PBMO: The Comprehensive Physics-Based Flow, Transport, and Management Optimization Tool Kit

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Why Optimize with PBMO?

Available Optimization Tools:

- Require multiple stops and starts
- Unable to solve complex problems in reasonable time frames
- Have embedded Flow and Transport (F&T) simulators with limited capabilities

PBMO Salient Features:

- Full automation
- Robust and efficient optimization algorithms
- Flexibility to utilize a variety of physics-based models to capture real-world conditions
Environmental Restoration Optimization

Approach:
- Integrates optimization algorithms and physics-based models
- Leverages all key decision information:
  - Management goals/constraints, stakeholder input, and regulatory requirements
- Realistically captures important site physics
- Uses state-of-the-art, robust optimization methods
- Achieves coherent interpretation of disparate site data
- Produces credible, structured solutions
Environmental Restoration Optimization

Benefits:

- Increased stakeholder confidence
  - Transparent solutions
  - Solutions honor site physics
  - Satisfies management/stakeholder constraints

- Increased management capability and control for site managers
  - Estimates the time and costs
  - Predicts if complete remediation is achievable
  - Quantifies expected system performance
  - Supports informed decisions:
    - Quantifies uncertainty
    - Balances fiscal resources and stakeholder needs
  - Accelerates site closure

- Achieves cost savings and minimizes long-term liabilities
The PBMO™ Medallion Conceptualization

**General Process Description:**
- Define scope of work and deliverable(s)
- Set up project objectives and constraints
- Select suitable model to predict future scenarios
- Solve and interpret results
- Achieve stakeholder acceptance
PBMO Application at: Umatilla Army Depot, OR

Work Objectives:
- Demonstrate newly developed PBMO Optimal Design of Remedial Systems module
  - Determine optimal Pump-and-Treat (P&T) strategy for Umatilla project
    - Well studied site with known credible estimate of global optimal solution
  - Demonstrate ability to find global optimal solution for active remediation faster than previously used optimization tools
  - Showcase PBMO automation and ability to run complete optimization problems from start to finish unattended

The “Umatilla” site was the subject of a well-conducted and documented ESTCP* multi-approach, multi-participant remedial design optimization study. HGL developed PBMO after this study concluded.

* DOD’s Environmental Security Technology Certification Program
Candidate Remediation Infrastructure Locations

Project Approach:

- Determine optimal flow rates / locations for pumping and injection
  - Infiltration trench locations: 7
  - Pumping areas (with movable wells): 3
- Use the same F&T models (MODFLOW/MT3DMS) and model files as in the original study
- Compare PBMO results with known solutions
- Use MGO optimal solution for Formulation 1 (minimizing the total remedy cost) as the search stopping criterion
Infrastructure Locations for Various Remedial Designs

MGO Optimal Solution

PBMO Optimal Solution

TNT

MGO-2

MGO-1

EW-3

EW-1

RDX

PBMO-1

PBMO-2

EW-3

EW-1
PBMO versus MGO: Year 1
PBMO versus MGO: Year 3
PBMO versus MGO: Cleanup Goals

PBMO and MGO optimal solutions attain cleanup goals with 4 extraction wells and 2 infiltration basins.

PBMO and MGO designs meet remedial goals in 4 years for RDX and TNT – a 13 year improvement over the existing RIP.

RDX

TNT
# Remedial Optimization Comparison:

## PBMO and MGO: Umatilla Army Depot

Optimal pumping strategy found using PBMO and MGO for Formulation 1

<table>
<thead>
<tr>
<th>Name</th>
<th>Location (Layer, Row, Column)</th>
<th>Pumping/Injection Rate (GPM)</th>
<th>Total remedy cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>RIP Design</td>
<td>Trial &amp; Error Design (2)</td>
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<tr>
<td>EW-1</td>
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<td>-280</td>
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<tr>
<td>EW-2</td>
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<td>-360</td>
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<td>-660</td>
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<td>EW-4</td>
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<td>-360</td>
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<tr>
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<td>-360</td>
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<tr>
<td>New-2 (T&amp;E)</td>
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<td>-360</td>
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<td>New-6 (PBMO)</td>
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<tr>
<td>IF-1</td>
<td>*</td>
<td>233</td>
<td>282</td>
</tr>
<tr>
<td>IF-2</td>
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<td>405</td>
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<tr>
<td>IF-3</td>
<td>*</td>
<td>483</td>
<td>482</td>
</tr>
<tr>
<td>IF-4</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total remedy cost ($)</strong></td>
<td>$3,836,285</td>
<td>$2,230,905</td>
<td>$1,664,395</td>
</tr>
</tbody>
</table>

