Overview of Available LTMO Methods

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LTMO

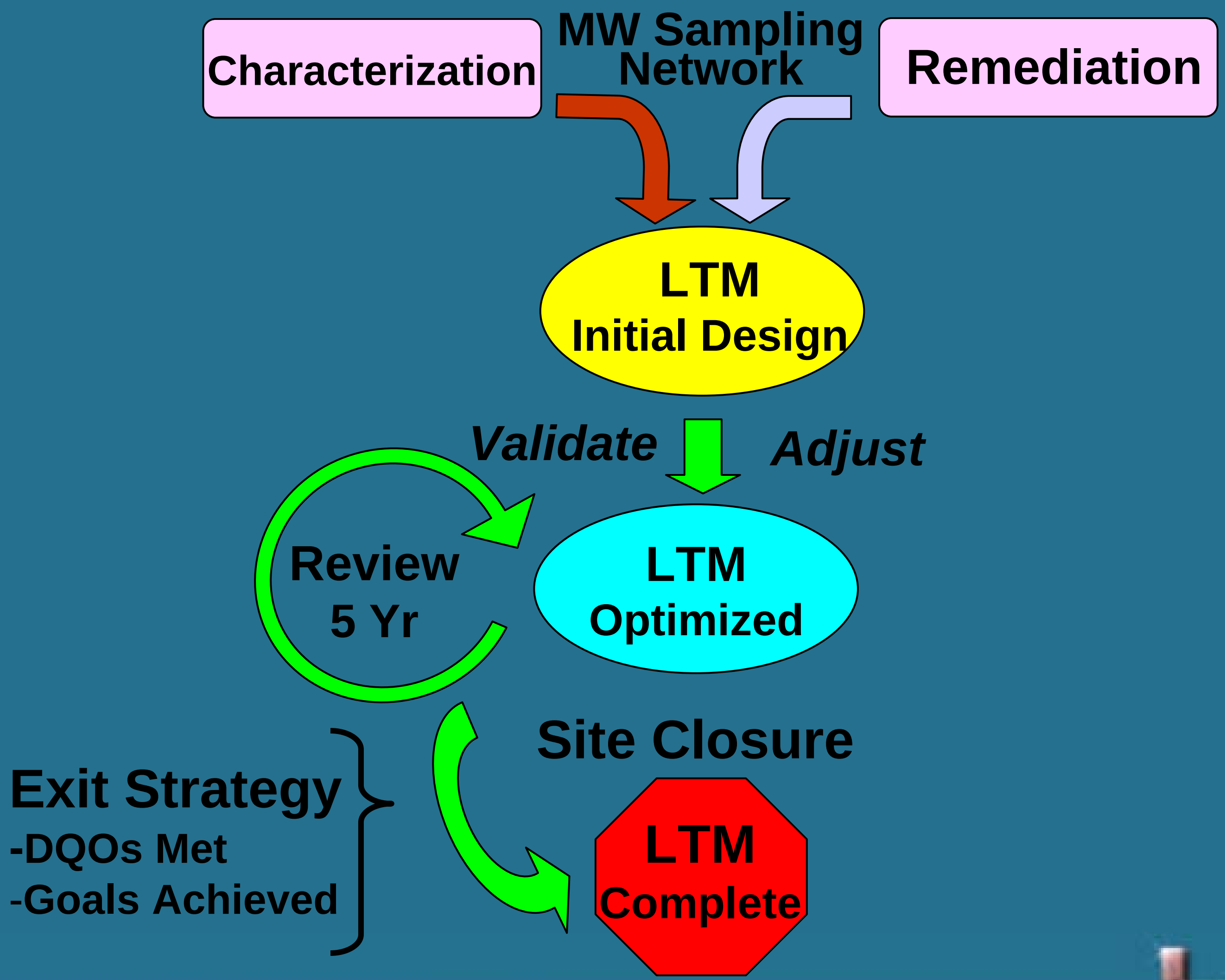
Overview

- Definitions; “Big Picture”
- Considerations when doing:
  - Qualitative reviews
  - Quantitative analyses
- Quantitative optimization approaches
- How qualitative & quantitative approaches fit together

