Long Term Monitoring Optimization Software

RITS Fall 2009

Presentation Overview

- Overview of LTMO and Software Products
- Summit Software Overview
- Results from ESTCP Demonstration
- Costs, Benefits, and Regulatory Issues
- Input Data, Using NIRIS, and Data Screening
- Case Study: NSA Mechanicsburg – Site 3
- Summary/Take-Home Messages

Long-Term Monitoring Optimization (LTMO)

- Primary Objective: to maximize cost-effectiveness without compromising program integrity
- Key Considerations
  - Formulate monitoring objectives consistent with RAO or LTM goals
  - Identify data requirements for adequate decision support
  - Optimize number and location of monitoring locations
  - Minimize frequency of monitoring
  - Streamline list of constituents to be monitored
  - Streamline data management, evaluation, and reporting

Purpose of LTMO Software

- Identify redundant sampling locations and/or frequency (i.e., attempt to reduce number of samples)
  - Cost savings and efficiency
- Other (depends on software)
  - Flag new sampling results that deviate from expectations
  - Identify trends in sampling data
    - Concentrations at individual wells
    - Mass versus time
    - Plume shape
  - Assess contaminants of concern (COCs) for relative priority
  - Identify areas of greatest sampling uncertainty

When Does an RPM Consider LTMO?

- Redundancy Evaluation
  - Periodically (every ~ 3 to 5 yrs)
- Assess new data for values outside expectations and/or trends
  - Each event (or perhaps annually)

Software is generally applied to groundwater data

Definitions

- Model
  - The manner in which actual data values are interpolated and extrapolated in space and/or time
    - Kriging, Inverse Distance Weighting, etc.
- Spatial Optimization
  - Optimization of sampling locations
- Temporal Optimization
  - Optimization of sampling frequency
    - Individual wells or perhaps an entire site
- Spatiotemporal Optimization
  - Optimization of sampling locations and frequency simultaneously

LTMO Software Packages

- Summit Software
  - Demonstrated in recently completed ESTCP project and partially funded by British Petroleum
  - Free for use by government and their contractors at government sites
- MAROS
  - Widely utilized
  - Developed for AFCEE
  - Free for use by any party
- GTS
  - Currently being demonstrated in an ESTCP project (testing expected to be complete Fall 2009)
  - Developed for AFCEE
  - Will be free for use by any party once finalized

Comparing These Software Products

- This presentation focuses primarily on the Summit software
  - Provide RITS participants with introduction to LTMO
  - Extensively tested in recently completed ESTCP project
  - Similarities and differences between Summit, MAROS, and GTS software packages will be noted on some slides

Comparison of Primary Functionality

	Summit	MAROS	GTS
Redundancy Analysis with Tradeoff Curves	●		●
Plume Maps (Baseline versus Optimized)	●		●
Redundancy Analysis "One-Well-at-a-Time"		●	
Are New Data "Out-of-Bounds"?	●		●
Indicates Concentration Trends		●	●
COC Assessment		●	●
Tracking of Relative Plume Mass Over Time	●	●	
Uncertainty Analysis	●	●	●

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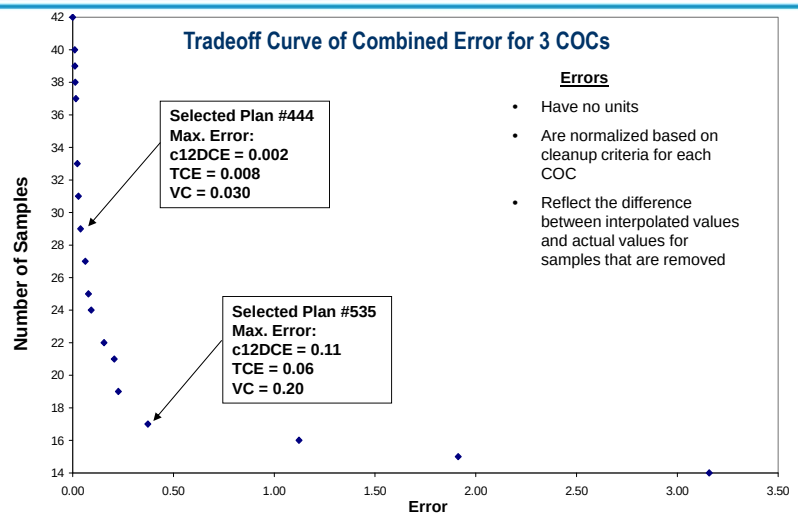
Summit Software Modules

- Sampling Optimizer
  - Identifies redundant sampling locations and/or frequencies
- Data Tracker
  - Flags new sample results that are outside of expectations
  - Can also track relative plume mass over time

Identifying Redundancy: Tradeoff Curve Approach

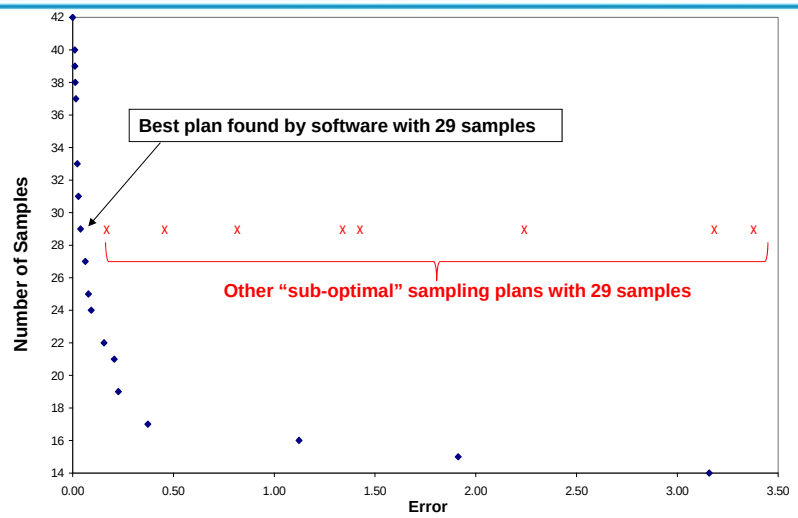
- Most powerful part of the software
- Provides tradeoff between number of samples vs. "error"
  - Considers sampling plans with fewer samples than the baseline plan
  - Error is calculated at locations where samples are removed
    - Based on actual value versus "modeled" value
    - Tradeoff curve indicates plan with least error for a given number of samples
  - Error on tradeoff curve increases as more samples are eliminated
- Select one or more plans from tradeoff curve for further consideration
  - Compare plume maps of baseline plan versus optimized plan(s)

Example of a Tradeoff Curve



This type of curve is very powerful and very useful for an RPM

Tradeoff Curve – What Makes it So Powerful



Searches "solution space" of potential sampling plans to find a very good plan for each number of samples

How Many Unique Sampling Plans Are There?

- **Class exercise**
  - **If there are 4 wells, how many unique sampling plans are there with only 2 of those wells sampled?**
    - Start with wells A, B, C, and D
  - **Tradeoff curve on previous slide starts with 42 wells, how many unique sampling plans are there with only 21 of the 42 wells sampled?**
  - **Starting with 42 wells, how many potential unique sampling plans are there in total (i.e., all unique combinations)?**

How Does It Work?

- **Uses form of mathematical optimization called a "Genetic Algorithm" (GA)**
  - **Searches a very large "solution space" in an efficient manner**
    - Start with a randomly generated "population" of sampling plans
    - Good sampling plans (i.e., with lower error) are preferentially combined to create promising "offspring"
    - Other modifiers (e.g., mutation) are also included to make sure other portions of the solution space are explored
  - **Doesn't guarantee the absolute "best" solutions are found, but does efficiently find "excellent" solutions**

How is Error Calculated?

