NUMERICAL MODELLING OF SURFACE AND SUBSURFACE FLOW INTERACTIONS IN PAYA INDAH WETLAND OF SELANGOR D. E., MALAYSIA

BAHAA-ELDIN ELWALI ABDEL RAHIM ELWALI

THESIS SUBMITTED IN FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SCIENCE
(PH. D.)

FACULTY OF SCIENCE
UNIVERSITY OF MALAYA
KUALA LUMPUR
2009

PEMODELAN NUMERIKAL INTERAKSI ALIRAN PERMUKAAN DAN SUB-PERMUKAAN DI TANAH LEMBAB PAYA INDAH, SELANGOR DE, MALAYSIA

BAHAA-ELDIN ELWALI ABDEL RAHIM ELWALI

TESIS YANG DIKEMUKAKAN UNTUK MEMPEROLEH IJAZAH
DOKTOR FASAFAH SAINS

FAKULTI SAINS
UNIVERSITI MALAYA
KUALA LUMPUR
2009

PREFACE

This thesis was prepared as one of the requirements for the Ph.D. Degree as well as a contribution to the formulation of the Paya Indah Water Resources Management Plan. The study has been carried out from March 2006 to December 2008. The Paya Indah Wetland Sanctuary with its ex-mining ponds at the southern portion and peat swamp forest at the northern portion may act as natural flood detention storage and therefore it is essential to understand the complex water balance of this wetland.

The research focused on the mathematical modelling approach to model the hydrology and the water balance of the Paya Indah wetland and the surrounding peat swamp forest. The mathematical model is based on the integrated hydrological modeling system, MIKE SHE.

This modeling system is particularly suited for wetland modeling because of its integration nature and the ability to count for both surface and subsurface flows and their interactions. Current and future researches will undoubtedly improve understanding of the basic concepts involved in this modelling project and may lead to more sophisticated flow and/or transport modelling(s).

The modelling protocol and related procedures in this thesis are therefore validated and aimed to be used as a management tool, thus the model subject to continuous refinement as new data become available and new questions arise.

This Ph.D. thesis contributes to the literature via participation in different national and international conferences; and publication in a few journals. Selective papers may include:

Bahaa-eldin E. A. R., Yusoff I., Azmi M. J, and Zainuddin O. 2009. Numerical modelling of tropical wetland catchment using MIKE SHE system: Calibration and Validation. *Water Resources Research*. Submitted

Bahaa-eldin E. A. R., Yusoff I., Azmi M. J, and Zainuddin O. 2009. Application of MIKE SHE modelling system to set up a water balance for Paya Indah wetland. *Journal of hydrology*. Submitted

Bahaa-eldin E. A. R., Yusoff I., Azmi M. J, and Zainuddin O. 2009. Predictions of hydrological modification on Paya Indah Wetland in Malaysia. *Water Resources Management*. Submitted.

Bahaa-eldin E. A. R., Yusoff I., Azmi M. J, and Zainuddin O. 2009. Simulation of integrated surface-water/groundwater flow for a freshwater wetland in Selangor State, Malaysia. *Geological Society of Malaysia, Bulletin* **55**: 95 – 100.

Bahaa-eldin E. A. R., Yusoff I., Azmi M. J, and Zainuddin O. 2007. MIKE SHE modelling of surface water and groundwater interaction. *National Geoscience Conference*. Kota Kinabalu, Sabah; Malaysia. 7-9 June. P5A-4.

Bahaa-eldin E. A.Rahim, Yusoff, I., Azmi M.J. and Zainudin O. 2006. Modelling of hydrological interactions at Paya Indah Wetland, Malaysia. *Proceedings of the 2nd Mathematics and Physical Science Graduate Conference.* Faculty of Science, Building, National University of Singapore. Singapore, 12 – 14 December.

