     

Long Term Monitoring Optimization

EPA
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Agency

Motivation for LTMO

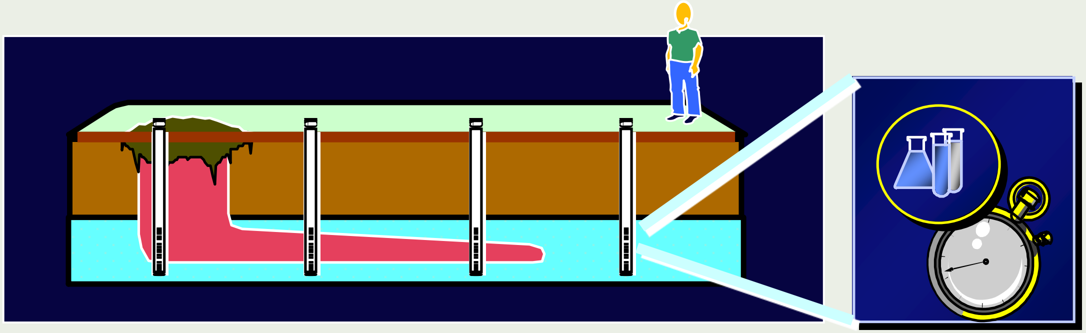
- **Long-term monitoring is a growing, persistent, and costly obligation for government agencies and private parties**
  - U.S. EPA spends over $100 million each year on monitoring - typically $10Ks - $100Ks/site
  - Private parties likely spend more

Motivation for LTMO

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

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.**



* U.S. Federal Register Executive Order 13423

Long Term Monitoring Optimization 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

Benefits of LTMO

- **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

Benefits of LTMO

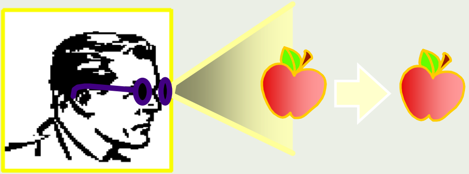
- **LTMO analysis can:**

Spectacular Results!

  - 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

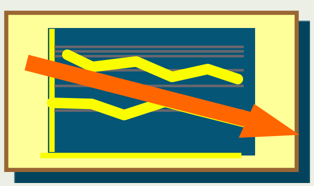
- *Qualitative evaluations based on professional judgment, intimate knowledge of site, decision rules, heuristic*

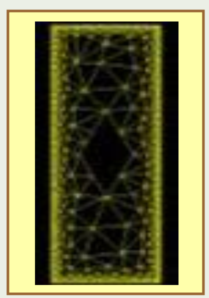


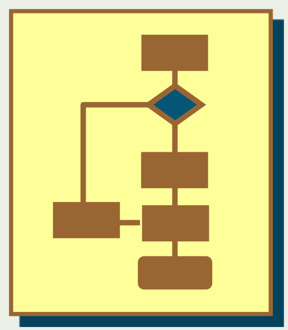
- *Quantitative evaluations based on statistical, mathematical, modeling or empirical evidence*