- **Several options in software**
- **Most useful option is "cutoff error calculator" which normalizes error two ways**
  - **Based on cleanup level of each COC**
    - If cleanup level is 5 µg/L, variation of 10 µg/L may be significant
    - If cleanup level is 200 µg/L, variation of 10 µg/L is not significant
  - **Location near plume boundary versus within plume interior**
    - Variation of 10 µg/L a bigger deal near plume boundary than in plume interior

Explanation of "Error"

	TCE (µg/L)
Acceptable error level for low concentrations (cleanup goal)	5
Cutoff between low and high concentrations	25
Acceptable percentage error for high concentrations	20%

Note: cutoffs and percentage errors are matched so that at the cutoff the error formula is continuous

User specifies these

Examples for error calculation (estimated value differs by 5 µg/L from actual value):

Plume Boundary (TCE)

actual value = 15 {below cut-off}
modeled value = 20
error = (20 – 15) / 5 = **1.0**

Emphasized (plume boundary)

Plume Interior (TCE)

actual value = 500 {above cutoff}
modeled value = 495
acceptable percentage error = 20%
error = (500 – 495) / (500 * 20%) = **0.05**

De-emphasized (plume interior)

General Approach for Spatial Optimization with Sampling Optimizer (To Reduce Redundancy)

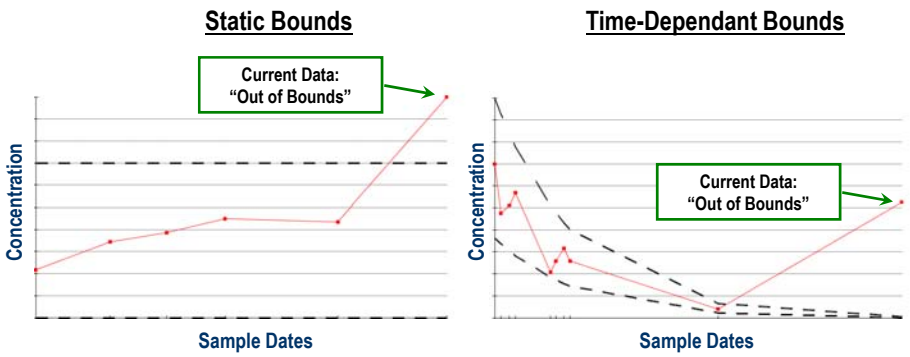
- Create input data for baseline model (one value per location)
- Decide which "model" to use ("Model Builder")
  - Two Interpolation Options: Inverse Distance Weighting (IDW), Kriging
  - Three Data Transformations: None, Logarithmic, Quantile
- Software generates tradeoff curve
- Compare plume maps generated with the "model"
  - Baseline plan versus plan(s) selected from tradeoff curve

Benefit of Using of Mathematical Optimization – GA

- Allows the tradeoff curve to be developed
  - RPM can evaluate increase in error as number of samples is reduced
- Other software:
  - GTS also uses tradeoff curve approach (error is calculated differently)
  - MAROS uses a less powerful approach that considers each well individually for elimination, rather than looking at different combinations of wells

Summit Software: Illustration of Data Tracker Plots

- Examples of "out-of- bounds" values



Values left off axes of these graphs for presentation purposes

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ESTCP Demonstration Sites – Summary Table

	NS Camp Allen Landfill	Former George AFB (GAFB) OU1	Former Ordnance Plant (NOP) OU2
Agency	Navy	Air Force	Army
Location	Norfolk, VA	Victorville, CA	Mead, NE
Geographic Location	East (coastal)	West (arid)	Midwest (plains)
Remediation System	P&T with air stripping for hydraulic containment	P&T started in 1991 and shut down since 2003	P&T with 10 extraction wells
Primary COCs	c12DCE, TCE, VC	TCE	TCE and RDX
Aquifers Evaluated	Shallow and deep aquifers	Upper aquifer	Shallow, intermediate, and deep aquifers
Sampling Frequency	Annual	Semi-annual	Varies by well
Monitoring Network	~70	~50	~220

Experimental Design (Key Items)

- For each site
  - Formulation developed with site personnel (meeting)
  - Screening of data prior to import into software ("data cleanup")
  - Software applied by a mid-level analyst with no LTMO expertise
  - Artificial anomalies added to "current data" for testing of Data Tracker (blind test)
- MAROS also applied at one of the three sites; data from one site being used in another ESCTP project to test GTS
- USEPA Region 5 also applied software at a site and provided feedback

Formulation Step – Prior to Using the Software

- Defines key objectives and constraints
  - COCs to be evaluated
  - Wells that cannot be eliminated
  - Definition of plume boundary vs. plume interior (optional)
  - Cleanup levels
  - Etc.
- Get "buy-in" up front
  - Without this step the analysis may proceed in a manner that is not acceptable to one or more site stakeholders

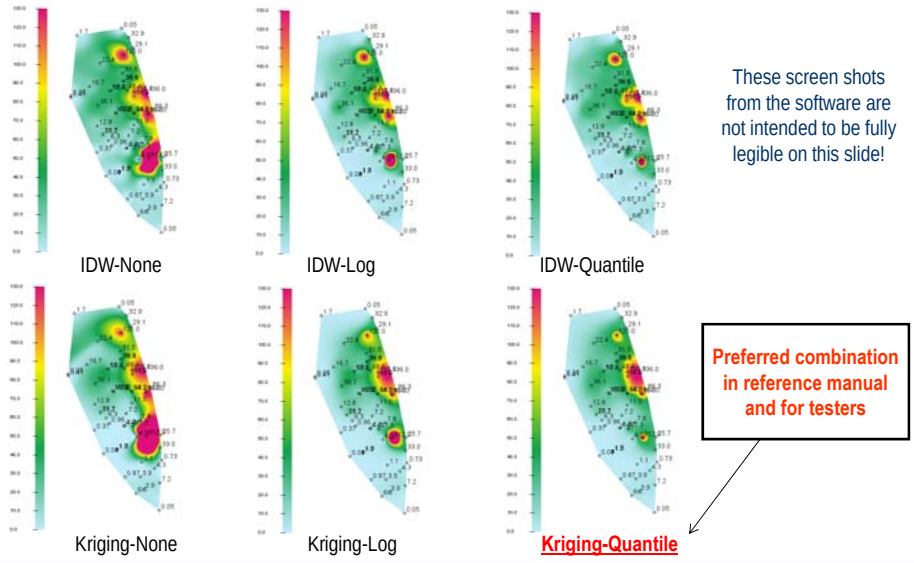
Examples of Types of Testing during ESTCP dem/val

- Combinations of interpolation and transformation options for the "model"
- Different values for genetic algorithm parameters
- Multiple COCs evaluated simultaneously versus separately
- Different options within the "error" calculation
- Spatial versus spatiotemporal optimization
- Tracking of mass over time

Ease of Use and No Bugs Identified

- Software easy to learn within 1-2 days
  - Site #1: mid-level analyst was provided a one-day training session by the software developer
  - Site #2 and Site #3: different mid-level analyst had no training provided, relied on user guide and infrequent phone support
- By the end of the demonstration project no bugs were known to exist

Best Modeling Algorithm (Summit Software)

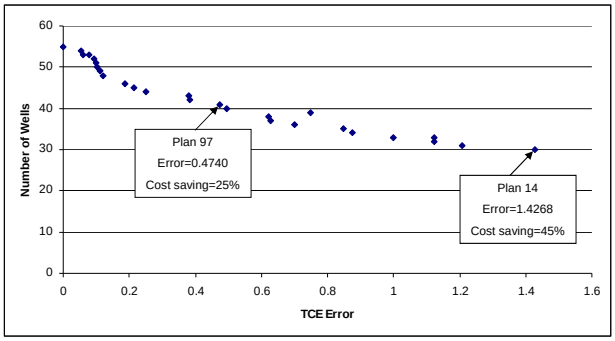


These screen shots from the software are not intended to be fully legible on this slide!

