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Determination of the Optimal Strategy for Pump-And-Treat Method

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Abstract

An optimization process for the design of groundwater remediation is developed by simultaneously considering the well location and the pumping rate. This process uses two independent models: simulation and optimization model. Groundwater flow and contaminant transport are simulated with MODFLOW and MT3D in simulation model. In optimization model, the location and pumping rate of each well are determined and evaluated by the genetic algorithm. In a homogeneous and symmetric domain, the developed model is tested using sequential pairs for pumping rate of each well, and the model gives more improved result than the model using sequential pairs. In application cases, the suggested optimal design shows that the main location of wells is on the centerline of contaminate distribution. The resulting optimal design also shows that the well with maximum pumping rate is replaced with the further one from the contaminant source along flow direction and that the optimal pumping rate declines when more cleanup time is given. But the optimal pumping rate is not linearly proportional to the cleanup time and the minimum total pumping volume does not coincide with the optimal pumping rate.

key word: optimization, pump-and-treat, genetic algorithm, minimum pumping rate

1. Introductoin

Pump-and-treat method may be the most conventional methods for large- and small-scale groundwater containment and cleanup problems. This method involves installing and operating a set of extraction wells so that the contaminated groundwater is hydraulically contained and can be pumped out for subsequent treatment. Nowadays, many management models have been developed for the optimal design of pump-and-treat system based on simulation and optimization techniques. However, most models assume steady-state flow (Culver and Shoemaker, 1992).

The main objective of this study is to develope a groundwater remediation design model using genetic algorithms for application to general field conditions. This model is divided into two independent models, simulation and optimization model. For the development of the simulation model, the common used three-dimensional groundwater flow model, MODFLOW (McDonald and Harbaugh, 1988), and solute transport model, MT3D (Zheng, 1990), are used for application to real-world problems. For optimization model, the simple genetic algorithm (Goldberg, 1989) is used.

2. Simulation-Optimization model

The simulation model calculates state variables, hydraulic heads and contaminant concentration, using decision variables, location and pumping rate of each well, which are made by optimization model. Further, optimization model evaluates the fitness of decision variables and searches the optimal design with it.

2-1 Simulation Model

The simulation model is consist of flow and transport simulation model. MODFLOW and MT3D. The governing equation for MODFLOW is given by;

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right) + q_s = S_s\frac{\partial h}{\partial t} \quad (1)$$

where K_{xx}, K_{yy}, K_{zz} are the components of hydraulic conductivity along the x, y, and z coordinate axes; h is the hydraulic head; q_s is the source/sink term; S_s is the specific storage; and t is time. And the governing equation for MT3D is given by;

$$\frac{\partial}{\partial x_i}\left(D_{ij}\frac{\partial C}{\partial x_i}\right) - \frac{\partial}{\partial x_i}(v_i C) + \frac{q_s}{\Theta}C_s = R\frac{\partial C}{\partial t} \quad (2)$$

where D_{ij} is the hydrodynamic dispersion coefficient; C is the concentration of contaminant; C_s is the concentration of the source/sink flux; Θ is the porosity of the porous medium; v_i is the average linear velocity; and R is the retardation factor.

2-2 Optimization model Using Genetic Algorithm

Objective function can be set for minimal pumping rate or minimal pumping volume. In this study, objective function is designed for minimal pumping rate. So objective function is given by;

$$\text{Maximum} \quad \frac{E_n}{\sum_{i=0}^{n} q_i + P} \quad (3)$$

where q_i is the pumping rate of well i; P is a penalty; E_n is an appropriate number for objective function to maintain reliable value. The lower pumping rate is assigned, the higher objective function and the fitness of the selected design is yielded. Penalty is set larger number than the maximum of pumping rate. If the selected decision variable is not satisfied concentration standard, P is assigned. If not, P is not assigned and these decision variables have a chance of the optimal design.

The concept of genetic algorithm is given by genetic evolution in biology (Goldberg, 1989). In genetics, a dominant gene can be successive and offsprings are more adaptable in surroundings than its parents. And many operators such as reproduction, crossover, and mutation work on gene's development. In genetic algorithm, binary-bit strings represent genes. As they works for genes, reproduction, crossover, and mutation do for strings.

3. Test Case for Developed Model

An ideal condition is assumed for evaluating applicability of genetic algorithm. Initial contaminant distribution is formed by a leakage of contaminant source with constant concentration for ten years (Figure 1). It is assumed that two extraction well is installed for remediation of contaminated zone (Figure 1). The optimal value suggested by genetic algorithm is compared with that suggested sequential pairs, which is that one variable is fixed and the other is variable. In respect of seeking similar optimal value, genetic algorithm take the three quarter time than that of sequential pairs, and finally calculate more optimal design (Table 1 & 2).