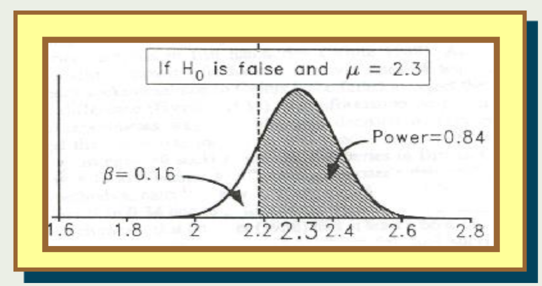
LTMO Methods

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





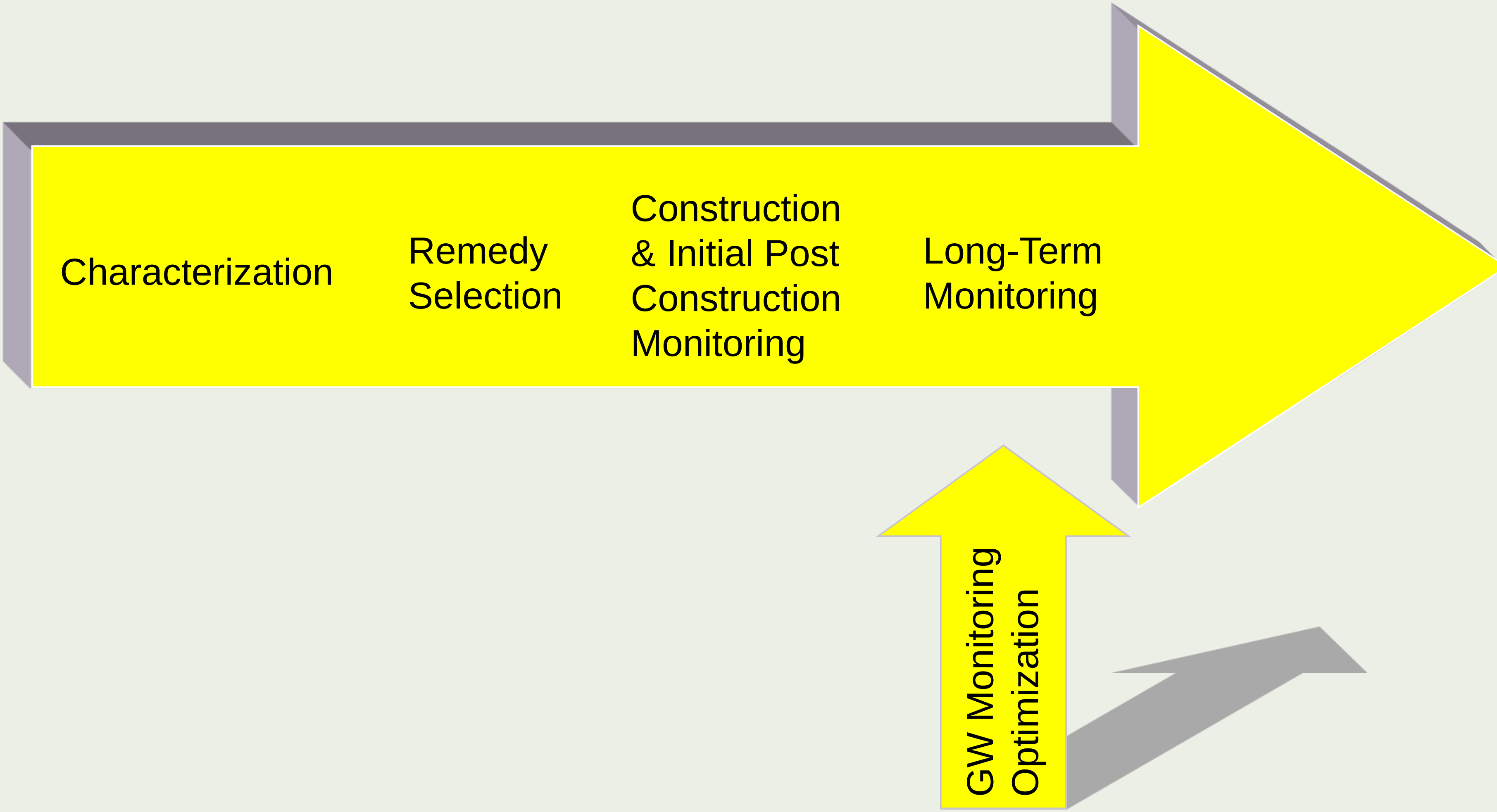




When to Apply LTMO

- **Is it Time?**

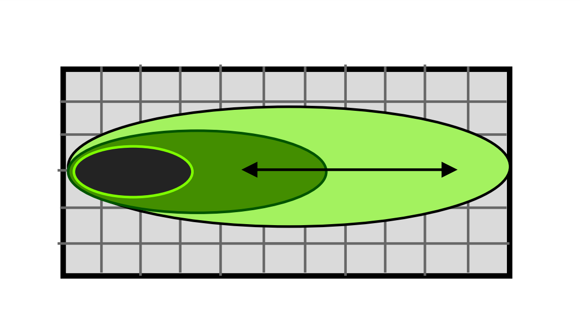
Groundwater Monitoring Timeline



Candidates for LTMO

- **Is my Site a Candidate? - Rules of thumb**

Easy!

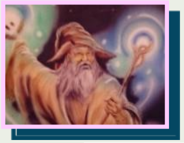


  - If Source is identified
  - If Plume is delineated
    - Vertical
    - Horizontal
  - If Database/Well Coordinates/ GW parameters in one place
  - If monitoring objectives exist...

7 Steps to LTMO

Roadmap to LTMO
Developed by U.S. EPA and USACE, May 2005

Implement Plan

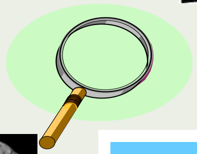


Perform Optimization

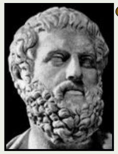
Choose LTMO Method

Determine the type of evaluation

Decide if site is a Candidate for LTMO



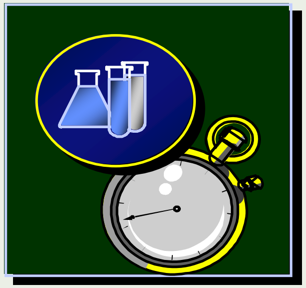
Examine Existing Data



Define and Document Current Program

Data Needs for LTMO

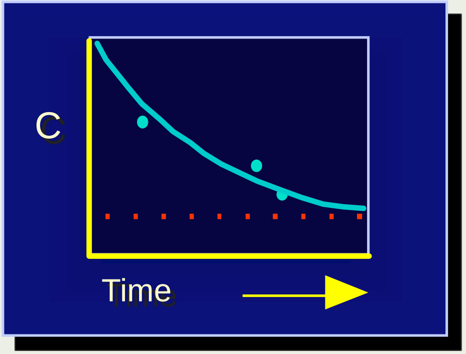
- Monitoring Objectives – Remedial Action Objectives
- Conceptual Site Model
- Temporal Data
- Spatial Data
- Budget



