AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Irrigation and Hydraulics

Groundwater Mounding Problems in Highly Heterogeneous Aquifers

A Thesis submitted in partial fulfillment of the requirements of the degree of

Doctor of Philosophy In Civil Engineering

(Irrigation and Hydraulics)

By

Eng. Samah Hassan Mahmoud Abd Elghany

Master of Science In Civil Engineering
(Irrigation and Hydraulics)
Faculty of Engineering, Ain ShamsUniversity, 2010

Supervised By

Prof. Dr. Ahmed Ali Ali Hassan
Professor of Environmental Hydrology
Irrigation and Hydraulics Department.
Ain shams University

Dr. Peter Hany Sobhy Riad
Lecturer of Groundwater Hydrology
Irrigation and Hydraulics Department.
Ain shams University

Dr. Rani Fouad Mohamed
Lecturer of Groundwater Hydrology
Irrigation and Hydraulics Department.
Al-Azhar University

Cairo - (2015)

AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Irrigation and Hydraulics

Groundwater Mounding Problems in Highly Heterogeneous Aquifers

By

Eng. Samah Hassan Mahmoud Abd Elghany

Master of Science In Civil Engineering

(Irrigation and Hydraulics)

Faculty of Engineering, Ain Shams University, 2010

Examiners' Committee

Name and Affiliation	**Signature**
Prof. Dr. Osama khairy Saleh Professor of Hydraulics Water and water structures Dep., Zagazig University Dean, EL OBOUR High Institute For Engineering and Technology.	……………….
Prof. Dr. Khaled Shafik El-Kholy Professor of Environmental Hydraulics Irrigation and Hydraulics Dep., Ain shams University	……………….
Prof. Dr. Ahmed Ali Ali Hassan Professor of Environmental Hydrology Irrigation and Hydraulics Dep., Ain shams University	……………….

Date: 24 December 2015

Statement

This thesis is submitted as a partial fulfilment of Doctor of Philosophy in Civil Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Eng. Samah Hassan Mahmoud Abd Elghany

Signature

…………...……….

Date: 24 December 2015

Researcher Data

Name	**Samah Hassan Mahmoud Abd Elghany**
Place of birth	: Cairo, Egypt
Last academic degree	: Master of Science in Civil Engineering
Field of specialization	: Civil EngineeringIrrigation and Hydraulics
University issued the degree	: Ain Shams University
Date of issued degree	: 2010
Current job	: Assistant Lecture at civil engineering Department at Higher Technological Institute. (HTI)

To my mother soul

To my father

To my dear husband

Mohammed

To my lovely daughters

Mariam and Sarah

Thesis Summary

Due to the nature of the reservoirs of Nile Delta in Egypt and its valley which are composed of several successive alluvial deposits, there are many silty clay layers with very low permeability which can be found with different depths all over the reservoirs. The existence of the low permeability layers hinders the recital flow of water between the water bearing formations of the aquifer system and arising many environmental problems such as water logging, water mounding and pollution.

In Egypt there are many aquifer systems of which the Nile Delta aquifer is considered as one of the most important aquifers. However, there are several environmental problems such as salinization, water pollution, logging and mounding of groundwater levels affect the development in eastern Nile Delta region. In order to overcome these problems and mitigate their negative impact on environmental and development projects, intensive studies should be carried out. These studies are morphological, hydrological, geological and geotechnical studies which define the factors affecting groundwater flow and water pollutions in the aquifer system.

The present research concerns with the water mounding and logging problems in highly heterogeneous aquifers in new cities. These problems are existing in many areas such as the eastern Nile Delta aquifer which is adjacent to and connected with the Delta aquifer system, where water logging and mounding appear in many places especially in El-Obour city and El-Shorouk City.

The objectives of this research are to Study the water mounding and logging problem with preventative case study, define the sources of problem in the case study area, clarify the different conditions lead to water logging and mounding, simulate and calibrate the groundwater flow, and to propose a solution that should be technically and environmentally feasible.

The region of concern in this study is El-Obour City which is located about 25 km Eastern of Cairo and lies on the hydrologic basin of Heliopolis. It comprises part of the desert area to the east of the Nile delta and covers about 200 Km^2. Due to the low permeability of some layers and the leakage from water networks and the seepage from the green areas near to the city the 6^{th} and 7^{th} districts suffered of the groundwater levels rise and logging. Vertical drainage wells were

suggested to drain water from the higher layers to the lower layers which have more permeability. However, the optimum number of the drainage wells is one of the big issues in such projects for the practical point of view and for economic purposes.

