Application of Transport Optimization Codes to Groundwater Pump and Treat Systems

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Today's Presenters

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Remedial Optimization For P&T Systems

- Remediation System Evaluation (RSE) or Remedial Process Optimization (RPO) provides a broad assessment of…
  - Goals and exit strategy
  - Below-ground performance
  - Above-ground performance
  - Monitoring and reporting
  - Potential for alternate technologies

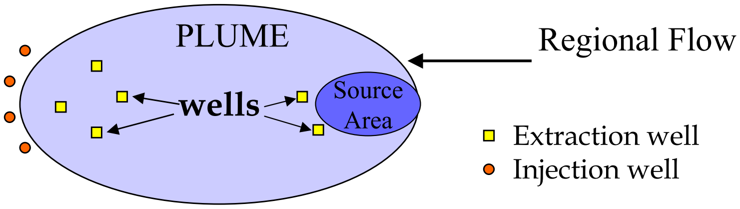
- Pumpage optimization is a subset or a component of these more general optimization evaluations
  - Trying to determine the "best" extraction/injection strategy assuming P&T is the most appropriate technology

Presentation Outline

- What is “transport optimization”?
- Why perform transport optimization?
- General optimization process
  - Formulating problems
  - Solving problems
- Recent DOD “ESTCP” groundwater remediation optimization study
  - Project Background
  - Example: Umatilla
  - Example: Blaine
  - Lessons Learned
- Further Information

What is “Transport Optimization”?

- Optimization algorithms coupled with existing groundwater flow and transport models that determine an “optimal” set of pumping/injection well rates & locations



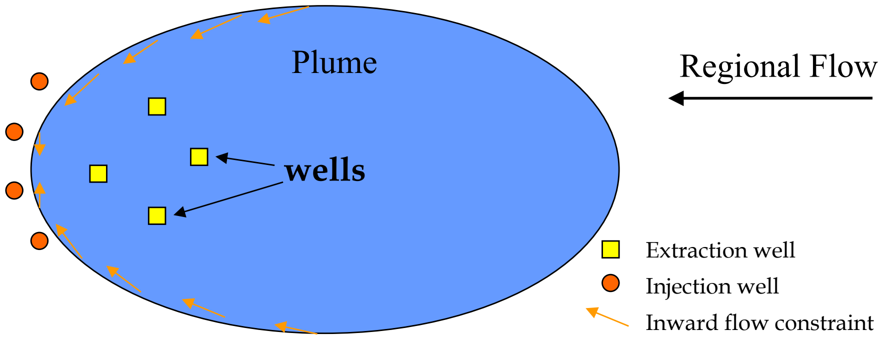
Example: Minimize total pumping rate subject to:
- TCE < 5 ppb at each cell within current plume extent after 5 yr.
- TCE < 1 ppb at each cell outside current plume extent (all times)
- extraction volume equals injection volume

Why Perform Transport Optimization?

- "Hydraulic Optimization" can be too limiting for many sites (1999 EPA Demonstration project)
  - Optimization based only on ground water FLOW model
  - Focus is on containment, cannot optimize based on concentration or cleanup times

Hydraulic Optimization

Hydraulic Optimization



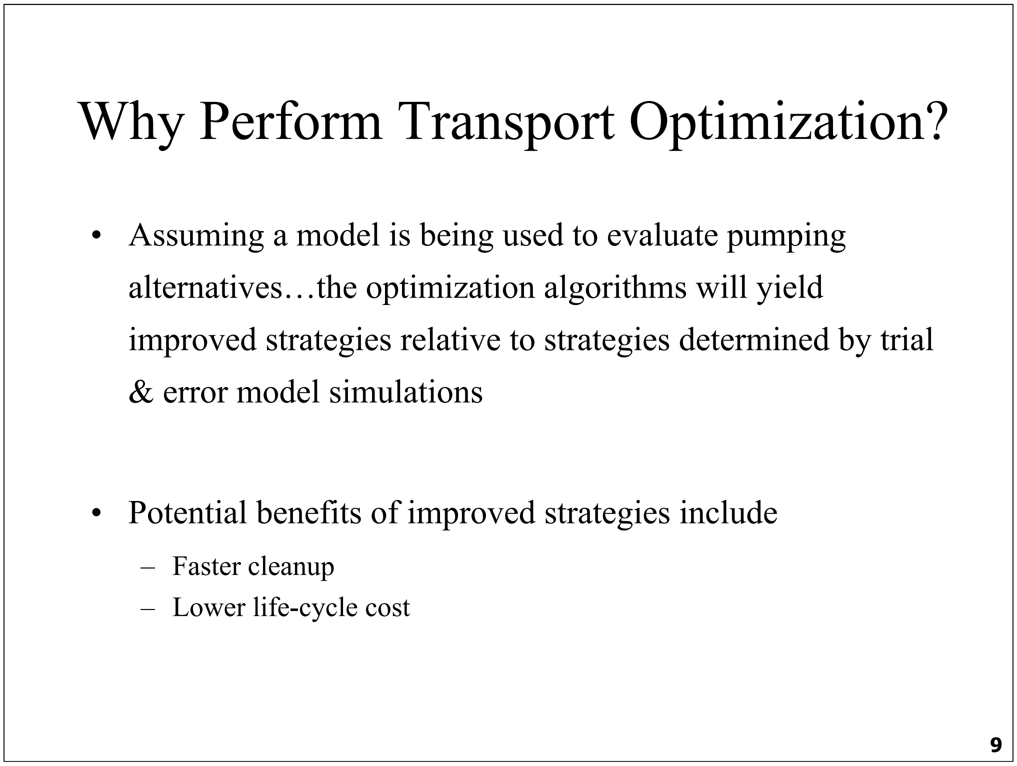
Example: Minimize total pumping rate subject to:

- inward flow at plume boundary = plume containment
- extraction volume equals injection volume

Why Perform Transport Optimization?

- "Hydraulic Optimization" can be too limiting for many sites (1999 EPA Demonstration project)
  - Optimization based only on ground water FLOW model
  - Focus is on containment, cannot optimize based on concentration or cleanup times

- Transport Optimization
  - Optimization based on ground water FLOW and TRANSPORT model
  - Not just containment…considers concentrations and cleanup times

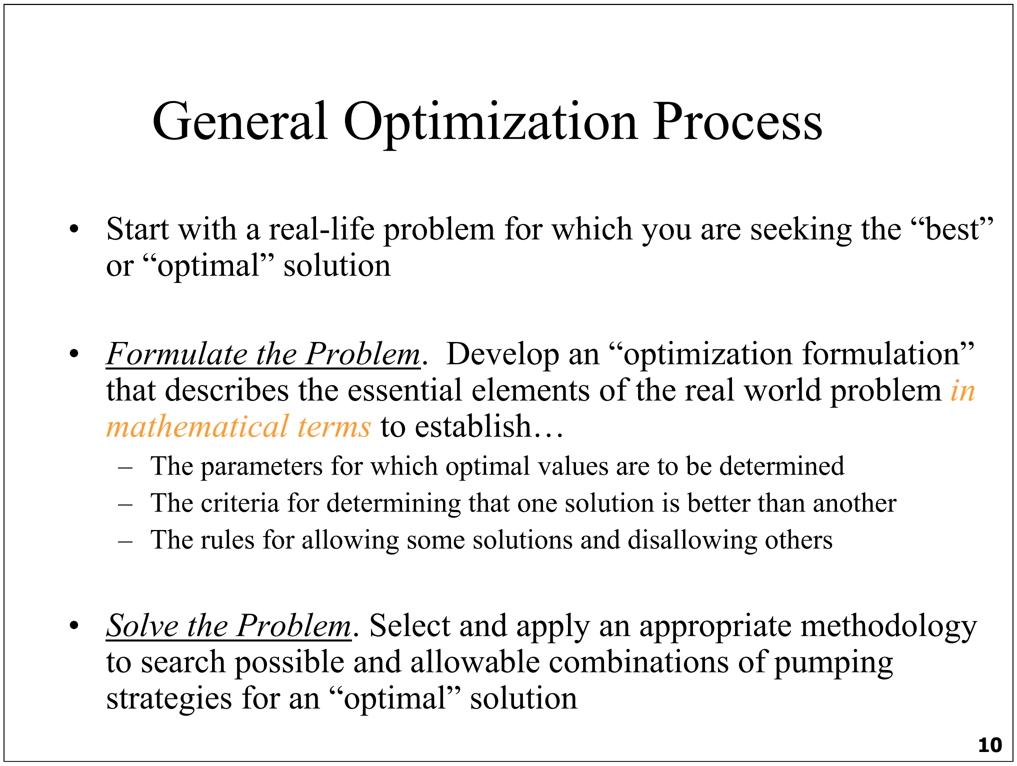


Why Perform Transport Optimization?

- Assuming a model is being used to evaluate pumping alternatives…the optimization algorithms will yield improved strategies relative to strategies determined by trial & error model simulations
- Potential benefits of improved strategies include
  - Faster cleanup
  - Lower life-cycle cost

The DoD has ~ 200 operating pump-and-treat systems for containment or containment and treatment. The total O&M cost of those sites is about 100M/yr. The optimization codes are expected to be cost effective at 25%-30% of those sites.

Studies completed by EPA and Navy indicate the majority of the p&t systems are not operating as designed, have unachievable or undefined goals, and have not been optimized since installation.

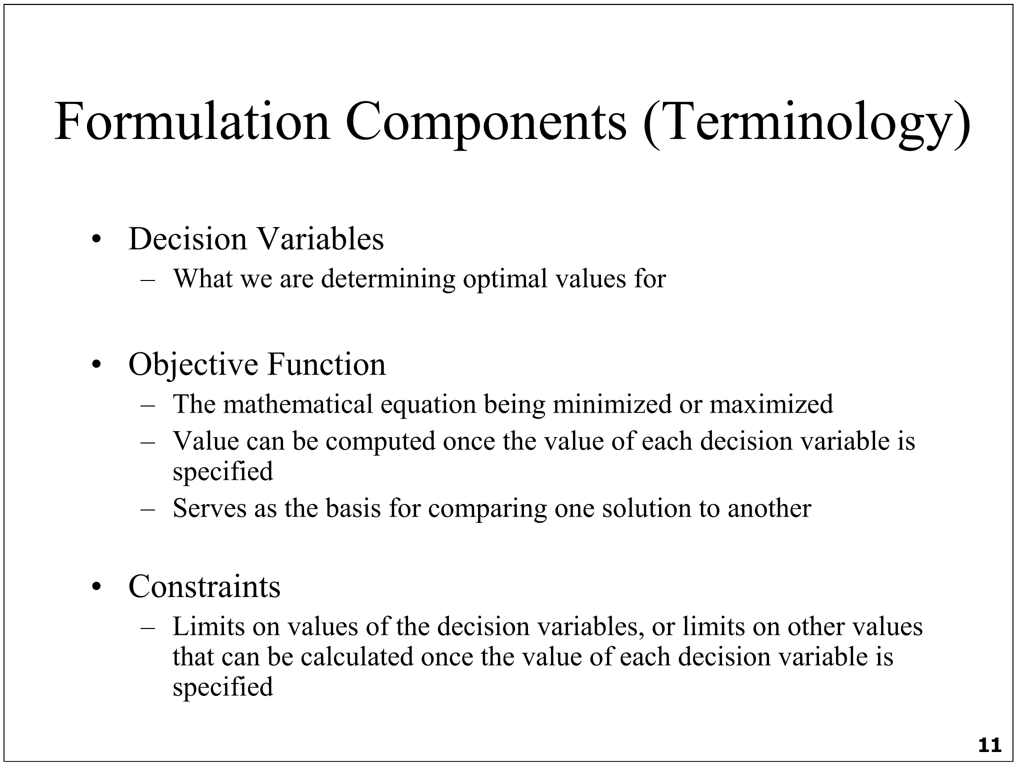


General Optimization Process

- Start with a real-life problem for which you are seeking the “best” or “optimal” solution