ACKNOWLEDGEMENTS

The production of this thesis was made possible by the complementary funding from two different bodies including the Malaysian Ministry of Sciences, Technology & Environment under IRPA grant No. 02-03-08-003-EA003 and the University of Malaya under the Fellowship Scheme. Thanks are extended to the Department of Geology, Faculty of Science, and University of Malaya for all the provided facilities and assistance.

My sincerest thanks are due to my Advisor Assoc. Prof. Dr. Ismail Yusoff for his constant guidance and encouragement throughout the study period. The author duly appreciates the cooperation and support of Hj. Mr. Azmi M. Jaffri the Head of Department of Drainage and Irrigation Department (DID) of Malaysia; Dr. Zainudin Othman from the Malaysian Nuclear Agency.

Special gratefulness and appreciation are due to the helpfulness and gentleness of Mr. Salim from Drainage and Irrigation Department of Malaysia; Mr. Yagambaram V. (Baram) from Minerals and Geoscience Department of Malaysia/Selangor State Office; and Mr Ahamed Zaki from Malaysia Meteorological Department. I am also thankful Brother Mohammed who kindly and generously rescued the flow of work of this research project (Appendix K; Photo K.8).

I am so grateful for Ir. Miss Azizah Abdul Gadir and Ir. Mrs. Atikah Shafae from Drainage and Irrigation Department of Malaysia for their special treatment. A sincere gratitude is extended also to all the staff of Department of Geology of University of Malaya, Drainage and Irrigation Department of Malaysia and Minerals and Geoscience Department of Malaysia.

My final and special gratefulness and appreciation are due to my parents, sisters and brothers for their putting up with me and being patient all this while.

UNIVERSITI MALAYA

ORIGINAL LITERARY WORK DECLARATION

Name of Candidate: Bahaa-eldin Elwaleed Abdel Rahim (I.C/Passport No: C 0605298)

Registration/Matric No: SHC 050025

Name of Degree: Ph.D

Title of Project Paper/Research Report/Dissertation/Thesis ("this Work"):
Numerical Modelling of Surface and Subsurface Flow Interactions in Paya Indah Wetland of Selangor D.E., Malaysia

Field of Study: Water Resource Management

I do solemnly and sincerely declare that:

(1) I am the sole author/writer of this Work;
(2) This Work is original;
(3) Any use of any work in which copyright exists was done by way of fair dealing and for permitted purposes and any excerpt or extract from, or reference to or reproduction of any copyright work has been disclosed expressly and sufficiently and the title of the Work and its authorship have been acknowledged in this Work;
(4) I do not have any actual knowledge nor do I ought reasonably to know that the making of this work constitutes an infringement of any copyright work;
(5) I hereby assign all and every rights in the copyright to this Work to the University of Malaya ("UM"), who henceforth shall be owner of the copyright in this Work and that any reproduction or use in any form or by any means whatsoever is prohibited without the written consent of UM having been first had and obtained;
(6) I am fully aware that if in the course of making this Work I have infringed any copyright whether intentionally or otherwise, I may be subject to legal action or any other action as may be determined by UM.

Candidate's Signature

Date 24 November 2009

Subscribed and solemnly declared before,

Witness's Signature

Date 24/11/09

Name: Prof. Madya Dr. Ismail Yusoff
Designation: Jabatan Geologi
Universiti Malaya
50603 Kuala Lumpur

