EFFECTIVE METHODS FOR DRAINAGE IN
THE DELTA AREA OF EGYPT

by

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B.Sc. of Civil Engineering

(Cairo University)

Submitted in partial satisfaction of the requirement
for the degree of

MASTER OF SCIENCE

in

Civil Engineering

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1973

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to each of:

Dr. Mostafa M. Soliman, Professor in charge of the author's graduate study for his guidance throughout the course of study.

Dr. Mohamed H. Amer for his suggestions, comments, and sincere following during the study.

The Direction, Engineers, and technicians of the Nile Delta Authority For Tile Drainage Projects for the facilities offered in doing the field investigations.

The Direction of the International Post-Graduate Course in Hydrology at Padova University-Italy, for the kind help in offering the facility of using the computer center.

بسم الله الرحمن الرحيم

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LIST OF SYMBOLS

The following symbols are used in this text:

d	Depth of impermeable layer under drains level.
d_e	Equivalent depth of impermeable layer for convergence correction.
D	Average depth of flow ($D = d + \frac{H_o}{2}$)
f	Drainable Porosity.
$f'(z)$	Drainable porosity function.
H	Height of water table above drain level at midpoint between drains, at any time t.
H_o	Initial height of water table above drain level at midpoint between drains.
h_o	Initial height of water table just over drain.
H/H_o	Drawdown ratio.
K	Hydraulic-conductivity.
Kt/fS	Dimensionless time parameter.
q	Discharge per unit length of tile drain.
R	Rate of rainfall or irrigation.
r	Outside radius of tile drain.
S	Spacing between two parallel tile drains.
t	Time
V_n	Drained volume of water when the water-table falls from height H_{n-1} to H_n
V'_n	Cumulative outflow volume when the water-table receds from H_o to H_n

x	Distance from drain center.
y	Height of water table above datum plane
$y_{x,t}$	Height of water table above drain level at distance x and time t
z	Depth of ground water table from ground surface.
α	Diffussivity of an aquifer (α = Kd/f)
ϕ	Hydraulic potential head.
η ,ξ	Rational factors.
Δx	Incremental horizontal distance.
Δy	Incremental vertical distance.
Δt	Incremental time interval.
ln	$\log_e$

INTRODUCTION

The control of natural water is the main concern of mankind since the creation of human life. The water in its global circulation, precipitates on the ground, runs on its surface towards streams, perculates through the soil to join the underground reservoir, and evaporates to the open atmosphere. The part of the hydrologic cycle which deels with ground-water is of valuable interest.

The control of ground-water in agricultural lands is of great importance to prevent water logging and salts accumulation. This is usually performed by providing the land with effective system of drainage. By drainage is meant the removal of excess gravitational water in such a manner that optimum crop yield results.

Although subsurface drainage in arid irrigated areas do not generally develop for a number of years after reclamation, they do arise as a direct result of irrigation. The cost of deferred drainage facilities which will be required must be considered as a part of the overall cost in developing an irrigation project. Because of the need in project planning of comparing total project costs with overall benefits of a proposed irrigation project, the planner must predict the ultimate drainage requirements and costs that can be expected as a result of irrigation. A large tile drainage project is now under construction in the agricultural area of Egypt. The project comprises provision of an adequate tile drainage system to an area of 950,000 feddan in the Delta Area of the River Nile.

The normal problem encountered in the design of tile drainage systems is to determine the maximum spacing between drains which will enable the water table to fall to a predetermined height above the drains, in a given time, under given conditions of permeability, voids ratio, and depth of aquifer. This problem can be attacked theoretically by mathematical formulation of the problem under idealized assumptions. The resulting equations can be checked by observing the behavior of soil water under different drainage conditions either in the laboratory or in the field.

Many of the equations have been criticized because of the idealized assumptions made in the derivation. Often these assumptions are at variance with the known facts, hence, lead to a lack of confidence in the final solution. While there are various theoretical equations for spacings of tile drains, the designing engineer still depends to a great extent on less elegant formulas.

This thesis is concerned with doing sound experimental field study of the water table response to tile drains. The data collected was used in exploring the actual field conditions which replace the idealized assumptions. A new water table shape equation is developed to suite the actual water table measurements. This equation is used in solving the basic differential equation numerically, and the solution is compared with other solutions based on the classical simple assumptions. The discrepancy between the results led to proposing practical scheme for designing the spacing between tile drains in the area of the Drainage Project in Egypt.

CHAPTER I

PREVIOUS INVESTIGATIONS ON SUBSURFACE DRAINAGE

In recent years subsurface drainage has become an applied science that provided engineers with a powerful tool to achieve given objectives of ground-water control. First, the steady state flow theory was developed to allow the designer to obtain mathematical answers to the problem of the proper spacing of subsurface drains if the rate of recharge is known. Although drain-spacing equations based upon the steady state flow theory represent considerable development in the practice of subsurface drainage, yet they do not give exact answers to many questions. The steady state ground water conditions rarely, if ever exist. The urgent need for more reliable methods of predicting subsurface drainage requirements in irrigated lands led to the development of equations based on the concept that subsurface drainage is a transient phenomenon. This thesis is concerned with the study of subsurface drainage for unsteady state conditions.