- *Formulate the Problem*. Develop an “optimization formulation” that describes the essential elements of the real world problem *in mathematical terms* to establish…
  - The parameters for which optimal values are to be determined
  - The criteria for determining that one solution is better than another
  - The rules for allowing some solutions and disallowing others

- *Solve the Problem*. Select and apply an appropriate methodology to search possible and allowable combinations of pumping strategies for an “optimal” solution



Formulation Components (Terminology)

- Decision Variables
  - What we are determining optimal values for
- Objective Function
  - The mathematical equation being minimized or maximized
  - Value can be computed once the value of each decision variable is specified
  - Serves as the basis for comparing one solution to another
- Constraints
  - Limits on values of the decision variables, or limits on other values that can be calculated once the value of each decision variable is specified

Formulation Components Example

Objective Function → $\text{Max } x^2+y^2$

Decision Variables

Subject to:

$-4 \le y \le 4$

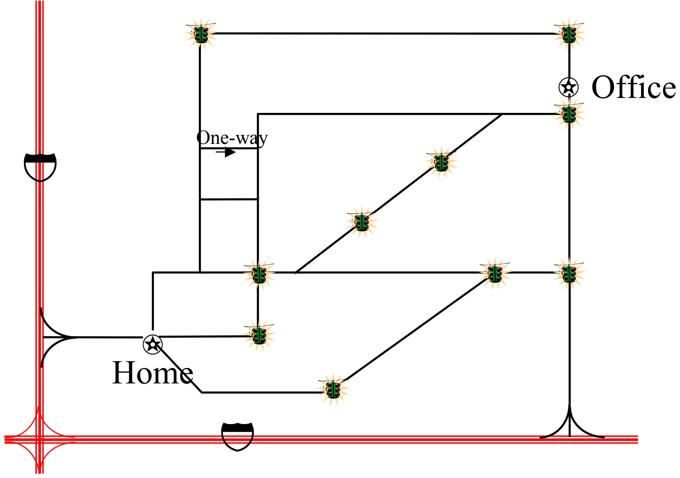
$-2 \le x \le 2$

$2x + 3y \le 12$

Constraints

Example of Formulation Process for a Real-Life Situation

- Real-Life Problem
  - What is the optimal driving route between home to work?



Example of Formulation Process for a Real-Life Situation

- Formulation must establish…
  - The decision variables
    - Combinations of roads/turns between my house and work

  - The objective function (some possibilities)
    - Minimize distance traveled
    - Minimize travel time
    - Minimize number of traffic lights

  - The constraints (some examples)
    - Must travel on paved roads
    - No more than four traffic lights allowed
    - Cannot go wrong way on a one-way street

Mathematical Descriptions are Often Difficult…

- Example: Minimize Travel Time
  - How do you mathematically account for traffic when calculating time of travel for a selected route of travel?
    - How do you estimate speed on the interstate?
    - Does it depend on time of day?
    - Does it depend on day of the week?

- Simplifications are invariably required in the formulation process

- Many alternative formulations are generally possible, each may have a different optimal solution

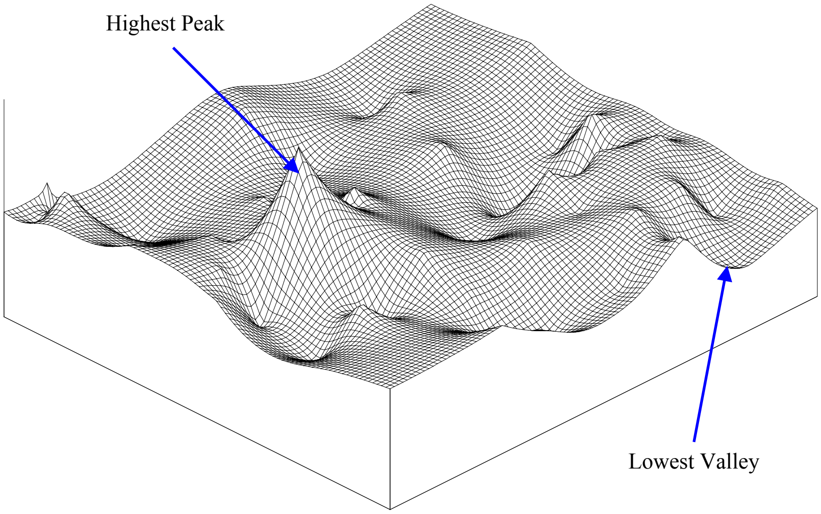
Solve the Formulation

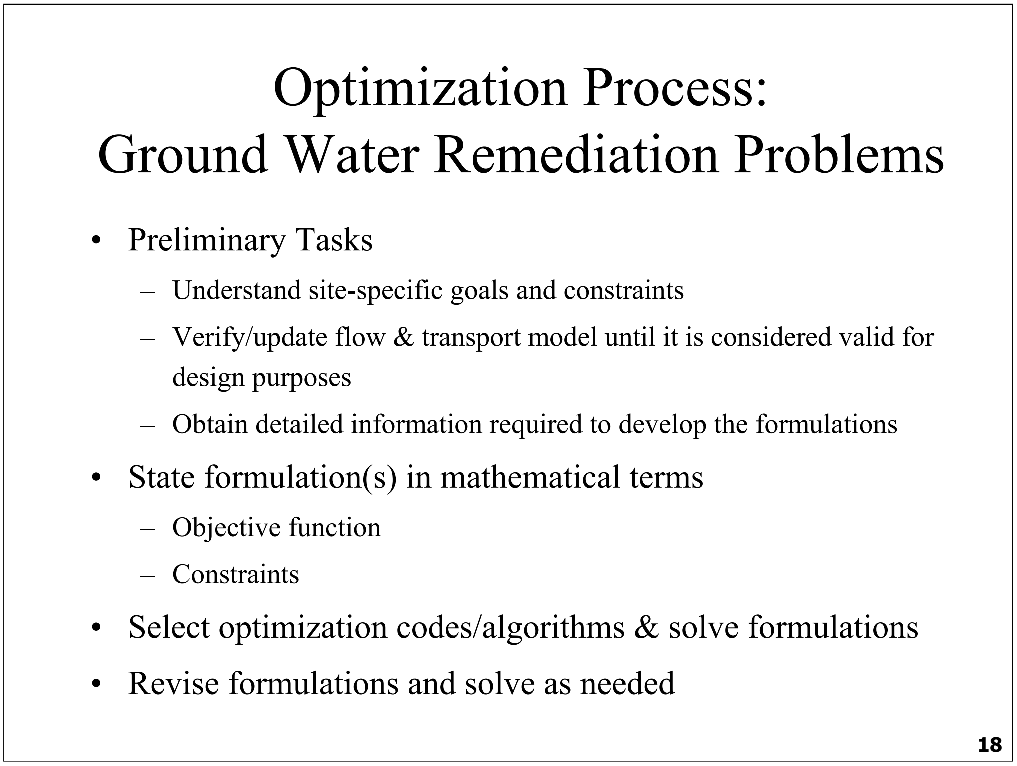
- Global optimization algorithms use “heuristic” approaches to find the highest peak or lowest valley
  - Genetic algorithm
  - Simulated annealing
  - Tabu search
  - Artificial neural network

Peaks and Valleys

“Heuristic” refers to methods that work based on “rules of thumb” but there is no specific mathematical proof that it does work and no guarantee of optimality

Real-World Problem:
Peaks and Valleys





Optimization Process: Ground Water Remediation Problems

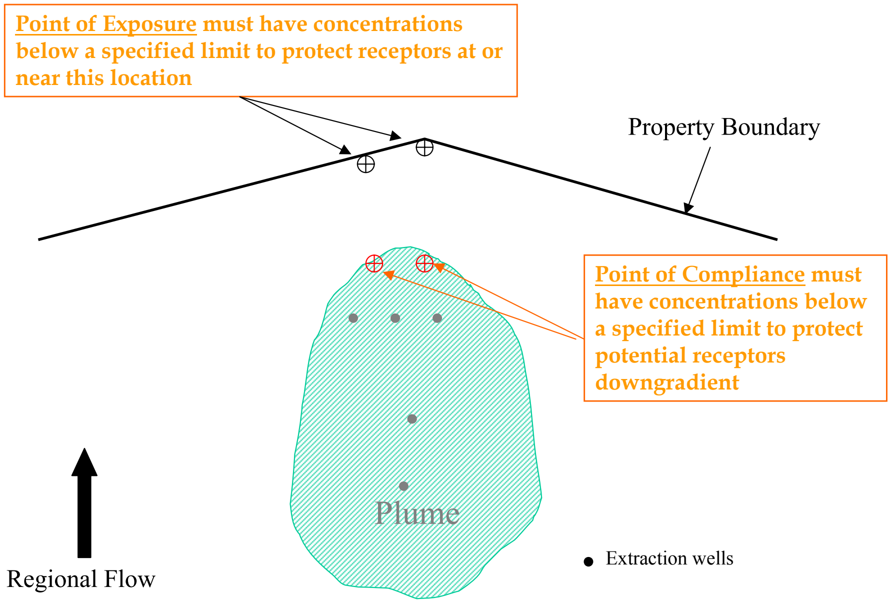
- Preliminary Tasks
  - Understand site-specific goals and constraints
  - Verify/update flow & transport model until it is considered valid for design purposes
  - Obtain detailed information required to develop the formulations
- State formulation(s) in mathematical terms
  - Objective function
  - Constraints
- Select optimization codes/algorithms & solve formulations
- Revise formulations and solve as needed

Types of Information Collected: Ground Water Remediation Problems

- Cost components
  - One-time “capital” costs (now or in the future)
  - Annual costs
- Point of exposure, point of compliance

