# Optimizing Long Term Monitoring at a BP Site Using Multi-Objective Optimization Software

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**June 15, 2004**

*Conference On Accelerating Site Closeout,*

*Improving Performance, and Reducing Costs Through Optimization*



Moiré Inc.

# Other Project Participants

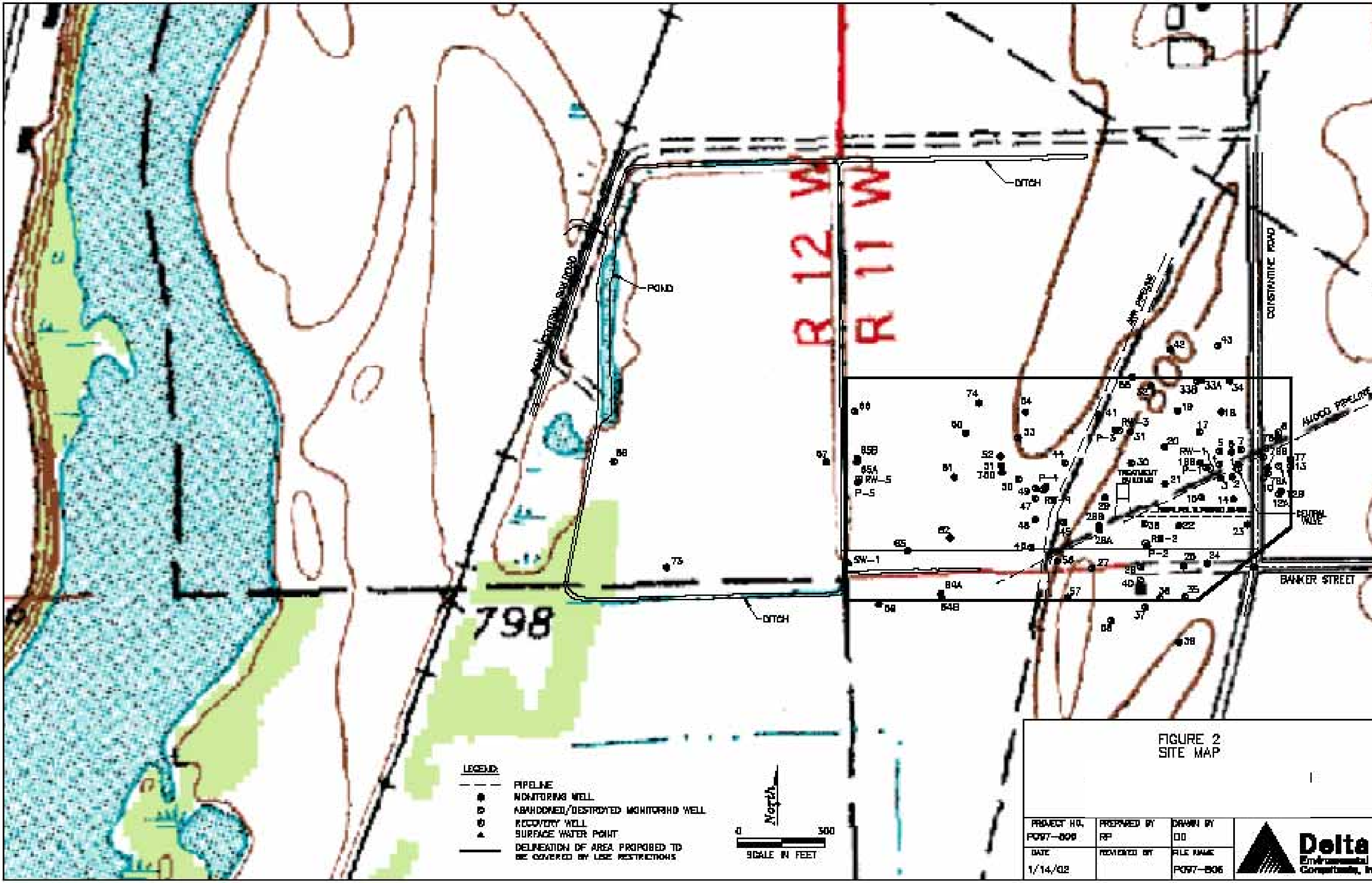
- **BP (formerly British Petroleum)**
  - Dennis Beckmann
- **Moiré, Inc.**
  - Peter Groves, Neil Kane, Tom Prudhomme
- **Delta Environmental Consultants, Inc.**
  - Jon Greetis
- **Meghna Babbar**