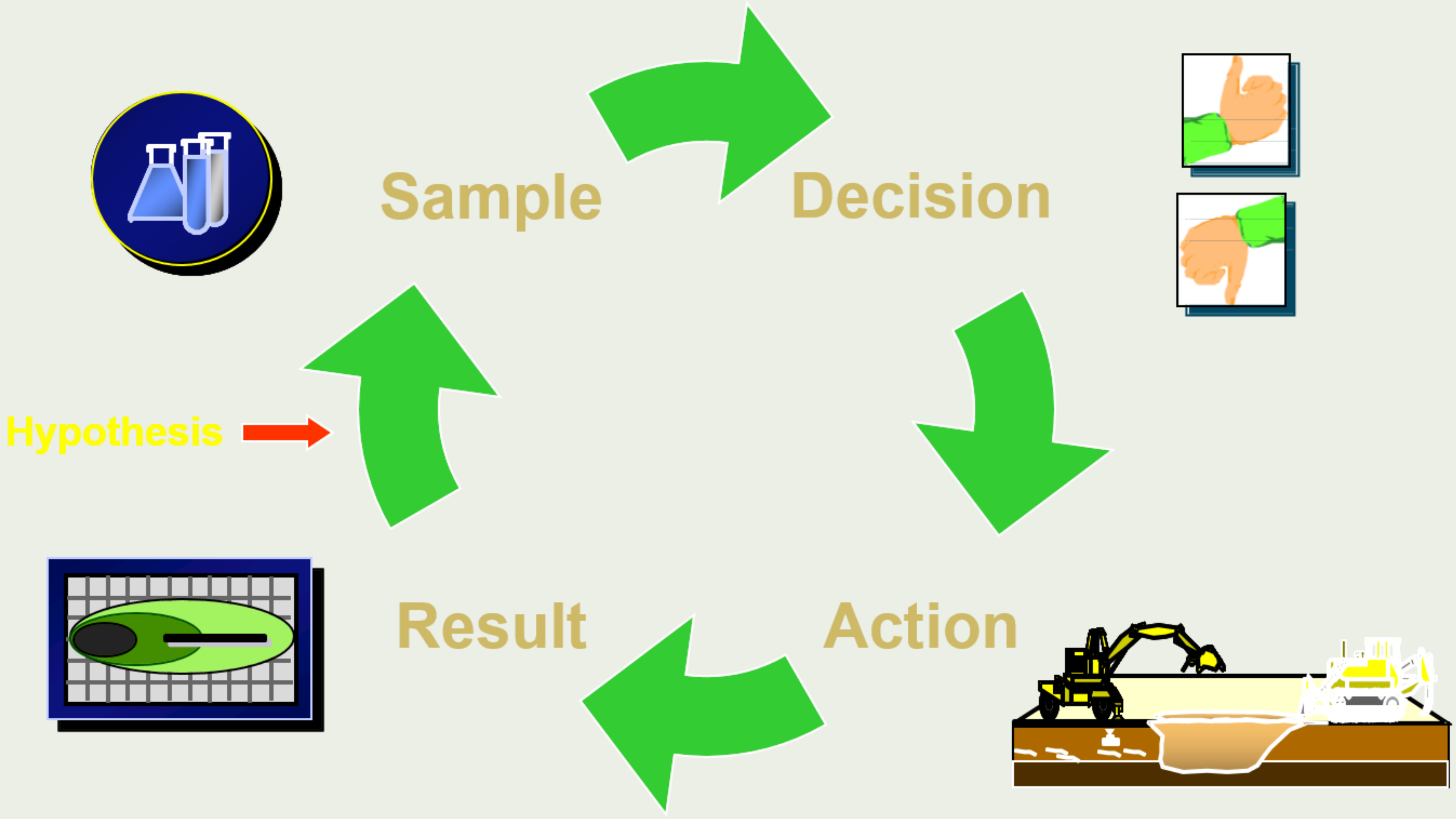
LTMO Challenges

- ♦ Quantity and diversity of data high, stored in multiple locations and formats

- ♦ LTMO more dependent on statistics and geostatistics

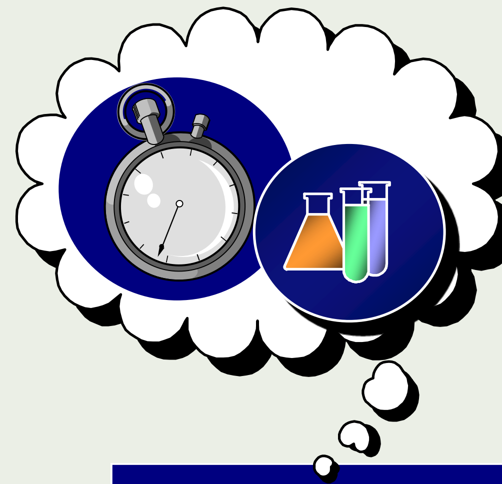


Why do we take samples?

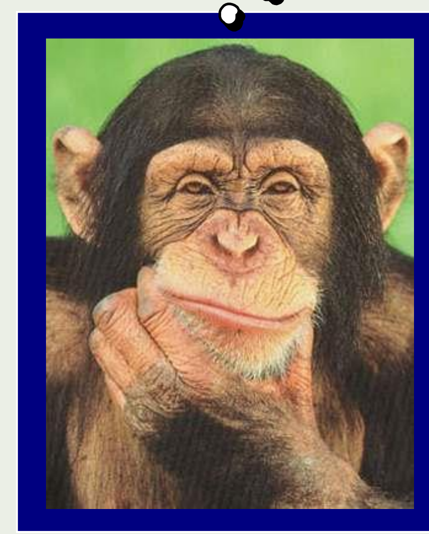


Monitoring Objectives

- **Monitoring Conceptual Site 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?

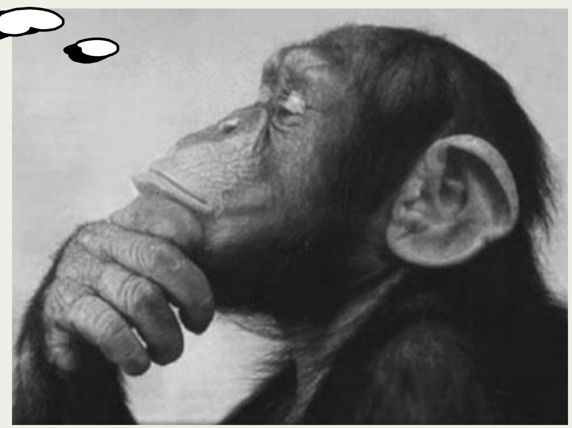


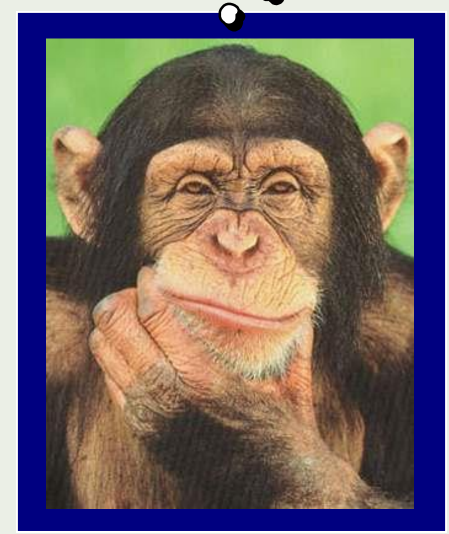
(Monitoring objectives…write them down)