Schematic

Point of Exposure and Point of Compliance



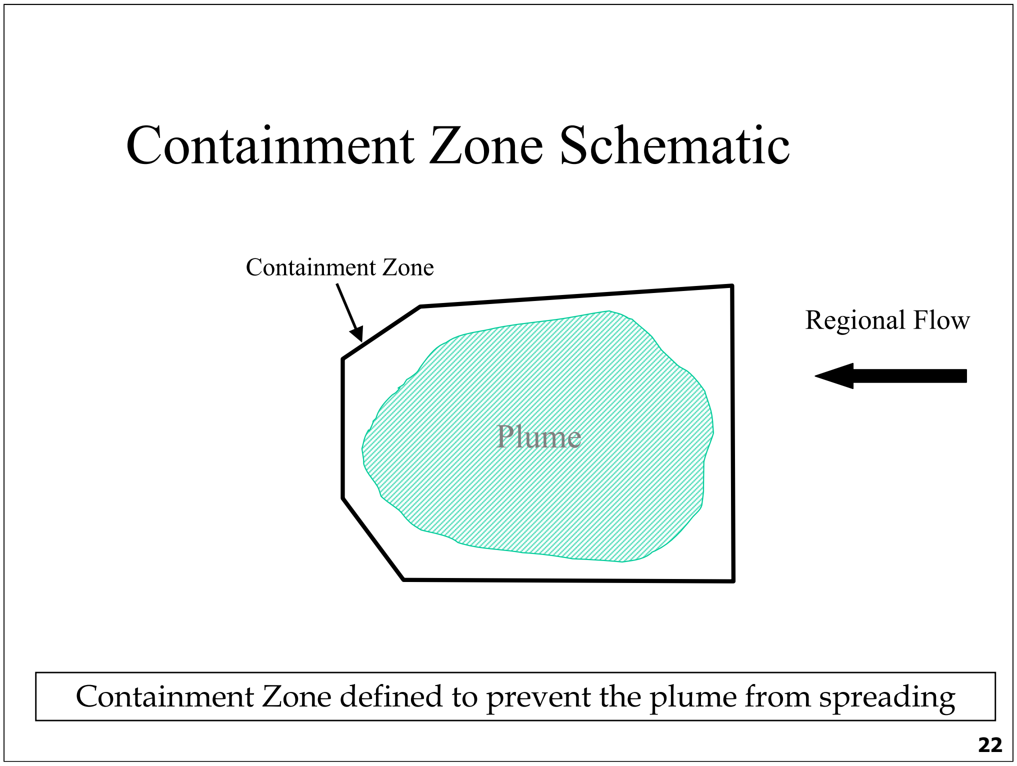
<u>**Point of Exposure**</u> **must have concentrations below a specified limit to protect receptors at or near this location**

<u>**Point of Compliance**</u> **must have concentrations below a specified limit to protect potential receptors downgradient**

Types of Information Collected: Ground Water Remediation Problems

- Cost components
  - One-time “capital” costs (now or in the future)
  - Annual costs
- Point of exposure, point of compliance
- Containment zones

Schematic



Containment Zone Schematic

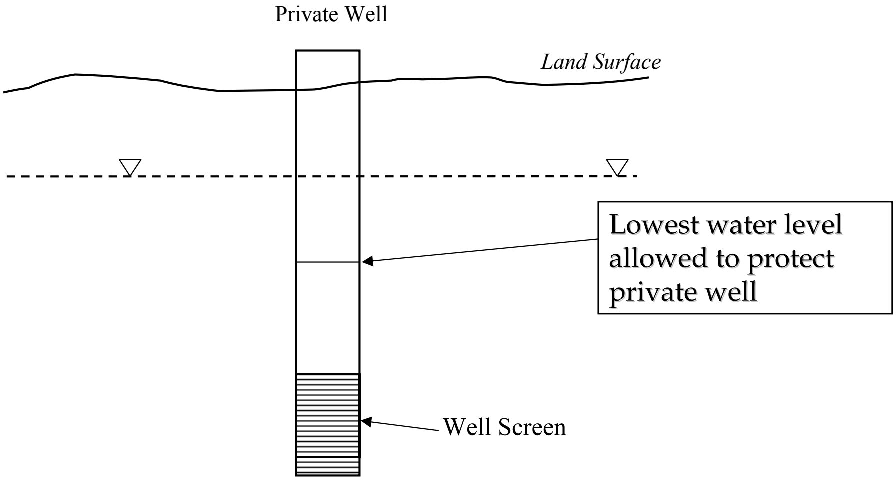
Containment Zone defined to prevent the plume from spreading

Types of Information Collected: Ground Water Remediation Problems

- Cost components
  - One-time "capital" costs (now or in the future)
  - Annual costs
- Point of exposure, point of compliance
- Containment zones
- Cleanup criteria and time period
- System capacity
- Pumping/injection limits
- Drawdown/water level limits

Schematic

Water Level Limit



Lowest water level allowed to protect private well

Types of Information Collected: Ground Water Remediation Problems

- Cost components
  - One-time "capital" costs (now or in the future)
  - Annual costs
- Point of exposure, point of compliance
- Containment zones
- Cleanup criteria and time period
- System capacity
- Pumping/injection limits
- Drawdown/water level limits
- Limit on capital cost, etc.
- Other planned actions (such as source removal) that may impact future remedy performance

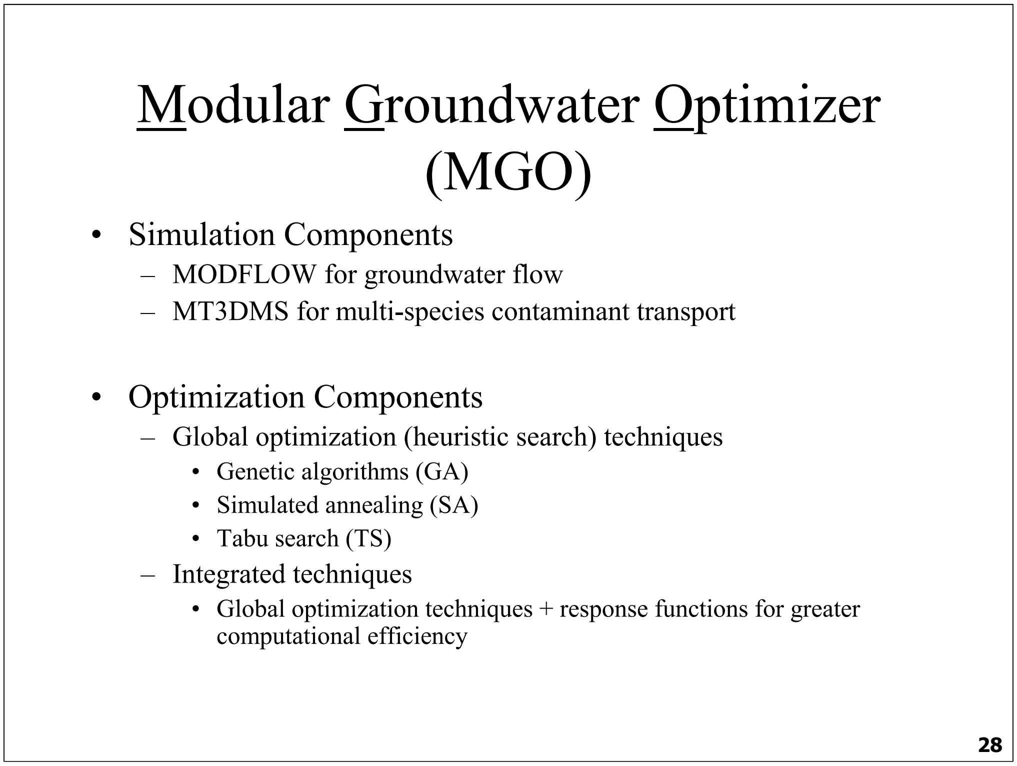
Formulation Components: Ground Water Remediation Problems

- Decision Variables
  - Locations of extraction/injection wells
  - Rates at each extraction/injection well over time
- Potential objective functions (select only one unless using a multi-objective algorithm)
  - Total life-cycle cost {minimize}
  - Cleanup time {minimize}
  - Contaminant mass remaining in aquifer {minimize}
  - Contaminant mass removed from aquifer {maximize}
- Potential constraints (as many as you want…here are some examples)
  - Limits on pumping rates at specific wells or total pumping rate
  - Limits on concentrations (at specific locations/times)
  - Restrictions on well locations
  - Limits on aquifer drawdown at specific locations
  - Financial constraints such as limits on capital costs

Optimization Codes: Ground Water Remediation Problems

- Dr. Chunmiao Zheng (University of Alabama), *Modular Groundwater Optimizer (MGO)*
  - Genetic algorithms
  - Simulated annealing
  - Tabu search

- Dr. Richard Peralta (Utah State Univeristy), *Simulation Optimization Modeling Systems (SOMOS)*
  - Genetic algorithms
  - Simulated annealing
  - Tabu search
  - Genetic algorithms coupled with artificial neural network

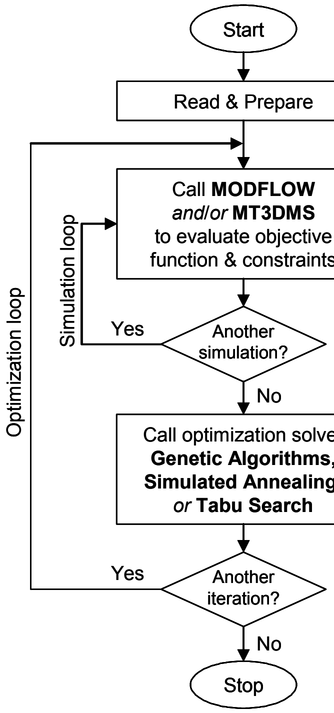


Modular Groundwater Optimizer (MGO)

- Simulation Components
  - MODFLOW for groundwater flow
  - MT3DMS for multi-species contaminant transport

- Optimization Components
  - Global optimization (heuristic search) techniques
    - Genetic algorithms (GA)
    - Simulated annealing (SA)
    - Tabu search (TS)
  - Integrated techniques
    - Global optimization techniques + response functions for greater computational efficiency

MGO
Program Structure



MGO: Setup of Optimization Modeling

- Input files for MODFLOW (no modification)
- Input files for MT3DMS (no modification)
- An optimization input file specifying
  - Optimization Solver (GA, SA, TS)
  - Output options
  - Decision variables (flow rates, well locations)
  - Objective function
  - Constraints

MGO: Additional Information

- Code Compatibility
  - MODFLOW
  - MT3DMS

- Platforms that incorporates MGO
  - Groundwater Vistas

Simulation / Optimization Modeling System (SOMOS)

- Optimization Software for Managing:
  - **Groundwater Flow**
  - **Solute Transport**
  - **Conjunctive Use**
- SOMOS is easy-to-use Windows-based S/O modeling software
- SOMOS has a comprehensive set of heavy-duty optimizers to most efficiently address the spectrum of management optimization problems
- SOMOS significantly improves planning and management and can help optimally manage water resources systems of unlimited size
- SOMOS results from twenty years experience developing optimization models and applying them to real-world problems, including 11 pump-and-treat (PAT) systems and many large and small scale water supply problems
- SOMOS has detailed documentation, tutorials, and error checking

Developed by:
Systems Simulation /Optimization Laboratory
Department of Biological and Irrigation Engineering
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Applications

