UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF A SALTWATER INTRUSION SOFTWARE USING VISUAL BASIC

TAN CHIAU SIANG

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By

TAN CHIAU SIANG

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Dedicated To

My Beloved Father, Mother, Sisters and Brothers

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Chairman : Associate Professor Dr. Salim b. Said

Faculty : Engineering

Coastal aquifers play important roles for sources of water. With growing concern on groundwater resources both in term of quantity and quality, proper assessments and computation tools are becoming more important. Groundwater regional scale phenomena usually cannot be studied accurately using laboratory scale physical models; therefore mathematical tools of analysis must be applied. The advance of the computer technology should be used to solve the complicated mathematical task in solving arithmetic operations.

The purpose of this study was to develop a user-friendly steady state model for simulation of saltwater intrusion into coastal aquifers. The model made use of the mathematical formulation developed by Ganfoud (1997). Two equations were derived, one for water flow, and the other for solute transport that were coupled through Darcy's velocity and concentration. In the numerical model formulation, two-dimensional Galerkin finite element approach was applied for deriving the elemental

matrix equation through quadrilateral elements. The system of linear equations was solved using successive substitution employing the Gaussian elimination techniques.

The whole formulation was set up by using the Visual Basic programming and Surfer graphic program (developed by Golden Software) to analyze the results. The results of intrusion were shown graphically under steady state conditions. The program has been proven to be user-friendly than other programming languages. For model verification, a hypothetical unconfined model and a physical model were used to compare the model's results with previous studies. These models applied the constant and velocity-dependent dispersion coefficient. The comparison showed a good agreement in numerical term between the proposed model and the previous ones. However, the Visual Basic program is not as powerful as the FORTRAN engineering programming and caused minor discrepancies when compared to the previous study.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PEMBENTUKAN PERISIAN PENEROBOSAN AIR MASIN DENGAN MENGGUNAKAN VISUAL BASIC

Oleh

TAN CHIAU SIANG

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Fakulti : Kejuruteraan

Akuifer tepi pantai memainkan peranan yang penting bagi sumber air. Dengan wujudnya kesedaran terhadap sumber air bawah tanah yang mementingkan kuantiti dan kualiti, keperluan alat pengiraan dan pengurusan pengiraan telah menjadi semakin penting. Oleh kerana fenomena kejituaan skala kawasan air bawah tanah biasanya tidak dapat dianggar dengan fizikal model dalam makmal, maka alat analisis matematik perlulah digunakan. Kelebihan dalam teknologi komputer perlulah digunakan untuk menyelesaikan masalah matematik dan dalam penyelesaian operasi aritmatik yang rumit.

Tujuan kajian ini adalah untuk membina satu model komputer untuk mengsimulasi penerobosan air masin di tepi pantai dalam keadaan keseimbangan. Model ini menggunakan persamaan matematik yang dikaji oleh Ganfoud (1997). Dua persamaan telah dihasilkan iaitu aliran air dan pengaliran larutan yang kemudiannya dikembarkan mengikut kelajuan dan keperkatan formula Darcy. Formulasi dua

dimensi elemen finit dengan menggunakan kaedah Galerkin telah digunakan untuk mengghasilkan persamaan elemen matrik secara quadrilateral. Sistem penyelesaian linear telah diselesaikan dengan menggunakan teknik penghapusan Gaussian.

Kesemua persamaan-persamaan yang dibentuk diaturcarakan dengan menggunakan Visual Basic dan Surfer grafik program yang dikaji oleh Golden Software untuk menanalisa keputusan. Keputusan telah ditunjukan dalam bentuk grafik dalam keadaan keseimbangan. Program yang dibentuk telah membuktikan ia lebih mudah digunakan oleh pengguna berbanding dengan program lain. Untuk menguji kejituan program yang dibentuk, satu hipotesis akuifer tak terkawal dan satu model fizikal telah digunakan untuk membandingkan hasil keputusan model dengan kajian awal yang bergantung kepada pemalar penyerakan sekata dan halaju. Perbandingan telah menunjukkan perhubungan yang baik dalam kaedah berangka di antara model tercadang denga model dahulu. Walaubagaimana pun, perisisan Visual Basic telah menunjukan ia kurang mampu untuk menyelesaikan masalah kejuruteraan berbanding dengan perisian kejuruteraan FORTRAN, ini kerana perisian Visual Basic menghasilkan kejituan yang lebih rendah dalam pengiraan jika dibandingkan dengan berbanding dengan pemyelidikan terdahulu.

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Symbol	Definition
c	Concentration corresponding to density
c_s	Concentration of sea water
D_d	Molecular diffusion coefficient
D_{xx}	Dispersion coefficient in radial direction
D_{zz}	Dispersion coefficient in vertical direction
g	Gravity acceleration
h_s	Equivalent freshwater head seaside
J	Jacobian matrix
k	Permeability of water
K	Hydraulic conductivity
n	Effective porosity
q_i	Darcy velocity
Q	Source and/or sink terms
S_s^f	Freshwater specific storage
S_y	Specific yeild
r,s	Local coordinate
z	Elevation about datum
ε	Density ratio
μ	Viscosity of water
α	Coefficient of compressibility of the matrix
β	Water compressibility

α_L	Longitudinal dispersivities
α_T	Transverrse dispersivities
Φ	Shape function
ρ	Mass density

CHAPTER 1

INTRODUCTION

General

Saltwater intrusion into aquifer is a common problem in many parts of the world. Both natural conditions and human activities can cause it. Saline intrusion of aquifers may originate from various sources such as seawater, return flows to stream from irrigated lands, leakage from disposal wells, and saline water in enclosed areas like tidal lagoon.