# Outline

- Introduction and project objectives
- Site background
- Optimization process
- Results
- Conclusions

# Introduction and Objective

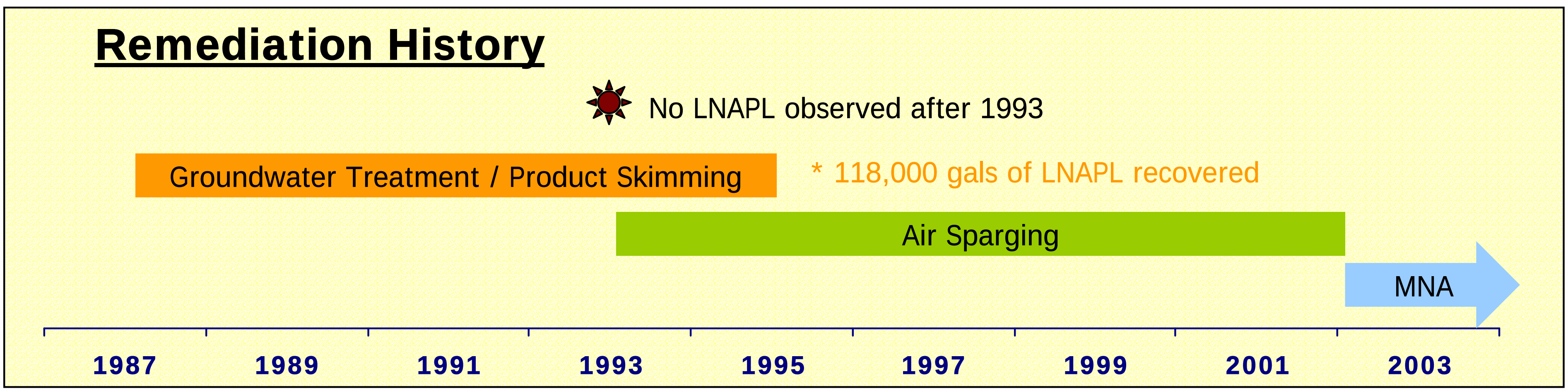
- **Long-term monitoring (LTM) costs can be substantial**
- **Optimization to eliminate data redundancies can help reduce costs**
- **Objectives:**
  - Demonstrate how mathematical optimization can be used to reduce LTM costs by eliminating data redundancies.
  - Develop an optimized long-term groundwater-monitoring plan for a BP site in Michigan
    - Number and placement of monitoring wells.



R 12 W
R 11 W
798
DITCH
POND
DITCH
CONSTANTINE ROAD
BANKER STREET
AMOCO PIPELINE
TREATMENT BUILDING
LEGEND:
PIPELINE
MONITORING WELL
ABANDONED/DESTROYED MONITORING WELL
RECOVERY WELL
SURFACE WATER POINT
DELINEATION OF AREA PROPOSED TO BE COVERED BY USE RESTRICTIONS
North
0
300
SCALE IN FEET
FIGURE 2
SITE MAP
PROJECT NO.
PREPARED BY
RP
DRAWN BY
DATE
1/14/02
REVIEWED BY
FILE NAME
Delta
Environmental
Consultants, Inc.