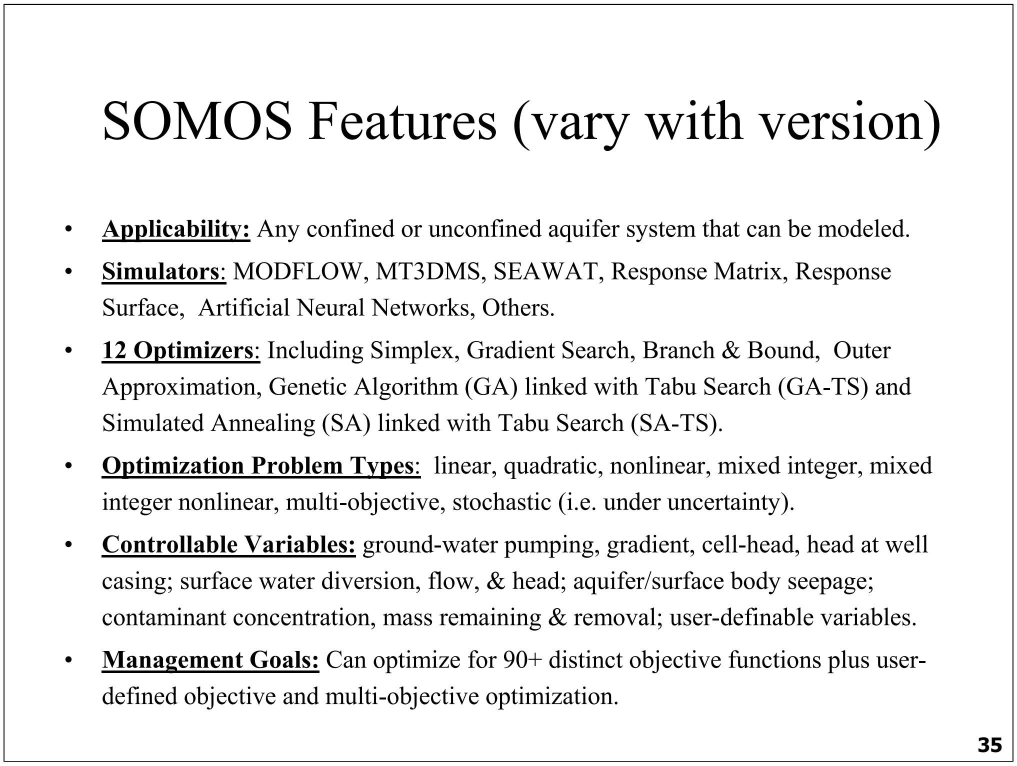
SOMOS handles large and complex problems and has been applied to many real-world problems. Some examples are:

- Minimizing cost of TCE plume containment at Norton AFB:
  - **Optimization yielded 23% cost reduction from base strategy**
  - **System was built, strategy was implemented and successful**
- TCE contaminant plume management: Minimizing TCE mass remaining at Massachusetts Military Reservation, CS-10 plume, while preventing plume expansion
  - **Optimization yielded 6% improvement from base strategy, at less cost**
  - **Constructed system is operating successfully**
- Cache Valley sustained yield optimization problem: Maximizing sustained yield of stream-aquifer system
  - **Optimal strategy showed sustainable pumping could increase 40%**
  - **causing management change**
- Applications performed at three sites for this ESTCP project

For more applications: http://www.usurf.org/units/wdl

SOMOS Features

- Windows-based SOMOS runs in background, while user employs other programs.
- SOMOS' spread-sheet based pre-processor, SOMOIN, simplifies input file preparation (availability depends on version).
- SOMOS' professional design has detailed input error-checking and error messages.
- Buttons on SOMOS' user-friendly interface speed accessing/editing I/O files, and optimizations.
- SOMOS' flexibility allows run restarts, result merges, stepwise, sequential, and simultaneous optimization, full control over constraints and bounds in time and space.
- SOMOS' automation allows considering multitudinous candidate wells in a run and speeds sequential running of multiple optimization actions.
- SOMOS includes a 2-D spreadsheet-based tool for mapping layered aquifer parameters, well locations and hypothetical capture zones (availability depends on version).
- SOMOS is being included within groundwater modeling packages such as Visual MODFLOW and Groundwater Vistas



SOMOS Features (vary with version)

- **Applicability:** Any confined or unconfined aquifer system that can be modeled.
- **Simulators**: MODFLOW, MT3DMS, SEAWAT, Response Matrix, Response Surface, Artificial Neural Networks, Others.
- **12 Optimizers**: Including Simplex, Gradient Search, Branch & Bound, Outer Approximation, Genetic Algorithm (GA) linked with Tabu Search (GA-TS) and Simulated Annealing (SA) linked with Tabu Search (SA-TS).
- **Optimization Problem Types**: linear, quadratic, nonlinear, mixed integer, mixed integer nonlinear, multi-objective, stochastic (i.e. under uncertainty).
- **Controllable Variables:** ground-water pumping, gradient, cell-head, head at well casing; surface water diversion, flow, & head; aquifer/surface body seepage; contaminant concentration, mass remaining & removal; user-definable variables.
- **Management Goals:** Can optimize for 90+ distinct objective functions plus user-defined objective and multi-objective optimization.

Questions

DOD Groundwater Remediation Optimization Study

ESTCP Demonstration Project

- Goal of project
  - Demonstrate application of “transport optimization” at real world sites
  - Evaluate the benefits and costs of using optimization algorithms versus the traditional trial-and-error modeling approach
  - Make transport optimization technology more accessible
    - Training
    - Code availability

Project Setup

- “Transport optimization” applied at 3 sites
  - Umatilla Chemical Depot, Oregon
  - Tooele Army Depot, Utah
  - Former Blaine Naval Ammunition Depot, Nebraska
- At each site, three different optimization formulations were developed
- Each formulation was solved (over a fixed time period) by…
  - two groups applying the coupled simulation-optimization approach
  - one group running the contaminant transport model using trial-&-error (to serve as a scientific control)
- Use of two groups provided greater confidence in results, a comparison of code performance, and more insight into the “beyond the code” efforts required to solve the problems

Project Team

- ESTCP and EPA provided funding, USACE also provided support
- Diverse project management team
  - NFESC - Karla Harre, Laura Yeh
  - EPA-TIO - Kathy Yager
  - USACE - Dave Becker
  - GeoTrans, Inc. - Rob Greenwald, Yan Zhang
  - University of Illinois - Dr. Barbara Minsker
- Transport optimization modelers
  - Utah State University - Dr. Richard Peralta (SOMOS)
  - University of Alabama - Dr. Chunmiao Zheng (MGO)

Demonstration Sites

Site Name	Pump rate (gpm) and Cost ($/yr)	# Existing Wells	Contam-inants	Groundwater Model Info.
Umatilla Army Depot	1300/$430K (operating)	3 ext. 3 inj.	RDX/ TNT	5 layers 10 min runs
Tooele Army Depot	5000/$1M (operating)	15 ext. 13 inj.	TCE	4 layers 10 min runs
Former Blaine NAD	4000/$2M (in preliminary design)	17 ext. (planned)	TCE*/ TNT	6 layers 2 hr runs

**** TCE simulated is combined plume of TCE, PCE, TCA, DCE, and RDX***

Formulation Process For Each Site

- Perform site visit and review site data
  - Understand the real-life situation
  - Explore real-life objectives and constraints with the installations
  - Initial discussion of how to convert real life situation into mathematical description

- Review site groundwater flow and transport model
  - Receive assurance from installation that they consider the model predictions acceptable for use for remediation design purposes
  - Important because the transport model provides the mathematical relationship between the decision variable values (the pumping locations/rates) and terms in the constraints/objective function

Formulation Process For Each Site

- Develop 3 “optimization formulations” based on further interaction with the installations
  - Select an “objective function” to be minimized (or maximized)
  - Specify a set of constraints to be satisfied

- Worked with installation to establish final mathematical representations of key problem components, such as…
  - Cost coefficients (e.g., cost of new well, cost to treat each gpm, etc.)
  - Nature of the relationships between the decision variables and other terms in the objective function and/or constraints (e.g., is the cost to treat each gpm constant, or does it change based on flow rate and/or contaminant concentrations?)

Optimization Formulations

Site Name		Objective Function	Major Constraints
Umatilla	Form. 1	Min life-cycle cost	1. Current treatment capacity 2. Cleanup of RDX and TNT
	Form. 2	Min life-cycle cost	1. Increased treatment capacity 2. Cleanup of RDX and TNT
	Form. 3	Min total mass remaining in layer 1	1. Cleanup of RDX and TNT
Tooele	Form. 1	Min total cost	1. POE concentration limit
	Form. 2	Min total cost	1. POE/POC concentration limits
	Form. 3	Min total cost	1. POE/POC concentration Limits 2. Declining source term 3. Cleanup (< 50ppb)
Blaine	Form. 1	Min life-cycle cost	1. Plume containment 2. Cleanup of TCE and TNT
	Form. 2	Min life-cycle cost w/ 2400gpm extracted water diversion	1. Plume containment 2. Cleanup of TCE and TNT
	Form. 3	Min maximum total pumping	1. Plume containment

POE = Point of Exposure; *POC = Point of Compliance*

Example: Umatilla

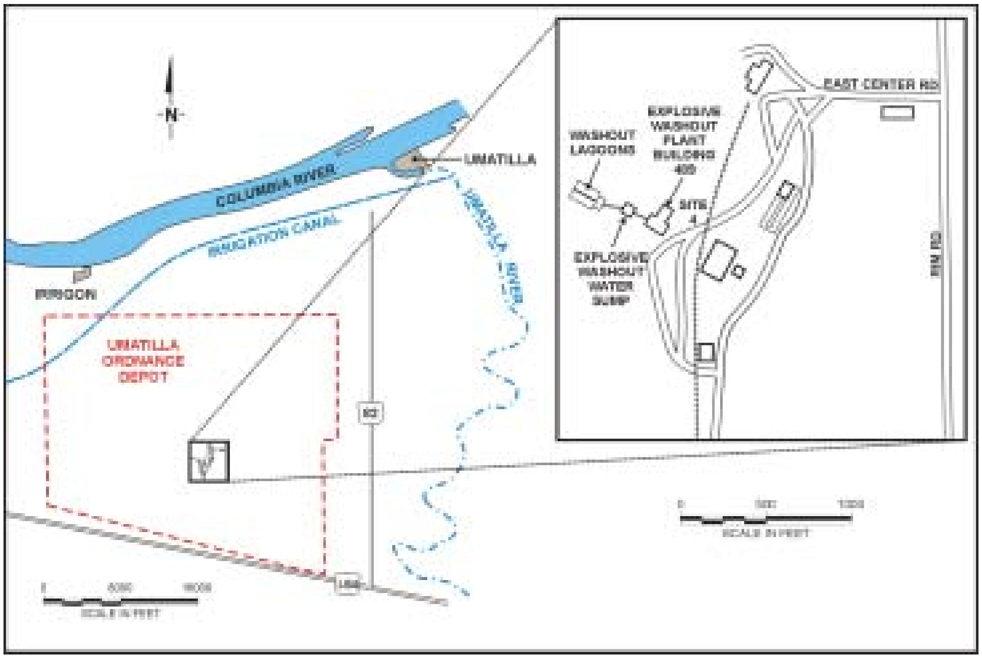
- Goal: cleanup 2 constituents
  - RDX: 2.1 ug/L
  - TNT: 2.8 ug/L
- Current system
  - System capacity: 2 GAC units @ 1300 gpm
    - 3 extraction wells
    - 3 infiltration basins
  - Expect cleanup in 17 years