Preferred combination in reference manual and for testers

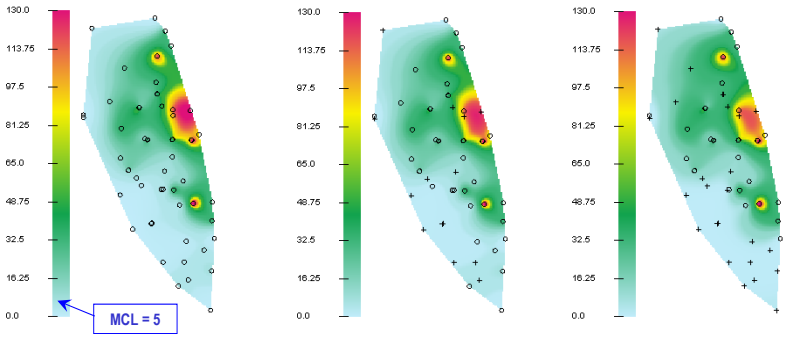
Example of Tradeoff Curve and Selected Plans

- Base plan has 55 wells
  - Plan 97 has 14 wells removed (25% savings)
  - Plan 14 has 25 wells removed (45 % savings)



Plume Maps for Plans Selected from Tradeoff Curve

All sampling locations (55 wells) | Plan 97 (41 wells) | Plan 14 (30 wells)



Note:

- "o" indicates wells recommended to be kept
- "+" indicates wells recommended to be removed

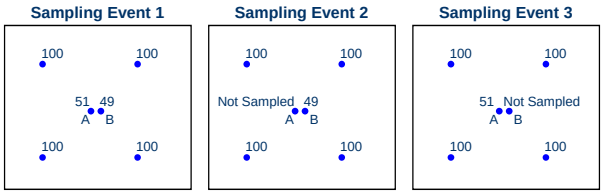
RPM and other stakeholders can use these types of plots to assess how much error is acceptable

Potential Sampling Reductions Identified

	Spatial Optimization	Spatiotemporal Optimization
NS Camp Allen Landfill	~ 30% to 60%	~15%
Former GAFB Site	~ 25% to 35%	~10%
NOP Site	~30% to 45%	N/A

- Range in results because many different scenarios were tested
- Spatiotemporal optimization consistently was more conservative (i.e., less savings)

Spatiotemporal Results More Conservative than Spatial – Why?

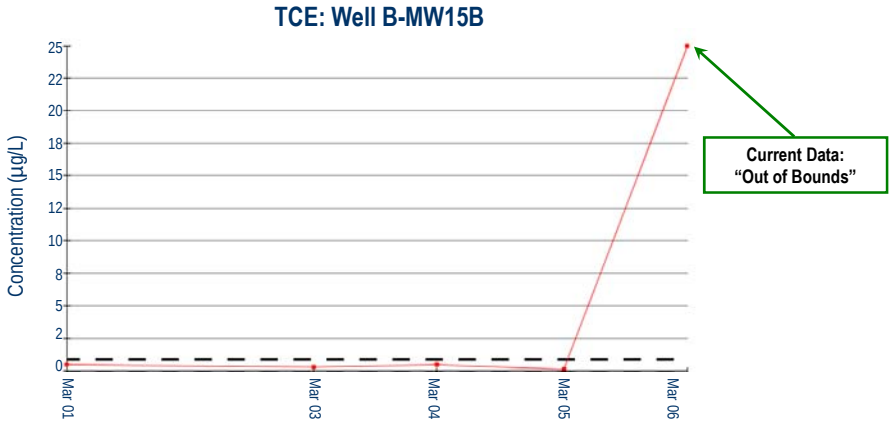


- Error is the maximum error at any removed location in any event, *based on spatial interpolation using the remaining samples in that event*
- Spatial optimization: likely savings of 1/6 = 17%
  - Eliminate either "A" or "B" (remove 1 of 6 locations)
- Spatiotemporal optimization (as implemented): likely savings of 1/16 = 6%
  - Eliminate either "A" or "B" in Event 1 only (remove 1 of 16 samples)
  - Would be different if temporal interpolation and extrapolation was also performed

Suggested Approach Using Summit Software

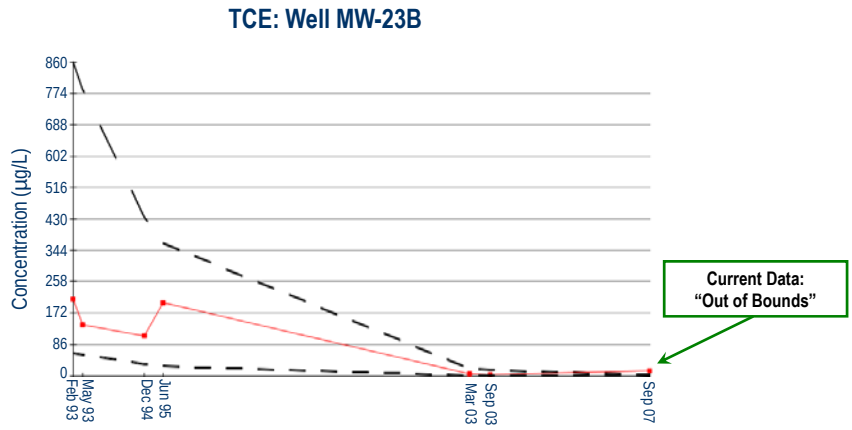
- Perform spatial optimization rather than spatiotemporal optimization
  - Less conservative
  - Much faster computationally
- Evaluate multiple COCs simultaneously rather than one at a time
- Establish sampling frequency with some other approach
- Develop rules for estimating the values at locations not sampled in a specific event for plume maps and/or mass calculations
  - Latest value
  - Moving average of latest values
  - May need to extrapolate backwards in time

Data Tracker Examples



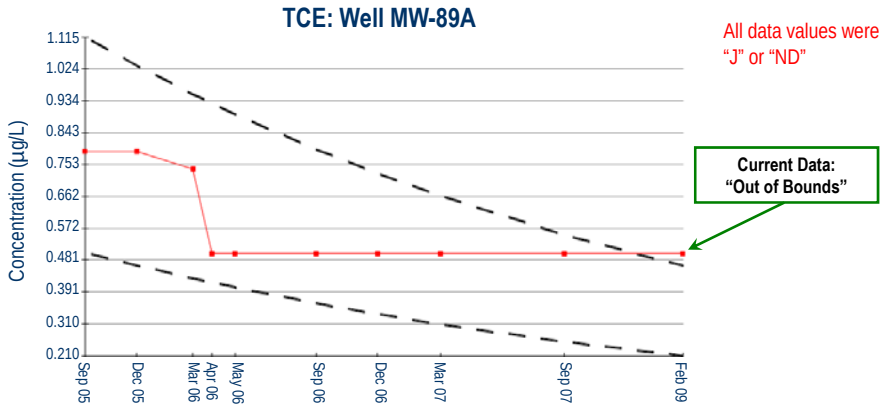
Suspect Data:
In this case, results for MW-15A and MW-15B were switched in database

Data Tracker Examples (cont.)



