SIMULATION OF NON-POINT SOURCES OF POLLUTION IN A HETEROGENEOUS MEDIA BY USING 2D REGIONAL GROUNDWATER FLOW MODEL

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Civil – Hydraulics and Hydrology)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JANUARY 2013

Dedicated to my beloved family specially my mother and father

ACKNOWLEDGEMENT

In the name of God, the Most Beneficent, the Most Merciful. All praise and thanks to God, lord of the universe and all that exists.

First I would like to express my sincere gratitude and thanks to Almighty God. I am indebted to my parents for their continuous support and love throughout my study.

It is with immense gratitude that I acknowledge the help and help of my supervisor AP Dr. Shamsuddin Shahid, for persuasion, guidance, critics and friendship. Without his continued support and interest, this thesis would not have been the same as presented here.

ABSTRACT

Shallow unconfined aquifer is one of the major sources for drinking and irrigation in many countries of the world. Unsustainable agricultural activities disperse nitrate into groundwater, and jeopardize human's health and socioeconomic growth in groundwater dependent regions. A two-dimensional steady-state solute transport model has been developed in the present research to simulate movement of non-point sources of Nitrate pollution in heterogeneous porous media. The migration of chemicals dissolved in groundwater is governed by advective-dispersive processes which are also affected by the velocity of the flowing groundwater. Therefore, Darcy equation is solved for hydraulic head and hydraulic conductivity to approximate the average linear velocity of the fluid. The advection-dispersion is used to approximate the spatial and temporal distribution of nonreactive dissolved chemical in a flowing groundwater. A Matlab code has been developed to solve the groundwater flow and solute transport equations by using finite difference methods. The developed program is verified by sand tank experimental data. Finally, the proposed solute transport model is used to simulate non-point source of nitrate pollution in an agriculture-intensive region of Northwest Bangladesh. Analysis of groundwater simulation results show that the aquifer in the region is very sensitive to pollution and Nitrate can travel up to 5 km horizontally and 25 m vertically in one single year. Geology, groundwater velocity, pollution concentration and type of pollution, and grid size are the factors that control pollution transportation in the area.

ABSTRAK

Akuifer cetek adalah salah satu sumber utama untuk minum dan tujuan pengairan di Barat Laut Bangladesh. Tidak mampan aktiviti pertanian bersurai nitrat ke dalam air bawah tanah, dan menjejaskan kesihatan manusia dan pertumbuhan sosioekonomi di rantau ini dalam jangka masa panjang. A tunda dimensi model keadaan mantap pengangkutan bahan larut akan dibangunkan dalam projek penyelidikan yang dicadangkan untuk mensimulasikan pergerakan bukan titik punca pencemaran nitrat dalam media berliang yang heterogen. Penghijrahan bahan kimia yang larut dalam air bawah tanah ditadbir oleh-proses serakan advective yang juga dipengaruhi oleh halaju air bawah tanah yang mengalir. Oleh itu, persamaan Darcy akan diselesaikan untuk kepala hidraulik dan konduktiviti hidraulik dengan halaju anggaran purata linear bendalir. Olahan-serakan akan digunakan untuk pengedaran anggaran spatial dan temporal kimia nonreactive dibubarkan dalam air bawah tanah yang mengalir. Suatu kod Matlab akan dibangunkan untuk menyelesaikan aliran air bawah tanah dan persamaan pengangkutan bahan larut dengan menggunakan kaedah perbezaan terhingga. Program yang dibangunkan akan disahkan dengan data sintetik serta dengan membandingkan output dengan yang diperolehi daripada data eksperimen tangki tanah. Model pengangkutan bahan larut yang dicadangkan akan digunakan untuk mensimulasikan bukan titik punca pencemaran nitrat di rantau pertanian intensif Northwest Bangladesh. Akhirnya, output model akan dianalisis untuk memahami faktor-faktor yang mempengaruhi pengangkutan pencemaran di kawasan kajian. Keputusan simulasi air bawah tanah menunjukkan bahawa akuifer adalah sangat sensitif kepada pencemaran dan Nitrat boleh bergerak sehingga 5 km mendatar dan 25 m menegak dalam satu tahun tunggal. Geologi, halaju air bawah tanah, kepekatan pencemaran dan jenis pencemaran, dan saiz grid adalah faktor-faktor yang mempengaruhi pengangkutan pencemaran.

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LIST OF SYMBOLS AND ABBREVIATIONS

BEM	Boundary Element Method
C	Concentration of the solute
C^0	Degree Centigrade
Cm	Centimetre
D	Dispersion Coefficient Tensor
D_0	Molecular Diffusion Coefficient Tensor
d_p	Particle Diameter
E	East
EC	Electrical Conductivity
F	Formation Electrical Resistivity Factor
FDM	Finite Difference Method
FEM	Finite Element Method
FTCS	Forward-Time Central-Space
F_t	Feet
FVM	Finite Volume Method
h	Hydraulic Head
K	Hydraulic Conductivity
KCL	Potassium Chloride
K_l	Longitudinal Dispersion Coefficient
Km	Kilometre
m	Meter
MIT	Massachusetts Institute of Technology
mm	Millimetre
MSL	Mean Sea Level
N	North
NH_3^+	Ammonia

