Restoring the Environment.
Protecting Our Future.

Optimization of Groundwater Remediation Design and Performance

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Optimization in Environmental Restoration

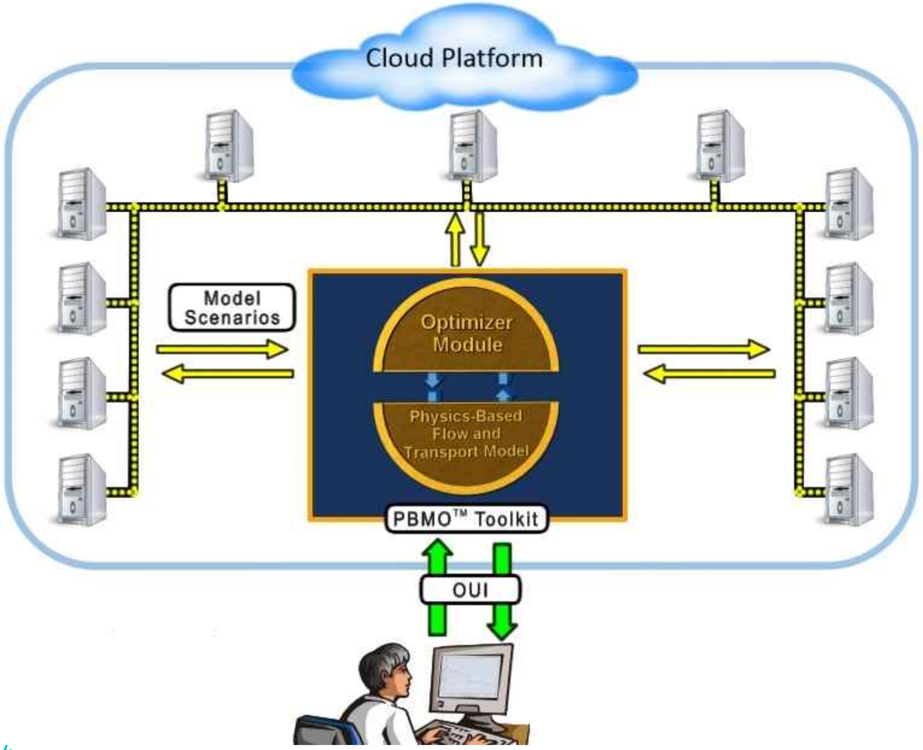
- Any incremental improvement at any phase of the project
- Engineering evaluations of existing systems with recommendations for improvements
- **Physics-based models linked with optimization algorithms to design new or optimize existing remedies**

Problem Formulation

- Objective Function (Find the Best Result)
  - Minimize: cost or time to achieve cleanup criteria
  - Maximize: mass removal/destroyed
- *Decision Variables (Possible Remedy Configurations)*
  - *Pumping and injection rates, treatment locations, bioremediation amendment strength and injection frequency*
- Constraints
  - Pump & treat system capacities, plume control areas, remediation time/cost

Physics-Based Management Optimization (PBMO™)