Monitoring Objectives

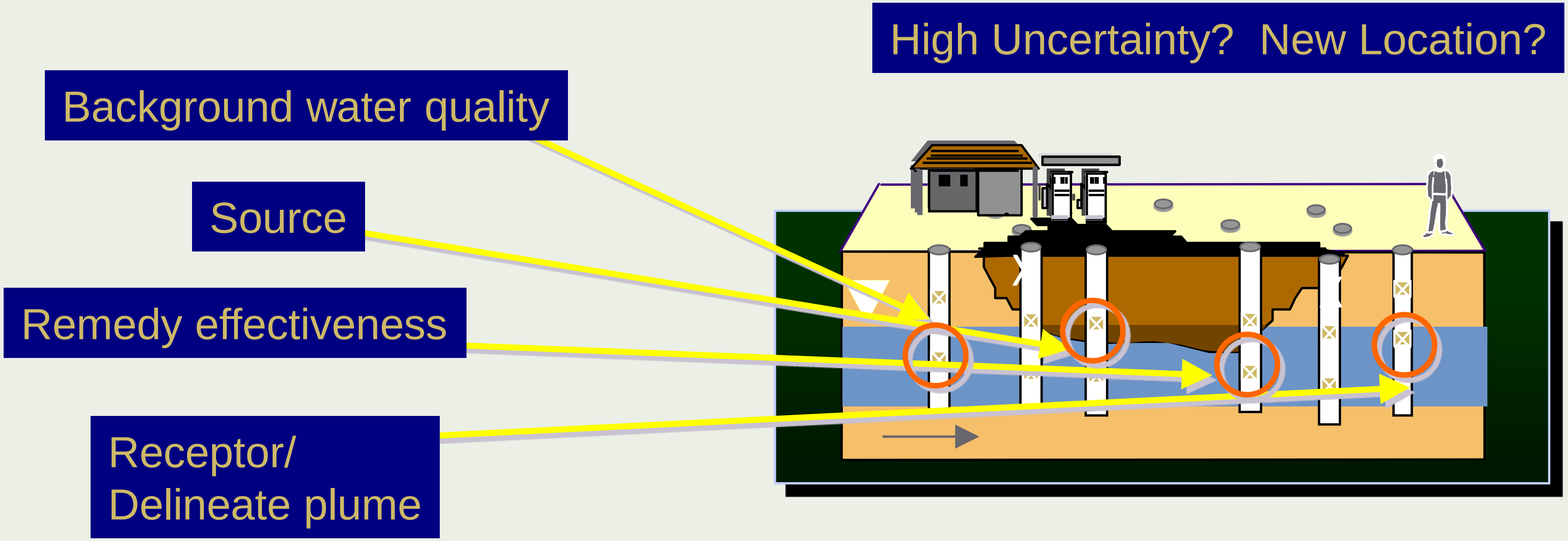
- Who else needs to know this?
- When do they need to know it?





Monitoring Objectives

- Monitoring objectives determine your sampling locations and frequency



Monitoring Objectives

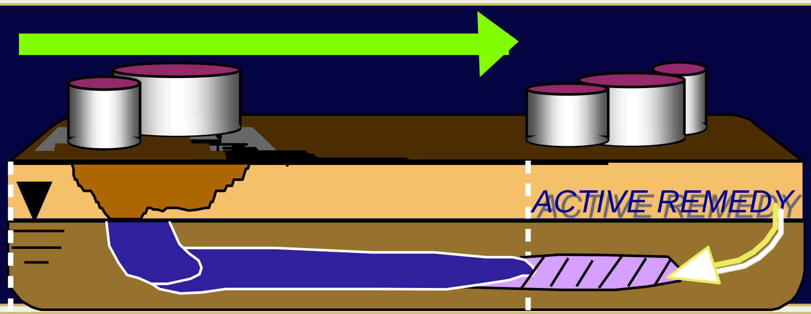
- **Example Monitoring Objectives**
  - Evaluate remedy effectiveness
  - Evaluate source depletion
  - Delineate plume
  - Evaluate contaminant migration
  - Evaluate background
  - Evaluate potential exposure pathways
  - Comply with regulatory requirements

Decision Points

Current Program

Scientific Management Decision Points

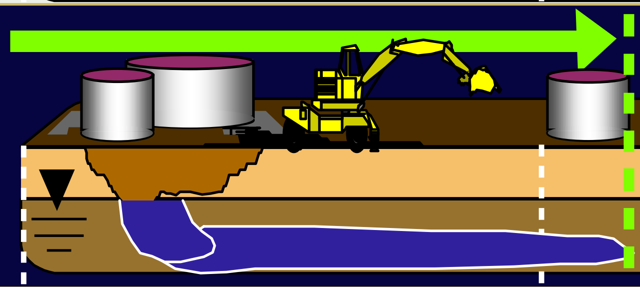
Active Remedy



Plume shrinking:

Reduce pumping

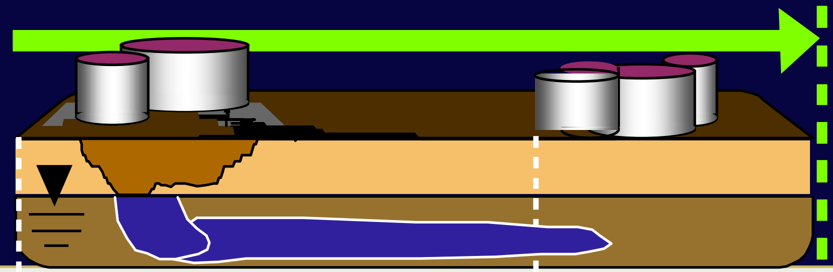
Monitored Natural Attenuation



500 ft plume growth:

Active Remedy

Ground Water Management Zone



Plume growth beyond GMZ:

Expand Inst. Control

Metrics of Success

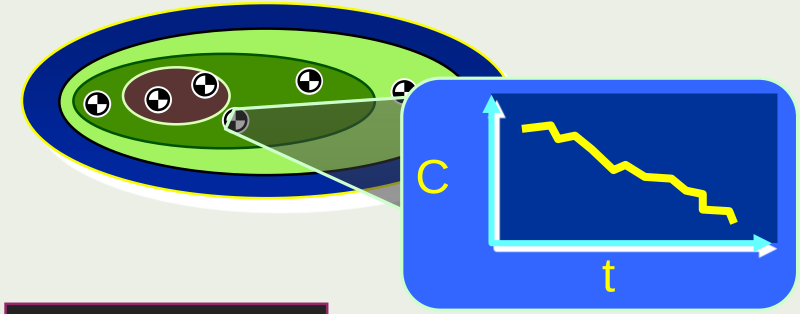
What type of data do you need to demonstrate?

