Purpose of presentation

Introduce concept of long-term monitoring optimization (LTMO) approaches, benefits, & pitfalls

Provide case study example

Provide technical resources information

Discuss regulatory role

Consolidated from 1 day course

Housekeeping

- Please mute your phone lines
  - press *6 to mute #6 to unmute your lines at anytime
- Do NOT put this call on hold
- Questions can be submitted throughout the presentation using the ? icon on the top of the screen. Oral questions will be taken during the 2 question and answer sessions.
- Also use the ? Icon to report technical problems
- You can move forward/backward in the slides by using the arrow buttons

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LTMO

Meet the Presenters

- Kathy Yager, Environmental Engineer
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- Mindy Vanderford, Ph.D.
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LTMO

Seminar Topics

- Definition and description of Long-Term Monitoring Optimization (LTMO)
- EPA's and USACE's roles in LTMO training
- Appropriate timing for LTMO
- Data needs and available methods
- Regulatory and technical reviews
- Case study example (Frontier Hard Chrome)
- Major obstacles to LTMO
- Links to additional resources

LTMO

Motivation for LTMO

- Long-term monitoring is a growing, persistent, and costly obligation for government agencies and private parties
  - Feds spend over $100 million each year on monitoring - typically $10Ks - $100Ks/site
  - Private parties likely spend more

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Motivation for LTMO, cont.

- Many LTM networks not evaluated carefully since remedy implemented
- Conditions evolve over time (for better or worse)
- Periodic evaluations necessary and beneficial

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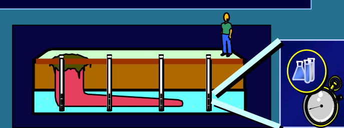
LTMO

Long-Term Monitoring Optimization - Defined

A *formal* review of the monitoring network using qualitative and quantitative tools, considering site management goals, in order to achieve an "environmentally, economically and fiscally sound, integrated, continuously improving, efficient and sustainable"* monitoring program.



* Federal Register
Executive Order 13423

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LTMO

LTMO Overview

- Confirms monitoring program matches monitoring needs
- Includes evaluation of
  - Sampling locations, sampling frequencies
  - Sampling and analytical methods
  - Data management
- Two primary approaches
  - Qualitative
  - Quantitative

LTMO

Benefits of LTMO

Amazing Claims!

LTMO analysis can identify:

- Reduction in effort:
  - Spatially (number of wells)
  - Temporally (sampling frequency)
- Need for more wells – to reduce spatial uncertainty
- Potential changes to sampling & analytical methods
- Areas where the plume is moving or changing

LTMO

Benefits of LTMO

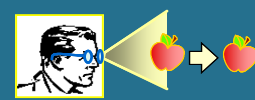
Spectacular Results!

LTMO analysis can:

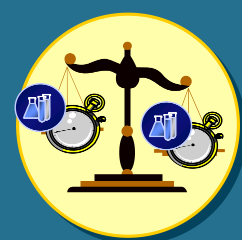
- Clarify monitoring objectives by facilitating discussion among stakeholders
- Provide important data to support remedy evaluation
- Provide a monitoring program that:
  - Is better focused on supporting decisions
  - Reduces data gaps
  - Is less costly, conserves resources (labor, fuel, supplies)

Evaluation Strategies

- *Qualitative evaluations* based on professional judgment, intimate knowledge of site, decision rules, heuristic



- *Quantitative evaluations* based on statistical, mathematical, modeling or empirical evidence



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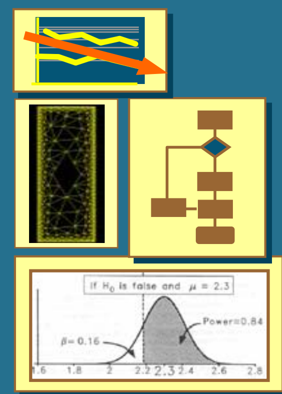
LTMO

LTMO Methods

LTMO Methods

- Parsons' 3-Tiered
- Monitoring and Remediation Optimization Software (MAROS)
- Geostatistical Temporal/ Spatial (GTS) optimization
- Mathematical optimization



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LTMO

Automated Data QA/QC
Summary statistics
Concentration trend analysis
Stability analysis
Statistical significance testing
Ranking methods
Interpolation/Geostatistics
Mathematical Optimization

When to Apply LTMO

Is it Time?

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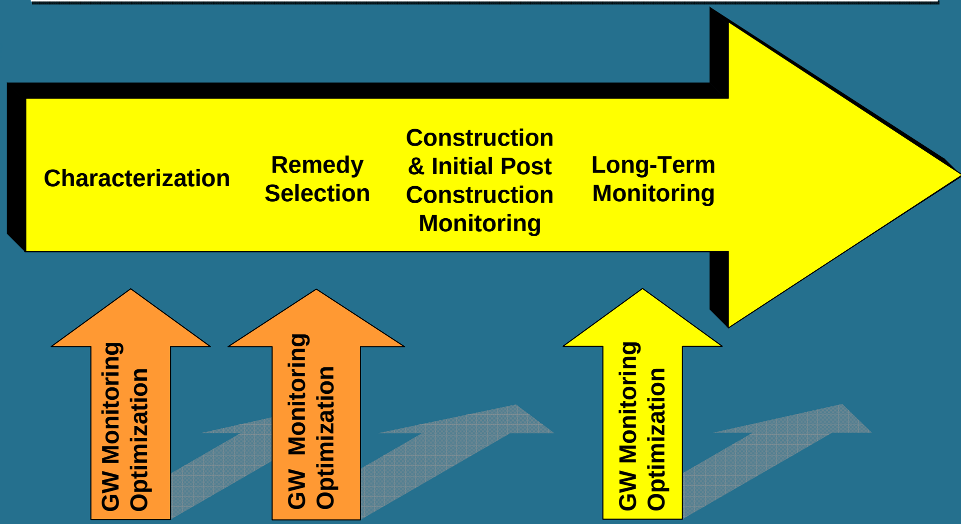
LTMO

Ground-Water Monitoring Timeline



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LTMO

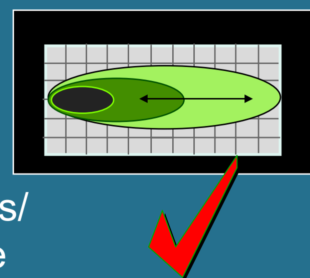
Candidates for LTMO

Is my Site a Candidate?

rules of thumb

- If Source is identified
- If Plume is delineated
  - Vertical
  - Horizontal
- If Database/Well Coordinates/ GW parameters in one place
- If monitoring objectives exist...

Easy!



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Timing of LTMO

- In preparation of upcoming 5-Year Review
- In conjunction with remedy evaluation
- Prior to property transfer

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Costs for LTMO

Cost

- Small site, stakeholder agreement, uncomplicated hydrology and constituents
  - $10,000 - $15,000
- Larger site, stakeholder reluctance, uncomplicated hydrology
  - $15,000 - $30,000
- Larger site, stakeholder skepticism, complicated hydrogeology, multiple units, legal issues
  - >$30,000

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LTMO

EPA & USACE Roles

- Training (in person, internet)
- Technology transfer (roadmap, websites, etc.)
- R&D (SERDP/ESTCP projects)
- Technical support
  - MAROS hotline (mvanderford@gsi-net.com)
  - Site-specific technical support to EPA
- For more information
  - www.cluin.org/optimization
  - www.frtr.gov/optimization

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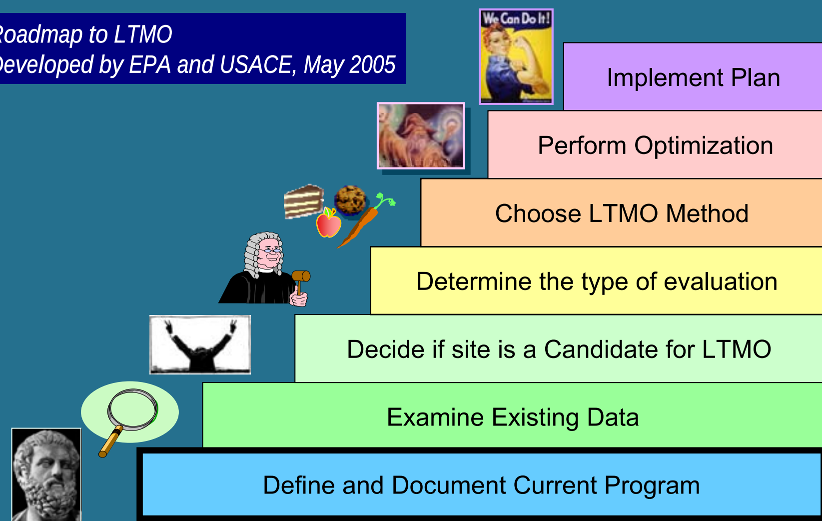
7 Steps to LTMO

Roadmap to LTMO
Developed by EPA and USACE, May 2005



Next Topic…..

LTMO Data Needs

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Long-Term Monitoring Optimization Data Needs

Mindy Vanderford, Ph.D.
GSI Environmental, Inc.

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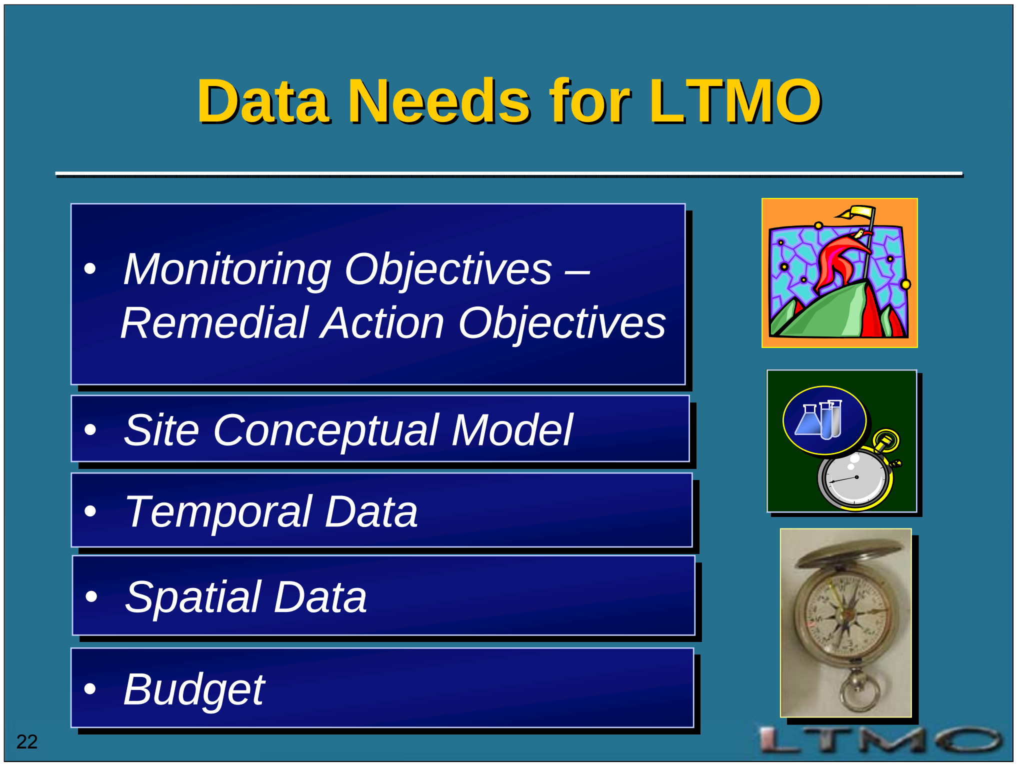
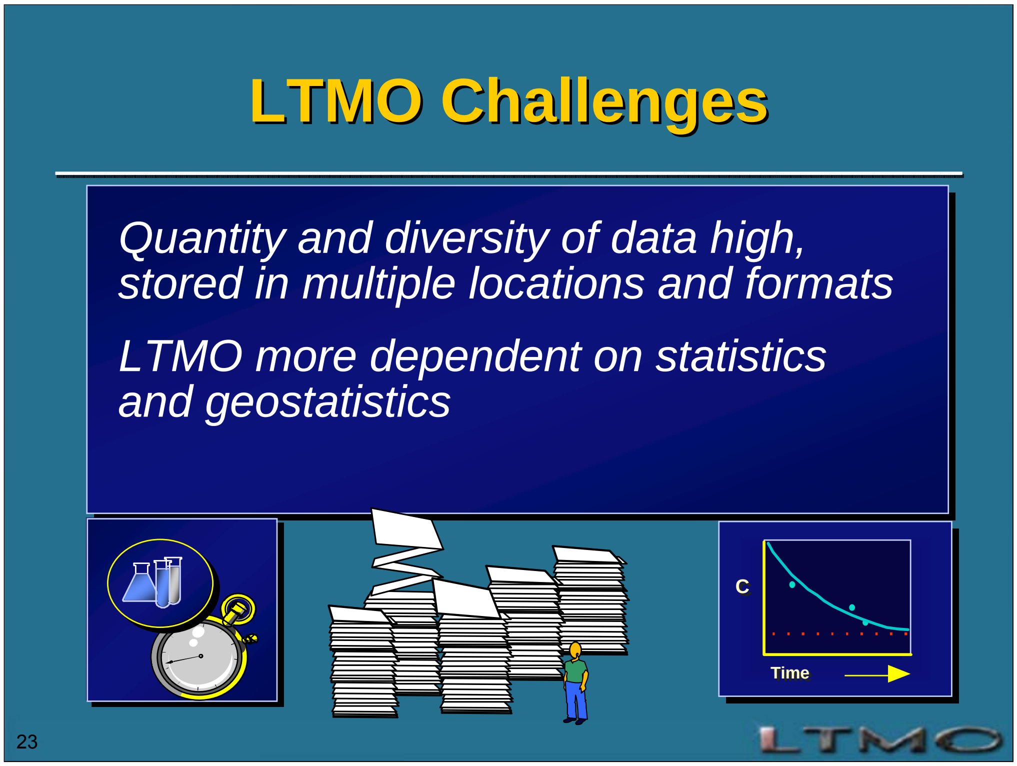
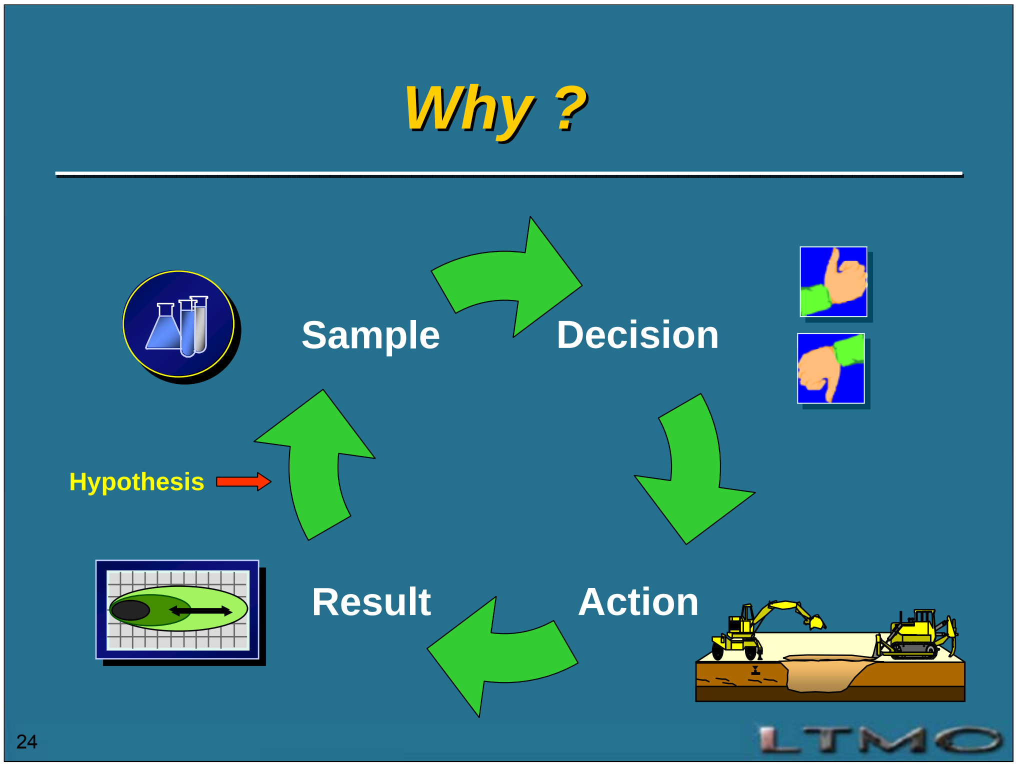