# Release History

- **Remedial Actions began in 1987 when a leaking pipeline gasket was discovered**
- **Catastrophic Release - estimates of the volume released are in the range of 350K gallons**



# Long-Term Monitoring Scenarios / Drivers

- **Discontinuation of air sparging operation primarily based on:**
  - Technical impracticability
  - Planned use of groundwater use restrictions
- **Natural attenuation provides plume stability with institutional controls to address residual hydrocarbons in source area.**
- **14 years of monitoring data to support plume stability assertion.**

# Long-Term Monitoring Scenarios / Drivers

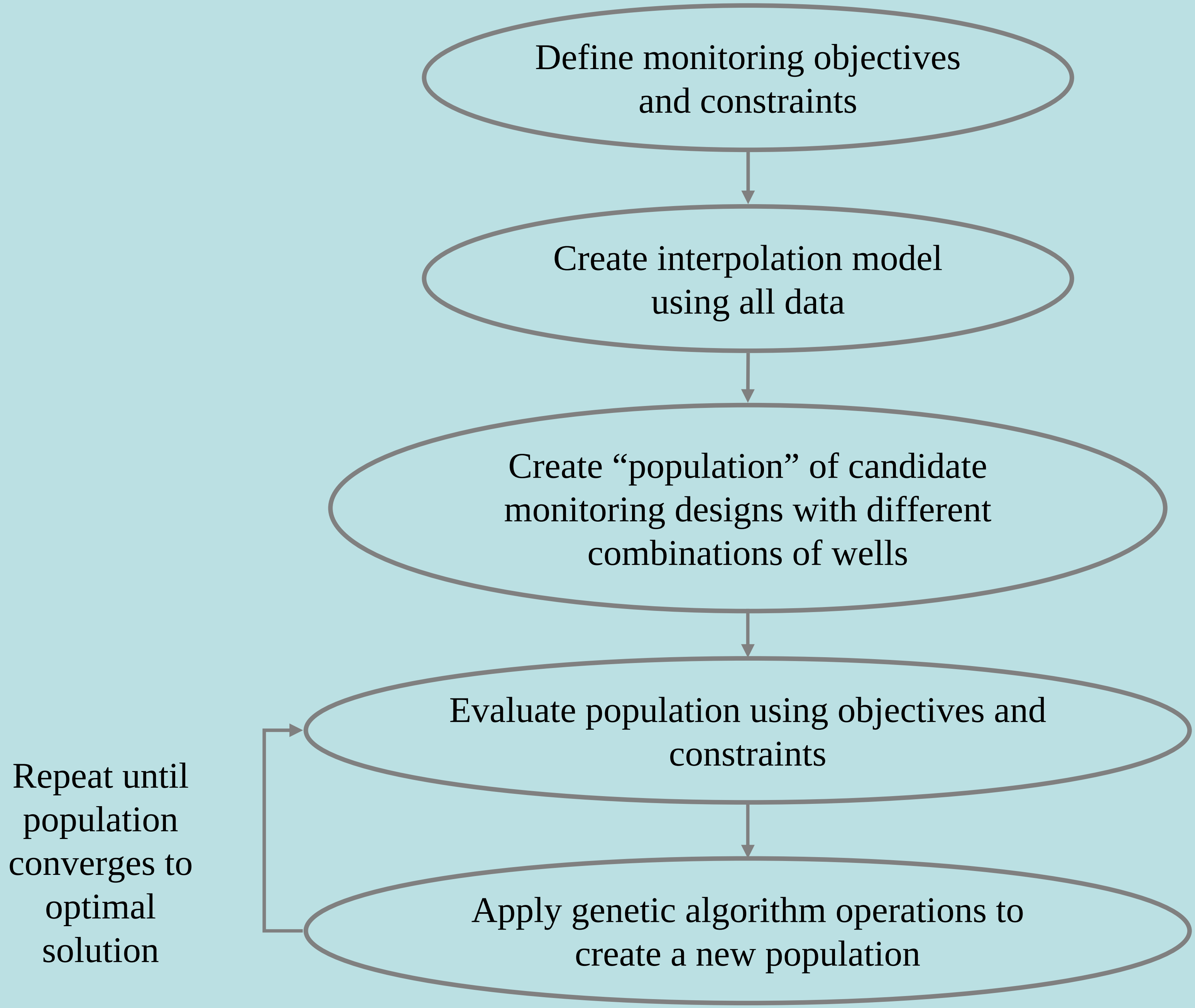
- **MDEQ Response:**
  - MDEQ will require 30 years of post-closure monitoring
  - Costs could reach $400,000 over 30 years
- **Optimization can be used to reduce costs of monitoring by eliminating data redundancy.**

