Optimizing LTM Networks with GTS: Three New Case Studies

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Basic Goal

- Need adequate & sufficient data to make good decisions
  - But not too much data
  - Want to minimize waste; maximize usefulness of data collected

- Optimization algorithm looks at two areas:
  - Monitoring network locations
  - Sampling frequencies in network
GTS Algorithm

- Designed with decision-logic framework
- Allows for separate identification of temporal & spatial redundancy
- Uses geostatistical and trend optimization methods
  - Variogram = correlation measure
  - Kriging = spatial interpolation = spatial regression
  - Locally-Weighted Quadratic Regression (LWQR)
Case Studies

- 3 AF sites with varied geology
  - Pease AFB, New Hampshire
    - Site 49, TCE plume from underground storage tank
    - Fractured bedrock; varied overlying geology
    - 67 wells used as baseline
Pease AFB Site 49 Plan View
Case Studies (cont.)

– Loring AFB, Maine

• Site OU-12, 30 contaminant sources, including BTEX, TCE
• Lightly to heavily-fractured bedrock; 3 distinct overburden units
• 115 wells used as baseline
Loring AFB OU-12 Plan View

Loring AFB Baseline Well Locations, Site OU-12

Well Locations
Edwards AFB, California
- Sites 133, 37; Contamination due to storage & waste disposal practices
- Fractured crystalline bedrock; weathered bedrock overlay
- 140 wells used as baseline

Question: could GTS be adapted to these situations?
Edwards Site 133 Plan View

Edwards AFB Baseline Well Locations, Sites 133 and 37

Well Locations

Diagram showing Edwards AFB Baseline Well Locations, Sites 133 and 37.
Note on Redundancy

- Practical definition: What happens when data removed from current system?
- **Temporal**
  - Can trends be re-constructed?
  - Do consecutive sampling events become uncorrelated?
- **Spatial**
  - Can surface map be re-constructed?
    - Plume extent and intensity
Optimality vs. Redundancy

- Redundancy a misnomer
  - All unique data points valuable
  - Always have loss of information if removed
- Must balance tradeoff between cost savings and loss of accuracy
  - Optimal system = minor information loss but large gain in resource savings
Optimality (cont.)

- **Common strategy**
  - Use existing data to estimate baseline
  - Remove some data (wells, sampling events)
  - Re-estimate baseline with reduced data set
  - Measure relative error incurred
  - Examine cost-accuracy tradeoff
Temporal Optimization

- Examine temporal redundancy
  - Too many sampling events at individual wells?

- Two approaches
  - Temporal variogram to estimate average correlation between sampling events
  - Iterative “thinning” of individual wells to adjust well-specific sampling frequencies
Temporal Variogram

- **Advantages**
  - Useful with irregularly spaced data
  - Data from multiple wells can be included
  - Single graph shows optimal global sampling interval
- Just need to determine sill and where it begins ("range")
  - Range can be taken as minimum global sampling interval
BZ Temporal Variogram
TCE Temporal Variogram

EDWARDS AFB, SITE 133: TCE TEMPORAL VARIOGRAM

FIT (BW 50%)
FIT (BW 70%)
LOWER 90% CONF BND
UPPER 90% CONF BND
Iterative Thinning

- Adjust individual well sampling frequencies
  - Global sill might not be evident
  - All wells may not behave the same way
  - **Operational target interval = median of individual well sampling intervals**

- Iterative thinning approach: overview
  - Estimate baseline trend
  - Randomly “weed out” data points
  - Re-estimate trend
Iterative Thinning Advantages

- Complex trends, seasonal patterns OK
  - LWQR fits non-linear trends
- Each well optimized uniquely
  - Not dependent on average correlation like temporal variogram
Iterative Thinning: Loring AFB

MN: Well JMW0301C

Sampling Date

Upper 90% Conf. Bnd.
Lower 90% Conf. Bnd.
Initial Fit
Med. Fit (0.30)
Med. Fit (0.35)
UQ Fit (0.35)
LQ Fit (0.35)
Sample Conc.
Spatial Optimization

- **Spatial redundancy**
  - Too many wells in network?