In order to simulate the study area and the existing conditions a simulation package of Ground modeling system (GMS 7.1) was used to simulate the study area for practical application in ground water flow. GMS is the most complete, and user-friendly, modeling environment for practical applications in three-dimensional groundwater flow and contaminant transport simulation. This fully-integrated package combines powerful analytical tools with a logical menu structure. Easy-to-use graphical tools. The model input parameters and results can be visualized in 2D (cross-section and plan view) or 3D at any time during the development of the model or the displaying of the results. For complete three-dimensional groundwater flow and contaminant transport modeling, MODFLOW is the best software package available. The vertical drainage wells were represented by large vertical hydraulic conductivities with respect to the horizontal conductivities. It was concluded that the ratio of horizontal hydraulic conductivity per vertical hydraulic conductivity (kh/kv) should not be less than 0.1, because beyond this ratio value there is no drop in the water level.

In order to select the optimum number of wells, five different scenarios have been applied with various numbers of wells to select the best economic solution. Numbers of wells in each scenario are changed. The optimum number for the drainage wells were select so as to be the minimum number after which the groundwater levels do not change significantly. A number of 35 wells distributed over the modeled area of the 6^{th}& 7^{th} districts, and then started to reduce the number of wells and observe the effect of this issue on the water level (35, 30, 27, 24, and 20 wells). The optimum number is that less number of wells which give a suitable drop in water levels, where the level after that start to be the same. it was noticed that when the number of wells are more than 27 wells, the drop in the water levels increases but the ratio of drop is less than 5%, which means that increasing the number of wells more than 27 wells does not affect the drop in water level significantly. So 27 wells are considered the optimum solution and it is recommended to be implemented in this area.

New technique has been used to simulate a vertical perforated pipe in MODFLOW by using Conduit Flow Process (CFP), a model was used to simulate the vertical drainage wells as a proposed solution. When the model operated in Mode1 it couples a discrete conduit network to the matrix and uses the Darcy-Weisbach equation to simulate turbulent flow and the Hagen-Poiseuille equation for laminar flow in the conduit network. Fluid exchange between the matrix and the conduit network in CFP Mode1 is considered with an iterative head dependent flux between the conduit network and matrix.

CFP Mode1 considers the conduits as pipes and required some information about the pipes diameter then can simulate the exchange between the matrix and these pipes. The conduit flow process for MODFLOW-2005 (CFP) has the ability to simulate turbulent or laminar groundwater flow conditions by coupling the traditional groundwater flow equation with formulations for a discrete network of cylindrical pipes (Mode1, CFPM1). Several techniques have been used to simulate a vertical perforated pipe in MODFLOW, which drains water from upper layer to the lower one. Despite of the approximated results, there are several questions still have no answers: how does pipe diameter can affect the recharging head and mounding height, what is the flow type inside the perforated pipe (Laminar or turbulent). In order to find out the solution of all the previous questions, ground-water was exchanged between MODFLOW and the perforated pipe network, and correcting ground-water exchange between MODFLOW and the perforated pipes due to partially or completely filled pipes. (Rate of filling the pipe from the upper layer may be different than the out filling to the lower one).A Conduit Flow Process (CFP) model was used to simulate a vertical perforated pipe in MODFLOW, which drains water from upper layer to the lower one by using Conduit Flow Process (CFP).

After Set parameter guidance for applying CFP code for drainage problem: Parameters such as pipe diameter, wall conductance, and penetration length which will influence the exchange of flow between matrix and the perforated pipes. It was concluded that parameters such as pipe diameter (pipes with 15& 30& 40& 50 and 60 cm diameter, and wall conductance equal 0.001) which will influence the exchange of flow between matrix and the perforated pipes.

It was proved that the increase of diameter more than 30 cm not effect on the drop of water level on upper layer according to increase the time.

The results of the drop in the water levels and the water budget by CFP are identical with the results of GMS.

Key words:

Groundwater Flow Modeling – Dewatering – GMS Model– Optimization of Vertical Drainage Wells Number– | CFP Model – Vertical Wells– model muse.

Acknowledgment

Praise is to Allah who guided and aided me to bring-forth to light this work and by whose grace this work has been completed.

I would like to thank my major advisor, **Prof. Dr. Ahmed Ali Hassan**, for giving me the opportunity to work on this fascinating topic. I acknowledge his invaluable contribution to this study and his insightful academic advising throughout my study.

I am particularly thankful to **Dr. Peter Hany Sobhy Riad** and **Dr. Rani Fouad Mohamed** for their suggestions on the design and structure of my subject.

Especial thanks to **Prof. Dr. Abd Elmohsen Mongy, Prof. Dr. Nagy Ali Hassan, Prof. Dr. Osama Khairy** and **Assistant Prof. Mostafa Ali** are much appreciated for being great co-advisors. Not only did they provide most helpful recommendations on relating my research to real world hydrology, but throughout countless meetings with them, they always left me motivated and excited about my work with his positive affirmation and enthusiasm .

Thanks are also extended to my examination committee. The lessons I have learned from them were fundamental.

I want to thank my friends and colleagues who helped me to grow with the challenges of this work.

