BARD

FINAL REPORT

PROJECT No. US-442-81

Developments of Methods for Designing Drainage Systems for Irrigated Lands with Nonuniform Boundary Conditions

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1987

Standard BARD Cover Page for Scientific Reports

Date April 15, 1987

BARD
P.O. Box 6
Bet Dagan, ISRAEL

BARD Project No. US-442-81

Title of Research Project:
Development of Methods for Designing Drainage Systems for Irrigated
Lands with Nonuniform Boundary Conditions

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Project's starting date: December 30, 1982

Type of Report: 1st Annual _____ 2nd Annual _____ Final X

Signatures:

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TABLE OF CONTENTS

	PAGE
TABLE OF CONTENTS.....	i
ABSTRACT.....	iv
OBJECTIVES.....	v
CHAPTER 1 DEVELOPMENT OF METHODS FOR DESIGNING DRAINAGE SYSTEMS FOR IRRIGATED LANDS WITH NONUNIFORM BOUNDARY CONDITIONS.....	1
INTRODUCTION.....	1
CHAPTER 2 MODELING LATERAL SEEPAGE TO AND FROM IRRIGATED FIELDS WITH SUBSURFACE DRAINAGE.....	4
2.1 Introduction.....	4
2.2 Drains as a Boundary Condition in Finite Elements.....	6
Introduction.....	6
Problem Definition.....	6
Governing Equations.....	7
Numerical Solutions.....	7
Soil Water Parameters.....	8
Drain Representations.....	8
Model Drain.....	8
Specified Flux.....	11
Specified Head.....	11
Resistance Adjustment.....	12
Results and Discussion.....	12
Ponded Surface.....	12
Transient Drainage.....	12
Interceptor Drainage.....	12
Summary and Conclusions.....	13
References.....	13
2.3 Effect of Canal Seepage on Drainage to Parallel Drains.....	15
Abstract.....	15
Introduction.....	15
Problem Definition.....	15
Governing Equations and Boundary Conditions.....	16
Soil Water Parameters.....	16
Numerical Solution.....	16
Results and Discussion.....	17
High Water Table Maintained by Steady Infiltration.....	17
Low Water Maintained by Steady Infiltration.....	17
Transient Drainage.....	17
Summary and Conclusions.....	19
References.....	20
2.4 An Approximate Method for Predicting Drawdown and Drainage Rates for Drained Fields with Lateral Seepage.....	21
Model Theory and Solution.....	22

Testing the Approximate Methods.....	28
Results and Discussion.....	36
Summary and Conclusions.....	46
2.5 Field Scale Model for Lateral Seepage.....	48
Modifications to DRAINMOD.....	48
Testing the Modified DRAINMOD.....	50
Transient Drainage Simulations.....	50
Transient Drainage and Recharge Simulations.....	52
30 Year Simulations.....	53
Results and Discussion.....	55
Transient Drainage Simulations.....	55
Transient Drainage and Recharge Simulations.....	60
30 Year Simulations.....	68
Summary and Conclusions.....	71
References.....	74
CHAPTER 3 DRAINAGE OF IRRIGATED LANDS UNDER SEQUENTIAL WATER APPLICATION.....	78
Abstract.....	78
Introduction.....	79
Theoretical.....	82
Computer Simulation.....	83
Irrigation Scanning Modes.....	84
Water-Table Shape Under Simultaneous and Sequential Irrigations.....	85
Water-Table Hydrographs and Location of Maximum Watertable Height.....	88
Effect of Irrigation Pattern on Drainage Objectives....	94
Effect of Irrigation Pattern on SEW ₃₀	95
Discussion and Conclusions.....	96
Effect of Irrigation Pattern on Water Table Rise..	97
Acknowledgements.....	99
References.....	99
CHAPTER 4 DESIGNING DRAINAGE SYSTEMS FOR SEMI-ARID REGIONS.....	101
4.1 Objectives.....	101
4.2 Comparison of Tile Drain Design.....	102
4.3 Time Series Analysis of Solar Radiation.....	111
Data.....	111
Methodology and Results.....	112
4.4 Salt Balance.....	116
4.5 Model Testing with Long-Term Drainage Data.....	121
References.....	132

Time Series Analysis of Daily Solar Radiation and Air Temperature Measurements for Use in Computing Potential Evapotranspiration.....	135
Abstract.....	135
Introduction.....	135
Methods and Procedures.....	136
Data.....	136
Procedures.....	136
Results and Discussion.....	138
Conclusions.....	143
References.....	143
CHAPTER 5 COOPERATION AND EVALUATION OF RESEARCH ACHIEVEMENTS...	144
5.1 Cooperation.....	144
5.2 Evaluation of Research Achievements.....	146
List of Publications.....	149

ABSTRACT

DEVELOPMENT OF METHODS FOR DESIGNING DRAINAGE SYSTEMS FOR IRRIGATED LANDS WITH NONUNIFORM BOUNDARY CONDITIONS

by

R. W. Skaggs, G. Sinai and A. Chang

The objective of the project was to develop methods for characterizing the effects of nonuniform boundary conditions on drainage of irrigated lands and to incorporate them in the water management simulation model DRAINMOD. The purpose is to provide scientists and engineers with an easily used method for design and analysis of these complex systems.

