UNIVERSITI PUTRA MALAYSIA

MODELLING OF INTERCEPTOR DRAINAGE EFFECT ON WATER TABLE AND SALINITY LEVELS IN AGRICULTURAL AREA OF ABYEK PLAIN, IRAN

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By

KARIM GHORBANI

Thesis Submitted to the School of Graduated Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2016

DEDICATION

Dedicate to my wife “Masoumeh” and my son “Amir Hossein”

Abstract of thesis presented to the Senate of Universiti Putra Malaysia, in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

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January 2016

Chairman : Aimrun Wayayok, PhD
Faculty : Engineering

Water and soil are two major elements in Nature that play critically important roles in agricultural production. Over the past decades, wide areas of irrigated lands have been faced with the problem of high groundwater tables which cause salinization and degradation of broad areas of irrigated or non-irrigated land. Due to land constraints and growing demand for food, it is essential to control the environmental instability and manage the precious natural resources. On the other hand, underground drainage schemes are widely being used to manage the groundwater table and reduce the salinity level in the arid and semi-arid regions, especially in Iran. Since the design and investigation of drainage system performance typically are costly and time consuming, a modelling approach can be a suitable technique to reduce the costs and at the same time offer quick access to highly accurate Results. In addition, employing a computer model can help to determine the hydrogeological parameters of aquifer and predict the groundwater flow behaviour in future conditions. Therefore, the main purpose of this research is to develop a practical technique in design of efficient drainage systems for implementation to protect agricultural area and solve the related problem of salinity using three-dimensional groundwater flow model (MODFLOW) and solute transport model (MT3D).

For this purpose, a total of ninety-nine observational wells were installed adjacent to the existing drainage channel in the Abyek Plain, Iran to monitor groundwater fluctuation and changes in salinity level. Groundwater level was measured monthly from December 2010 to December 2014. In addition, the quality of water and soil was tested at every season (January, April, August. and November) during the four years. The analysis of the recorded data indicated that level of groundwater on the study site has been dropped in a wide - 500 m from the existing drainage system. Evaluation of measured data also indicted that the salinity level had been reduced substantially during the four-year period. The MODFLOW models that is supported by groundwater modelling system (GMS), was calibrated to the study area in two states, the steady state and transient state to reproduce the measured data for one year and three years, respectively. The calibrated model was used to predict the future conditions and possible changes in groundwater level. According to simulated results, water table can be lowered approximately 1.48 and 1.59 m in August 2015 and 2020, respectively. Six drainage scenarios together with existing drains were defined in the calibrated model to simulate the function of the drains separately. Simulated results revealed that installation of an additional parallel interceptor drainage system at a distance of 1000 m from the existing drainage scheme could be a most effective drainage design. This design is able to maintain the groundwater table at an acceptable level of ground surface and improve large areas of the study site compared to other designs. The solute transport model (MT3D) was also calibrated in the transient state to reproduce observed salinity data. The calibrated model was used to simulate magnitude of the electrical conductivity of groundwater from 1st January 2011 to 30th December 2013. The results of this study indicated that the model has the ability to accurately predict dissolved solids in groundwater. Results also revealed that reduction in salinity level varied in the range between 4.4 and 137.7 dS.m^{-1} during the three years. As a result, modelling can be a feasible technique for decision makers to design efficient drains in agricultural land faced with a high water table and salinity problem.

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

PEMODELAN PEMINTAS SALIRAN UNTUK PENGURUSAN KETINGGIAN AIR BAWAH TANAH DAN KADAR KEMASINAN DI KAWASAN PERTANIAN TANAH RATA ABYEK, IRAN

Oleh

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Air dan tanah adalah dua elemen utama dalam Alam Semulajadi yang memainkan peranan amat penting dalam pengeluaran pertanian. Sejak beberapa dekad yang lalu, kawasan pengairan telah yang luas berhadapan dengan masalah air bawah tanah yang tinggi yang menyebabkan kemasinan dan degradasi bagi tanah pengairan atau bukan pengairan yang besar. Disebabkan kekurangan tanah dan permintaan yang semakin meningkat untuk makanan, ia adalah penting untuk mengawal ketidakstabilan alam sekitar dan menguruskan sumber-sumber semula jadi yang berharga. Sebaliknya, skim saliran bawah tanah digunakan secara meluas untuk menguruskan air bawah tanah dan mengurangkan tahap kemasinan di kawasan gersang dan separa gersang, terutama di Iran. Oleh kerana reka bentuk dan penyiasatan prestasi sistem saliran biasanya adalah mahal dan memakan masa, pendekatan pemodelan boleh menjadi teknik yang sesuai untuk mengurangkan kos dan pada masa yang sama menawarkan akses cepat dengan keputusan yang sangat tepat. Selain itu, penggunaan model komputer boleh membantu untuk menentukan parameter hidrogeologi akuifer dan meramalkan tingkah laku aliran air bawah tanah untuk keadaan di masa depan. Oleh itu, tujuan utama kajian ini adalah untuk mereka bentuk sistem saliran berkesan untuk dilaksanakan di kawasan pertanian bagi menyelesaikan air bawah tanah yang tinggi dan masalah yang berkaitan kemasinan menggunakan aliran air bawah tanah tiga dimensi model (MODFLOW) dan model pengangkutan bahan larut (MT3D).

