-	0.4	1.0	13.0	-	28.2	-
23	-	-	-	-	47.6	-	-	-	35.4	-	36.2	-
24	-	-	-	-	51.4	-	-	12.4	-	-	-	-
25	-	-	-	19.60	-	-	-	7.8	3.6	-	1.6	-
26	-	-	-	-	-	-	-	2.6	1.2	-	-	-
27	-	-	-	-	-	-	-	1.0	1.0	16.0	2.0	-
28	-	-	-	-	-	-	-	-	-	6.4	-	-
29	-	-	-	-	-	-	-	4.0	5.4	10.0	6.4	-
30	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	8.6	-	-	-	-	17.0	-	-
Total	1.2	0.0	0.0	38.8	161.2	41.8	61.2	91.8	93.4	139.8	475.2	0.0

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2011

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	40.00	-	-	-	1.1	-	-	-
2	-	-	-	-	-	9.8	1.6	-	20.0	-	-	-
3	-	-	-	-	-	5.2	-	-	17.2	-	-	-
4	-	-	-	-	34.4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	3.3	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	2.6	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	12.1	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	1.4	-	-	-	-
16	-	-	-	-	-	-	-	4.2	-	-	-	-
17	-	-	-	-	-	-	-	17.0	-	-	-	-
18	-	-	-	-	-	-	-	24.0	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	1.0	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-	76.60	-	-	-	-	-	-	-	-
23	-	-	-	62.00	-	-	-	-	-	-	-	-
24	-	-	-	10.00	1.00	-	-	-	-	-	-	-
25	-	-	-	23.40	7.00	-	-	-	-	-	-	-
26	-	-	-	18.40	35.4	-	1.0	-	-	-	-	-
27	-	-	1.00	-	-	-	3.6	1.0	-	-	-	-
28	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.0	0.0	1.0	190.4	117.8	20.9	18.3	38.6	0.0	0.0	0.0	0.0

RAINFALL STATEMENT FOR THE RAINFALL STATION: GOBI IN MM FOR THE YEAR 2012

Date/	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUGUST	SEP	OCT	NOV	DEC
1	-	-	-	-	40.00	-	-	-	1.1	-	-	-
2	-	-	-	-	-	9.8	1.6	-	20.0	-	-	-
3	-	-	-	-	-	5.2	-	-	17.2	-	-	-
4	-	-	5 mm	-	5 mm	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	3.3	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-	-
8	-	-	-	-	-	2.6	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	11.0	-	-	-	-	-	-
11	-	-	-	-	-	32.4	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	12.1	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	1.4	-	-	-	-
16	-	-	-	-	-	3.6	-	4.2	-	-	-	-
17	-	-	-	-	-	-	-	17.0	-	-	-	-
18	-	-	-	-	-	-	-	24.0	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	1.0	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-
22	-	-	-		-	-	-	32	-	-	-	-
23	-	-	-		-	-	-	-	-	-	-	-
24	-	-	-	20		-	-	-	-	-	-	-
25	-	-	-	16		-	-	-	-	-	-	-
26	-	-	-	-		-	1.0	-	-	-	-	-
27	-	-	1.00	-		-	3.6	1.0	-	-	-	-
28	-	-	-	14		-	-	-	-	-	-	-
29	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-	-
Total	0.0	0.0	6.0	50.0	45.0	67.9	18.3	80.6	38.3	0.0	0.0	0.0

Appendix - II

Flow Depth (m) Readings taken at 15/0 mile Thadapalli Channel-2009												
Calender Day	January	February	March	April	May	June	July	August	September	October	November	December
1					1.39	1.3	1.44	1.5	1.4	1.32	1.2	1.46
2					1.4	1.2	1.44	1.5	1.2	1.46	1.2	1.46
3					1.4	1.2	1.44	1.5	1.15	1.46	1.28	1.46
4					1.4	1.2	1.41	1.5	1.15	1.46	1.4	1.49
5					1.4	1.3	1.41	1.45	0.93	1.52	1.52	1.5
6					1.4	1.3	1.44	1.42	1.38	1.56	1.47	1.49
7					1.4	1.3	1.44	1.42	1.38	1.56	1.35	1.48
8					1.4	1.3	1.4	1.39	1.38	1.56		1.53
9					1.38	1.3	1.4	1.4	1.38	1.56		1.53
10					1.38	1.4	1.39	1.4	1.42	1.55		1.53
11					1.4	1.38	1.44	1.4	1.1	1.55		1.48
12					1.42	1.26	1.44	1.47	1.1	1.6		1.48
13					1.42	1.26	1.42	1.47	1.05	1		1.43
14				1.45	1.42	1.38	1.43	1.47	1.25			1.4
15				1.45	1.42	1.38	1.43	1.47	1.25		1.4	1.4
16				1.45	1.4	1.38	1.42	1.47	1.1			1.4
17				1.45	1.38	1.38	1.4	1.47	1.1		1.2	1.4
18				1.45	1.38	1.37	1.39	1.35	1.1	1.45	1.25	1.5
19				1.45	1.42	1.43	1.39	1.25	1.1	1.48	1.42	1.5
20				1.45	1.35	1.43	1.39	1.2	1.1	1.52	1.52	1.2
21				1.45	1.25	1.42	1.43	1.2		1.52	1.44	1.4
22				1.47	1.2	1.39	1.43	1.18		1.56	1.44	1.47
23				1.45	1.2	1.33	1.41	1.18		1.56	1.44	1.49
24				1.45	1.34	1.31	1.4	1.18		1.56	1.4	1.46
25				1.45	1.3	1.35	1.38	1.18		1.55	1.3	1.46
26				1.45	1.36	1.4	1.4	1.18		1.55	1.34	1.5
27				1.32	1.36	1.4	1.4	1.25		1.55	1.3	1.5
28				1.28	1.36	1.4	1.38	1.25		1.55	1.35	1.52
29				1.27	1.36	1.39	1.4	1.3		1.55	1.37	1.5
30				1.27	1.38	1.39	1.4	1.42		1.5	1.41	1.48
31					1.28		1.43	1.42		1.28		1.41

APPENDIX III								
DRAINMOD 6.1 OUTPUT FOR 60cm drain depth								
Calender Day	6m		9m		12m		15m	
	DRAIN	DTWT	DRAIN	DTWT	DRAIN	DTWT	DRAIN	DTWT
01-06-2012	1.00E+00	40.27	1.00E+00	40.27	1.00E+00	40.27	1.00E+00	40.27
02-06-2012	9.36E-01	50.79	7.51E-01	46.67	7.51E-01	46.67	6.13E-01	43.42
03-06-2012	3.93E-01	59.36	4.38E-01	56.31	4.38E-01	56.31	4.43E-01	53.36
04-06-2012	1.40E-02	62.32	8.02E-02	60.64	8.02E-02	60.64	1.47E-01	59.17
05-06-2012	0.00E+00	63.97	0.00E+00	62.52	0.00E+00	62.52	1.71E-02	61.38
06-06-2012	0.00E+00	64.54	0.00E+00	63.34	0.00E+00	63.34	0.00E+00	62.2
07-06-2012	0.00E+00	65.12	0.00E+00	63.96	0.00E+00	63.96	0.00E+00	63.05
08-06-2012	0.00E+00	65.68	0.00E+00	64.55	0.00E+00	64.55	0.00E+00	63.75
09-06-2012	0.00E+00	66.23	0.00E+00	65.13	0.00E+00	65.13	0.00E+00	64.35
10-06-2012	0.00E+00	67.51	5.87E-03	66.47	5.87E-03	66.47	1.10E-02	65.77
11-06-2012	2.50E-01	12.13	2.39E-01	10.06	2.39E-01	10.06	2.31E-01	8.66
12-06-2012	1.00E+00	39.52	1.00E+00	45.72	1.00E+00	45.72	1.00E+00	46.27
13-06-2012	7.79E-01	59.69	4.52E-01	58.03	4.52E-01	58.03	3.52E-01	56.38
14-06-2012	8.12E-03	60.73	3.27E-02	60.58	3.27E-02	60.58	6.59E-02	59.86
15-06-2012	0.00E+00	61.63	0.00E+00	61.5	0.00E+00	61.5	2.80E-03	60.71
16-06-2012	0.00E+00	62.48	0.00E+00	62.35	0.00E+00	62.35	0.00E+00	61.62
17-06-2012	0.00E+00	63.33	0.00E+00	63.2	0.00E+00	63.2	0.00E+00	62.47
18-06-2012	0.00E+00	63.95	0.00E+00	63.85	0.00E+00	63.85	0.00E+00	63.32
19-06-2012	0.00E+00	64.55	0.00E+00	64.45	0.00E+00	64.45	0.00E+00	63.94
20-06-2012	0.00E+00	65.12	0.00E+00	65.02	0.00E+00	65.02	0.00E+00	64.54
21-06-2012	0.00E+00	65.68	0.00E+00	65.58	0.00E+00	65.58	0.00E+00	65.11
22-06-2012	0.00E+00	66.23	0.00E+00	66.13	0.00E+00	66.13	0.00E+00	65.67
23-06-2012	0.00E+00	66.76	0.00E+00	66.67	0.00E+00	66.67	0.00E+00	66.22
24-06-2012	0.00E+00	67.28	0.00E+00	67.19	0.00E+00	67.19	0.00E+00	66.75
25-06-2012	0.00E+00	67.79	0.00E+00	67.7	0.00E+00	67.7	0.00E+00	67.27
26-06-2012	0.00E+00	68.29	0.00E+00	68.2	0.00E+00	68.2	0.00E+00	67.78
27-06-2012	0.00E+00	68.77	0.00E+00	68.68	0.00E+00	68.68	0.00E+00	68.28
28-06-2012	0.00E+00	69.25	0.00E+00	69.15	0.00E+00	69.15	0.00E+00	68.76
29-06-2012	0.00E+00	69.71	0.00E+00	69.61	0.00E+00	69.61	0.00E+00	69.24
30-06-2012	0.00E+00	70.15	0.00E+00	70.06	0.00E+00	70.06	0.00E+00	69.7
01-07-2012	0.00E+00	70.59	0.00E+00	70.49	0.00E+00	70.49	0.00E+00	70.14
02-07-2012	0.00E+00	71.01	0.00E+00	70.93	0.00E+00	70.93	0.00E+00	70.58
03-07-2012	0.00E+00	71.42	0.00E+00	71.35	0.00E+00	71.35	0.00E+00	71.01
04-07-2012	0.00E+00	71.83	0.00E+00	71.76	0.00E+00	71.76	0.00E+00	71.41
05-07-2012	0.00E+00	72.22	0.00E+00	72.15	0.00E+00	72.15	0.00E+00	71.82
06-07-2012	0.00E+00	72.61	0.00E+00	72.54	0.00E+00	72.54	0.00E+00	72.22
07-07-2012	0.00E+00	72.99	0.00E+00	72.92	0.00E+00	72.92	0.00E+00	72.6
08-07-2012	0.00E+00	73.36	0.00E+00	73.29	0.00E+00	73.29	0.00E+00	72.99
09-07-2012	0.00E+00	73.72	0.00E+00	73.65	0.00E+00	73.65	0.00E+00	73.36
10-07-2012	0.00E+00	74.07	0.00E+00	74	0.00E+00	74	0.00E+00	73.72

