IN-SITU BIOREMEDIATION AND UNCERTAINTY ANALYSIS OF CONTAMINATED GROUNDWATER – A SIMULATION-OPTIMIZATION APPROACH

by

RAM KAILASH PRASAD

Department of Civil Engineering

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TO

Almighty GOD

Certificate

This is to certify that the thesis entitled **"IN-SITU BIOREMEDIATION AND UNCERTAINTY ANALYSIS OF CONTAMINATED GROUNDWATER – A SIMULATION - OPTIMIZATION APPROACH"** being submitted by **Mr. Ram Kailash Prasad** 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.

Shashi Mathur

(Shashi Mathur)
Professor
Department of Civil Engineering
Indian Institute of Technology, Delhi
Hauz Khas, New Delhi - 110016

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(RAM KAILASH PRASAD)

Abstract

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. It is important to determine the optimal well locations as well as optimal pumping rates for an in-situ bioremediation system to remediate the contaminated aquifer in a cost effectively manner. In this study a methodology for an optimal in-situ bioremediation system design is developed.

A bioremediation model is first developed using U.S. Environmental Protection Agency (USEPA) developed software BIOPLUME III, which yields the spatial and temporal distribution of contaminant concentration under the defined initial and boundary conditions. The developed model is then used to study an in-situ bioremediation problem of Shieh and Peralta (2005). The model is validated by comparing the simulation results with the results of Shieh and Peralta (2005), which are found to be in close agreement. A sensitivity analysis is also conducted to observe the model output when it is subjected to changes in the aquifer parameters.

A neural network embedded Monte Carlo approach is used to determine the potential well locations for two different scenarios. In the first scenario only oxygen is considered as terminal electron acceptors while both oxygen and nitrate are taken in the second case. A regrouping or clustering of the preselected well locations into potential well locations is achieved, which in turn results into a considerable reduction in the dimension of the problem since the redundant well locations are eliminated. Once the potential well locations are identified, an artificial

neural network and genetic algorithm (ANN-GA) methodology is adopted to determine the optimal well location and pumping rates of injection and extraction wells to achieve a near optimal cost of the in-situ bioremediation system. The results show that the costs associated with the proposed management solution is consistent with those resulting from other optimization techniques which otherwise use linked bioremediation simulation models. The computational burden of Monte Carlo simulations and genetic algorithms is managed within the practical time frame by replacing the BIOPLUME III simulation model with a trained ANN model. This in turn results into a considerable reduction in the number of simulations involved. Furthermore, a penalty parameter-less approach adopted in this study does not require any penalty coefficient and has been found to work well for an in-situ bioremediation problem. A considerable reduction in the optimal system cost is further achieved if both oxygen and nitrate are used as terminal electron acceptors in comparison to a scenario where only oxygen is used as an terminal electron acceptor. It is further observed that an optimal transient pumping strategy results in a reduction of the pumping cost by about 20 % in comparison to cases where a steady state pumping strategy is adopted.

An ANN-GA technique is further adopted to estimate the uncertainties in output quantities due to imprecision in input parameters. Five different cases involving radial flow to a well, one-dimensional solute transport in steady uniform flow, a two-dimensional heterogeneous steady flow, a two-dimensional solute transport and a two-dimensional unsteady groundwater flow to demonstrate the efficiency and effectiveness of the developed algorithm respectively are considered. The result shows that one could successfully measure the uncertainties associated with groundwater flow and contaminant transport simulations in addition to achieving a considerable reduction in computational effort using ANN-GA framework as compared to the popular vertex method.

Furthermore, a human health risk assessment model taking a number of remedial alternatives is also studied. Later, different combinations of pump-and-treat remediation systems are *compared with the bioremediation strategy. The computed residual risk and the costs associated with the reduction of the risks are used as parameters for justification of a better remedial alternative. The bioremediation method is found to be a much better remedial alternative even when the parameter uncertainties in aquifer parameters prevail compared to other popular hazardous waste clean up strategies.*

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