# Redundancy Analyses

- **Spatial**
  - Wells that are spatially redundant provide information (usually on concentrations) that can be obtained from other nearby wells without substantially increasing errors
- **Temporal**
  - Temporal redundancy analyses identify reductions in monitoring frequencies based on redundant information from the same set of wells

- **Spatial Redundancy (BTEX) was evaluated in this case**

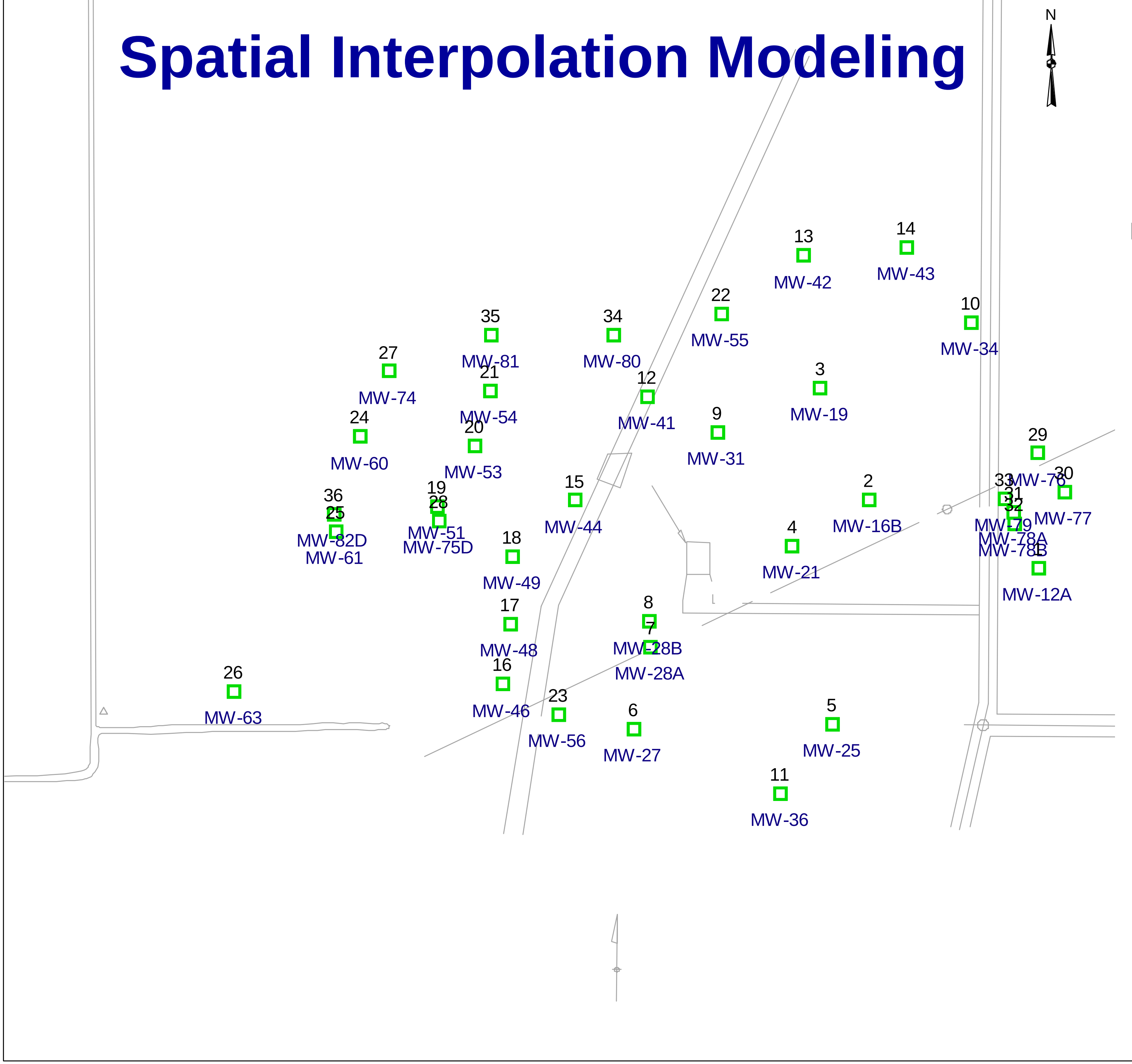
# LTM Optimization Process



# Interpolation Modeling Process

- Identify key contaminants of concern (COC)
- Create spatial grid for interpolating COC concentrations
- Fit interpolation models
- Test interpolation model fit and choose model with best performance