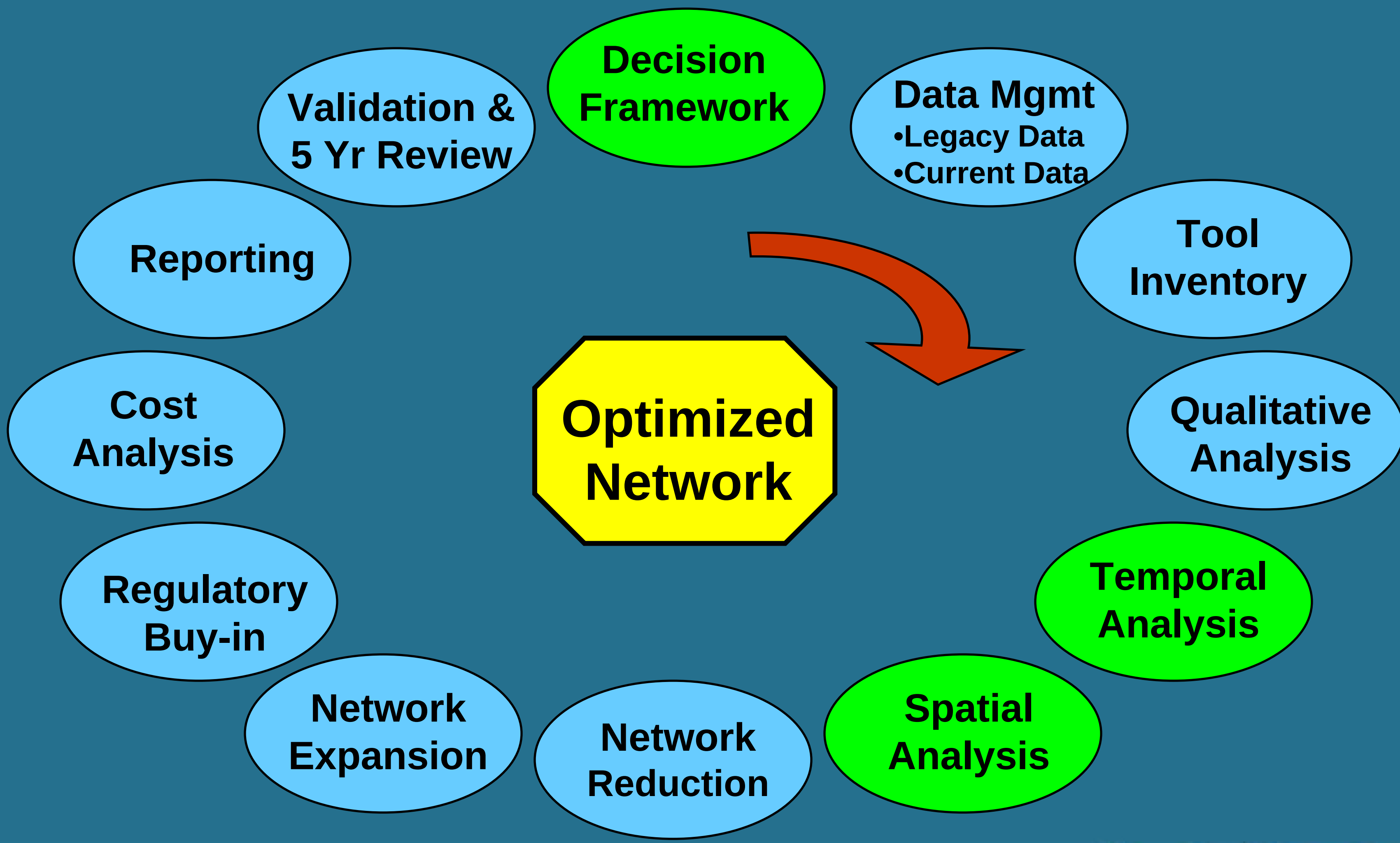
Definitions

- Qualitative Evaluation
  - Using technical expertise, professional judgment to assess LTM programs
- Quantitative Evaluation
  - Using statistical, numerical analysis to assess LTM programs
- What are we evaluating?
  - Temporal analysis: frequency of sampling
  - Spatial analysis: network of monitoring points
  - Relative importance of individual wells

LTMO "Big Picture"
Roadmap to Site Closure



LTMO Major Components
General Process



Qualitative Starting Point

- Understand GW & contaminant flow paths (present & future)
  - Rate & direction of advective transport (in 3-D)
  - Mobility & fate of contaminants
- Conceptual site model (CSM):
  - CSM includes:
    - Nature & extent of site contaminants
    - Fate & paths of COCs to reach receptors
    - Nature & location of possible receptors
    - Effects of current or planned remediation activities
    - Future conditions (e.g., land use)
  - Verify current CSM consistent with data recently collected as part of LTM

Qualitative Considerations

- Look at Sampling Frequency/Location
  - GW – monitoring wells, extraction wells
  - Surface water, air
  - Treatment plant
- Consider other aspects
  - Analytical & sampling methods
  - Data management
  - Visualization approach
  - Project-specific public or other stakeholder concerns

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Qualitative Considerations (cont.)

- Temporal analysis – experienced professional recommends sampling frequency based on:
  - Frequency of data assessment by project team
    - How often does the team assess the data?
  - Rate of contaminant migration
    - Usually, faster = more frequent sampling
  - Rate / nature of contaminant concentration change
    - Concentration trend slope, variability in concentrations
  - Time lag before action if monitoring indicates a problem
  - Public concerns / regulatory requirements

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Example Qualitative Logic for Optimization of Sampling Frequency

Reasons for Increasing Sampling Frequency	*Reasons for Decreasing Sampling Frequency*
Ground water velocity is high	Ground water velocity is low
Change in concentration would significantly alter a decision or course of action	Change in concentration would not significantly alter a decision or course of action
Well is close to source area or operating remedy	Well is farther from source area or operating remedy
Cannot predict if concentrations will change significantly over time	Concentrations are not expected to change significantly over time, or contaminant levels have met standards for some period of time

Qualitative Considerations (cont.)

- Spatial analysis - experienced professional recommends sampling locations based on:
  - Use of well as sentinel for exposure point
  - Past well performance (goes dry, poor construction)
  - Proximity to other wells in same aquifer
  - Proximity to known plume boundary
    - Near source for assessing impact of source control
    - Near leading edge of plume (lateral & vertical) to assess migration / capture

Qualitative Considerations (cont.)

- Other spatial considerations
  - Compliance point well?
  - Is well used to define BG?
  - Does well have long sampling history?
  - Identified data gaps

Example Qualitative Logic for Spatial Optimization

Reasons for Retaining or Adding a Well	***Reasons for Removing a Well From a Monitoring Network***
Well is needed to further characterize site, monitor concentration changes over time	Well provides spatially redundant information with a neighboring well (same constituents, short distance)
Well important for defining lateral or vertical extent of contaminants	Well has been dry for more than two years
Well is needed to monitor water quality at a compliance point or receptor exposure point	Contaminant concentrations are consistently below laboratory detection limits or cleanup goals
Well is important for defining background water quality	Well is completed in same water-bearing zone as nearby well(s)

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Quantitative LTMO Approaches

- Application of numerical and/or statistical techniques to LTMO:
  - Sampling frequency for existing wells/points
  - Sampling locations
  - Filling data gaps
- Provides degree of objectivity and repeatability
- Requires familiarity with statistical methods, some specialized expertise

Quantitative Approaches (cont.)

- Sample frequency – quantitative temporal analysis
  - Evaluate nature & strength of statistical trend
- Compute measure of variability, periodicity
  - Rule-based decision tree to recommend sampling frequency based on trend, variability, average concentration
  - Simulation approach – recommend sampling frequency based on observed & projected rate of concentration change

Quantitative Approaches (cont.)