11-07-2012	0.00E+00	74.4	0.00E+00	74.33	0.00E+00	74.33	0.00E+00	74.07
12-07-2012	0.00E+00	74.74	0.00E+00	74.67	0.00E+00	74.67	0.00E+00	74.4
13-07-2012	0.00E+00	75.06	0.00E+00	74.99	0.00E+00	74.99	0.00E+00	74.73
14-07-2012	0.00E+00	75.37	0.00E+00	75.31	0.00E+00	75.31	0.00E+00	75.06
15-07-2012	0.00E+00	75.68	0.00E+00	75.62	0.00E+00	75.62	0.00E+00	75.37
16-07-2012	0.00E+00	75.99	0.00E+00	75.93	0.00E+00	75.93	0.00E+00	75.67
17-07-2012	0.00E+00	76.28	0.00E+00	76.23	0.00E+00	76.23	0.00E+00	75.98
18-07-2012	0.00E+00	76.57	0.00E+00	76.51	0.00E+00	76.51	0.00E+00	76.28
19-07-2012	0.00E+00	76.85	0.00E+00	76.79	0.00E+00	76.79	0.00E+00	76.56
20-07-2012	0.00E+00	77.12	0.00E+00	77.07	0.00E+00	77.07	0.00E+00	76.85
21-07-2012	0.00E+00	77.38	0.00E+00	77.33	0.00E+00	77.33	0.00E+00	77.12
22-07-2012	0.00E+00	77.64	0.00E+00	77.58	0.00E+00	77.58	0.00E+00	77.38
23-07-2012	0.00E+00	77.9	0.00E+00	77.84	0.00E+00	77.84	0.00E+00	77.64
24-07-2012	0.00E+00	78.06	0.00E+00	78.04	0.00E+00	78.04	0.00E+00	77.9
25-07-2012	0.00E+00	78.16	0.00E+00	78.13	0.00E+00	78.13	0.00E+00	78.06
26-07-2012	0.00E+00	78.25	0.00E+00	78.23	0.00E+00	78.23	0.00E+00	78.16
27-07-2012	0.00E+00	78.35	0.00E+00	78.33	0.00E+00	78.33	0.00E+00	78.25
28-07-2012	0.00E+00	78.44	0.00E+00	78.42	0.00E+00	78.42	0.00E+00	78.35
29-07-2012	0.00E+00	78.54	0.00E+00	78.52	0.00E+00	78.52	0.00E+00	78.45
30-07-2012	0.00E+00	78.64	0.00E+00	78.61	0.00E+00	78.61	0.00E+00	78.54
31-07-2012	0.00E+00	78.73	0.00E+00	78.71	0.00E+00	78.71	0.00E+00	78.64
01-08-2012	0.00E+00	78.83	0.00E+00	78.8	0.00E+00	78.8	0.00E+00	78.73
02-08-2012	0.00E+00	78.92	0.00E+00	78.9	0.00E+00	78.9	0.00E+00	78.83
03-08-2012	0.00E+00	79.02	0.00E+00	79	0.00E+00	79	0.00E+00	78.93
04-08-2012	0.00E+00	79.11	0.00E+00	79.09	0.00E+00	79.09	0.00E+00	79.02
05-08-2012	0.00E+00	79.21	0.00E+00	79.19	0.00E+00	79.19	0.00E+00	79.12
06-08-2012	0.00E+00	79.31	0.00E+00	79.28	0.00E+00	79.28	0.00E+00	79.21
07-08-2012	0.00E+00	79.4	0.00E+00	79.38	0.00E+00	79.38	0.00E+00	79.31
08-08-2012	0.00E+00	79.5	0.00E+00	79.47	0.00E+00	79.47	0.00E+00	79.4
09-08-2012	0.00E+00	79.59	0.00E+00	79.57	0.00E+00	79.57	0.00E+00	79.5
10-08-2012	0.00E+00	79.69	0.00E+00	79.66	0.00E+00	79.66	0.00E+00	79.59
11-08-2012	0.00E+00	79.78	0.00E+00	79.76	0.00E+00	79.76	0.00E+00	79.69
12-08-2012	0.00E+00	79.88	0.00E+00	79.85	0.00E+00	79.85	0.00E+00	79.78
13-08-2012	0.00E+00	79.97	0.00E+00	79.95	0.00E+00	79.95	0.00E+00	79.88
14-08-2012	0.00E+00	80.07	0.00E+00	80.04	0.00E+00	80.04	0.00E+00	79.97
15-08-2012	0.00E+00	80.16	0.00E+00	80.14	0.00E+00	80.14	0.00E+00	80.07
16-08-2012	0.00E+00	79.99	0.00E+00	79.97	0.00E+00	79.97	0.00E+00	79.9
17-08-2012	0.00E+00	72.52	0.00E+00	72.47	0.00E+00	72.47	0.00E+00	72.3
18-08-2012	2.08E-01	37.62	1.99E-01	37.29	1.99E-01	37.29	1.89E-01	36.75
19-08-2012	8.58E-01	59.42	7.07E-01	55.76	7.07E-01	55.76	6.11E-01	53.15
20-08-2012	1.76E-02	61.38	1.08E-01	59.62	1.08E-01	59.62	1.62E-01	58.2
21-08-2012	0.00E+00	63.1	1.15E-02	61.53	1.15E-02	61.53	2.40E-02	60.42
22-08-2012	2.50E-01	20.06	2.44E-01	17.98	2.44E-01	17.98	2.36E-01	16.51
23-08-2012	1.00E+00	47.13	1.00E+00	45.14	1.00E+00	45.14	9.80E-01	43.17
24-08-2012	5.07E-01	60.52	4.71E-01	57.84	4.71E-01	57.84	4.35E-01	55.29

25-08-2012	0.00E+00	61.6	5.59E-02	59.9	5.59E-02	59.9	1.17E-01	58.71
26-08-2012	0.00E+00	62.45	3.05E-03	60.76	3.05E-03	60.76	2.62E-02	59.93
27-08-2012	0.00E+00	63.3	0.00E+00	61.66	0.00E+00	61.66	1.14E-04	60.86
28-08-2012	0.00E+00	63.93	0.00E+00	62.51	0.00E+00	62.51	0.00E+00	61.75
29-08-2012	0.00E+00	64.53	0.00E+00	63.35	0.00E+00	63.35	0.00E+00	62.6
30-08-2012	0.00E+00	65.1	0.00E+00	63.97	0.00E+00	63.97	0.00E+00	63.42
31-08-2012	0.00E+00	65.66	0.00E+00	64.56	0.00E+00	64.56	0.00E+00	64.02
01-09-2012	0.00E+00	66.21	0.00E+00	65.14	0.00E+00	65.14	0.00E+00	64.61
02-09-2012	2.08E-01	53.27	1.89E-01	51.22	1.89E-01	51.22	1.69E-01	49.97
03-09-2012	5.25E-01	34.31	4.90E-01	31.08	4.90E-01	31.08	4.57E-01	28.86
04-09-2012	9.42E-01	58.61	8.50E-01	53.69	8.50E-01	53.69	7.91E-01	50.41
05-09-2012	3.83E-02	61.77	1.74E-01	59.7	1.74E-01	59.7	2.36E-01	57.78
06-09-2012	0.00E+00	62.62	9.18E-03	60.69	9.18E-03	60.69	5.19E-02	59.58
07-09-2012	0.00E+00	63.44	0.00E+00	61.6	0.00E+00	61.6	8.69E-03	60.56
08-09-2012	0.00E+00	64.03	0.00E+00	62.45	0.00E+00	62.45	0.00E+00	61.48
09-09-2012	0.00E+00	64.62	0.00E+00	63.3	0.00E+00	63.3	0.00E+00	62.33
10-09-2012	0.00E+00	65.19	0.00E+00	63.93	0.00E+00	63.93	0.00E+00	63.18
11-09-2012	0.00E+00	65.75	0.00E+00	64.52	0.00E+00	64.52	0.00E+00	63.84
12-09-2012	0.00E+00	66.3	0.00E+00	65.1	0.00E+00	65.1	0.00E+00	64.44
13-09-2012	0.00E+00	66.83	0.00E+00	65.66	0.00E+00	65.66	0.00E+00	65.01
14-09-2012	0.00E+00	67.36	0.00E+00	66.2	0.00E+00	66.2	0.00E+00	65.57
15-09-2012	0.00E+00	67.86	0.00E+00	66.74	0.00E+00	66.74	0.00E+00	66.12
16-09-2012	0.00E+00	68.36	0.00E+00	67.26	0.00E+00	67.26	0.00E+00	66.65
17-09-2012	0.00E+00	68.85	0.00E+00	67.77	0.00E+00	67.77	0.00E+00	67.18
18-09-2012	0.00E+00	69.32	0.00E+00	68.27	0.00E+00	68.27	0.00E+00	67.68
19-09-2012	0.00E+00	69.78	0.00E+00	68.75	0.00E+00	68.75	0.00E+00	68.18
20-09-2012	0.00E+00	70.22	0.00E+00	69.22	0.00E+00	69.22	0.00E+00	68.67
21-09-2012	0.00E+00	70.66	0.00E+00	69.68	0.00E+00	69.68	0.00E+00	69.14
22-09-2012	0.00E+00	71.08	0.00E+00	70.13	0.00E+00	70.13	0.00E+00	69.6
23-09-2012	0.00E+00	71.49	0.00E+00	70.56	0.00E+00	70.56	0.00E+00	70.05
24-09-2012	0.00E+00	71.9	0.00E+00	71	0.00E+00	71	0.00E+00	70.48
25-09-2012	0.00E+00	72.29	0.00E+00	71.42	0.00E+00	71.42	0.00E+00	70.91
26-09-2012	0.00E+00	72.68	0.00E+00	71.83	0.00E+00	71.83	0.00E+00	71.34
27-09-2012	0.00E+00	73.05	0.00E+00	72.22	0.00E+00	72.22	0.00E+00	71.74
28-09-2012	0.00E+00	73.41	0.00E+00	72.61	0.00E+00	72.61	0.00E+00	72.14
29-09-2012	0.00E+00	73.77	0.00E+00	72.99	0.00E+00	72.99	0.00E+00	72.53
30-09-2012	0.00E+00	74.12	0.00E+00	73.36	0.00E+00	73.36	0.00E+00	72.91

DRAINMOD 6.1 OUTPUT FOR 80cn drain depth

	6m		9m		12m		15m	
Calender Day	**DRAIN**	**DTWT**	**DRAIN**	**DTWT**	**DRAIN**	**DTWT**	**DRAIN**	**DTWT**
01-06-2012	1.00E+00	40.37	1.00E+00	40.37	1.00E+00	40.37	1.00E+00	40.37
02-06-2012	1.00E+00	52.37	1.00E+00	52.37	1.00E+00	52.37	9.87E-01	52.08
03-06-2012	1.00E+00	69.59	1.00E+00	69.59	9.14E-01	68.33	7.61E-01	65.91
04-06-2012	6.89E-01	78.96	5.09E-01	77.87	4.19E-01	76.63	3.90E-01	73.84