LTMO – Long-term monitoring optimization. In our work we have found five basic areas of data you need to collect in order to support an effective LTMO. I will summarize each of these categories.



LTMO is more dependent on time-series and spatial analysis rather than single point data. The main challenges are diversity of data, storage and management of historic data, diverse sources and formats and lack of comparability across data sets.



Why do we take samples? Generally it follows the scientific method. Sampling is fueled by our uncertainty about the site and the need to make regulatory decisions. As uncertainty decreases and the rate of decision making is reduced, we should reduce the sampling frequency or extent.

Monitoring Objectives

Monitoring Conceptual Model

What do you need to know?
What do you want to know?
When do you need to know it?
What are you trying to prove?

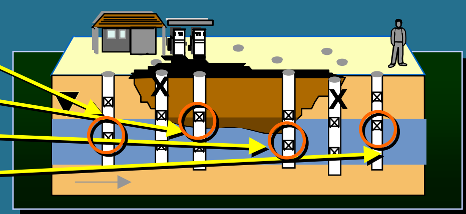
(Monitoring objectives-- write them down)

LTMO

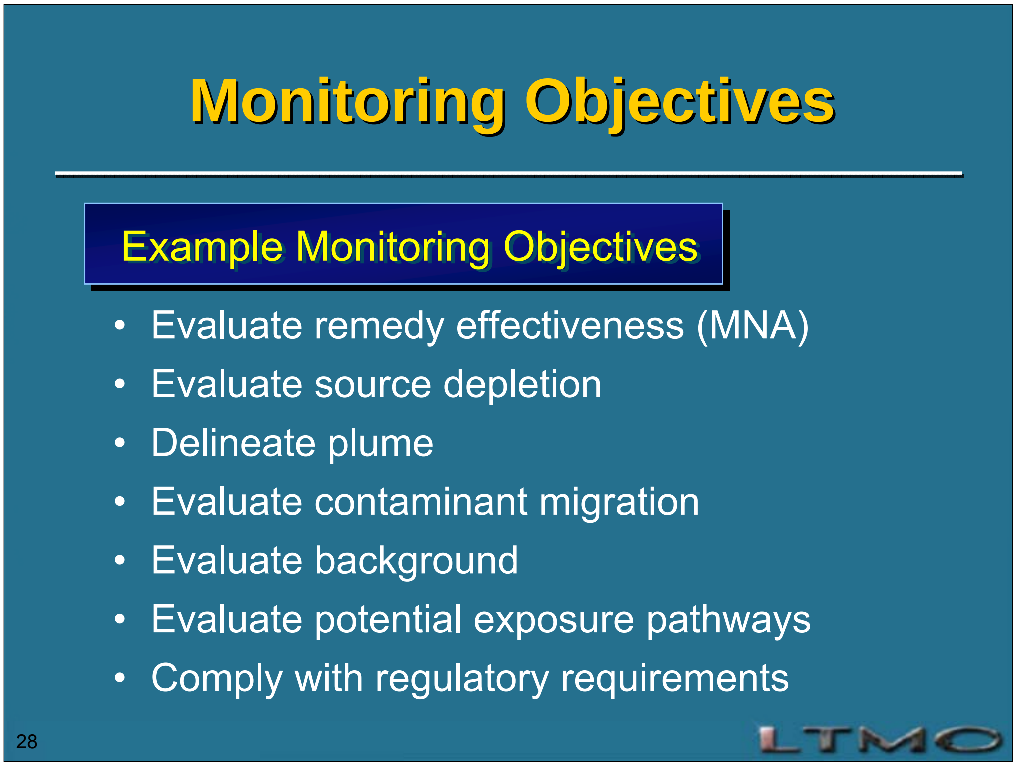
Monitoring to support site management is both a scientific and a social process. An essential part of the process is communicating the results of sampling and interpreting the significance of the process. LTMO is a good time to really sit back and think about where you are in the process and how you are proceeding toward the goal of closure.

Monitoring Objectives

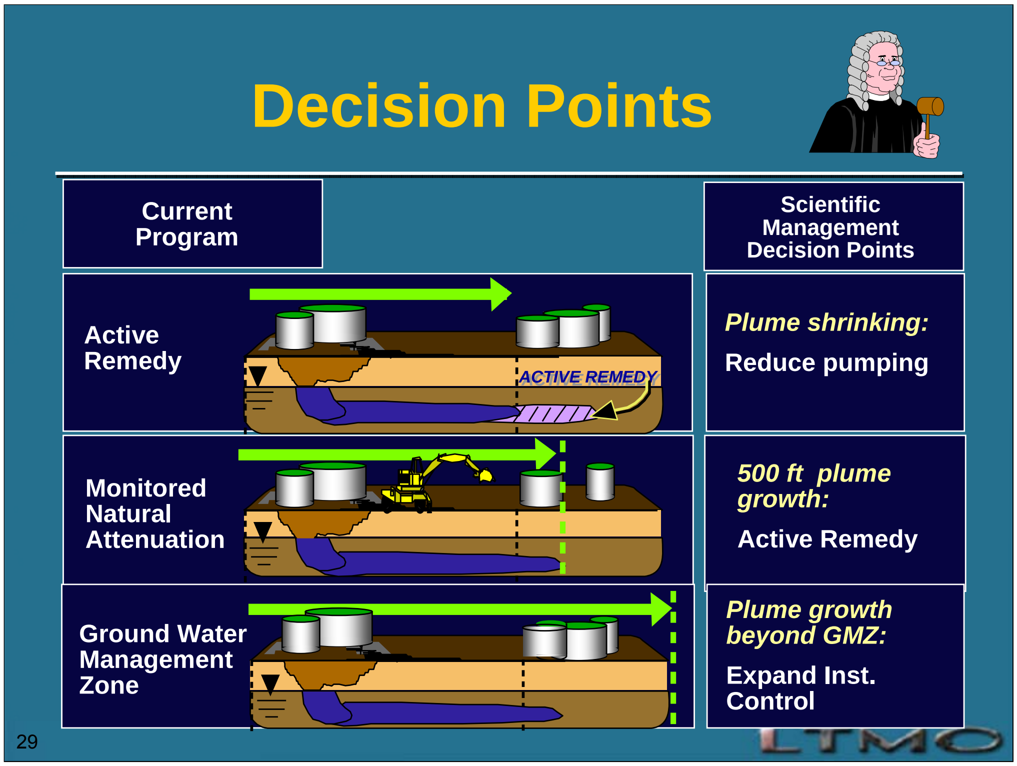
Monitoring objectives determine your sampling locations and frequency



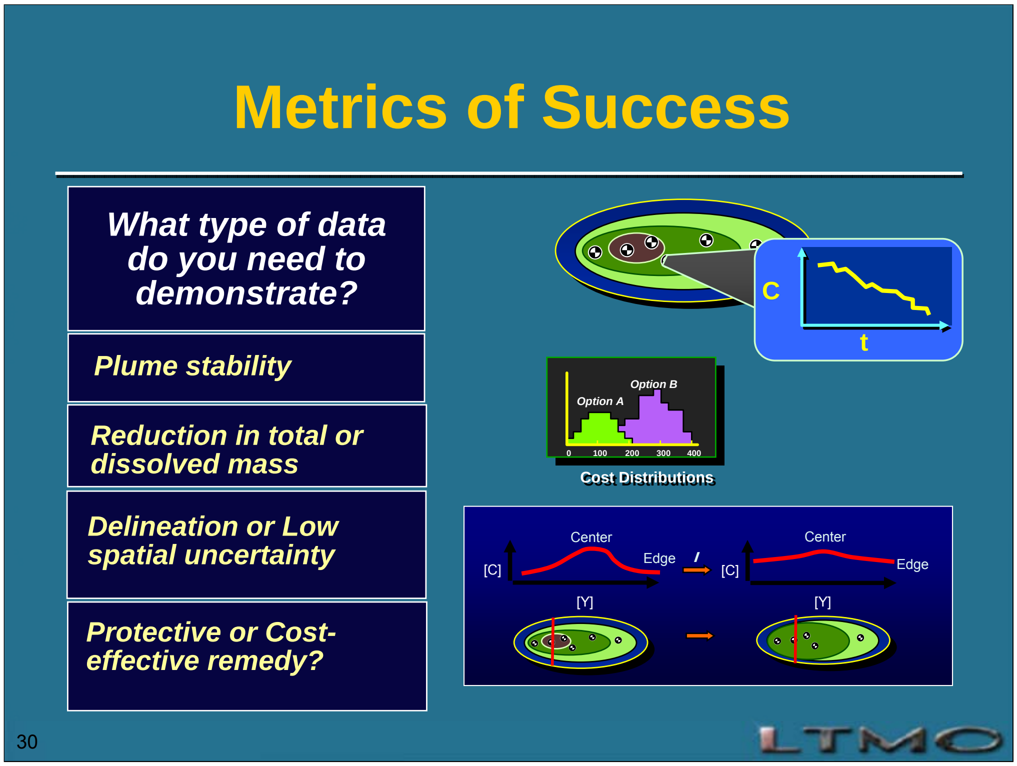
LTMO



Other meta-objectives may include Build trust between stakeholders, Collect data to support model, Support statistical analysis, Pending property redevelopment, Pending litigation?, Extreme weather events?



In addition to monitoring objectives, site documents should identify the “trigger points” for action at a site.

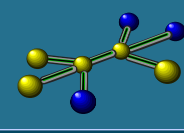


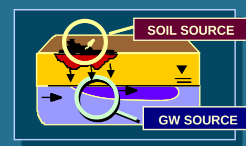
How will you know when you have achieved success? What data do you need to confirm your metrics of success. Which statistics or interpretations will be used?

