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

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Larry M. Deschaine, P.E.
Theodore Lillys, P.E.

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

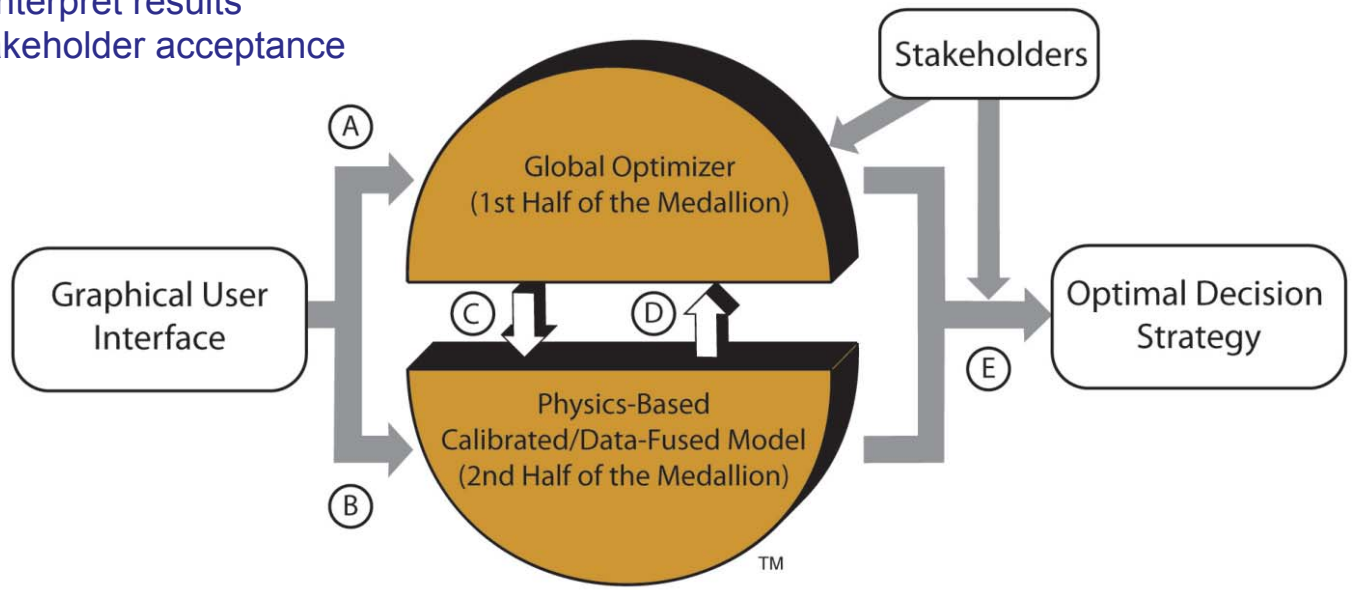
Benefits:

- 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

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

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

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Candidate Remediation Infrastructure Locations