Untuk tujuan ini, sebanyak 99 telaga pemerhatian telah dipasang bersebelahan dengan terusan saliran yang sedia ada di tanah rata Abyek, Iran untuk memantau turun naik air bawah tanah dan perubahan tahap kemasinan. Paras air bawah tanah telah diukur setiap bulan dari Disember 2010 hingga Disember 2014. Selain itu, kualiti air dan tanah telah diuji pada setiap musim (Januari, April, Ogos, dan November) dalam tempoh empat tahun. Analisis data yang direkodkan menunjukkan bahawa paras air bawah tanah di tapak kajian telah menurun dengan ketara pada jark 500 m daripada sistem saliran yang sedia ada. Penilaian data yang diukur juga mendakwa bahawa tahap kemasinan telah dikurangkan dengan ketara dalam tempoh empat tahun. Model-model MODFLOW yang disokong oleh sistem pemodelan air bawah tanah (GMS), telah ditentukan bagi kawasan kajian pada dua negeri, keadaan mantap dan sementara untuk menghasilkan

data yang diukur selama satu tahun dan tiga tahun. Model ditentukur telah digunakan untuk meramal keadaan masa depan dan kemungkinan perubahan dalam paras air bawah tanah. Menurut keputusan simulasi, aras air boleh diturunkan kira-kira 1.48 dan 1.59 m pada bulan Ogos 2015 dan 2020, secara berasingan. Enam senario saliran bersama-sama dengan saliran sedia ada di dalam model ditentukur untuk mensimulasikan fungsi saliran secara berasingan. Hasil simulasi menunjukkan bahawa pemasangan sistem pemintas saliran selari tambahan pada jarak 1000 m daripada skim saliran yang sedia ada boleh menjadi reka bentuk saliran yang paling berkesan. Reka bentuk ini mampu mengekalkan air bawah tanah pada tahap yang boleh diterima di permukaan tanah dan meningkatkan kawasan-kawasan tapak kajian berbanding dengan reka bentuk yang lain. Model pengangkutan bahan larut (MT3D) juga ditentukur di keadaan sewentara untuk menghasilkan semula data kemasinan yang diperhatikan. Model ditentukur digunakan untuk mensimulasikan magnitud kekonduksian elektrik air bawah tanah dari 1 Januari 2011 hingga 30 Disember 2013. Keputusan kajian ini menunjukkan bahawa model ini mampu untuk meramalkan pepejal terlarut dalam air bawah tanah itu. Keputusan juga menunjukkan bahawa pengurangan tahap kemasinan berubah dalam julat di antara 4.4 dan 137.7 dSm^{-1} dalam tempoh tiga tahun. Akibatnya, pemodelan boleh menjadi teknik yang berkemungkinan untuk pembuat keputusan dan mereka bentuk saliran dengan cekap dalam pengurusan tanah pertanian yang berhadapan dengan masalah paras air dan kemasinan yang tinggi.

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I certify that a Thesis Examination Committee has met on 15 January 2016 to conduct the final examination of Karim Ghorbani on his thesis entitled "Modelling of Interceptor Drainage Effect on Water Table and Salinity Levels in Agricultural Area of Abyek Plain, Iran" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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A	Cross- sectional area of water flow
$\frac{\partial e}{\partial x}$	Concentration gradient
B	The width of the cannel bottom
BIAS	Bias error
C	Concentration of contaminant dissolved
C_d	Hydraulic conductance
C_p	Precise heat
C_s	Concentration of source
D	Distance between drain and barrier layer
D_f	Diffusion coefficient
D_y	Mean percent dilatation
$\frac{dh}{dx}$	Hydraulic gradient
$e_{a.}$	Saturate pressure of vapor
e_d	Mean vapor pressure
EFF	Model efficiency
E_c	Electrical concentration
E_t	Evaporation
F	Salt flow per surface unit
H_1	Elevation of hydraulic head
H_2	Elevation of drain bottom
H_L	Depth of water table in second cross-sectional area
K_1	Hydraulic conductivity above drain
K_2	Hydraulic conductivity below drain
K_{xx}	Horizontal Hydraulic conductivity
K_{yy}	Vertical Hydraulic conductivity
K_{zz}	Radial Hydraulic conductivity
L	Drain spacing
MAE	Mean absolute error
MSE	MEAN Square error
MSL	Elevation of above sea level
O	Observation data
q_1	Interflow from downstream
q	Drainage coefficient
q_s	Volumetric flux of water
q_x	Unit flow in X direct
q_w	Specific discharge
r	Correlation efficiency
R	Hydraulic radius of drain
R_k	Chemical reaction
RMSE	Root mean square error
r_s	Net resistance value for diffusion
S	Simulated data
SEE	Standard error
s_s	Specific storage
s_y	Specific yield
t	time

T	Transmissivity of aquifer
V	Velocity of water flow
V_i	Seepage per water velocity
v_b	Volume of water released from storage
v_d	Drainable water volume
v_t	Total the soil volume
v_w	Bulk volume of portion
W	Volumetric flux
X	Distance from drain
y	Average depth of groundwater table
Z	Side slope of channel
θ	Porosity

CHAPTER 1

INTRODUCTION

1.1 Background

Water and soil are among the most crucial elements in Nature and play significant roles in crop productions. On the other hand, threats to agricultural land by salinization among others have become a serious concern in arid and semi-arid areas. Considering that there is relatively limited land for development and even as there is a growing demand for food, it is essential that all attempts should be made to conserve soil water resources in all aspects.

