Advances in Water Resources 25 (2002) 51–65

Advances in Water Resources

www.elsevier.com/locate/advwatres

Multi-objective optimal design of groundwater remediation systems: application of the niched Pareto genetic algorithm (NPGA)

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Received 19 October 2000; received in revised form 3 May 2001; accepted 19 May 2001

Abstract

A multiobjective optimization algorithm is applied to a groundwater quality management problem involving remediation by pump-and-treat (PAT). The multiobjective optimization framework uses the niched Pareto genetic algorithm (NPGA) and is applied to simultaneously minimize the (1) remedial design cost and (2) contaminant mass remaining at the end of the remediation horizon. Three test scenarios consider pumping rates for two-, five-, and 15 fixed-location wells as the decision variables. A single objective genetic algorithm (SGA) formulation and a random search (RS) are also applied to the three scenarios to compare performances with NPGA. With 15 decision variables, the NPGA is demonstrated to outperform both the SGA algorithm and the RS by generating a better tradeoff curve. For example, for a given cost of $100,000, the NPGA solution found a design with 75% less mass remaining than the corresponding RS solution. In the 15-well scenario, the NPGA generated the full span of the Pareto optimal designs, but with 30% less computational effort than that required by the SGA. The RS failed to find any Pareto optimal solutions. The optimal population size for the NPGA was found by sensitivity analysis to be approximately 100, when the total computational cost was limited to 2000 function evaluations. The NPGA was found to be robust with respect to the other algorithm parameters (tournament size and niche radius) when using an optimal population size. The inclusion of niching produced better results in terms of covering the span of the tradeoff curve. As long as some niching was included, the results were insensitive to the value of the parameter that controls niching ($\sigma_{\text{share}} > 0$).

1. Introduction

When faced with subsurface remediation management problems, decision makers must frequently weigh multiple objectives such as minimizing cost, minimizing health risk, minimizing cleanup time, and maximizing reliability. In these cases, it may be of value to the decision makers to view the tradeoffs between the conflicting objectives, providing a more effective means of selecting and implementing the best-suited remedial alternative for a given site.

The majority of applications of optimization tools to subsurface remediation problems have been based on single objective optimization methods. Single objective methods can accommodate multiobjective problems in several ways, such as minimizing a weighted, linear combination of the objective functions or minimizing a single objective while transforming the remaining objectives into constraints. However, these methods rely on a priori knowledge of the appropriate weights or constraint values. Furthermore, they are only capable of finding individual points on the tradeoff curve (or surface) for each problem solution.

True multiobjective methods have the potential to simultaneously generate all possible optimal combinations of objectives, with less effort than other approaches. Multiobjective problems involve several objective functions, each of which is a function of decision (d) and state variables (s). A generic multiobjective problem can be stated as:

$$O_1 = \max/\min[f_1(d_1, d_2, \ldots d_{n_1}; s_1, s_2, \ldots s_{n_2})]$$
$$O_2 = \max/\min[f_2(d_1, d_2, \ldots d_{n_1}; s_1, s_2, \ldots s_{n_2})]$$
$$\vdots$$
$$O_m = \max/\min[f_m(d_1, d_2, \ldots d_{n_1}; s_1, s_2, \ldots s_{n_2})]$$

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0309-1708/02/$ - see front matter
PII: S0309-1708(01)00020-3