05-06-2012	4.55E-02	80.34	9.83E-02	79.55	1.18E-01	78.62	1.57E-01	77.36
06-06-2012	2.32E-02	80.56	5.32E-02	79.91	7.85E-02	79.14	8.71E-02	78.32
07-06-2012	0.00E+00	80.66	4.13E-03	80.01	4.02E-02	79.43	5.58E-02	78.7
08-06-2012	3.69E-03	80.76	1.46E-02	80.17	3.65E-02	79.69	4.97E-02	79.04
09-06-2012	0.00E+00	80.86	0.00E+00	80.27	1.30E-02	79.82	3.07E-02	79.27
10-06-2012	1.11E-01	80.26	7.28E-02	79.44	5.78E-02	78.86	5.73E-02	78.32
11-06-2012	2.61E-01	46.85	2.65E-01	43.7	2.62E-01	41.15	2.51E-01	38.59
12-06-2012	1.00E+00	68	1.00E+00	66.04	1.00E+00	64.57	9.57E-01	62.46
13-06-2012	7.07E-01	78.8	6.67E-01	77.45	5.78E-01	74.74	5.01E-01	71.58
14-06-2012	1.36E-01	79.66	1.63E-01	78.8	2.03E-01	77.89	2.47E-01	75.42
15-06-2012	3.64E-02	79.92	8.54E-02	79.36	9.77E-02	78.59	1.32E-01	77.52
16-06-2012	5.01E-02	80.27	6.76E-02	79.81	8.06E-02	79.12	8.43E-02	78.36
17-06-2012	0.00E+00	80.36	1.05E-02	79.92	4.10E-02	79.42	5.44E-02	78.74
18-06-2012	0.00E+00	80.46	3.69E-03	80.01	2.59E-02	79.62	4.18E-02	79.03
19-06-2012	0.00E+00	80.55	0.00E+00	80.11	1.66E-02	79.76	3.11E-02	79.26
20-06-2012	0.00E+00	80.65	0.00E+00	80.2	9.84E-03	79.87	2.34E-02	79.45
21-06-2012	0.00E+00	80.74	0.00E+00	80.3	5.00E-03	79.94	1.73E-02	79.6
22-06-2012	0.00E+00	80.84	0.00E+00	80.39	1.66E-03	80.02	1.24E-02	79.72
23-06-2012	0.00E+00	80.93	0.00E+00	80.49	0.00E+00	80.12	8.42E-03	79.81
24-06-2012	0.00E+00	81.03	0.00E+00	80.58	0.00E+00	80.21	5.26E-03	79.89
25-06-2012	0.00E+00	81.12	0.00E+00	80.68	0.00E+00	80.31	2.73E-03	79.95
26-06-2012	0.00E+00	81.21	0.00E+00	80.77	0.00E+00	80.4	8.63E-04	80.03
27-06-2012	0.00E+00	81.31	0.00E+00	80.87	0.00E+00	80.49	0.00E+00	80.12
28-06-2012	0.00E+00	81.4	0.00E+00	80.96	0.00E+00	80.59	0.00E+00	80.22
29-06-2012	0.00E+00	81.5	0.00E+00	81.05	0.00E+00	80.68	0.00E+00	80.31
30-06-2012	0.00E+00	81.59	0.00E+00	81.15	0.00E+00	80.78	0.00E+00	80.41
01-07-2012	0.00E+00	81.68	0.00E+00	81.24	0.00E+00	80.87	0.00E+00	80.5
02-07-2012	0.00E+00	81.78	0.00E+00	81.34	0.00E+00	80.97	0.00E+00	80.6
03-07-2012	0.00E+00	81.87	0.00E+00	81.43	0.00E+00	81.06	0.00E+00	80.69
04-07-2012	0.00E+00	81.97	0.00E+00	81.52	0.00E+00	81.16	0.00E+00	80.79
05-07-2012	0.00E+00	82.06	0.00E+00	81.62	0.00E+00	81.25	0.00E+00	80.88
06-07-2012	0.00E+00	82.15	0.00E+00	81.71	0.00E+00	81.34	0.00E+00	80.98
07-07-2012	0.00E+00	82.25	0.00E+00	81.81	0.00E+00	81.44	0.00E+00	81.07
08-07-2012	0.00E+00	82.34	0.00E+00	81.9	0.00E+00	81.53	0.00E+00	81.16
09-07-2012	0.00E+00	82.43	0.00E+00	81.99	0.00E+00	81.63	0.00E+00	81.26
10-07-2012	0.00E+00	82.53	0.00E+00	82.09	0.00E+00	81.72	0.00E+00	81.35
11-07-2012	0.00E+00	82.62	0.00E+00	82.18	0.00E+00	81.81	0.00E+00	81.45
12-07-2012	0.00E+00	82.71	0.00E+00	82.27	0.00E+00	81.91	0.00E+00	81.54
13-07-2012	0.00E+00	82.81	0.00E+00	82.37	0.00E+00	82	0.00E+00	81.63
14-07-2012	0.00E+00	82.9	0.00E+00	82.46	0.00E+00	82.1	0.00E+00	81.73
15-07-2012	0.00E+00	82.99	0.00E+00	82.56	0.00E+00	82.19	0.00E+00	81.82
16-07-2012	0.00E+00	83.09	0.00E+00	82.65	0.00E+00	82.28	0.00E+00	81.92
17-07-2012	0.00E+00	83.18	0.00E+00	82.74	0.00E+00	82.38	0.00E+00	82.01
18-07-2012	0.00E+00	83.27	0.00E+00	82.84	0.00E+00	82.47	0.00E+00	82.1
19-07-2012	0.00E+00	83.36	0.00E+00	82.93	0.00E+00	82.56	0.00E+00	82.2

20-07-2012	0.00E+00	83.46	0.00E+00	83.02	0.00E+00	82.66	0.00E+00	82.29
21-07-2012	0.00E+00	83.55	0.00E+00	83.11	0.00E+00	82.75	0.00E+00	82.38
22-07-2012	0.00E+00	83.64	0.00E+00	83.21	0.00E+00	82.84	0.00E+00	82.48
23-07-2012	0.00E+00	83.74	0.00E+00	83.3	0.00E+00	82.94	0.00E+00	82.57
24-07-2012	0.00E+00	83.83	0.00E+00	83.39	0.00E+00	83.03	0.00E+00	82.66
25-07-2012	0.00E+00	83.92	0.00E+00	83.49	0.00E+00	83.12	0.00E+00	82.76
26-07-2012	0.00E+00	84.01	0.00E+00	83.58	0.00E+00	83.21	0.00E+00	82.85
27-07-2012	0.00E+00	84.11	0.00E+00	83.67	0.00E+00	83.31	0.00E+00	82.94
28-07-2012	0.00E+00	84.2	0.00E+00	83.76	0.00E+00	83.4	0.00E+00	83.04
29-07-2012	0.00E+00	84.29	0.00E+00	83.86	0.00E+00	83.49	0.00E+00	83.13
30-07-2012	0.00E+00	84.38	0.00E+00	83.95	0.00E+00	83.59	0.00E+00	83.22
31-07-2012	0.00E+00	84.48	0.00E+00	84.04	0.00E+00	83.68	0.00E+00	83.32
01-08-2012	0.00E+00	84.57	0.00E+00	84.13	0.00E+00	83.77	0.00E+00	83.41
02-08-2012	0.00E+00	84.66	0.00E+00	84.23	0.00E+00	83.86	0.00E+00	83.5
03-08-2012	0.00E+00	84.75	0.00E+00	84.32	0.00E+00	83.96	0.00E+00	83.59
04-08-2012	0.00E+00	84.84	0.00E+00	84.41	0.00E+00	84.05	0.00E+00	83.69
05-08-2012	0.00E+00	84.93	0.00E+00	84.5	0.00E+00	84.14	0.00E+00	83.78
06-08-2012	0.00E+00	85.03	0.00E+00	84.59	0.00E+00	84.23	0.00E+00	83.87
07-08-2012	0.00E+00	85.12	0.00E+00	84.69	0.00E+00	84.33	0.00E+00	83.96
08-08-2012	0.00E+00	85.21	0.00E+00	84.78	0.00E+00	84.42	0.00E+00	84.06
09-08-2012	0.00E+00	85.3	0.00E+00	84.87	0.00E+00	84.51	0.00E+00	84.15
10-08-2012	0.00E+00	85.39	0.00E+00	84.96	0.00E+00	84.6	0.00E+00	84.24
11-08-2012	0.00E+00	85.49	0.00E+00	85.05	0.00E+00	84.69	0.00E+00	84.33
12-08-2012	0.00E+00	85.58	0.00E+00	85.15	0.00E+00	84.79	0.00E+00	84.43
13-08-2012	0.00E+00	85.67	0.00E+00	85.24	0.00E+00	84.88	0.00E+00	84.52
14-08-2012	0.00E+00	85.76	0.00E+00	85.33	0.00E+00	84.97	0.00E+00	84.61
15-08-2012	0.00E+00	85.85	0.00E+00	85.42	0.00E+00	85.06	0.00E+00	84.7
16-08-2012	0.00E+00	85.67	0.00E+00	85.24	0.00E+00	84.88	0.00E+00	84.53
17-08-2012	5.33E-02	79.98	3.41E-02	79.43	2.40E-02	79.01	1.84E-02	78.62
18-08-2012	2.60E-01	61.12	2.56E-01	59.47	2.48E-01	57.82	2.34E-01	56.03
19-08-2012	9.80E-01	76.59	9.15E-01	74.72	8.08E-01	72.01	6.73E-01	68.9
20-08-2012	3.07E-01	79.39	2.76E-01	78.25	2.82E-01	77.18	3.06E-01	74.52
21-08-2012	2.19E-02	80.44	8.05E-02	79.63	1.06E-01	78.73	1.40E-01	77.62
22-08-2012	2.66E-01	54.7	2.74E-01	51.76	2.87E-01	48.69	2.86E-01	45.42
23-08-2012	1.00E+00	72.91	1.00E+00	70.99	9.55E-01	68.34	8.76E-01	65.07
24-08-2012	4.93E-01	79.5	4.32E-01	78.36	4.28E-01	76.33	4.23E-01	73.04
25-08-2012	4.56E-02	79.9	1.12E-01	79.16	1.40E-01	78.26	1.99E-01	76.29
26-08-2012	9.16E-03	80.03	5.91E-02	79.56	8.29E-02	78.8	1.07E-01	78
27-08-2012	8.60E-03	80.16	3.67E-02	79.83	6.06E-02	79.21	6.93E-02	78.47
28-08-2012	0.00E+00	80.26	9.33E-03	79.93	3.69E-02	79.48	5.08E-02	78.82
29-08-2012	0.00E+00	80.35	3.22E-03	80.02	2.31E-02	79.66	3.90E-02	79.1
30-08-2012	0.00E+00	80.45	0.00E+00	80.12	1.45E-02	79.79	2.89E-02	79.32
31-08-2012	0.00E+00	80.54	0.00E+00	80.21	8.38E-03	79.89	2.17E-02	79.49
01-09-2012	0.00E+00	80.63	9.75E-04	80.3	8.77E-03	79.99	1.92E-02	79.65
02-09-2012	2.36E-01	74.18	2.12E-01	73	1.80E-01	71.73	1.37E-01	70.25

03-09-2012	7.23E-01	65.37	5.71E-01	61.97	4.89E-01	59.18	4.41E-01	55.95
04-09-2012	8.63E-01	77.9	8.37E-01	76.07	7.72E-01	72.69	6.71E-01	69.08
05-09-2012	1.43E-01	80.24	2.07E-01	79.09	2.52E-01	78	2.98E-01	75.15
06-09-2012	0.00E+00	80.34	6.44E-02	79.52	9.53E-02	78.62	1.40E-01	77.37
07-09-2012	0.00E+00	80.43	3.29E-02	79.77	6.52E-02	79.06	7.84E-02	78.26
08-09-2012	0.00E+00	80.53	1.36E-02	79.89	4.41E-02	79.37	5.78E-02	78.65
09-09-2012	0.00E+00	80.62	5.06E-03	79.97	2.80E-02	79.58	4.45E-02	78.97
10-09-2012	0.00E+00	80.72	1.45E-03	80.05	1.81E-02	79.74	3.40E-02	79.22
11-09-2012	0.00E+00	80.81	0.00E+00	80.14	1.09E-02	79.85	2.50E-02	79.41
12-09-2012	0.00E+00	80.91	0.00E+00	80.24	5.79E-03	79.93	1.85E-02	79.57
13-09-2012	0.00E+00	81	0.00E+00	80.33	2.08E-03	79.99	1.34E-02	79.69
14-09-2012	0.00E+00	81.09	0.00E+00	80.43	3.98E-04	80.06	9.23E-03	79.8
15-09-2012	0.00E+00	81.19	0.00E+00	80.52	0.00E+00	80.15	5.91E-03	79.88
16-09-2012	0.00E+00	81.28	0.00E+00	80.62	0.00E+00	80.25	3.25E-03	79.94
17-09-2012	0.00E+00	81.38	0.00E+00	80.71	0.00E+00	80.34	1.11E-03	79.99
18-09-2012	0.00E+00	81.47	0.00E+00	80.81	0.00E+00	80.44	1.36E-04	80.06
19-09-2012	0.00E+00	81.57	0.00E+00	80.9	0.00E+00	80.53	0.00E+00	80.16
20-09-2012	0.00E+00	81.66	0.00E+00	80.99	0.00E+00	80.63	0.00E+00	80.25
21-09-2012	0.00E+00	81.75	0.00E+00	81.09	0.00E+00	80.72	0.00E+00	80.35
22-09-2012	0.00E+00	81.85	0.00E+00	81.18	0.00E+00	80.82	0.00E+00	80.44
23-09-2012	0.00E+00	81.94	0.00E+00	81.28	0.00E+00	80.91	0.00E+00	80.54
24-09-2012	0.00E+00	82.03	0.00E+00	81.37	0.00E+00	81	0.00E+00	80.63
25-09-2012	0.00E+00	82.13	0.00E+00	81.47	0.00E+00	81.1	0.00E+00	80.73
26-09-2012	0.00E+00	82.22	0.00E+00	81.56	0.00E+00	81.19	0.00E+00	80.82
27-09-2012	0.00E+00	82.32	0.00E+00	81.65	0.00E+00	81.29	0.00E+00	80.92
28-09-2012	0.00E+00	82.41	0.00E+00	81.75	0.00E+00	81.38	0.00E+00	81.01
29-09-2012	0.00E+00	82.5	0.00E+00	81.84	0.00E+00	81.48	0.00E+00	81.1
30-09-2012	0.00E+00	82.6	0.00E+00	81.93	0.00E+00	81.57	0.00E+00	81.2