A broad area of the cultivated land has been faced with salinization and degradation risk, especially in Iran. The Abyek plain that covers an area of about 2000 km^2 and located at 80 km west of Teheran, Iran, suffers severely from high salinity and groundwater table problem. The Northern part of the plain has gradually lost its productivity and converted to saline land due to rise in the groundwater table and increased salinity level of water and soil. Groundwater table in the South portion of the plain has reached the surface land, and the salinity level has increased to a range between 80 and 280 dSm^{-1}. Soil salinity and high groundwater table have a severe impact on plant root growth and cause reduction in agricultural yield. Excess water in the root zone decreases yields of wheat and barley by an average of 14 and 4 bus/ac, respectively (Rigaux & Singh, 1977). Over irrigation, impermeable layer existence and lack of adequate subsurface drainage system are major factors in the rise of the groundwater table and spread of salinity. Seasonal floods from upstream rivers entering the plain are another significant factor for the rise in the level of the groundwater table and increase of salts. A drainage system has been constructed at a distance of about 1500 m from the agricultural area to intercept groundwater flow. It was expected that this scheme would be able to protect the agricultural area and convert the saline land into arable land. However, given the complicated behavior of groundwater in aquifers and based on the performance of the interceptor drainage systems, it is difficult to justify proposing the system for other areas. Investigation of solute transport often requires a solution to the complex equations. Considering the salinity and high groundwater problems in Iran, it is expected that the findings of this study will encourage the exploration of appropriate solutions for the salinity and shallow groundwater table problem. Although there have been, numerous studies conducted in efforts to improve the performance and efficiency of drainage systems, but besides the lowering of the groundwater level and leaching out of the salt, there is still a gap in the literature on the construction of drains, cost and time factors, design type and appropriate installation location.

1.2 Hypothesis

Based on the evidences, the soil salinization domain under different factors is continuously being expanded, especially in arid and semi - arid regions. In addition to the surface flow and seepage from upstream areas such as irrigation canals, over – exploitation of groundwater can lead to a decrease in the water quality and the extent of the soil or water salinity (Arasteh, 2010). In the past, the level and the hydraulic gradient of fresh water has been upward in the studied aquifer, Iran, so that saline water was situated below the fresh water. During the recent decade, due to lack of a suitable drainage system, the upper layers of the soil profile have been gradually saturated by saline water as a result of the flow gradient being reversed. It means the fresh water gradually has been replaced by saline water. Based on this theory, it is expected, that the determination of a hydrological relationship between subsurface drainage system and groundwater table, could contribute to the exploration of a possible solutions to prevent the expansion of saline land toward the (cultivated) upstream portions of the area. Therefore, the function of a subsurface drainage system in solving the salinity problem and changing the hydraulic gradient direction of saline water movement is questionable.

1.3 Problem Statements

The sustainability of an agricultural area is threatened by a high groundwater table and salinization. About 14% of agriculture land in Iran, is adversely affected by salinity problems. In the Abyek plain, the fertile land has converted to salt-affected soil and the affected area has been expanding in recent years. Increase in water table level and salinity are the main causes of reduction in crop yields, especially in semi-arid region (Homaee et al., 2002). Main reasons of salinization of the study area can be attributed parent material, water shortage to leach salt out, water seepage from irrigated land, high evaporation and high groundwater table, lack of drainage system, and seasonal floods. Annual precipitation is relatively low and insufficient to remove the salt from root environment. A drainage system has been constructed at a distance of about 1500 m from the agricultural area to intercept groundwater flow. It was expected that this scheme would be able to protect the agricultural area and convert the saline land into arable land. Modelling is a suitable approach in water resources studies, which todays is widely used in studies and designs, especially in groundwater flow. Despite, there are various studies on groundwater management, but modelling rarely was used to design the agricultural drainage system. Thus, the use of computer model not only can reduce the high costs of design but also results obtained can be reliable to implement.

Groundwater flow is complex, so investigation of fluctuations and behaviour of water flow in an aquifer is difficult because it requires sufficient knowledge. Thus, the use of analytical method for investigating of groundwater fluctuation requires application of complicated equations, especially in the aquifer of plain, as a results the design of drainage system based on the present methods may be ineffective to attain an aim defined. Hence, effect of drainage system on groundwater table needs to be evaluated using simulation process that already never or rarely has been employed.

During the past few decades, despite a large area of the agricultural land being served by the irrigation system, a considerable portion of the land still lack a subsurface drainage system to maintain the water table at the desired level. Therefore, high groundwater table and salinity are two major problems in the study area and a suitable subsurface drainage system is urgently needed to solve the problem and prevent further loss of fertile arable land.

Experience indicates that installation and maintenance of subsurface drainage systems are invariably time consuming and costly and these are the factors that have prevented the construction of much-needed drainage systems and in the long-term the damage will be considerable. To avoid this it is essential to develop a proper method to design and implement a drainage system that is cost-effective and efficient.

There appears to be a lack of expertise and experience in the areas of land reclamation and rehabilitation of saline plains. Although there have been many drainage schemes implemented in the irrigated areas to control groundwater table and salinity, there has been no attention paid to the reclamation and rehabilitation of affected non-cultivated areas, which will eventually encroach into the cultivated areas. As such the cultivated areas are exposed to potential salinization. In light of this, there is therefore an urgent necessity to conduct comprehensive research on the saline plain to investigate practical techniques to solve the problem.

The importance of the present research is the development of a practical solution for the problems mentioned above that concern the agricultural land and its activities in the Abyek plain of Iran based on the evaluation of performance of the interceptor drainage system.

1.4 Objective of the study

The main objective of this study is to attain a practical approach in design of efficient drainage systems to protect agricultural lands from the risk of water table and salinization using numerical models. The specific objectives of this research are:
1. To investigate and evaluate the effectiveness of the existing interceptor drainage system in lowering water table and salinity levels in the aquifer of the study area.

2. To apply a hydrological models (MODFLOW) to the study area with the existing interceptor drain to predict the water table depths in several future periods.

3. To use the MODFLOW and MT3D models to simulate the effect of different modifications to the interceptor drain on water table depths and salinity levels with respect to the agricultural requirements.