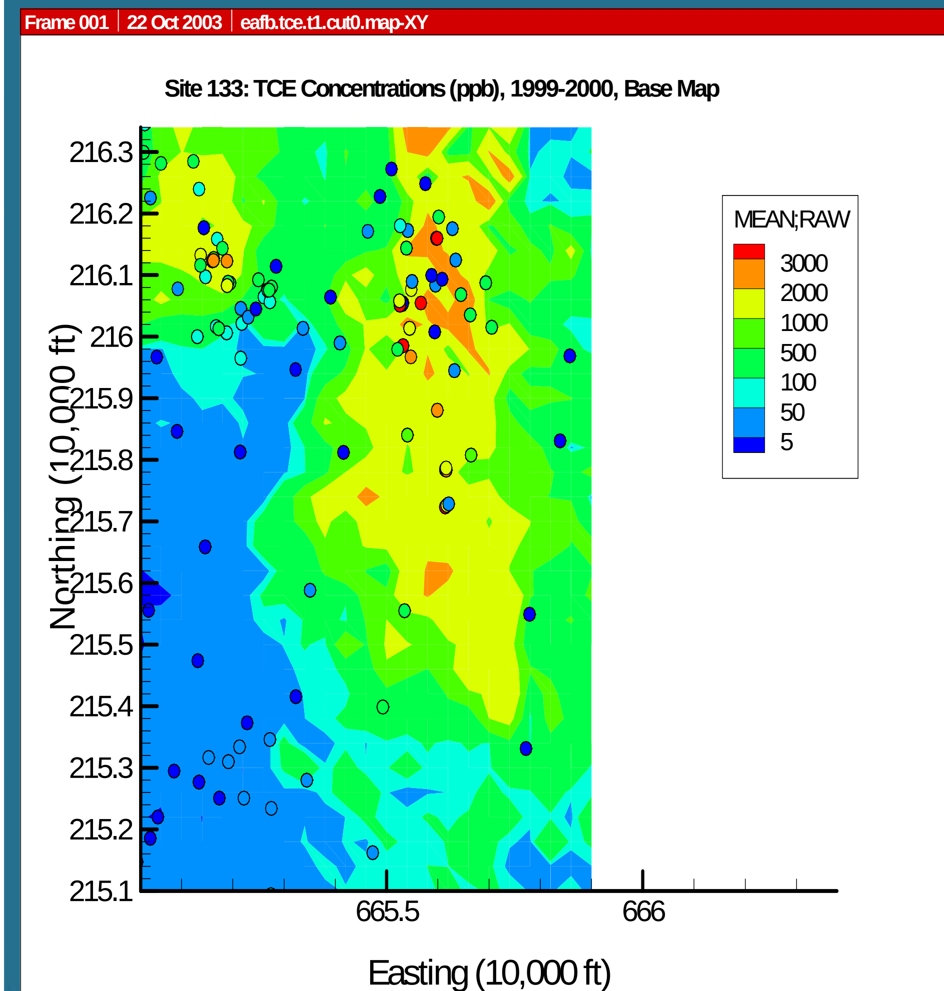
- Sample network optimization – quantitative spatial analysis
  - Ranking approaches
    - Use geostatistical or other weighting techniques to evaluate contribution of each well to plume definition
    - Identify areas of high uncertainty
  - Simulation approaches
    - Combine transport simulations with numerical optimization algorithms to minimize error in plume definition
    - Consider impact of additional well locations
  - Wells that contribute little are candidates for removal
  - Identify areas for additional wells

Quantitative LTMO: What Is the Opportunity?

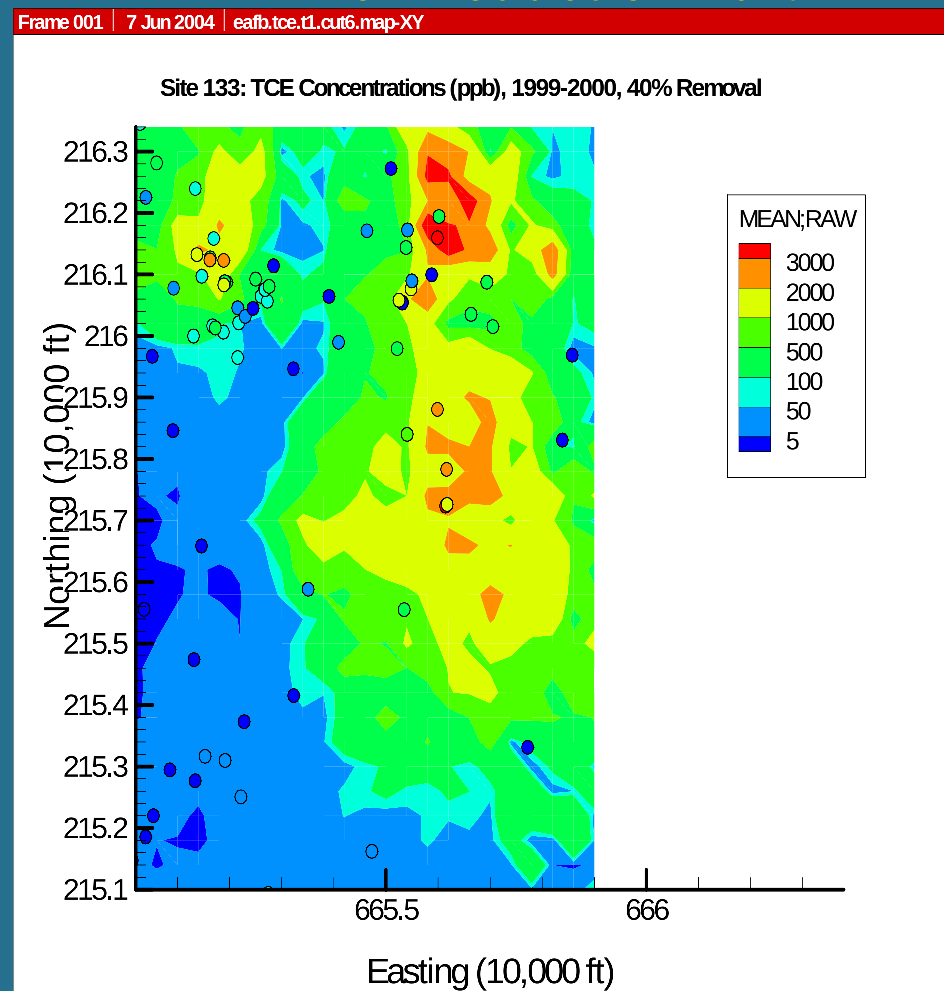
- LTMO case studies demonstrate redundancy in well networks
- Typical LTM sampling effort can be reduced by 20% – 40%
- LTMO focuses on essential data
  - Tolerable uncertainty in environmental decision-making accepted
- Helps to improve & simplify LTM programs