DRAINMOD 6.1 OUTPUT FOR 80cn drain depth

	6m		9m		12m		15m	
Calender days	**DRAIN**	**DTWT**	**DRAIN**	**DTWT**	**DRAIN**	**DTWT**	**DRAIN**	**DTWT**
01-06-2012	1.00E+00	40.55	1.00E+00	40.55	1.00E+00	40.55	1.00E+00	40.55
02-06-2012	1.00E+00	52.69	1.00E+00	52.69	1.00E+00	52.69	1.00E+00	52.69
03-06-2012	1.00E+00	69.91	1.00E+00	69.91	1.00E+00	69.91	1.00E+00	69.91
04-06-2012	1.00E+00	80.99	1.00E+00	80.99	1.00E+00	80.99	8.50E-01	80.09
05-06-2012	1.00E+00	88.12	1.00E+00	88.12	8.23E-01	87.05	5.97E-01	84.8
06-06-2012	1.00E+00	95.01	8.21E-01	93.22	5.79E-01	90.61	4.71E-01	87.71
07-06-2012	4.14E-01	99.29	3.88E-01	97.24	4.06E-01	93.23	3.70E-01	90.02
08-06-2012	7.90E-02	100.22	1.66E-01	99.04	2.70E-01	96.07	3.02E-01	91.92
09-06-2012	0.00E+00	100.36	5.03E-02	99.68	1.50E-01	97.71	2.37E-01	93.71
10-06-2012	1.36E-01	101.29	9.41E-02	100.41	1.34E-01	98.94	2.05E-01	95.65
11-06-2012	2.60E-01	82	2.50E-01	81.28	2.42E-01	80.29	2.48E-01	78.36
12-06-2012	1.00E+00	89.76	1.00E+00	89.05	8.50E-01	87.15	6.53E-01	84.04
13-06-2012	8.18E-01	98.13	6.68E-01	95.44	5.28E-01	91.73	4.63E-01	88.23

14-06-2012	1.50E-01	99.77	2.58E-01	98.16	3.49E-01	94.52	3.53E-01	90.44
15-06-2012	1.29E-02	100.04	1.01E-01	99.31	2.11E-01	96.78	2.84E-01	92.23
16-06-2012	3.23E-02	100.5	5.49E-02	99.99	1.34E-01	98.25	2.33E-01	94.19
17-06-2012	0.00E+00	100.64	2.64E-04	100.13	6.47E-02	99.04	1.59E-01	95.91
18-06-2012	0.00E+00	100.77	0.00E+00	100.27	3.43E-02	99.52	1.10E-01	97.16
19-06-2012	0.00E+00	100.91	0.00E+00	100.41	1.41E-02	99.8	7.57E-02	98.05
20-06-2012	0.00E+00	101.05	0.00E+00	100.55	4.77E-03	99.98	5.11E-02	98.7
21-06-2012	0.00E+00	101.18	0.00E+00	100.68	3.74E-04	100.13	3.33E-02	99.17
22-06-2012	0.00E+00	101.32	0.00E+00	100.82	0.00E+00	100.26	1.95E-02	99.51
23-06-2012	0.00E+00	101.46	0.00E+00	100.96	0.00E+00	100.4	1.08E-02	99.75
24-06-2012	0.00E+00	101.59	0.00E+00	101.1	0.00E+00	100.54	4.32E-03	99.93
25-06-2012	0.00E+00	101.73	0.00E+00	101.23	0.00E+00	100.68	1.01E-03	100.08
26-06-2012	0.00E+00	101.87	0.00E+00	101.37	0.00E+00	100.81	0.00E+00	100.22
27-06-2012	0.00E+00	102	0.00E+00	101.51	0.00E+00	100.95	0.00E+00	100.36
28-06-2012	0.00E+00	102.14	0.00E+00	101.64	0.00E+00	101.09	0.00E+00	100.5
29-06-2012	0.00E+00	102.27	0.00E+00	101.78	0.00E+00	101.22	0.00E+00	100.63
30-06-2012	0.00E+00	102.41	0.00E+00	101.91	0.00E+00	101.36	0.00E+00	100.77
01-07-2012	0.00E+00	102.54	0.00E+00	102.05	0.00E+00	101.5	0.00E+00	100.91
02-07-2012	0.00E+00	102.68	0.00E+00	102.19	0.00E+00	101.63	0.00E+00	101.04
03-07-2012	0.00E+00	102.81	0.00E+00	102.32	0.00E+00	101.77	0.00E+00	101.18
04-07-2012	0.00E+00	102.95	0.00E+00	102.46	0.00E+00	101.91	0.00E+00	101.32
05-07-2012	0.00E+00	103.07	0.00E+00	102.59	0.00E+00	102.04	0.00E+00	101.45
06-07-2012	0.00E+00	103.17	0.00E+00	102.73	0.00E+00	102.18	0.00E+00	101.59
07-07-2012	0.00E+00	103.28	0.00E+00	102.86	0.00E+00	102.31	0.00E+00	101.73
08-07-2012	0.00E+00	103.39	0.00E+00	103	0.00E+00	102.45	0.00E+00	101.86
09-07-2012	0.00E+00	103.5	0.00E+00	103.11	0.00E+00	102.58	0.00E+00	102
10-07-2012	0.00E+00	103.6	0.00E+00	103.21	0.00E+00	102.72	0.00E+00	102.13
11-07-2012	0.00E+00	103.71	0.00E+00	103.32	0.00E+00	102.85	0.00E+00	102.27
12-07-2012	0.00E+00	103.82	0.00E+00	103.43	0.00E+00	102.99	0.00E+00	102.41
13-07-2012	0.00E+00	103.93	0.00E+00	103.54	0.00E+00	103.1	0.00E+00	102.54
14-07-2012	0.00E+00	104.03	0.00E+00	103.64	0.00E+00	103.21	0.00E+00	102.68
15-07-2012	0.00E+00	104.13	0.00E+00	103.75	0.00E+00	103.31	0.00E+00	102.81
16-07-2012	0.00E+00	104.22	0.00E+00	103.86	0.00E+00	103.42	0.00E+00	102.95
17-07-2012	0.00E+00	104.32	0.00E+00	103.96	0.00E+00	103.53	0.00E+00	103.07
18-07-2012	0.00E+00	104.42	0.00E+00	104.07	0.00E+00	103.64	0.00E+00	103.17
19-07-2012	0.00E+00	104.51	0.00E+00	104.16	0.00E+00	103.74	0.00E+00	103.28
20-07-2012	0.00E+00	104.61	0.00E+00	104.26	0.00E+00	103.85	0.00E+00	103.39
21-07-2012	0.00E+00	104.71	0.00E+00	104.36	0.00E+00	103.96	0.00E+00	103.5
22-07-2012	0.00E+00	104.8	0.00E+00	104.46	0.00E+00	104.06	0.00E+00	103.6
23-07-2012	0.00E+00	104.9	0.00E+00	104.55	0.00E+00	104.16	0.00E+00	103.71
24-07-2012	0.00E+00	105	0.00E+00	104.65	0.00E+00	104.25	0.00E+00	103.82
25-07-2012	0.00E+00	105.09	0.00E+00	104.75	0.00E+00	104.35	0.00E+00	103.92
26-07-2012	0.00E+00	105.18	0.00E+00	104.84	0.00E+00	104.45	0.00E+00	104.03
27-07-2012	0.00E+00	105.27	0.00E+00	104.94	0.00E+00	104.55	0.00E+00	104.13
28-07-2012	0.00E+00	105.35	0.00E+00	105.03	0.00E+00	104.64	0.00E+00	104.22