Site Location

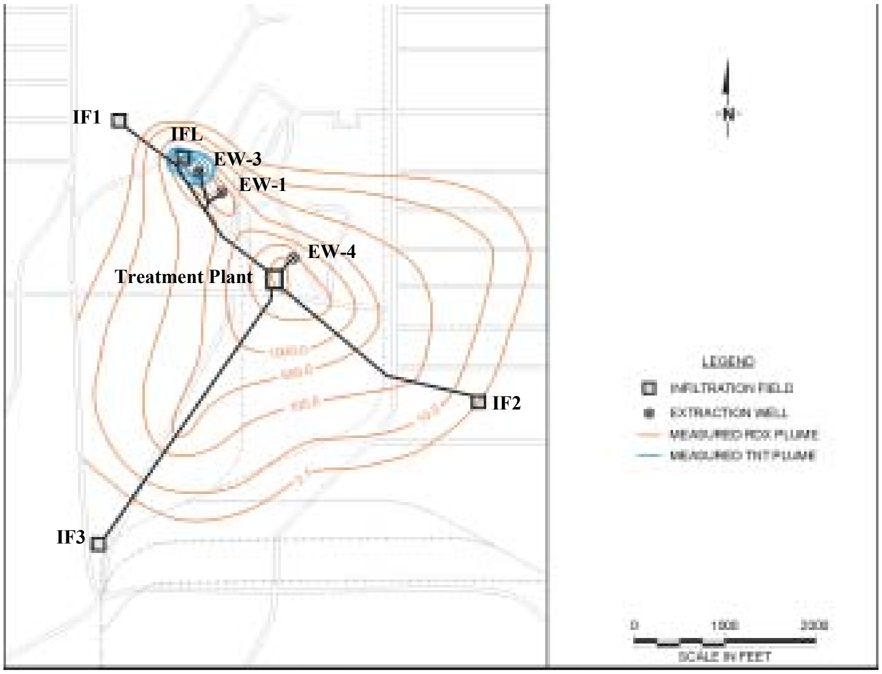
Current System & Plume Distribution

SITE LOCATION MAP

FACILITY AND SITE LOCATION MAP



CURRENT SYSTEM



Umatilla Objective Function: Formulation 1

- Minimize Total Cost Until Cleanup

Total Cost = CCW + CCB + CCG + FCL + FCE + VCE + VCG + VCS

- CCW: Capital Costs of new Wells
- CCB: Capital Costs of new Recharge Basins
- CCG: Capital Costs of new GAC units
- FCL: Fixed Costs of Labor
- FCE: Fixed Costs of Electricity
- VCE: Variable Costs of Electricity
- VCG: Variable Costs of changing GAC units
- VCS: Variable Costs of Sampling

future costs are discounted to yield Net Present Value

Umatilla: Cost Terms

- Up-Front costs
  - New well and piping: $75K
  - Put EW-2 in service: $25K
  - New recharge basin: $25K
  - New GAC unit (325 gpm): $150K
- Fixed Annual Costs (each year until cleanup)
  - Labor (fixed): $237K/yr
  - Electric (fixed): $3.6k/yr
- Variable Costs Depending on Solution (*complicated*)
  - Electric based on pump rate at specific wells
  - GAC changeout based on influent concentration
  - Sampling costs due to plume area

Details:
Variable Electric Costs

Example of Actual Details – Cost Term VCE

- VCE: Variable Cost of Electricity over system life-cycle

$$VCE = \sum_{i=1}^{ny} \sum_{j=1}^{nwel} \left(CW_{ij} \times IW_{ij} \right)^{d}$$

Where

$$CW_{ij} = 0.01(Q_{ij}) \quad \text{for} \quad 0 \text{ gpm} < Q_{ij} \leq 400 \text{ gpm}$$

$$CW_{ij} = 0.025(Q_{ij}) - 6 \quad \text{for} \quad 400 \text{ gpm} < Q_{ij} \leq 1000 \text{ gpm}$$

ny	is the elapsed time when cleanup occurs
$nwel$	is the total number of extraction wells
CW_{ij}	is the electrical cost of well j in year i. Costs differ for wells depending on the extraction rates Q_{ij}
IW_{ij}	is a flag indicator; 1 if the well j is on in year i, 0 otherwise
d	indicates application of the discount function to yield Net Present Value (NPV)

Umatilla Constraints: Formulation 1

- Cleanup must be achieved within 20 years
- Current treatment capacity, 1300 gpm
- Limits on extraction rates imposed by hydrogeology of the site
  - Zone 1, maximum rate at well ≤ 400 gpm
  - Zone 2, maximum rate at well ≤ 1000 gpm
- Concentration buffer zone
  - Prohibits concentrations from exceeding the cleanup levels outside a specified area
- Balance of extraction and injection rates

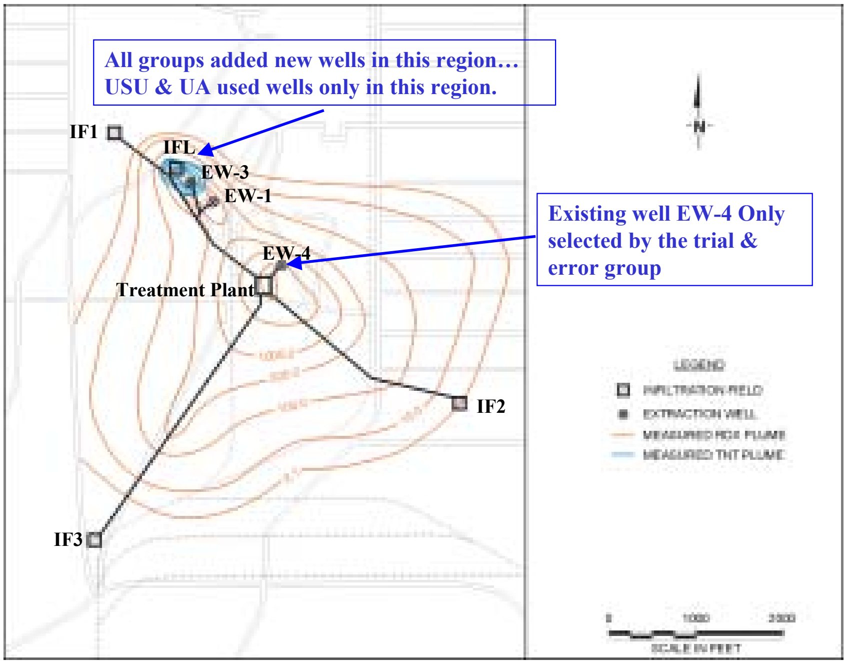
Umatilla Results: Formulation 1

	Transport Optimization Algorithms		Trial-&-Error
Objective Function Value	**$1.66M**	**$1.66M**	**$2.23M**
# new wells	**2**	**2**	**2**
# new recharge basins	**0**	**0**	**1**
# new GAC units	**N/A**	**N/A**	**N/A**
RDX Cleanup (yrs)	**4**	**4**	**6**
TNT cleanup (yrs)	**4**	**4**	**6**

Improvement using transport optimization: ~26%

Results Summary

Umatilla – Formulation 1 Results



All groups added new wells in this region…
USU & UA used wells only in this region.

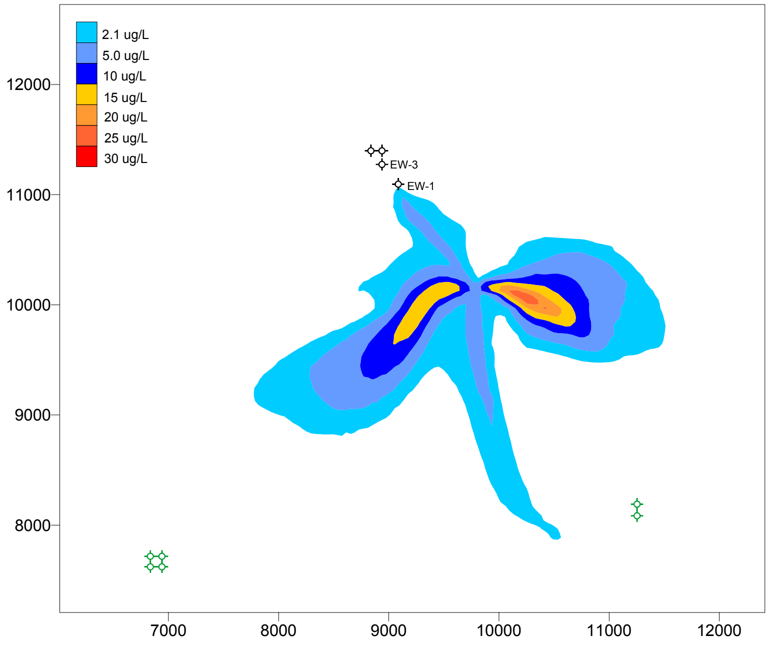
Existing well EW-4 Only selected by the trial & error group

Umatilla Results: Formulation 1

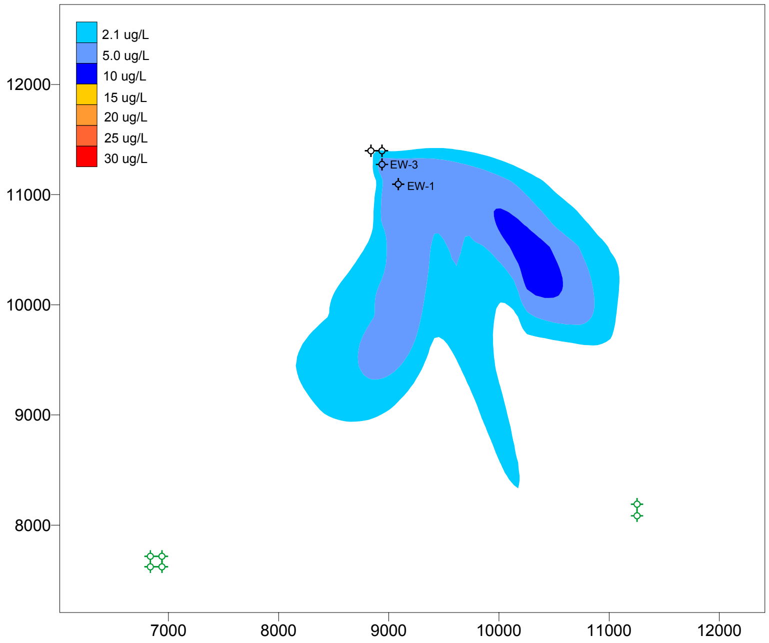
- RDX results for an “optimal solution”

