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A Simulation-Optimization Model to Study the Control of Seawater Intrusion in Coastal Aquifers

Submitted by

Hany Farhat Abd-Elhamid

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other university.

Hany F. Abd-Elhamid

ABSTRACT

Groundwater contamination is a very serious problem as it leads to the depletion of water resources. Seawater intrusion is a special category of groundwater contamination that threatens the health and possibly lives of many people living in coastal areas. The focus of this work is to develop a numerical model to study seawater intrusion and its effects on groundwater quality and develop a control method to effectively control seawater intrusion. Two major approaches are used in this study: the first approach is the development of a finite element model to simulate seawater intrusion; the second is the development of a simulation-optimization model to study the control of seawater intrusion in coastal aquifers using different management scenarios. The simulation-optimization model is based on the integration of a genetic algorithm optimization technique with the transient density-dependent finite element model developed in this research.

The finite element model considers the coupled flow of air and water and solute transport in saturated and unsaturated soils. The governing differential equations include two mass balance equations of water and air phases and the energy balance equation for heat transfer, together with a balance equation for miscible solute transport. The nonlinear governing differential equations are solved using the finite element method in the space domain and a finite difference scheme in the time domain. A two dimensional finite element model is developed to solve the governing equations and provide values of solute concentration, pore water pressure, pore air pressure and temperature at different points within the region at different times. The mathematical formulation and numerical implementation of the model are presented. The numerical model is validated by application to standard examples from literature followed by application to a number of case studies involving seawater intrusion problems. The results show good agreement with previous results reported in the literature. The model is then used to predict seawater intrusion for a number of real world case studies. The developed model is capable of predicting, with a good accuracy, the intrusion of seawater in coastal aquifers.

In the second approach, a simulation-optimization model is developed to study the control of seawater intrusion using three management scenarios: abstraction of brackish water, recharge of fresh water and combination of abstraction and recharge. The objectives of these management scenarios include minimizing the total costs for construction and operation, minimizing salt concentrations in the aquifer and determining the optimal depths, locations and abstraction/recharge rates for the wells. Also, a new methodology is presented to control seawater intrusion in coastal aquifers. In the proposed methodology ADR (abstraction, desalination and recharge), seawater intrusion is controlled by abstracting brackish water, desalinating it using a small scale reverse osmosis plant and recharging to the aquifer. The simulation-optimization model is applied to a number of case studies. The efficiencies of three different scenarios are examined and compared. Results show that all the three scenarios could be effective in controlling seawater intrusion. However, ADR methodology can result in the lowest cost and salt concentration in aquifers and maximum movement of the transition zone towards the sea. The results also show that for the case studies considered in this work, the amount of abstracted and treated water is about three times the amount required for recharge; therefore the remaining treated water can be used directly for different proposes. The application of ADR methodology is shown to be more efficient and more practical, since it is a cost-effective method to control seawater intrusion in coastal aquifers. This technology can be used for sustainable development of water resources in coastal areas where it provides a new source of treated water. The developed method is regard as an effective tool to control seawater intrusion in coastal aquifers and can be applied in areas where there is a risk of seawater intrusion.

Finally, the developed FE model is applied to study the effects of likely climate change and sea level rise on seawater intrusion in coastal aquifers. The results show that the developed model is capable of predicting the movement of the transition zone considering the effects of sea level rise and over-abstraction. The results also indicate that the change of water level in the sea side has a significant effect on the position of the transition zone especially if the effect of sea level rise is combined with the effect of increasing abstraction from the aquifer.

TABLE OF CONTENTS