Quantitative LTMO Involves Spatial Comparisons

All Wells



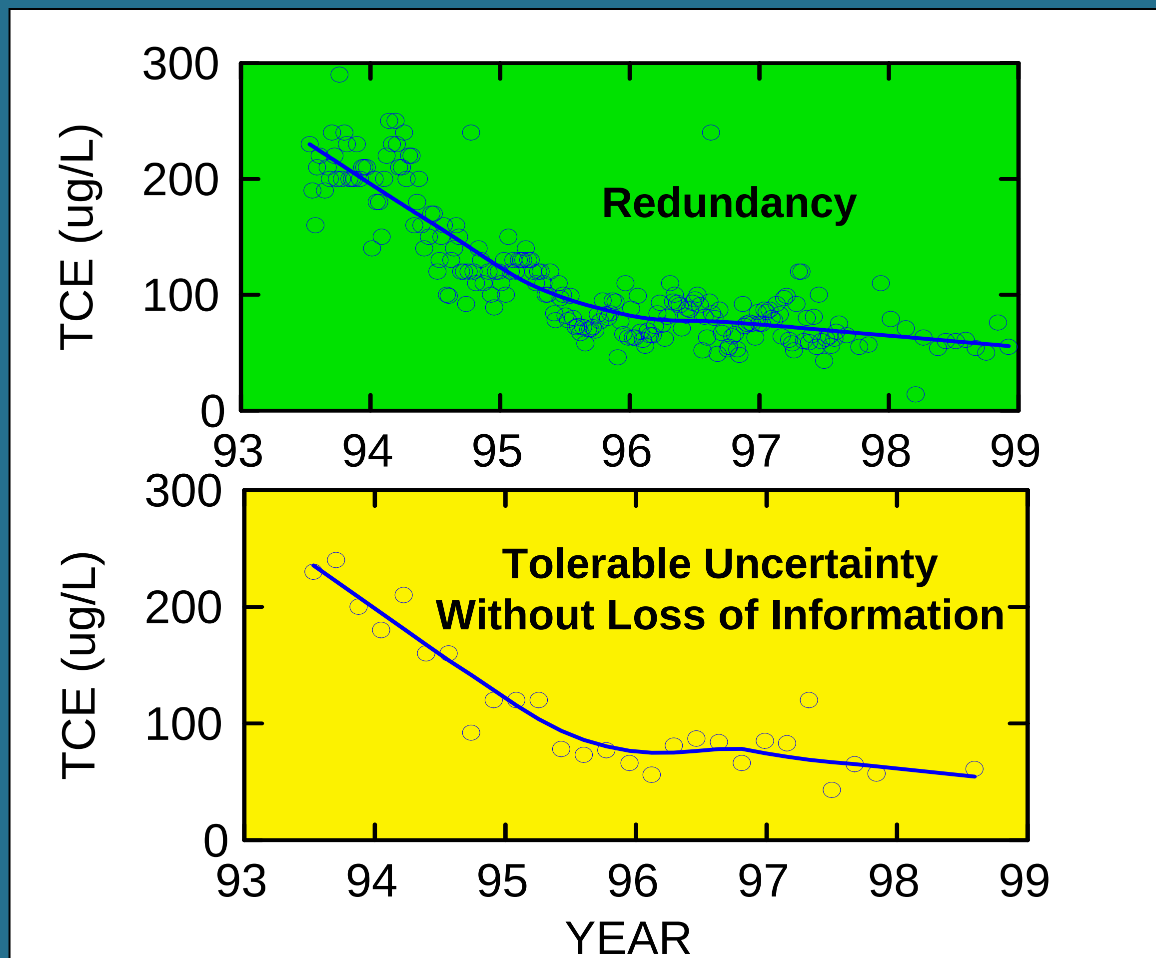
Well Reduction 40%



Quantitative LTMO Involves Temporal Comparisons

"Nice to have"
All Data
Samples = 240

"Essential"
90% Reduction
Samples = 27



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What's Out There?

PARSONS
3-Tiered LTMO

MAROS Decision Support System
for Optimizing LTM Programs

LONG-TERM MONITORING OPTIMIZATION GUIDE

FINAL
Version 1.1

October 1997

INTERIM FINAL

Guide to Optimal Groundwater Monitoring

Prepared for:
Naval Facilities Engineering Service Center
Port Hueneme, California

Remediation Optimization

Federal Remediation Technologies Roundtable

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Data Quality Objectives and Long-Term Monitoring Guidance

Navy and Marine Corps Working Group

Optimizing Remedial Action Operations and Long Term Monitoring

Long-Term Monitoring (COMING SOON!!)
Cost-Effective Sampling (Subterranean Research,

Geostatistical Temporal/Spatial (GTS) Optimization Algorithm

Long-Term Groundwater Monitoring: The State of the Art

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What is MAROS?

Monitoring and Remediation Optimization Software

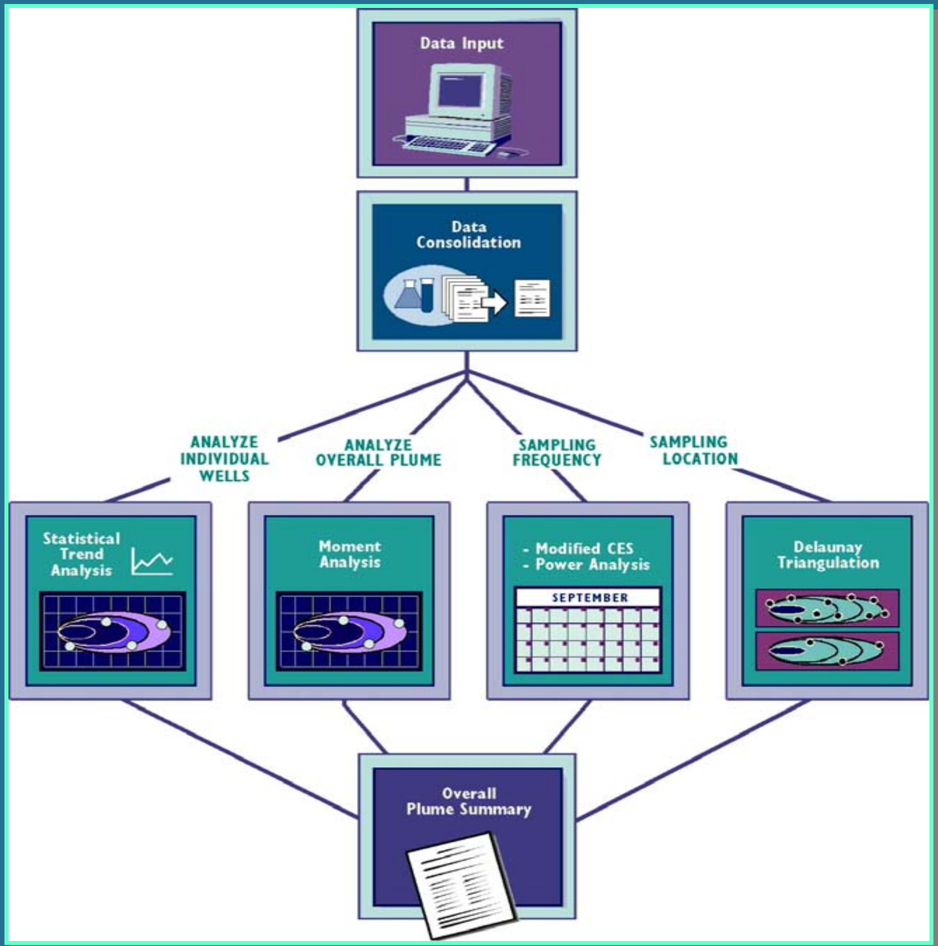
- **MS Access Database application** → ***YES***

- Simple statistical and heuristic tools
- Not mathematical optimization
- Modular
- Simple database input
- Employed after site characterization and remediation activities are largely complete