29-07-2012	0.00E+00	105.44	0.00E+00	105.12	0.00E+00	104.74	0.00E+00	104.32
30-07-2012	0.00E+00	105.53	0.00E+00	105.2	0.00E+00	104.84	0.00E+00	104.42
31-07-2012	0.00E+00	105.61	0.00E+00	105.29	0.00E+00	104.93	0.00E+00	104.52
01-08-2012	0.00E+00	105.7	0.00E+00	105.38	0.00E+00	105.02	0.00E+00	104.61
02-08-2012	0.00E+00	105.79	0.00E+00	105.47	0.00E+00	105.11	0.00E+00	104.71
03-08-2012	0.00E+00	105.87	0.00E+00	105.55	0.00E+00	105.2	0.00E+00	104.81
04-08-2012	0.00E+00	105.96	0.00E+00	105.64	0.00E+00	105.29	0.00E+00	104.9
05-08-2012	0.00E+00	106.04	0.00E+00	105.72	0.00E+00	105.37	0.00E+00	105
06-08-2012	0.00E+00	106.12	0.00E+00	105.81	0.00E+00	105.46	0.00E+00	105.09
07-08-2012	0.00E+00	106.19	0.00E+00	105.9	0.00E+00	105.55	0.00E+00	105.18
08-08-2012	0.00E+00	106.27	0.00E+00	105.98	0.00E+00	105.63	0.00E+00	105.26
09-08-2012	0.00E+00	106.35	0.00E+00	106.06	0.00E+00	105.72	0.00E+00	105.35
10-08-2012	0.00E+00	106.42	0.00E+00	106.14	0.00E+00	105.8	0.00E+00	105.44
11-08-2012	0.00E+00	106.5	0.00E+00	106.22	0.00E+00	105.89	0.00E+00	105.52
12-08-2012	0.00E+00	106.57	0.00E+00	106.29	0.00E+00	105.98	0.00E+00	105.61
13-08-2012	0.00E+00	106.65	0.00E+00	106.37	0.00E+00	106.06	0.00E+00	105.7
14-08-2012	0.00E+00	106.73	0.00E+00	106.45	0.00E+00	106.13	0.00E+00	105.78
15-08-2012	0.00E+00	106.8	0.00E+00	106.52	0.00E+00	106.21	0.00E+00	105.87
16-08-2012	0.00E+00	106.62	0.00E+00	106.34	0.00E+00	106.03	0.00E+00	105.7
17-08-2012	8.09E-02	100.17	4.56E-02	99.51	3.03E-02	98.97	2.22E-02	98.46
18-08-2012	2.65E-01	85.51	2.60E-01	85.05	2.10E-01	84.43	1.52E-01	83.78
19-08-2012	1.00E+00	93.98	9.22E-01	92.44	6.62E-01	89.82	4.77E-01	88.05
20-08-2012	4.32E-01	99.32	3.90E-01	97.38	4.05E-01	93.9	3.39E-01	91.06
21-08-2012	2.04E-02	100.45	1.11E-01	99.41	2.13E-01	96.96	2.46E-01	93.69
22-08-2012	2.65E-01	84.44	2.76E-01	83.89	3.15E-01	82.65	3.02E-01	80.61
23-08-2012	1.00E+00	92.35	9.60E-01	91.2	7.44E-01	88.67	5.80E-01	85.64
24-08-2012	5.54E-01	99.55	4.70E-01	97.38	4.61E-01	93.07	4.13E-01	89.73
25-08-2012	2.93E-02	100	1.44E-01	98.99	2.69E-01	95.92	3.06E-01	91.66
26-08-2012	5.29E-05	100.14	5.36E-02	99.66	1.56E-01	97.62	2.46E-01	93.37
27-08-2012	2.51E-03	100.3	2.11E-02	100.01	9.23E-02	98.68	1.83E-01	95.35
28-08-2012	0.00E+00	100.44	0.00E+00	100.15	4.81E-02	99.3	1.26E-01	96.75
29-08-2012	0.00E+00	100.58	0.00E+00	100.28	2.42E-02	99.68	8.70E-02	97.76
30-08-2012	0.00E+00	100.71	0.00E+00	100.42	8.28E-03	99.9	5.92E-02	98.49
31-08-2012	0.00E+00	100.85	0.00E+00	100.56	2.33E-03	100.06	3.92E-02	99.02
01-09-2012	0.00E+00	100.99	0.00E+00	100.7	1.49E-03	100.22	2.71E-02	99.43
02-09-2012	2.30E-01	92.98	2.03E-01	92.42	1.27E-01	91.17	9.91E-02	90.11
03-09-2012	7.25E-01	88.23	5.76E-01	87	4.41E-01	85.44	3.33E-01	84.15
04-09-2012	8.94E-01	97.73	7.96E-01	94.69	6.09E-01	90.77	4.61E-01	88.6
05-09-2012	1.16E-01	100.43	2.52E-01	98.76	3.49E-01	95.26	3.18E-01	92
06-09-2012	0.00E+00	100.57	6.63E-02	99.56	1.82E-01	97.22	2.34E-01	93.81
07-09-2012	0.00E+00	100.71	2.06E-02	99.91	1.05E-01	98.41	1.69E-01	95.65
08-09-2012	0.00E+00	100.85	3.71E-03	100.08	5.86E-02	99.13	1.18E-01	96.96
09-09-2012	0.00E+00	100.98	0.00E+00	100.22	3.06E-02	99.58	8.11E-02	97.91
10-09-2012	0.00E+00	101.12	0.00E+00	100.36	1.20E-02	99.84	5.49E-02	98.6
11-09-2012	0.00E+00	101.26	0.00E+00	100.5	3.88E-03	100.01	3.61E-02	99.1

12-09-2012	0.00E+00	101.39	0.00E+00	100.63	0.00E+00	100.15	2.15E-02	99.45
13-09-2012	0.00E+00	101.53	0.00E+00	100.77	0.00E+00	100.29	1.22E-02	99.71
14-09-2012	0.00E+00	101.67	0.00E+00	100.91	0.00E+00	100.43	5.37E-03	99.91
15-09-2012	0.00E+00	101.8	0.00E+00	101.05	0.00E+00	100.56	1.47E-03	100.06
16-09-2012	0.00E+00	101.94	0.00E+00	101.18	0.00E+00	100.7	0.00E+00	100.2
17-09-2012	0.00E+00	102.07	0.00E+00	101.32	0.00E+00	100.84	0.00E+00	100.33
18-09-2012	0.00E+00	102.21	0.00E+00	101.46	0.00E+00	100.98	0.00E+00	100.47
19-09-2012	0.00E+00	102.34	0.00E+00	101.59	0.00E+00	101.11	0.00E+00	100.61
20-09-2012	0.00E+00	102.48	0.00E+00	101.73	0.00E+00	101.25	0.00E+00	100.75
21-09-2012	0.00E+00	102.62	0.00E+00	101.86	0.00E+00	101.39	0.00E+00	100.88
22-09-2012	0.00E+00	102.75	0.00E+00	102	0.00E+00	101.52	0.00E+00	101.02
23-09-2012	0.00E+00	102.89	0.00E+00	102.14	0.00E+00	101.66	0.00E+00	101.16
24-09-2012	0.00E+00	103.02	0.00E+00	102.27	0.00E+00	101.79	0.00E+00	101.29
25-09-2012	0.00E+00	103.12	0.00E+00	102.41	0.00E+00	101.93	0.00E+00	101.43
26-09-2012	0.00E+00	103.23	0.00E+00	102.54	0.00E+00	102.07	0.00E+00	101.57
27-09-2012	0.00E+00	103.34	0.00E+00	102.68	0.00E+00	102.2	0.00E+00	101.7
28-09-2012	0.00E+00	103.45	0.00E+00	102.81	0.00E+00	102.34	0.00E+00	101.84
29-09-2012	0.00E+00	103.55	0.00E+00	102.95	0.00E+00	102.47	0.00E+00	101.97
30-09-2012	0.00E+00	103.66	0.00E+00	103.07	0.00E+00	102.61	0.00E+00	102.11

List of Publications

LIST OF PUBLICATIONS

STUDIES ON WATER TABLE MANAGEMENT SYSTEM IN THE WATERLOGGED AREA OF LOWER BHAVANI IRRIGATION PROJECT

Research Scholar
H.V.Hema Kumar, (10-644-001)
Research Scholar
Dept. of Soil and Water Conservation Engg.
AEC &RI, TNAU, CBE-3

Chairman
Dr. K. Ramaswamy
AEC & RI,
Kumulur.

S.No.	Title	Journal	NAAS Rating
1.	Drainage Investigations for the design of water table management systems at Gopichettipalayam, Erode District, Tamil Nadu	Madras Agricultural Students Union (MASU) 127(a)/13	4.0
2.	Use of Easy Fit Software for Probability Analysis of Rainfall of Gopichettipalayam, Erode District, Tamil Nadu	Madras Agricultural Students Union (MASU) 127(b)/13	4.0

Drainage Investigations for the design of water table management systems at Gopichettipalem, Erode District, Tamil Nadu

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Abstract

The canals of Thadapalli and Arakkankottai leading from Kodiveri anicut of Lower Bhavani project, Tamil Nadu are unlined and cause continuous seepage all along the lower side. Due to this the paddy growers are experiencing two main problems namely lower yield and trafficability problem of combine harvestor at the time of harvest. A water table management system synonymously refered as Controlled Drainage and Subirrigation Sytem or Controlled and Reversible Drainage System was designed and executed in farmer's field as on-farm research.This research article reports the pre-drainage investigations carried out in the study area for arriving at certain improtant design parameters for the design of water table management sytem for both drainage and subirrigation modes separately. Steady state Hooghoudt equation was used for the design of drainge spacing and similarly the procedure followed by Doty at North Carolina University using Moody Equation and convergence analysis was used for subirrigation mode spacing. The spacing arrived for drainage mode was 20m and to that of subirrigation was 11m. respectively.

Introduction

In Tamil Nadu state, parts of Trichy,Tanjore, Nagapattinam, Tiruvarur, Erode districts (old ayacuts) are frequently under the problem of waterlogging during North-East monsoon heavy rainfall periods (October-December). At the same time, the above areas are under the realms of water scarcity for a few months (February-May) during canal non-supply periods. Exact quantification of this seasonal waterlogging is not available for the state. Essentially drainage technology is vital to alleviate the waterlogging problem, but at the same time, the same system technically, if used for irrigation through conjunctive strategy of ground water in the above areas, the crop production and productivity could be increased all round the year(2 to 3 crops).

**corresponding author*

Many research studies in the advanced countries were carried out to accomplish dual purposes with water table management system synonymously referred as Controlled Draiange and Subirrigation system. Roy L.Fox et al (1956) reported the procedure of sub irrigation systems design and requirements. They have evolved criteria for sub irrigation, the design dimensions of feeder ditch. Skaggs et al (1973) reported that the movement of water table for sub irrigation conditions was characterized by numerically solving a non-linear differential equation describing unsteady flow above a horizontal impervious layer. Solutions were presented for both initial draining and horizontal water table profiles.

Materials and Methods

The project site is located in Lower Bhavani Irrigation Project (LBP) of north western part of Tamil Nadu state in India. The study area for conducting experiment for the proposed research is selected in one of the farmer's fields near 13/6th mile (at Gopichettipalem, 11.454°N 77.438°E, 35 km from Erode, District Head Quarters) Thadapalli channel (one of the channel from Kodiveri) command (Fig 1) of Lower Bhavani Project(LBP). The seasonal waterlogging problems of the area has been addressed on a pilot scale experiment and thereby, results could be extended to large scale adaption. The catchment area of Kodiveri (3 km away from the experimental site) anicut is 253.35 sq.km. There are two canals below the reservoir system. They are river sluice and canal sluice. Thadapalli main canal and Arakkankottai main canal commands 7,144 ha and 2,772 ha respectively totaling to 9,916 ha.

The canals of the area are also unlined and the canal seepage rises the water table encroaching the root zone during cropping season. The impervious layer lies at almost 1.0 to 1.5 m from the surface. Paddy is grown mainly in both the crop periods. Most of the tail end areas are kept without any cultivation due to inadequacy of water. An interaction was initially made with Tamil Nadu State Agricultural Engineering Department Engineers, prior to selection of the experimental field for conducting the on farm research keeping the post maintenance and extension activities into account by the farmer himself. The contour map of the selected experimental plot is drawn after taking levels at a grid spacing (40m x 40m) with manual levelling work (Fig.2). It can be seen the valley portion in the centre of the field which is natural drain towards main drain.

For finding out in-situ saturated lateral hydraulic conductivity, Eijkel Kamp Hydraulic Conductivity test kit was used to conduct auger hole experiment at two locations. Hooghoudt's formula was used for finding out the hydraulic conductivity. From standard Hooghoudht's equation,

$$K = \frac{2.3aS}{(2d + a)\Delta t} \log_{10} \frac{y_o}{y_1}$$

Where, K = saturated hydraulic conductivity, 'a' = radius of the auger hole, 'd'=depth of the hole below ground level, S is defined by 'ad'/0.19. 'y_0 & y_1 are the initial and final water levels measured from ground level over a time interval (Δt).

Factors considered in computation of the closed sub-surface drainage spacing are i) Desirable water table depth for crop production ii) Drain depth iii) Water table height above the drains iv) Depth of impermeable layer v) Effective flow depth.vi) Type of drainpipe. Vii) Hydraulic conductivity of the soil. Commonly used steady state, Hooghoudt equation was employed to design the lateral drain spacing. The equation used is as follows (Ritzema H.P.1994).

