Cairo University

NESTING AND DISCRETIZATION TRANSITION IN GROUNDWATER FLOW MODELING

By

Ahmed Tarek Fawzy Elsayed

A Thesis Submitted to
the Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE

In

IRRIGATION AND HYDRAULICS ENGINEERING

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Nesting and Discretization Transition In Groundwater Flow Modeling.

Key Words:
Regional Models; Local Models; Groundwater flow modeling; Nesting; High Resolution Models.

Summary:

Regional models are commonly constructed such that they reach out to well-defined boundaries and then they are used as reference models for detailed studied for local area. For such detailed study, it becomes essential to use a high resolution numerical model to simulate the local features that may have significant impact on the system dynamics. This high resolution level in groundwater model is not feasible as the regional model area is very large to reach out to well-defined boundaries. So, in regional models coarse grid size will be sufficient; however, local models may require more detailed three dimensional modeling with fine grid size. The main objective of this research is to link the two different discretization models and transfer boundary conditions from the coarse regional model to the fine local one. Two approaches for mapping the regional information over the local domains are developed. The two approaches are the tri-linear interpolation approach (TIA) and artificial neural networks (ANN) approach. Both of them are tested to assess the efficiency of each one in transferring the information from coarse grid model to the fine grid one. The overarching conclusion is that it is better to use ANN technique with generating several scenarios than relying on the TIA in linking the two different discretization models.

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DEDICATION

I would like to express my gratitude to the Irrigation and Hydraulics Department at Cairo University for providing me with the time and resources needed to carry out this work as one of the earliest studies in the department concerning Groundwater Flow Modeling and allowing me to be one of the youngest teaching assistants who obtained the master of science degree over the history of the department.

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ABSTRACT

Regional models are commonly constructed such that they reach out to well-defined boundaries and then they are used as reference models for detailed studies for local area. For such detailed study, it becomes essential to use a high resolution numerical model (fine level of discretization) in order to simulate the local features that may have significant impact on the system dynamics (faults, wells, soil lenses). This high resolution level in groundwater model is not feasible when the model area is very large, which is the common case in most of the regional models that reach out to well-defined boundaries. In such regional models simple areal two-dimensional modeling with coarse grid size may be sufficient, whereas local models may require more detailed three-dimensional models and fine grid size. The connection between a regional model and a local one with a finer discretization has not received sufficient attention in the hydrogeologic literature. This magnifies the need a nested modeling approach where a regional model is established for the purpose of feeding information into higher-dimension local models that focus on particular features and problems of interest. Linking the two models in dynamic mode needs to be investigated.

The main objective of this research is to develop and evaluate approaches for dynamically linking groundwater models with different discretization and dimensionality. Thus, a hypothetical model with certain dimensions is developed and used as a reference model for validation purposes. Modeling tools such as the Groundwater Modeling System (GMS) package, native MODFLOW and FORTRAN are used to study the impact of nesting and discretization transition. Also, many scenarios are developed to evaluate the sensitivity of results to the model parameters. To find the relation between these parameters, we rely on Artificial Neural Networks (ANN) toolbox in MATLAB.

Based on the simulations and different scenarios, it is found that the accuracy of information transferring depends on several model parameters. Overall and based on the conducted sensitivity analysis, the loss of information during linking between regional and local models is acceptable. Furthermore, constructing more scenarios and case studies will enhance the performance of the model. This model can be used as guideline for applications that need nesting and fine mesh in a particular area of the domain. So, it would be an appropriate choice for areas that have series of wells with moderate or high discharge rate.

CHAPTER (1)

1. INTRODUCTION

1.1 General

Groundwater represents the major component of the available fresh water on the Earth. It is crucial to areas with limited annual precipitation. Moreover, it is considered as one of the most dominant sources for drinking water and irrigation since the dawn of recorded history. Groundwater is also encountered in many civil fields such as construction dewatering. Therefore, groundwater effects are important to be considered when establishing and designing underground structures and subsurface drainage for agricultural lands.

Groundwater development programs require knowledge of the flow system. This is a prerequisite to understanding the availability of groundwater and the interaction between groundwater and other elements of the environment. This awareness can be achieved through groundwater flow understanding at both local and regional scales. The understanding of groundwater flow at the appropriate scale is crucial for studies involving engineering, agriculture, ecology, geography and any environmental related issue.