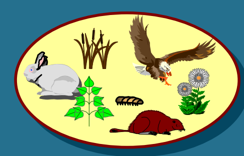
Conceptual Site Model

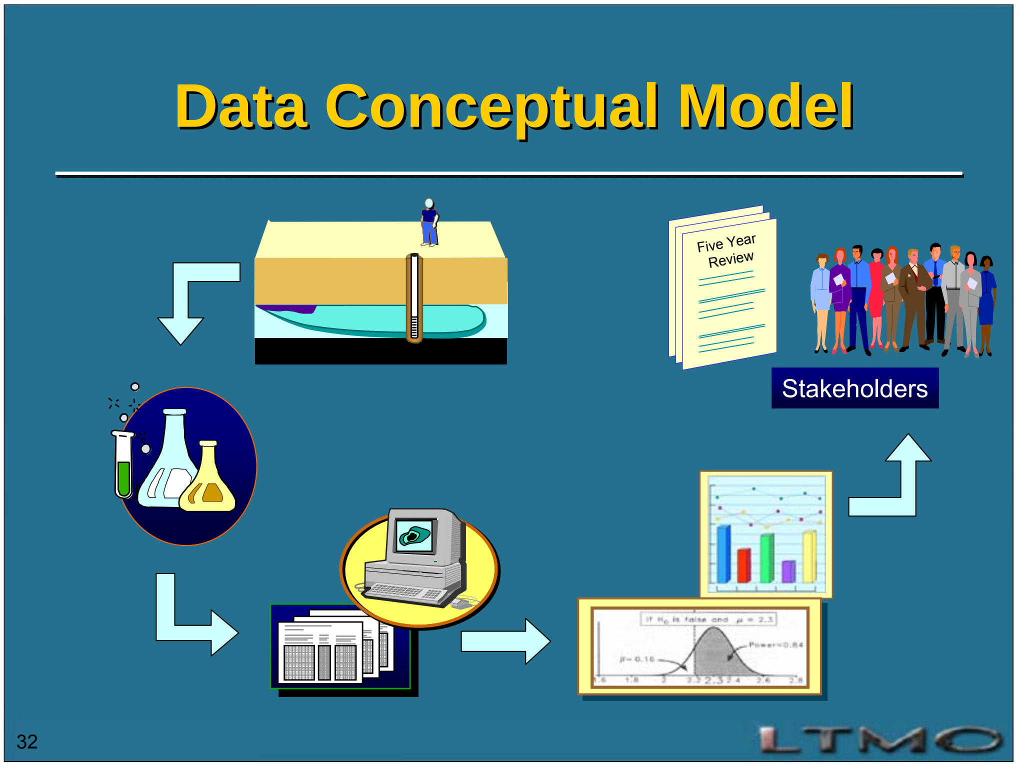
Site Characteristics

- Sources
- Tails (Delineate)
- Analytes
- Geology/Hydrology
- Potential receptors
- Regulatory framework
- Property use/community issues







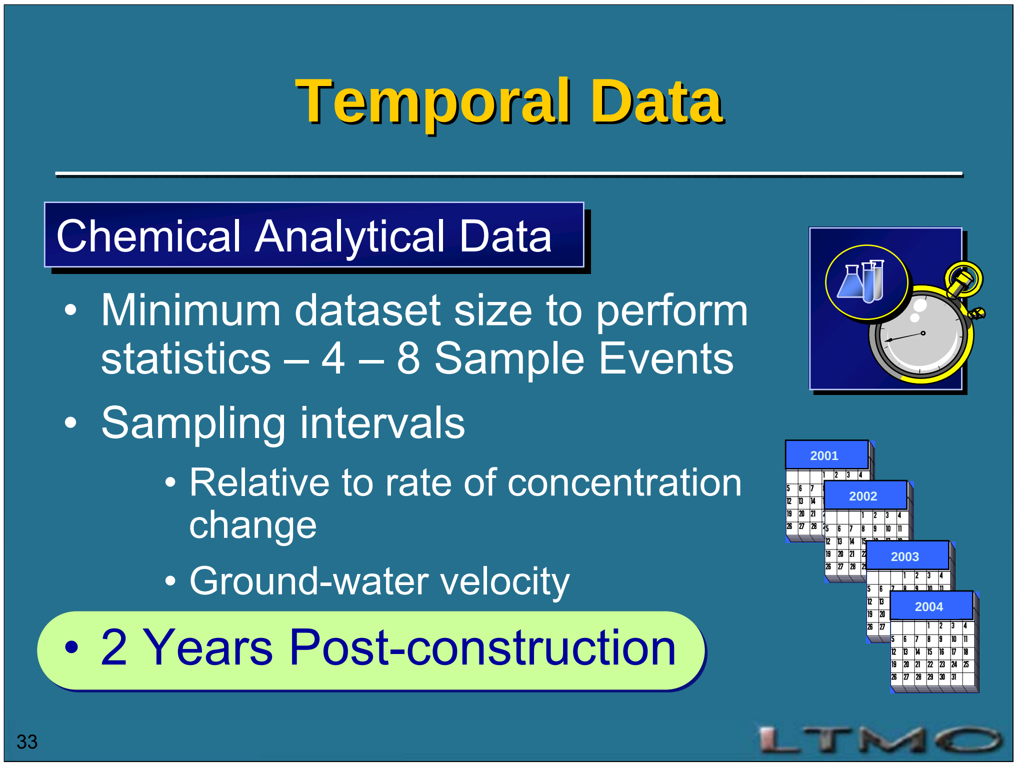


What decisions have been made?

What decisions are pending?

What decisions will be made in the future?

Does the monitoring program provide sufficient data quality and quantity to support an evaluation of the remedy?



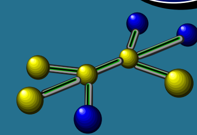
Temporal data – information with a time component. Temporal data – information with a time component. Data like concentrations at a point – along with relevant metadata.

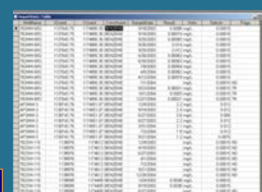
Data which are true for a limited time-frame. Limited Time-frame during which fact is true.

Analytical Database

Essential Database Features

- Consistent COC names and CAS No’s;
- Full COC list;
- Analytical results;
- Detection Limits;
- Consistent well names;
- Data flags;
- Sample dates;
- Analytical method;





Quality data is everyone’s responsibility

Data Look Like This

LocationID	Easting	Northing	Sample Matrix	Sample Date	Method	CAS Number	FinalConstituent	Final Result	Units	Qualifier	MDL	Sampl
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	79-34-5	1,1,2,2-Tetrachloroethane		mg/L	U	0.00031	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	79-00-5	1,1,2-Trichloroethane		mg/L	U	0.00036	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	75-34-3	1,1-Dichloroethane	0.00245	mg/L		0.00021	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	75-35-4	1,1-Dichloroethene	0.106	mg/L		0.00024	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	563-58-6	1,1-Dichloropropene		mg/L	U	0.00022	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	87-61-6	1,2,3-Trichlorobenzene		mg/L	U	0.00035	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	96-18-4	1,2,3-Trichloropropane		mg/L	U	0.00067	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	120-82-1	1,2,4-Trichlorobenzene	0.00054	mg/L	J	0.00026	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	95-63-6	1,2,4-Trimethylbenzene		mg/L	U	0.00026	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	96-12-8	1,2-Dibromo-3-chloropropane		mg/L	U	0.00088	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	106-93-4	1,2-Dibromoethane		mg/L	U	0.00024	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	95-50-1	1,2-Dichlorobenzene		mg/L	U	0.00023	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	107-06-2	1,2-Dichloroethane		mg/L	U	0.00025	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	78-87-5	1,2-Dichloropropane		mg/L	U	0.00022	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	108-67-8	1,3,5-Trimethylbenzene		mg/L	U	0.00023	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	541-73-1	1,3-Dichlorobenzene		mg/L	U	0.00024	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	142-28-9	1,3-Dichloropropane		mg/L	U	0.00022	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	106-46-7	1,4-Dichlorobenzene		mg/L	U	0.00019	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	594-20-7	2,2-Dichloropropane		mg/L	U	0.00029	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	110-75-8	2-Chloroethylvinyl ether		mg/L	U	0.00036	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	591-78-6	2-Hexanone		mg/L	U	0.00034	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	108-10-1	4-Methyl-2-pentanone (MIBK)		mg/L	U	0.0006	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	67-64-1	Acetone		mg/L	U	0.00085	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	107-13-1	Acrylonitrile		mg/L	U	0.00157	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	71-43-2	Benzene		mg/L	U	0.00024	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	108-86-1	Bromobenzene		mg/L	U	0.00025	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	74-97-5	Chlorobromomethane		mg/L	U	0.00016	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	75-27-4	Bromodichloromethane		mg/L	U	0.0002	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	75-25-2	Bromoform		mg/L	U	0.00033	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	74-83-9	Bromomethane		mg/L	U	0.00021	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	75-15-0	Carbon Disulfide		mg/L	U	0.00025	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	56-23-5	Carbon Tetrachloride		mg/L	U	0.00027	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	108-90-7	Chlorobenzene		mg/L	U	0.00025	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	75-00-3	Chloroethane (ethyl chloride)		mg/L	U	0.00026	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	67-66-3	Chloroform		mg/L	U	0.00019	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	74-87-3	Chloromethane		mg/L	U	0.00024	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	156-59-2	cis-1,2-Dichloroethene	0.00152	mg/L		0.00024	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	10061-01-5	cis-1,3-Dichloropropene		mg/L	U	0.00019	May 20C
MW-B	3127371.9438	13905083.2131	GW	5/2/2006	SW-846 8260B	98-82-8	Isopropylbenzene		mg/L	U	0.00024	May 20C

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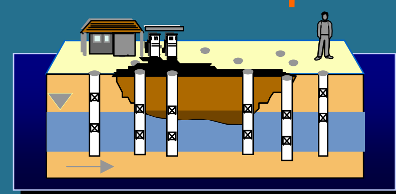
Database format is distinguished from cross-tab format. It is not pretty from a human eye perspective, but easier to manipulate in machine language.

Spatial Database

Spatial Database

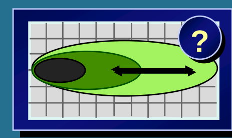
- Location coordinates
- Well construction/location details
- Well function (monitoring, extraction)
- Construction date
- Screened intervals
- Aquifer or unit
- Elevation



Spatial Data

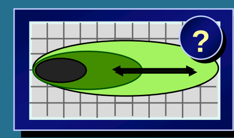
Spatial Data

- Geographic coordinates
  - Sampling locations
  - Receptors
  - Property boundaries
- Shape or dxf files – major features in GIS files
- Source areas or areas of peak concentrations



Spatial Data

Spatial Data



- Delineation
  - Plume contours (historic) and boundaries
- Major discontinuities or heterogeneities, surface water

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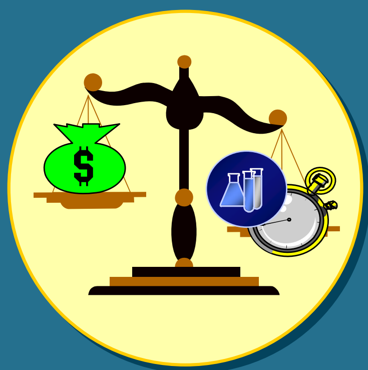
LTMO

Budget$ for LTMO

Cost of LTMO vs Savings



Cost of monitoring program:
- Lab costs
- Data management/Reporting

Benefit of LTMO:
- Reduce overall monitoring costs?
- Speed property redevelopment?
- Support for remedial process decisions?

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LTMO

How Do We Get to LTMO? Qualitative Approach

Dave Becker

US Army Corps of Engineers

Environmental and Munitions
Center of Expertise

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LTMO

Introduce myself

Considerations for Any Analysis
Data Set Comparability

– Spatial and temporal comparability
– Cleanup impacts
– Climatic/hydrologic changes: drought, pumping Changes
– Differences or changes in:
  • Sampling techniques (e.g. purge & bail vs low-flow)
  • Well construction
  • Analytical differences (e.g. method, dilution, detection limit)

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Primary Qualitative Considerations

- Temporal Analysis –Frequency based on:
  - Rate/nature of contaminant concentration change – trend and variability – as function of location in plume
- Spatial Analysis - Locations based on:
  - Proximity to other wells in same aquifer
- Other Major Considerations
  - Ground-water flow conditions
  - Monitoring objectives
  - Current and future exposure risk
  - Clean-up actions and timeframes

Qualitative Consideration of Ground Water Flow

- Question of likely flow paths – now/future
  - Wells in higher permeability paths – priority, higher frequency
  - Cross- and up-gradient wells - less frequently
  - Variable flow directions (e.g. seasonal)
  - Consider vertical migration in spatial optimization

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Qualitative Consideration of Ground Water Flow

- Transport Rates
  - Higher ground-water velocities = more frequent sampling
  - Contaminant behavior
  - Most sites: slow contaminant migration

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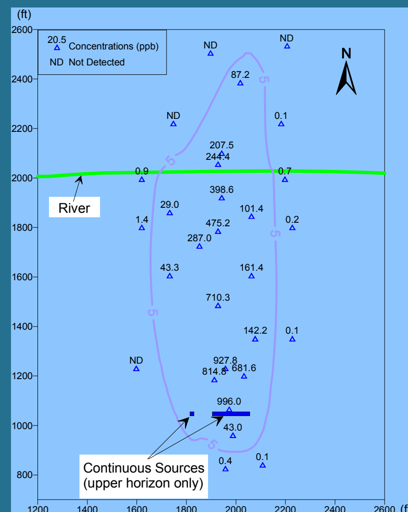
LTMO

Qualitative Consideration of Site Monitoring Objectives

- Emphasis on plume boundary monitoring = detect plume expansion, contraction
- Internal plume axis wells - assess plume stability
- Assess remedy performance



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Qualitative Consideration of Current and Future Exposure Risk

- Generally, the less risk to human, ecological health, the less intense the monitoring
- Consider future land use changes
  - Future residential use may lead to qualitative adjustments
  - Maintain sampling network density, future increases in sampling frequency
  - Example – vapor intrusion issues
- Changing land use impacts on well network

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Qualitative Consideration of Cleanup Actions & Timeframes

- Consider short-term cleanup impacts on trends
- Related to ground water flow, risk posed by site
- Generally, the more time available to start actions, the less frequent the sampling

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Other Considerations for Qualitative Analysis

- Public Concerns / Regulatory Requirements
- Temporal Analysis
  - Frequency of Data Assessment by Project Team Rate of Contaminant Migration
- Spatial Analysis
  - Compliance Point or Sentinel Well
  - Background Definition
  - Past Well Performance (Goes Dry, Poor Construction)
  - Continuity for Wells with Long Sampling History
  - Identified Data Gaps

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•There are considerations that go into recommending sampling frequency – see slide for examples. Emphasize that ground water does not move that quickly under most circumstances – unless quite near a well or a stream.