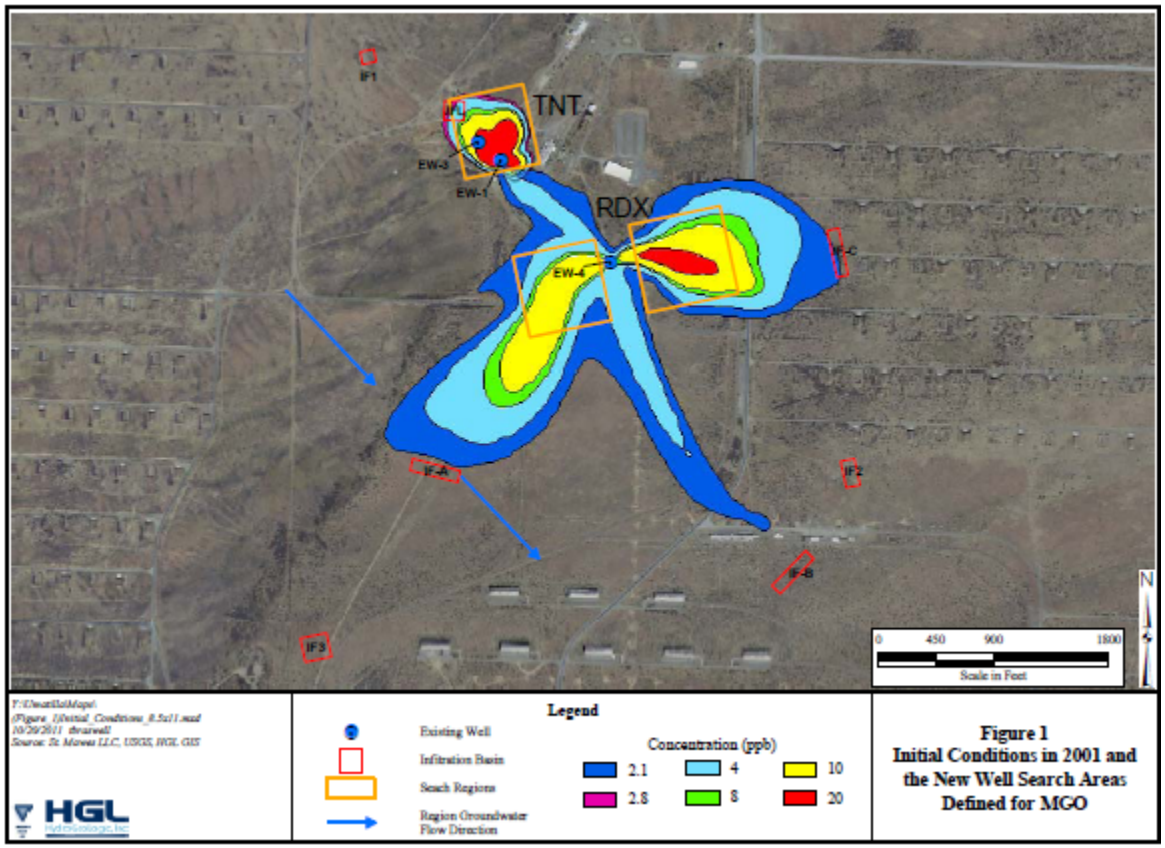
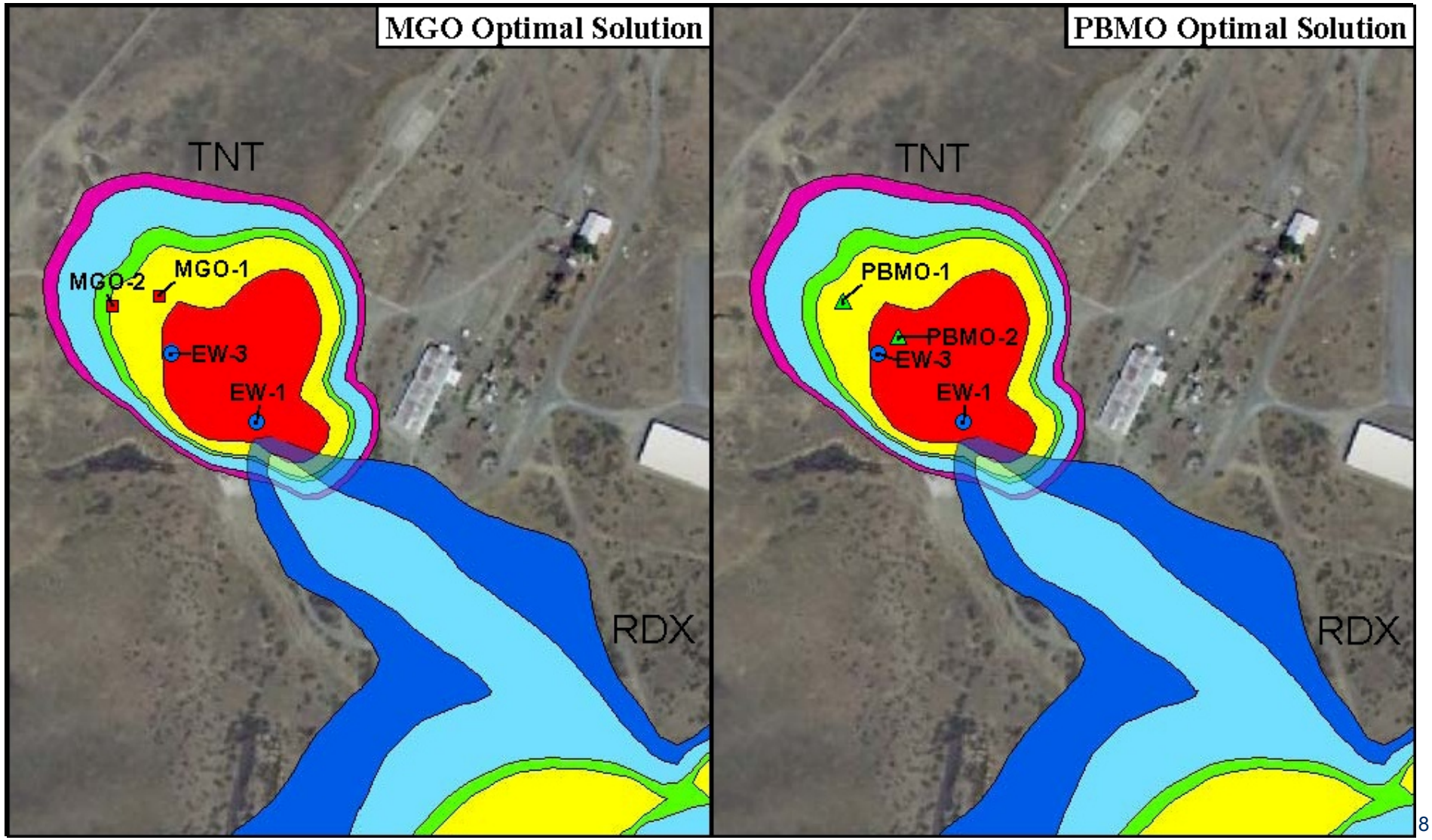


Figure 1
Initial Conditions in 2001 and the New Well Search Areas Defined for MGO