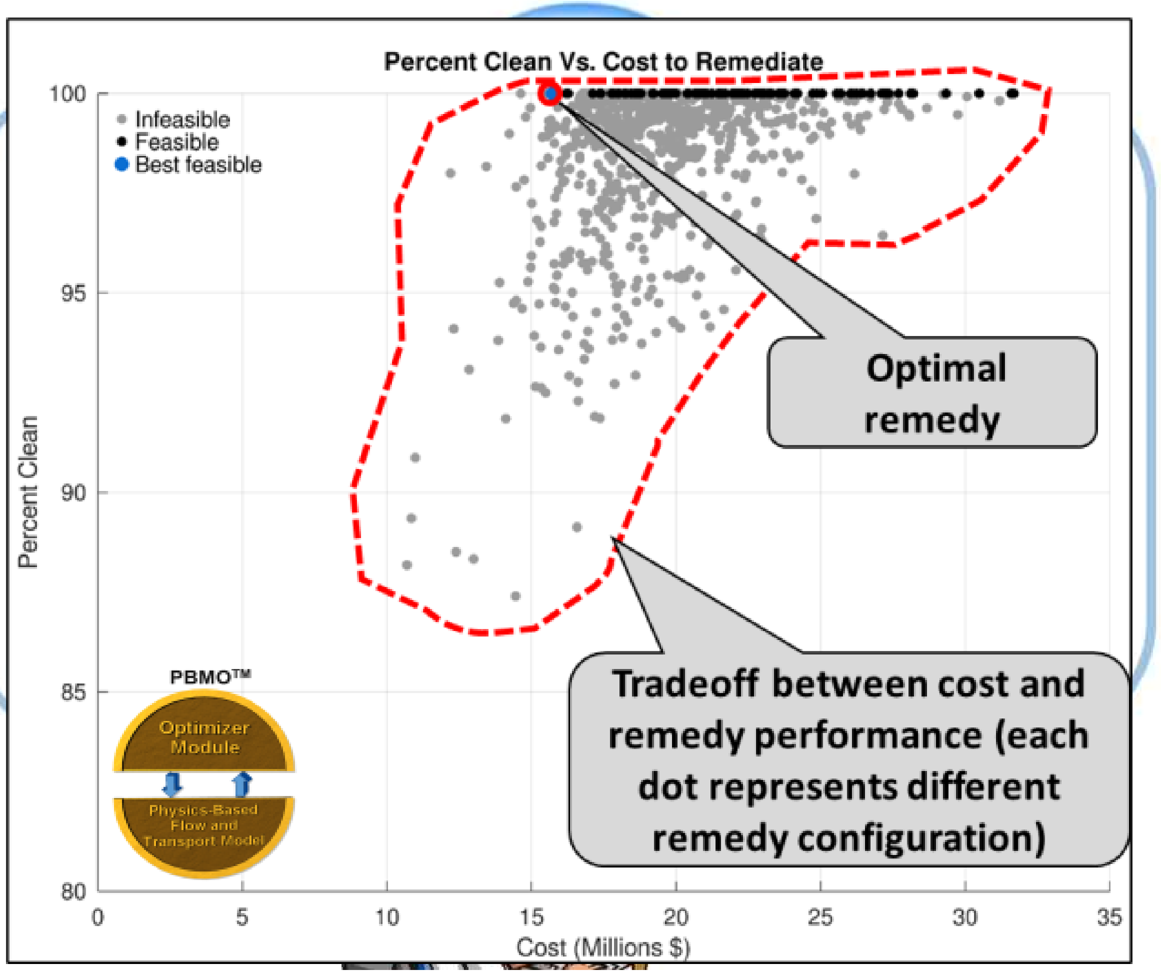
- Links optimization with flow and transport modeling to find the best solution



- Utilizes cloud or distributed computing
- Enables rapid evaluation of hundreds to thousands of remedy configurations
- Prioritizes the timing, location, and strength of activities
- Illustrates tradeoffs between remedy performance and cost