ABSTRACT

MIKE SHE modelling system was used to simulate the surface and subsurface flow interactions at the Paya Indah wetland catchment which covers an area of 242.21 km^2 and lies in Selangor State in west of Malaysian peninsular. The watershed hydrology has been changed considerably due to the increased anthropogenic activities, producing different hydro-ecological problems for the catchment. These include frequent peat forest fires and dropping of the surface water level in the Paya Indah lakes system. Being physically-based distributed hydrologic model, the MIKE SHE model set-up, therefore, requires a vast set of input data which precisely include rainfall, evapotranspiration, river cross-section, detailed soil hydraulic properties and aquifer characteristics. The model was calibrated and validated against three targets including surface water, channel flow and groundwater head. The multi-criteria evaluation and hydrographs visual judgments revealed that the model performance was satisfactory which allowed running the water balance and assessing the impact of the predicted future scenarios. Results revealed that elevated rate of the evapotranspiration losses and the landuse change impacts considerably influence the water level in the Paya Indah lakes system at rechargeable area of peat cover. On contrast during both calibration and validation periods it was found that groundwater abstraction controlled the dynamics of the groundwater within a large zone covered most of the downstream area of the catchment. The impact of over-abstraction at the Megasteel Co. Ltd. property on surface water level of the Paya Indah lakes system was investigated. It was found that the exchangeable flow between unsaturated zone and saturated is very limited at the area of the lakes system due to occurrence of impermeable clay layer of 10 m – 15 m thick and of a low permeability of an average value of 4.8E-7 m/s which acts as barrier that controls exchangeable flow between the unsaturated and saturated zones at this part of the catchment. Nonetheless, it was found that the current rate of pumping had influenced the groundwater table to drop as low as ~ 4.0 m below sea level within the influenced zone of the Megasteel pumping wells which in turn, may rise up the potentiality of seawater intrusion and deep aquifer collapse. Looking at the overall water balance it is clear that evapotranspiration accounted for the largest water loss of ~ 60 % of the total rainfall. The model was slightly underestimated the total water balances by 0.45 % and 0.21 % the total rainfall for the calibration and validation periods respectively. Hydrological scenarios that likely might alter the quantity and timing of water exiting the Paya Indah wetland catchment were simulated with the validated model (baseline scenario) in order to evaluate their impacts on the watershed's hydrology. In this context, decreasing of the North-Inlet-Canal (SWL1) inflow as a result of launching the flood mitigation new channel that diverts Cyberjaya water towards Klang River Basin is one of the expected impacts of the full development of the adjacent Cyberjaya City and E-village. While as the results revealed that the deep aquifer might deplete partially or totally depending on the quantity of the groundwater withdrawal.