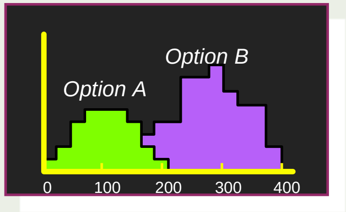
Plume stability

Reduction in total or dissolved mass

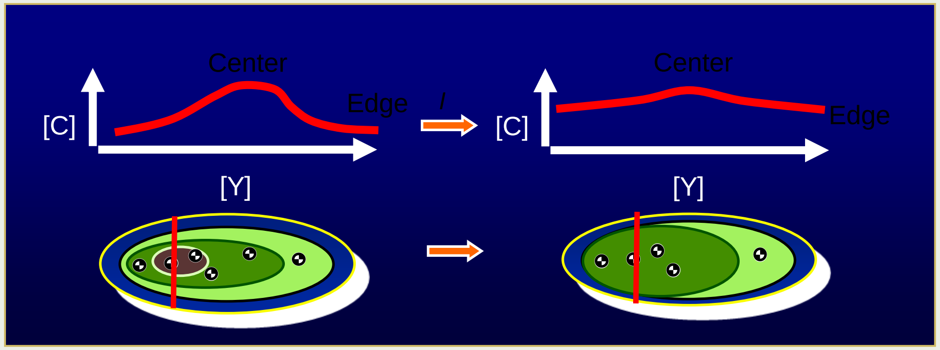
Delineation or Low spatial uncertainty

Protective or Cost-effective remedy?

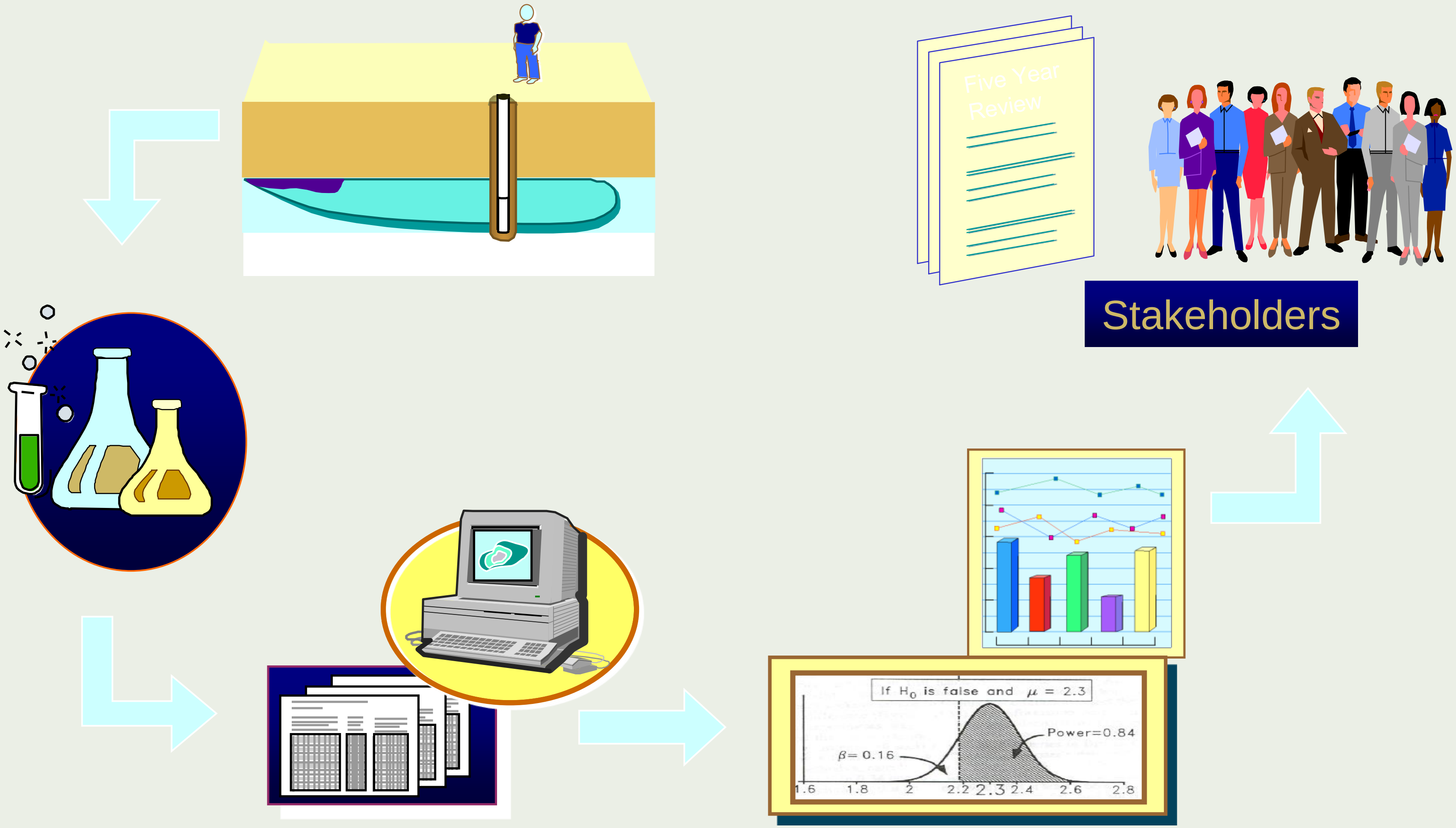




Cost Distributions

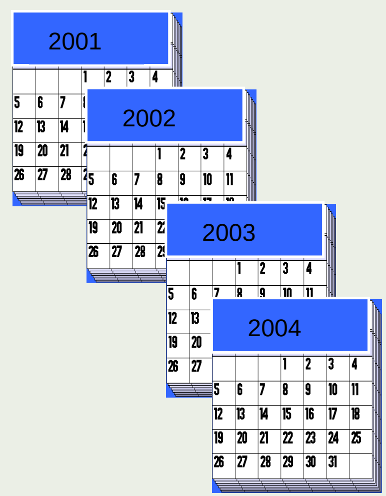


Data Conceptual Model



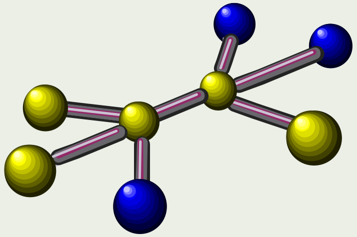
Temporal Data

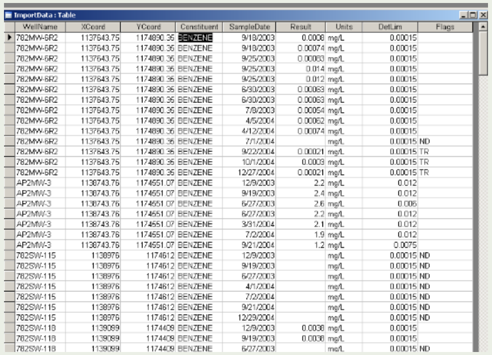
- ♦ **Chemical Analytical Data**
  - » Minimum dataset size to perform statistics:
    - › 4 - 8 Sample Events
  - » Sampling intervals
    - › Relative to rate of concentration change
    - › Groundwater velocity
  - » 2 Years Post-construction