Illustrate Applications at Three Sites

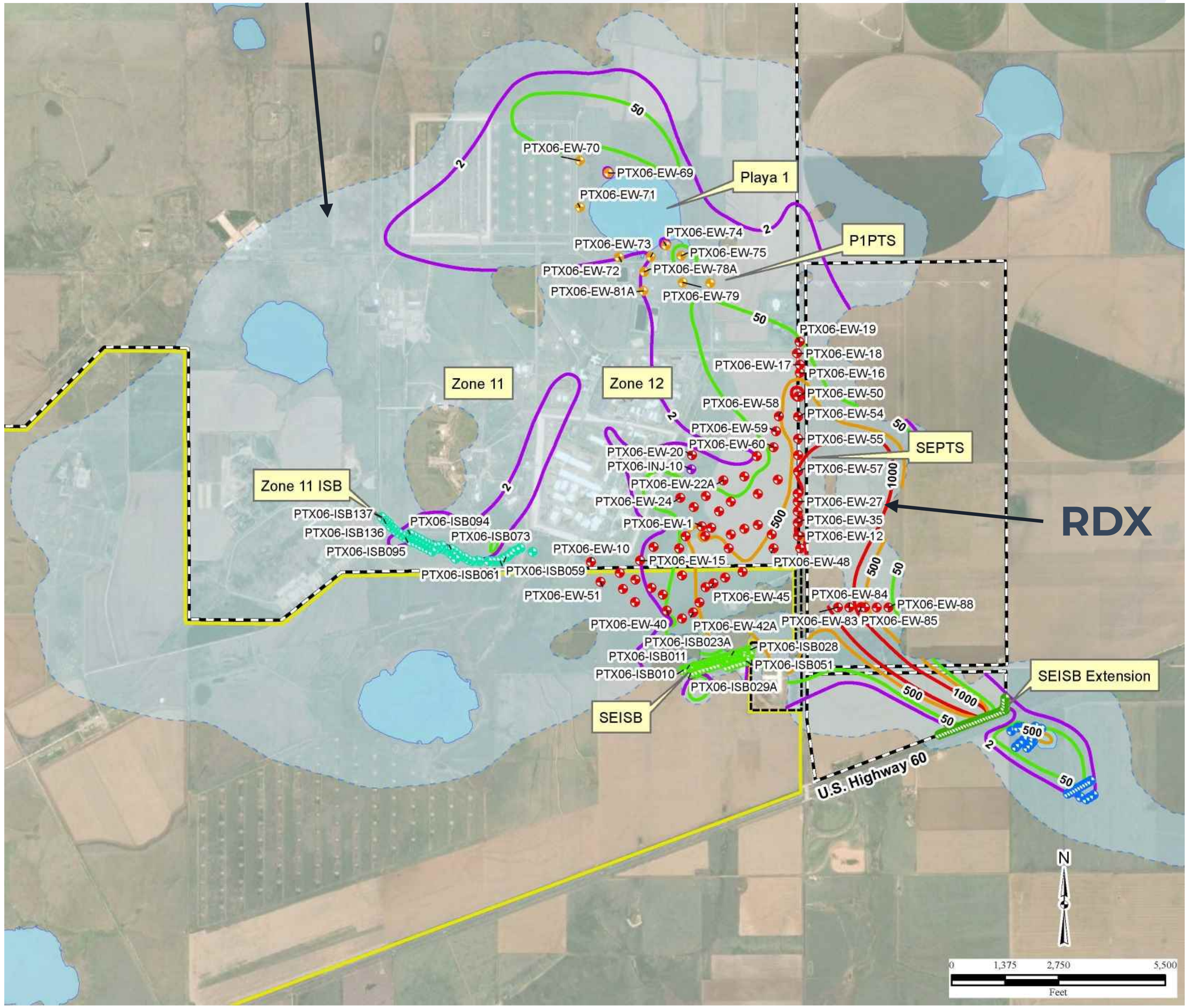
- Approach
  - Develop/update conceptual site model (CSM)
  - Calibrate flow and transport model
    - Transient flow and transport
    - Single or multiple contaminants
  - Link model with optimization algorithm (PBMO™)
  - Evaluate and report results



Site 1: Pantex Pump & Treat Systems

- **Key features**
  - Thin perched groundwater overlying Ogallala Aquifer
  - ~5 square-mile plume areas (VOCs, metals, high explosives)
  - 2 pump & treat (P&T) systems
    - Up to 94 total extraction wells
  - 500 gallons per minute (gpm)
- **Key Objectives**
  - Maximize water and mass removal
  - Minimize plume migration/expansion