1.5 Scope of the study

The scope of this study encompasses the calibration of a numerical model to predict future conditions of the study region and design an efficient drainage system. For this purpose. A field study was carried out on a plain located to the west of Tehran and south of Abyek city. The study site is relatively flat and covered by saline soil ranging between 80 and 280 dS.m-1 and with the groundwater reaching a critical depth. The following explanation provides a more detailed description of the scope of this study:
1. Collecting daily and monthly evaporation, precipitation data from the adjacent stations of the site.
2. Monitoring on a monthly basis the existing drainage system installed on the site and measuring groundwater table through observation wells installed in the vicinity of the existing drainage system from above mean sea level (MSL).

3. Determining of soil salinity and measuring the salinity level of groundwater in every season (November, January, April and August). Soil sampling from different layers to determine percent distribution of soil particles and identify texture and soil classification.

4. Measuring hydraulic conductivity via auger hole method at several sub-sections of the study site in order to generate hydraulic conductivity layer and hydraulic conductance on the vicinity of the drains.

5. Evaluation of several models related to groundwater flow and drainage systems to select a proper model for simulation of groundwater fluctuation and solute transport.

6.Generation of the required layers to enter the model such as top layer, starting layer ,hydraulic conductivity, recharge, evaporation and bottom layer and spatial distribution of observation well.

7. Calibration of the models in two states, steady and transient state to represent measured data. The calibration period continues until the model is able to simulate measurement accurately via adjusting some parameters.

8. Determination of sensitivity model to input data to understand which parameters have greater effect on the results.

Assessment of several scenarios of drainage system to simulate and select an effective option for implementation based on appropriate indicators.

9. Using the calibrated model to predict future condition of aquifer.

1.6 Limitation

1. Number of meteorological stations to obtain annual precipitation and evaporation were limited
2. Manual method was used to record water table in every observation well that may affect on measured data.
3. Duration of the measurement was 48 months that may affect to accuracy of calibration hence long-term data can increase the accuracy of the work
4. There is a gap (interval) between construction period of drainage system and commencement of measurements.

1.7 Organization of the thesis

This thesis is divided into five chapters to explain the problems, recognize the research objective, review the literature, design the research methodology, and discuss the obtained results and finally provide the conclusion.

In Chapter One, besides the presentation of general information associated with the proposed research issue, the problem statement is identified, followed by the research objective, scope of the study, significance of the study and expected outcomes. The chapter ends with a concluding summary.

Chapter Two, provides a review of the literature and introduces and discusses the existing theory underlying this work. Also included is research associated with the study objective. Based on the evidence in the literature, existing gaps are identified and discussed while other relevant works in the literature are presented, analyzed and explained.

The method and materials required in this current study comprise the methodology in Chapter Three. Location of the study area, data collection, sampling, classification, of necessary equipment and software needed together with relevant research instruments are presented and considered.

Chapter Four is an important part of the study and encompasses the analysis and findings of the experiments and collected data. Also, the reasons for the use of the computer models are discussed in detail Furthermore, comprehensive examples based on the study objective are discussed to better understand the main contribution and innovation of this study.

In Chapter Five, which is the concluding chapter, the conclusion of the whole study is presented including an overview of the answers to the research objectives proposed in Chapter One. This chapter also presents the contributions of the study and makes some recommendations for further research.

REFERENCES

Abrol, I. P., Yadav, J. S. P., & Massoud, F. I. (1988). Salt-affected soils and their management. In F. a. A. Organization (Ed.), *Soil Bulletin* (Vol. 39). Rome: FAO

Abu-El-Sha'r, W. Y., & Hatamleh , R. I. (2007). Using Modflow and MT3D Groundwater Flow and Transport Models As a Management Tool for the Azraq Groundwater System. *Jordan Journal of Civil Engineering, 1*(2), 153-172.

Afinowicz, J. D., Munster, C. L., & Wilcox, B. P. (2005). Modeling effects of brush management on the rangeland water budget: Edwards plateau Texas. *Journal of American Water Resources, 41*(1), 181–193.

Akhbari, M., & Grigg, N. S. (2014 a). Water Management Trade-offs between Agriculture and theEnvironment: A Multiobjective Approach and Application. *Journal of Irrigation and Drainage Engineering, 5*(11), 1-11. doi: 10.1061/(ASCE)IR.1943-4774.0000737.©2014

Akram, M., Azari, A., Nahvi, A., Bakhtiari, Z., & Safaee, H. D. (2013a). Subsurface Drainage in Khuzestan, Iran: Environmentally Revisited Criteria. *Irrigation and Drainage, 62*(3), 306-314. doi: 10.1002/ird.1774

AL-Fatlawi, A. N. (2011). the Application of the Mathematical model (Modflow) to simulate the behavior of Groundwater flow in Umm Er Radhama Unconfined Aquifer. *Euphrates Journal of Agriculture Sciences, 3*(1), 1-16.

Ali, R., Elliot, R., Ayars, J., & Stevens , E. (2000). Soil Salinity Modeling over Shallow Water table *Journal of Irrigation and Drainage Engineering, 126*, 234-242.

Amatya, D., Jha, M., Edwards, A. E., Williams, T. M., & Hitchcock, D. R. (2011). SWAT-based streamflow and embayment modeling of karst-affected Chapel branch watershed, South Carolina. *American Society of Agricultural and Biological Engineers, 54*(4), 1311–1323.

Amer, M. H., & Ridder, N. A. (1989). Land drainage in Egypt (pp. 377). Cairo Drainage Research Institute,Egypt.