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**



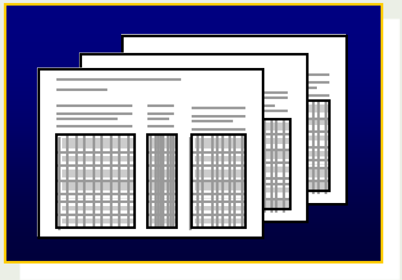


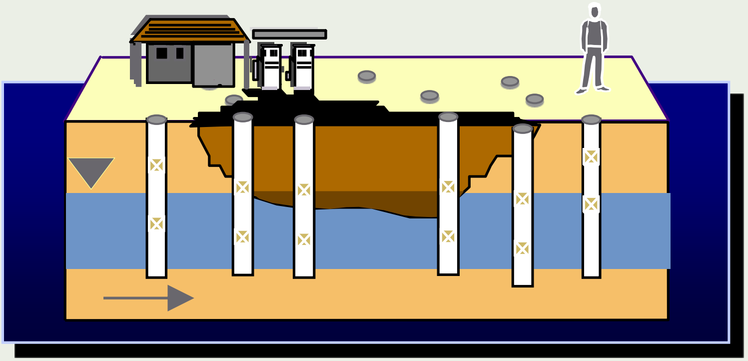
ImportData : Table

WellName	XCoord	YCoord	Constituent	SampleDate	Result	Units	DetLim	Flags
782MW-6R2	1137643.75	1174890.36	BENZENE	9/18/2003	0.0008	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	9/18/2003	0.00074	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	9/25/2003	0.00063	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	9/25/2003	0.014	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	9/25/2003	0.012	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	6/30/2003	0.00063	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	6/30/2003	0.00063	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	7/8/2003	0.00054	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	4/5/2004	0.00062	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	4/12/2004	0.00074	mg/L	0.00015	
782MW-6R2	1137643.75	1174890.36	BENZENE	7/1/2004		mg/L	0.00015	ND
782MW-6R2	1137643.75	1174890.36	BENZENE	9/22/2004	0.00021	mg/L	0.00015	TR
782MW-6R2	1137643.75	1174890.36	BENZENE	10/1/2004	0.0003	mg/L	0.00015	TR
782MW-6R2	1137643.75	1174890.36	BENZENE	12/27/2004	0.00021	mg/L	0.00015	TR
AP2MW-3	1138743.76	1174551.07	BENZENE	12/9/2003	2.2	mg/L	0.012	
AP2MW-3	1138743.76	1174551.07	BENZENE	9/19/2003	2.4	mg/L	0.012	
AP2MW-3	1138743.76	1174551.07	BENZENE	6/27/2003	2.6	mg/L	0.006	
AP2MW-3	1138743.76	1174551.07	BENZENE	6/27/2003	2.2	mg/L	0.012	
AP2MW-3	1138743.76	1174551.07	BENZENE	3/31/2004	2.1	mg/L	0.012	
AP2MW-3	1138743.76	1174551.07	BENZENE	7/2/2004	1.9	mg/L	0.012	
AP2MW-3	1138743.76	1174551.07	BENZENE	9/21/2004	1.2	mg/L	0.0075	
782SW-115	1138976	1174612	BENZENE	12/9/2003		mg/L	0.00015	ND
782SW-115	1138976	1174612	BENZENE	9/19/2003		mg/L	0.00015	ND
782SW-115	1138976	1174612	BENZENE	6/27/2003		mg/L	0.00015	ND
782SW-115	1138976	1174612	BENZENE	4/1/2004		mg/L	0.00015	ND
782SW-115	1138976	1174612	BENZENE	7/2/2004		mg/L	0.00015	ND
782SW-115	1138976	1174612	BENZENE	9/21/2004		mg/L	0.00015	ND
782SW-115	1138976	1174612	BENZENE	12/29/2004		mg/L	0.00015	ND
782SW-118	1139099	1174409	BENZENE	12/9/2003	0.0038	mg/L	0.00015	
782SW-118	1139099	1174409	BENZENE	9/19/2003	0.0038	mg/L	0.00015	
782SW-118	1139099	1174409	BENZENE	6/27/2003		mg/L	0.00015	ND

Spatial Database

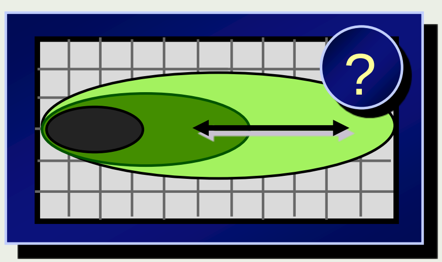
- **Spatial Database**
  - » Location coordinates
  - » Well construction/location details
  - » Well function (monitoring, extraction)
  - » Construction date
  - » Screened intervals
  - » Aquifer or unit
  - » Elevation





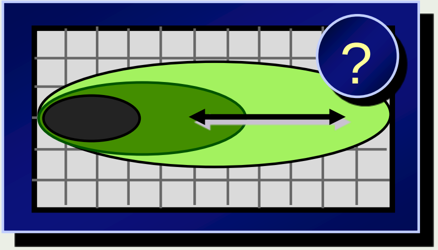
Spatial Data

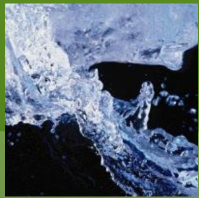
- **Spatial Data**
  - » Geographic coordinates
  - » Sampling locations
  - » Receptors
  - » Property boundaries
  - » Shape or dxf files – major features in GIS files
  - » Source areas or areas of peak concentrations