Perched Groundwater Extent



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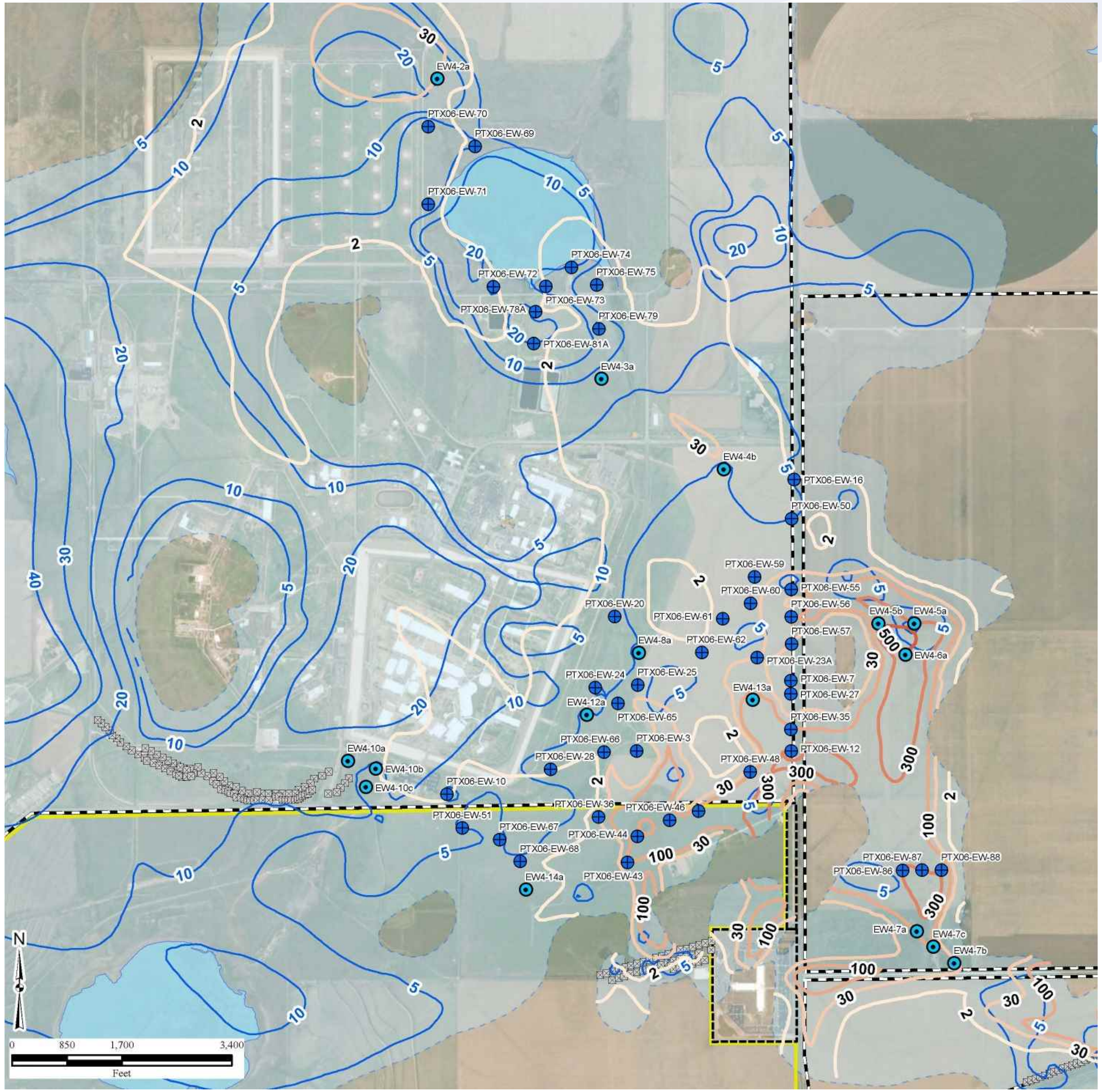
Site 1: Pantex P&T Systems, continued

- **Key Elements**
  - Groundwater remedy includes source control, P&T, and in situ bioremediation (ISB)
  - Maximize RDX, Cr(VI), and perchlorate mass removal
  - Time = 20 years
  - Optimal analysis performed on individual P&T systems and blend of the top 40, 60, and 80 performing wells
    - Compared against predicted baseline performance
  - Best solution chosen for additional analysis (new wells versus new ISB)