Andrea, L., Welker, A. M., Robert, B., & Gilbert , A. M. (2003). Calibration of Flow and Transport Model with a Bench-Scale Prefabricated Vertical Drain Remediation System. *Journal of Geotechnical and Geoenvironmental Engineering, 129*(1), 81-90. doi: 10.1061//ASCE/1090-0241/2003/129:1/81

Aquaveo, L. L. C. (2009). Groundwater Modeling System (Version Version 7.1) [build date May 27, 2009]. UT, USA. Retrieved from http://www.aquaveo.com/software/gms

Arasteh, P. D. (2010). *Soil Salinity Change Detection in Irrigated Area under Qazvin Plain Irrigation Network Using Satellite Imagery*. Paper presented at the XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR), Québec City, Canada.

Aryafar, A., Doulati Ardejani, F., & Singh, R. N. (2009). Numericalmodelling of groundwater inflow froma confined aquifer into Sangan open pit mine, northeast of Iran. *International Journal of Geomechanics and Geoengineering, 4*(3), 189-198.

Ashraf, M., Rahmatullah, T. M., Maqsood, T., & M.A. Tahir, M. A. (2006 a). Contribution of Shallow Water Table to Salinity / Sodicity Development under Fallow and Cropped Conditions. *Journal of Agriculture science., 43*(1-2), 7-12.

Ashraf, M., Rahmatullah, T. M., Maqsood, T., & M.A. Tahir, M. A. (2006 b). Contribution of Shallow Water Table to Salinity / Sodicity Development under Fallow and Cropped Conditions. *Journal of Agriculture science., 43*(1-2), 7-12.

Askri, B., Bouhlila, R., & Job, J. O. (2010). Development and application of a conceptual hydrologic model to predict soil salinity within modern Tunisian oases. *Journal of Hydrology, 380*(1-2), 45-61. doi: 10.1016/j.jhydrol.2009.10.022.

Ayars, J. E., Christen, E. W., & Hornbuckle, J. W. (2006). Controlled drainage for improved water management in arid regions irrigated agriculture. *Agricultural Water Management, 86*(1-2), 128-139. doi: 10.1016/j.agwat.2006.07.004.

Bahcec, I., Cakir, R., Nacar, A. S., & Bahcec, P. (2008). Estimating the Effect of Controlled Drainage on Soil Salinity. *Turky Journak of Agricultur, 32*(2008), 101-109.

Bahrami, S., Doulati Ardejani, F., Aslani, S., & Baafi, E. (2014). Numerical modelling of the groundwater inflow to an advancing open pit mine: Kolahdarvazeh pit, Central Iran. *Environmental Monitoring and Assessment*. doi: 10.1007/s10661-014-4025-x.

Banejad, H., Mohebzadeh, H., Ghobadi, M. H., & Heydari, M. (2014). Numerical Simulation of Groundwater Flow and Contamination Transport in Nahavand Plain Aquifer,West of Iran. *Journal Geological Society of India*, *83*, 83-92.

Bear, J., & Cheng, A. H. D. (2010). *Modeling Groundwater Flow and Contaminant Transport* (Vol. 23). New York: Springer.

Bhattacharjya, R. K. (2011). Solving Groundwater Flow Inverse Problem Using Spreadsheet Solver. *Journal of Hydrologic Engineering, 16*(5), 472-477. doi: 10.1061/(asce)he.1943-5584.0000329

Bilal, S. M., & Sarwar, T. (2008). Effect of Tube Well Drainage on Water Logging And Salinity in Kafur Dheri Unit Peshawar. *Sarhad journal of Agricultural and, 24*(1), 49-58.

Borgia, A., Cattaneo, L., Marconi, D., Delcroix, C., Rossi, E. L., Clemente, G., . . . Tozzato, E. (2011). Using a modflow grid, generated with gms, to solve a transport problem with tough2 in complex geological environments: The intertidal deposits of the venetian lagoon. *Computers and Geosciences, 37*(6), 783-790. doi: 10.1016/j.cageo.2010.11.007

Borisov, V. A. (1990). Groundwater resources and their use in national economy. Tashkent: fan.

Bos, M. G. (1994). Land drainage: why and how?. (Vol. 16, pp. 23-31). ILRI Publication,Wageningen.

Cammalleri, C., Rallo, G., Agnese, C., Ciraolo, G., Minacapilli, M., & Provenzano, G. (2013). Combined use of eddy covariance and sap flow techniques for partition of ET fluxes and water stress assessment in an irrigated olive orchard. *Journal of Agricutural Water Management, 120*, 89-97.

Chitrakar, P., & Sana, A. (2015). Groundwater Flow and Solute Transport Simulation in Eastern Al Batinah Coastal Plain, Oman: Case Study. *Journal of Hydrologic Engineering*, 0501-5020. doi: 10.1061/(asce)he.1943-5584.0001284.

Cho, J., Mostaghimi, S., & Kang, M. S. (2010). Development and application of a modeling approach for surface water and groundwater interaction. *Agricultural Water Management, 97*(1), 123-130. doi: 10.1016/j.agwat.2009.08.018.

Cooper, H. H., & Jacob, C. E. (1964). A generalized graphical method for evaluating formation constants and summarizing well field history. *AmericanGeophysicsUnion Transactions, 27*, 526-534.

Daniel, B. S., Kuo-Chin, H., Mark, A. P., Mark, D. A., Neil, B. d., & Julia, R. W. (1998). A comparison of estimated and calculated effective porosity. *Hydrogeology Journal, 6*, 156-165.