- **Spatial analysis**
  - Use LWQR to estimate typical contribution from each well to plume maps (global regression wgts)

- Wells tagged for removal if their contributions are essentially duplicated by nearby wells
  - Redundant wells have low regression wgts
Basic Approach

- Create basemap using all available data
- Iteratively remove lowest contributing wells; re-estimate map
- Measure loss of map quality/accuracy compared to baseline
  - Stop when maps deteriorate too much
Features of Spatial Algorithm

- Advantages to LWQR approach
  - A priori spatial model not required
  - Smoother, not an interpolator

- Can build site maps either in:
  - 3-D space
  - Separately by depth horizon or geologic unit
  - Separately by regulatory or geographic unit
    - As long as enough data available per unit
Edwards AFB: Base Map

Site 133: TCE Concentrations (ppb), 1999-2000, Base Map

Northing (10,000 ft)

Easting (10,000 ft)

Legend:
- Mean (RAW)
- 3000
- 2000
- 1000
- 500
- 100
- 50
- 5
Features (cont.)

- Semi-objective spatial optimization
  - Iterative “removal” of lowest contributing wells/sampling locations
  - At each stage, measure:
    - Differences in site maps from baseline
    - Increases in global uncertainty and average bias
    - Prevalence of areas of high local uncertainty
    - Misclassification bias
Pease AFB: Map Differences
Pease AFB: Map Differences

Site 49: DCA11 Indicator Differences, 2002, 55% Removal

Northing (10,000 ft)

Easting (10,000 ft)

IDIFF

-0.4

-0.3

-0.2

-0.1

0

0.1

0.2

0.3

0.4
Site 49: DCA11 Indicator Differences, 2002, 70% Removal

Map showing the differences in DCA11 indicator values for Site 49 at Pease AFB, with a color gradient indicating the magnitude of the differences from 0 to 0.4. The map includes a legend with color scales, and the axes are labeled as Northing (10,000 ft) and Easting (10,000 ft).
### Case Study Results

<table>
<thead>
<tr>
<th></th>
<th>Edwards</th>
<th>Loring</th>
<th>Pease</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original Interval</strong></td>
<td>Annual</td>
<td>Qtrly</td>
<td>Annual</td>
</tr>
<tr>
<td><strong>Optimized Interval</strong></td>
<td>Every 7 Qtrs</td>
<td>Every 2-3 Qtrs</td>
<td>Biennial</td>
</tr>
<tr>
<td><strong>Redundant Wells</strong></td>
<td>20-34%</td>
<td>20-30%</td>
<td>10-36%</td>
</tr>
<tr>
<td><strong>Cost Reduction</strong></td>
<td>54-62%</td>
<td>33-39%</td>
<td>49-52%</td>
</tr>
<tr>
<td><strong>Annual Cost Savings</strong></td>
<td>$230 K-$266 K</td>
<td>$306 K-$358 K</td>
<td>$85 K-$89 K</td>
</tr>
</tbody>
</table>
Edwards: Optimized Wells

Edwards AFB, Sites 133 and 37, Spatial Optimization Results

- Redundant Wells
- Essential Wells
Loring: Optimized Wells

Loring AFB, Site OU-12, Spatial Optimization Results

- Redundant Wells
- Essential Wells
Pease: Optimized Wells

Pease AFB, Site 49, Spatial Optimization Results

- Redundant Wells
- Essential Wells
Summary

- Novel use of geostatistical & spatial tools
  - Semi-objective optimization process
- “Plug-in” architecture, flexibility
  - Temporal, spatial, or both
- Recommendations can be combined with other optimization, sampling, or monitoring objectives
  - Clarify which wells are vital to monitoring program
Summary (cont.)

- **Flexible temporal optimization**
  - Iterative thinning for individual wells
  - Temporal variogram for broad selection of sampling locations
  - Edwards AFB
    - Not enough historical data for iterative thinning
    - Temporal variogram reduced sampling from annually to once every 7 quarters
  - Loring AFB
    - Both iterative thinning and temporal variograms suggested once every 2-3 quarters
Summary (cont.)

- Emphasis on visual/graphical output
  - Graphs of temporal variograms
  - Site maps of concentration levels
  - Maps of local uncertainty
  - Plots of redundant and essential sampling locations
- Substantial cost savings