Of Concern:
In this case, "out-of-bounds" value in the current data suggest increasing concentrations above the MCL of 5 µg/L)

Data Tracker Examples (cont.)

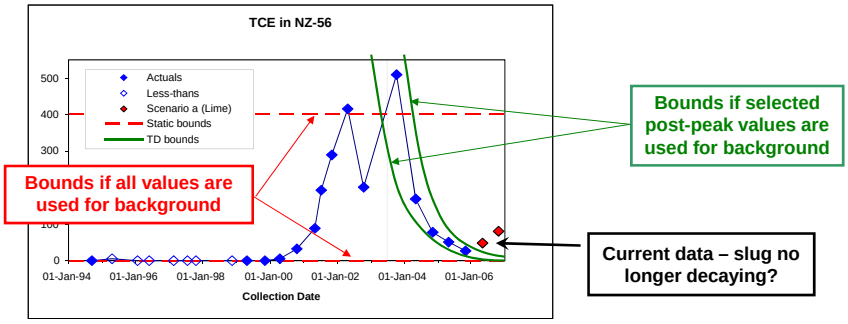


All data values were "J" or "ND"

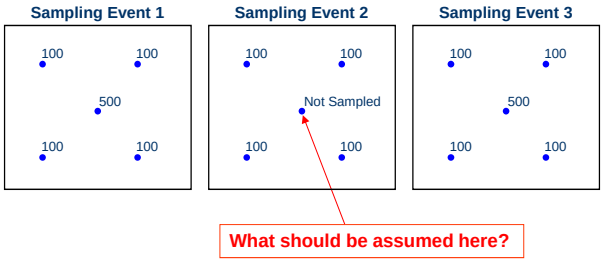
Not of Concern:
In this case, "out-of-bounds" value in current data is ND (all values are low)

Data Tracker Results

- Easy to use
- Most of the artificial anomalies placed into the data for testing were successfully detected as "out-of-bounds"
- Selecting the background data is not always straightforward
  - Determining when and how to update background data also a challenge



Mass Over Time Can Also Be Tracked… But There is an Issue



- If locations are not consistent from event to event, mass calculations are impacted
- Scenarios where this comes into play
  - Wells not sampled in some events
  - New wells added over time
  - Wells abandoned over time

- MAROS has this same issue
- GTS does not track mass over time

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Estimated Level of Effort and Costs for Using Summit Software

- Time requirements (labor and computation)

Task	Time*
Data Cleanup, Screening, and Formatting	Several days (labor)
Model Builder	Minutes**
Spatial Optimization	Minutes to Hours**
Spatiotemporal Optimization	Hours to Days**
Data Tracker	Minutes to hours (data prep and interpretation)

** for tasks where computation time is indicated, additional time is required for interpretation of result*
*** computation time per problem (e.g., per aquifer)*

Approximate Costs – Detail

Cost Element	Estimated Level of Effort	Estimated Cost
Start-Up		
Software Cost	Free	$ 0
Software Download	1 hr @ $100/hr	$ 100
Training/Learning	16 hrs @ $100/hr	$1,600
	Subtotal	**--------->$1,700**
Redundancy Evaluation (Periodic)		
Per Site:		
Formulation	Lump sum	$5,000
Data Prep	24 hrs @ $100/hr	$2,400
Import Data Into Software	2 hrs @ $100/hr	$ 200
	subtotal	**--------->$7,600**
Per Plume Evaluated:		
Model Builder	2 hrs @ $100/hr	$ 200
Optimization	24 hrs @ $100/hr	$2,400
Interpret Results and Write Up	20 hrs @ $100/hr	$2,000
	subtotal	**--------->$4,600 (per plume)**
Data Tracker		
First Time:		
Develop Initial Background Data File	(Part of Data Prep listed above)	$ 0
Each Year:		
Evaluate Need to Update Background	16 hrs @ $100/hr	$1,600
	subtotal	**--------->$1,600 (per year)**
Each Event:		
Create CSV File for New Data	2 hrs @ $100/hr	$ 200
Import Data and Run DT	1 hrs @ $100/hr	$ 100
Export Charts, Print Charts, Interpret	5 hrs @ $100/hr	$ 500
	Subtotal	**--------->$800 (per event)**

Approximate Costs – Summary

Cost Element	Frequency	Estimated Cost
Start-Up	**Once**	**$1,700**
Redundancy Evaluation	**Every 3-5 years**	
Per Site:		**$7,600**
Per Plume Evaluated		**$4,600**
Data Tracker		
Evaluate Need to Update Background	**Annual (typically)**	**$1,600**
Run DT with New Monitoring Data	**Each Event**	**$800**

Key Benefits of the Summit Software

- Uses mathematical optimization to search solution space
- Enables users to evaluate tradeoff of sampling cost versus error
  - Can simultaneously consider multiple COCs
- Provides visualizations of the plume for the baseline plan (with all samples) versus improved plans with reduced number of samples
- Data tracking capabilities semi-automatically identify unexpected values in recently collected data

GTS appears to offer these same benefits and some added features, but is not yet available and testing is still ongoing

Regulatory Issues

- Interaction with regulators was not a specific part of the ESTCP project
  - Site personnel for the demonstration sites indicated that tradeoff curves and associated plume visualizations (with and without redundant data) would be expected to be convincing
- Obtaining regulatory acceptance of the software will require two major steps
  - Increasing awareness of LTMO in general, and awareness of this type of software in particular, within the regulatory community
  - Making site-specific requests to regulators for modifying an LTM program based on results of the software (not yet done for the demonstration sites)
- ITRC was briefed on project and results and reacted favorably

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Input Formats

- Input formats for software

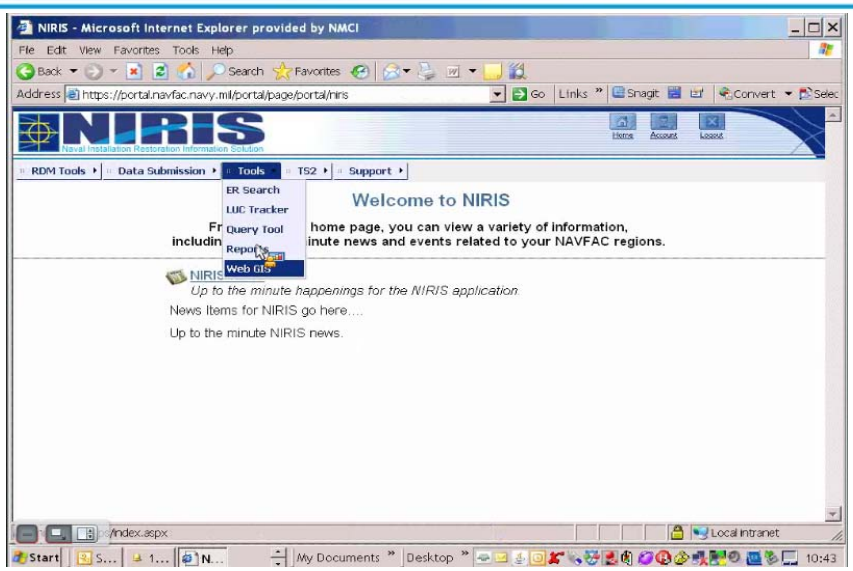
Summit:	Comma-delimited text files
GTS:	Tab-delimited text files
MAROS:	EXCEL or ACCESS files

- Each software has specific needs; for example
  - GTS wants CAS numbers for analytes
  - MAROS insists on analyte names matching its glossary
  - Allowable data flags differ (e.g., “U”, “ND”, etc.)
  - Summit does not allow data flags, duplicates, re-analyses