(1) DOD; (2) GeoTrans; (3) Zheng (University of Alabama); (4) HGL

## PBMO Results and Advantages:

- PBMO is robust and efficient: found a similar cost solution in ~100 simulations
- ESTCP MGO report stated that “Roughly, a total of 5000 flow and transport simulations were executed by the optimization code.” Numerous manual interventions, tunings, and restarts were required
- PBMO run is completely automated
PBMO: Robustness Testing
Candidate Wells Starting Positions

PBMO Results:
- Six trial runs were made with starting well positions at various corners of the search area.
- For these runs PBMO takes ~100 - 110 simulations to attain the optimal solution.
- PBMO is insensitive to the starting locations for new wells.
Performance Comparison of Global Optimization Algorithms in PBMO and MGO Software

PBMO Vs. MGO:

- PBMO is based on the Lipschitz Global Optimizer (LGO) algorithm
- MGO is implemented with Simulated Annealing (SA), Genetic Algorithms (GA), and Tabu Search (TS)

PBMO Application: Former Fort Ord NPL Site, CA

Site Background:
- Former military facility in California
  - Operable Unit-1 (OU-1) is a former fire drill area
- Aquifer Cleanup Levels (ACLs) defined in 1995 Record of Decision (ROD) for 10 Contaminants of Concern (COCs)
  - TCE is the only COC with concentration > ACL
  - TCE concentration has exceeded ACL since 1988
TCE Contamination in Groundwater: Former Fort Ord OU-1

Remedy-In-Place:

- HGL collaborated with CH2MILL to design the P&T system for remediating the TCE plume (~4,000 ft long inside Fort Ord property boundary)
- HGL has implemented the system and provided its Operation and Maintenance (O&M) services since 2005
- The remedy-in-place (RIP) has eliminated offsite migration of TCE and resulted in substantial reduction in the plume size
Impact of the P&T Remedy-In-Place on the TCE Plume: Former Fort Ord OU-1
PBMO Application: Former Fort Ord OU-1

Work Objectives:
- Develop Optimal P&T program and Optimized Exit Strategy

Project Approach:
- Determine optimal flow rates / locations for pumping and injection to find point in time to stop active extraction/reinjection and transition to Monitored Natural Attenuation (MNA) such that ACL is achieved in 10 years
- For this application, PBMO requires ~ 75 flow/transport simulations and 4.5 CPU hrs to attain the optimal solution
- HGL recently received favorable feedback on the optimal remedial solution from EPA and State Regulators

Observed TCE Plume in March 2011
PBMO Application:
Standard Chlorine of Delaware, DE

Site Background:
- 65-Acre EPA Region 3 Superfund site located near the Delaware River
- Chemical wastes including PCBs, dioxins and chlorinated benzenes in groundwater, surface water and sediment/soil

Remedy-In-Place:
- Well/slurry trench system hydraulic containment

PBMO Application:
- Performance evaluation; identifying potential enhancements
- This application involves only GW flow simulations
- PBMO requires < 30 CPU minutes to attain the optimal solution
Optimization Formulation & Results: Standard Chlorine of Delaware

PBMO Results:
- PBMO analysis identifies several areas of improvement for the existing remedy
- Rectifications were made leading to increased system throughput from less than 10,000 gpd to over 43,000 gpd in 8 months
- System has extracted and treated > 2 tons of contaminants since July 2009
Summary and Conclusions

Umatilla Army Depot, OR:

- RDX/TNT plume Remedial Design Optimization case study: PBMO benchmarked against public domain MGO flow/transport optimization software
  - PBMO attains the globally optimal solution \(~50\ times\ faster\ than\ MGO\)
- Each flow/transport simulation took 2 CPU minutes; PBMO finished in 3.5 CPU hrs
  - Had we been able to run MGO from start to finish, it would have taken 168 hrs (one week) of CPU time

Fort Ord NPL Site, CA:

- O&M of existing P&T system for TCE plume cleanup: PBMO application for Pumping Scheme Optimization – Provides Optimal Scheme, Optimized Exit Strategy as well as \(~$300K\) cost savings
- Identifies when to switch from P&T remediation to MNA

Standard Chlorine of Delaware Superfund Site, DE:

- Well/slurry trench system hydraulic containment remedy: PBMO application for Performance Evaluation and Potential Enhancements
  - Rectifications were made resulting in \(4.3\ fold\ increase\ in\ system\ throughput\ within\ 8\ months\)