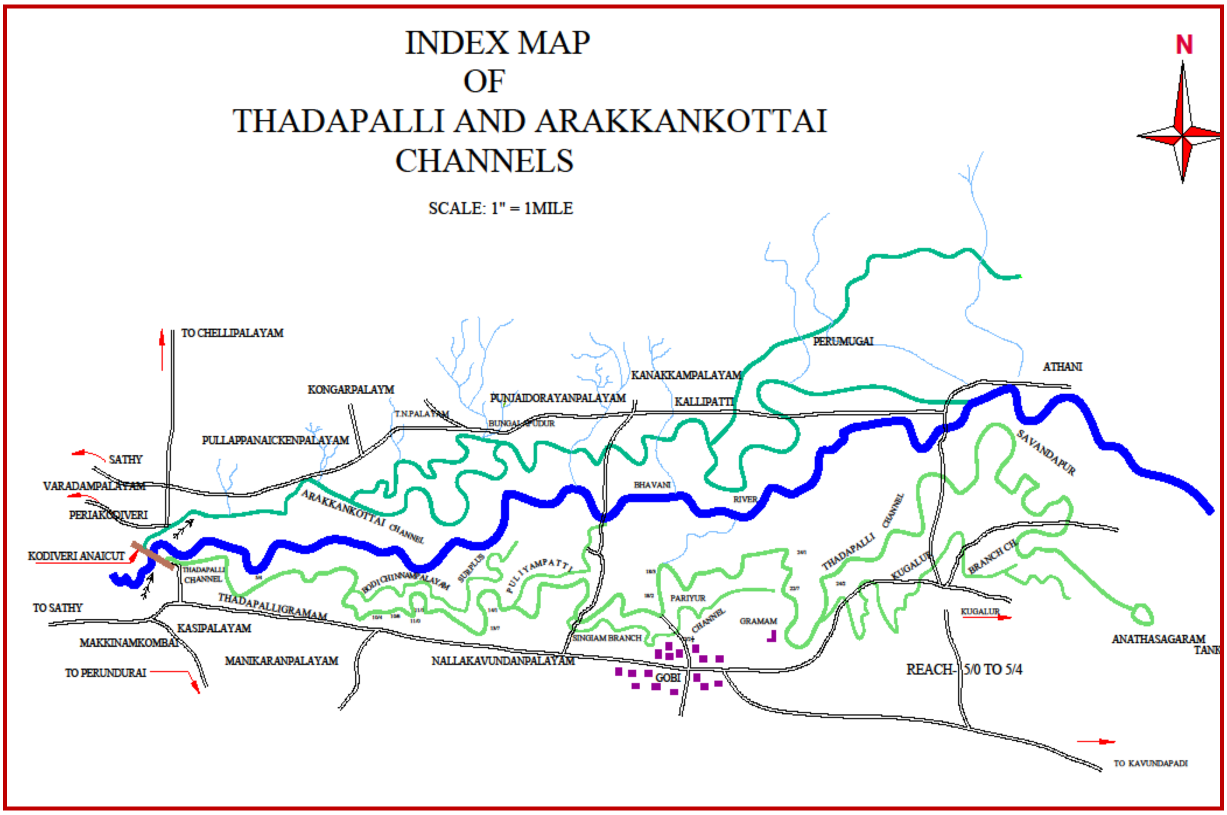

Fig. 1 Index map of Thadapalli and Arakankattai channels

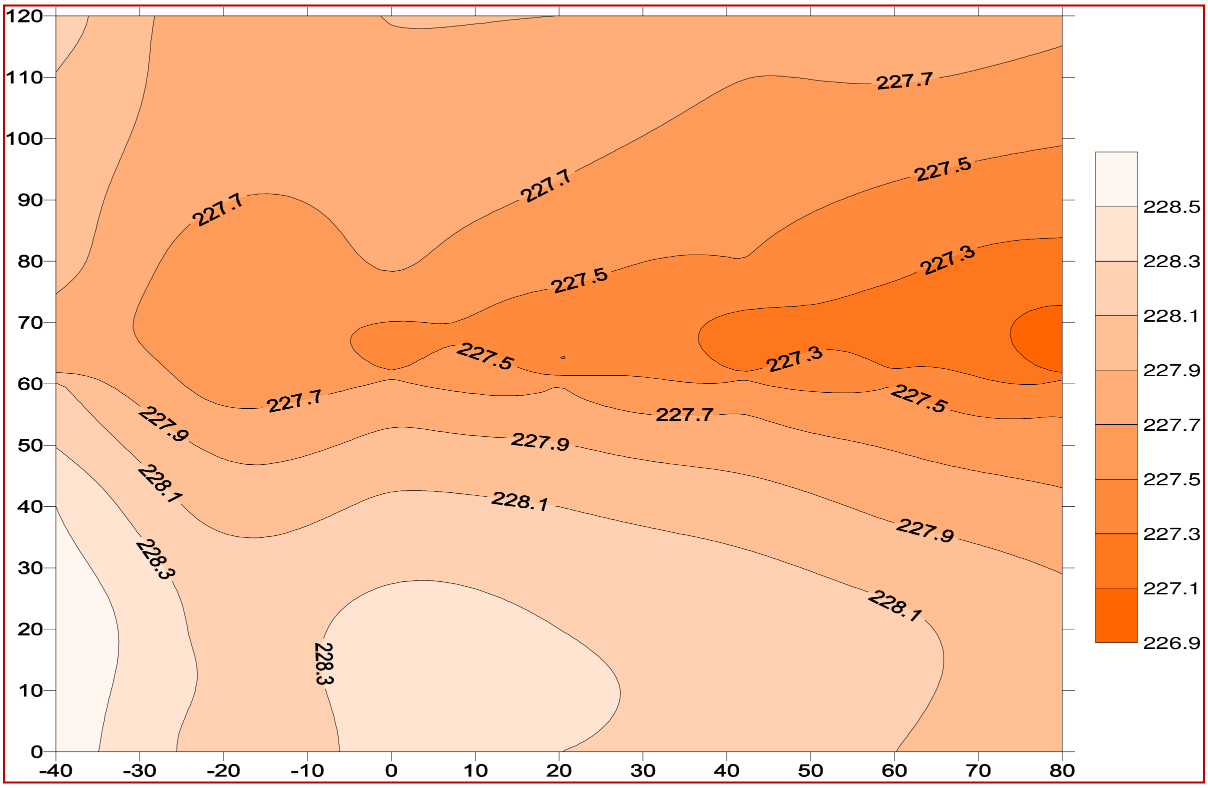

Fig.2 Contour map of study area in Kattadipalayam near Gobichettipalayam

$$R = q = \frac{8k_bDh + 4k_ah^2}{L^2} \quad \text{------------------------------(1)}$$

Where,

R = Recharge rate per unit surface area (m/d)

q = Drain discharge rate per unit surface area (m^3/m^2/day)

k_a = Hydraulic conductivity of the layer above the drain level (m/day)

k_b = Hydraulic conductivity of the layer below the drain level (m/day)

h = Water table height above drains at mid point between drain(m)

D = Height of the water level in the drains above the impervious layer (m)

L = drain spacing (m)

Spacing calculations under drainage system mode operation

Schematic view of the spacing of the drains is shown in Fig.3., As the soil is considered as single layer.,, Eq. 1 ., is reduced to

$$S^2 = \frac{4KH(2d_e + H)}{R} \quad \text{........ (2)}$$

Where

S= Lateral spacing of drains (m)

K= Hydraulic conductivity (m/day)

De= equivalent depth (m)

Ground level

Based on the data collected on water table fluctuations, soil water quality and hydraulic conductivity in the project site, the design parameters were worked out for the subsurface drainage systems and were presented in Table 2.. Incorporating various parameters from the Table 2, in Eq.1, the drain spacing was determined.

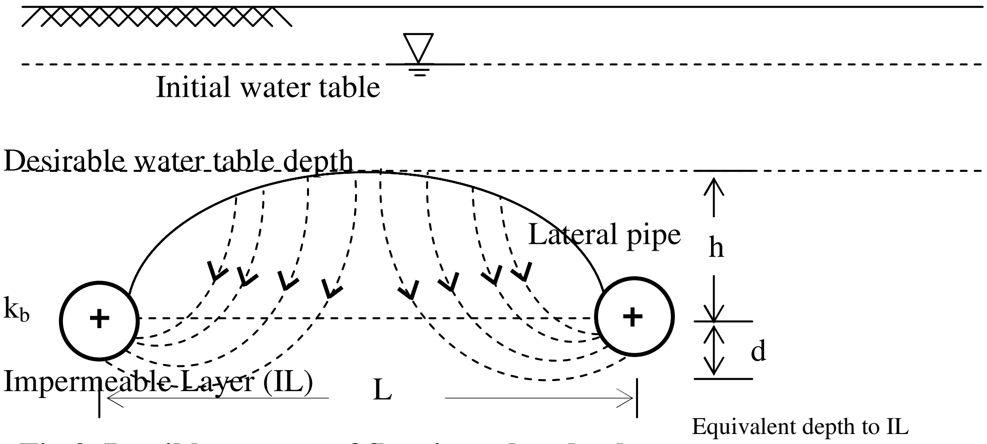

Fig.3 Possible pattern of flow into closed sub-surface drains

Design of subirrigation systems(SI)

Water table movement between parallel drains can be predicted by solving Boussinesq equation for the appropriate initial and boundary conditions. The Boussinesq equation neglects flow in the unsaturated zone and is based on continuity, Darcy's law and the Dupuit Forchheimer (D-F) assumptions. Referring to Fig. 4,

h= elevation of water table above the impermeable layer,

t = time,

x= the horizontal position

e= the rate of vertical infiltration into the saturated zone ('e' is negative for Evapotranspiration or vertical seepage)

K = lateral saturated hydraulic conductivity

f = drainable porosity.

The position and shape of the water table during steady state subirrigation can be approximated by making the Dupuit Foreheimer (D-F) assumptions using the approach of Fox et al (1956)., If water movement in the unsaturated zone is neglected, spacing of drains and could be determined from Eq.3.

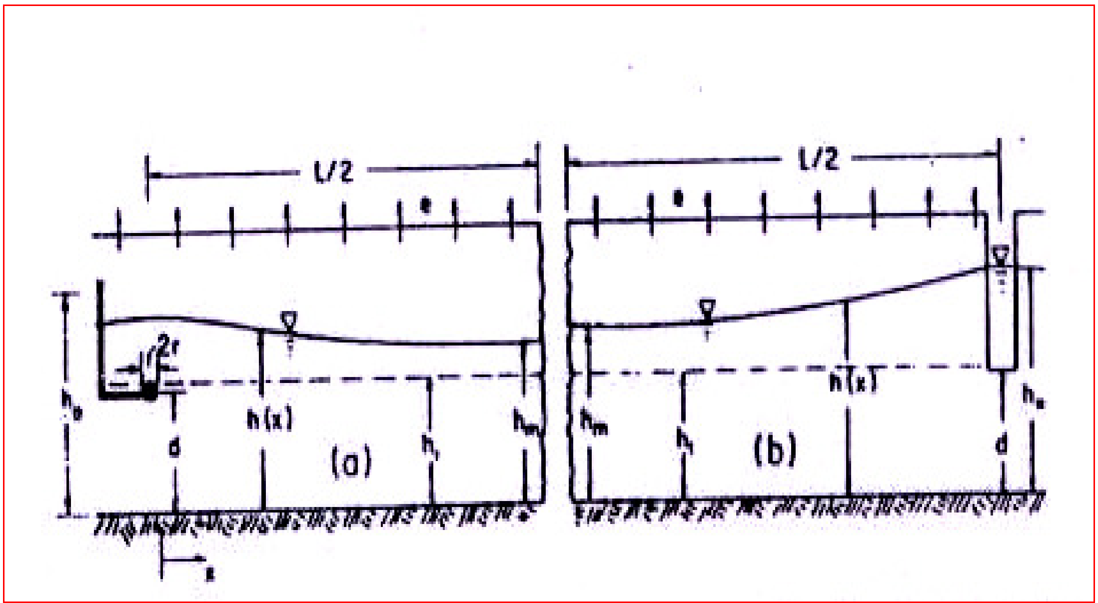

Fig. 4 Water table response to subirrigation through a) drain tubes and b) open ditches

$$L = \left[\frac{4K_S\left(h_0{}^2 - h_1{}^2\right)}{e} \right]^{\frac{1}{2}} \qquad \text{....Eq.3}$$

Where,

Ks = saturated hydraulic conductivity (m/day)

h_0= water table ht. above the drains (m)

h_1= water table at midway between drains(m)

e = evaporation rate (m/day)

The equivalent depth from the drain to the impermeable layer, 'd_e' can be calculated from equations presented by Moody (1966)

$$d_e = \frac{d}{\left[1 + \frac{d}{l}\left(\frac{8}{\pi} \ln \frac{d}{r_e} - 3.4 \right) \right]} \qquad \text{......Eq.4}$$

Where r_e, is the effective drain tube radius which is smaller than the actual radius because the tube wall is not permeable but has only a small percentage of open area. 'd' is the depth from drains to impervious layer By taking suitable corrections for convergence, the final equation for spacing reduces to,

$$L = \sqrt{4KsM\,(2ho' - \frac{ho'}{ho}M)\,/\,e} \quad \text{.......Eq.5}$$

Where, M = difference between water tbale levels= h_0-h_1= h_0'-h_1'

h_0' equivalent water table elevation, = d_e+y_0,

The calculations performed to compute the spacing under subirrigation mode with estimated design values (Table 2) was furnished.