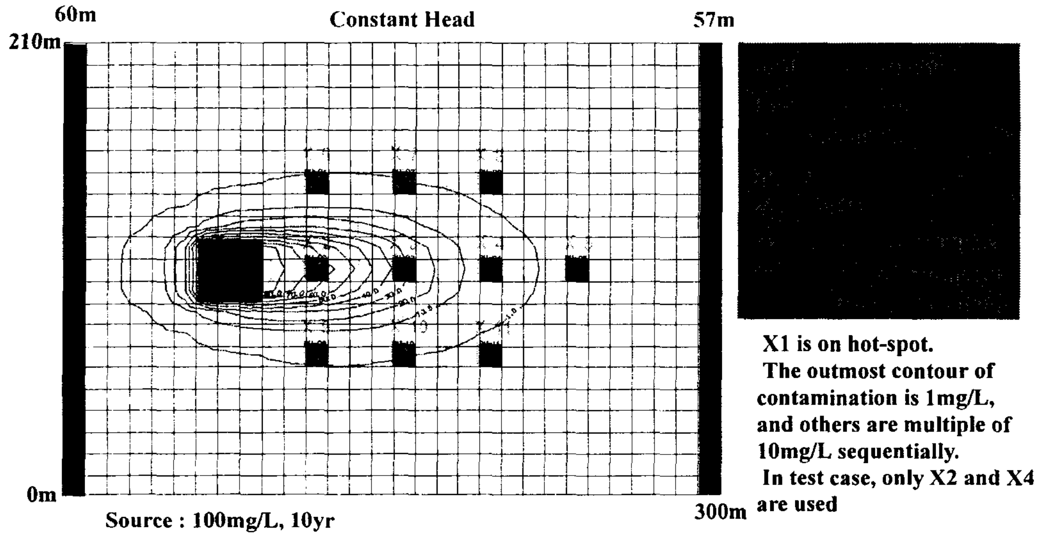

Figure 1. Initial condition of test and problem case

Pumping rate (m^3/day)			Objective function
X2	X4	Sum	
0	0	0	1.000000
⋮	⋮	⋮	⋮
90	155	245	40.81633
⋮	⋮	⋮	⋮
180	180	360	27.77778

Table 1. Optimal value in sequential pairs (Number of calculation is 37×37=1369)

Pumping rate (m^3/day)			Objective function	Number of Calculation
X2	X4	Sum		
95.191	153.959	249.150	40.13653	800
82.698	163.284	245.982	40.65331	3750
90.792	153.431	244.223	40.94621	4400
99.982	142.874	242.856	41.15375	10750
79.883	162.581	242.464	41.24345	14300

Table 2. Optimal value in genetic algorithm

4. Model Application

Year	Pumping rate (m^3/day)								
	X1	X2	X3	X4	X5	X6(=X9)	X7(=X10)	X8(=X11)	Sum
1	(infeasible)								
2	117.537	179.472	179.824	166.804	30.264	8.798	98.182	54.370	996.598
3	92.903	109.326	119.883	115.543	41.642	3.050	50.909	2.463	592.141
4	13.842	118.592	104.751	16.657	10.909	5.279	3.050	12.551	306.510
5	10.792	116.598	110.264	6.100	7.859	1.056	1.760	0.235	257.713
6	17.713	60.059	83.871	7.859	10.088	0.000	6.804	7.390	207.977
7	25.572	45.161	73.079	27.801	1.760	0.587	0.235	3.050	181.114
8	7.742	49.032	59.003	8.094	14.663	7.977	8.563	1.056	173.724
9	10.205	12.903	71.672	47.625	8.328	2.111	4.927	0.235	165.279
10	3.167	3.050	109.560	18.416	13.724	3.754	0.469	4.223	164.809

Table 3. Optimal pumping rate for different cleanup time

It is assumed that eleven extraction well is installed for remediation of contaminated zone for determination of the location and the optimal pumping rate of each well in the same domain. The cleanup time is given from two to ten years. The more time is given, the less pumping rate is calculated (Figure 2). And the main pumping wells that have relatively high pumping rate are on the centerline of contaminant distribution. It is coincided with conventional concept (Huang and Mayer, 1997). The well with maximum pumping rate is replaced with the further one from the contaminant source along flow direction (Table 3). The minimum total pumping volume does not coincide with the optimal pumping rate (Figure 3).

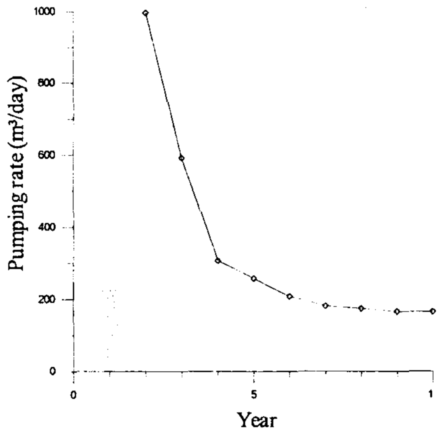

Figure 2. Pumping rate vs. Cleanup time

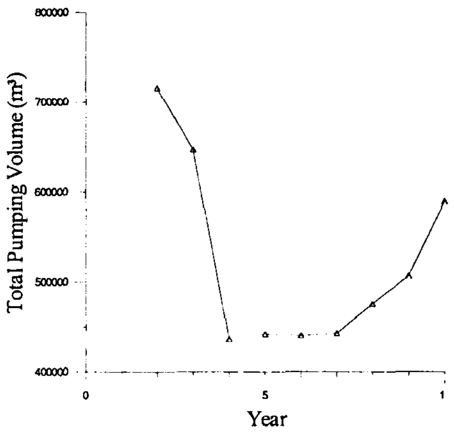

Figure 3. Pumping volume vs. Cleanup time

5. Conclusions

It is evaluated that optimization process with genetic algorithm is effective in respect of optimal value and calculating time in this study. In application case, pumping mainly happens on the centerline of concentration distribution. If the more cleanup time is given, the center of transporting concentration moves further from hot-spot. It makes the change of effectiveness of well location, so the maximum pumping well is changed into the neighbor well from hot-spot, and pumping rate is lower. But the total pumping volume is not optimal. It shows that remediation using pump-and-treat method must set the appropriate cleanup time.

6. References

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