Limitations of MAROS

- Site modeled as a single plume
- Two-dimensional analysis
  - Different units analyzed separately
  - Multiple sources analyzed separately
- Simplifies and consolidates data
- Does not evaluate plume outside of current network
- Does not include purely regulatory requirements

MAROS Modules



- Database Input:
- Automated Data Consolidation
- Optimization Tools:
  - *Plume Trend Analysis*
  - *Moment Analysis*
  - *Well Redundancy*
  - *Well Sufficiency*
  - *Sample Frequency*
  - *Data Sufficiency*

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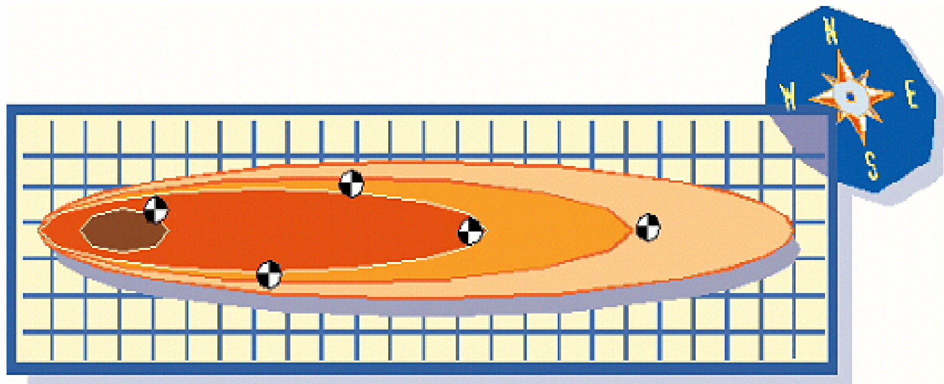
Data Input & Data Reduction

Monitoring and Remediation Optimization System (MAROS)

SITE DETAILS

Well Coordinates



Enter the coordinates for the wells that are missing data. This data will be used in the MAROS analysis and is mandatory. All coordinates must be in units of feet,(e.g., State Plane or arbitrary site coordinates can be used).

Well	Source/ Tail	X Coordinate (ft)	Y Coordinate (ft)
MW-1	S	13	-20
MW-12	S	100	-8
MW-13	S	65	23
MW-14	S	102	20
MW-15	S	190	-125
MW-2	T	-2	30
MW-3	T	35	10

<< Back | Next >> | Help | Well Map

Well Network Input Data:

- Source Wells (DNAPL)
- Tail Wells
- Extraction Wells

Data Consolidation:

- Non-detect values set to minimum or 1/2 detection limit.
- Average Duplicates
- Trace Values set to actual values
- Time Consolidation

Plume Characterization

Characterization of plume assumed to be complete

- Seasonality known
- Hydrology is known
- Significant COCs known
- Source areas known

MAROS reveals broad trends; individual data points less significant

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Uses Delaunay Triangulation

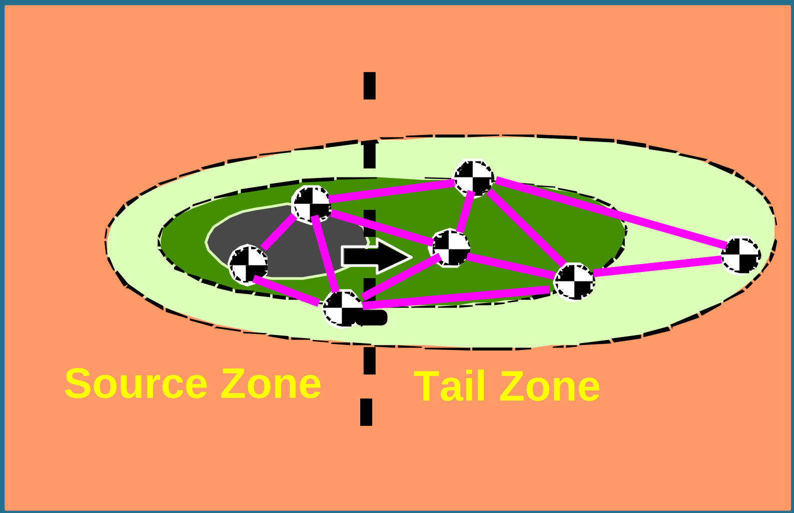
Well Redundancy and Sufficiency Analysis

Delaunay Method:

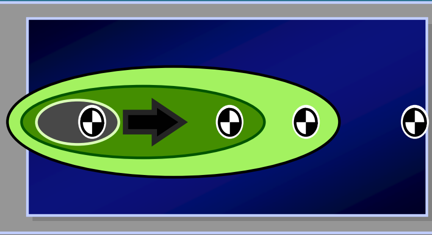
- Eliminate "redundant" wells

  OR

- Add wells in areas with high concentration uncertainty



KEY POINT: **Does estimated concentration change if well is removed?**



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Geostatistical Temporal-Spatial (GTS) Algorithm

- Emphasizes decision-logic framework
- "Plug-in" architecture
- Uses 'semi-objective' geostatistical and trend optimization methods
  - Variogram = spatial correlation measure
  - Locally-Weighted Quadratic Regression (LWQR)
    - Used for both spatial regression & fitting time series trends
- Prototype software available end of May 2005

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GTS Temporal Analysis

- Flexible strategies for optimizing sampling frequencies
  - Individual well analysis; “iterative thinning”
  - Temporal variogram for well groups & broad areas

