A SIMULATION - OPTIMIZATION APPROACH TO GROUNDWATER MANAGEMENT PROBLEMS

by

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CERTIFICATE

This is to certify that the thesis entitled **"A SIMULATION - OPTIMIZATION APPROACH TO GROUNDWATER MANAGEMENT PROBLEMS "** being submitted by **Mr. Sudheer Chintalapati** to the **Indian Institute of Technology, Delhi** for the award of the degree of **Doctor of Philosophy** is a bonafide record of research work carried out by him under my supervision and guidance. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirements for the degree of Doctor of Philosophy.

The results contained in this thesis have not been submitted, in part or full, to any other University or Institute for the award of any degree or diploma.

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Abstract

Four groundwater management problems are studied using advanced simulation and optimization techniques. The first problem deals with an estimation of aquifer parameters using Particle Swarm Optimization (PSO) trained neural network. Support Vector Machines (SVM) are used in the second problem to model groundwater level. The problem of uncertainties in flow and solute transport model using Adaptive Neuro Fuzzy Inference System (ANFIS) and Particle Swarm Optimization is studied next. Finally, a simulation optimization technique, SVM-PSO is used to determine the minimum cost required to remediate an aquifer using in-situ bioremediation process.

Numerical simulation in aquifers require knowledge of parameters that govern flow through aquifers, however, at times, these parameters are not available. Estimation of such parameters has thus gained importance in the recent years and researchers have suggested various ways by which these parameters can be obtained. Amongst the various methods used for parameter estimation, artificial neural networks (ANN) has shown promise in determining parameters for non leaky confined aquifers. Usually some gradient algorithms including the back propagation (BP) technique are used for training a network, however these procedures exhibit slow convergence. Besides this, the solution gets easily entrapped in a local minima. The ANN proposed in this study employs a Particle Swarm Optimization(PSO) technique to train the preceptrons to predict the storage coefficient and transmissivity of aquifers. PSO technique could be an effective alternate training algorithm for ANN's since it is found to

converge much faster when compared to the existing conventional algorithms. Besides this, since PSO is a heuristic optimization technique, a global optimal solution can be obtained . Further, a sensitivity analysis is later carried out in the study to evaluate the most suitable ANN characteristics which includes the learning rate, the momentum factor, and the number of neurons in the input, hidden and output layers. Also, the impact of maximum velocity and acceleration constants of PSO on ANN convergence is studied so as to obtain the best possible value of parameters to minimize error. Thus the evaluated ANN characteristics predict minimum error when the proposed Particle Swarm Optimization trained Neural Network is employed in aquifer Parameter Estimation for the specific cases.

Likewise, the prediction of groundwater levels in a basin is of immense importance for the management of groundwater resources. In this study, Support Vector Machines (SVM) is used to construct a ground water level forecasting system. Moreover, application of SVM as an estimation model for ground water head is investigated in the Rentachintala region of Andhra Pradesh in India. The SVM model with various input structures is constructed and the best structure is determined. In addition to this, various training/testing data sets are constructed and the best data set amongst these is determined using the k-fold cross validation method. Later, the performance of the SVM model for training and testing set is compared with the adaptive neuro fuzzy inference system, another popular technique commonly used in the forecasting problem. The results indicate that SVM is a far better technique for predicting ground water levels as it provides a high degree of accuracy and reliability.

Similarly, a methodology for an optimal in-situ bioremediation system design is developed in this study. An in-situ bioremediation system requires the *location and pumping rates of the extraction and injection wells in addition to the quantity and type of electron acceptors, microorganism and nutrients for effective clean up of contaminated aquifers. The methodology integrates the benefits of the Support Vector Machines and Particle Swarm Optimization algorithms to explore an optimal pumping pattern and optimal number of well locations required. This methodology comprises two stages. In the first stage, the optimal number of wells and their location is determined from the preselected candidate well locations. Subsequently, in the second stage, an optimal pumping rate is determined for the same wells using the SVM-PSO algorithm.*

A Finite difference model is also developed to simulate the process of in-situ bioremediation using Alternate-Direction Implicit technique. This model (BIOFDM) yields the spatial and temporal distribution of contaminant concentration for predefined initial and boundary conditions. The simulated model is later validated by comparing the simulated results with those obtained using BIOPLUME III model of the case study of Shieh and Peralta (2005). The results are found to be in close agreement.

Later, eight different scenarios are considered in the first stage of optimization. A database comprising well locations and well discharges is generated randomly for each scenario. This database is used for training and testing the SVM's for all possible input ranges. Once the database is generated, the residual concentration and the maximum and minimum heads in the aquifer are simulated by using the developed model, BIOFDM for each pumping pattern. The generated pumping pattern is considered successful when it meets all the regulatory constraints. Once the SVM is trained, the total system cost function is minimized by using PSO algorithm that searches through all possible pumping realizations to find an optimal realization. SVM is then used to predict *the value of the objective and / or constraint functions for the possible combined realizations. Finally, the recommended management solutions are validated using the simulation model (BIOFDM). Since the PSO is unable to handle all the constraints, a penalty function method is used to deal with the constraints of the defined objective function.*

In the second stage, a near optimal cost of the system is determined by adopting a time variant discharge of the wells obtained through the first stage. It is found that a time varying pumping strategy is more effective in managing in-situ bioremediation when compared to steady state pumping from wells since a significant reduction in the operational cost is achieved.

Furthermore, a methodology is developed in this study wherein a neural-fuzzy model based on an adaptive neuro fuzzy inference system (ANFIS) is integrated with the particle swarm optimization to estimate the uncertainties in output parameters due to imprecision in input parameters. The particle swarm optimization technique is used to find a global optimal solution to a groundwater flow and contaminant transport problem. This is achieved by incorporating the Adaptive Neuro Fuzzy Inference System (ANFIS) to evaluate the objective function within the PSO framework. Later, the ANFIS-PSO algorithm is applied to four problems taking a) a single imprecise parameter for radial flow to a well, b) two imprecise parameters for one dimensional solute transport in steady uniform flow, c) three imprecise parameters for a two-dimensional heterogeneous steady flow problem and finally d) four imprecise parameters for the problem of two-dimensional solute transport. The results show that with the ANFIS-PSO algorithm, the computational burden is reduced considerably when compared to the commonly used vertex method.

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