AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
CIVIL ENGINEERING - IRRIGATION AND HYDRAULICS

Ph.D. THESIS

GROUND WATER QUALITY MODEL WITH DECAYING POLLUTANTS

BY

Eng. NAGY ALI ALI HASSAN
M. Sc. C.E.

A Thesis submitted in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY
IN CIVIL ENGINEERING
IRRIGATION AND HYDRAULICS

Supervised by

Prof. Dr. - Eng.
Mostafa Mohamed Soliman
Professor of Irrigation
and Drainage.
Irrigation & Hydraulics Dept.,
Faculty of Engineering,
Ain Shams University.

Assoc. Prof. Dr. - Eng.
Mohamed M. Nour El-Din
Associate Professor
Irrigation & Hydraulics Dept.,
Faculty of Engineering,
Ain Shams University,

Cairo, 1993

STATEMENT

This dissertation is submitted to Ain Shams University for the degree of **Philosophy Doctor in Civil Engineering.**

The work included in this thesis was carried out by the author in the Department of Irrigation and Hydraulics, Ain Shams University, from September 1989 to September 1993

No Part of this thesis has been submitted for a degree or a qualification at any other University or Institution.

Date :

Signature:

Name : Nagy Ali Ali Hassan

بسم الله الرحمن الرحيم

Examiners Committee

1. **Prof. Dr. Kamal H. Hefny**

   Director of the Research Institute for Groundwater

   Water Research Center

   Ministry of Public Works and Water Resources

   Cairo - Egypt

2. **Prof. Dr. Abdelmohsen E. El-Mongy**

   Professor of Harbors and Hydraulics

   Irrigation and Hydraulics Dept.,

   Faculty of Engineering, Ain Shams University,

   Cairo, Egypt.

3. **Prof. Dr. Mostafa M. Soliman**

   Professor of Irrigation and Drainage Design,

   Irrigation and Hydraulics Dept.,

   Faculty of Engineering, Ain Shams University,

   Cairo, Egypt.

ACKNOWLEDGEMENTS

I am indebted and deeply grateful to my professor and supervisor Prof. Dr. Mostafa M. Soliman for his indispensable advice, encouragement, invaluable guidance and since the start of my M. Sc. study.

Thanks and gratitude are presented to Dr. Mohamed M. Nour El-Din for his great help and continuous encouragement during the progress of this dissertation.

Deep thanks are presented to director and the staff members of the research Institute for Groundwater, Ministry of Public Works and Water Resources, Cairo, Egypt, for their cooperation.

Sincere thanks are presented to Dr. Eng. Ahmed A. Hassan for his great help and invaluable advises.

Thanks are due to Dr. Eng. Ali Talaat, Dr. Eng. Mahmoud Samy, Dr. Eng. Khaled El-Kholy and Dr. Sohair M. for their assistance.

Thanks are due to the staff members of Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University for their cooperation.

Ain Shams University
Faculty of Engineering

Dept. of : Irrigation and Hydraulics

Abstract of the Ph.D. Thesis Submitted by : **Nagy Ali Ali Hassan**

Title of Thesis:

" Ground water Quality Model with Decaying Pollutants"

Supervisors: (1) Prof. Dr. **M. M. Soliman**

(2) Assoc. Prof. **M. M. Nour El-Din**

Registration Date:15-1-1990 Examination Date: 12/9/1993

Abstract:

Groundwater constitutes an important component of many water resource system, supplying for domestic use, for industry, and for agriculture. Therefore, groundwater must be managed carefully to be the most beneficial use. Good management requires the ability to forecast the aquifer's response to planned operations, such as pumping and recharging. The response may take the form of changes in water levels, changes in water quality, or land subsidence. Any planning measures to consider mitigation, clean-up operations, once contamination has been detected in the saturated or unsaturated zones, requires the prediction of the path and the fate of the contaminants in response to the planned activities. For most practical problems, because of the heterogeneity of the considered domain, the irregular shape of its boundaries, and the nonanalytic form of various source functions, only a numerical model can provide the required forecasts. In this work, a numerical model has been developed to simulate the groundwater flow and conservative and nonconservative pollutant transport through the saturated porous media. The Finite Element Method has been used to solve the partial differential equations that govern the groundwater flow and solute transport. Problems with available analytical or numerical solutions have been used in order to verify the capability of the model in simulating the different field situations in one- or two- or three-dimensions. The model has been applied to a selected region in the East Nile Delta in Egypt in order to calibrate the aquifer properties. Also the model has been applied to hypothetical three-dimensional problems which may be occurred in the real world. It is concluded that the model can be used efficiently and successfully in simulating and predicting the fate of conservative and nonconservative pollutants in aquifers under a variety of conditions with the minimum of simplifying assumptions.