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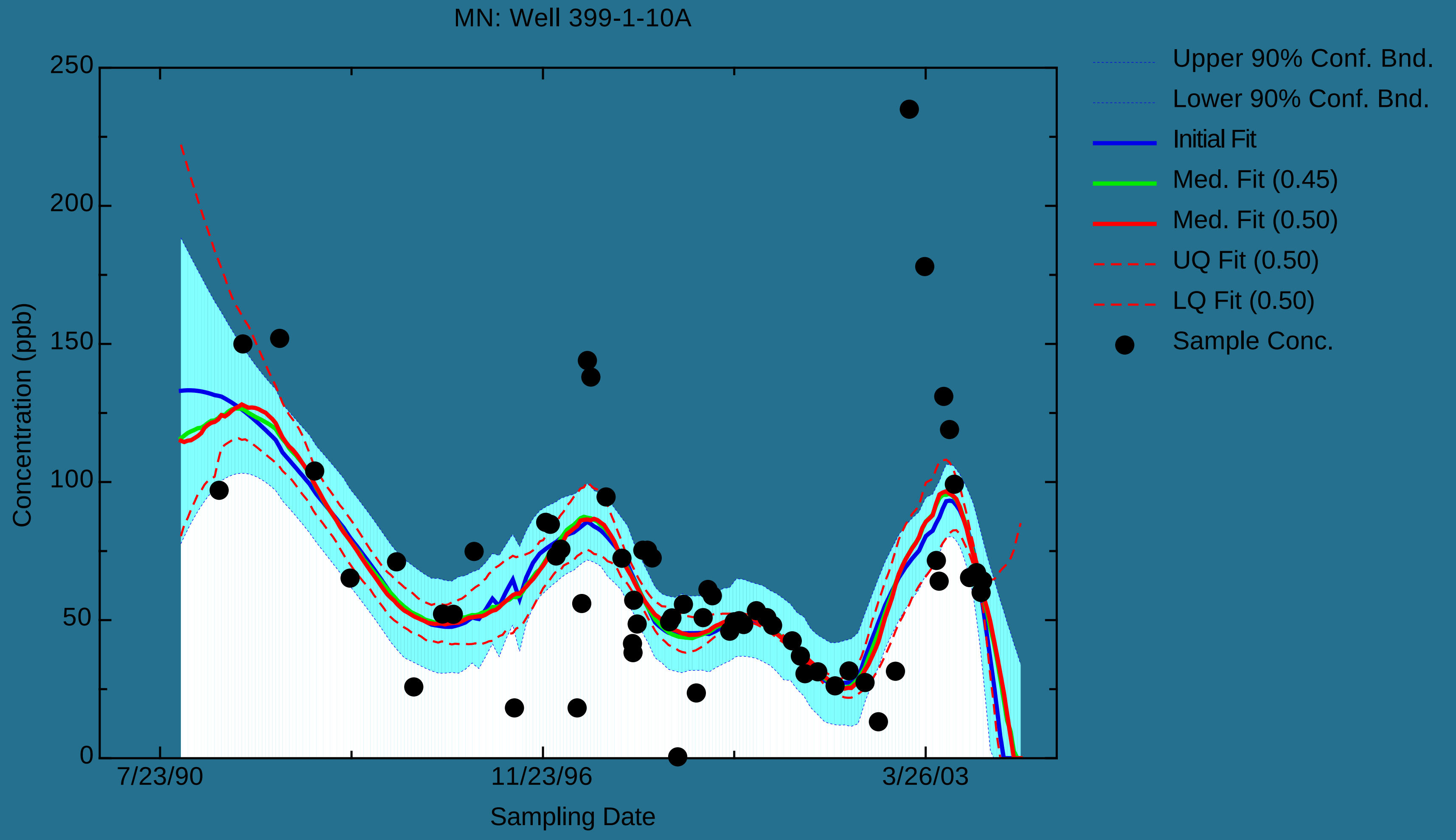
Iterative Thinning

- Individual well analysis
  - Estimate baseline trend
  - Randomly “weed out” data points
  - Re-estimate trend
  - Assess significant departure from baseline

Iterative Thinning Example



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Iterative Thinning Details

- At least 8 sampling events per well
- NDs set to common imputed value
- Complex trends, seasonal patterns OK
  - LWQR fits non-linear trends
- Median optimized interval can be used to set operational sampling schedule

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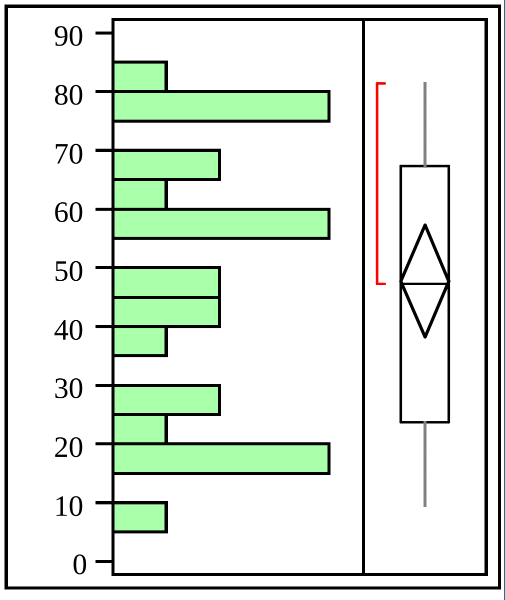
Iterative Thinning Summary



N Wells	25
LQ	24 wks
Median	47 wks
UQ	67 wks

GTS Spatial Analysis

- Uses Locally-Weighted Quadratic Regression (LWQR) to build maps
  - Create base map first
  - Iteratively remove wells that least change base map
    - Track bias, uncertainty
  - Construct cost-accuracy tradeoff curves