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



PBMO versus MGO: Year 1

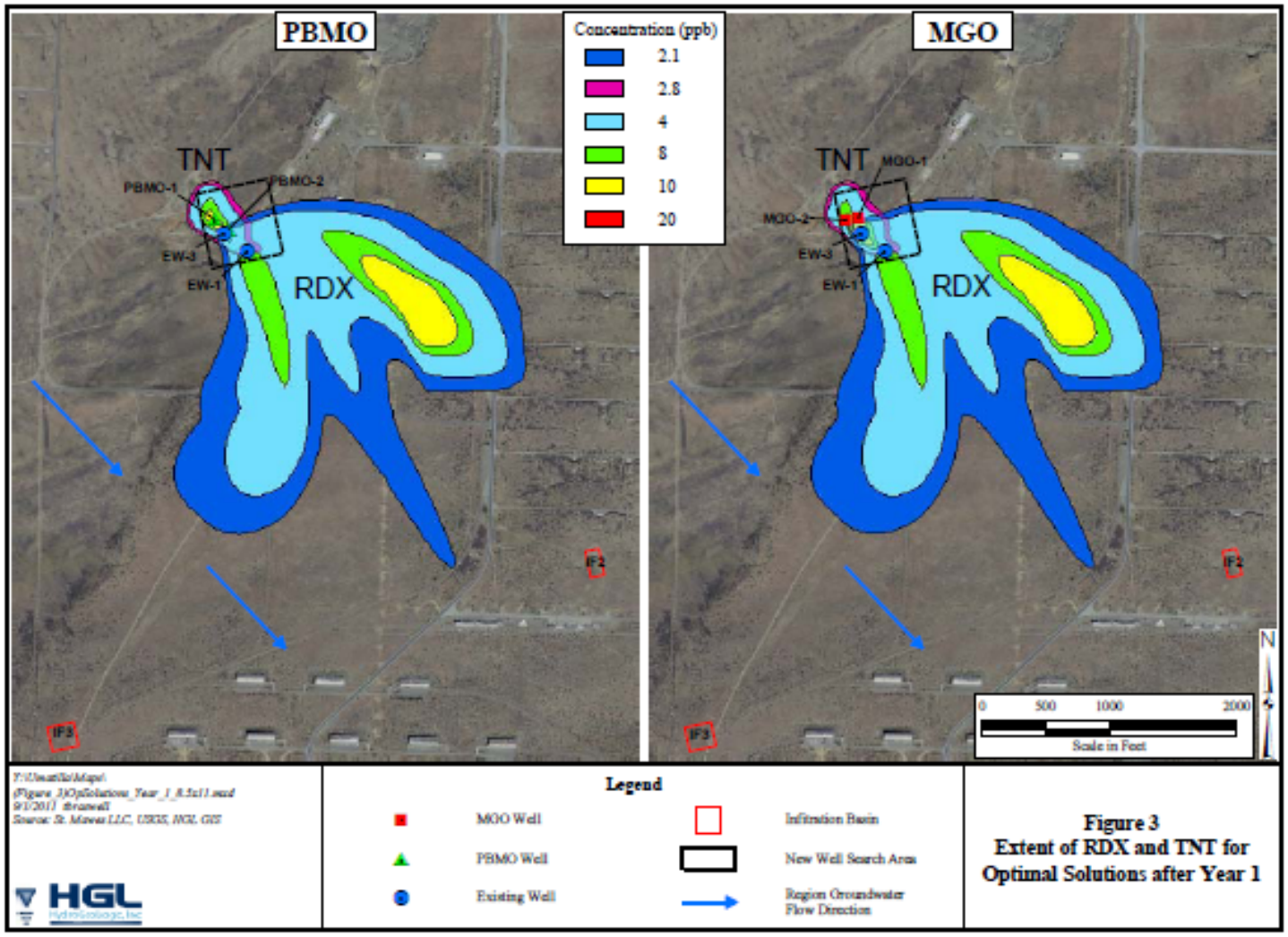


Figure 3
Extent of RDX and TNT for Optimal Solutions after Year 1

PBMO versus MGO: Year 3

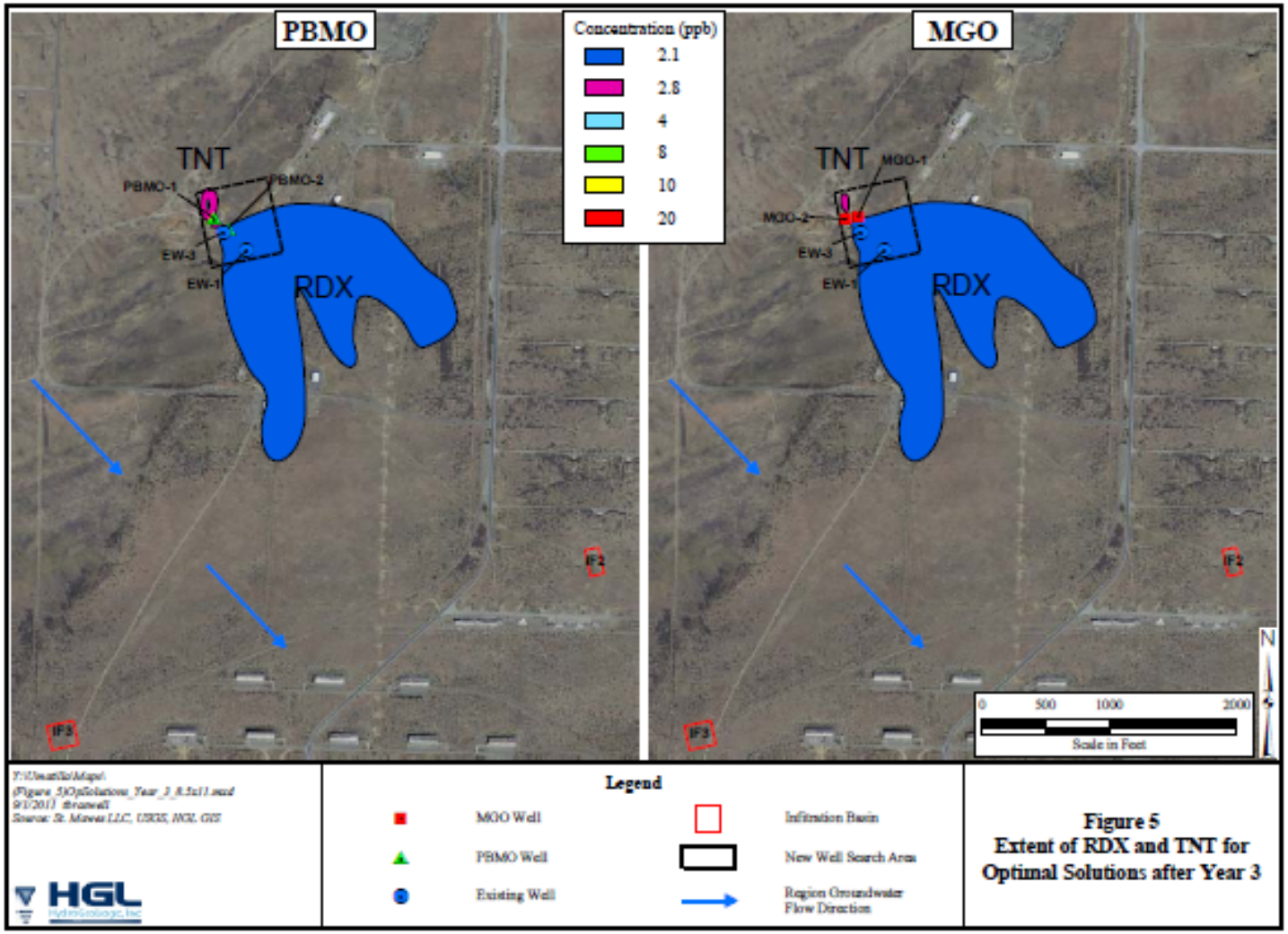
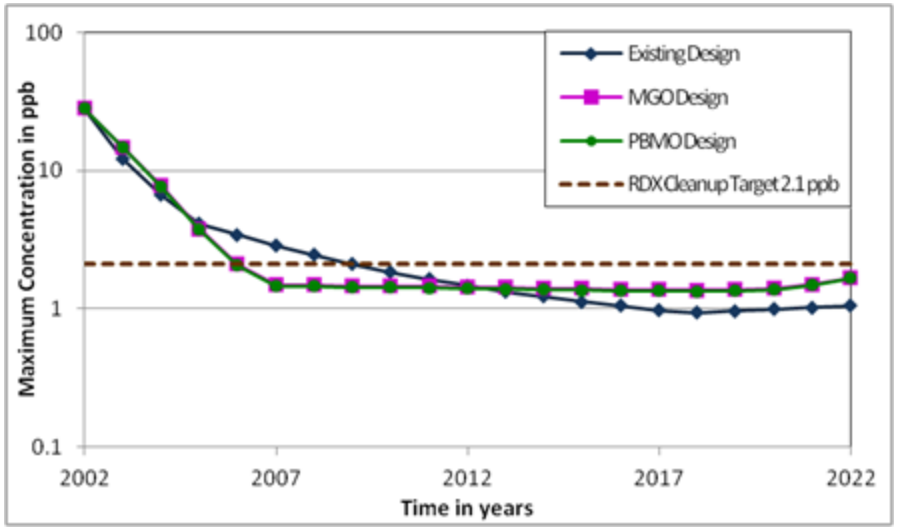


Figure 5
Extent of RDX and TNT for Optimal Solutions after Year 3