Numerical solutions to the Richards equation were used to describe seepage from drainage or irrigation canals to or from drained fields. These solutions provided a basis for the development of approximate procedures which were incorporated into DRAINMOD. The modified simulation model can be applied to analyze the effects of lateral seepage to drained lands next to unlined irrigation canals or from fields to deep drainage channels.

An analysis of drainage resulting from sequential application of irrigation water was conducted. Results illustrate the important role of the pattern of irrigation water application in determining the shape of the water table and the rate of drainage. Neglecting the effect of sequential irrigation may lead to underestimating the water table rise by 50% in some cases and overestimating by 60% in others.

A mass balance approach was used to develop an algorithm to calculate soil salinity in the root zone. The method was incorporated into DRAINMOD. Although the methods have not been fully tested, the modified model can be used to estimate the effect of drain system design, irrigation water salinity and water management on soil salinity.

OBJECTIVES

1. To develop methods to quantify the effect of lateral seepage to or from irrigated fields that are artificially drained.
2. To characterize drainage processes and the soil water regime under irrigation schemes that are not symmetrical with the drainage layout; e.g. an irrigation set that covers only a portion of the land area between parallel drains.
3. To incorporate the methods developed in objectives 1 and 2 into the water management model, DRAINMOD, and to test the methods in field situations.
4. To modify the water management model to include existing methods of approximating the effects of less than optimum leaching and salinity control on crop yields, so that drainage design can be directly related to crop responses.

DEVELOPMENT OF METHODS FOR DESIGNING DRAINAGE SYSTEMS FOR IRRIGATED LANDS WITH NONUNIFORM BOUNDARY CONDITIONS

by

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CHAPTER 1

INTRODUCTION

Artificial drainage is needed for efficient production on many of the world's richest lands. Although it is well recognized that the design of drainage systems should depend on soil, crop, irrigation and climatological factors, few systems are in fact rationally designed. A computer based water management model recently adopted by the U.S. Soil Conservation Service shows promise in providing not only an objective method for drainage design, but of also including the interactive effects of irrigation water management. Although originally developed and field tested for humid regions, Chang et al. (1983) showed that the model can also be used for irrigated soils in semi-arid regions when irrigation water is applied uniformly over the area and when lateral seepage can be neglected. Unlike other design procedures for irrigated lands, the model allows consideration of rainfall during the wet season and the effects of alternative irrigation management schemes on the drainage requirements. Approximate methods have been developed to relate drainage design to long-term yields for certain crops in humid regions. The addition of similar methods relating drainage intensity, salinity and yields appears feasible. However, application of the model in many situations is currently limited by the lack of systematic methods to consider lateral seepage to or from irrigated fields.

The rate of lateral seepage from relatively flat irrigated fields is often as great or greater than the rate that water is removed by

subsurface drains. Consideration of lateral seepage from fields on the higher elevations of the landscape may drastically reduce the drainage intensity required. Conversely, seepage into fields on the lower landscape elevations would require an increased drainage intensity. Methods for characterizing lateral seepage for various boundary conditions were developed in this project and included in the water management model.

Present methods for designing drainage systems assume that irrigation water is applied in a pattern that is symmetrical with the drainage system layout. This is not necessarily the case in practice where an irrigation set may often cover only a part of the area between drainage laterals. Studies were conducted to determine the effect of nonuniform space-time distribution of irrigation water on water table elevations and drainage rates.

Objectives of the project were:

1. To develop methods to quantify the effect of lateral seepage to or from irrigated fields that are artificially drained.
2. To characterize drainage processes and the soil water regime under irrigation schemes that are not symmetrical with the drainage layout; e.g. an irrigation set that covers only a portion of the land area between parallel drains.
3. To incorporate the methods developed in objectives 1 and 2 into the water management model, DRAINMOD, and to test the methods in field situations.
4. To modify the water management model to incorporate a salt balance for prediction soil salinity of irrigated cropland.