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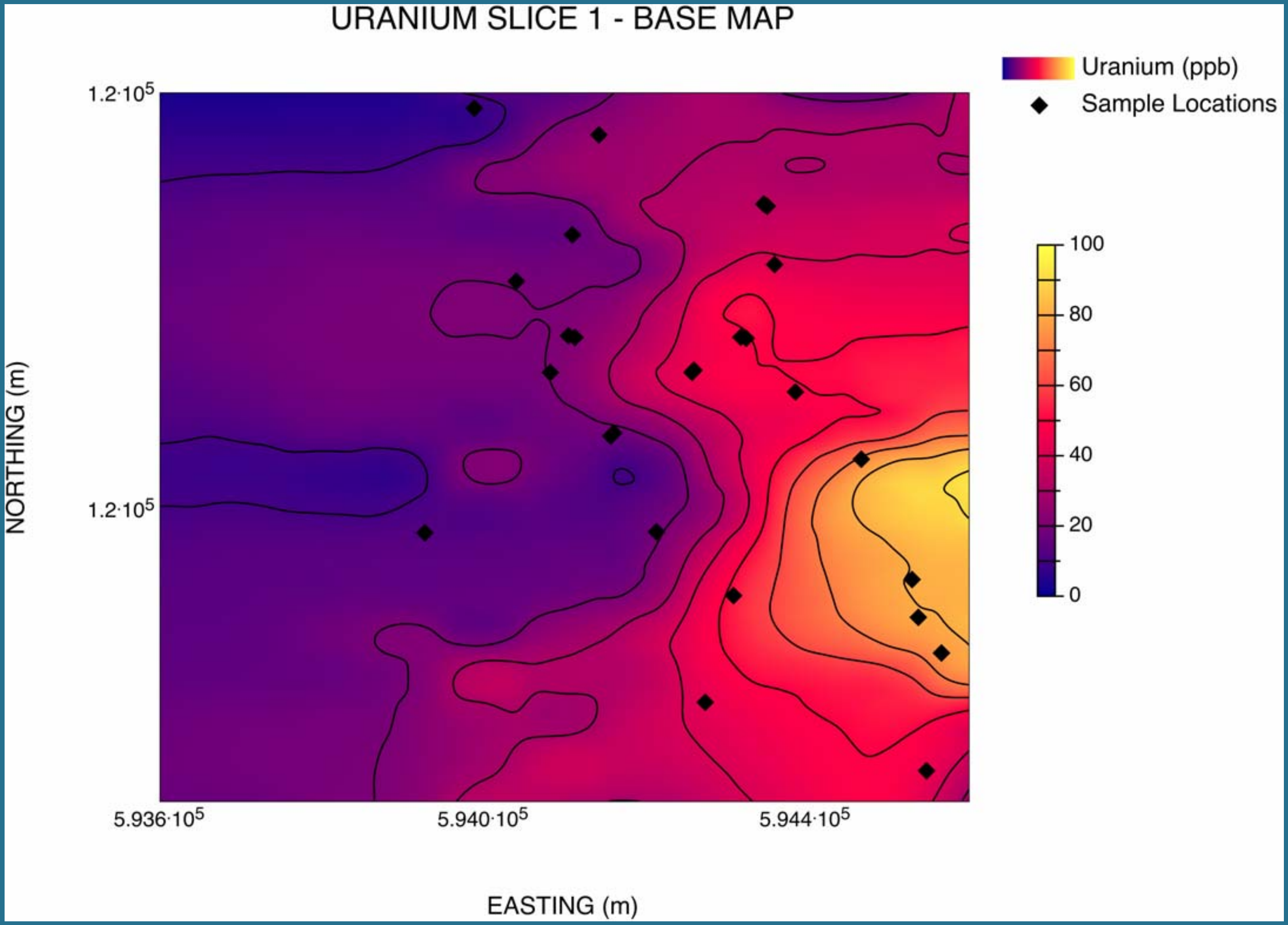
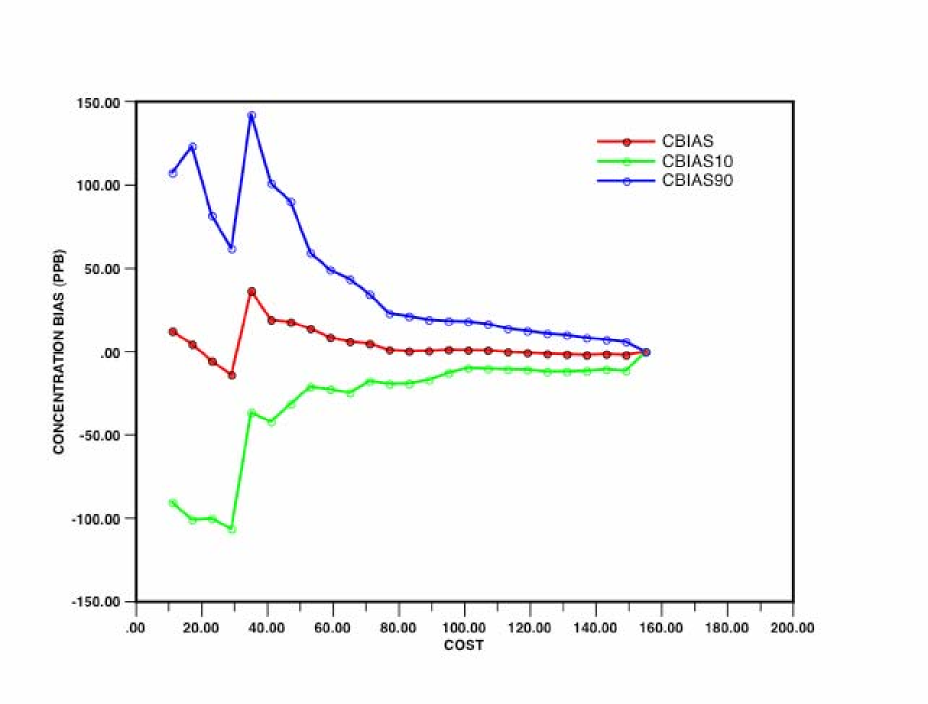
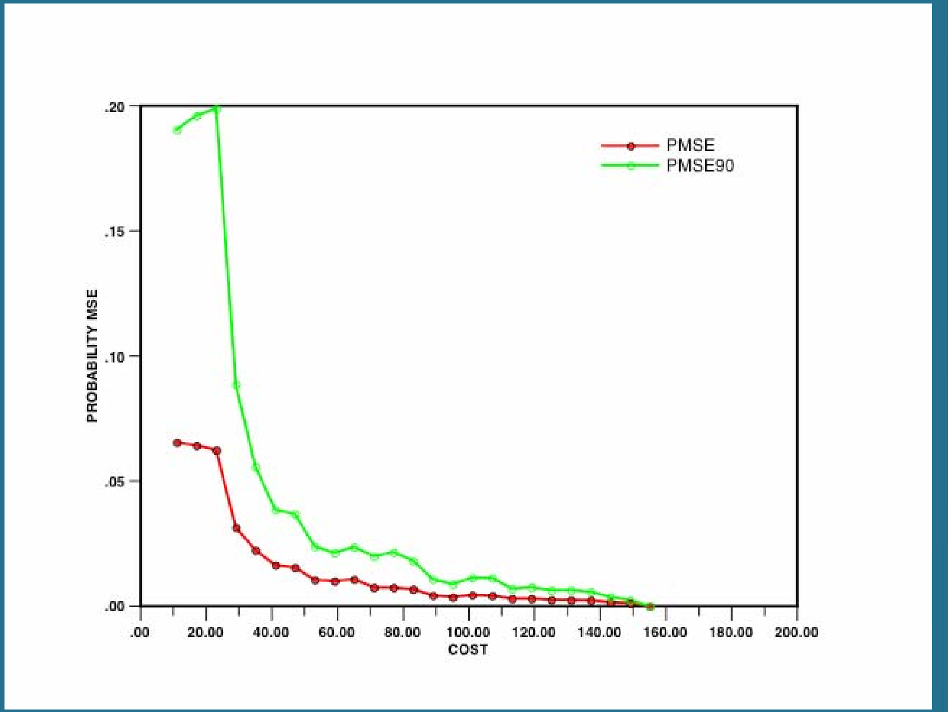
Base Map Example



Cost-Accuracy Curves





Spatial Analysis (cont.)