Darzi-Naftchali, A., Mirlatifi, S. M., Shahnazari, A., Ejlali, F., & Mahdian, M. H. (2013). Effect of subsurface drainage on water balance and water table in poorly drained paddy fields. *Agricultural Water Management, 130*, 61-68. doi: 10.1016/j.agwat.2013.08.017.

Datta, K. K., Dejong, C., & Singh, O. P. (2002). Feasibility of Subsurface Drainage for Salinity Control InThe Trans-Gangetic Region of India. *Journal of irrigation & Drainage, 51*, 275-292. doi: 10.1002/ird.61.

Doulati Ardejani, F., Singh, R. N., Baafi, E., & Porter, I. (2003). A finite element model to: 1. predict groundwater inflow to surface mining excavations. *Mine Water and the Environment, Development and Sustainability, 22*(1), 31–38.

Evan , W. C., James, E. A., & John , W. H. (2001). Subsurface drainage design and management in irrigated areas of Australia. *Irrigation Science, 21*(1), 35-43. doi: 10.1007/s002710100048.

Fallah-Mehdipour, E., Haddad, O. B., & Mariño, M. A. (2014). Genetic Programming in Groundwater Modeling. *Journal of Hydrologic Engineering*, 1-13. doi: 10.1061/(asce)he.1943-5584.0000987.

Fattahi, M. (2009). *Optical dating of Holocene alluvial sediments from the Qazvin plain, central Iran*. Paper presented at the geology, Tehran.

Ferjani, N., Dhagari, H., & Morri, M. (2012). Estimation of root-zone salinity using SaltMod in the irrigated area of Kalaât El Andalous (Tunisia). *Agriculture and Biology Journal of North America*, *3*(3), 105-116. doi: 10.5251/abjna.2012.3.3.105.116.

Fethi, L., Ammar, M., Mourad, B., Jamila, T., & Christian, L. (2012). Implementation of a 3-D groundwater flow model in a semi-arid region using MODFLOW and GIS tools: The Zéramdine–Béni Hassen Miocene aquifer system (east-central Tunisia). *Computers & Geosciences*, *48*, 187-198. doi: 10.1016/j.cageo.2012.05.007.

Framji, K. K., Garg, B. C., & Kaushish, S. P. (1984). *Design Practices of Open Drainage Channels in an Agricultural Land Drainage System: A Worldwide Survey*. Paper presented at the Internatinal Commission Irrgation Drainage New Dehli.

Ghafari, H., & Neyshabouri, M. R. (2012). Salinity and Sodicity Effects of Irrigation Water on Soil Physical Quality Criteria. *Iranian Journal of Water and Soil, 26*(1), 2012.

Ghassemi, F., Jackeman, A. J., & Nix, H. A. (1995). Salinization of land and water resources: hman causes, extent, management and case studies. Wallingford Oxon,Uk: CAB International.

Ghodoosipour, B. (2014). *A simplified groundwater modeling approach for Quaternary deposits in Laxemar-Simpevarp, Sweden*. Paper presented at the World Environmental and Water Resources Congress 2014: Water without Borders.

Goyal, M., Madramootoo, C., & Richards, J. (2014). Simulation of the Streamflow for the Rio Nuevo Watershed of Jamaica for Use in Agriculture Water Scarcity Planning. *Journal of Irrigation and Drainage Engineering*, *0*(0), 1-9. doi: doi:10.1061/(ASCE)IR.1943-4774.0000802.

Hanna, T. M., Azrag, E. A., & Athinson, L. C. (1994). Use of an analtical solution for preliminary estimats of groundwater inflow to a pit. *Mining Egineering*, *48*(2), 149-154.

Heath, R. C. (1983). Basic ground-water hydrology, U.S. Geological Survey Water-Supply Paper 2220, 86p.

Homaee, M., Feddesb, R. A., & Dirksen, C. (2002). A Macroscopic Water Extraction Model for Nonuniform Transient Salinity and Water Stress. *soil Science Society of America Journal*, *66*(6), 1764-1772.

Immerzeel, W. W., Gaur, A., & Zwart, S. (2008). Integrating remote sensing and a process-based hydrological model to evaluate water useand productivity in a south Indian catchment. *journal of Agricultural Water Management*, *95*(1), 11–24.

Iranhydrology. (2013). Database Meteorological Data. *Meteorological Organization.* from http://www.iranhydrology.net/meteo/meteo.htm.

Jafari, T. M., Shahnazari, A., Ahmadi, M. Z., & Darzi, N. A. (2015). Drain Discharge and Salt Load in Response to Subsurface Drain Depth and Spacing in Paddy Fields. *Journal of Irrigation and Drainage Engineering, 141*(11), 04015017-04015011-04015016. doi: 10.1061/ (ASCE)IR.1943-4774.0000904.

Kandil , H. M., Skaggs, R. W., Abdel Dayem, S., & Aiad, Y. (1995). DRAINMOD-S: Water management model for irrigated arid lands, crop yield and applications. *Irrigation and Drainage Systems, 9*(3), 239-258. doi: 10.1007/BF00880866.

Karatas, B. S., Camoglu, G., & Olgen, M. K. (2013). Spatio-Temporal Trend Analysis of the Depth and Salinity of the Groundwater, Using Geostatistics Integrated with GIS, of the Menemen Irrigation System, Western Turkey. *Ekoloji, 22*(86), 36-47. doi: 10.5053/ekoloji.2013.865.

Kellenersa, T. J., Kamrab, S. K., & Jhorarc, R. K. (2000). Prediction of long term drainage water salinity of pipe drains. *Journal of Hydrology, 234*(2000), 249-263.

Khan, G. S., & Akram.M. (1986a). *Dynamics of groundwater of semi-arid area in Pakistan.* Paper presented at the Abs.XIII.Cong. International Soc.Soil Science, Hamburg (Germany).