Malaysia receives an annual average rainfall of more than 2500mm, mainly due to the Southwest and Northeast monsoons. The country is therefore rich in water resources when compared to the other regions of the world. The average annual water resources on a total landmass of 330,000km^2 amount to 990 billion m^3. Out of which, 36% returns to the atmosphere as evaporation, 57% appear as surface runoff and 7% go to the recharge of groundwater. Groundwater storage potential has been estimated to be 63 billion m^3 for Peninsular Malaysia, 14 billion m^3 for Sabah and 22 billion m^3 for Sarawak. Groundwater is important as a source of drinking as well as for irrigation and industrial uses. (Jabatan Parit dan Taliair Malaysia, 1998). Since water shortage in Klang Valley occurred in the year 1998, groundwater has become an importance resource to overcome the problem. So, it is a challenge to engineers to develop groundwater resource in this country.

With increasing demand for water and with the intensification of water utilization, the quality problem becomes the limiting factor in the development of water resources, especially in coastal areas where population is more condensed. Groundwater quality and management has recently emerged as a national public concern within Malaysia. Just a few years ago, hydrogeologist and water resources managers were unaware of many potential pollution sources and the extent of groundwater contamination. Seawater intrusion is an example of this pollution. The scope of this study is concerned with the environmental pollution that is caused by the saltwater intrusion.

Coastal aquifers constitute important sources for water. Many coastal areas are also heavily urbanized, a fact which makes the need for fresh water even more acute. Invasion of saline water into fresh groundwater due to groundwater withdrawal commonly occurs in coastal aquifers, where seawater moves inland if groundwater levels decline. Saltwater can also move upward into fresh groundwater in aquifers (coastal or inland) underlain by saline water. However, the proximity of the sea, with contact between fresh water and seawater in a coastal aquifer, requires special attention and special management techniques.

In many countries groundwater is one of the major drinking water resources. With growing concern about groundwater resources both with respect to quantity and quality, the need for calculations management tools is increasing. As such it must be managed and protected carefully. With growing development of the resource and with growing human impact on the aquifers, the management needs to become more visible. Problems like over pumping of aquifers and pollution of groundwater occur

with increasing frequency. To mitigate conflicts of interests and avoid severe, even irreversible environmental damage, engineers must be able to predict the reactions of aquifers to human impact with respect to both groundwater quality and quantity. As regional scale phenomena usually cannot be studied on laboratory scale physical models, mathematical tools of analysis must be applied.

Because of the fallibility in solving operations, a computer should do any complicated mathematical task. As well as almost never making arithmetical errors, computers are much quicker in any arithmetical operation. Complex mathematical operations could be done manually only when the person can fully understand it. Thenceforth it should be computerized. The computer should be used in any situation where it offers the best available method of achieving the desired result.

Objectives of the Study

The aim of the study was to develop a user-friendly computer model that will enable to predict intrusion of seawater into coastal aquifers, in response to variation in the components of the fresh water balance of the latter. This information is required for the management of coastal aquifers. The computer model will be developed using Visual Basic version 6 programming based on the numerical model formulated by Ahmed Abulaid Ganfoud in 1997 at Universiti Putra Malaysia.

The specific objectives of this study are:

1. To solve a numerical model formulated with two-dimensional Finite Element Method based on solute transport approach using the Gelerkin method with (a) linear interpolation function, and (b) quadratic interpolation functions to solve the saltwater intrusion. Ahmed Abulaid Ganfoud formulated the numerical model in 1997 at University Putra Malaysia;
2. To develop a computer model using Visual Basic Version 6 programming for simulated saltwater intrusion based on the numerical model for the steady state;
3. To verify the present computer model using a hypothetical coastal aquifer. Compare the present results with the results from some previous study.

Thesis Organization

The organization of this dissertation is arranged in five chapters. Chapter 2 represents a detailed literature review on saltwater intrusion. The review includes the application of the numerical models in simulating saltwater intrusion, sharp interface approach, solute transport approach, finite element method in solving saltwater intrusion, and visual basic programming.

Chapter 3 gives a brief description of the mathematical formulations derived by Ganfoud, 1997, numerical analysis for the principle of finite element method and Galerkin technique for flow and solute transport. Also, a brief description was discussed on the program organization for the computer model developed and application of the Golden Software Surfer.

Chapter 4 gives a description on the operation and function of the computer model and verification model. It covers the following topics: data input, program execution, error handling, and model verification. The computer model verified with a hypothetical coastal aquifer from Gandfoud research. The results were compared with previous studies.

Chapters 5 gives a summery on the work described in this dissertation, discusses the results of the study, and present some conclusions and suggestions for further studies.

CHAPTER 2

LITERATURE REVIEW

Introduction

Groundwater is defined as water below the water table in soil and geologic formations that are fully saturated; the pore spaces within the rock or soil matrix are filled or saturated with water (Freeze, 1979). Groundwater is that portion of the water beneath the surface of the earth that can collect with wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs.

Subsurface water is a term used to denote all the water found beneath the surface of the ground. Hydrologists use the term groundwater to denote water in the zone of saturation. In drainage of agricultural lands, or agronomy, the term groundwater is sometimes used also to denote the water in the partially saturated layers above the water table. Practically all groundwater constitutes part of the hydrologic cycle (Figure 2.1).