Result w/optimization:
RDX

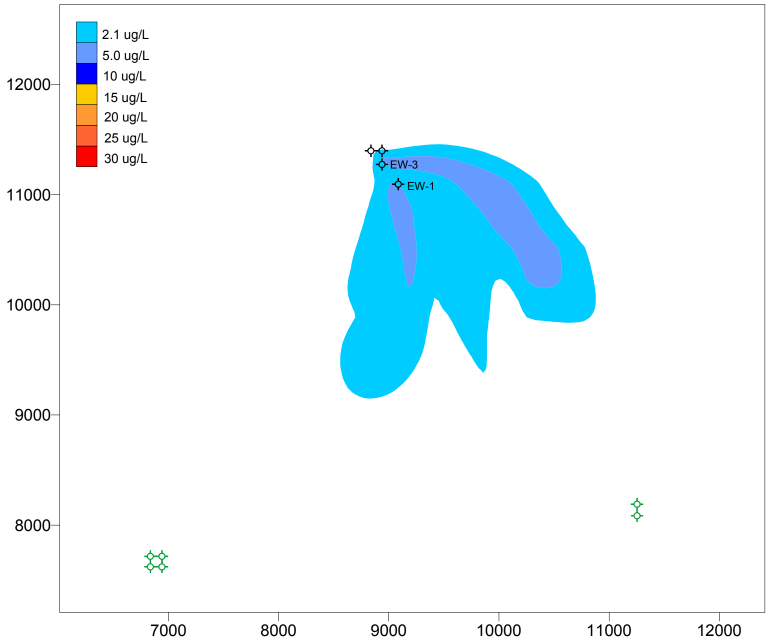
RDX Plume in Layer 1, 2002



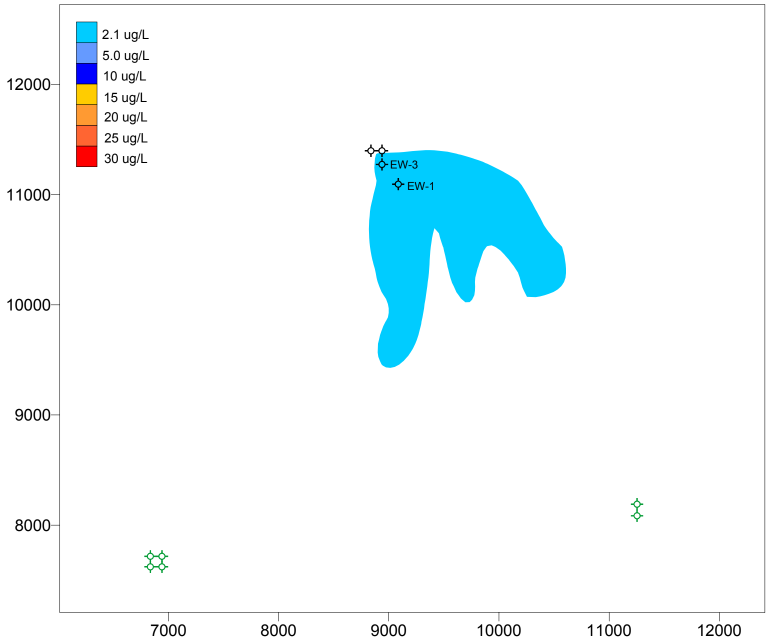
RDX Plume in Layer 1, 2003



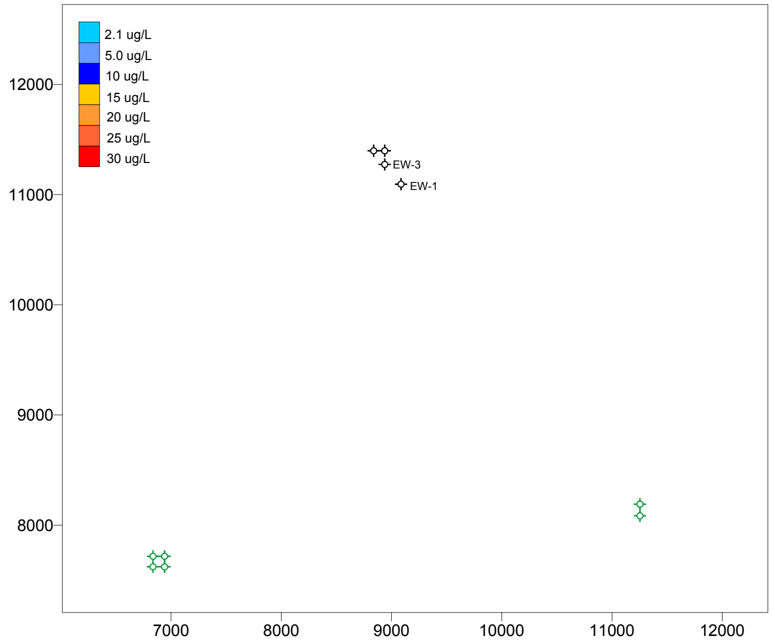
RDX Plume in Layer 1, 2004



RDX Plume in Layer 1, 2005



RDX Plume in Layer 1, 2006

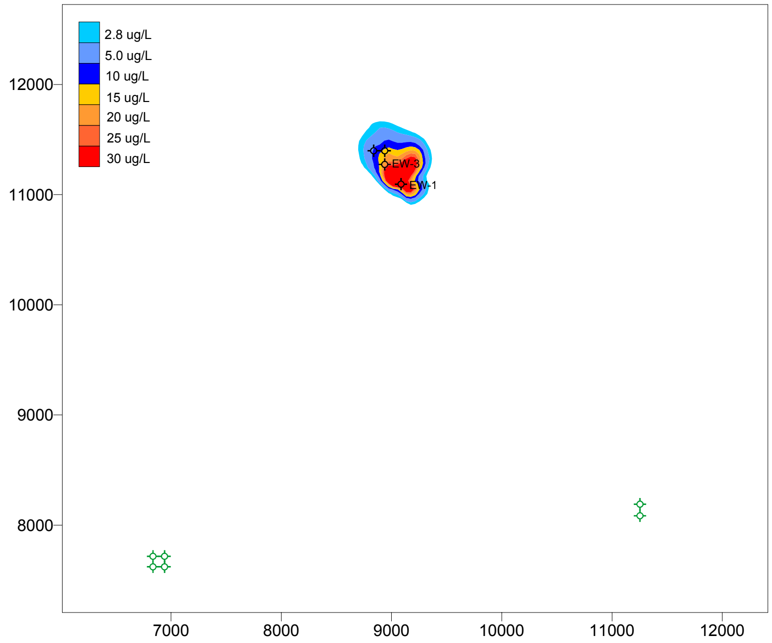


Umatilla Results: Formulation 1

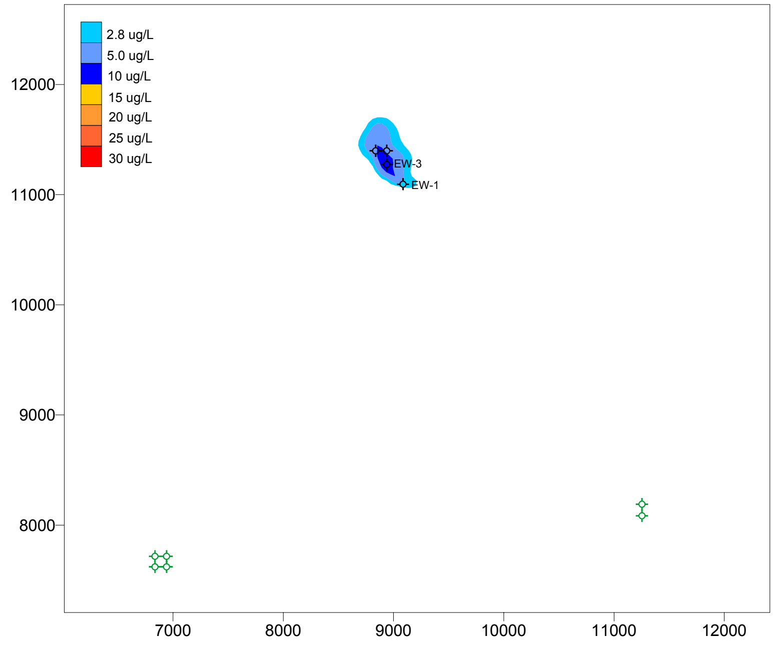
- TNT results for an “optimal solution”

Result w/optimization:
TN9T

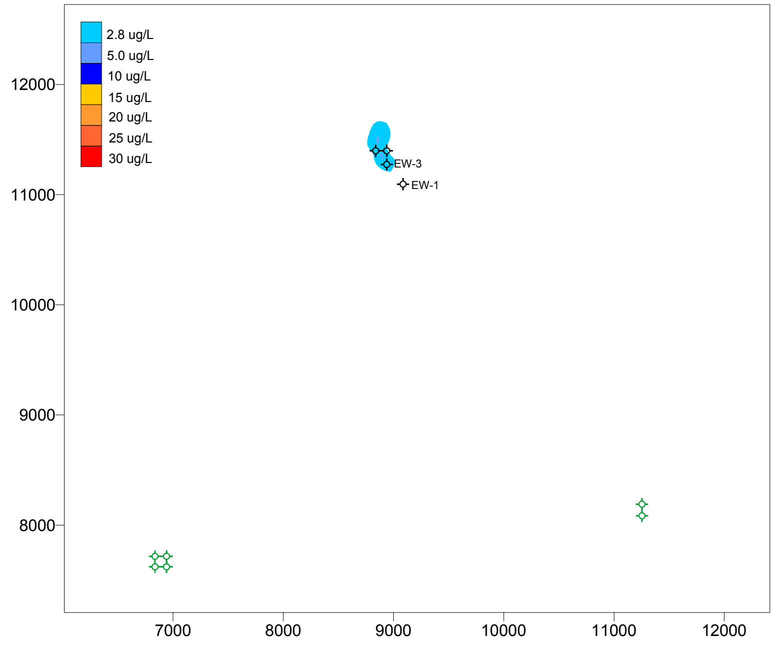
TNT Plume in Layer 1, 2002



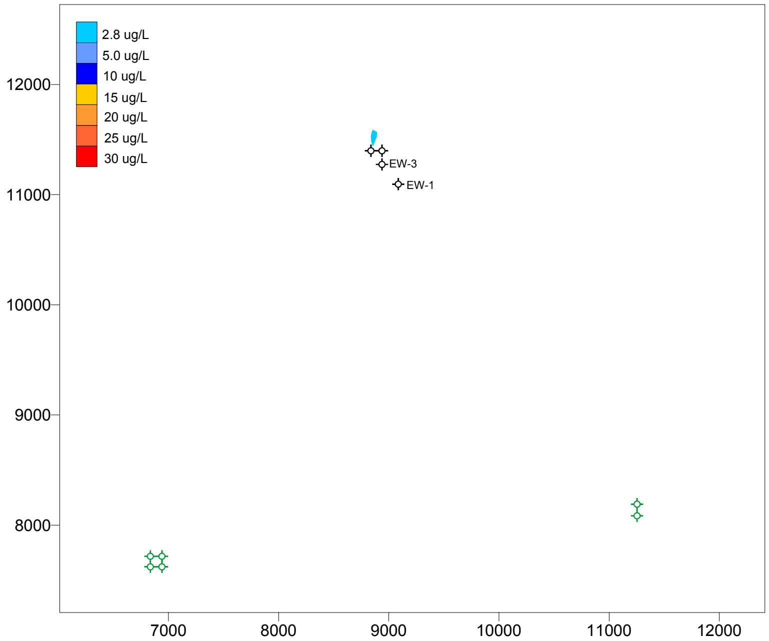
TNT Plume in Layer 1, 2003



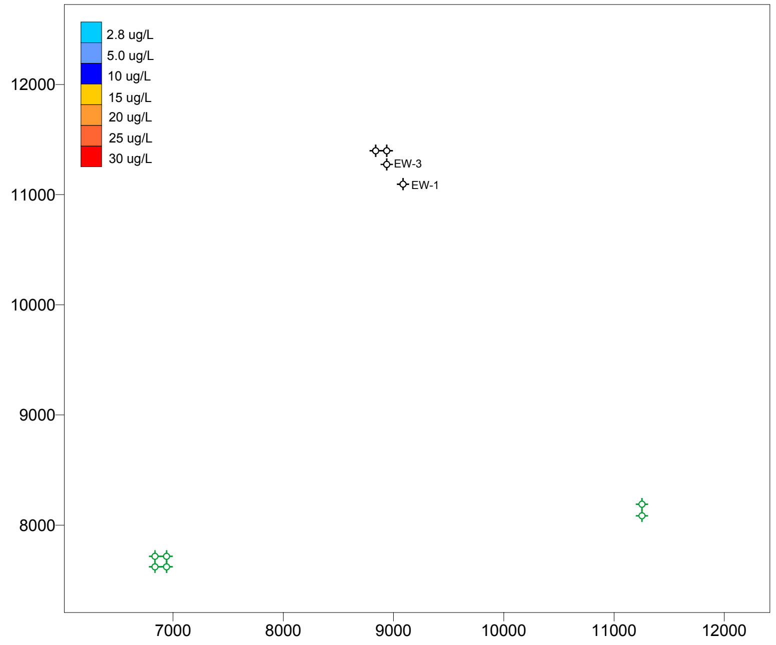
TNT Plume in Layer 1, 2004



TNT Plume in Layer 1, 2005



TNT Plume in Layer 1, 2006



Example: Blaine

- Primary Contaminants:
  - VOCs
    - TCE
    - 1,1,1-TCA
    - PCE
    - 1,1-DCE
  - Explosives
    - TNT
    - RDX