# Spatial Interpolation Modeling




**Legend:**

Current Monitoring Network - 7-Jan-04

14 Interpolation ID

MW-21 Monitoring Well ID

0 100 200 Feet

# Site Map

Date:
16 Jan 2004

Delta Environmental Consultants, Inc.

# Interpolation Model Evaluation

- **To test interpolation model, use cross-validation**
  - Eliminate data from well 1
  - Interpolate concentration at well 1 from data at all other wells
  - Compare interpolated concentration with measured concentration
  - Repeat for all other wells

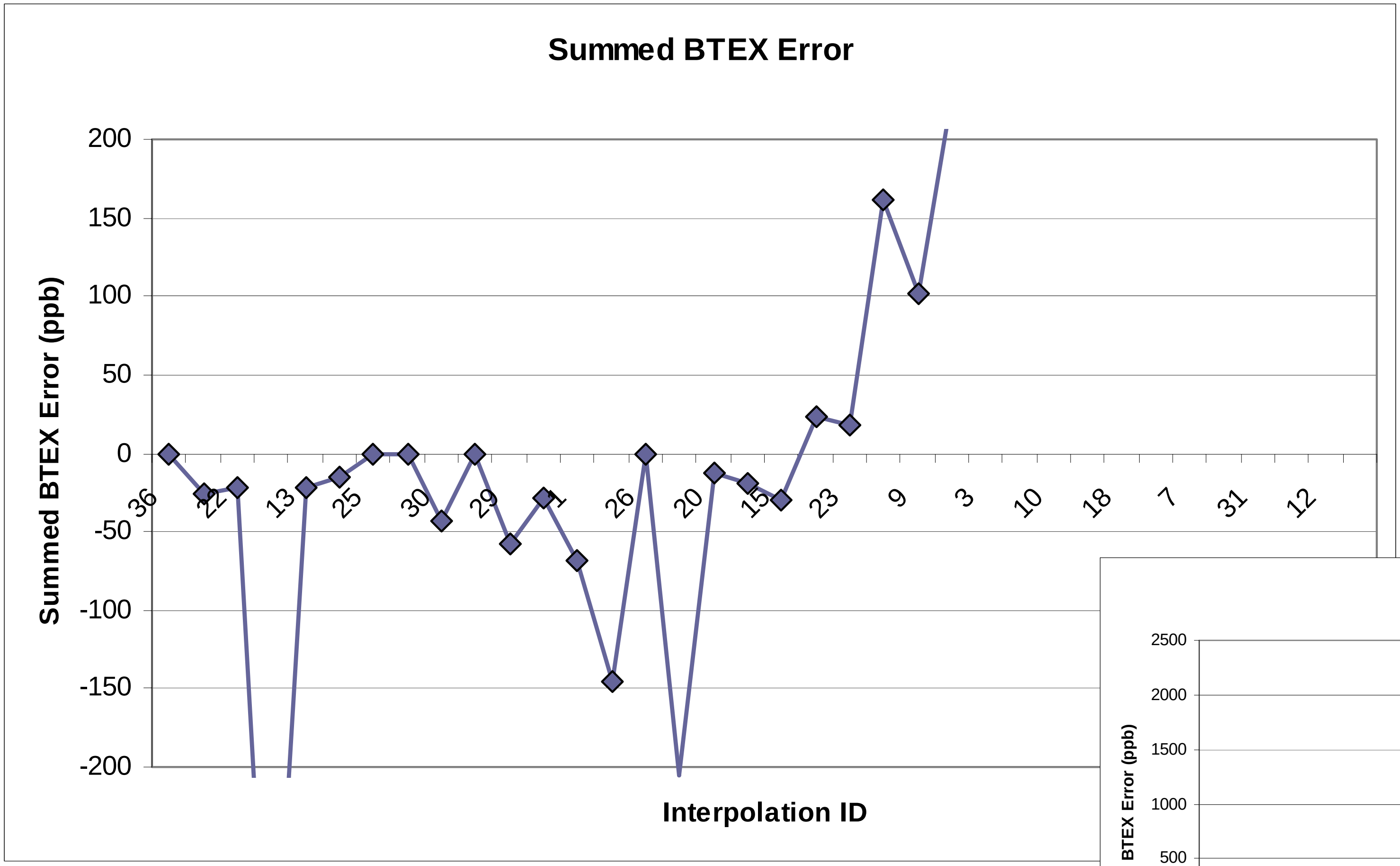
# Interpolation Modeling Results Summary

