UNIVERSITI PUTRA MALAYSIA

ANALYSIS AND FIELD STUDIES OF SALTWATER INTRUSION IN A COASTAL AQUIFER : A CASE OF BACHOK, KELANTAN

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By

RUSLAN HASSAN

Dissertation Submitted in Fulfilment of the Requirement for the Degree of Doctor of Philosophy in the Faculty of Engineering Universiti Putra Malaysia

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DEDICATION

I wish to dedicate this work to the poor farmers of Bachok, Kelantan, who simply refused to give up.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy

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Chairman : Dato' Prof. Ir. Dr. Muhamad Zohadie Bardaie

Faculty : Engineering

This dissertation deals with the extent of saltwater/chloride distribution in a two-layered coastal aquifer. The area chosen for the study is located in the Mukim of Bachok, Kelantan which covers an area of 72 km^2 about 20 km South East of Kota Bharu. The area mainly consists of a large flat plain, with soils belonging to the Bris complex (82 - 99% sand) and drained mainly by the meandering Kemasin River and its tributaries. Groundwater contamination by chloride has become a threat to this area, economically and to health. Chloride concentrations have exceeded their permissible limits thereby limiting their eventual uses in tobacco farming and as drinking water. The objectives of this study are therefore to analyse the saltwater intrusion and contamination in the area; to obtain the necessary understanding of the chloride movement and distribution; and finally, to ascertain and make reasonable predictions as to the future contamination of the area by the saltwater.

The approach taken was two-folds, namely to investigate the chloride distribution in the upper aquifer which is mainly utilized for tobacco farming and to analyse the saltwater intrusion using sharp interface and dispersive approaches in the lower aquifer. The analysis on the extent of chloride distribution in the upper aquifer was based on the field investigation covering a period between 1991 - 1995. The field studies were carried out by comprehensive data collection on the upper aquifer for a period of four (4) years which preceded the one (1) year MARDI study. Field studies on the lower aquifer were carried out for a period of two (2) years (1994 and 1995).

The analysis on the Bachok coastal aquifer groundwater systems was done by means of the Regional Groundwater model. The middle stretch of the Kampong Cap transect (DDM1-5) was studied further using the data obtained from Pfeiffer study and the two-zone model. The latter model made use of the discrete space-discrete time approach. To understand the flow paths within the aquifer, an analogue model and PSpice were used.. The parameters thus determined were incorporated in the Regional Groundwater model. Chloride distribution for the upper aquifer was then analysed. As for the upper aquifer, there was an increase in the content of chloride concentration compared to the earlier MARDI study despite the seasonal flushing of the saline water. The chloride increased with higher precipitation (November and December annually) in the flood plains, which was opposite to the long held theory that dilution would decrease the concentration.

The cross-section P-Q which had the most data and better defined than the other cross-sections was chosen for simulating the saline intrusion using SUTRA model. A single unified aquifer was chosen for the purpose since, the aquifer is

hydraulically connected at this cross-section. Cross-sectional intrusion analysis was accomplished in two stages. In the first stage, a steady- state calibration procedure was performed to obtain a match between the theoretical Ghyben-Herzberg position of the interface with that of the computed one and the observed field values. In the second stage, the transient behaviour of the interface was analysed using the dry period and discharge (production wells) and average recharge rates plus the discharge.

It was found that for the aquifer system of Bachok, the groundwater in the lower aquifer is being contaminated by saline water. The saltwater wedge had reached a distance of 6 km (DDM4) from the sea. The chloride concentrations had exceeded 1000 mg/L for a 10-months period in 1995. The degree and extent of saline intrusion depends on the season and was obviously furthest inland during the dry season. As a long-term prediction, it is envisaged that within 25 years from 1994, at the present withdrawal rate of 45,000 gallons per day, the chloride concentration at Kg. Cap will attain a value of 103 mg/L (within the 0.1 isochlor line). The dispersive approach was more applicable here rather than the sharp interface. It described with reasonable accuracy the movement of the interface of the P-Q transection in the lower aquifer, with the hydraulic connection existing between the upper and lower aquifer. It is recommended that for the tobacco farming, the activity should be limited to an area, one (1) km away from both the river and the sea. For saltwater intrusion control in this study area, it is proposed that the water withdrawal be regulated, producing wells be redistributed and monitoring system (including the use of SUTRA) be incorporated in such a way that saltwater intrusion remains in equilibrium while developing the aquifer to its maximum possible yield.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANALISIS DAN KAJIAN LAPANGAN SUSUPAN AIR MASIN KE SUATU AKUIFER BERHAMPIRAN PANTAI : KAJIAN KES DI BACHOK, KELANTAN

Oleh

RUSLAN HASSAN

Oktober 2001

Pengerusi : Dato' Prof. Ir. Dr. Muhamad Zohadie Bardaie

Fakulti : Kejuruteraan

Disertasi ini menangani setakat mana agihan klorida/air masin di dalam akuifer yang berlapisan dua berhampiran dengan sebuah pantai. Kawasan kajian yang dipilih terletak dalam Mukim Bachok, Kelantan yang luasnya adalah 72 km^2, dan jauhnya lebih kurang 20 km di Selatan hala Timur Kota Bharu. Kawasan ini terdiri daripada tanah rata yang luas yang tanahnya tergolong daripada jenis kompleks Beris (pasir 82 - 99%) dan disalirkan oleh Sungai Kemasin dan alur-alur yang berliku-liku. Pencemaran oleh kemasukan air masin mengakibatkan kesan buruk kepada kegiatan tanaman tembakau dan kesihatan. Pada kebanyakan tempat, nilai klorida melebihi hadnya yang memberi kesan kepada penggunaannya. Objektif kajian ini meliputi menganalisis kedudukan kemasukan air masin, memahami pergerakannya dan kemudian membuat jangkaan potensi penerobosannya pada masa akan datang.