Results and Discussion

The results obtained in the analyses of soil samples and water samples were presented in Table1. It is evident that the irrigation water is of non-saline in nature. Only water logging is the constraint. The presence of clay would greatly decide the use of envelope material around the drain pipe. Hence mechanical analysis of two representative soil samples were taken up. The soil is majorly sandy clay loam and little patch of land with sandy clay. The various textural presence is presented in Table 1. This analysis was used in arriving at many parameters directly or indirectly, like volume drained, upward flux etc., in further modeling studies of this research.

In the auger hole method, the water in the auger hole was bailed out with a bailer and the rise of water level within one minute was recorded and the average of 5 readings was taken as the measure. As per the auger hole dimensions and the experiment, it was found that 'a' = 0.02m, d = 0.9 m, y_0 & y_1 are 0.6m and 0.22m respectively. Time interval = 120 seconds. S= 0.0947. K works out to be 0.75 m/day. In other location i.e. representing sandy clay, the values were found 'a' = 0.02m d= 0.9m y_0 & y_1 are 0.52m and 0.33m respectively, Time interval = 120 seconds. S = 0.0947, K works out to be 0.4m/day.

Table 1 Analysis of Soil samples of the pilot site

Sl. No.	Parameters (%)	Sample –I (Near road)	Sample –II (Near drain)
1	Total Sand	55.2	50.4
2	Coarse Sand	11.8	6.2
3	Fine Sand	43.4	44.2
4	Silt	10.5	12.4
5	Clay	33.8	36.4
6	pH	7.82	7.33
7	EC	0.48	0.53
8	Textural Class	Sandy Clay Loam	Sandy Clay
9	Class	Non-saline neutral water	Non-saline neutral water

Spacing Calculation under drainage mode of water table management system

Using Eq.2, and the following parameters computed, the drain spacing was calculated K = 0.75 m/day.

i= 0.0125, (Hydraulic gradient is 2 m head of water acts at 160m as seepage)

V= Ki = 1 cm/day.

D_s= 0.05 cm/day (Taking 5% as deep seepage)

R = 0.75 cm/day (Mean recharge = (0.05+1.00)/2=1.50/2= 0.75 cm/day

Considering the controlled drainage convenience, removal rate at the time of harvest and accounting for removal of high rainfall events, R is rounded to 1 cm/day or 0.01m/day which is nothing but the drainage coefficient or design drainage discharge rate (DDR).

Spacing calculation under subirrigation mode of water table management system

The hydraulic conductivity appears to decrease with depth so that it is restrictive to water movement below a depth of about 1.-1.5 m. A water table management system is to be designed for the production of a third crop during summer either growing for less water requiring pulse crop or any other fodder crops remunerative to the farmers of the region.

In Gopichettipalayam area, the ET rate during summer usually did not exceed 5.5mm/day as per the previous weather records and was taken as design value for 'e' in Mody's equation. The water table should be maintained at depths within 0.4 m taking a conservative estimate of the average root zone depth of 0.25m, the mid point water table should be held at a depth, no greater than 0.5m from the surface.

This would give a h_1= 1.5-0.5 = 1m at mid point i.e at x= L/2. The water table depth to be maintained at the above drain points depends on the rootzone depth and crop tolerance for wet conditions. Generally the study location., for the summer crop., the water table must be raised for few life saving irrigations. Hence the effective root zone depth is assumed to be limited to 0.3m for this soil and a water table depth at the drains of 0.45m is assumed.

Then h_0= 1.5-0.30 = 1.2 and the parameter M is equal to 0.15 m. Substituting the above values in Eq.3, preliminary L works out to be 10.77m . Substituting this L value by considering re effective radius of drains as 0.036m. for 80mm corrugated perforated UPVC pipes, by Eq. 4 we get the d_e value as 0.8.

h_o'= 1.4m (0.15 +0.8)

Using Eq.5, L works out to be 9.96m say 10 m.

The design parameters under both drainage and subirirgation mode are presented in Table 2.

Table 2.Design Parameters of estimated for spacing under subirrigation mode for water table management systems at Gopichettipalayam

S.No	Design Parameters	Specification	
		Drainage	**Subirrigation**
1.	Average Hydraulic Conductivity	0.75m/day	0.75 m/day
2	Drainage Coefficient	1 cm/day	-
3	Hydraulic head above the drains	0.4-0.25 m	0.3-0.45m
4	Equivalent depth	1.05m	0.8m
5.	Evaporation rate	0.0055m/day	0.0055m/day
6	M	-	0.15 m
7	Effective raidius r_e	0.036m	0.036 m
8	Drainable pore space	10%	10%
9.	Drain spacing	20m	10m

The system water table management system was installed with the design spacing of 10 m, which could be functionally adaptable for subsurface drainage mode also. It was successfully implemented in the study area (0.8 acres) in a farmer's field at Thadapalli channel ayacut of Lower Bhavani Project of Tamil Nadu. The system was efficiently functioning both under subsurface drainage systems for Rice crop in one crop season in the year 2012, and subsequently for taking dry land fodder millet crop with subirrigation mode in the consecutive season (2012-13).

Table 3 Cost details of water table management systems per acre basis

Sl No.	Item	Cost/acre (Rs.)
1	UPVC pipes	87500
2	Labour	28500
3	Trenching	16250
4	PVC pipes	5250

5	Cement rings	6250
6	Valves & fittings	5000
	Total	**1,48,750**

The cost of the system per acre works out to Rs.1,48,750 per acre (Table 3). It was also observed that the trafficability was improved considerably and the tillage operation could be taken very efficiently with tractor ploughing without any time delay (for sorghum crop). It was also gathered from farmers that it took at least 20-25 days in system not installed area (nearby farmers' fields). It was observed that on an average, 0.30 to 0.4 m lowering of water table during subsurface drainage mode during waterlogging condition could be attained resulting in good aeration and rice yields increased to a tune of 25% increase from 2.64 tons/acre to 3.32 tons/acre compared to non-installed areas and conventional yield of the farmer apart from foreseeing of ease in harvesting paddy with combine harvester without wheel sinkage problems.

Conclusions

pre-drainage investigations carried out in the study area for arriving at certain improtant design parameters for the design of water table management sytem for both drainage and subirrigation modes separately. Steady state Hooghoudt equation was used for the design of drainge spacing and the procedure followed by Doty, at North Carolina University using Moody Equation and convergence analysis was used for subirrigation mode spacing. The spacing arrived for drainage mode was 20m and to that of subirrigation was 10m. respectively. Considering the feasibility of operation of both subsurface drainage and subirrigation, the spacing of 10m could be recommended for water table managment system of Lowr Bhavani Project area in Thadapalli region.

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Use of 'Easy Fit Software for Probability Analysis of Rainfall of Gopichettipalem Area, Erode District, Tamil Nadu

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Abstract

Rainfall analysis is one of the important components in hydrological processes for either using it as a random chance constrained input or for taking a risk at certain level for crop planning. Hitherto, in rainfall analysis scientists used a few probability distributions and whichever is close fit., represented the data accordingly. Some researchers had used some transformation techniques like Box-Cox square root transformation etc., for bringing the data to suit to either Normal distribution or so. The latest mathematical tool "Easy Fit" a Windows based user friendly software tests about 70 probability distributions and performs two types of goodness of fits Kolmogorov and Anderson and provides ranks as per the goodness of fit. An attempt was made to analyze the rainfall of Gopichettipalem, the study area for water table management system by etymyzing the data to annual, summer, winter and rainy seasons. The best fitted distributions were listed in this paper for all these 4 sets of data. The available 9 years data was used for the study.

Introduction

Rainfall plays a predominant role in many of the agricultural operations. The occurrence or non-occurrence of rainfall at decisive times can resolute the accomplishment or miscarriage of a venture in agricultural production, germination of seeds, drying of crops, application of irrigation, fertilizers, insecticides and herbicides. Rainfall forecasting is the prominent aspect of hydrologic investigation.

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Rainfall distribution is a function of time. Therefore it is important to investigate the rainfall data with regard to expected rainfall in relation to plotting position which gives anticipated depth of occurrence of rainfall at a given probability level during specific period. Weekly and monthly and seasonal rainfall analysis may be helpful in better crop design, specifying and establishing the time of sowing, cultural operations and irrigations of crops grown in variety of seasons and regions.

Probability is a chance or likelihood based on the sampled data. The hydrologic phenomena are highly stochastic and random in nature and therefore are amenable to statistical interpretation and probability analysis. A common use of rainfall data is in the assessment of probabilities or return periods of given rainfall at a given location. Such data can then be used in assessing flood discharges of given return period through modelling or some empirical system and can thus be applied in schemes of flood alleviation or forecasting and for the design of bridges and culverts. Frequency analysis usually involves the fitting of a theoretical frequency distribution using a selected fitting method, although empirical graphical methods can also be applied. The fitting of a particular distribution implies that the rainfall sample of annual maxima were drawn from a population of that distribution. For the purposes of application in design it is assumed that future probabilities of exceedence will be the same as past probabilities. However there is nothing inherent in the series to indicate whether one distribution is more likely to be appropriate than another and a wide variety of distributions and fitting procedures has been recommended for application in different countries and by different agencies. Different distributions can give widely different estimates, especially when extrapolated or when an outlier (an exceptional value, well in excess of the second Frequency Distribution for Monthly Rainfall) (Megharaj 1962 & 1997)

Graphical as well as numerical output should always be inspected. Higher the degree of aggregation of data, more normal the data will become. The following frequency distributions are generally tried by hydrologists for rainfall analysis. 1) Normal and log-normal distributions 2) Pearson Type III or Gamma distribution 3) Log-Pearson Type III 4) Extreme Value type I

(Gumbel), II, or III 5) Goodrich/Weibull distribution 6) Exponential distribution 7) Pareto distribution

The following fitting methods are available for fitting the distribution: 1) Modified maximum likelihood 2) Method of moments. For each distribution one can obtain the following: 1)Estimation of parameters of the distribution, 2) A table of rainfalls of specified exceedance probabilities or return periods with confidence limits 3) Results of goodness of fit tests 4) A graphical plot of the data fitted to the distribution

Data and Methodology

In the present article, the mathematical software " Easy Fit" was used for distribution fit for the seasonal and annual rainfall data. The Key Features of the software includes i)Support for over 55 continuous & discrete distributions ii) Automated & manual distribution fitting iii) Advanced Excel integration iv) Interactive graphs v) Goodness of fit tests vi) Distribution viewer & probability calculator vii) Descriptive statistics calculation viii) Random number generation ix) Excel-like spreadsheet x) Data import (Excel, ASCII) xi) Easy to use interface xii) Built-in and online help.