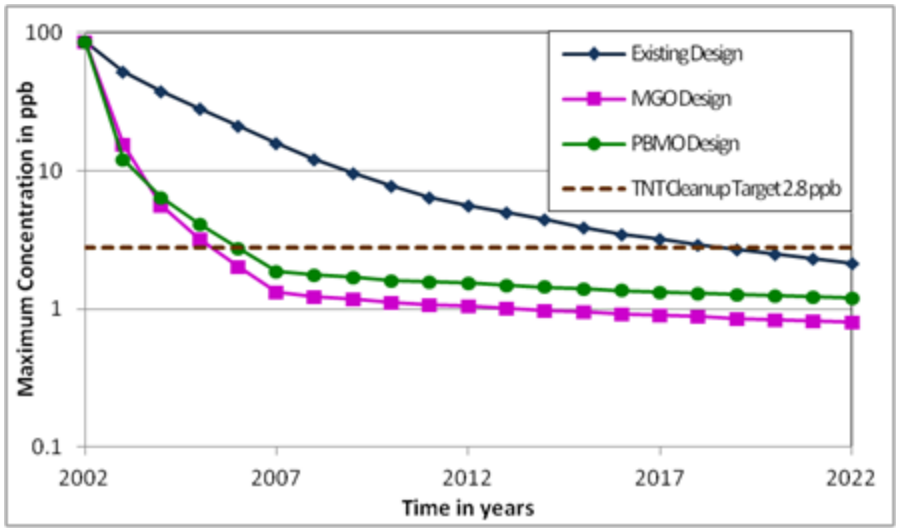
PBMO versus MGO: Cleanup Goals

RDX



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

TNT



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

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Remedial Optimization Comparison: PBMO and MGO: Umatilla Army Depot