Pendekatan yang diambil ialah mengkaji akuifer atas yang airnya digunakan untuk tanaman tembakau kemudian menganalisa kemasukan air masin ke dalam akuifer bawah dengan pendekatan permukaan antara jelas dan dispersif.. Kajian di akuifer atas meliputi kajian di tapak di antara tahun 1992 – 1995. Bagi kajian akuifer di bawah, data dikumpul selama 2 tahun (1994 dan 1995).

Penganalisisan sistem air tanah di kawasan pantai Bachok dilakukan dengan menggunakan model air tanah wilayah ('regional ground water model'). Bahagian tengah Kampong Cap (DDM1-5) dipilih untuk kajian lanjutan dengan menggunakan hasil kajian Pfeiffer dan model dua-zon. Model dua zon menggunakan pendekatan ruang diskrit-ruang masa. Untuk memahami laluan air di keratan pilihan ini model analog kemudiannya digunakan. Nilai yang didapati digunakan balik dalam model wilayah. Agihan klorida bagi akuifer dikaji dan ianya menunjukkan peningkatan nilai klorida berbanding dengan kajian MARDI yang terdahulu. Kandungan klorida didapati tinggi bila terdapatnya banjir dan ini berbeza dengan pendapat sebelum ini yang hujan akan mencairkan kandungan klorida.

Keratan P-Q dipilih untuk kajian simulasi dengan menggunakan model SUTRA kerana mempunyai data yang mencukupi berbanding dengan yang lain. Anggapan suatu akuifer tunggal digunakan dalam analisis kerana terdapat kaitan hidraul antara akuifer atas dan bawah pada keratan ini. Analisis kemasukan air masin di keratan rentas ini disempurnakan dengan membuat dua langkah. Pertama, prosedur kalibrasi keadaan stabil didapati dengan menggunakan kedudukan Ghyben-Herzberg dan data yang diukur di tapak. Kedua, kelakuan transien permukaan antara dianalisa

dengan menggunakan kadar musim kering dan pengambilan air (kadar alir keluar) dan purata kadar recaj dengan kadaralir.

Adalah didapati bagi sistem akuifer di Bachok, airnya telah dicemari oleh air masin. Air masin telah sampai di takat 6 km dari pantai iaitu di DDM4. Kepekatan klorida pada jangka masa 10 bulan dalam setahun (1995) telah melebihi 1000 mg/L. Tahap dan sejauh mana penorobosan air masin bergantung kepada musim dan adalah lebih jauh ke darat dalam musim kering. Dalam jangkamasa yang panjang, adalah dianggarkan dalam masa 25 tahun (daripada 1994), pada kadar pengambilan air sekarang iaitu 45,000 gelen sehari, kepekatan klorida di Kg. Cap akan mencapai 103 mg/L (dalam lingkungan 0.1 isoklor). Pendekatan dispersif lebih terpakai di kawasan ini berbanding dengan pendekatan permukaan antara tepat ('sharp-interface'). Pendekatan dispersif menunjukkan dengan agak tepat, pergerakan permukaan antara di keratan P-Q bilamana terdapat kaitan hidraul antara akuifer atas dan bawah.

Berdasarkan hasil kajian, beberapa langkah dicadangkan untuk menangani masalah klorida. Tanaman tembakau mestilah dijalankan pada jarak satu (1) km daripada sungai Kemasin dan juga pantai. Bagi kawalan kemasukan air masin di akuifer bawah, adalah dicadangkan, bahawa pendekatan yang sebaik-baiknya ialah dengan mengatur ekstraksi air daripada akuifer, diagih semula lokasi takat pengeluaran air dan melakukan pemantauan yang rapi dan terkini (termasuk menggunakan model SUTRA ini). Langkah ini adalah untuk memastikan keseimbangan permukaan antara, bilamana akuifer hendak dimajukan ke tahap pengeluaran semaksima mungkin.

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last but not least my wife, Nadirah Yahya who is very supportive and the six children who have endured my intermittent but sometimes long absence from home since embarking on this study.

I certify that an Examination Committee has met on 8th October 2001 to conduct the final examination of Ruslan b. Hassan on his Doctor of Philosophy thesis entitled "Analysis and Field Studies of Salt Water Intrusion in a Coastal Aquifer : A Case of Bachok, Kelantan" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommended that the Candidate be awarded the relevant degree. The Committee Members for the candidate are as follows:

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This Thesis submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy.

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Date : 13 DEC 2001

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

Ruslan Hassan

Date : 24th October 2001

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATIONS

b	thickness occupied by the indicated fluid (L)
c	concentration (ML^{-3})
C	the fluid solute mass fraction
C^*	the solute mass fraction of fluid sources
cumecs	cubic metres per second
D	hydrodynamic dispersion coefficient (L^2T^{-1})
D	the dispersion tensor
D_m	the apparent molecular diffusivity of solutes in solution in a porous medium including tortuosity effects
g	gravitational acceleration (LT^{-2})
h_F	fresh-water head (L)
h_s	salt-water head (L)
h	head in overlying aquifer (L)
I	identity tensor
K	hydraulic conductivity (a tensor quantity)
k	intrinsic permeability (L^2)
MARDI	Malaysian Agricultural Research and Development Institute
p	pressure ($ML^{-1}\ T^{-2}$)
ppm	parts per million
Q_p	fluid mass source
q	Darcy velocity (LT^{-1})
R	recharge (L)
S_F	specific storage in fresh-water zone