DRAINAGE
OF
AGRICULTURAL LANDS

Edited by
JAMES N. LUTHIN
Department of Irrigation
University of California
Davis, California

AMERICAN SOCIETY OF AGRONOMY, Publisher
MADISON, WISCONSIN
1957
E. C. Childs, School of Agriculture, University of Cambridge, England.
William W. Donnan, U. S. Salinity Laboratory, Riverside, California.
Frank Engelund, Copenhagen F., Denmark.
Milton Fireman, Agriculture Extension Service, University of California, Riverside, California.
Robert M. Hagan, Department of Irrigation, University of California, Riverside, California.
Don Kirkham, Department of Agronomy, Iowa State College, Ames, Iowa.
James N. Luthin, Department of Irrigation, University of California, Davis, California.
Marinus Maasland, (formerly Commonwealth Research Station, Merbein, Victoria, Australia) now Bureau of Reclamation, McCook, Nebraska.
Philip W. Manson, Division of Agricultural Engineering, University of Minnesota, St. Paul, Minnesota.
Dean F. Peterson, Jr., (formerly Colorado State University, Fort Collins, Colorado) Department of Civil Engineering, Utah State University, Logan, Utah.
Ronald C. Reeve, U. S. Salinity Laboratory, Riverside, California.
Glen O. Schwab, Department of Agricultural Engineering, Ohio State University, Columbus, Ohio.
Jan van Schilfgaarde, Department of Agricultural Engineering, North Carolina State College, Raleigh, North Carolina.
W. R. van Wijk, Laboratory of Physics and Meteorology, Netherlands Agricultural College, Wageningen, The Netherlands.
Bessel D. van't Woudt, Agricultural Experiment Station, University of Hawaii, Honolulu, Hawaii.
J. Wesseling, Laboratory of Physics and Meteorology, Institute for Land and Water Management Research, Wageningen, The Netherlands.
DRAINAGE is a word of many meanings. For example, the drainage of an area may refer to the physical network of streams and surface waterways in an area, or it may refer to the water which is being carried by these streams. Neither of the above definitions is pertinent to this book because we are primarily interested in the drainage of agricultural land, and we have narrowed our attention to consider, in the main, the removal of excess subsurface water by means of conduits or other water-conveying devices. Our interest centers therefore on the “act” of drainage—the methods and means that can be used to drain the land. Additionally, since we have specified that our concern is with the drainage of “agricultural lands,” it follows that we are concerned with water tables, movement of water through soil, and the relationships that exist between water tables and crops. It is on this broad base that the monograph is developed.

The practice of the art of drainage is probably as old as the art of agriculture. The first recorded examples occurred during the times of the Roman Empire and probably earlier. The Romans recognized the importance of soils information as a basis of drainage design and the superiority of deep and covered drains under certain circumstances. The methods used by these people were little improved until present day tile drainage had its origin in England on the estate of Sir James Graham in Northumberland in 1810. (An earlier use of tile in France in 1620 in the Convent Garden at Maubeuge was not followed by widespread adoption of the practice.)

While the practice of drainage dates from antiquity, the theoretical development of the science of drainage may be considered to have started 100 years ago in France with the experiments performed under the direction of Henry Darcy. Because of the scarcity of copies of this work and the fact that an erroneous conception of the original apparatus used has crept into the literature, the pertinent part of Darcy’s article (p. 594) is reproduced below with a copy of the drawing of his original apparatus. The subsequent development of drainage theory is adequately treated in Chapter II and no more need be said here.
Ainsi, en appelant $e$ l'épaisseur de la couche de sable, $s$ sa superficie, $P$ la pression atmosphérique, $h$ la hauteur de l'eau sur cette couche, on aura $P + h$ pour la pression à laquelle sera soumise la base supérieure; soient, de plus, $P \pm h$, la pression supportée par la surface inférieure, $k$ un coefficient dépendant de la perméabilité de la couche, $q$ le volume débité, on a

$$q = k \frac{e}{h} [h + e \mp h_s]$$

qui se réduit à $q = k \frac{e}{h} (h + e)$

quand $h_s = 0$, ou lorsque la pression sous le filtre est égale à la pression atmosphérique.

Although the foundations for these scientific developments were established in the last century, it is only in the past decade and a half that we have witnessed an outpouring of information in the various journals, scientific and popular, on the subject. The need for collation and correlation and evaluation of this intelligence is apparent to all who work in the field of agriculture. It is the aim of this book to perform such a task, that is, to glean the information from the various journals and
magazines and bring it together in one compact volume so that it will be available to all who desire the knowledge. In view of the essential nature of drainage as a factor in the yield of farm lands in our struggle to produce food and fiber for our increasing population, it is important that the best information about the theory and practice of drainage for agriculture be within easy reach.

Interest in drainage fluctuates widely with the economic tenor of the times. During periods of low agricultural prices little drainage work is accomplished. During this period, research activity drops off as well. Methods and practices which have been used during previous prosperous times lie idle and become forgotten. Then with a return to high agricultural prices, the interest in drainage resumes but the old methods have to be rediscovered and redeveloped. It is for this reason that one frequently sees articles in popular magazines describing some "new method of drainage that has just been invented"; it may well be a method used before the times of the Roman Empire.