Optimal pumping strategy found using PBMO and MGO for Formulation 1

Name	Location (Layer, Row, Column)	Pumping/Injection Rate (GPM)				
		RIP Design[1]	Trial & Error Design[2]		MGO Design[3]	PBMO Design[4]
			Stress Pd. 1	Stress Pd. 2		
EW-1	(1,60,65)	-128	-280	-350	-307.5	-292.5
EW-2	(1,83,84)					
EW-3	(1,53,59)	-105		-360	-219.5	-292.5
EW-4	(1,85,86)	-887	-660			
New-1 (T&E)	(1,48,57)			-100		
New-2 (T&E)	(1,49,58)		-230	-360		
New-3 (MGO)	(1,48,59)				-360	
New-4 (MGO)	(1,48,55)				-283	
New-5 (PBMO)	(1,48,57)					-292.5
New-6 (PBMO)	(1,52,61)					-292.5
IF-1	*	233	282	585		
IF-2	*	405	405		380	390
IF-3	*	483	482		790	780
IF-4	*			585		
Total remedy cost ($)		$3,836,285	$2,230,905		$1,664,395	$1,664,085

(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

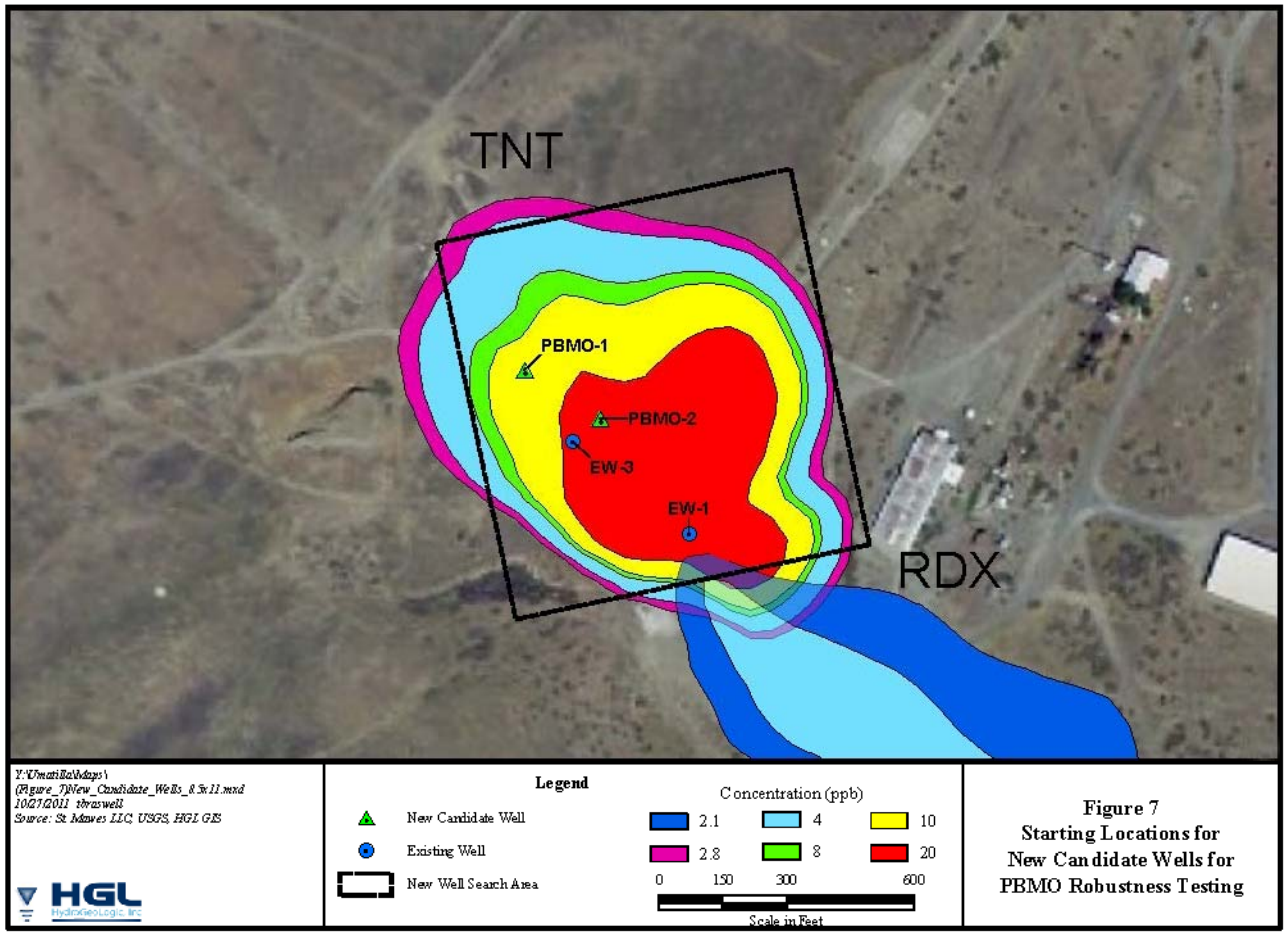

Figure 7
Starting Locations for
New Candidate Wells for
PBMO Robustness Testing

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

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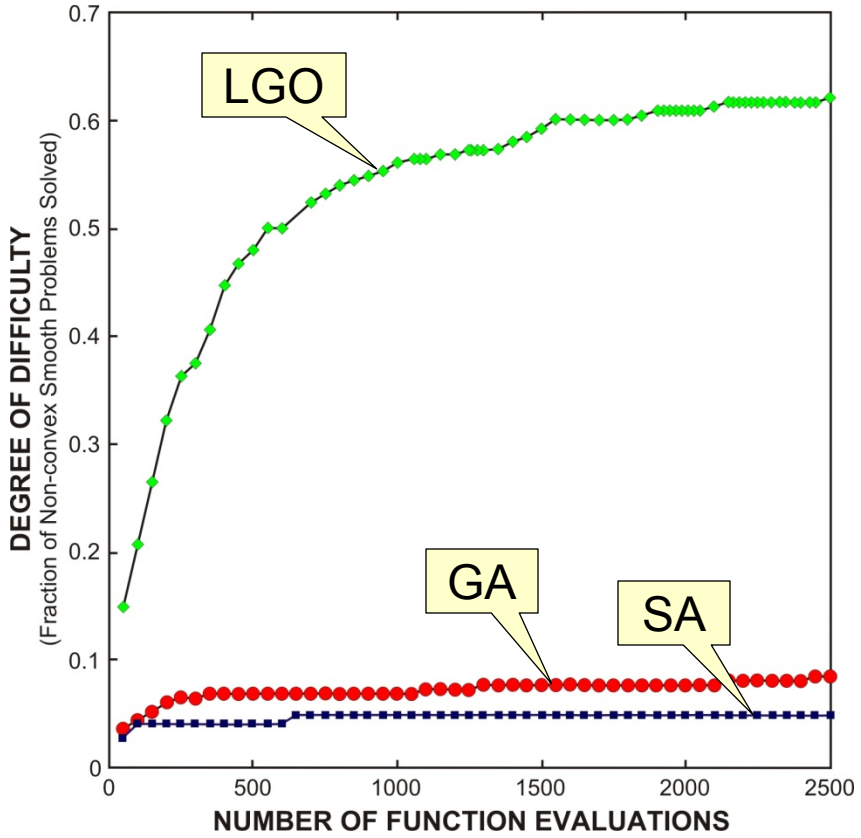
Performance Comparison of Global Optimization Algorithms in PBMO and MGO Software



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)

Adapted from: M. Rios and N. Sahinidis, (2009) "Derivative-free optimization: A review and comparison of software implementations" Optimization Research Report, Carnegie Mellon University.

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

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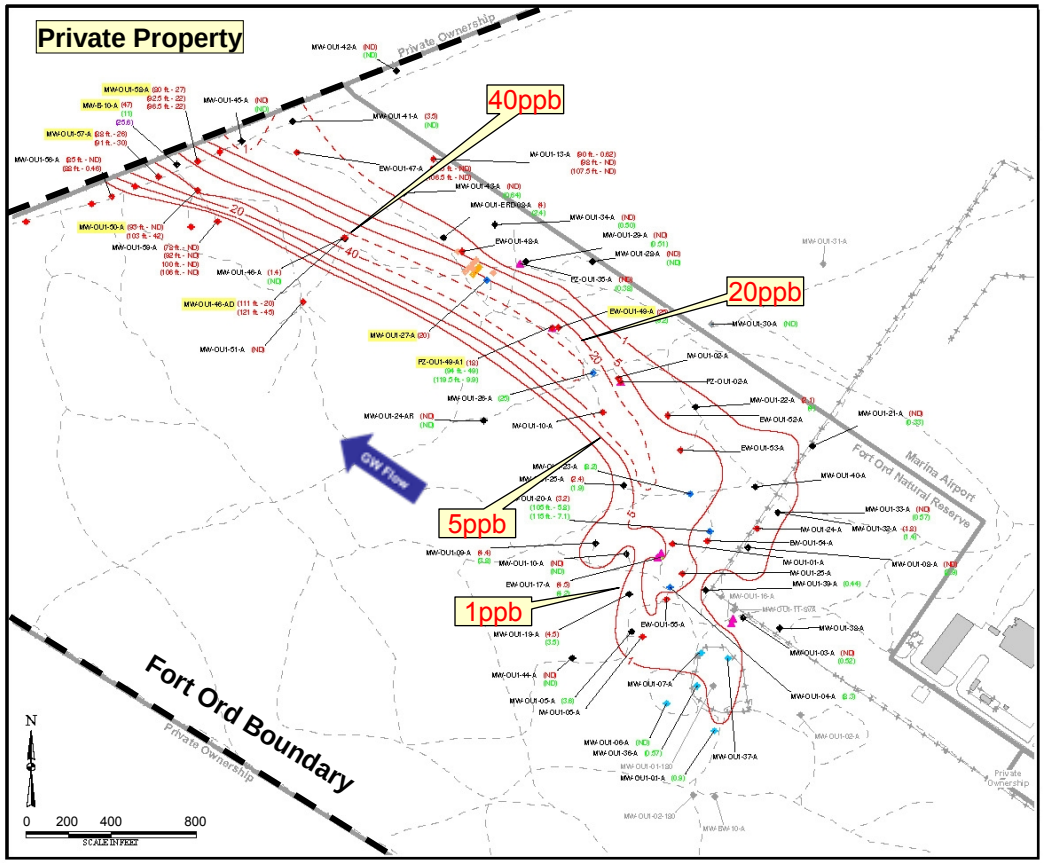
TCE Contamination in Groundwater: Former Fort Ord OU-1

