Application of Optimization Algorithms to Groundwater Pump and Treat Systems

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Presentation Outline

- Project overview
  - Background and objectives
  - Description of optimization algorithm
  - Project design
- Results from 3 installations
- Findings and lessons learned
- Next Steps

Background

- 1999 EPA hydraulic optimization simulation study
  - Indicated potential savings of millions of dollars at 2 of 3 sites
  - Focused on containment sites where reductions in pumping lead to substantial life-cycle cost savings
- Limitation of hydraulic optimization
  - Cannot optimize contaminant concentrations or clean-up times
- Optimization algorithms have been used at Air Force sites

Project Team

- ESTCP and EPA provided funding for demonstration of optimization algorithms
- Diverse project management team
  - Navy, EPA, USACE, GeoTrans, Dr. Barbara Minsker
- Transport optimization modelers
  - Dr. Richard Peralta, Utah State University
  - Dr. Chunmiao Zheng, University of Alabama

Project Goals

- Primary project goal
  - Compare results of:
    - Two groups applying transport optimization algorithms
    - One group applying traditional trial&error as a scientific control
  - Determine if the optimization algorithms provide improved solutions versus trial & error, and are cost effective to apply
- Secondary project goal
  - Provide useful information to the installation, ideally in the form of an improved strategy to be implemented

Optimization Codes

- SOMOS Code, Dr. Peralta
  - Simulation Optimization Modeling System
  - Multiple algorithms – genetic algorithm, simulated annealing, and artificial neural network coupled with genetic algorithm
  - Artificial neural network can be trained to replace a time-consuming simulation model during optimization

Optimization Codes, Cont'd.

- **MGO Code, Dr. Zheng**
  - **Modular Groundwater Optimizer**
  - **Multiple algorithms, including genetic algorithm, simulated annealing, and tabu search**
- **Trial & Error, GeoTrans, Inc (Scientific Control)**
- **Codes compatible with MODFLOW/MT3D and others**

Project Design

- Select 3 DoD demonstration sites
- Approach at each site
  - Review each site model
  - Develop 3 optimization "formulations," consisting of:
    - An "objective function" (to be minimized)
    - A set of constraints that must be satisfied
  - Formulations based on input provided by installation
  - Each group independently solved each of the 3 formulations

Example Formulation

- **Identify optimal well locations and pumping rates so as to minimize project cost subject to the following:**
  - **Pumping cannot exceed current treatment capacity**
  - **Clean-up goal must be achieved at property boundary within 3 years**
  - **Limits on individual well extraction and injection rates**
  - **Limits on interior plume growth in hot spots**

Demonstration Sites

Site Name	Pump rate (gpm) and Cost ($/yr)	# Wells	Contam-inants	Groundwater Model Info.
Tooele Army Depot	8000/750K (operating)	15 ext. 13 inj.	TCE	4 layers 10 min. RT
Umatilla Army Depot	1300/430K (operating)	3 ext. 3 inj.	RDX/ TNT	5 layers 10 min. RT
Hastings (F. Blaine NAD)	4000/2M (in preliminary design)	10 ext.	TCE/ TNT	6 layers 2 hours RT

Optimization Formulations

	Minimization objective (constraints)		
Site Name	Form. 1	Form. 2	Form. 3
Tooele Army Depot	$$ (POE)	$$ (POE/POC)	$$ (POE/POC/ source term reduction, conc. <50 @ yr 9
Umatilla Army Depot	$$ (cleanup)	$$ (cleanup, increase to total pumping ok)	Minimize residual mass in layer 1, cleanup
Hastings (former Blaine NAD)	$$ (cleanup)	$$ (cleanup, subtract 2400 gpm treatment costs)	Minimize total pumping (containment)

Results

Algorithms Average ~20% Improvement

	Percentage Improvement Using Optimization Algorithms (over Trial and Error)		
Site Name	**Form. 1**	**Form. 2**	**Form. 3**
Tooele	**3 to 13**	**11**	**Infeasible**
Umatilla	**23**	**15**	**50**
Hastings	**10 to 20**	**15 to 33**	**5 to 26**

Findings/Lessons Learned

- **Transport optimization algorithms….**
  - **Found 3 to 50% improved solutions over trial & error, average 20% (Improvement better [to 50%] if fixed costs are removed)**
  - **Had corresponding cost savings that varied depending on complexity of site**
    - **At Blaine, up to $10 million in cost savings possible**
    - **At Umatilla, up to $600,000 in cost savings**

Findings/Lessons Learned

- **Optimization algorithms….**
  - **Allow thousands more simulations**
    - **For example, 39 trial & error runs vs. 5000 runs under the MGO optimization code for one formulation**
  - **Are estimated to cost $40-100K per site ($0-40K over trial & error design)**
    - **Range varies with site complexity, model size, and # of contaminants**
    - **Does not include transport model development**

Findings/Lessons Learned

- **Optimization algorithms…**
  - **Can assist sites in screening alternative strategies (e.g., aggressive pumping vs. containment only)**
  - **Have potential application during the design and operation of P&T systems**
  - **Require development of formulations, which helps project team quantify and understand objectives**

Findings/Lessons Learned

- Applying optimization algorithms can reveal useful information about site/model
  - Have no preconceptions; they "think outside the box"
  - For example, at Umatilla, identified possible savings from shutting down wells in RDX plume
- Good to evaluate and update existing flow and transport models before optimization
  - Though reasonably good, the models at all 3 sites were refined before optimization (not a trivial step)

Findings/Lessons Learned

- More complex models (longer simulation times, more contaminants) require more expertise to overcome excessive computing times
  - Iterative, sequential approach
    - E.g., Optimize well locations with fixed pumping rates first, then optimize pumping rates at fixed well locations
  - Complicated sites with extended clean-up times more likely to benefit from optimization

Findings/Lessons Learned

- **Optimization provided potential improvement in cost over existing systems (as much as 42-55%)**
  - **<u>However</u>, the optimization was performed with:**
    - **different objectives than original modeling**
    - **improved model**
    - **more site knowledge from operation and additional characterization**
  - **Project teams very open to optimization results**

Next Steps

- Project Report to ESTCP
  - Spring 2003
- Case study / site follow-up
  - Through early 2004
- Outreach
  - Training via internet seminars
  - 1-2 day in-person training
  - Both codes to be available free to public via website