Any quantitative LTMO needs to be reviewed by someone familiar with the site. Some of the considerations are given here. These are really the same considerations for qualitative review. This may be the deciding step since the quantitative approaches are really just tools.

Qualitative Input to Quantitative Methods

- Parameters, assumptions for some aspects of quantitative methods based on professional judgment
  - Settings that affect quantitative optimization outcomes
  - Selection of time “window” for quantitative analysis
  - Examples from MAROS
    - Slope factors, rate of change temporal optimization
  - Require consensus, negotiation
  - Explore sensitivity to parameter selection

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LTMO Quantitative Methods

Mindy Vanderford, Ph.D.
Groundwater Services, Inc.

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Quantitative Evaluations

Quantitative evaluations **-** *based on statistical, mathematical, modeling or empirical evidence*

- Optimal system = minor information loss but large gain in resource savings.
- Try to remove temporal and spatial redundancy in practical, statistically defensible ways.

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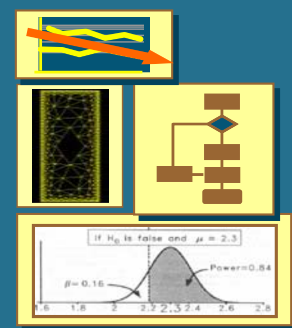
Quantitative methods are used to identify the cost – accuracy trade-off

Methods

Common Analyses

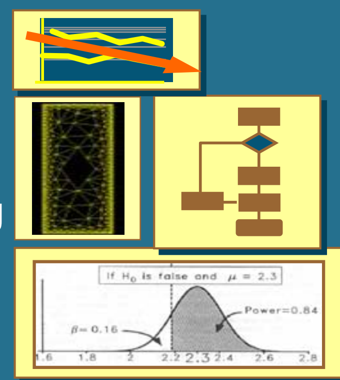
- Statistical Summary
- Trend Analysis
- Spatial – Locations
  - Remove redundant wells
  - Recommend new wells
- Temporal – Sampling frequency



Methods

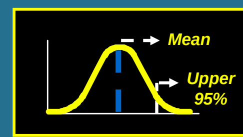
LTMO Tools

- Statistical trend analysis
  - Individual well
  - Plume-level
- Statistical significance testing
- Interpolation/geostatistics
- Mathematical optimization
- Ground-water flow models

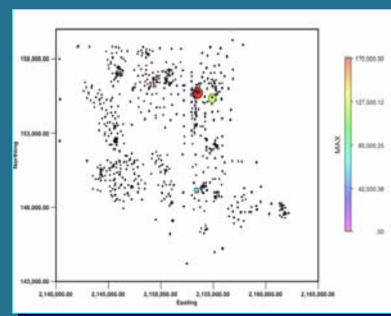


Data Exploration

- Examine summary statistics
  - Detection rates
  - MCL exceedances
  - Outliers, 95%UCL
  - Cumulative distribution function



- Concentration maps
  - Well medians, maximums
  - Dot maps and bubble plots identify “hot spots”



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Prioritize Constituents

Toxicity:

Contaminant of Concern	Representative Concentration (mg/L)	PRG (mg/L)	Percent Above PRG
BENZENE	2.7E-02	3.9E-04	6784.4%
TRICHLOROETHYLENE (TCE)	2.3E-02	5.0E-03	356.6%
VINYL CHLORIDE	3.4E-03	2.0E-03	71.2%

Note: Top COCs by toxicity were determined by examining a representative concentration for each compound over the entire site. The compound representative concentrations are then compared with the chosen PRG for that compound, with the percentage excedence from the PRG determining the compound's toxicity. All compounds above exceed the PRG.

Prevalence:

Contaminant of Concern	Class	Total Wells	Total Excedences	Percent Excedences	Total detects
BENZENE	ORG	51	30	58.8%	35
VINYL CHLORIDE	ORG	51	18	35.3%	35
TRICHLOROETHYLENE (TCE)	ORG	51	6	11.8%	21

Note: Top COCs by prevalence were determined by examining a representative concentration for each well location at the site. The total excedences (values above the chosen PRGs) are compared to the total number of wells to determine the prevalence of the compound.

LTMO

Mann-Kendall Test: Approach

	Event 1	Event 2	Event 3	Event 4	Event 5	TOTAL POINTS
	13.95	42.08	33.90	33.67	18.05	
Compare To Event 1		+ 1	+ 1	+ 1	+ 1	+ 4
Compare To Event 2			- 1	- 1	- 1	- 3
Compare To Event 3				- 1	- 1	- 2
Compare To Event 4					- 1	- 1
Conclusion: decreasing trend					***S =***	***- 2***

Mann-Kendall Approach

- Confidence Factor
  - *p* from the Kendall probability table for value of S and n (# of samples).
  - *p* = probability of accepting H_0 – No trend
  - Confidence Factor = (1-*p*)%
    - $\alpha = 0.05$ 95% CF Strong trend
    - $\alpha = 0.1$ 90% CF Moderate trend
- Coefficient of Variation
    - COV = Standard deviation/mean

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Mann-Kendall Test Results

		Confidence Factor		
Mann-Kendall Statistic		CF > 95%	90% <CF< 95%	CF < 90%
	S < 0	*Decreasing*	*Prob. Decreasing*	If COV < 1, *Stable* If COV > 1, *No Trend*
	S > 0	Increasing	Prob. Increasing	No Trend

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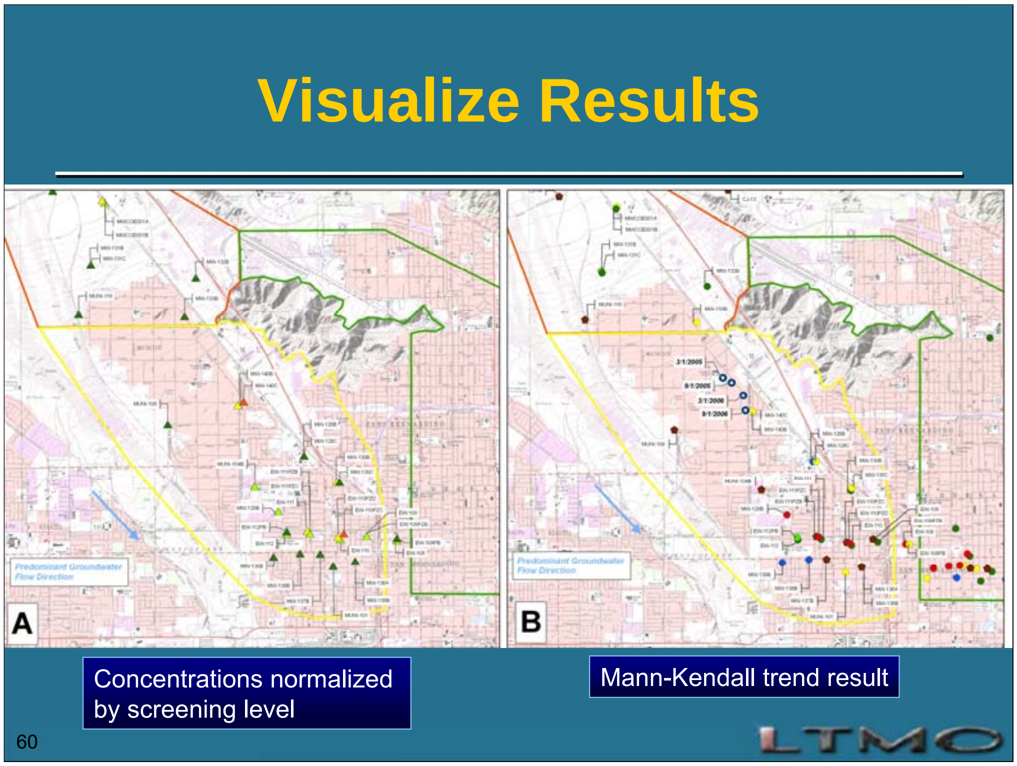


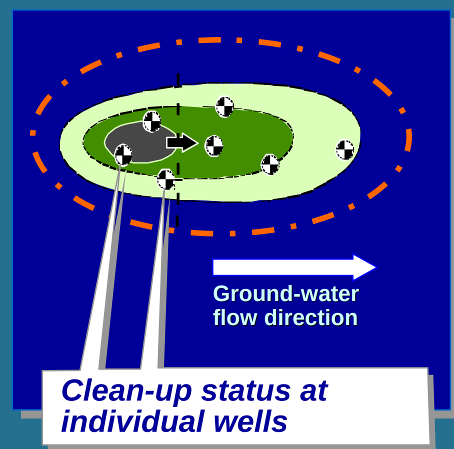
A visualization step highlights the results of simple quantitative methods. It will also tell you pretty quickly if you have good quality spatial data. When the GIS data and analytical result databases

Data Sufficiency: Statistical Power

Is ground water statistically below clean-up level?

Power equation relies on:

1. False positive rate (α = 0.05)
2. Number of samples (n).
3. Critical Effect Size (detection limit).
4. Variability in data



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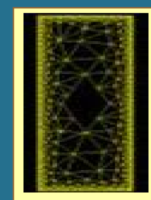
Statistical power is a measure of the level of confidence we have that the dataset can prove what we purport to be true. Technically, high power means we have a low chance of a Type II error (false negative) – appropriate for compliance programs.

Spatial Analysis

Mesh Creation – Delaunay/Theissen/Voronoi
- Moments
- Spatial uncertainty

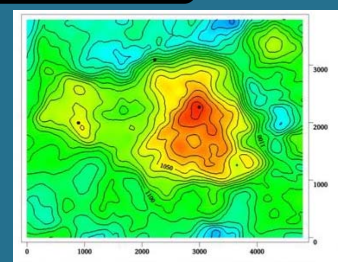


Statistical Surface Creation
Stepwise regression with linear estimators

Geostatistics-Kriging

Ground-water Modeling

Mathematical Optimization



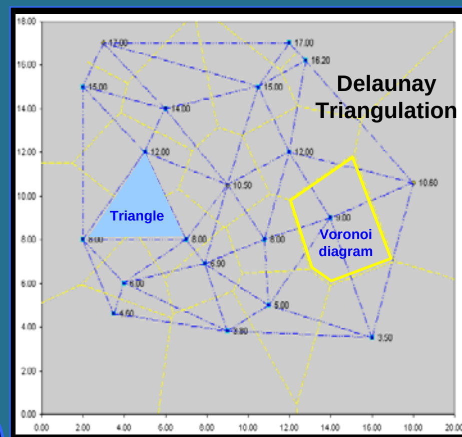
LTMO

MAROS Spatial Analyses

Moment Analysis

- Numerical approximation
  - *Total dissolved mass*
  - *Center of mass*
  - *Distribution of mass*
- Mass estimate built on Delaunay Triangulation