NOTATION

a	Compressibility of water	$[LT^2M^{-1}]$
A_{ij}	Conductance matrix	$[L^2T^{-1}]$
A_e	Elemental area	$[L^2]$
a_T	Transversal dispersivity	[L]
a_L	Longitudinal dispersivity	[L]
a_v	Vertical dispersivity	[L]
B_{ij}	Storage matrix	$[L^2]$
b	Compressibility of the aquifer	$[LT^2M^{-1}]$
b'	Thickness of the layer that represents the stream bottom.	[L]
C	Concentration of the solute	$[ML^{-3}]$
Cn	Courant number	
C"	Ratio between the mass held on the solid surface and the mass of the solids in solution	
C_{in}	Concentration of the inflowing water in the case of infiltration or the average concentration in the aquifer in the case of abstraction of water	$[ML^{-3}]$
d'	Effective grain diameter	[L]
d_i	Thickness of the aquitard	[L]
D'_{ij}	Hydrodynamic dispersion-diffusion coefficient	$[L^2T^{-1}]$
D_{md}	Molecular diffusion coefficient	$[L^2T^{-1}]$
D_0	Diffusion coefficient in a free water system	$[L^2T^{-1}]$
Δt	Time step size	[T]
Δ	Elemental cross-sectional area of cubic element perpendicular to the pore-water velocity	$[L^2]$

e	Element number	
erfc(x)	Complementary error function= 1- erf(x);	
G_{ij}	Capacitance matrix	$[L^2]$
g	Gravity acceleration	$[LT^{-2}]$
h	Hydraulic head	[L]
k	Permeability	$[L^2]$
Kij	Hydraulic conductivity tensor	$[LT^{-1}]$
K_{vi}	Vertical hydraulic conductivity of the aquitard	$[LT^{-1}]$
K_d	Distribution coefficient	$[L^3M^{-1}]$
k'	Hydraulic conductivity of the layer that represents the stream bottom	$[LT^{-1}]$
$J_{disp.}$	Dispersive flux	$[MT^{-1}]$
l_i	Aquitard resistance i	$[T^{-1}]$
λ	Decay constant	$[T^{-1}]$
m	Aquifer thickness	[L]
N_e	Total number of elements.	
μ	Viscosity	$[ML^{-1}T^{-1}]$
n_e	Effective Porosity	
NP	Total number of the nodal points	
$N_i(x, y)$	Shape function.	
υ	Kinematic viscosity	$[L^2T^{-1}]$
$\partial h/\partial x_j$	Hydraulic gradient in the j-direction;	
$\partial C/\partial x_i$	Concentration gradient in the direction i	$[ML^{-4}]$
P_n	Peclet number	
P_{ij}	Solut tran. conductance matrix	$[L^2T^{-1}]$
$\pm Q_i$	Sink or source flow rate at the node i	$[L^3T^{-1}]$
QC'	Concentration of the solute of a source or sink of a strength which is assumed to be known	$[ML^{-3}T^{-1}]$

q_i	Average discharge in the direction i	$[L^3T^{-1}L^{-2}]$
Γ_{liquid}	Water filled area perpendicular to the direction of Darcy's velocity	[L2]
Re	Reynold's number	
ρ	Density of water	$[ML^{-3}]$
R	Retardation factor.	
r	Distance from the pumped well	[L]
ρ_b	Bulk density of the porous media	$[ML^{-3}]$
ρ_{dry}	Dry matrix material	$[ML^{-3}]$
S	Storativity of the aquifer	
S_0	Specific storativity)	$[L^{-1}]$
T	Transmissivity of the aquifer	$[L^2T^{-1}]$
t	Time	[T]
$t_{.5}$	Half-life of the isotop	[T]
V	Velocity resultant	$[LT^{-1}]$
V_b	Elemental bulk volume	$[L^3]$
V_e	is the volume of the element	$[L^3]$
W(u,r/B)	Hantush well function	
∇	vectorial-delta $(\partial/\partial x+ \partial/\partial y+ \partial/\partial z)$	$[L^{-1}]$
!	the factorial	
τ	Time factor	

CONTENTS

TITLE **PAGE**

Chapter IV

LIST OF FIGURES

FIGURE NO.		PAGE