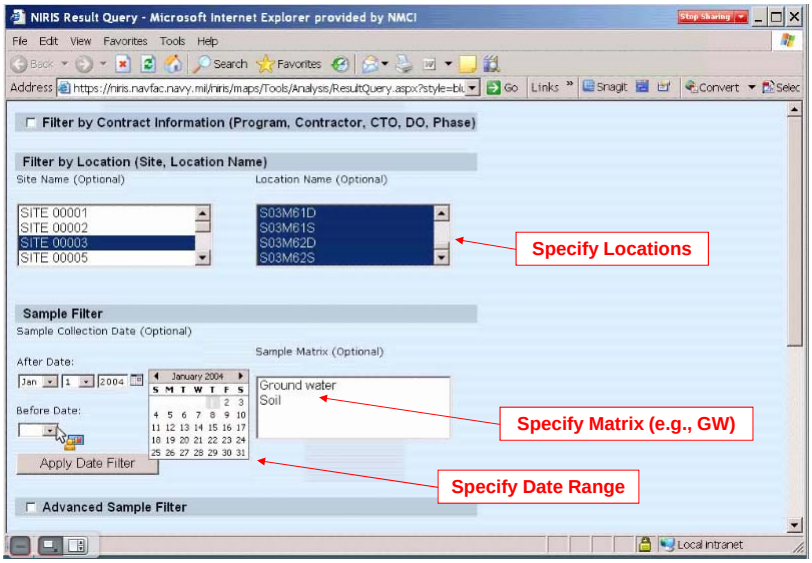
Extracting Data from NIRIS

- NIRIS has map and database components
- Data can be queried many ways
  - Date ranges
  - Individual compounds
  - Groups of compounds (e.g., VOCs)
  - By site (e.g., NSA Mechanicsburg Site 3)
  - By well
- Some re-formatting and cleanup still required
  - Navy may work on a more automated "bridge" to the LTMO software

Extracting Data from NIRIS (cont.)



Extracting Data from NIRIS (cont.)



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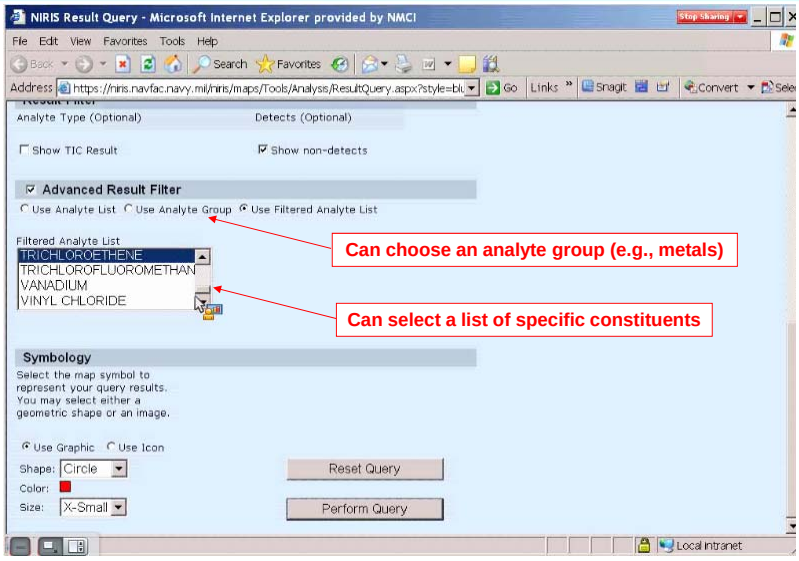

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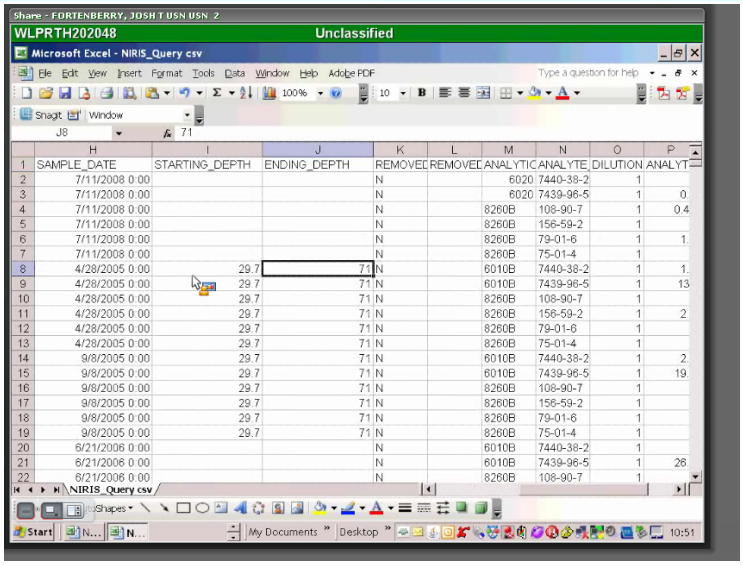
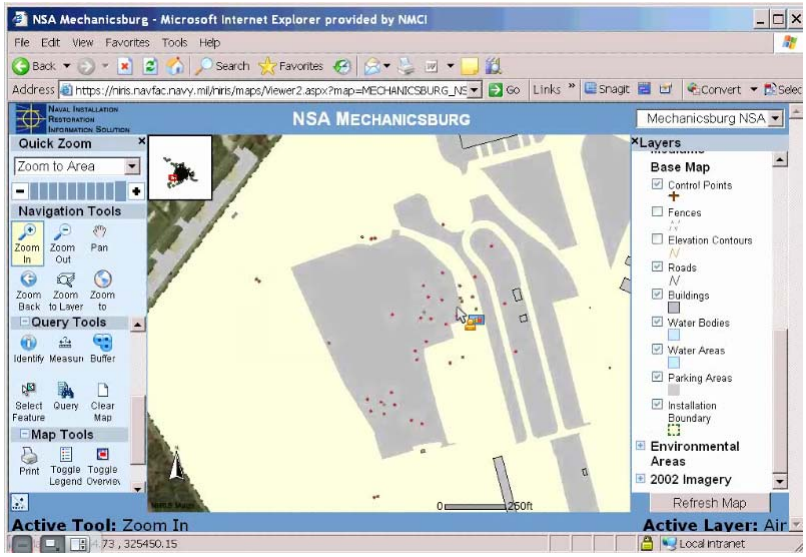


	H	I	J	K	L	M	N	O	P
1	SAMPLE_DATE	STARTING_DEPTH	ENDING_DEPTH	REMOVED	REMOVED	ANALYTIC	ANALYTE	DILUTION	ANALYT
2	7/11/2008 0:00			N		6020	7440-38-2	1	
3	7/11/2008 0:00			N		6020	7439-96-5	1	0
4	7/11/2008 0:00			N		8260B	108-90-7	1	0.4
5	7/11/2008 0:00			N		8260B	156-59-2	1	
6	7/11/2008 0:00			N		8260B	79-01-6	1	1.
7	7/11/2008 0:00			N		8260B	75-01-4	1	
8	4/28/2005 0:00	29.7	71	N		6010B	7440-38-2	1	1.
9	4/28/2005 0:00	29.7	71	N		6010B	7439-96-5	1	13
10	4/28/2005 0:00	29.7	71	N		8260B	108-90-7	1	
11	4/28/2005 0:00	29.7	71	N		8260B	156-59-2	1	2
12	4/28/2005 0:00	29.7	71	N		8260B	79-01-6	1	
13	4/28/2005 0:00	29.7	71	N		8260B	75-01-4	1	
14	9/8/2005 0:00	29.7	71	N		6010B	7440-38-2	1	2
15	9/8/2005 0:00	29.7	71	N		6010B	7439-96-5	1	19
16	9/8/2005 0:00	29.7	71	N		8260B	108-90-7	1	
17	9/8/2005 0:00	29.7	71	N		8260B	156-59-2	1	
18	9/8/2005 0:00	29.7	71	N		8260B	79-01-6	1	
19	9/8/2005 0:00	29.7	71	N		8260B	75-01-4	1	
20	6/21/2006 0:00			N		6010B	7440-38-2	1	
21	6/21/2006 0:00			N		6010B	7439-96-5	1	26
22	6/21/2006 0:00			N		8260B	108-90-7	1	

Data can be exported to CSV files that can be used by spreadsheets and LTMO software

Extracting Data from NIRIS (cont.)