PEMODELAN NUMERIKAL INTERAKSI ALIRAN PERMUKAAN DAN SUB-PERMUKAAN DI TANAH LEMBAB PAYA INDAH, SELANGOR D.E., MALAYSIA

ABSTRAK

Sistem pemodelan MIKE SHE telah digunakan untuk mengsimulasi interaksi aliran air permukaan dan sub-permukaan di lembangan tanah lembab Paya Indah yang merangkumi kawasan seluas 242.21 km^2 yang terletak di Negeri Selangor, di barat Semenanjung Malaysia. Hidrologi lembangan ini telah berubah secara ketara akibat peningkatan aktiviti antropogenik yang menyumbang kepada masalah hidro-ekologi lembangan. Ini termasuklah kekerapan kebakaran hutan paya bakau dan kejatuhan paras air di sistem tasik-tasik Paya Indah. MIKE SHE merupakan model hidrologi dasaran fizikal yang memerlukan pemasukan data yang banyak yang diantaranya termasuklah data kerpasan, evapotranspirasi, keratan rentas sungai, sifat hidraulik tanih dan ciri-ciri akuifer. Model ini telah dikalibrasi dan divalidasi dengan tiga sasaran kalibrasi termasuklah aras air permukaan, saliran dan air tanah. Penilaian yang dibuat menggunakan multi-kriteria dan pengvisualan hidrograf menunjukkan kebolehan model ini adalah memuaskan dan membolehkan kajian keseimbangan air dan kesan senario masa depan diramalkan. Hasil kajian ini menunjukkan peningkatan kadar kehilangan air secara evapotranspirasi dan perubahan guna tanah memberi perubahan ketara kepada aras air di dalam sistem tasik Paya Indah di kawasan imbuhan yang ditutupi oleh tanah gambut. Secara perbandingannya pula, sepanjang tempoh masa kalibrasi dan validasi adalah didapati pengambilan air tanah yang mengawal dinamik air tanah di dalam zon luas yang merangkumi sebahagian besar kawasan hilir lembangan. Kesan pengambilan air tanah secara ketara oleh Syarikat MegaSteel Sdn. Bhd kepada aras air di tasik-tasik Paya Indah juga dikaji. Adalah didapati aliran yang bertukarganti di antara zon tak tepu dan zon tepu amat terhad bagi kawasan tasik dimana terdapatnya lapisan lempung tak telap yang berketebalan antara 10 m-15 m dengan kadar ketelapan yang rendah dengan nilai puratanya adalah 4.8E-7 m/s yang juga bertindak sebagai penghalang kepada aliran tukarganti di antara zon tak tepu dan zon tepu di sebahagian lembangan ini. Apapun adalah didapati kadar pengepaman air tanah pada masa ini telah menyebabkan aras air tanah jatuh sedalam 4.0 m di bawah paras laut bagi kawasan yang dipengaruhi oleh telaga pengepaman Megasteel yang berpotensi besar menjadi penyebab kepada intrusi air laut dan kegagalan akuifer dalam. Berdasarkan keseimbangan air secara keseluruhan adalah jelas didapati evapotranspirasi menjadi penyumbang besar kepada kehilangan air lembangan sehingga mencapai 60 % dari keseluruhan kerpasan. Model ini memberi kurangan anggaran keseimbangan air semasa proses kalibrasi dan validasi masing-masing sebanyak 0.45% dan 0.21 % dari jumlah hujan keseluruhan. Model yang telah divalidasi digunakan untuk melihat senario hidrologi yang bakal mengubah kuantiti dan masa kedapatan air di lembagan tanah lembab Paya Indah bagi menilai kesan perubahan kepada tindakbalas hidrologi lembangan. Bagi kontek ini, pembangunan sepenuhnya kawasan Bandar Cyberjaya dan E-Village yang bersebelahan dengan model lembangan akan meyebabkan terbentuknya saliran pemulihan baru yang mengalihkan aliran air dari Cyberjaya ke lembagan Sg. Klang dan menghilangkan kemasukan air dari saluran North-Inlet (SWL1). Disamping itu, keputusan pemodelan menunjukkan akuifer dalam mungkin mengalami kejatuhan secara separa atau keseluruhan bergantung kepada kuantiti pengeluaran air tanah.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Paya Indah Wetland Catchment

LIST OF PHOTOGRAPHS

LIST OF SYMBOLS AND ABBREVIATIONS

b.s.l.:	below the sea level
BH:	Borehole
CE:	Coefficient of efficiency
DID:	Drainage and Irrigation Department of Malaysia
ET:	Actual Evapotranspiration
Evap:	Evaporation
Exfilt:	Exfiltration
GIS:	Geographic information system
Infilt:	Infiltration
k:	Hydraulic conductivity
Kg:	Kampung (village)
KLIA:	Kuala Lumpur International Airport
m:	Meter
M:	The reciprocal of Manning's n
MAE:	Mean average error
ME:	Mean error
MLD:	Mined Land
MMD:	Malaysia Meteorological Department
n:	Manning's number
NSECL:	North-South Expressway Central Link
OL:	Overland flow
P:	Probability
P:	Precipitation

PRG:	Perang soil series
QG,in:	Groundwater flow into the model area
QG,out:	Groundwater flow out of the model area
QS:	Surface water inflow
QS,out:	Surface water flow out of the model area
R:	hydraulic radius
R:	Coefficient of correlation
R^2:	Pearson type-I distribution index
RMSE:	Root mean square error
Sc:	Storage coefficient of groundwater
S:	channel bed slope
SBM.	Serdang-Bungor-Munchong soil series
Sg:	Sungai (River)
SKG:	Selangor-Kanchung soil series
STD_{res}:	Standard deviation of the residuals
SZ:	Saturated zone
UZ:	Unsaturated zone
T:	Transmissivity
Trans:	Transpiration
V:	Flow velocity
ΔS:	Change in storage of surface water, unsaturated zone and groundwater (Ss+(Suz+(S sz)