NO_2^-	Nitrite
NO_3^-	Nitrate
NPS	Non-Point Source
NWR	North West Region
PDE	Partial Differential Equation
q_i	Specific Discharge
R_c	Sources or Sinks
S_s	Specific Storage
t	Time
U	Average Interstitial Velocity
US EPA	United States Environmental Protection Agency
V	Seepage Velocity
V_i	Velocity Tensor
W^*	Volumetric Flux Per Unit Volume
WHO	World Health Organization
X_i	Cartesian Coordinates
ε	Effective Porosity of Porous Medium
Φ	Porosity
Φ_t	Total Porosity
σ	Measure of Inhomogeneity of Porous Pack
µg	Micro Gram
2D	Two Dimensional
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Groundwater is found underground in the cracks and spaces in soil, sand and rock. Groundwater is stored in a geological media which is called aquifer. Aquifers typically consist of gravel, sand, sandstone, or fractured rock, like limestone. These materials are permeable because they have large connected spaces that allow water to flow through. Groundwater is comparatively less polluted and easily accessible in any point of interest on earth surface. These have made groundwater as the major source of drinking and other domestic purposes in most of the countries of the world.

Though groundwater is naturally fresh in most of cases, unsustainable land use activities often affect the quality of groundwater. The land surface is exposed to different contaminant sources such as fertilizers, pesticides, household cleaners, human and animal waste, etc. Precipitation at land surface moves through soil and takes the surface contaminant to groundwater. Rapid population growth and intensive agricultural activities to feed the growing population with sufficient food in the recent decades have caused a huge change in land use in many countries of the world. Change in groundwater quality is a major concern in all over the world due to agricultural activities especially intensive use of fertilizer and insecticides. As groundwater is the major source of clean water supply in many countries of the

world, pollution of groundwater is a growing concern among scientist in the recent years.

1.2 Problem Statement

Groundwater encompasses one sixth of the total freshwater resources available in the world. Surface water resources in many countries of the world are dwindling due to population growth, urbanization, economic development and climate changes. Consequently, use of groundwater has increased rapidly in the recent years in all over the world. In many countries household nutrition is in a critical situation because of reduced supply of natural resources due to degradation or overexploitation of resources. Increased agricultural production is considered an important alternative to overcome this situation.

Nitrogen based fertilizers are widely used in order to increase production and feed the growing population with sufficient food. However, intensive use of Nitrogen based fertilizers has caused Nitrate pollution in groundwater in many countries. Exceeding level of Nitrate in drinking water leads serious health risks especially for infant children and pregnant women. The discovery of Nitrate in groundwater has exacerbated the health problems and shortage of sanitary water in many parts of the world. Methemoglobinemia and other diseases become common phenomena in the rural area of developing countries due to consumption of high level of nitrate with drinking water. High level of Nitrate in drinking water has also been cited as a risk factor in developing gastric and intestinal cancer. Due to these heath risks, a great deal of emphasis has been placed on finding effective solution by reduce Nitrate concentrations to safe levels.

Therefore, it is necessary to understand the fate and transport of Nitrate in subsurface media in order to take action for remediation, prevention, control and reduction of pollution in the aquifer. Groundwater models can help to improve our

understanding on how aquifer systems behave. The model can also be used to make predictions about the system's future behaviour.

1.3 Study Objectives

The major objective of the research project is to simulate the movement of non-reactive non-point sources of pollution through a heterogeneous porous media by using two-dimensional regional groundwater flow model. The specific objectives of the project are:

1. To solve groundwater flow and advection-dispersion equations by using finite difference methods in Matlab for modelling pollution movement through groundwater system.
2. To calibrate the model by using sand tank experiment data.
3. To apply the model to simulate non-point sources of Nitrate movement through heterogeneous media in a study area located in Northwest Bangladesh.
4. To analysis the results to identify the influences of various geological factors in controlling pollution movement through subsurface in the study area.

1.4 Scope of Study

Beneath agricultural lands, Nitrate is the primary form of nitrogen. It is soluble in water and can easily pass through soil to ground-water table. Nitrate can persist in ground water for decades and accumulate to high levels as more nitrogen is applied every year to the land surface. Nitrate pollution to groundwater through agricultural and other anthropogenic activities is a major problem in many countries of the world. Therefore, it is very import to understand the movement of this non-point source of pollution to groundwater to

take necessary initiatives for pollution control and sustainable management of groundwater resources. The scope of the present study is to understand the movement of Nitrate and/or other non-reactive non-point source of pollution through groundwater system.

1.5 Importance of Study

Groundwater in many countries is exposed to Nitrate pollution due to rapid development of agricultural activities. Contaminated aquifer can cause serious effects on human's health. The solute transport models are mainly focused on the hydrogeological problems dealing with spreading of contaminants in aquifers. Despite this, the solute transport model with flow model is increasingly applied in recent scientific research works since it enables to explore the flow regime behaviour in depth. Modelling solute transport in order to predict future movement is one of the essential components of groundwater management. Groundwater pollution transportation model can be a useful tool to prevent aquifer pollution in the areas where drinking water heavily relies on groundwater resources and can play an important role in uplifting people's livelihood and economy.

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