Trends for plume-wide mass and distribution



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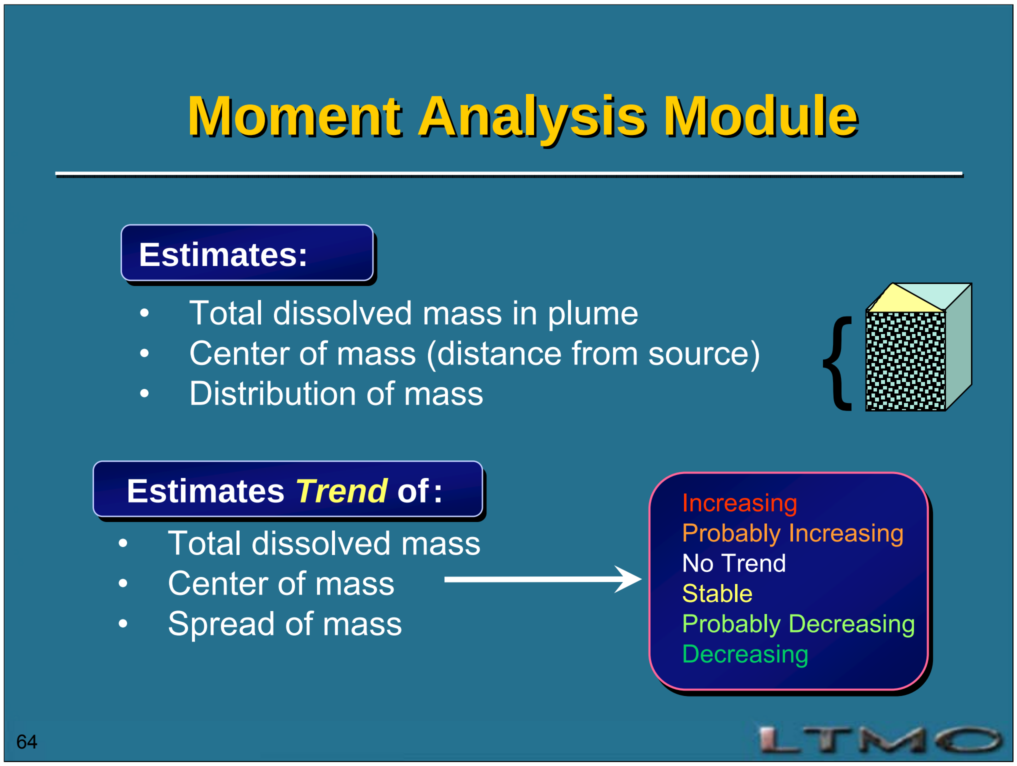
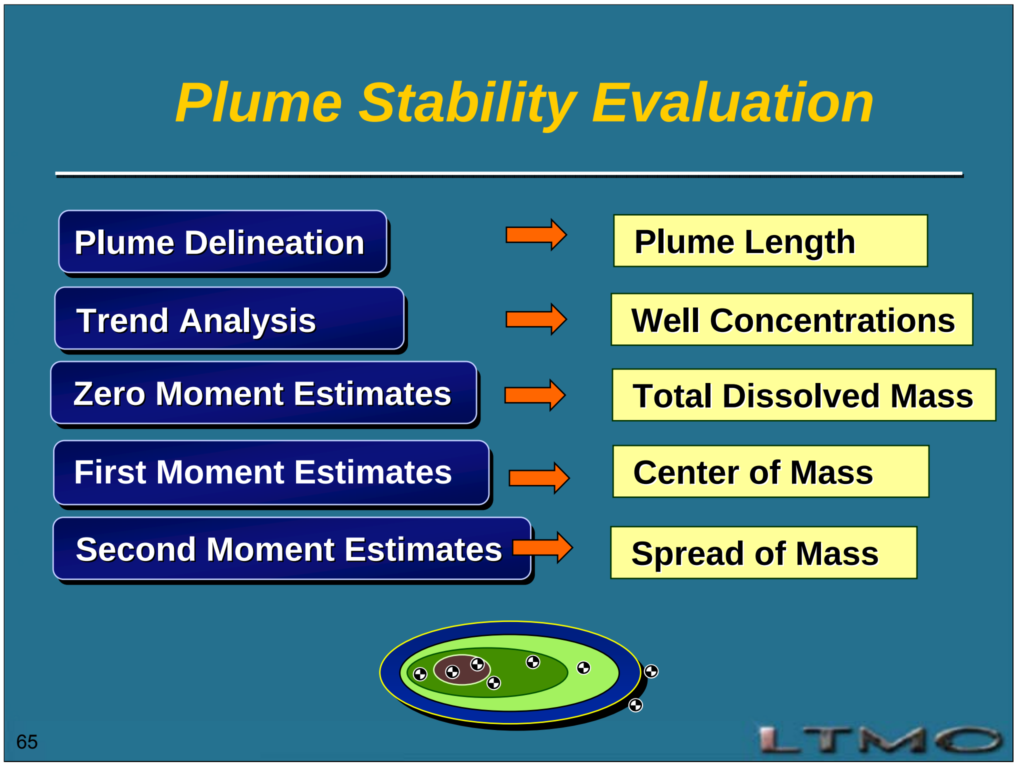
Triangles built such that no point in **P** is inside the circumcircle of any triangle



by evaluating the trend of metrics such as total dissolved mass, center of mass and spread of mass – you can evaluate areas where more monitoring intensity is needed and identify areas of low concern. Moments can also be used to demonstrate remedial efficacy.



By demonstrating that a plume is stable, an argument can be made for a reduction in sampling effort. many state regulations call for a demonstration of plume stability but do not specify how this is to be done.

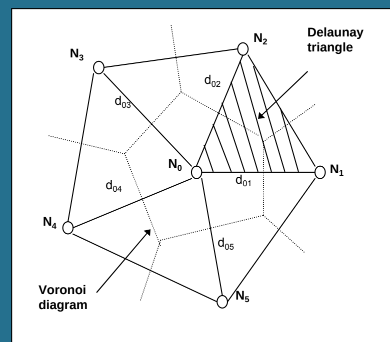
Measures *of Information* Loss

Calculate Slope Factor (SF) as

$$SF_i = \left| \frac{EC_i - NC_i}{Max(EC_i, NC_i)} \right|$$

SF → 1, well is important

SF → 0, well is not important



Concentration Ratio

$$CR = \frac{C_{avg\ ,Proposed}}{C_{avg\ ,\ Original}}$$

CR → 1, information loss minimal

CR → 1, information loss significant

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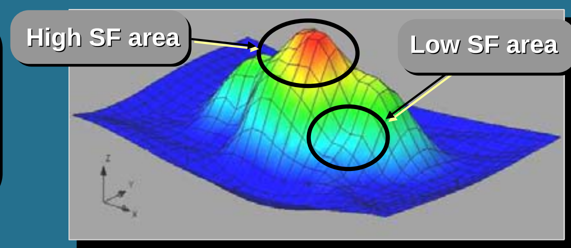
Area-weighted average of triangle concentration surrounding the node

SF = 0 meaning the concentration at the node can be accurately estimated by other nodes

Well Sufficiency and Redundancy

Generate **estimation uncertainty plot** based on SF values



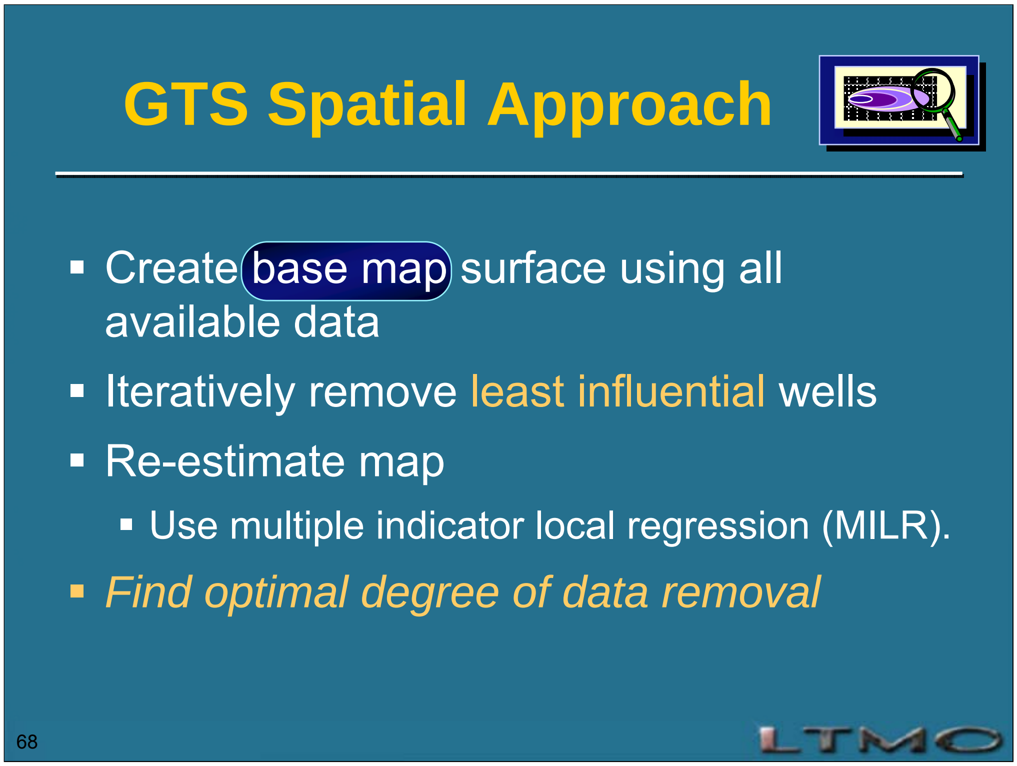
High estimation error →

Possible need for new locations

Low estimation error →

Eliminate sampling locations

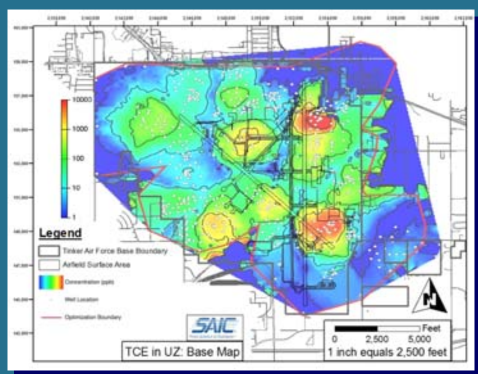
LTMO



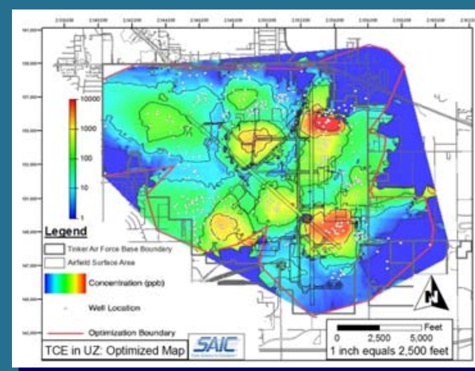
Locally-weighted quadratic regression. Multiple Indicator Local Regression

Spatial Comparison

Base Map (All Wells)



Optimized Map (38% less Wells)



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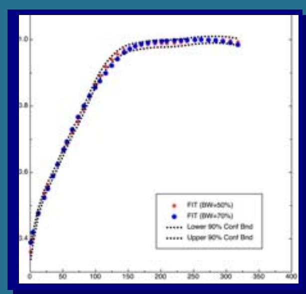
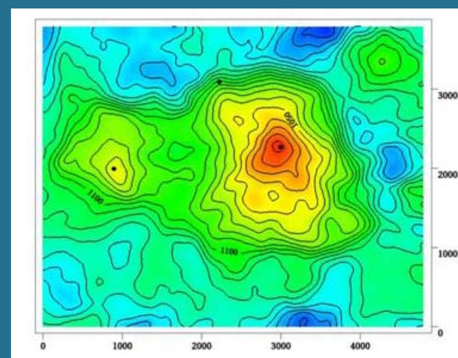
Compare original map constructed from full data with one constructed from reduced data set.

Geostatistics Kriging





Kriging – an interpolation method that estimates a value based on existing data locations and on a stochastic model of the spatial dependence – ‘*before and after’ optimization*

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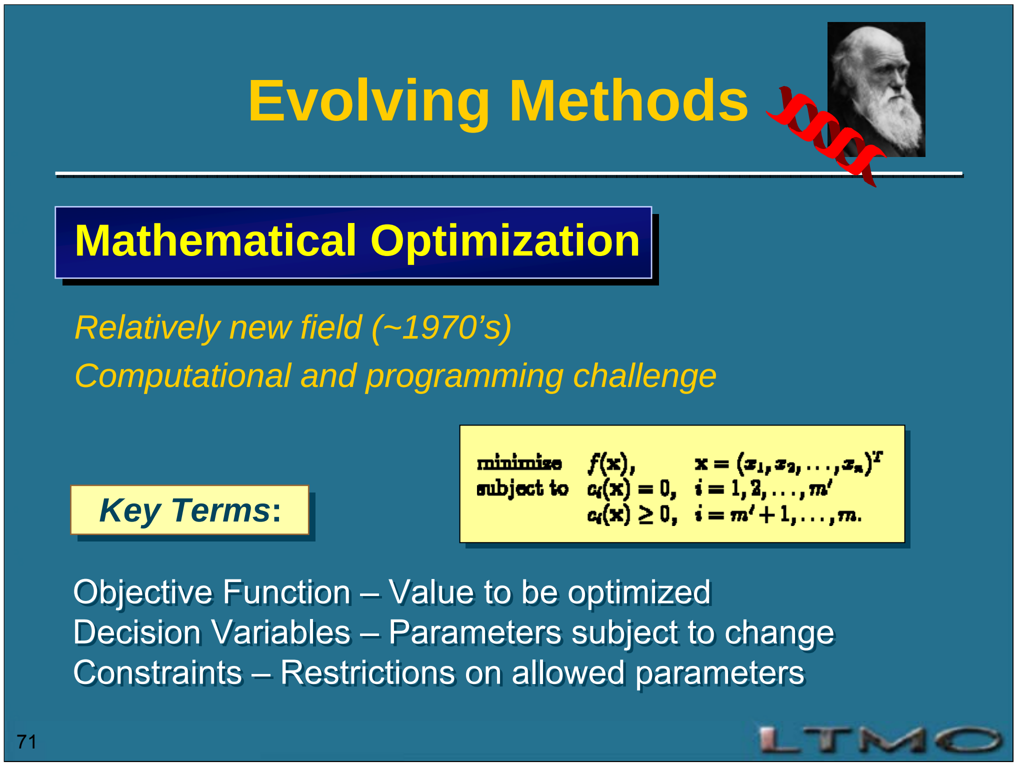
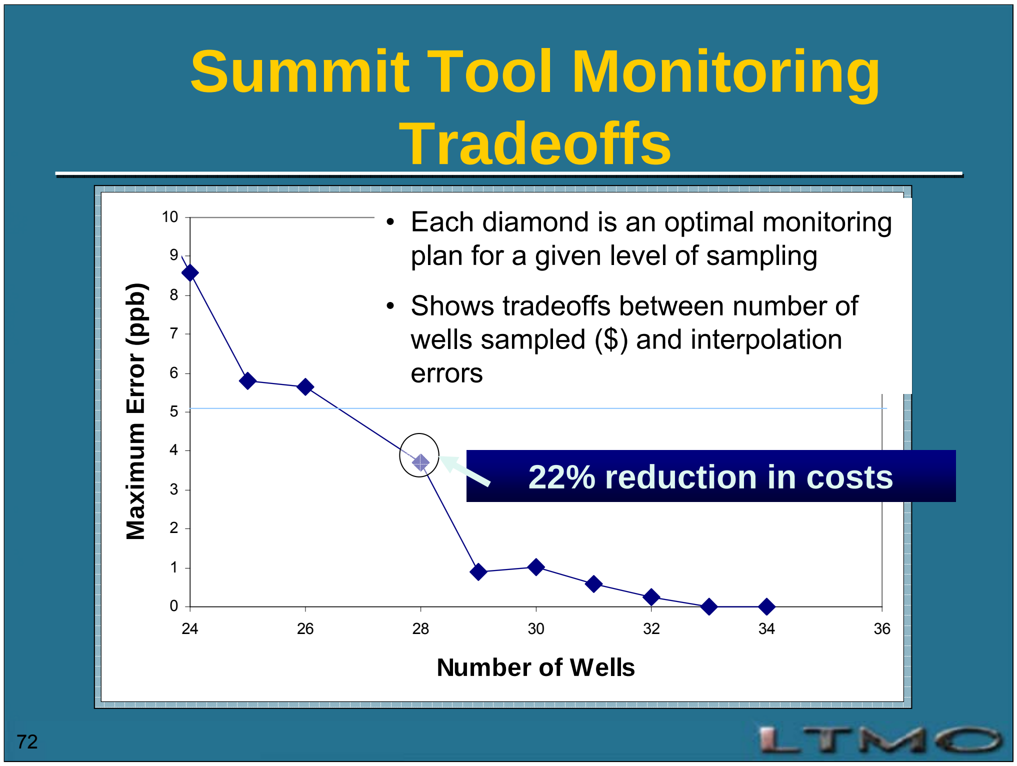
Kriging computes the best linear unbiased estimator of *Z*(*x*0) based on a stochastic model of the spatial dependence quantified either by the variogram γ Kriging is based on the assumption that the parameter being interpolated can be treated as a regionalized variable. A regionalized variable is intermediate between a truly random variable and a completely deterministic variable in that it varies in a continuous manner from one location to the next and therefore points that are near each other have a certain degree of spatial correlation, but points that are widely separated are statistically independent (Davis, 1986). Kriging is a set of linear regression routines which minimize estimation variance from a predefined covariance model.