Easy Fit supports all the commonly used continuous distributions. Some of them have alternative names (indicated in parentheses): 1. Beta 2. Burr (Burr Type 12, or Singh-Maddala), 3. Cauchy (Lorentz), 4. Chi-Squared 5. Dagum (Burr Type 3, or Inverse Burr), 6. Erlang, 7. Error (Exponential Power, or Generalized Error), 8. Error Function, 9. Exponential, 10. F Distribution, 11. Fatigue Life (Birnbaum-Saunders), 12. Frechet (Maximum Extreme Value Type 2), 13. Gamma, 14.Generalized Gamma, 15. Gumbel Max (Maximum Extreme Value Type 1), 16. Gumbel Min (Minimum Extreme Value Type 1), 17. Hyperbolic Secant, 18. Inverse Gaussian, 19. Johnson SB, 20. Johnson SU21. Kumaraswamy, 22. Levy, 23. Laplace (Double

Exponential), 24. Logistic, 25. Log-Gamma, 26. Log-Logistic (Fisk), 27. Lognormal, 28. Nakagami (Nakagami-m), 29. Normal (Gaussian), 30. Pareto - first kind, 31. Pareto - second kind (Lomax), 32.Pearson Type 5 (Inverse Gamma, 33. Pearson Type 6 (Beta dist. of the second kind), 34. Pert, 35. Power Function, 36. Rayleigh, 37.Reciprocal, 38. Rice (Ricean, or Nakagami-n), 39. Student's t, 40. Triangular, 41. Uniform, 42. Weibull,

Many distributions are available in two versions. For example, both two-parameter and three-parameter Weibull distributions are supported. In addition, seven advanced distributions are available: 1) Generalized Extreme Value, 2) Phased Bi-Exponential, 3) Generalized Logistic 4) Phased Bi- 5) Weibull 6) Wakeby 7) Generalized Pareto Log-Pearson 3 (LP3)

The use of advanced distributions for data analysis essentially increases the validity of models, which, in turn, leads to better decisions. The following discrete distributions are supported: 1.Bernoulli, 2.Binomial, 3.Hypergeometric, 4.Discrete 5.Uniform 6. Logarithmic and 7.Negative Binomial distributions.

EasyFit displays a variety of graphs enabling to perform a comprehensive analysis of data like 1) probability density function (PDF), 2) cumulative distribution function (CDF), 3) survival function, 4) hazard function (failure rate) , 5) cumulative hazard function, 6) P-P plot, 7) Q-Q plot, 8) probability difference.

Easy Fit allows to display several graphs of the same type on a single chart, making it easy to compare two or more distribution curves. All graphs support interactive zooming and panning. One can easily switch between the different graph types, export graphs to various formats, copy graphs to the Clipboard, or print them. Excel Integration In addition to a stand-alone application, the Professional Edition of Easy Fit works as a comprehensive Excel add-in, enabling you to perform data analysis and simulation right in Excel. Easy FitXL (Easy Fit for Excel) allows to fit probability distributions to worksheet data, generate random numbers, and view distribution graphs without entering the data.

“Stat Assist” option displays the following statistical values depending on the distribution parameters: 1) min, max, mode, mean, variance, standard deviation, 2) skewness, kurtosis, quantiles (inverse CDF values), 3) tail probabilities. This helpful tool can be used independently of the other product features. The goodness of fit (GOF) tests measure the compatibility of a random sample with a theoretical probability distribution function. In other words, these tests show how well the distribution , one selected fits to the data. EasyFit supports the following GOF tests:1) Kolmogorov-Smirnov 2) Anderson-Darling 3) Chi-Squared. The Summary report lists the distributions ordered by the GOF statistics, enables one to select one or more models which best fit to the data.

Rainfall analyses were performed with Gopichettipalem rainfall data collected from PWD office seasonally and annually using “Easy Fit’ Software. The analyis is carried out to have overall understanding about the rainfall pattern and its distribution over annually and seasonally in the study area. This analysis was utilized in planning for life saving irrigation of fodder sorghum crop through the water table management systems installed in the farmer’s field at Gopichettipalem. This would be of highly useful for crop selection and planning for irrigation when subirrigation system is used.

Results and Discusssion

Gen Gamma, Frechet, Beta and Beta probability distributions were the best fits for the annual rainfall, south-west, north-east and summer rainfall data of Gopichettipalem respectively. The probability density functions for these data sets analyzed through the above software are given in Fig. 1. The statistical parameters like mean, variation, standard deviation, kurtosis, skewnes coefficient along with scale and shape parameters of various distributions are tabulated in Table 1. Using the scale, shape and other parameters, one can easily find out the occurrence of rainfall at certain level of probability. This analysis would be useful for planning purposes to take certain risk levels and proceed further with irrigation or soil water conservation structures.

In the present study, the investigation was carried out to know whether any rainfall contribution was needed into a small secondary storage especially at the times of subirrigation was required to be given for third crop, some times even to second crop. The probability density function of 4-P Generalized Gamma Distribution is given as,

$$f(x) = \frac{k(x-\gamma)^{k\alpha-1}}{\beta^{k\alpha}\Gamma(\alpha)} \exp(-((x-\gamma)/\beta)^{k}) \text{ with doman } \gamma \le x < +\propto$$

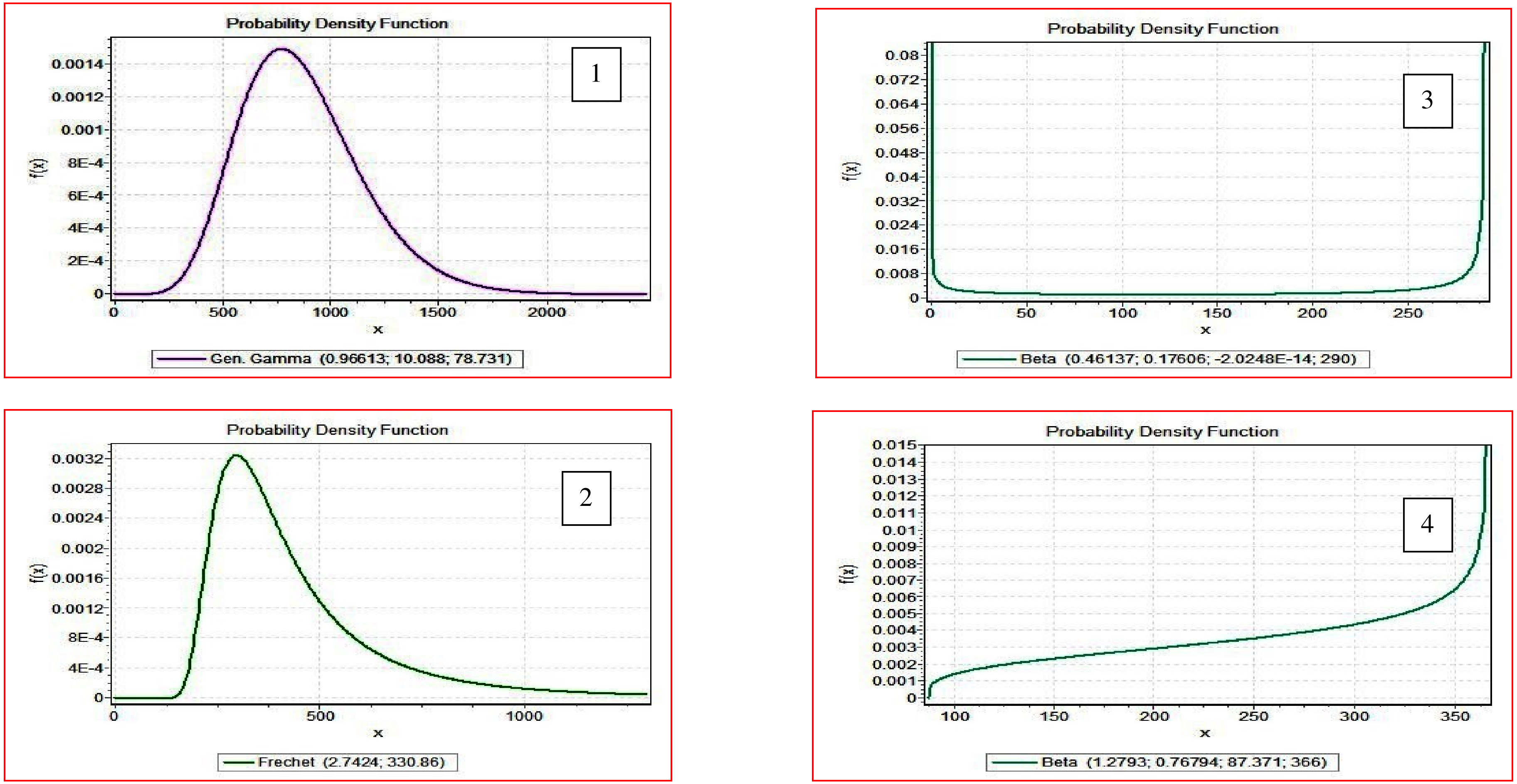

Fig. 1 The probability density functions for Annual rainfall, South-West, North-East and Summer Monsoon rainfall of Gopichettipalem (1-2-3-4 columnwise)

Table 1 Descriptive statistics of average annual rainfall analysis

Sl. No.	Statistic	Annual rainfall	South west monsoon	North east monsoon	Summer
1	Sample Size	10	10	10	10
2	Range (mm)	924.9	629	290	265
3	Mean (mm)	863.46	404.99	230.94	267.59
4	Variance	67980.0	32244.0	4222.8	5403.2
5	Std. Deviation	260.73	179.57	64.983	73.507
5	Coef. of Variation	0.30196	0.44339	0.28139	0.2747
7	Std. Error	82.45	56.784	20.549	23.245
8	Skewness	-0.18928	-0.1925	-1.1302	-0.28401
9	Excess Kurtosis	-0.64058	-0.65142	1.4474	-1.1768
10.	Distribution & parameters associated.	Gen. Gamma $k=0.96613$ $\alpha=10.088$ $\beta=78.73$	Frechet $\alpha=2.7424$, $\beta=330.86$	Βετα $\alpha_1=0.46137$ $\alpha_2=0.17606$ a=2.0248E14 b=290.0	Beta $\alpha_1=1.2793$ $\alpha_2=0.7679$ 4 a=87.371 b=366.0

k is continuous hape parameter (>0), α = continuous shape parameter(>0), β = continuous shape parameters. γ = 0 yields to 3-P Gamma distribution.

The probability density function of Frechet Distribution is given as,

$$f(x) = \frac{\alpha}{\beta}\left(\frac{\beta}{x-\lambda}\right)^{\alpha-1} \exp\left(-\left(\frac{\beta}{x-\lambda}\right)^{\alpha}\right) \text{ with doman } \gamma \le x < +\propto$$

α = continuous shape parameter(>0), β = continuous shape parameters. γ = 0 yields to 2-P Frechet distribution.

The probability density function of Beta Distribution is given as,

$$f(x) = \frac{1}{B(\alpha_{1,}\alpha_2)} \frac{(x-a)^{\alpha_1-1}(b-x)^{\alpha_2-1}}{(b-a)^{\alpha_1+\alpha_2-1}} \text{ with doman } a \le x \le b$$

α_1 = continuous shape parameter(>0), α_2= continuous shape parameters.a and b are continuous boudnary parameters (a>b). The above distributions fitted for the 4 sets of data were ranked no.1 out of all the distributions tested., by the model based on the null hypothesis, Kolmogorov's goodness of fit. Hence the either from graphs or from equations, either 'x_i' or 'p_i'could be easily predicted with highest degree of accuracy possible with probability analysis.

Conclusion

In many day to day real life stochastic and random processes, hitherto, the data was tried to fit to some few distributions like normal distribution, log-normal distribution etc., for simiplication with rainfall data. But due to the advances in mathematical applications, use of softwares like 'Easy Fit' would enable the goodness in fitting the rainfall data in the form of a probability distribution function for further analysis in any optimization processes. In the present study for the annual, southwest, northeast and summer season's average rainfall data fitted to Gen Gamma, Frechet, Beta and Beta Probability distributions respectively. This analyses could be used for arriving at water requirement for fodder sorghum crop during summer under water table management system subirrigation trials including crop water use planning under various rainfall patterns.

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