Spatial Data

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








Qualitative Approach to Long Term Monitoring Optimization

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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)

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**
  - Groundwater flow conditions
  - Monitoring objectives
  - Current and future exposure risk
  - Clean-up actions and timeframes

Qualitative Consideration of Groundwater Flow

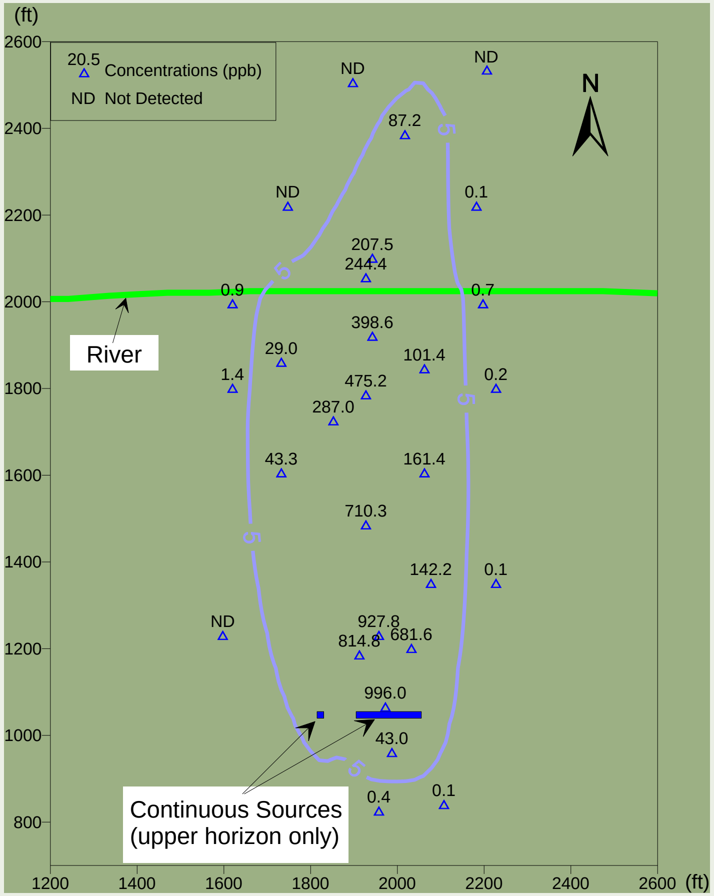
- **Question of likely flow paths – now/future**
  - Wells in higher permeability paths
    - Priority
    - Higher frequency
  - Cross- and up-gradient wells
    - Less frequently
  - Variable flow directions (e.g., seasonal)
  - Consider vertical migration in spatial optimization

Qualitative Consideration of Groundwater Flow

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

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**



Qualitative Consideration of Current/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**

Qualitative Consideration of Cleanup Actions & Timeframes

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

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

Combining Qualitative and Quantitative Approaches

- **Coupled Analysis has Advantages**
  - Subjectivity vs. Repeatability
- **Quantitative Results Need Qualitative "Reality Check"**
  - Consider Data Quirks
  - Consider Site Hydrogeology
  - Consider Well Construction, Sampling Depths
  - Address Stakeholder Needs
  - Consider Recent and Future Changes
  - Production and Land Use
  - Impacts of Climate, Other Factors
  - Qualitative Review May Trump Quantitative Results

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

Quantitative Approach to Long Term Monitoring Optimization

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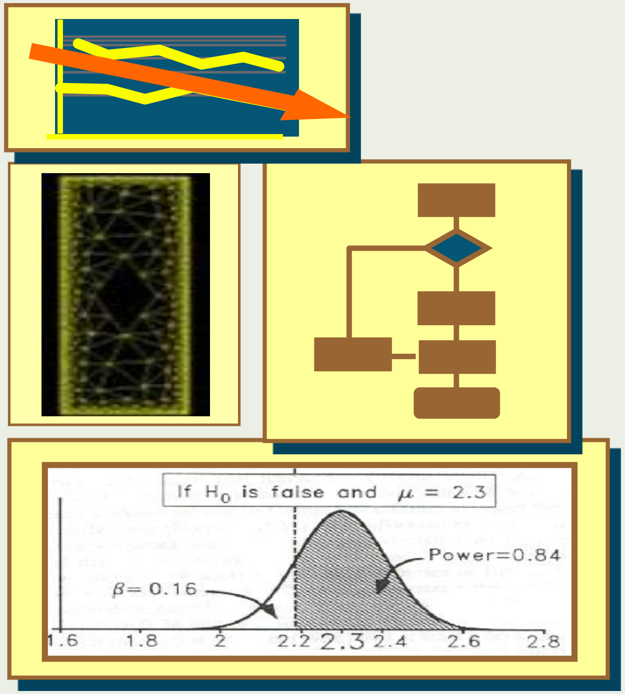
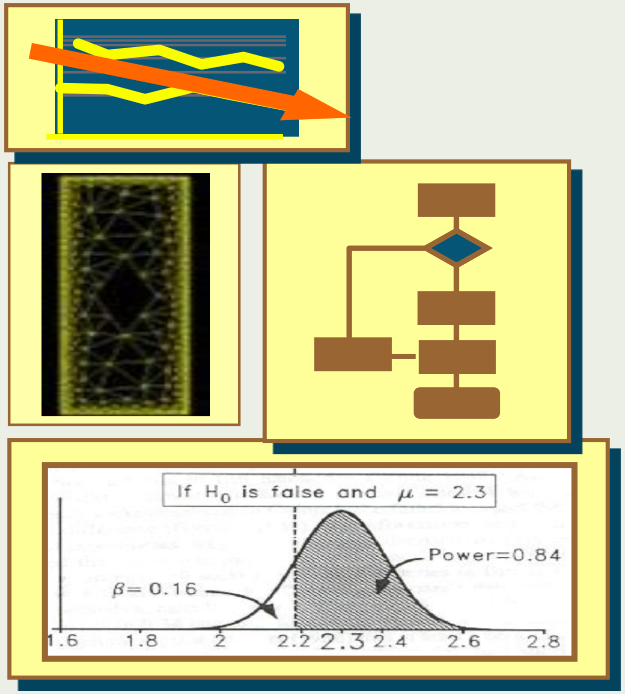
Methods