NIRIS also has map capabilities

Extracting Data from NIRIS (cont.)

- Use CSV export option from NIRIS
  - Well Information File (name, coordinates, etc.)
  - Water Quality File (header record, then one record per analyte per well per date)
- Water Quality Results
  - The format from NIRIS is the same general format used by MAROS and GTS
  - Summit uses a different column for each analyte and requires easting and northing in the same file
    - Requires some reformatting to merge in coordinates and arrange columns
    - Date, SiteID, EastCoordinate, NorthCoordinate, Benzene, Toluene, Ethylbenzene, Xylenes (analyte names may be abbreviated arbitrarily)
  - Some effort required to remove data fields that are not needed, re-order fields, align dates, modify flags, etc.

Data Preparation Considerations for Summit Software

MAROS and GTS have routines that attempt to address these considerations

- For Spatial Optimization
  - Must assign values for non-detects
    - Can be a problem if RLs are elevated
  - Duplicate values not allowed, must be dealt with before importing data into the software
  - Must select a single value per COC per well
- For Data Tracker
  - Must assign values for non-detects
  - One file for background data, one for new (current) data
  - Background data may be subset of all historical data
    - Can decide to "manufacture" background data if not enough real samples (need at least 4)

Importance of Data Screening (GIGO)

- For any LTMO software, look at the data before importing into software
  - Consider changes at site over time (new sources, remedial actions, etc.)
  - Presence of trends (especially increasing) or slugs
  - Outliers (possible database or well ID errors)
  - Are data being mixed from different hydrogeologic units?
    - Water level data may be useful
  - Compare NIRIS data with latest Annual Monitoring Report for inconsistencies
  - For Data Tracking, may need to exclude outliers or early data from "historical data"

"Data preparation prior to import … is often the most difficult and time-consuming part of the optimization analysis" (GTS Draft Documentation)

Presentation Overview

- Overview of LTMO and Software Products
- Summit Software Overview
- Results from ESTCP Demonstration
- Costs, Benefits, and Regulatory Issues
- Input Data, Using NIRIS, and Data Screening
- Case Study: NSA Mechanicsburg – Site 3
- Summary/Take-Home Messages

Case Study: NSA Mechanicsburg – Site 3

- Used Summit Software
- Purpose was to provide additional example for RITS
  - Getting data from NIRIS
  - Confirm level of effort required to perform analysis

Review CSM and History

- Two former Burn Pits inside Ball Road Landfill
- Single saturated zone, some residual NAPL in bedrock
- Primary COCs
  - c12DCE (*cis*-1,2-Dichloroethene) (PRG = 70 µg/L)
  - TCE (Trichloroethene) (PRG = 5 µg/L)
  - CBenz (Chlorobenzene) (PRG = 100 µg/L)
- Monitoring report also discusses VC, Mn, and As
- High values are very localized in Burn Pit areas
- Injection treatment (March to October, 2004)

Data Acquisition from NIRIS

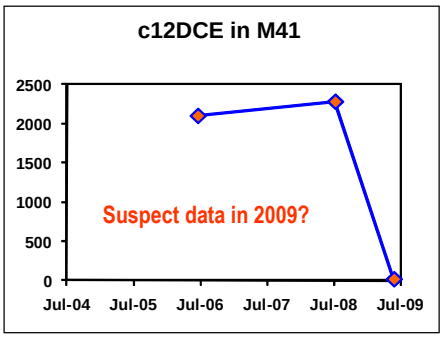
- One CSV file with well coordinates
- One CSV file with water quality data
- Some effort to merge those files and re-format for software input
- Used data obtained with "Site 3" data query
  - Includes a few wells from adjacent sites
  - Does not include some wells/springs mentioned in Site 3 monitoring report
  - Noticed that the list of "Site 3" wells from NIRIS is somewhat inconsistent for "coordinates" versus "water quality" files

Problem Formulation (Spatial Redundancy)

- Evaluate three primary COCs simultaneously
- Future remedy is passive remediation and/or MNA
  - Focus on boundary concentrations
  - Use "Cutoff Error Calculator" in software to de-emphasize high concentration areas
  - Always include 2 downgradient wells that pertain to an adjacent site
    - Likely to be monitored for that site anyway
- Need to select one representative value per COC per well
  - Used latest 2006 to 2009 value at each well (all post-chemox)
  - Omitted well if no 2006-2009 data available

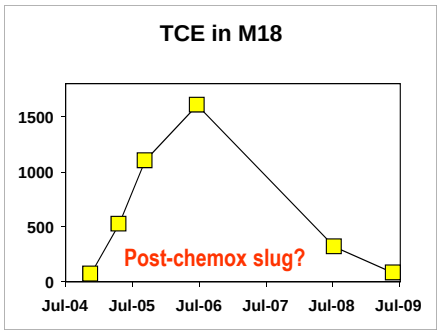
Data Screening

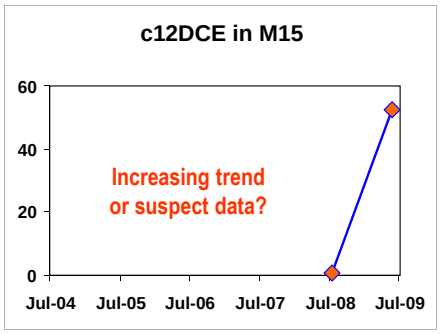
- Looked at all Time Series Plots (Microsoft Excel)
- Identified a few potential items of interest, such as…



Data Screening (cont.)

Examples of potential items of interest from data screening





Input to Software for Spatial Optimization

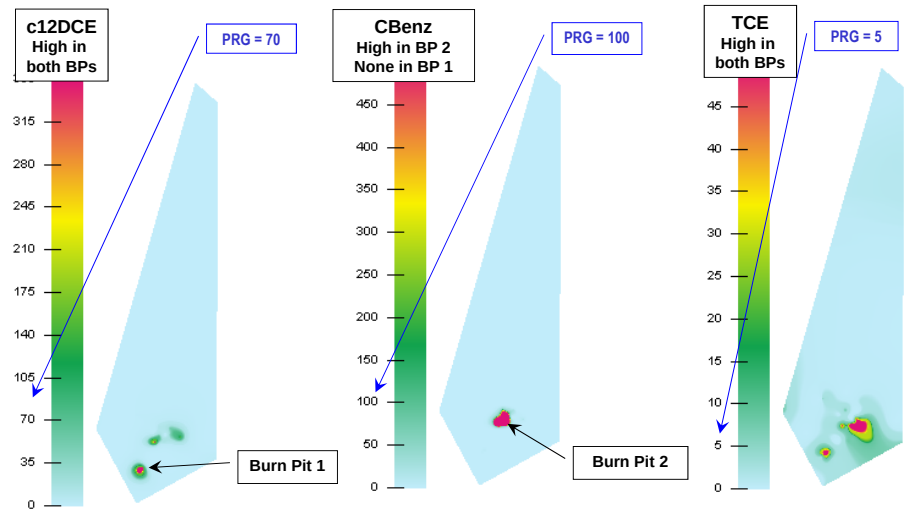
- **First few rows…**

Date	SiteID	EastCoordinate	NorthCoordinate	c12DCE	CBenz	TCE
6/15/2009	BF-3	2180004	328510	0.05	0.42	1.1
6/15/2009	DD02	2179842	329632	0.05	0.05	0.36
6/15/2009	DD2D	2180118	329388	0.05	0.05	0.38
6/15/2009	S03M01	2178651	325488	1.7	0.05	8.8
6/15/2009	S03M02	2179135	325654	1	0.05	4.7
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.

