AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Irrigation and Hydraulics Department

Artificial Recharge of Groundwater by Treated Wastewater

A Thesis Submitted for Partial Fulfillment of the Requirements

for the Degree of Doctorate of Philosophy in Civil Engineering

(Water Resources Management and Hydrology)

By

PETER HANY SOBHY RIAD

M.Sc. of Civil Engineering

(Water Science Engineering: Hydraulic Engineering and River Basin Development)

UNESCO-IHE Institute for Water Education, Delft- The Netherlands, 2008

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Cairo 2012

Approval Sheet

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STATEMENT

This thesis is submitted to Ain Shams University for the degree of Doctor of Philosophy in Civil Engineering “Irrigation and Hydraulics Department”.

The work presented in this thesis was carried out by the author as a joint research between Ain Shams University and Leibniz Universität Hannover (Channel System) at the Institute of Water Resources Management, Hydrology and Agricultural Hydraulic Engineering, Leibniz University of Hannover, Germany from October 2009 to August 2012.

No part of this thesis has been submitted for a degree or a qualification at any other institute or university.

Date: / /
Signature:
Name: Peter Hany Sobhy Riad

Dedicated to My Parents
and to My Angel Ovemia

Dedicated Also to the 25th January Egyptian Revolution Martyrs, Who Poured Their Blood for the Sake of a Better Future for Egypt,
God Rest Their Souls

Acknowledgment

Praise to God, Who guided and aided me to bring-forth to light this work and by His grace this work has been completed.

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Abstract

Artificial Recharge of Groundwater by Treated Wastewater

In arid and semi-arid regions, where water scarcity is almost endemic, artificial recharge of groundwater by treated wastewater is one of the most effective techniques for the augmentation of groundwater resources. El-Sadat Industrial City in the western desert of the Nile Delta fringes in Egypt was selected here as a typical case study for the new industrial cities which are constructed in a semi-arid areas and suffering of groundwater depletion, water supply shortage and deterioration of its groundwater quality due to the unplanned and unmanaged over exploitation of the groundwater, as this city is depending mainly on the groundwater in its industrial, agricultural and domestic activities, while the aquifers have no replenishment due to the limited rainfalls.

The main objective of this research is presenting an integrated study for planning and implementing such projects in a city located in arid or semi-arid areas and to find solutions for the most likely challenges which can face the project planners; like the best convenient recharging techniques which allows for suitable infiltration rates to reduce the water losses by evaporation due to the high temperatures or the problems of the groundwater mounds increase, especially in case of the small unsaturated zone thickness. Also this research is aiming at studying the short and long terms impacts of this project on the ambient groundwater quantity and quality. This research project is a water management proposal for El-Sadat City to provide it with non-conventional water resources by storing the excess of the treated waste water in the subsurface to be reused in times of shortage in irrigation or industrial purposes, in addition to the recharged water quality improvement by the natural purification.

The present research was divided into several parts, first of all a detailed deep literature review was collected about the different techniques of artificial recharge of groundwater. Each technique advantages, disadvantages, considerations and hydraulic analysis, in addition to the world experiences in this field were discussed in Chapter 2. The treated waste water quality as a source for recharging the subsurface aquifers and the groundwater quality changes and the water quality standards for recharging in several countries, especially in Arid and semi-arid areas are discussed separately in Chapter 3 for its importance in such studies.

Chapter 4 is devoted mainly for the study area (El-Sadat Industrial City). Several aspects about the city have been discussed; like the population increasing rates, activities, groundwater consumption rates, and in addition to the city hydrogeology and geophysical characteristics, also the last part in the chapter is dealing with the wastewater treatment plants in the city, the existed one and the new one under construction, from their components, capacity and treatment degree. Most of the data in this chapter are collected from different sources; like the previous studies which have been done by the Research Institute of Groundwater (RIGW) in Egypt, published papers from the internet, some topographic maps

from the Egyptian Survey Authority (ESA), new updated investigation studies and reports from some consultant companies (like El Dar group) and some field visits by the author to the study area municipality and its treatment plant.

Then the research study followed, in the next chapters, a logic structure for planning and designing the project, as the first stage started in chapter 5 for determining the best locations for the project implementation. For this purpose an overlay weighted model was created in ArcGIS by using thematic layers for number of parameters which have been prepared from the available data, some maps and satellite images. The output of this weighted model was a suitability map which was compared with a true or false map implemented by Boolean logic on ArcGIS also. Moreover another relatively new technique, Fuzzy logic principles, was applied by using MATLAB 2010 to obtain on the best locations. From these different approaches it could be determined the best location of the artificial recharge project in this study area which was taken in the north east of the city and near to the existed treatment plant.

Chapter 6 presented the governing equations, which are used in numerical modeling to study the flow transport in aquifers. This chapter is considered as an introduction for the next chapters which are dealing mainly with numerical models to study the different techniques application in the study area and their impacts. Chapter 7 explains the regional model construction, calibration and validation by using MODFLOW v.3 and v.4 to represent the city aquifers hydrologic system in the nature and its response for different applications. The data used here in the calibration process are taken mainly from chapter 4.

Chapter 8 is presenting the applications of the different recharge techniques on the implemented numerical model from the previous chapter to answer several questions; what are the short and long-term impacts of recharging the groundwater aquifer, on the surrounding environment? After how long can the recharged water be recovered and what are the best pumping locations? Is the quality of the extracted water will be suitable to be used immediately for irrigation and/or industry or does it need further treatment? What are the most effective recharging techniques (from the economy and practical points of view)? For this purpose 3 techniques have been applied; deep injection wells, shallow wells “vadose zone wells” and the surface spreading basins.

One of the research first conclusions is rejecting the deep injection wells as an alternative for groundwater recharge in this area, as the models showed that it does not restore the depletion in the groundwater levels, moreover it can pollute the deep aquifers which have the high quality of drinking water. For the other techniques, surface spreading basins showed more influences on the groundwater levels than the vadose zone wells and the propagation of the recharged water was faster and wider (approx. 0.5 km/yr), while in vadose wells was 0.36 Km/yr. Total Dissolved Solids (TDS) changes have been also studied, as high TDS (more than 1000 mg/l) can adversely affect many crops. For this purpose the non reactive transport model MT3DMS has been applied along with the flow model MODFLOW 2000. TDS was taken as an indicator parameter for the water mixing and the quality improvement of the