Only 2 constituents simulated for optimization:

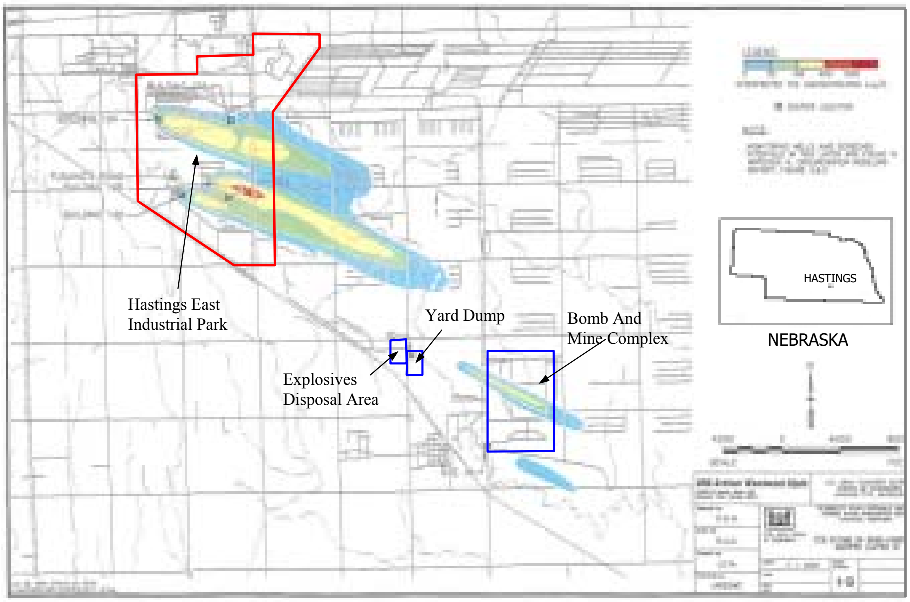
1. ***TNT***
2. ***TCE (represents TCE, TCA, PCE, DCE, and RDX)***

Site Location

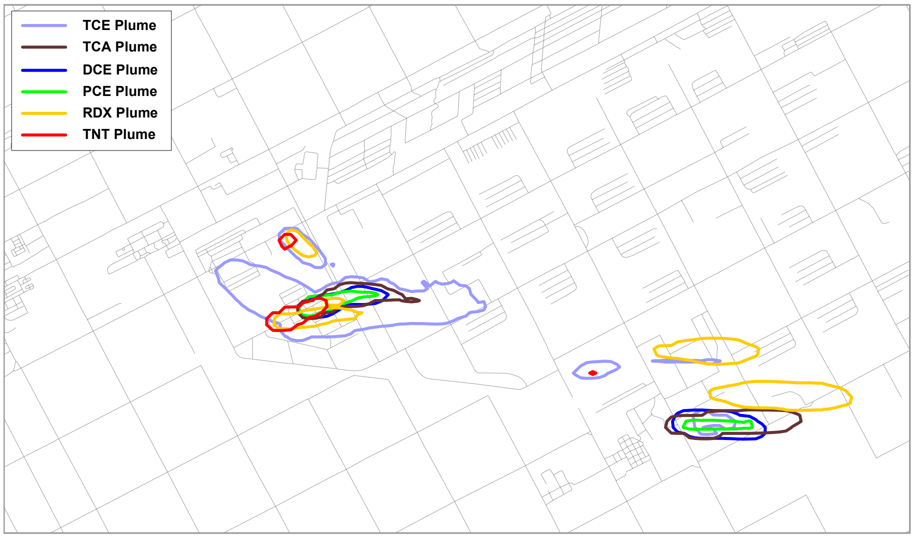
Pre-Remedy Plumes

- FS Recommended Design (Hydraulic Containment)
  - 12 deep wells @ 4,050 gpm
  - 5 shallow wells @ 18 gpm
  - Expect cleanup up to 60 years

Site Location With TCE Distribution in Upper Semi-Confined Aquifer



Commingled Plumes in Model Layer 1, 8/30/2002



Blaine Objective Function: Formulation 1

- Minimize Total Cost Until Cleanup

Total Cost = CCE + CCT + CCD + FCM + FCS + VCE + VCT + VCD

- CCE: Capital cost of new extraction wells
- CCT: Capital cost of treatment
- CCD: Capital cost of discharge
- FCM: Fixed cost of management
- FCS: Fixed cost of sampling
- VCE: Variable cost of electricity
- VCT: Variable cost of treatment
- VCD: Variable cost of discharge

future costs are discounted to yield Net Present Value

Blaine: Cost Terms

- Up-Front Costs
  - New extraction well: $400K
  - Capital Treatment: $1.0K/gpm
  - Capital Discharge: $1.5K/gpm

- Fixed Annual Costs (each year until cleanup)
  - Fixed O&M: $115K/yr
  - Sampling: $300K/yr

- Variable Costs
  - Electric: $0.046K/gpm/yr
  - Treatment: $0.283K/gpm/yr
  - Discharge: $0.066K/gpm/yr

Blaine Constraints: Formulation 1

- Cleanup within 30 years
- Containment limits to prevent plume spreading
- Limits on extraction well rates
  - Well screens one model layer: 350 gpm
  - Well screens two model layers: 700 gpm
  - Well screens three model layers: 1050 gpm
- Restricted areas where no wells allowed
- Remediation wells not allowed in same cells as irrigation wells
- No dry cells allowed

Blaine Results: Formulation 1

	Transport Optimization Algorithms		Trial-&-Error
Objective Function Value	**$45.28M**	**$40.82M**	**$50.34M**
# New Extraction Wells	**15**	**10**	**8**
Pumping Rate by Management Period	**1968 gpm 3104 gpm 3356 gpm 3700 gpm 3750 gpm 3750 gpm**	**2486 gpm 2632 gpm 2644 gpm 2752 gpm 3306 gpm 3378 gpm**	**3995 gpm 3975 gpm 3995 gpm 3995 gpm 3925 gpm 3105 gpm**
Elapsed Years Until Cleanup for TCE	**30**	**30**	**30**
Elapsed Years Until Cleanup for TNT	**30**	**29**	**25**