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



Methods

- **Quantitative LTMO Tools**
  - Statistical trend analysis
    - Individual well
    - Plume-level
  - Statistical significance testing
  - Interpolation/geostatistics
  - Mathematical optimization
  - Groundwater flow models



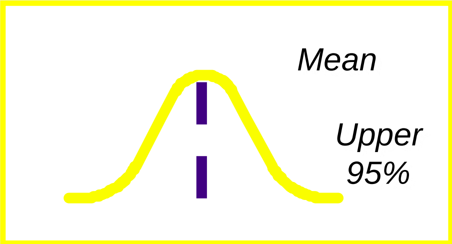
Example Tool: Monitoring and Remediation Optimization Software (MAROS)

Lines of Evidences	Method
Individual well trend	Mann-Kendall (linear regression)
Plume wide trends	Moment analysis: Total dissolved mass, center of mass, and distribution of mass
Well redundancy and sufficiency	Delaunay triangulation and slope factor calculation, along with area ratios and concentration ratios
Sampling frequency	Modified cost effective sampling
Data Sufficiency	Sequential T-Test, Student's T-Test and Power analysis
Qualitative Evaluation	Hydrogeologic factors, monitoring objectives, stakeholder concerns and all statistical results to develop final recommendations

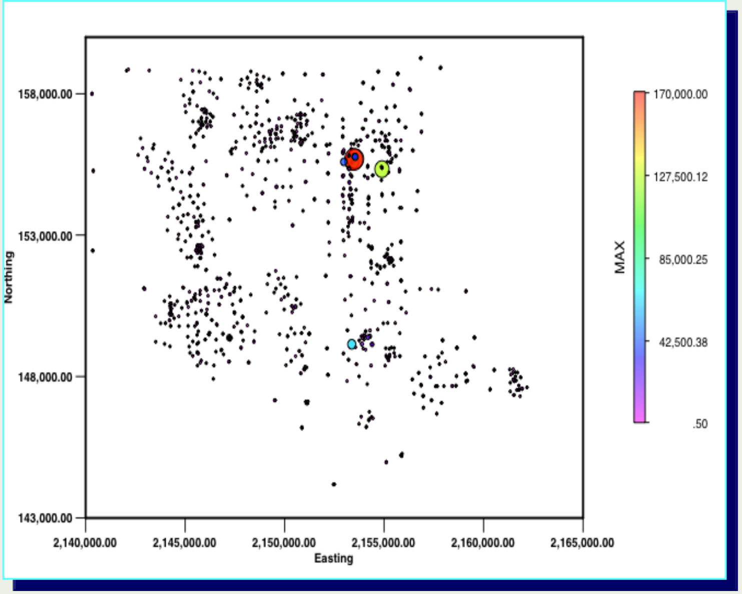
Uses Several Lines of Evidence to Develop Recommendations for the Monitoring Network

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"



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
					S =	- 2

Conclusion: decreasing trend

Mann-Kendall Test 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

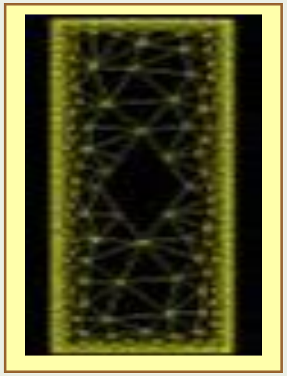
- **Coefficient of Variation**
  - COV = Standard deviation/mean

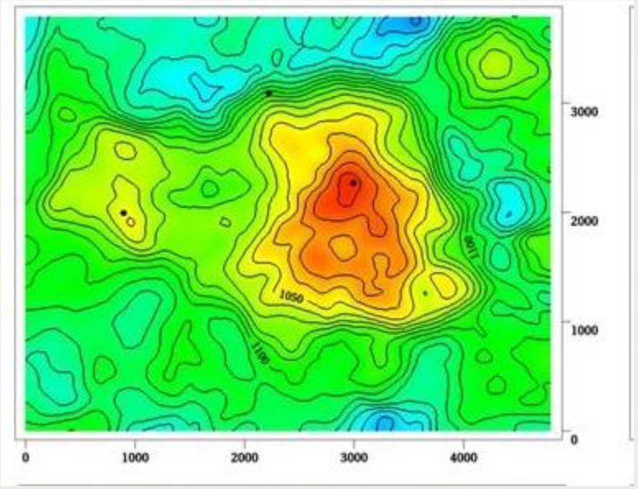
Mann-Kendall Test Results

Mann-Kendall Statistic		Confidence Factor: 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

Spatial Analysis

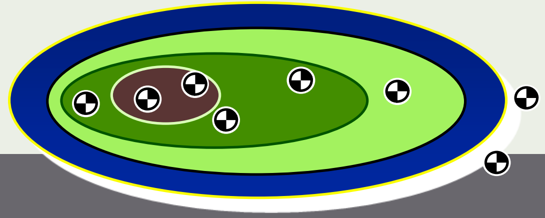
- **Mesh Creation – Delaunay/Theissen/Voronoi**
  - » Moments
  - » Spatial uncertainty
- **Statistical Surface Creation**
  - » Stepwise regression with linear estimators
- **Geostatistics-Kriging**
- **Groundwater Modeling**
- **Mathematical Optimization**





Plume Stability Evaluation

- Plume Delineation → Plume Length
- Trend Analysis → Well Concentrations
- Zero Moment Estimates → Total Dissolved Mass
- First Moment Estimates → Center of Mass
- Second Moment Estimates → Spread of Mass



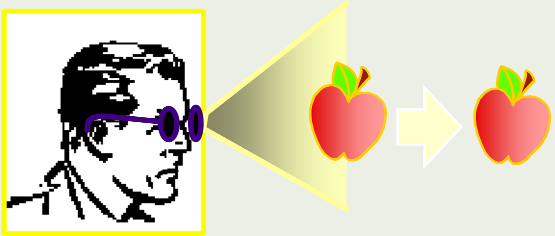
Temporal Analysis

- **Sampling frequency based on**
  - » Groundwater flow velocity
  - » Rate of concentration change

- **Decision logic methods**
- **Iterative thinning**
- **Combined spatial/temporal optimization**

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!

Questions?

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