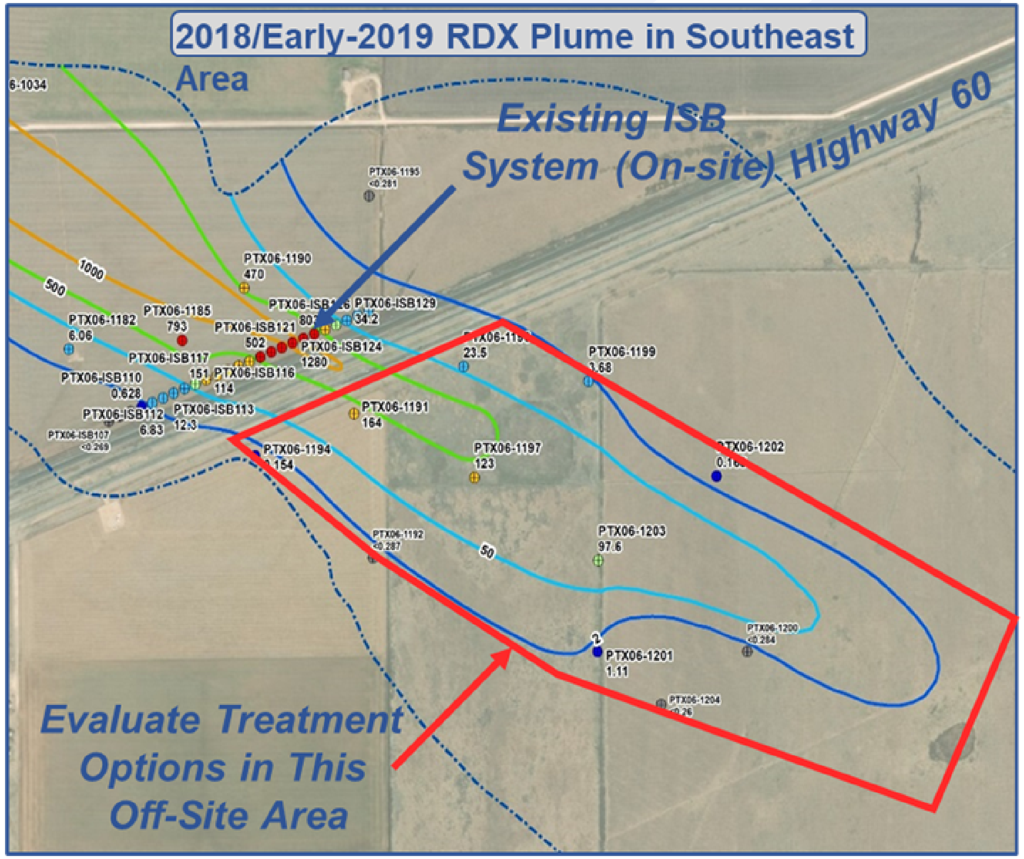
Site 1: Pantex P&T Systems, continued

- **Optimal Design**
  - Dynamically-Dimensioned Search Algorithm (DDSA)
    - Completed over 300,000 total model runs
    - Cloud costs ~$450 for 20,000 runs
  - Improved migration control by 32 kg (49%)
  - Combined mass removal and decay increased by 200 kg (13%)



Site 2: Combined Treatments

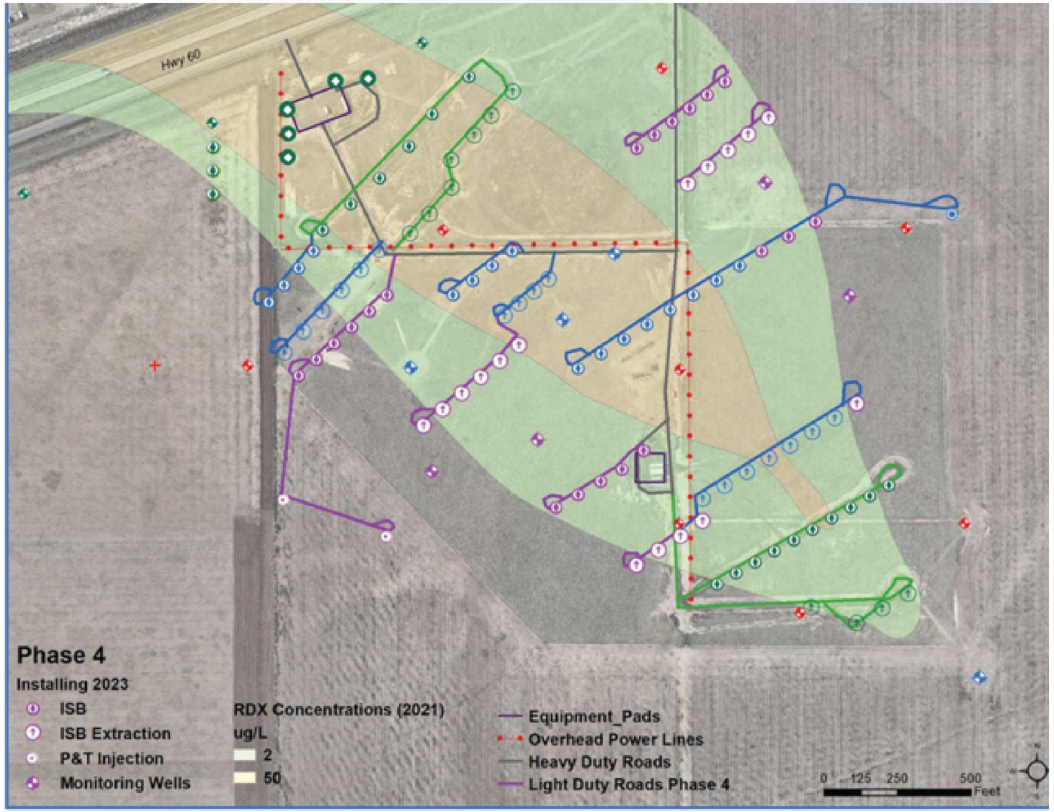
- **Key Features**
  - Perched groundwater overlying Ogallala Aquifer
  - ~2,800 ft long by 1,600 ft wide RDX plume (offsite)
  - Saturated thickness <20 ft
  - Depth to water >280 ft
- **Key Objectives**
  - Find lowest cost solution to remediate RDX in 25 years or less using a combination of ISB/P&T/MNA