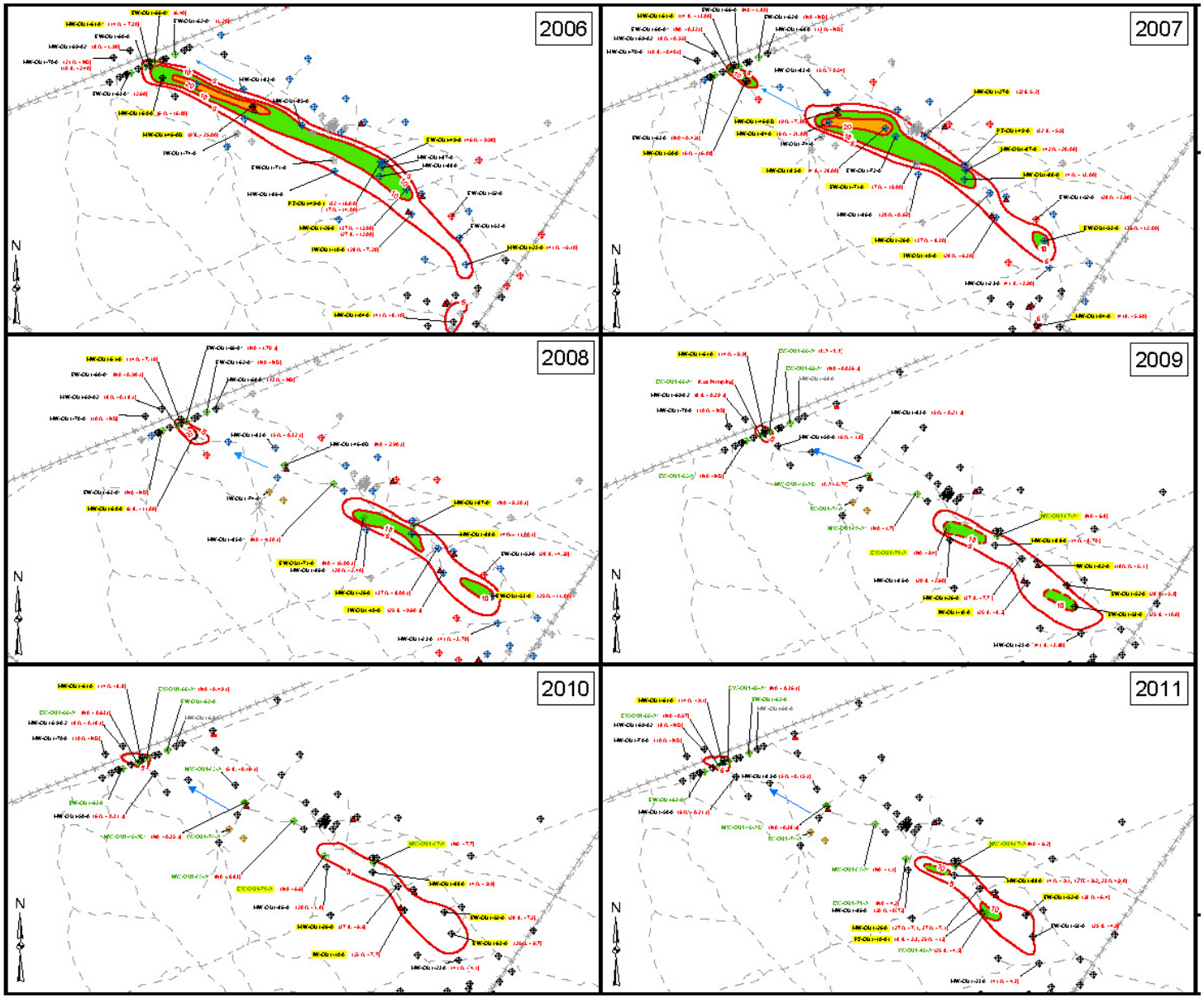


Observed TCE Plume in December 2004

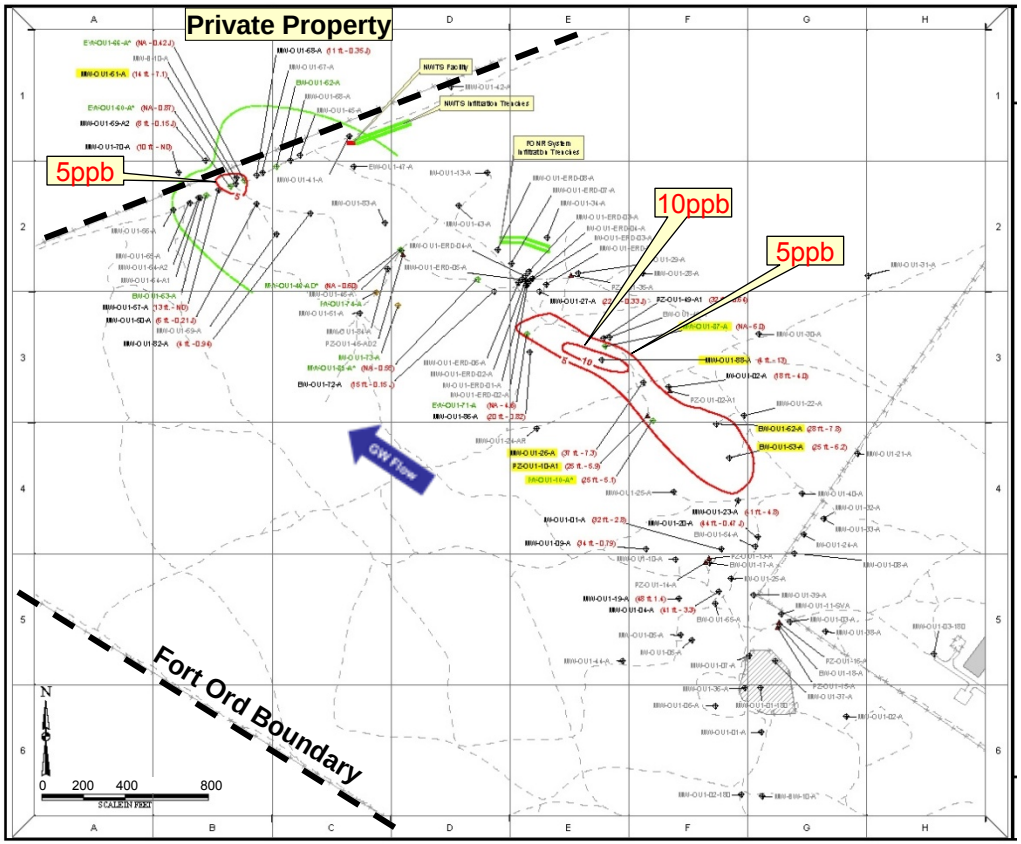
Remedy-In-Place:

- HGL collaborated with CH2MHILL 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



Observed TCE Plume in March 2011

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