1. Basic Approaches

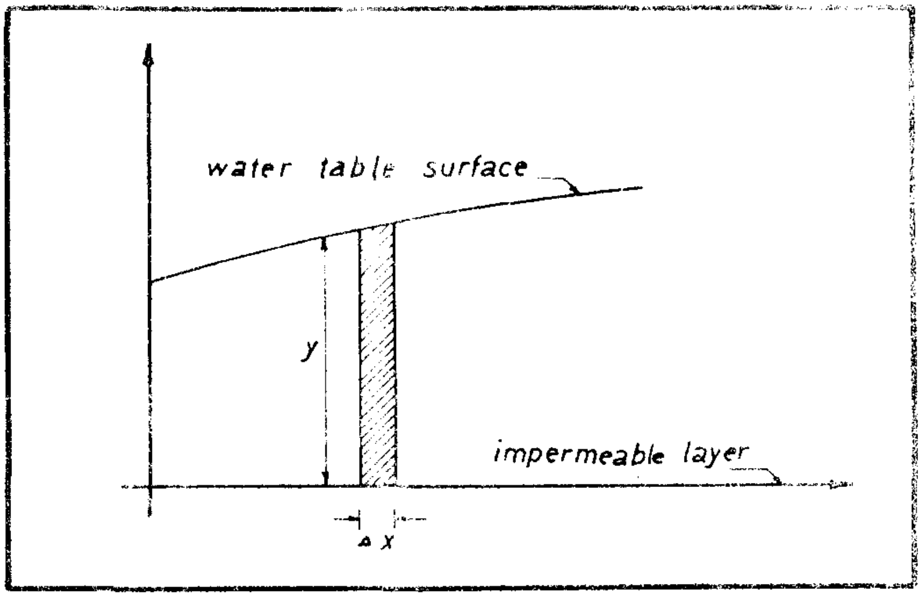
The spacing equations developed in the last two decades were based upon two main approaches.

The first approach is the so called the Dupuit-forchheimer theory. It postulates a saturated permeable barrier underlying the aquifer. The basic differential equation applies the continuity principle which describes the requirement that the flow through the sides of a vertical column of an infinitesmal cross sectional area (figure 1) must be compensated for by a corresponding drop of the water-table at the top of the column. The Dupuit-Forchheimer assumptions (25)* are: (a) all stream-lines in a system of gravity flow towards a shallow sink are horizontal, and (b) the velocity along these stream-lines is proportional to the slope of the free-water surface, but independent of the depth. The final differential equation is in the form.

$$\frac{\partial}{\partial x}\left(ky\frac{\partial y}{\partial x}\right) = f\frac{\partial y}{\partial t} \qquad (1)$$

where, k is the hydraulic-conductivity, f is the drainable porosity, y is the height of water table above the impermeable layer, and t is the time.

* Number in parentheses refer to the appended bibliography



Fig(1)- Ground water flow system in a dynamic equilibrium.

Equation (1) is a non-linear second order differential equation. To avoid the mathematical difficulties posed by this nonlinearity it is customary to neglect the effects of changes of transmissivity due to changes of water table levels. Under this simplification the equation reads:

$$\frac{\partial^2 y}{\partial x^2} = \frac{f}{kD} \frac{\partial y}{\partial t} \qquad (2)$$

where, D is the depth defined by Glover as:

$$D = d + H_0/2 \qquad (3)$$

and d is the depth of impermeable layer under drains level, and H_0 is the initial height of water-table above drain level at midpoint between the drains. Such simplification imposes the restriction that the linearized differential equation become inaccurate if the change of water table levels become considerable with respect to the initial saturated depth.

The second approach is based upon the requirement that there can be no accumulation of water in any elementary cubical volume located in the zone of complete saturation. The differential equation obtained on such basis for a homogeneous and isotropic aquifer is the so called Laplace's equation:

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} = 0 \qquad (4)$$

where ϕ is the hydraulic-potential head at any point (x,y) in the flow region. This second approach is the more general of the two (see Massland and Shery 19), but leads in nonsteady cases to serious mathematical difficulties.

2. Review of Tile Drain-Spacing Equations

Among the investigators who have used the approach of Dupuit and Forchheimer theory are Ferris and Glover as reported by Dumm . Ferris found an expression for the shape and height of the water table as a function of time around a single ditch drain penetrating into an impermeable layer. Ferris analysis was found to be faulty in the mathematical derivation. Glover proposed a formula for the spacing required for tile drains to maintain the water table below a specified level.

The formula is a solution of equation (2), assuming an initial flat water table. The major shortcoming of Glover's formula is that it does not take into account the restricting effect of convergence of flow near the drains. Kemper , modified Glover's solution by introducing a correction factor obtained by comparing the equation with the results of an electric analogue study and restricted its use to open ditches. Dumm (6,7) and Schilfgaarde (26) used the same approach of Dupuit and forchheimer to derive spacing equations. Their solutions will be given in detail since they will be compared with the result of field investigations.

Moody, solved the nonlinear partial differential equation (2) numerically on the electronic computer with an initial parabolic water table configuration. He derived an equation to correct for the effect of losses due to convergence of flow to the drains.

Kirkham and Gaskel (14) treated the falling water table as a series of successive steady states solved on the basis of Laplace's equation and used the relaxation method to find specific solutions to some problems. The relaxation technique has the disadvantage of being laborious and extremely time consuming. In an attempt to overcome this difficulty Luthin (4, 11) constructed