Research on objectives 1 and 3 was primarily conducted at North Carolina State University and is reported in Chapter 2. Objective 2 was addressed by Dr. Sinai at the Technion. Results of this research are

summarized in Chapter 3. Dr. Andrew Chang at the University of California - Riverside, worked on objective 4. He also developed methods for estimating daily potential ET and compared subsurface drainage system design with DRAINMOD to conventional design methods for semi-arid conditions. These results are presented in Chapter 4.

MODELING LATERAL SEEPAGE TO AND FROM IRRIGATED
FIELDS WITH SUBSURFACE DRAINAGE

by

G. Fipps, G. M. Chescheir and R. W. Skaggs

2.1 Introduction

Models currently used for irrigation and drainage design do not take into account lateral seepage, the horizontal movement of groundwater into or out of a field. Commonly an analysis for design will use approximate methods to perform a water balance at the center of the field of interest, while ignoring the effects of such boundaries as canals or large, uncultivated adjoining areas. The amount of lateral seepage under certain conditions may be of sufficient magnitude to effect the system design.

Objectives 1 and 3 of the project were to develop an approximate method for quantifying the effect of lateral seepage to and from irrigated fields that are artificially drained, and to incorporate the approximate methods into the water management model, DRAINMOD. For this study field situations were simulated by finite element solutions to Richards equation. These objectives were accomplished in the following four steps:

1. Methods for representing drains as boundary conditions in finite elements were developed and tested against analytic solutions. This work was conducted by Mr. G. Fipps as part of his M.S. thesis and was published in Water Resources Research (1986, Vol. 22(11):1613-1621).

Methods, procedures and results are given in Section 2.2 of this chapter which is a reprint of the Water Resources article.

2. Using the appropriate method to represent drains, two dimensional finite element solutions to Richards equation were used to analyze the effect of canal seepage on drainage to parallel drains. These analyses were also part of Mr. Fipps' M.S. thesis; results were published in the Transactions of the ASAE (1986, Vol. 29(5):1278-1283) which is included as Section 2.3 of this chapter.

3. A approximate method for quantifying the effect of lateral seepage on an artificially drained field was developed and compared to the finite element solutions.

4. The approximate method was incorporated into the water management model DRAINMOD and the modified version of DRAINMOD was compared to the approximate method and to the field scale finite element solutions.

Results of steps 3 and 4 were presented as a technical paper at the 1986 Winter ASAE meeting in Chicago, IL (ASAE Paper No.). This paper is being submitted to the Transactions of ASAE for publication. Results are presented in the Sections 2.4 and 2.5 of this chapter.

CHAPTER 5

COOPERATION AND EVALUATION OF RESEARCH ACHIEVEMENTS

by

R. W. Skaggs

5.1 Cooperation

Research reported in the three previous chapters was conducted by Skaggs and graduate students at Raleigh, NC (Chapter 2), Sinai and graduate students at the Technion in Israel (Chapter 3) and Chang and colleagues at Riverside, California (Chapter 4). However, there was constant interaction and cooperation among the investigators during the course of the project. In addition to the investigators mentioned above, Dr. Jan van Schilfgaarde, Director of the USDA, ARS Salinity Lab when the project was initiated, had an active role in advising and guiding the project direction during its early stages. There was also interaction and cooperation between the investigators and engineers and scientists from the USDA SCS in America and the SC&D in Israel. These agencies are primary users of the research results; their participation at this stage is important to the acceptance and application of the products of the research.

In addition to working together to develop computer programs and sharing the results of research in the form of written reports, several site visits and meetings were held to facilitate cooperation among the investigators and between the investigators and personnel from the action agencies (SCS and SC&D).

All investigators (Sinai, Chang, van Schilfgaarde and Skaggs) met in Riverside, California in October 1982 to discuss procedures and coordinate plans for the project. In April 1984, Dr. Skaggs, Walter

Ochs (USDA, SCS, National Drainage Engineer) and Richard Wenberg (USDA, SCS Regional Drainage Engineer) met with Drs. van Schilfgaarde and Chang in Riverside, California. They discussed progress on the project, and use of DRAINMOD for designing drainage systems in irrigated semi-arid areas. They were joined in those discussions by SCS drainage engineers from California and from the western region.

Dr. van Schilfgaarde traveled to Israel in May 1984 as part of his TAC responsibilities. While there he visited the Sodom and Kalia drainage areas with Dan Rosenzweig, Gideon Sinai and Zvi Revhon. They discussed local drainage problems and made suggestions concerning drainage for salinity control. The next day the group was joined by Ezra Hankin (head of Israel SC&D), P. K. Jain and S. Rebinfeld for a one-half day workshop on design of drainage systems for semi-arid irrigated fields.