Kiani, A. R., & Abbasi, F. (2009). Assessment of the water-salinity crop production function of wheat using experimental data of the Golestan province, Iran. *Irrigation and Drainage, 58*(4), 445-455. doi: 10.1002/ird.438.

Kijne, J. W. (1998). Yield response to moderately saline irrigation water: Implications for feasibility of management changes in irrigation systems for salinity control. *journal of Applied irrigation science*, 249-277.

Kresic, N. (1997). Quantitative solutions in hydrogeology and groundwater modelling. Lewis, New York, NY.

Lambert, K., Willem, F., & David, W. (2004). *Moder Land Drainage-planning,Design and Management of Agricultyral Drainage Systems*. Taylor&Francis The Netheland,Leiden: Balkema,A.A.

Laronne, B. I. L., & Gvirtzman, H. (2005). Groundwater flow along and across structural folding: an example from the Judean Desert, Israel. *Journal of Hydrology, 312*(1-4), 51-69.

Luo, W., Jia, Z., Fang, S., Wang, N., Liu, J., Wang, L., . . . Zhang, Y. (2008). Outflow reduction and salt and nitrogen dynamics at controlled drainage in the YinNan Irrigation District, China. *Agricultural Water Management, 95*(7), 809-816. doi: 10.1016/j.agwat.2008.02.004.

Luo, W., Sands, G. R., Youssef, M., Strock, J. S., Song, I., & Canelon, D. (2010). Modeling the impact of alternative drainage practices in the northern Corn-belt with DRAINMOD-NII. *Agricultural Water Management, 97*(3), 389-398. doi: 10.1016/j.agwat.2009.10.009.

Mahdian.M.H. (2005). Soil Hydraulic Conductivity and its Application in Drarinage Design. *Iranian Journal of Agriculturar Engineering Research, 6*(23), 160-170.

Manjunatha, M. V., Oosterbaan, R. J., Gupta, S. K., Rajkumar, H., & Jansen, H. (2004). Performance of subsurface drains for reclaiming waterlogged saline lands under rolling topography in Tungabhadra irrigation project in India. *Agricultural Water Management, 69*(1), 69-82. doi: 10.1016/j.agwat.2004.01.001.

Mc Donald, M. G., & Harbaagh, A. W. (1988). *A modular threedimensional finite-difference groundwater flow model,Techniques water resource investigations of the United States Geological Survey*. U.S. Geological Survey, Washington.

Metternicht, G. I., & Zinck, J. A. (2003). Remote sensing of soil salinity: potentials and constraints. *Remote Sensing of Environment, 85*(1), 1-20. doi: 10.1016/s0034-4257(02)00188-8.

Mirlas, V. (2013). MODFLOWModeling to Solve Drainage Problems in the Argaman Date Palm Orchard, Jordan Valley, Israel. *Journal of Irrigation and Drainage Engineering, 139*(8), 612-624. doi: 10.1061/(asce)ir.1943-4774.0000593.

Mizumura, K., & Kaneda, T. (2010). Boundary Condition of Groundwater Flow through Sloping Seepage Face, *Journal of Hydrologic Engineering, 15*(9), 718-724. doi: 10.1061//ASCE/HE.1943-5584.0000233

Mohanty, S., Madan, J. K., Kumar, A., & Panda, D. K. (2013). Comparative evaluation of numerical model and artificial neural network for simulating groundwater flow in Kathajodi–Surua Inter-basin of Odisha, India. *Journal of Hydrology, 495*, 38-51. doi: 10.1016/j.jhydrol.2013.04.041

Morris, D. A., & Johnson, A. I. (1967). Summary of hydrologic and physical properties of rock and soil materials as analyzed by the Hydrologic Laboratory of the U.S. Geological Survey, U.S. Geological Survey Water-Supply Paper 1839-D, 42p.

Nezami, M. T., & Alipour, Z. T. (2012). Preparing of the soil salinity map using geostatistics method in Iran. *Journal of Soil Science and Environmental Management, 3*(2), 36-41. doi: 10.5897/JSSEM11.031

Noorduijn, S. L., Harrington, G. A., & Cook, P. G. (2014). The representative stream length for estimating surface water–groundwater exchange using Darcy's Law. *Journal of Hydrology, 513*, 353-361. doi: 10.1016/j.jhydrol.2014.03.062

Panagos, P., & Liedekerke, M. V. (2012). land resource management unit., from http://eusoils.jrc.ec.europa.eu

Pazira, E., & Homaee.M. (2010). *Salt Leaching Efficiency of Subsurface Drainage Systems At Presence of Diffusing Saline Water Table Boundary: A Case Study in Khuzestan Plains, Iran*. Paper presented at the XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR), Québec City, Canada.

Porseyedi, A., & Kashkoli, H. A. (2010). Investigation of groundwater level at the Jiroft plain, Iran *Iranian Journal of lrrigation engineering, 35*(2), 51-63.

Provenzano, G., Tarquis, A. M., & Rodriguez-Sinobas, L. (2013). Soil and irrigation sustainability practices. *Journal of Agricultural Water Management, 120*, 1–4.

Raiesi , T., Tabatabaei, S. H., & Beigi-Harchegani , H. (2011). Solute Transport in a Saline Soil using Bromide Tracer under Three Conjunction Irrigation Schemes. *Iranian Journal of lrrigation and drainage, 4*(3), 387-396.

Rashvand, S., Mosafaee, J., Darvish, M., & Rafee, A. (2013). Investigation on potential of desertification in terms of decay of vegetation Case study: Rude shoor, Qazvin. *Iranian Journal of Range and Desert Reseach, 20*(1), 38-49.