Groundwater modeling is a powerful and efficient tool that has been used widely through the past four decades to study different groundwater problems. Groundwater modeling is an effective tool which can be used to test and examine different management alternatives and scenarios. Also, it can be used to run different sensitivity analyses to identify the most influential parameters. As field characterization related to groundwater studies is fairly expensive and time consuming, such modeling provides an important tool for guiding field efforts. That has the benefit of directing the limited financial resources to the most beneficial filed activities and data collection efforts.

Modern numerical modeling techniques allow the inclusion of hydrological and hydrogeological properties obtained by both direct and indirect measurements to produce improved simulations of groundwater conditions. Numerical methods have the flexibility of simulating complex geological geometry and boundary conditions. Moreover, numerical models are effective to use for stochastic analysis of flow and contaminant transport processes in groundwater systems. In this case, the Monte Carlo framework is implemented and the numerical model is run as many times as necessary to produce converging statistical results.

With increasing human activities and climate pressure on groundwater resources, accurate and reliable predications of groundwater flow are essential for sustainable groundwater management practices. Typically, however, the geological structure is only partially known and point measurements of subsurface properties or groundwater heads are sparse and prone to error. Consequently, high resolution grid refinement is needed in groundwater flow modeling to achieve a relevant accuracy and avoid biased and incomplete results.

Zhou and Li (2011) stated that the need to predict the regional impacts of human activities on the groundwater systems and the related environment led to significant advances and development in the modeling of regional groundwater flow. Additionally, an exponential evolution of regional groundwater modeling was achieved due to using powerful computers, GIS and user friendly modeling systems. Many transient groundwater models were constructed to optimize scenarios of groundwater development. These models were built to simulate the change in the components of the water budget and analyze regional flow systems.

1.2 Problem Statement

Regional models are commonly constructed such that they reach out to well-defined boundaries and then they are used as reference models for detailed studies for local area(s). For a detailed study at local scales, it becomes essential to use a high resolution numerical model (fine level of discretization) to simulate the local features that may have significant influence on the system dynamics (faults, wells, soil lenses). This high resolution level in groundwater model is not feasible when the model area is very large, which is the common case in most of the regional models that reach out to well-defined boundaries. In such regional models simple areal two-dimensional modeling may be sufficient, whereas local models may require more detailed three-dimensional analysis. The connection between a regional model and a local one with a higher dimensionality level has not received sufficient attention in the hydrogeologic literature. This magnifies the need for a nested modeling approach where a regional model is constructed for the purpose of feeding information into higher-dimension local models that focus on particular features and problems of interest. Linking the two models in dynamic mode needs to be investigated.

Particle tracking methods have been extensively used for flow paths tracing within groundwater flow modeling. Also, development of these methods has significantly enhanced the ability of determining the subsurface contaminant movement and to select the optimum strategy for aquifer remediation and protection. These methods have also been used for delineating the so called well capture zones which are the areas contributing to wells. According to Franke et al. (1998), these areas can be defined as the surface areas which collect the recharge water to the well. These areas can be determined by particle tracking programs and groundwater flow models. Therefore, linking between the two models is essential to obtain accurate results. Frederick et al. (2001) endorsed that spatial discretization effects are the most serious parameter during groundwater modeling.

Finite difference methods have been widely used for simulating groundwater and fate of contaminant transport during the last two decades. Conventional methods of finite differences depend on fixed grid size for the model discretization across the domain. To get accurate solutions, fine sampling intervals in the three directions are needed during modeling. Although using fine discretization achieves higher accuracy in results obtained from modeling, it consumes more running time than the coarse discretization. This is special crucial if stochastic analysis and Monte Carlo frameworks are implemented.

Many solutions are suggested to achieve balance between the accuracy of results and the running time of the model. One of these solutions was to establish a grid refinement in the horizontal direction at a specific area of the domain. In MODFLOW-2000 (Harbaugh et al., 2000), grid refinement can be formulated at a certain location of the domain. Then, the grid size starts in increase with a certain multiplier factor till it becomes similar in size to the original coarse size. Another potential solution is to divide the domain into two parts with different discretization. The first part is the coarse regional model and the second one is the fine local domain which focuses on the location of concern.

To link the second solution with reality, we can have a look on the typical stages of groundwater modeling which includes two main steps. The two significant steps are determining the location of interest and defining the boundary conditions. If the boundary conditions are located near the location of interest, there is no need for establishing regional and local models. However, if the boundary conditions are located away from the local domain, we have to extent the domain till reaching well defined boundaries. Consequently, the large domain will be called regional domain and the location of concern will represent the local domain. Finally, linking the two different discretization models represents the most dominant part of the groundwater modeling.