Dr. Skaggs visited Israel in June 1984. He reviewed the stage of the research in Israel, and discussed progress at NCSU and UCR. He also gave a seminar to students, engineers and faculty of the Technion Agricultural Engineering Department. On the next day, Sinai and Skaggs conducted a workshop for senior engineers in Israel. Among them were Dan Rosenzweig, Aba Niv, Zvi, Shein, David Zeichner, and Zvi Revhon. In both the seminar and workshop, Skaggs demonstrated the use of DRAINMOD and other water management techniques to students, teachers, and drainage engineers. In addition, Dr. Skaggs visited the Jordan Valley region with G. Sinai, and was introduced to local water management problems by Aba Niv, the senior regional SC&D engineer. The use of models for design and analysis was discussed there.

In December 1984, G. Sinai visited R. W. Skaggs at NCSU and attended the ASAE winter meeting in New Orleans where several studies on drainage of irrigated fields were reported. While in Raleigh, Gideon Sinai reported to Skaggs the research findings of his group in Israel and discussed the methods for incorporating results of his work, drainage of sequentially irrigated fields into DRAINMOD.

5.2 Evaluation of Research Achievements

A primary objective was to develop methods to characterize effects of lateral seepage to and from irrigated fields that are artificially drained and to incorporate them into DRAINMOD. Finite element methods were used to develop methods to describe seepage from the field to deep drainage ditches and from unlined irrigation canals into drained fields. These methods were published by Fipps et al. (1986) and Fipps and Skaggs (1986) and are described in sections 2.2 and 2.3 of this report. The finite element solutions were used as a base to develop approximate procedures which were incorporated into DRAINMOD as described in sections 2.4 and 2.5. The modified DRAINMOD can be used to analyze the effects of lateral seepage to or from boundary canals. In humid regions seepage to deep drainage canals causes overdrainage and reduction in yields near the banks (Doty et al., 1984). In irrigated semiarid regions, seepage from irrigation canals often results in the loss of productive lands adjacent to the canals due to water logging and salinity buildup. As a result of this project we have a tool that can be used to analyze the effects of seepage to or from boundary canals on a more-or-less routine basis. DRAINMOD is familiar to a large number of users and its availability is increasing with time. Thus, these advances have the potential of affecting the analysis and design of

drainage and irrigation systems on thousands of hectares in humid and semiarid regions.

Additional research is needed to assess the effects of seepage from upslope areas on drainage system design. Research in this area is continuing at NCSU with the expectation of incorporating results into the DRAINMOD format. However the work is incomplete at this time.

The development of methods to characterize drainage processes under irrigation schemes that are not symmetrical with the drainage layout was another objective of the project. An analysis of drainage of irrigated lands under sequential water application was conducted by Sinai's group at the Technion and is presented in Chapter 3 of this report. Since in practice most irrigation water is applied sequentially rather than uniformly, knowledge gained in this study is extremely important to our understanding of the interaction between drainage and irrigation. For example, results of this work show that neglecting the effects of sequential irrigation may lead to underestimating the water table rise by 50 percent in some cases and overestimation by as much as 60 percent in others. Additional research is needed, and is ongoing to further develop these concepts and to incorporate them in design methods, including DRAINMOD.

Work at the University of California, Riverside by Chang and colleagues compared subsurface drainage design by DRAINMOD with conventional design procedures. It was concluded (section 4.2) that the simulation approach considered more of the soil properties, water inputs and distribution patterns and should provide a more reliable design than conventional methods. Improved methods for predicting daily potential evapotranspiration based on a time series analysis of solar radiation were also proposed (section 4.3). Another important objective of the

project was to develop methods for computing a salt balance in the soil profile. Chang and colleagues at Riverside used a simplified mass balance approach to calculate soil salinity in the root zone and incorporated the algorithm into a modified version of DRAINMOD (section 4.4). Although the approach is approximate and has not been fully tested, the model can be used to predict the effects of drain spacing, salinity of irrigation water, irrigation amounts and management on soil salinity. Effects on crop yields can then be estimated using methods such as given by Mass and Hoffman (1977). The overall result is a model that needs more testing and perhaps development, but which promises to be extremely important for design and evaluation of drainage systems in irrigated, semiarid regions.

LIST OF PUBLICATIONS

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- Sinai, G., P. K. Jain and D. Hillel. 1986. On the drainage of irrigated lands under sequential water application. Advances in Irrigation, Vol. 4, Nov. 1986.
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- Fipps, G. Modeling lateral seepage in relation to the design of irrigation and drainage systems. 1984. M.S. thesis, Department of Biological and Agricultural Engineering, North Carolina State University, Raleigh, 121 pp.