True mathematical optimization for environmental applications is based on mathematics taken from fields such as electrical engineering/computer science. The goal of optimization is to find the best combination of parameters that you can control that will result in a maximization or minimization of the quantity you want optimized.



The line on the graph shows the MCL for benzene, which gives an idea of the relative magnitude of the errors. Summit software tool is currently in late beta phase.

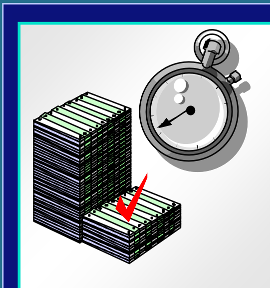
Temporal Analysis

Sampling frequency based on
- Ground-water flow velocity
- Rate of concentration change

Decision logic methods

Iterative thinning

Combined spatial/temporal optimization



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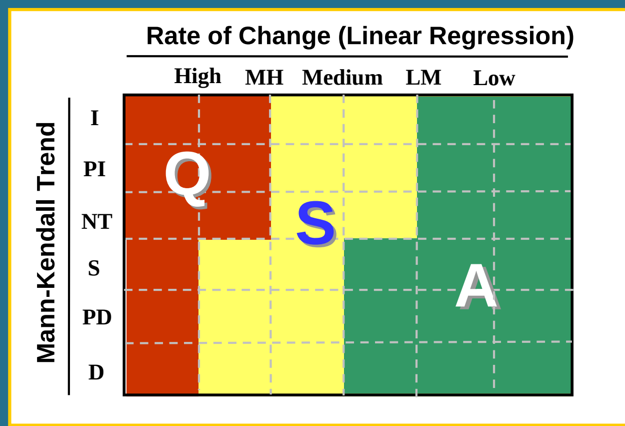
Sampling Frequency – Decision Map

Sampling Frequency

Q: Quarterly
S: Semiannual
A: Annual



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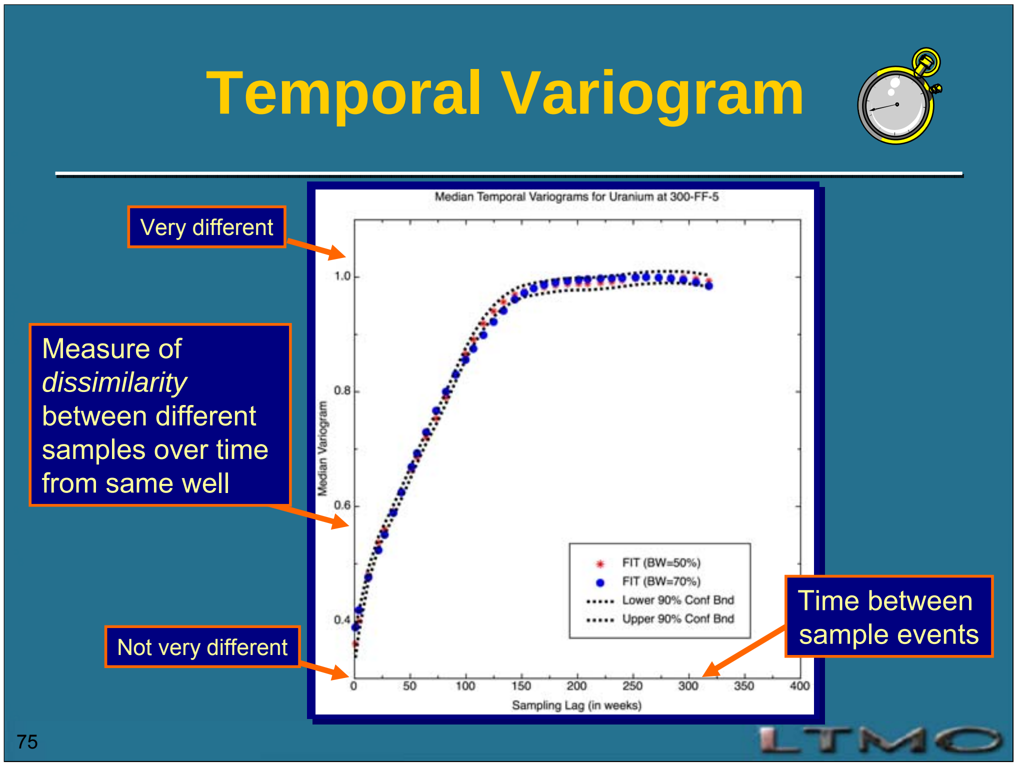
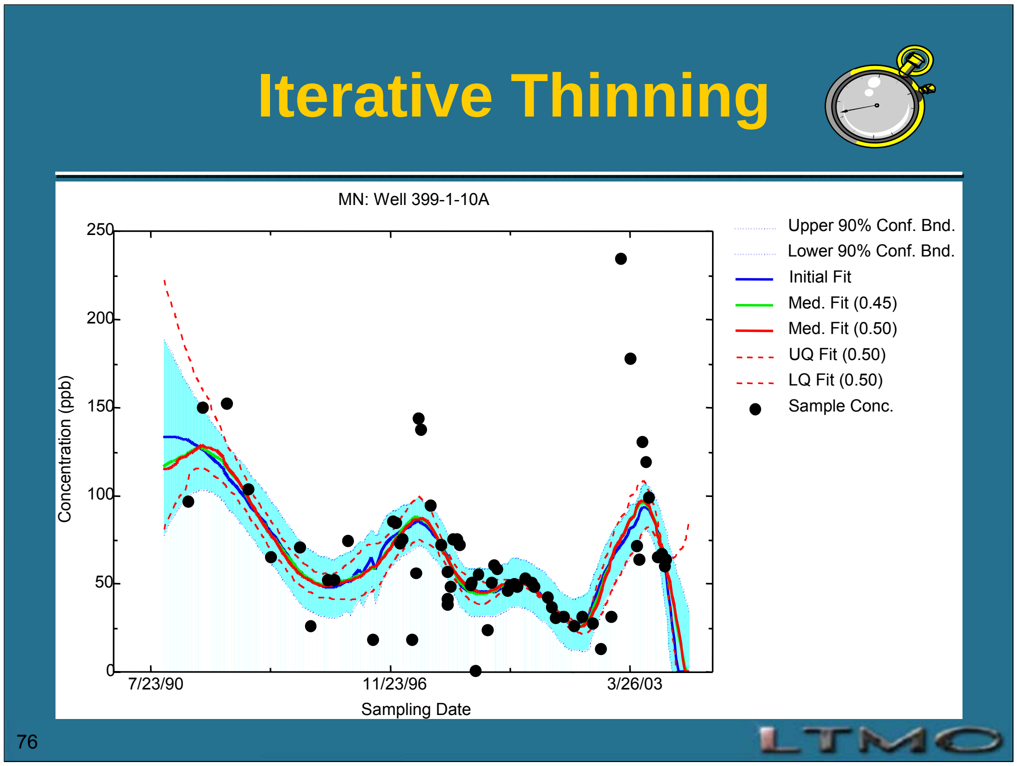


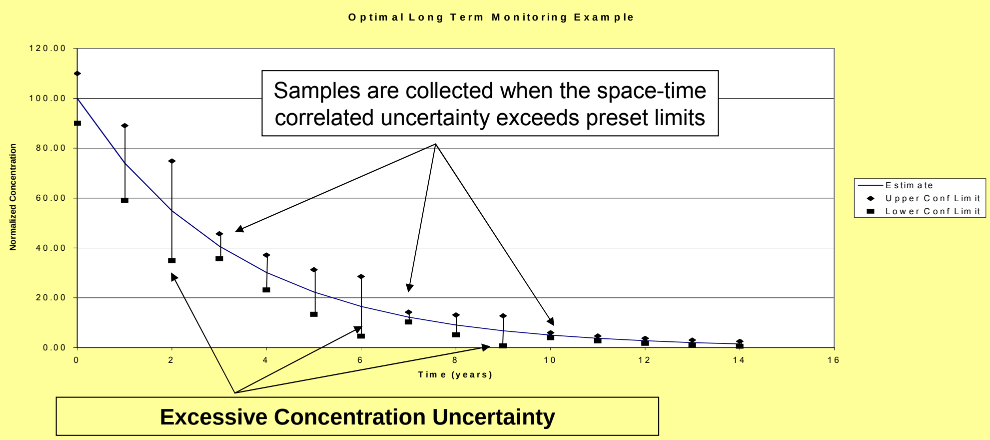
Range located approximately at 3 years (155 wks); current sampling plan for most wells was semi-annual to annual

Also note that complex trends and/or seasonal effects can impact performance of temporal variogram



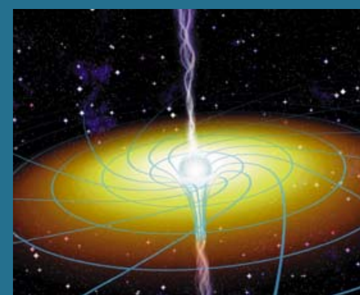
Recreate trends seen in full data set by iteratively eliminating sample points. What is the minimum sample frequency to recreate the trend.

Combined Space-Time Approach



Combined Approach

- Integrated algorithms
  - Ground-water transport and simulation models
  - Data models
  - Signal processing (i.e. Kalman Filters, etc.)
  - Genetic programming
- Optimal system estimate
  - Optimal estimate of “system” for locating plume at given time



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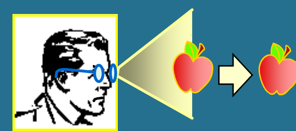
Kalman filter estimates the state of a dynamic system from a series of incomplete and noisy measurements

Evidence

Evaluation Strategies



- Develop lines of evidence
  - Evaluate quality of information from each location and how it meets monitoring goals;
  - Detection frequency, trends, plume stability;
  - Spatial redundancy/uncertainty;
  - Sampling frequency consistent with rate of change.

Result

Recommendations

- Monitoring locations that serve monitoring objectives and decision needs;
- Remove redundant locations;
- Add wells where uncertainty is high;
- Optimal sampling frequency

Qualitative Review!

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Questions?
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LTMO


5-Minute Break
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DJB1
Reviewing and Implementing
LTMO Results
Dave Becker, P.G.
US Army Corps of Engineers
Environmental and Munitions Center of
Expertise
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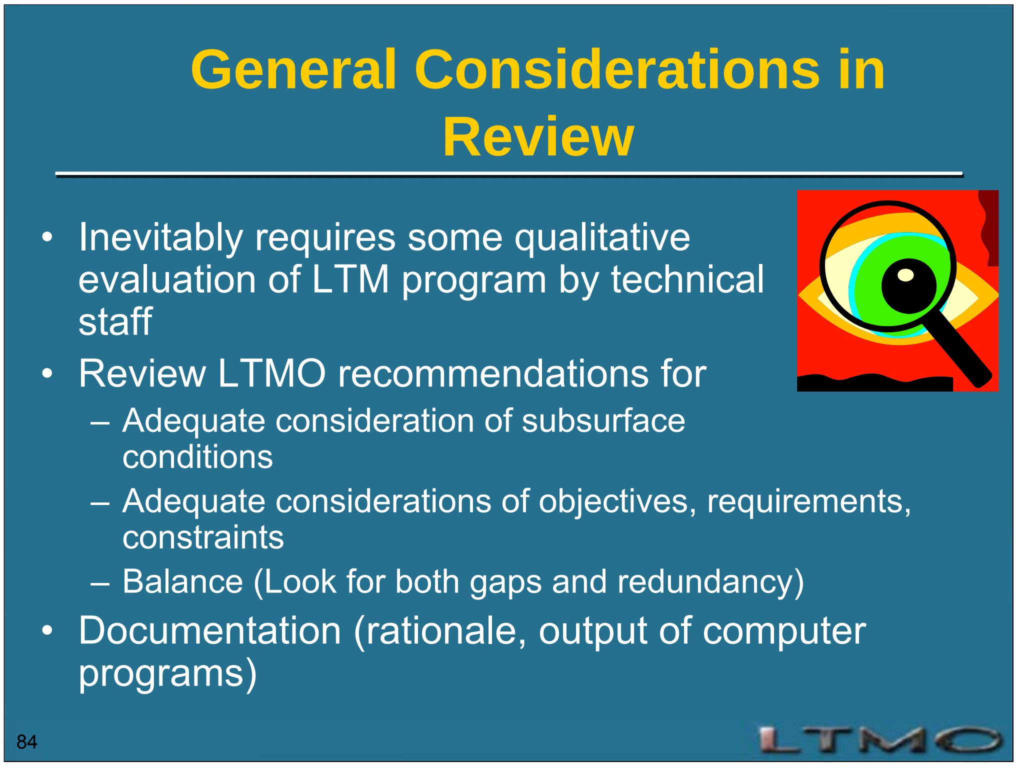
LTMO



One "take-home" message is that the review requires some qualitative review of the LTM program, even if you don't re-run the quantitative tools, you will find yourself looking at the data, the network, and the hydrogeology to see what you would have recommended and to see if the recommendations make sense.