- LWQR Benefits
  - Smoothing technique, not an interpolator
  - Robust; does not assume or require a spatial covariance model (variogram)
  - Can handle highly-skewed data
  - Handles multiple values in time and space

GTS Spatial Details

- At least 20-30 regularly-monitored wells
  - Irregular sampling schedules OK
- Best COCs have:
  - Higher detection frequencies
  - Greater spatial spread & intensity
- Good to have 2-3 years of most recent monitoring data at each well

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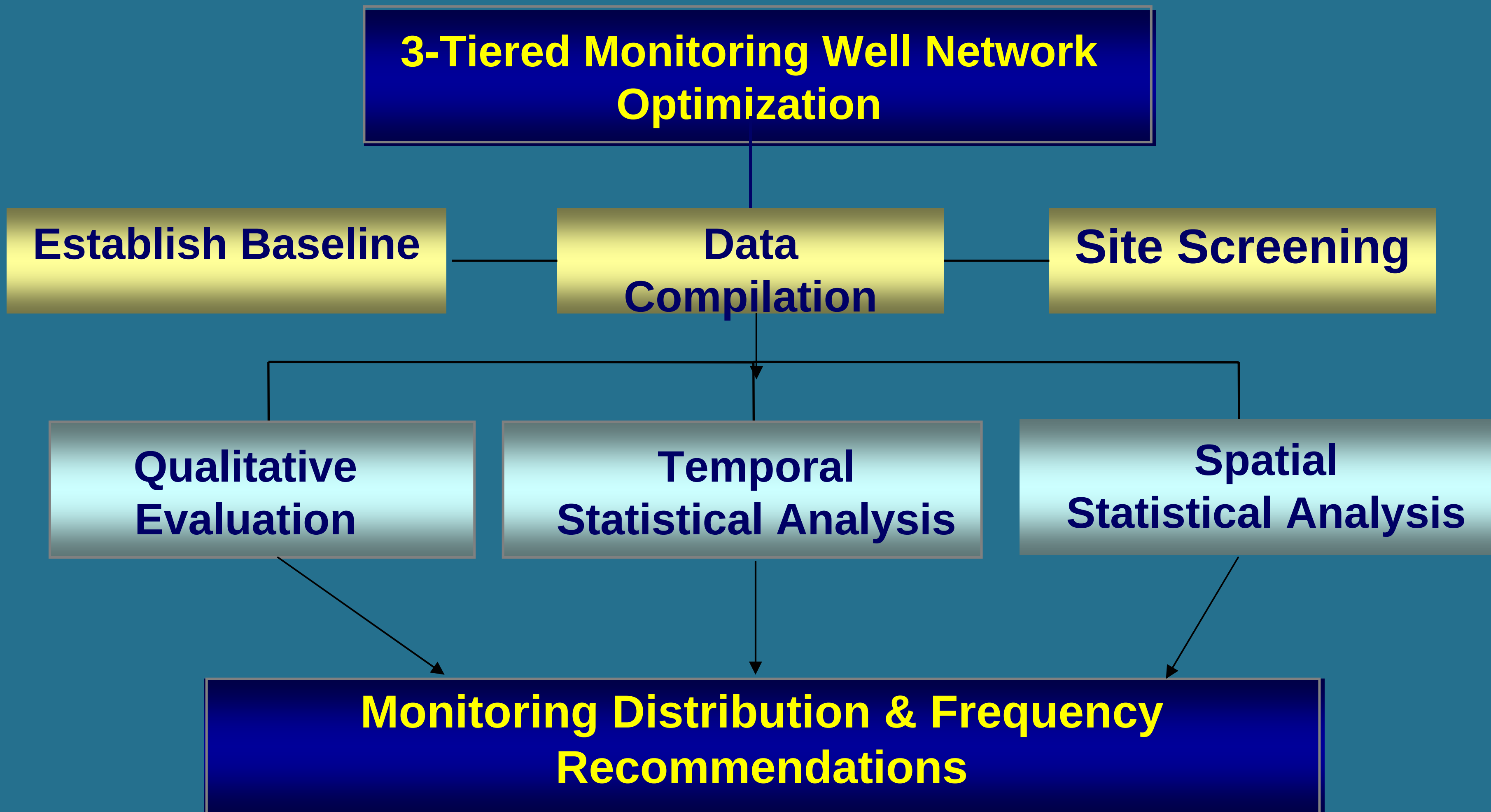
Parsons' 3-Tiered LTMO At A Glance



3-Tiered LTMO Strategy

- Qualitative Evaluation
  - Experienced geologist big-picture analysis
- Temporal Statistical Evaluation
  - Mann Kendall trend analysis
- Spatial Statistical Evaluation
  - Geostatisical Kriging relative predicted error analysis

3-Tiered LTMO Analysis

Combines three evaluations to optimize the distribution and frequency of ground water sampling.

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3-Tiered Approach
Qualitative Evaluation

- DATA
  - Site characterization
  - Monitoring results
  - Monitoring Network DQOs, etc.
- INFORMATION
  - Value of each well in big picture context
- SOLUTION
  - Recommend:
    - Well retention or removal
    - Optimal sampling frequency

Requires Experienced Hydrogeologist Familiar With Site

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3-Tiered Approach
Temporal Evaluation

- DATA:
  - >4 sampling results over time
  - Well/plume location & GW direction
  - Concentration relative to MDLs and PQLs
- INFORMATION:
  - Mann-Kendall Trend analysis
  - Automated process (MAROS/GIS script)
- SOLUTION:
  - Recommend retention or removal/reduction based on decision rationale

3-Tiered Approach
Spatial Evaluation

- DATA
  - Spatial "Snapshot" of Plume
    - Most recent chemical concs
    - Indicator chemical
    - Wells in same zone
- INFORMATION
  - Geostatistical (Kriging) Evaluation
    - Develop spatial model (semivariogram)
    - Calculate Kriging predicted standard error metric for each well
  - Conducted Using ArcGIS Geostatistical Analyst Extension
- SOLUTION
  - Recommend removal or retention based on relative value of spatial information of each well

Requires Experience with Geostatistics & Semivariogram Development

LTMO Tool Selection Factors

- Site conditions & existing network
  - Scale of network; # wells & sampling events
  - Single vs. multiple sites
  - 2D vs. 3D analysis
  - Single vs. multiple aquifers
- Choice of spatial & temporal algorithms
- Human resources & available technical expertise
- Regulatory input & concurrence

Combining Qualitative & Quantitative Approaches

- Quantitative results must be reviewed qualitatively by technical staff
  - Consider site hydrogeology
  - Address stakeholder needs
  - Consider recent & future changes
    - Production & land use
    - Impacts of climate, other factors
  - Qualitative review may "trump" quantitative results

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Combining Qualitative & Quantitative

- Might perform both qualitative and quantitative methods
  - Use rules, decision tree to adopt specific recommendations
    - Example: Parsons three-tiered approach

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Summary

- A variety of LTMO tools are available
- Many factors determine choice of tools for specific application
- Multiple LTMO tools may be used over time at any given site
- Key goals: Improving LTM programs & supporting environmental decisions