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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

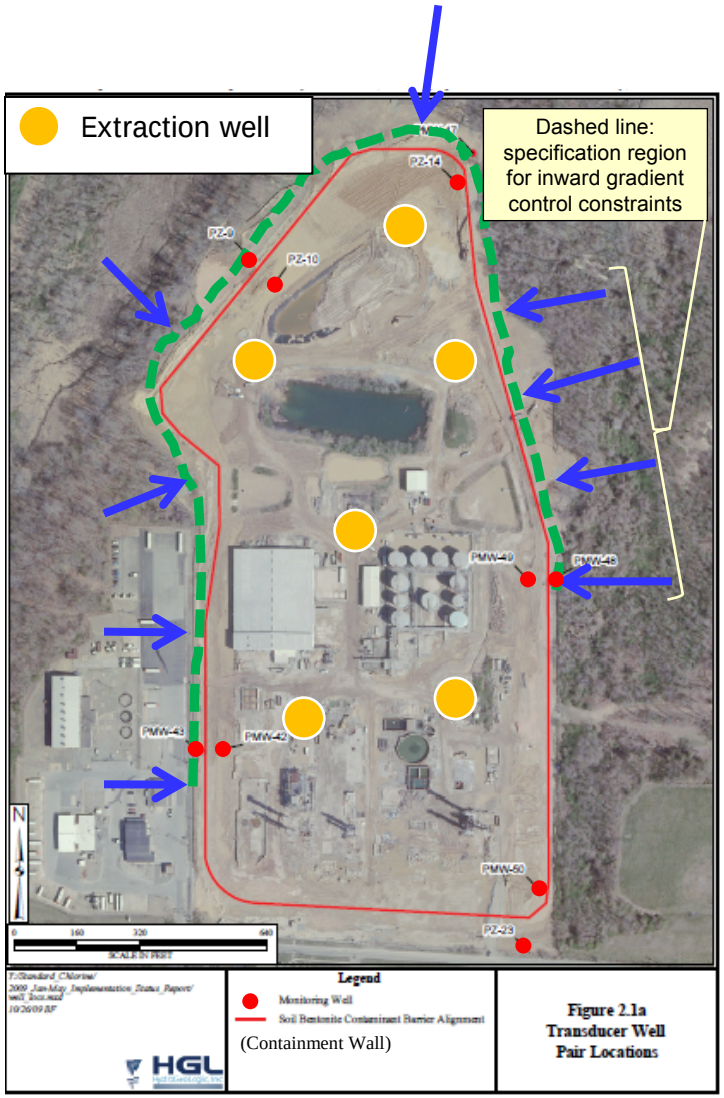
Remedy-In-Place:

- 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

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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**