At the present time we are enjoying agricultural prosperity and interest in drainage is probably at an all time high. Farmers interested in obtaining maximum yields are installing many miles of drains each year. Many of the drains installed today are still based on the trial and error system used in the past, a system that has produced costly failures in terms of financial loss and human disappointment. We have progressed far in our understanding of the basic principles of drainage. That there is additional work for us in the future is also indicated by the unanswered questions that continually confront the worker in the field of drainage.

A book of this nature covers a subject that ranges from the physical principles of the movement of water through soil to the mechanics of installing drainage systems. The art and practice of drainage involves integration of a multitude of ideas and techniques garnered from soil science, plant science, and engineering. The vastness of the scope of this monograph brings with it both advantages and disadvantages. There must necessarily be some overlapping of subject matter and duplication of material in its various sections. On the other hand, such duplication is frequently desirable since the reader may find himself tempted, because of time limitation, to confine his attention to the sections which are of particular interest at the moment.

In the public mind misconceptions from lack of understanding are frequently associated with drainage. Both floods and droughts have been blamed on drainage. Still another feature associated with large scale drainage work is the opposition which stems from a resistance to change in the existing conditions due to a conflict of interest. It is recorded that
the drainage of the Fens of Eastern England, comprising over 200,000 acres of land subject to the storm tides of the North Sea, was attended with difficulties and discouragements, chief of which was the opposition of the fenmen who occupied the lands and derived a precarious livelihood from hunting and fishing and livestock raising. Present day drainage projects are sometimes subjected to opposition from conservation groups interested in preserving the natural habitats of wildlife.

In spite of the misunderstandings and outright opposition which have occasionally arisen, progress in drainage has resulted in the addition of millions of acres of highly productive land for the production of food and fiber for the ever-increasing numbers of people inhabiting the earth. That the reclamation and preservation of land by drainage has only begun is attested to by the observations of many trained agricultural scientists. Large areas in the Eastern United States can profit by drainage. The permanency of irrigated agriculture depends to a degree on drainage, and many additional miles of drains are needed in arid regions. That the United States is not alone in her drainage potential is revealed in the experience of many of our scientists and engineers who travel abroad on foreign missions.

It was soon evident that the preparation of this book required the services of many specially trained people, some of them not directly associated with the American Society of Agronomy. For their fine cooperation and splendid service your editor wishes to express the appreciation of the American Society of Agronomy. The American Society of Agricultural Engineers has been especially helpful through the activity of its members and the interest expressed at its annual meetings.

JAMES N. LUTHIN

Davis, California
July, 1957
# CONTENTS

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>vii</td>
</tr>
</tbody>
</table>

## I. The Physics of Land Drainage

E. C. Childs

- I. The Nature of Soil Constituents .................................. 1
- II. The Internal Soil Architecture .................................... 11
- III. The Static Equilibrium of Soil Water .......................... 14
- IV. The Laws of Soil Water Movement .................................. 38
- V. The Physical Nature of Drainage Problems ........................ 66

## II. The Theory of Land Drainage

JAN VAN SCHILFGAARDE, FRANK ENGELUND, DON KIRKHAM, DEAN F. PETERSON, JR., AND MARINUS MAASLAND

- I. Approximate Solutions to Drainage Flow Problems .............. 79
  JAN VAN SCHILFGAARDE
- II. The Water Table in Equilibrium with Rainfall or Irrigation Water ........................................ 113
  FRANK ENGELUND
- III. The Ponded Water Case ........................................... 139
  DON KIRKHAM
- IV. The Theory of Drainage by Pumping From Wells ............... 181
  DEAN F. PETERSON, JR.
- V. Soil Anisotropy and Land Drainage .............................. 216
  MARINUS MAASLAND

## III. Engineering Aspects of Land Drainage

G. O. SCHWAB, PHILIP W. MANSON, JAMES N. LUTHIN, RONALD C. REEVE, AND T. W. EDMINSTER

- I. Engineering For Land Drainage—General ......................... 287
  G. O. SCHWAB AND PHILIP W. MANSON
- II. Drainage of Irrigated Lands .................................... 344
  JAMES N. LUTHIN AND RONALD C. REEVE
- III. Drainage in Humid Areas ....................................... 371
  T. W. EDMINSTER AND G. O. SCHWAB
### IV. Drainage Investigation Methods

Ronald C. Reeve, James N. Luthin, and William W. Donnan

I. Methods of Measuring Soil Permeability .......................... 395  
Ronald C. Reeve and James N. Luthin

II. Field Investigations ............................................... 446  
William W. Donnan

### V. Land Drainage in Relation to Soils and Crops

J. Wesseling, W. R. van Wijk, Milton Fireman,  
Bessel D. van’t Woudt, and Robert M. Hagan

I. Soil Physical Conditions in Relation to Drain Depth ..... 461  
J. Wesseling and W. R. van Wijk

II. Salinity and Alkali Problems in Relation to High Water  
Tables in Soils .................................................... 505  
Milton Fireman

III. Crop Responses at Excessively High Soil Moisture Levels 514  
Bessel D. van’t Woudt and Robert M. Hagan

### REFERENCES  .......................................................... 579

### INDEX  .............................................................. 613
DRAINAGE OF AGRICULTURAL LANDS