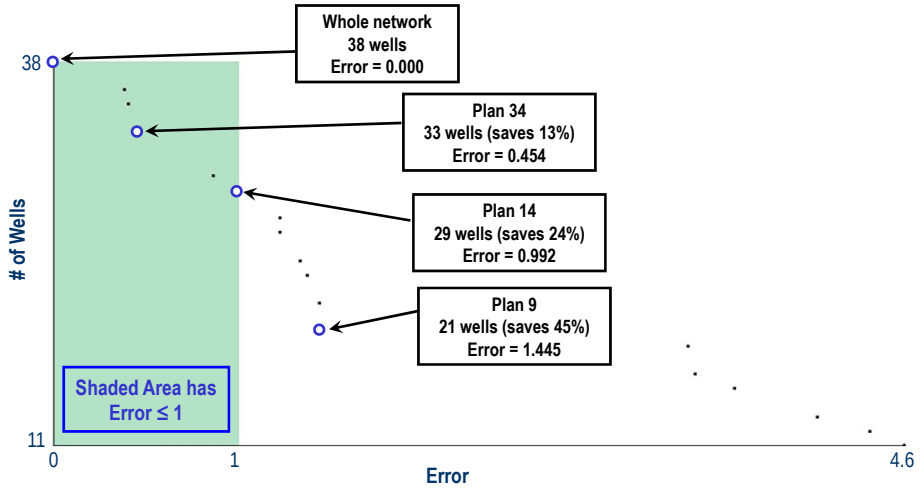
Spatial Optimization Results

- **Sample Optimizer**
  - **Used default and recommended options**
    - Quantile Kriging
    - Cutoff Error Calculator
      - –PRG is allowable error near plume boundary
      - –Cutoff between plume boundary and interior is PRG x 5
      - –20% interpolation error allowed in plume interior
      - –Use *max error for any COC* to make tradeoff curve
- **Model Builder**
  - **Plume maps consistent with those in site monitoring report**

Model Builder Results (all 38 locations)

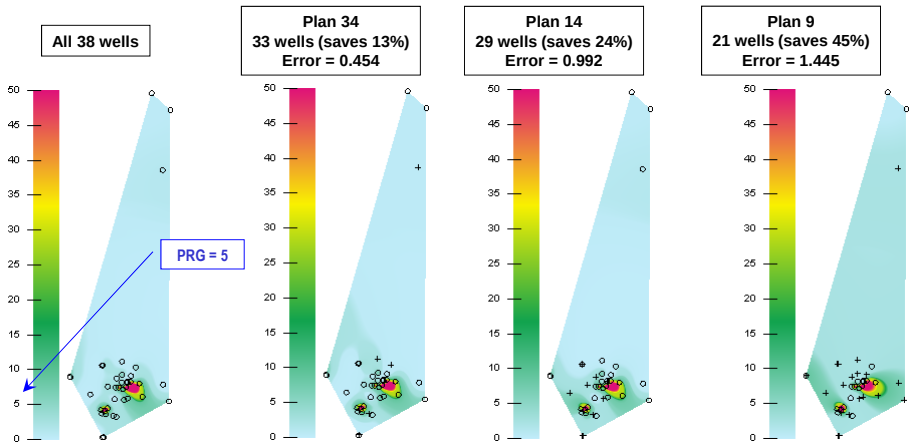


Spatial Optimization Tradeoff Curve

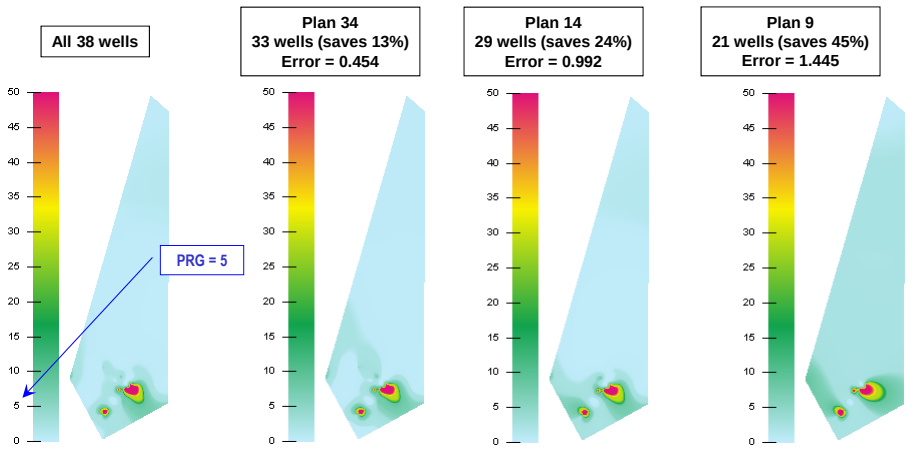


Comparing Plume Maps for TCE (with Well Locations)

- "+" indicates eliminated sampling locations

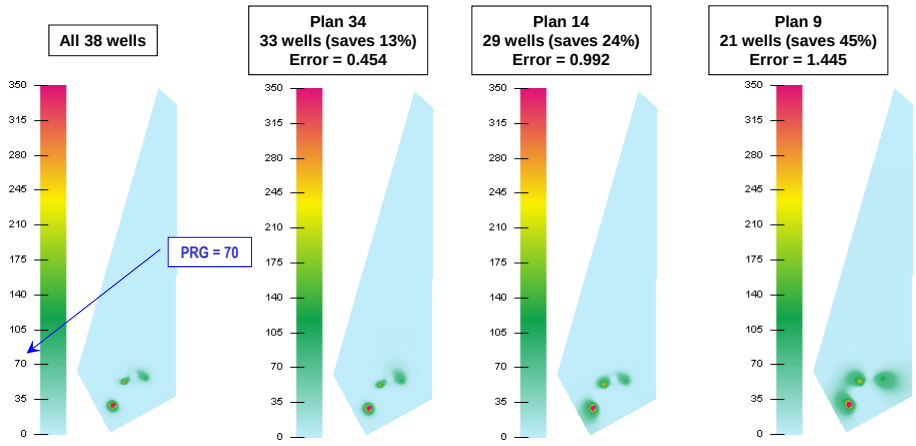


Comparing Plume Maps for TCE (w/o Well Locations)