Rigaux, L. R., & Singh, R. H. (1977). Benefit-Cost Evaluation of Improved Levels of Agricultural Drainage in Manitoba *77-1* (Vol. 1). University of Manitoba: Department of Agricultural Economics and Farm Management.

Ritzema, H. P. (1994). Drainage Principles and Applications. (pp. 47). Wageningen,The Netherlands: International Institute for Land Reclamation and Improvement.

Ritzema, H. P., Nijland, H. J., & Croon, F. W. (2006). Subsurface drainage practices: From manual installation to large-scale implementation. *Agricultural Water Management, 86*(1-2), 60-71. doi: 10.1016/j.agwat.2006.06.026

Savab, M. R. (1993). Modeling Subsurface Drainage and Surface Runoff with Wepp. *Journal of Irrigation and Drainage Engineering, 119*, 801-818.

Schmid, W., & Hanson, R. T. (2007). Simulation of Intra- or Transboundary Surface-Water-Rights Hierarchies Using the Farm Process for MODFLOW-2000 *Journal of Water Reasources plannining and management, 133*, 166-178. doi: 10.1061//asce/0733-9496/2007/133:2/166

Sema, K. (2012). Impact of drained and un-drained soil conditions on water table depths, soil salinity and crop yields. *African Journal of Agricultural Reseearch, 7*(19). doi: 10.5897/ajar12.101

Serfase, M. E. (1992). Determining the Mean hydraulic Gradient of Groundwater Affected by tidal Fluctuations. *Ground Water, 29*(4), 559-555.

Serge, M., Fethi, B., & Akissa, B. (2009). Water and salt balance at irrigation scheme scale: A comprehensive approach for salinity assessment in a Saharan oasis. *Agricultural Water Management, 96*(9), 1311-1322. doi: 10.1016/j.agwat.2009.04.016

Singh, A., panda, N. S., & Asce, M. (2012). Integrated Salt and Water Balance Modeling for the Management of Waterlogging and Salinization. *Journal of Irrigation and Drainage Engineering, 138*, 964-971. doi: 10.1061/(ASCE)IR.1943-4774.0000510

Singh.K. (2009). Drawdown due to Pumping a Partially Penetrating Large-Diameter Well Using MODFLOW. *Journal Irrigation and Drainage Engineering*, *135*, 388-392. doi: 10.1061//asce/ir.1943-4774.0000066

Skaggs, R. W., Youssef, M. A., & Chescheir , G. M. (2012). Drainmod: Model Use, Calibration, and Validation. *American Society of Agricultural and Biological Engineers*, *55*(4), 1509-1522.

Skaggs, R. W., Youssef, M. A., & Chescheir , G. M. (2012b). Drainmod: Model Use, Calibration, and Validation. *American Society of Agricultural and Biological Engineers*, *55*(4), 1509-1522.

Suresh Kumar, G. (2014). Mathematical Modeling of Groundwater Flow and Solute Transport in Saturated Fractured Rock Using a Dual-Porosity Approach. *Journal of Hydrologic Engineering*, 1-7. doi: 10.1061/(asce)he.1943-5584.0000986

Sushil, K. S. (2008). Simulating the Well Function for Large-Diameter Wells Using MODFLOW. *Journal of Irrigation and Drainage Engineering*, *134*(3), 414-416. doi: 10.1061//ASCE/0733-9437/2008/134:3/414

Szabolcs, I. (1986). *Agronomical and Ecological Impact of Irrigation on Soil and Water Salinity* (Vol. 4). New York: Springer.

Todd, D. K. (2005). Groundwater Hydrology, 3ed ed., John Wiley & Sons, New York, 535p.

USGS. (2013). Science for a Changing World. from http://earthexplorer.usgs.gov/

Van de Ven, G. P. (1994). *Man-made Lowlands.History of water managemet and land Reclamation in the Netherlands*. Utrecht.: University Matrijs.

Wahba, M. A. S., El-Ganainy, M., Abdel-Dayem, M. S., Kandil, H., & Gobran, A. (2002). Evaluation of DRAINMOD-S for simulating water table management under semi-arid conditions. *Irrigation and Drainage*, *51*(3), 213-226. doi: 10.1002/ird.54

Wang, K., Wang, P., Li, Z., Cribb, M., & Sparrow, M. (2007). A simple method to estimate actual evapotranspiration from a combination of net radiation, vegetation index, and temperature. *Journal of Geophysical Research*, *112*(D15107), 1-14. doi: 10.1029/2006JD008351

Wichelns, D. (1999). An economic model of waterlogging and salinization in arid regions. *Ecological Economics*, *30*(1999), 475-491.

Xu, X., Huang, G., Zhan, H., Qu, Z., & Huang, Q. (2012). Integration of SWAP and MODFLOW-2000 for modeling groundwater dynamics in shallow water table areas. *Journal of Hydrology*, *412-413*, 170-181. doi: 10.1016/j.jhydrol.2011.07.002.

Yang, Q., Lun, W., & Fang, Y. (2011). Numerical Modeling of Three Dimension Groundwater Flow in Tongliao (China). *Procedia Engineering, 24*, 638-642. doi: 10.1016/j.proeng.2011.11.2709.

Yee Yet, J. S., & Silburn , D. M. (2003). Deep drainage estimates under a range of land uses in the QMDB using water balance modelling. (pp. 68): Department of Natural Resources and Mines, Toowoomba.

Zheng, C. (1990). A Modular Three-Dimensional Transport Model for Simulation of Advection, Dispersion and Chemical Reaction of Contaminants in Groundwater Systems. (20852). From Rockville,Maryland