The LTMO must have considered the hydrogeology and the objectives of the program

The review must make sure the LTMO had a balanced approach – not just to save money, did it look for data gaps?

The reports need to provide adequate documentation providing the backup for the recommendations.

Data Review

- LTMO evaluation hinges on historical data
- Requires some familiarity with data
  - Valid data used?
  - Comparable data?
- ***Red Flags***
  - Poor quality, mixed data,
  - Non-representative conditions
  - Insufficient data

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Need to review the historical data since it is a key component of the analysis.

In many cases a reviewer will already know this if they know the project. The amount of data need to be adequate. Some rules of thumb are given here. Depends on the technique. The data should reflect the history since remedy. The data should be comparable over that time. Identify major issues – some issues identified here. Mixed data – different sampling/analytical methods. Could be insufficient data – perhaps too soon to do LTMO?

Review of LTMO Recommendations & Site Hydrogeology

- Requires technical knowledge of site conditions, hydrogeology
- Have well developed conceptual model
- Consider
  - Speed of contaminant transport *(Is there time to react?)*
  - Impacts of pumping and preferred pathways *(fractures, channels?)*
  - Vertical distribution of wells *(Retain 3-D definition in all aquifers?)*
  - Plume behavior (d*egradation/dispersion, sorption?*)
- Assumptions in methods consistent with site conditions?

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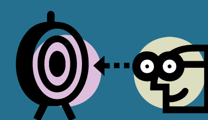
LTMO

Now let’s focus on the review of the recommendations. First, lets consider hydrogeology.

The reviewer (and the person who performed the LTMO) must have knowledge of site and technical fundamentals shown here. Were the assumptions used in the methods consistent with the site conditions? For example, could have significant seasonality. If the method didn’t account for that, may not give the best recommendations. Or if there is a channel of high permeability aquifer material, a geostatistical analysis may not have weighted that area appropriately.

Recommendations Relative to Monitoring Objectives

- Verify current LTM objectives are stated
- Compare recommended frequency, network (and analytical changes) to objectives – Are these adequate to:
  - Assess migration?
  - Assess progress toward remediation?
  - Assess unexpected behavior (e.g. rebound, outside contaminants)?
  - Provide early warning to exposure point?
  - Meet stakeholder concerns?



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Now lets consider recommendations relative to the LTM objectives. The LTMO report must indicate they knew the objectives. Some of the review considerations are listed here.

Review for Regulatory Compliance

- Do recommendations meet minimum State and Federal regulatory requirements?
  - Permit requirements (or propose changes consistent with regulatory program)
  - Minimum sampling
    - Upgradient and downgradient
    - Spacing of perimeter wells
    - Point of compliance wells
    - Within plume
    - Number of rounds
  - Analytical parameters

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Do the recommendations meet regulatory requirements or permit requirements?

Again, California requires a minimum sampling program. The analytical list is less flexible, but can recommend changes in frequency. Again, some questions for reviewers in comparing the recommendations against regulatory requirements.

A more difficult review task is to assess if the personnel performing the LTMO were qualified to perform the analysis. Best to look for qualification in a work plan. For some methods, need expertise in the statistics/geostatistics. If not qualified, need to review recommendations in much more detail (or throw it back).

Implementation

- Consensus Building
  - Involve stakeholders in LTMO planning
  - Make process transparent
  - Present all results, good and bad
  - Changes to sampling locations, frequency, methods to be discussed
    - Focus on technical merits
    - Support site decision-making

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LTMO

Implementation, Continued

- Changes to Sampling Plans
  - Flexible decision documents
  - Acknowledge LTMO process in plans, exit strategy
  - Account for cost to change plans
- Disposition of Excluded Wells
  - Abandon/decommission
  - Use for piezometric measurements
  - Future plume changes
  - Verification
- Future LTMO: Periodic Re-Evaluations

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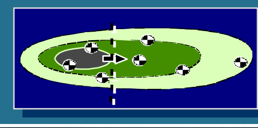
LTMO

Frontier Hard Chrome Case Study

Mindy Vanderford, Ph.D.
GSI Environmental, Inc.

LTMO

MAROS



General Objectives

- – Determine overall plume *stability;*
- – Evaluate concentration *trends;*
- – Remove *redundant wells* without information loss;
- – Add *new wells* where uncertainty is high;
- – Sampling *frequency* recommendations;
- – *Reality* check.

Case Study

Frontier Hard Chrome

- Former chrome plating facility 1958 – 1983;
- Shallow ground water affected by Cr(VI);
- Former downgradient GW extraction well
- Major remediation effort (ISRM).
- *Strong redevelopment pressure.*

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Recent view of FHC site in Vancouver Washington, source area is the orange rectangle and the green rectangle identifies new residential development along the Columbia River.

Monitoring Objectives

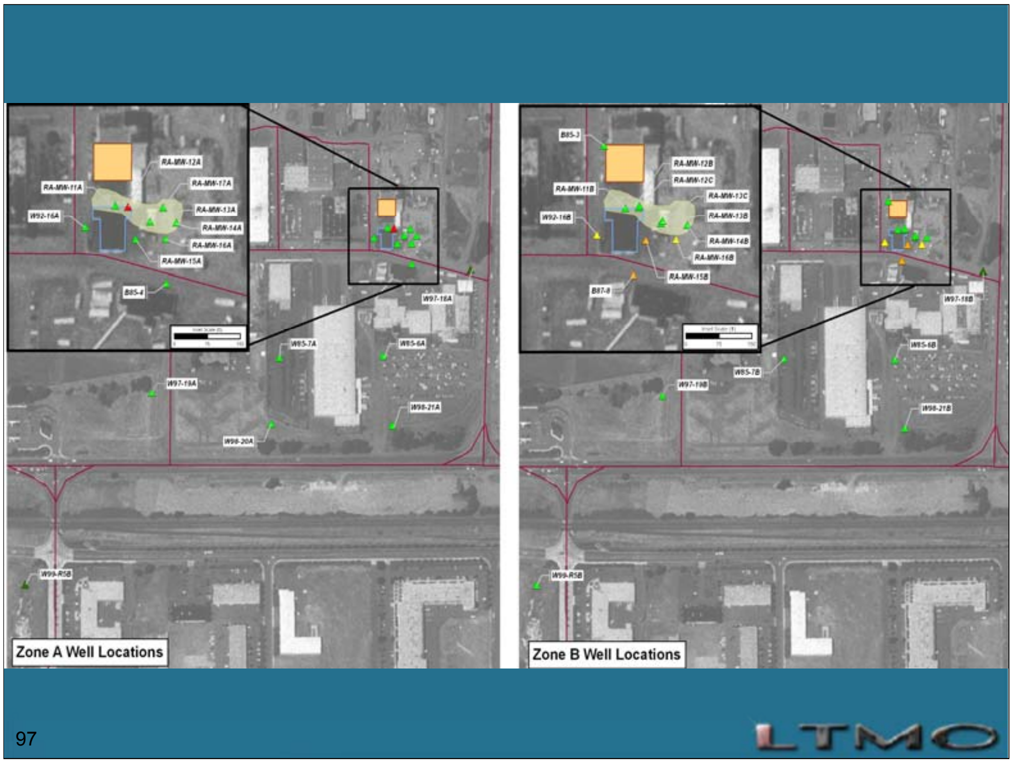
"ensure dilution and dispersion of affected ground water"

Ground water currently below screening levels

Ensure that remedy provides long-term protectiveness

Support site redevelopment

LTMO



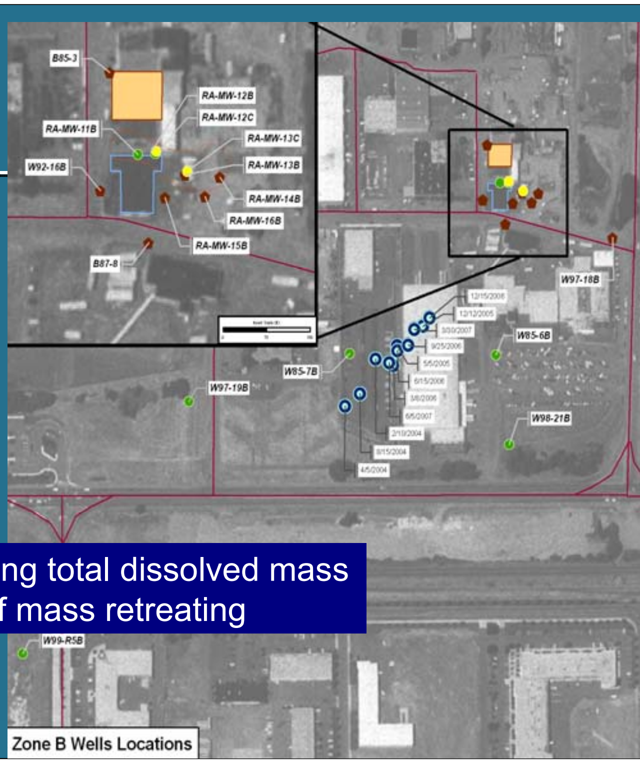
Map shows average concentrations normalized by screening levels; Two depth intervals, ISRM barrier wall yellow blob,

Trend Results

Alluvial Aquifer Zone	Total Wells	Number and Percentage of Wells for Each Trend Category				
		Non Detect	PD, D	S	I, PI	No Trend
Zone A	16	0	5 (31%)	7 (44%)	0	4 (25%)
Zone B	17	0	7 (41%)	2 (12%)	0	8 (47%)
All Wells	33	0	12 (36%)	9 (27%)	0	12 (36%)

Note: Number and percentage of total wells in each category shown. Decreasing trend (D), Probably Decreasing trend (PD), Stable (S), Probably Increasing trend (PI), and Increasing trend (I).

LTMO



Decreasing total dissolved mass
Center of mass retreating

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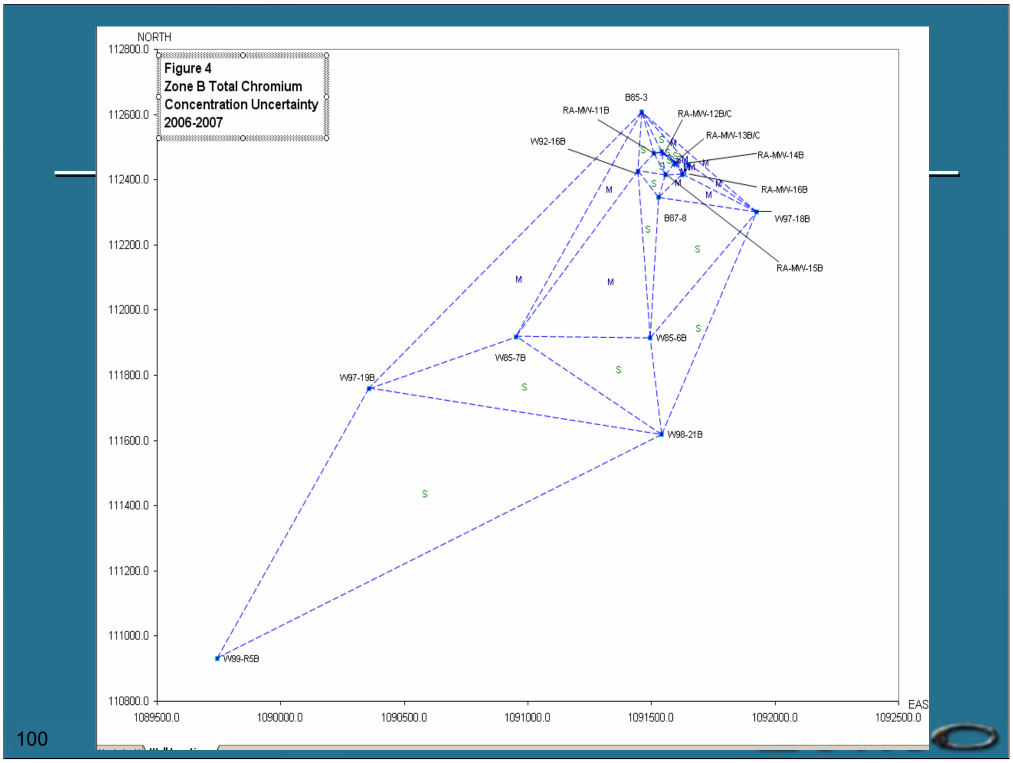