Site 2: Combined Treatments, continued

- **Key Elements**
  - No migration beyond lease boundary
  - Last injection within 15 years or less
  - Active remediation 25 years or less
  - All water from treatment area and water balance
  - RDX degradation rate tied to total organic carbon
  - Meet budgetary phased-installation requirements (4 phases)
  - Address uncertainty from geologic heterogeneity

Planned System after Phase 4 (2023) Install



Modified from November Public Meeting Presentation
CNS, November 1, 2022; T. Biggs
https://pantex.energy.gov/sites/default/files/Public_Meeting_2022.pdf

Site 2: Combined Treatments, continued

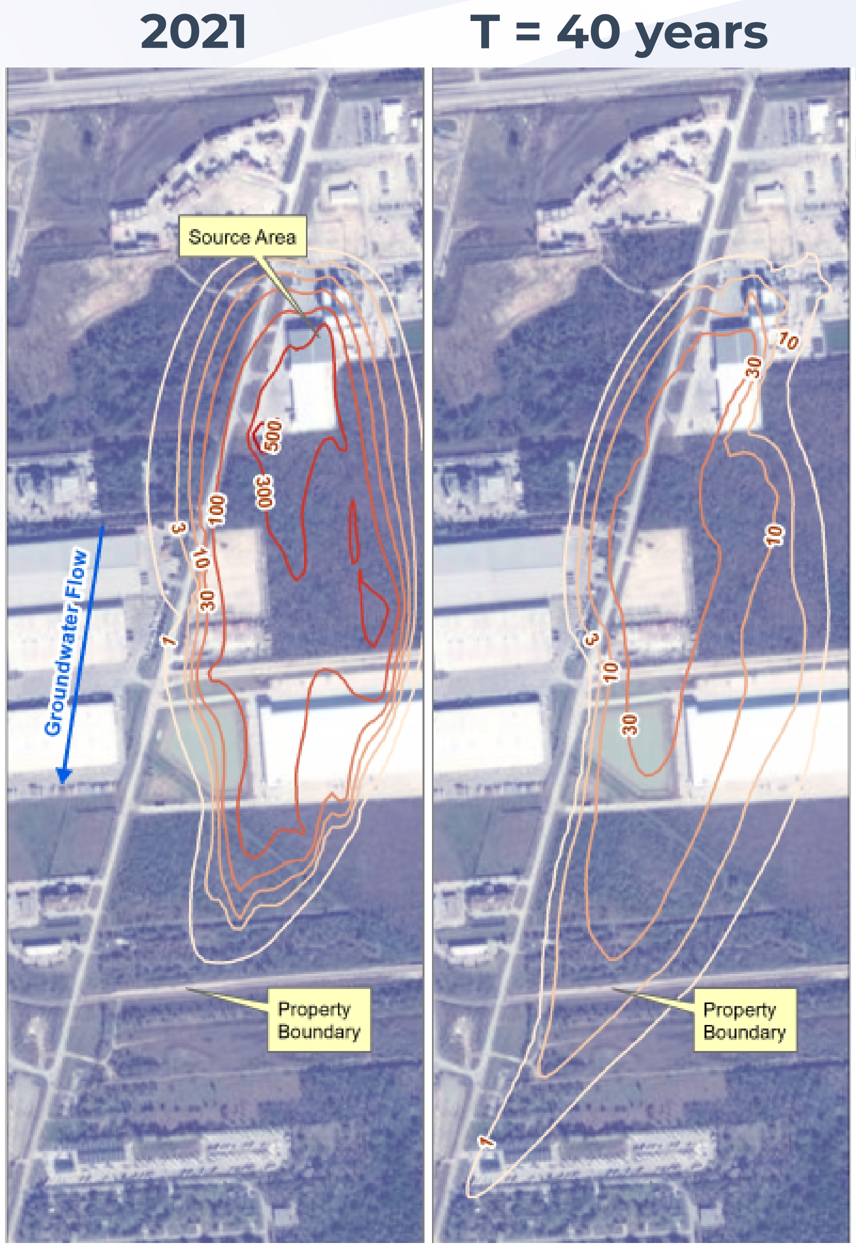
- **Optimal Design**
  - Globally Adaptive Stochastic Search Algorithm
  - Evaluated over 2,900 different designs
  - Top 65 designs assess within *20 calibrated flow systems*
  - Ranked 1,300 designs to identify best solution that met performance criteria across all 20 flow systems
  - 53 ISB extraction wells; 64 ISB injection wells; 8 P&T wells