Improvement using transport optimization: ~10 - 20%

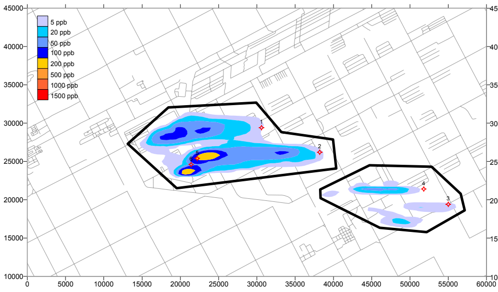
Blaine Results: Formulation 1

- Optimization result from all three groups

Optimization Results:
TCE Layer 3

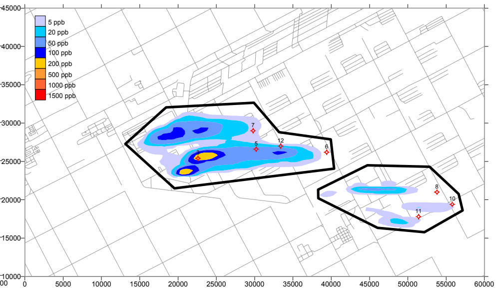
Transport Optimization Group 1

TCE Concentration in Layer 3, 8/31/2003



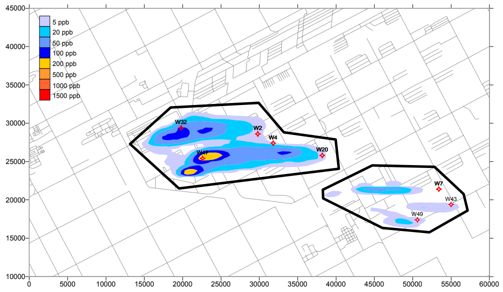
Transport Optimization Group 2

TCE Concentration in Layer 3, 8/31/2003



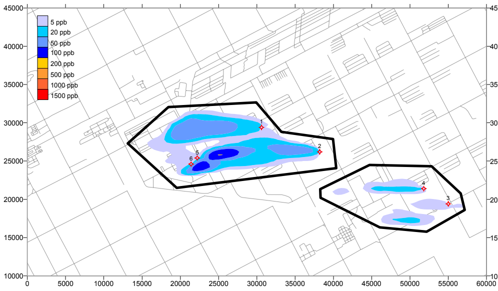
TCE Concentration in Layer 3, 8/31/2003

Trial-and-Error Group



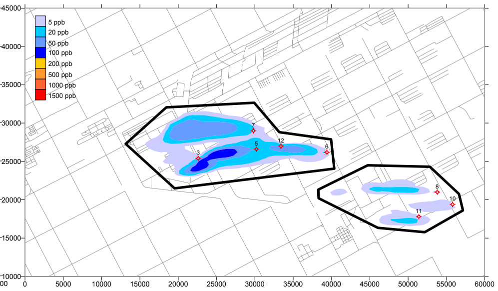
Transport Optimization Group 1

TCE Concentration in Layer 3, 8/31/2008



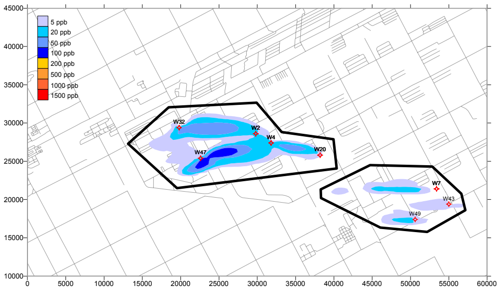
Transport Optimization Group 2

TCE Concentration in Layer 3, 8/31/2008



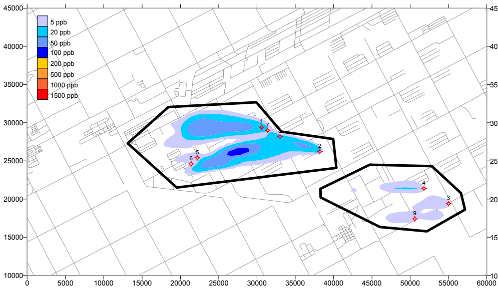
Trial-and-Error Group

TCE Concentration in Layer 3, 8/31/2008



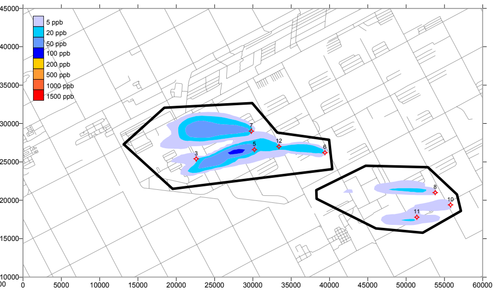
Transport Optimization Group 1

TCE Concentration in Layer 3, 8/31/2013



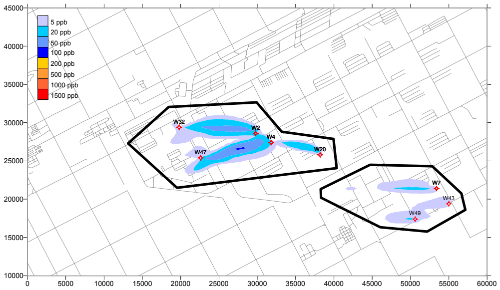
Transport Optimization Group 2

TCE Concentration in Layer 3, 8/31/2013



Trial-and-Error Group

TCE Concentration in Layer 3, 8/31/2013



Transport Optimization Group 1

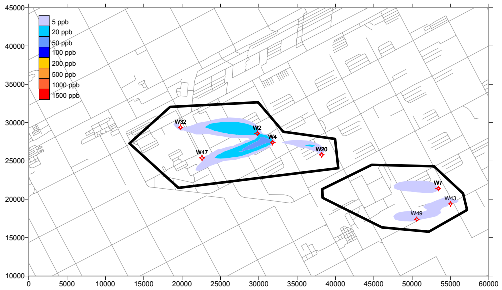
TCE Concentration in Layer 3, 8/31/2018

Transport Optimization Group 2

TCE Concentration in Layer 3, 8/31/2018

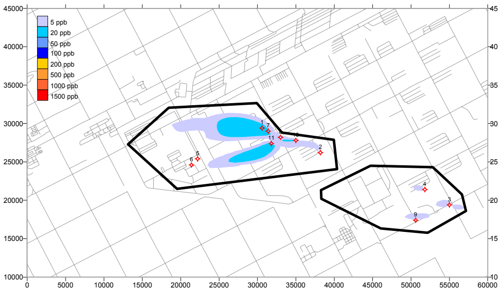
Trial-and-Error Group

TCE Concentration in Layer 3, 8/31/2018



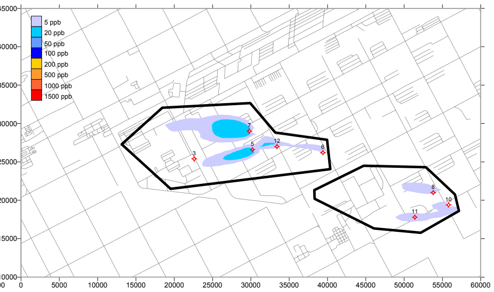
Transport Optimization Group 1

TCE Concentration in Layer 3, 8/31/2023



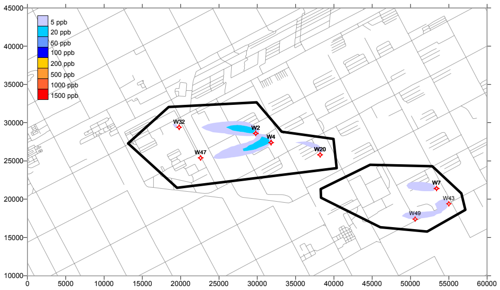
Transport Optimization Group 2

TCE Concentration in Layer 3, 8/31/2023



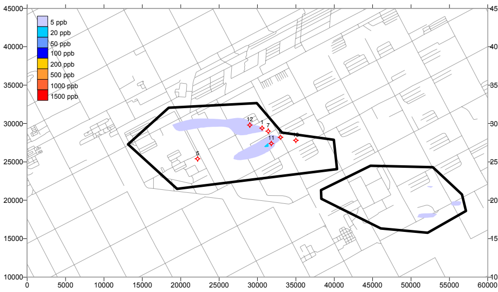
Trial-and-Error Group

TCE Concentration in Layer 3, 8/31/2023



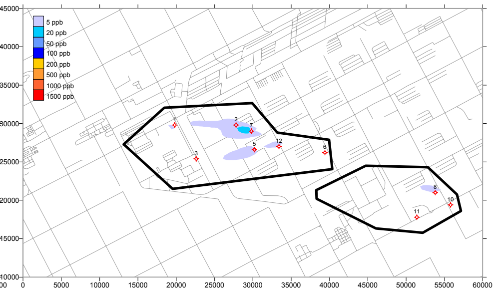
Transport Optimization Group 1

TCE Concentration in Layer 3, 8/31/2028



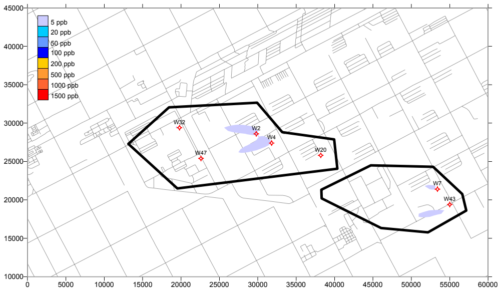
Transport Optimization Group 2

TCE Concentration in Layer 3, 8/31/2028



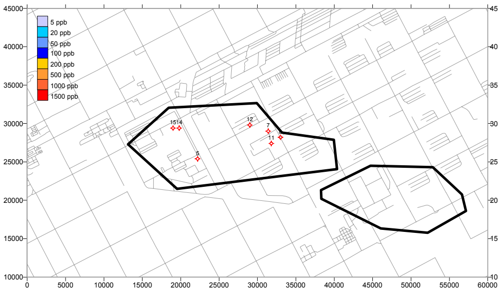
Trial-and-Error Group

TCE Concentration in Layer 3, 8/31/2028



Transport Optimization Group 1

TCE Concentration in Layer 3, 8/31/2033



Transport Optimization Group 2

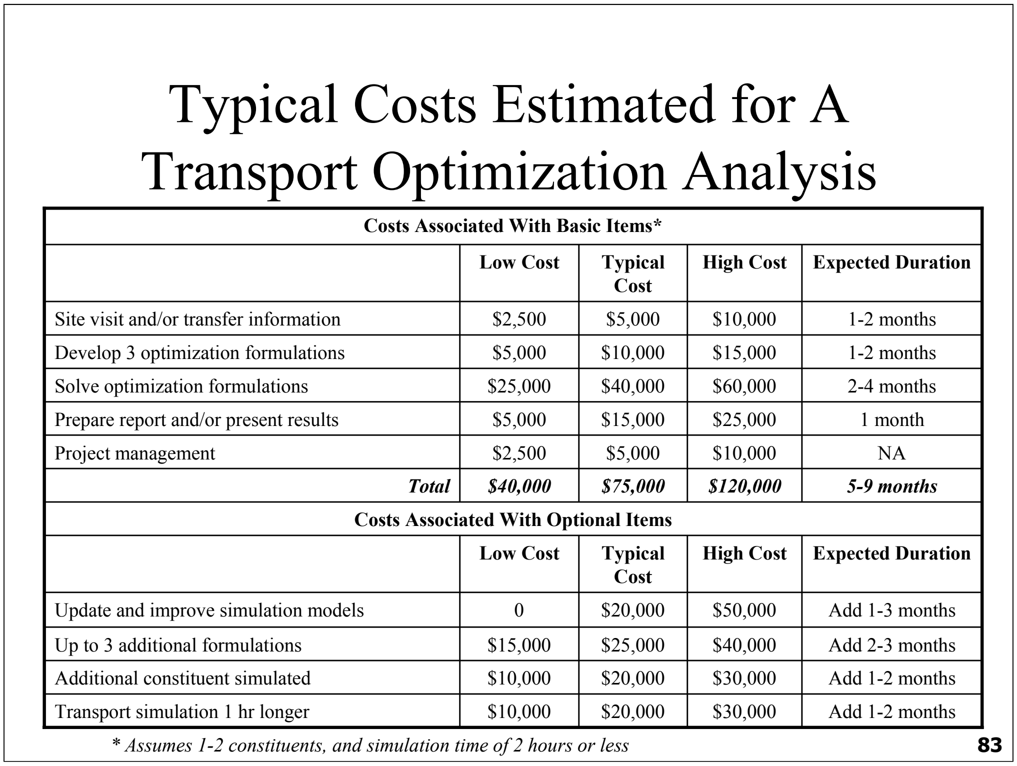
TCE Concentration in Layer 3, 8/31/2033

Trial-and-Error Group

TCE Concentration in Layer 3, 8/31/2033

Findings/Lessons Learned

- Transport optimization algorithms
  - Can be applied at real-world sites
  - Provided improved solutions compared to trial-&-error (representative improvement was 20%)
  - Found “outside of the box” solutions
    - Pumping only within TNT plume at Umatilla
    - Pumping less in early time periods and installed new wells later at Blaine
  - Are estimated to cost $40-120K per site to apply ($0-40K more than trial-&-error design)
    - Range varies with site complexity, model size, and number of contaminants



Typical Costs Estimated for A Transport Optimization Analysis

Costs Associated With Basic Items*				
	Low Cost	**Typical Cost**	**High Cost**	**Expected Duration**
Site visit and/or transfer information	$2,500	$5,000	$10,000	1-2 months
Develop 3 optimization formulations	$5,000	$10,000	$15,000	1-2 months
Solve optimization formulations	$25,000	$40,000	$60,000	2-4 months
Prepare report and/or present results	$5,000	$15,000	$25,000	1 month
Project management	$2,500	$5,000	$10,000	NA
Total	***$40,000***	***$75,000***	***$120,000***	***5-9 months***
Costs Associated With Optional Items				
	Low Cost	**Typical Cost**	**High Cost**	**Expected Duration**
Update and improve simulation models	0	$20,000	$50,000	Add 1-3 months
Up to 3 additional formulations	$15,000	$25,000	$40,000	Add 2-3 months
Additional constituent simulated	$10,000	$20,000	$30,000	Add 1-2 months
Transport simulation 1 hr longer	$10,000	$20,000	$30,000	Add 1-2 months

** Assumes 1-2 constituents, and simulation time of 2 hours or less*

Findings/Lessons Learned

- Transport optimization algorithms
  - Allow thousands more simulations
    - For example, 39 trial-&-error runs vs. ~5000 runs with the MGO transport optimization code for one formulation
  - Can assist sites in screening alternative strategies (e.g., aggressive pumping vs. containment only)
  - Have potential application during both the design and operation of P&T systems
  - Require development of optimization formulations, which helps the project team understand and quantify objectives and constraints

Technology Transfer Activities

- Project Website (http://www.frtr.gov/optimization/simulation/transport/general.html)
  - Optimization codes and documentations
  - Final project report
  - Modeling files for each demonstration site
  - Sample optimization code input and output files for Blaine
  - Powerpoint animations illustrating results for Each group

- Training
  - 2-day workshop - 2004

- Case Study / Site Follow-Up
  - Through summer 2004

Questions

Thank You

After viewing the links to additional resources, please complete our online feedback form.

Thank You

Links to Additional Resources