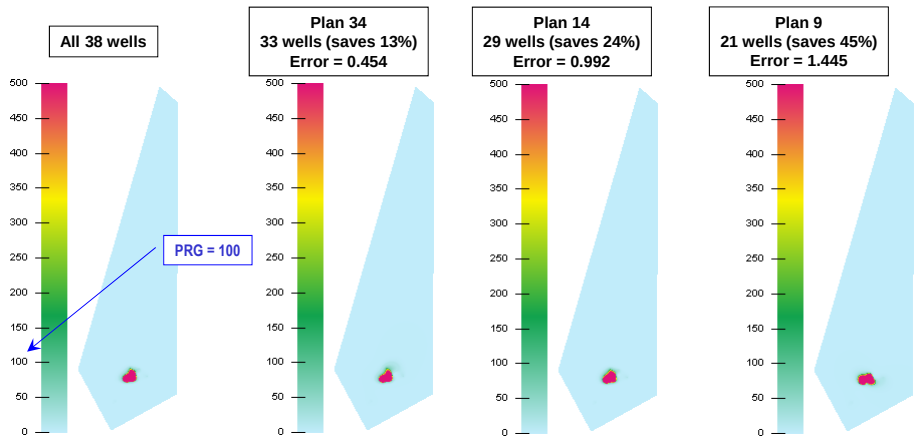
Comparing Plume Maps for c12DCE

- More serious differences with Plan 9 for c12DCE

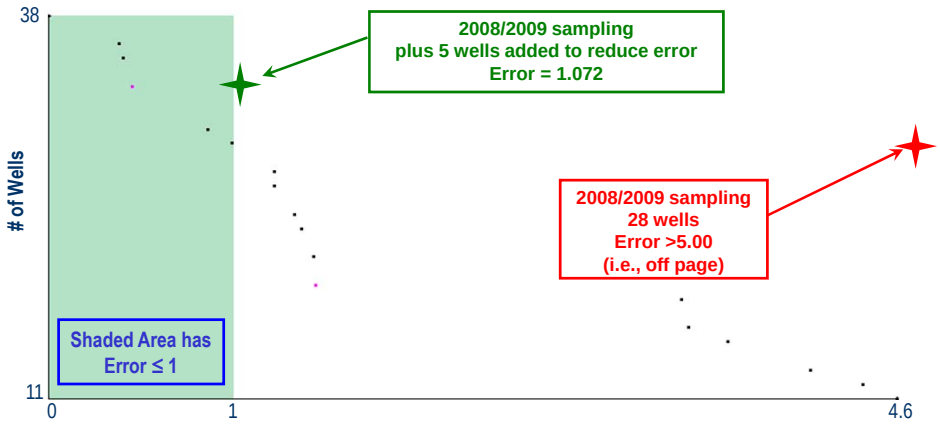


Comparing Plume Maps for CBenz

- Differences almost not noticeable for CBenz



Where Does 2008/2009 Sampling Fit on Tradeoff Curve?

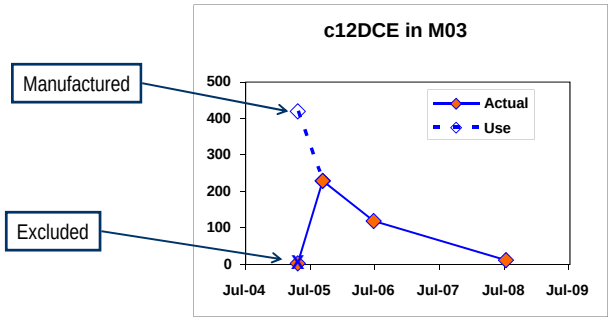


Data Tracker

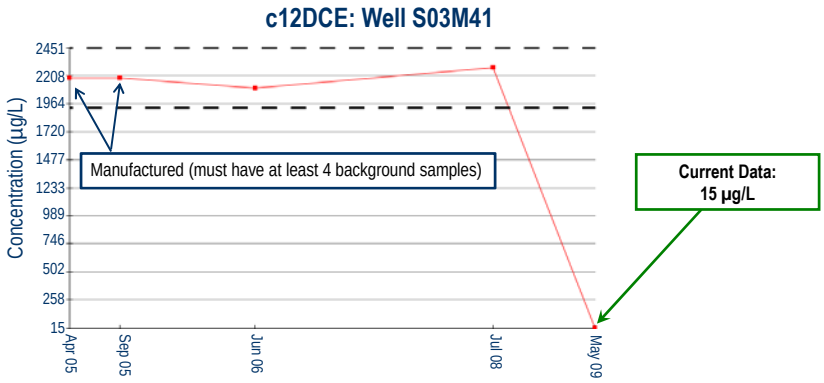
- 2009 data ("current data") for only 21 wells
  - Of those, only six have at least 4 background values
  - Twelve have only 1 background value
- Software requires at least 4 background values
  - Suggests need to "manufacture" background data at some wells to use tracking function in software

Data Preparation for Data Tracker

- Look at data histories first, using Microsoft Excel plots, to determine if some background data should be excluded and/or manufactured <u>for tracking purposes only</u>

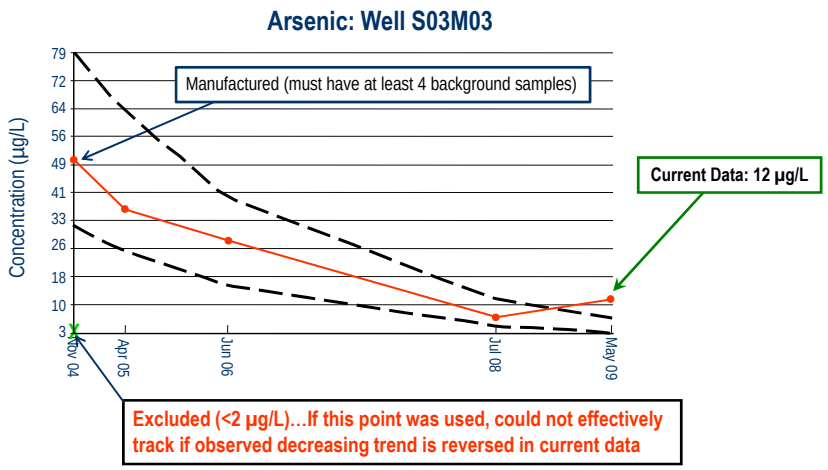


Example of Data Tracker Results



Data Tracker flags the low value in current data as "out of bounds", it is up to the analyst to determine the cause…

Example of Data Tracker Results (cont.)



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Summary – Summit Software

- Easy to learn and use for a typical DoD analyst or contractor
- Kriging with Quantile Transformation is best "model"
- Tradeoff curves coupled with plume visualizations are powerful and useful
- Spatiotemporal redundancy analysis provides more conservative results, not recommended
- Data Tracker quickly identifies many situations in which current data deviate significantly from historical values and patterns
- The software is available at no cost for government projects
- The software was extensively tested as part of an ESTCP project

Summary – Other Software

- MAROS is also easy to use
  - Free software
  - Adds features such as trend analysis, COC assessment, data consolidation
  - Does not do mathematical optimization or tradeoff curves
  - Does not make maps within the software
- GTS appears to be very comprehensive
  - Will be free software
  - Includes mathematical optimization, tradeoff curves, maps, trend analysis, COC assessment, data consolidation, etc.
  - Appears to include many enhancements (may be more complicated)
  - Testing not yet completed, expected to be available late 2009 or early 2010

Take-Home Messages

- Software is available for Long Term Monitoring Optimization (LTMO)
- Relatively easy to learn and apply
- Data from NIRIS can be readily adapted for import into these software products
- There are a lot of options and technical nuance – not simply "push a button"
  - Case studies help to explore and explain those options/nuances
- Tradeoff curve, coupled with plume maps that compare baseline plan versus optimized plan, is an effective way to illustrate redundancy

Other References

- Navy Monitoring Optimization Documents
- Introduction to Genetic Algorithms
- Roadmap to Long-Term Monitoring Optimization (EPA 542-R-05-003, May 2005)
  - co-published by EPA and USACE