Figure 4
Zone B Total Chromium
Concentration Uncertainty
2006-2007
NORTH
EAS
112800.0
112600.0
112400.0
112200.0
112000.0
111800.0
111600.0
111400.0
111200.0
111000.0
110800.0
1089500.0
1090000.0
1090500.0
1091000.0
1091500.0
1092000.0
1092500.0
B85-3
RA-MW-11B
RA-MW-12B/C
RA-MW-13B/C
RA-MW-14B
W92-16B
RA-MW-16B
B87-8
W97-18B
RA-MW-15B
W85-6B
W85-7B
W97-19B
W98-21B
W99-R5B

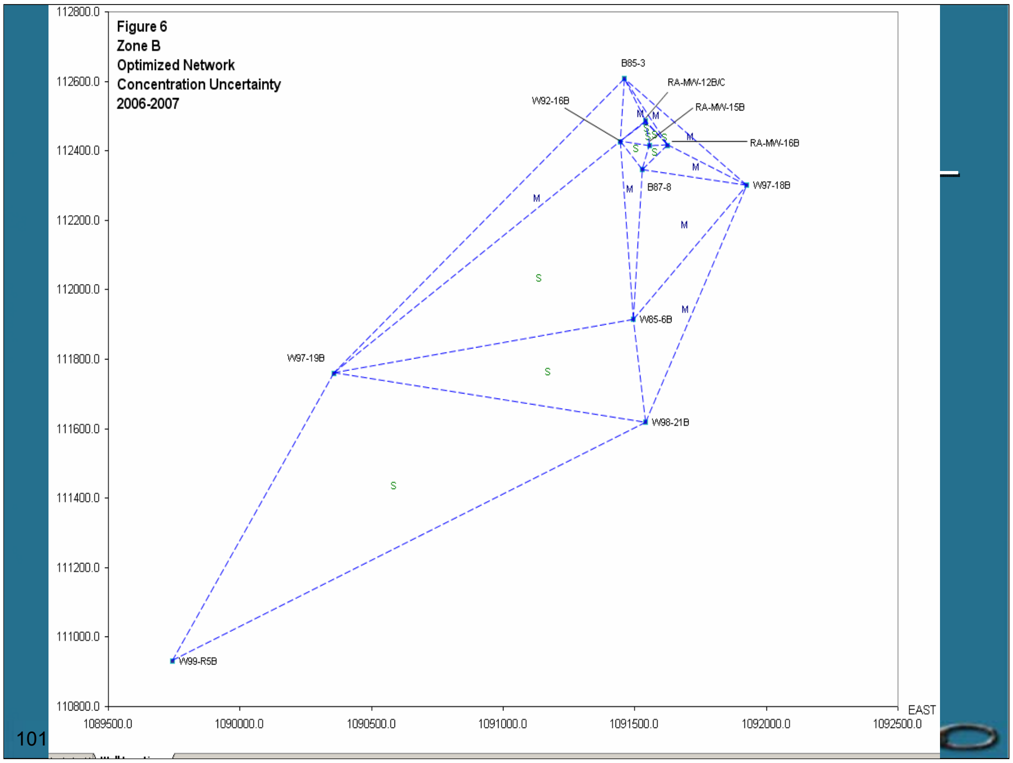
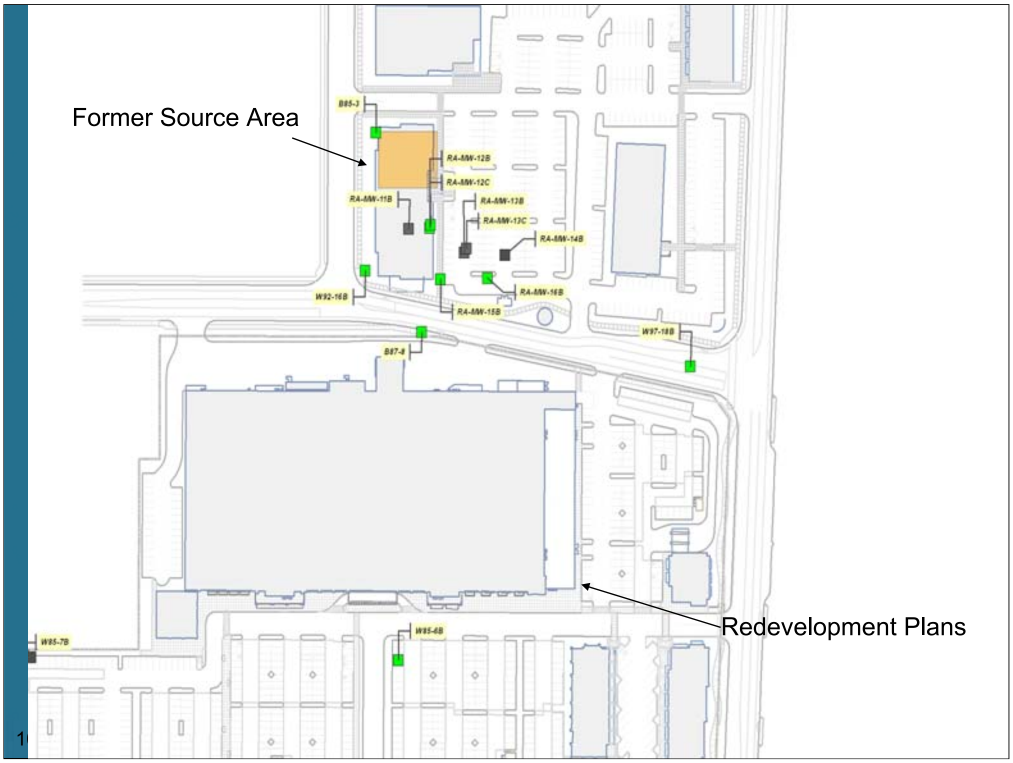


Figure 6
Zone B
Optimized Network
Concentration Uncertainty
2006-2007
B85-3
RA-MW-12B/C
RA-MW-15B
RA-MW-16B
W92-16B
B87-8
W97-18B
W85-6B
W97-19B
W98-21B
W99-R5B
EAST



Former Source Area
B85-3
RA-MW-12B
RA-MW-12C
RA-MW-11B
RA-MW-13B
RA-MW-13C
RA-MW-14B
W92-16B
RA-MW-16B
RA-MW-15B
W97-18B
B87-8
Redevelopment Plans
W95-7B
W95-6B

Results

SAMPLING FREQUENCY	CURRENT PROGRAM	FINAL RECOMMENDATION
Quarterly	33	0
Semi-annual	0	0
Annual	0	23
Biennial	0	0
Total Samples (per year)	132	23
Total Wells	33	23

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Results

Data Sufficiency

Ground-water Zone	Total Wells	Wells Statistically Below MTCA	"Attained" Clean-up Goal
A	16	15 (94%)	4 (25%)
B	17	12 (71%)	1 (5%)
Total Wells	33	27 (82%)	5 (15%)

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Lesson

- Vertical project integration
- High quality GIS important for site redevelopment.

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LTMO Challenges

Mindy Vanderford, Ph.D.
GSI Environmental, Inc.

LTMO

Challenges

- *Data*
- *Hydrogeology*
- *Cost*
- *Stakeholders*

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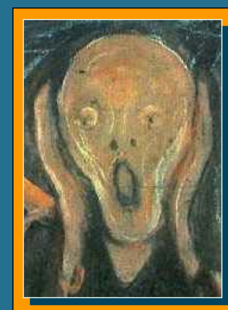
Data Challenges

Lack of Data Management

- No electronic data, multiple files/consultants, disorganized
- Data not reviewed
- Data gaps



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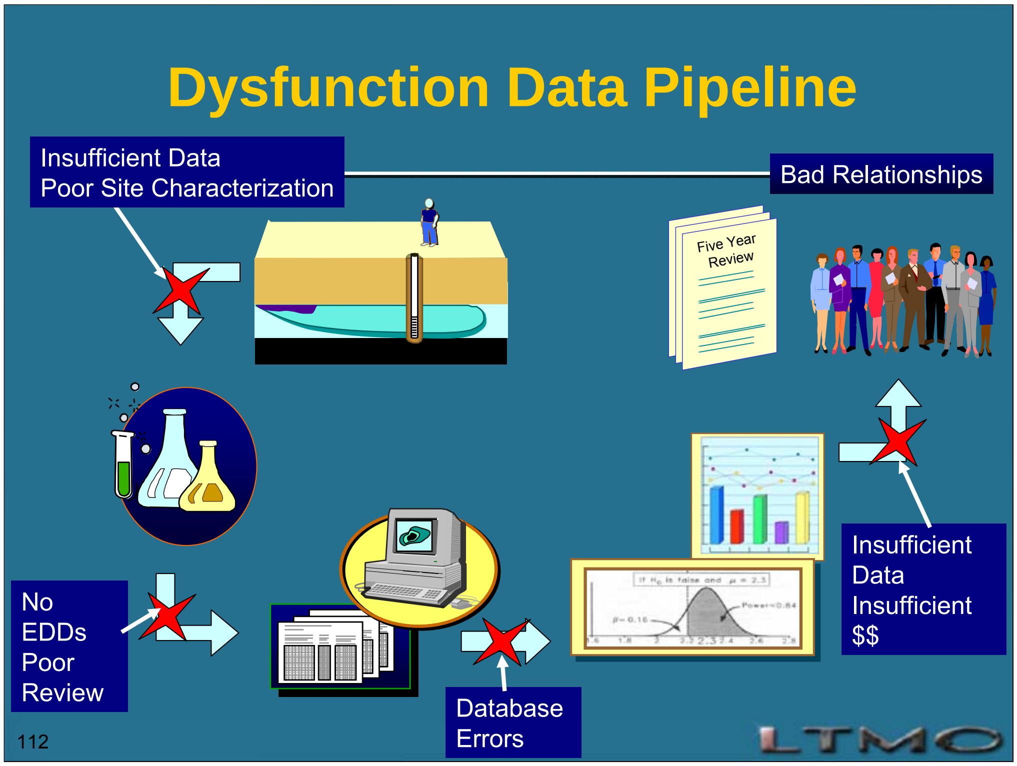
Information disorganized, contained in many reports, not centralized;



What decisions have been made?

What decisions are pending?

What decisions will be made in the future?

Does the monitoring program provide sufficient data quality and quantity to support an evaluation of the remedy?

Top Challenges

- Information disorganized, contained in many reports, not centralized;
- No electronic database, missing data, lack of detection limits;
- Database errors: wrong CAS numbers, multiple names for the same well, multiple COC names;
- Data not well reviewed: dilutions in database, filtered samples; laboratory artifacts not identified;

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Top Challenges

- Lack of vertical integration of information; managers don't supervise database; poor communication among stakeholders;
- Lack of a statistically significant data set, big data gaps, uneven sampling intervals;
- No location coordinates, missing location coordinates, no shape/GIS files;
- No monitoring objectives, no decision points identified.

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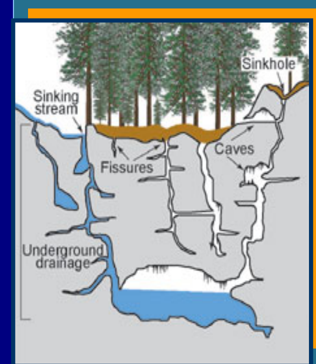
Hydrogeology

- Seasonality (drought/flood/agriculture)
- Variable Ground-water Flow Directions
- Catastrophic Events
- Karst and Fractures
- Delineation



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Hydrogeology

- Sufficient spatial information to characterize subsurface?
- Spatial database sufficient?
- How well do spatial statistics apply?
- Do data support site conceptual model?

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In the cost-benefit analysis of LTMO, costs for performing the analysis and instituting the optimized system may approach the benefits from performing the analysis.

Consensus?

Potential Challenges

- Consensus on site characterization?
- Consensus on remedy?
- Multiple consultants, PRPs
- Resistance to implementation

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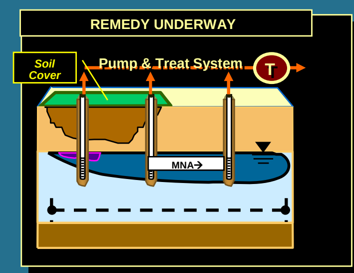
Completed LTMO, regulator asks how this plan characterizes a lower groundwater unit.

Consensus?

Potential Challenges

- Remedy optimization (system shut down?)
- Pump and treat or natural attenuation remedies on-going
- Property redevelopment



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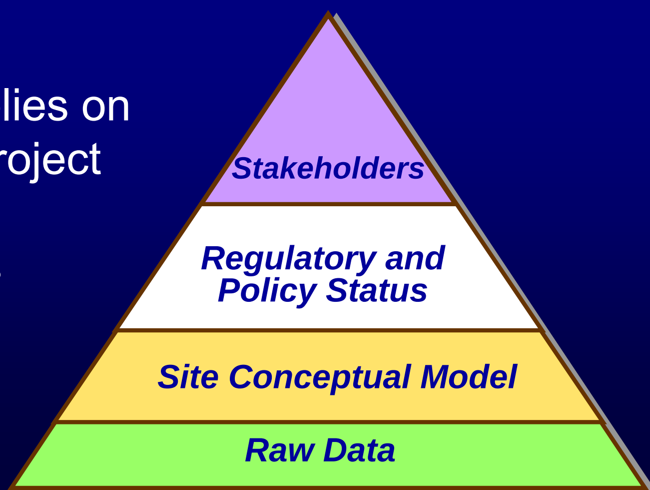
Completed LTMO, regulator asks how this plan characterizes a lower groundwater unit.

Summary

LTMO Relies on Sum of Project Data and Decisions



Questions?

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THANKS FOR PARTICIPATING!

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

Links to Additional Resources

Feedback Form

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