# OPTIMIZATION OF PUMP AND TREAT SYSTEMS: AUTOMATED GROUNDWATER MODELING OPTIMIZATION

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## Background

With the recent focus on lowering the operating costs of environmental remediation systems, including groundwater pump and treat systems, there has been increased interest in algorithmic approaches to optimization. The Department of Defense and United States Environmental Protection Agency (USEPA) sponsored a study to evaluate the benefits and utility of transport optimization algorithms, operable on desktop computers, against trial and error approaches for pump and treat system design. This follows upon an earlier USEPA effort to determine the efficacy of a hydraulic optimization algorithm designed for MODFLOW. Mathematical optimization problems are formulated to minimize an objective and satisfy a set of constraints. Hydraulic optimization typically applies to plume containment problems, while transport optimization typically applies to problems associated with reduction of contaminant concentrations or contaminant mass. Transport optimization can consider life-cycle costs and cleanup time as components of the objective or as part of the constraints. Application of transport optimization could potentially reduce the costs for pump and treat systems by millions of dollars over the life of the projects, as this study has demonstrated. Note that these types of optimization tools have previously been (and currently are being) applied to Air Force projects.

## Methods

In this project, various criteria were applied to screen DoD facilities appropriate for demonstrating pump-and-treat transport optimization algorithms, with three systems selected at the Umatilla Army Depot, Oregon, the Tooele Army Depot, Utah, and the former Blaine Naval Ammunition Depot, Nebraska. For each facility selected, the existing MT3D transport model was assumed to be adequate for remedial design purposes. Administrative objectives and constraints such as desirable points of compliance, permissible well locations, pumping rate limitations, and new well costs were established with agreement from the facility personnel and contractors, and set forth as mathematical formulations. Three optimization formulations were developed for each pump and treat system for optimization modeling by two modeling groups applying transport optimization algorithms and a third group applying trial and error to serve as a control. The concept of management periods was used to allow pumping strategies and locations to change at the end of each 3 to 5 year period, when the performance of the pump and treat systems would typically be reviewed.

Robert Greenwald and Yan Zhang at GeoTrans, Inc applied the trial-and-error approach. The optimization algorithm applications were conducted by Dr. Richard Peralta and others at Utah State University and Dr. Chunmiao Zheng and others at the University of Alabama. They used their own independently developed simulation-optimization software for this study. Dr. Zheng used Modular Groundwater Optimizer (MGO), which is implemented with genetic algorithm (GA), simulated annealing (SA), and tabu search (TS) optimization algorithms. Dr. Peralta used the SOMO3 Module of SOMOS, which is implemented with genetic algorithm (GA) and simulated annealing (SA) optimization algorithms, as well as artificial neural networks (ANN) for approximating simulation models.

For each formulation, an initial solution was established by the trial and error modeling group to ensure that each had at least one feasible solution. This was followed by a four-month computational period for each group at each site. During this four-month period, the three groups were prohibited from discussing their findings with the others. In addition to the three problems posed for each facility, the modelers were provided the opportunity to propose and solve new problems with modified constraints that they felt might be of interest to the facility. Efforts were undertaken to reduce the run times of the transport model for each site while maintaining the desired accuracy.

## Results

This project clearly demonstrated that mathematical optimization is capable of identifying substantially improved solutions to actual field-scale problems. The two modeling groups applying the optimization algorithms were able to evaluate far more alternatives than the trial and error modeling group and found improved solutions. The solutions found by the algorithms for these three “real-world” sites were 5% to 50% better than those obtained using trial-&-error (measured using optimal objective function values), with an average improvement of about 20%. For Blaine, which has substantial costs, these results would give cost savings of up to $10M over the 30-year duration of the cleanup. The cost savings at Umatilla were lower, with savings up to $600,000, but the Umatilla cleanup is much less expensive and complex than the Blaine site. As the complexity of the site increased, more cost savings were obtained. These savings are substantially greater than the incremental cost of applying mathematical transport optimization over a more traditional trial-and-error approach, which we estimate to range from zero to $40,000. These costs do not include the cost of developing mathematical objective functions and constraints, which we estimate to cost $5,000 to $15,000. The cost estimates also do not include the costs of developing a transport simulation model, which would be needed regardless of whether trial-and-error or optimization algorithms were used.

Prior to developing optimal solutions for each site, mathematical formulations need to be established. This was a difficult and time-consuming process. However, this formulation process forces development of a concise and quantifiable set of objectives and allows comparison of potential project objectives and constraints. As such, the effort is worthwhile whether or not mathematical optimization algorithms are ultimately applied.

Due to the specific needs of this demonstration project, the optimization formulations were fixed at the beginning of the simulation period, and simulation period length was defined. However, normally the optimization modeler would iterate with the installation to develop revised formulations as optimization proceeds, to incorporate new knowledge and potentially revise formulations. This project demonstrates that such iterations should be a component of real-world applications.

This project also demonstrated that applying the transport optimization algorithms required expertise to reduce computational time. If a single optimization run were set up to solve the entire problem as formulated, with all possible pumping rates and well locations in all potential management periods, the number of decision variables would be much larger and the computational times associated with the optimization algorithms would be prohibitive on today’s computers for these time-intensive applications (the model for the Blaine site, e.g., required nearly two hours of computing for every run of the simulation model). Instead, the transport optimization teams employed sequential solution approaches to reduce computational effort, in which some parts of the problem were fixed while others were optimized. In some cases, problems were solved one management period at a time. In others, well locations were identified first, assuming steady-state pumping rates, followed by optimizing well rates for those pre-determined well locations. The optimization teams also used approximate models such as neural networks, which can be fit to the simulation model results and then used to replace the simulation models within the optimization to reduce computing time. The application of these optimization tools requires expertise and professional insight.