I would not have completed this work without the encouragement and support of my family Dad, My husband Mohammad and my two little daughters Mariam and Sarah. Particular thanks go to my father, who always believed in me when I didn't. Also thanks, Dad, for being my manager at the `home front. ` But most importantly, I would like to thank my husband Mohammad for his love and understanding, and all the sacrifices he had to endure. Thanks for being there when I needed you, and thanks for your patience during the many weekends I spent on my research instead of with you.

December 2015

Chapter 1
Introduction

1.1 General Background

Nile River is considered the main and the most important source of water in Egypt. In the last decades, groundwater reservoirs have become of great concern because of the highly promising storage of good quality water that can be considered the second main water source in Egypt. These reservoirs are the Nile Delta aquifer, Upper Egypt aquifer, Greater Cairo aquifer, Western Desert aquifer, Eastern Desert aquifer and the Nubian sandstone reservoir. Due to the nature of the reservoirs of Nile Delta and its valley which are composed of several successive alluvial deposits, there are many silty clayey layer of very low permeability which can be found with different depths all over the reservoirs. The existence of the low permeability layers hinders the vertical flow of water between the water bearing formations of the aquifer system arising many environmental problems such as water logging, water mounding and pollution.

In order to overcome these problems and mitigate their negative impact on environment and development projects, intensive studies should be carried out. These studies are morphological, hydrological, geological and geotechnical studies which define the factors affecting groundwater flow and water pollution in the aquifer system.

The present research work concerns with the water mounding and logging problem in highly heterogeneous aquifers in new cities. This problem which can be presented by eastern Nile Delta aquifer that is in adjacent to and connected with the Delta aquifer system, since water logging and mounding appear in many places especially in El-Obour City.

A review of the literature related to the problem of water logging and mounding is presented followed by numerical modeling applied to simulate the existing conditions and test the proposed solution.

1.2 Problem Definition

El-Obour City is a newly constructed city in East Delta located 25 km from Cairo. The city covers almost 200 km^2 and is characterized by variations in topography and geology. The area is characterized by a low relief, while it is bounded from the north by Hamza ridge (220-210 m above MSL). It shows variable topographic features, from about 30 m above MSL in the South to about 173 m above MSL in the north, sloping regionally in a south ward direction. Geologic structures, especially the faults, have a direct influence on the topographic features of the study.

The variations in topography in the study area helped to collect water from the various sources up to the clay layer which led to rising water levels above the ground layer of the clay layer up a reservoir surface. Over the time and the continued leakage of water from surface sources of ground water level rise gradually until it reached a level close to the surface of ground, especially in low-lying areas. This problem is severely recorded at the southern part of the city where the area is topographically low, especially in 6^{th} and 7^{th} districts. Solution concerns the efficiency of vertical drains which used as a dewatering solution for the problem of water logging in the study area.

1.3 Research Objectives

The objectives of this research can be summarized as follow:

1. Study the water mounding and logging problem with preventative case study.
2. Define the sources of problem in the case study area.
3. Clarify the different conditions lead to water logging and mounding.
4. Simulate and calibrate the groundwater flow.
5. Propose a solution that should be technically and environmentally feasible (vertical drains positions and its effect on solution).

1.4Research Methodology

The methodology to achieve the study objectives is as following:

1. Introduce a detailed review of the previous works for groundwater flow modeling.
2. Review the literatures related to the problem of water logging and mounding and the methods of dewatering and water level lowering.
3. Present the theories and governing equations of the groundwater flow with their initial and boundary conditions.
4. Collect and analyze the different data sets addressing the topography, geophysical, geotechnical, hydrological and environmental conditions of El-Obour City region as a case study representing the Eastern Nile Delta aquifer.
5. Study most common Alternative solutions.
6. Review of the Existing Models: An extensive survey of the literature is carried out in order to examine existing models. Based on the review, the limitations of the available models and suggestions for improvement are identified. The most appropriate condition rating, deterioration models, and cost of models are selected to be the subcomponents of the proposed model.
7. Describe of the initial Model: Constructing a numerical model using the GMS 7.1 to simulate the existing conditions and test the proposed solution of water logging and mounding in the study area. A detailed description of procedure of the model including the following:

- Set parameter guidance for applying CFP code for drainage problem: Parameters such as pipe diameter, wall conductance, and penetration length which will influence the exchange of flow between matrix and the perforated pipes.
- Design GIS-based three-dimensional-finite difference groundwater flow model using MODFLOW 2005: This model will include the input of CFP code and other inputs of the groundwater flow models.
- Field scale study, which will demonstrate the logic and functionality of the GIS-Groundwater flow model accompanying the CFP code. The field study will show the representation of the CFP code to simulate the vertical drainage between two layers using perforated pipes at El-Obour city.

8. Case Study and Validation: obtain the case study results and then compared it with the results from the literature.
9. Conclusion and recommendations of this study will be presented.