Realization	Capital Cost ($)	OM Cost ($)	Total Cost ($)
5	1.53E+07	3.66E+06	1.90E+07
3	1.53E+07	3.67E+06	1.90E+07
6	1.53E+07	3.75E+06	1.90E+07
16	1.53E+07	3.78E+06	1.91E+07
18	1.53E+07	3.80E+06	1.91E+07
8	1.53E+07	4.01E+06	1.93E+07
14	1.53E+07	4.04E+06	1.93E+07
7	1.53E+07	4.04E+06	1.93E+07
2	1.53E+07	4.06E+06	1.94E+07
4	1.53E+07	4.52E+06	1.98E+07
9	1.53E+07	4.59E+06	1.99E+07
19	1.53E+07	4.65E+06	1.99E+07
12	1.53E+07	4.66E+06	2.00E+07
17	1.53E+07	4.67E+06	2.00E+07
10	1.53E+07	4.88E+06	2.02E+07
20	1.53E+07	5.05E+06	2.03E+07
13	1.53E+07	5.09E+06	2.04E+07
1	1.53E+07	5.13E+06	2.04E+07
11	1.53E+07	5.57E+06	2.09E+07
15	1.53E+07	6.02E+06	2.13E+07

Realization #																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Time to Clean-up (years)																			
24.0	23.0	17.5	23.0	20.5	17.5	23.5	24.0	21.0	23.5	25.0	24.0	23.5	22.0	24.5	17.5	21.0	23.0	25.0	22.0
Last Injection (years)																			
15.0	11.0	10.5	15.0	10.5	11.0	12.0	11.0	14.0	15.0	15.0	13.0	15.0	11.5	15.0	10.5	13.0	10.5	15.0	14.5

Site 3: Commercial Site

- **Key Features**
  - Dense brine with organics/inorganics released to alluvial system
  - Contaminant storage within alluvium and underlying bedrock (diffusion between mobile and immobile domains)
  - Plumes extend >4,000 ft from source impinging on site boundary
  - Current remedy at boundary limited effectiveness and long durations (>100-150 yrs) needed



Site 3: Commercial Site, continued

- **Key Objectives**
  - Conduct a feasibility-level multi-objective optimization
    - Minimize pumping rate and minimize pumping duration such that offsite migration above clean up criteria is prevented
  - **Key Elements**
    - No migration beyond property boundary
    - Account for back diffusion
    - Combined extraction rate <360 gpm
    - Active remediation time <40 years

Site 3: Commercial Site, continued

- **Optimal Design**
  - Pareto Dynamically-Dimensioned Search Algorithm
  - Set of solutions representing tradeoffs between combined pumping rate and pumping duration
    - Total extraction 204 to 244 gallons per minute
    - Duration 32.2 to 36.2 years (reduced from >100 years)
  - Allowed pulsed pumping to address back diffusion
  - Analysis supported decision to include P&T remedy and identified data gaps for additional characterization

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Conclusions

- Linking optimization with physics-based process models
  - Provides a framework for more informed decisions pertaining to groundwater remediation
  - Increases confidence that the problem has been thoroughly examined and best option has been chosen, which will result in cost savings/cost avoidance and stakeholder agreement

Lessons Learned

- Including transport processes provides insights beyond flow-only optimization
  - Concentrations can stagnate due to well interference
  - Determine when to transition from one technology to another
  - Assess impacts from tailing due to back diffusion
  - Identification of key data gaps
- Communication at key points in the project
  - CSM, flow and transport calibration, optimization plan, and then results
- Review/incorporate data during system installation; adjust design, if necessary
- Plan for uncertainties

CONTACT

Thank you

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