- **A suite of interpolation approaches were tested**
  - Ordinary kriging
  - Quantile kriging
  - Inverse distance weighting
  
  } Most recent data only
  - Neural network for detrending in time, with quantile kriging for residual - historical data
- **Quantile kriging performed best of first 3 approaches, with variograms fit to each BTEX constituent and then summed**
- **Detrending using historical data provided small increase in accuracy, but very large computational time increase**

# Interpolation Modeling Results Summary (cont'd.)

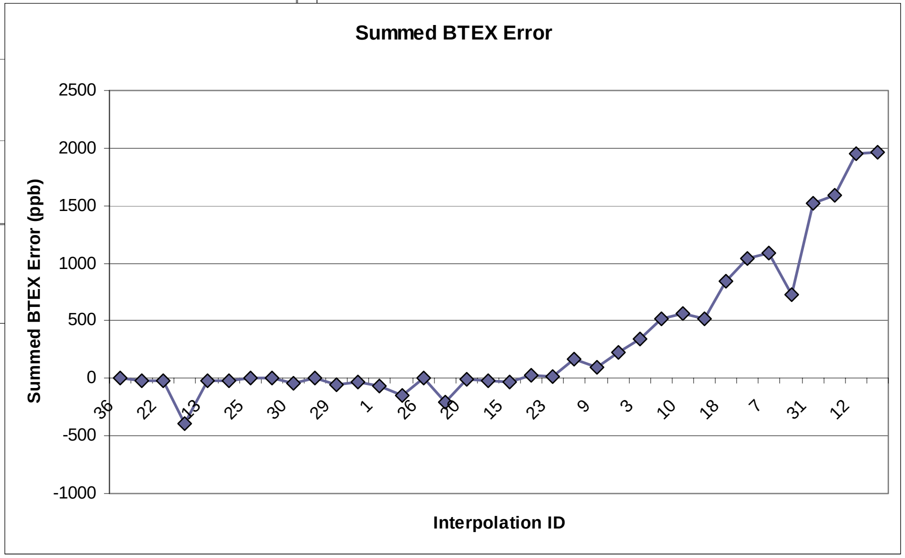
- **Of the 36 wells, the following numbers of wells were predicted sufficiently accurately during cross-validation:**
  - Benzene: 17 (within 5 ppb)
  - Toluene: 32 (within 100 ppb)
  - EthylBenzene: 28 (within 100 ppb)
  - Xylene: 23 (within 100 ppb)
  - BTEX: 19 (within 100 ppb)
- **Benzene performs quite well, but has a much stricter acceptability threshold.**
- **Summing the predictions of the components of BTEX gives a small boost in accuracy over predicting it directly.**

# Cross-Validation Results for BTEX (summed from constituents)




Zoomed In

Zoomed Out




Interpolation ID (Well ID) sorted by true concentration

# Optimization Process

- **Create Optimization Formulation**
  - Decision Variables
  - Objective Functions
  - Constraints (none for this site)
- **Use genetic algorithms to search for monitoring designs that best meet the objective functions and constraints**
  - When more than one objective exists, find optimal tradeoffs among objectives (e.g., cost vs. errors)

# Decision Variables for This Site

$$x_i = \begin{cases} 1 \ \textit{if well } i \textit{ is sampled} \\ 0 \ \textit{otherwise} \end{cases}$$

Optimization problem is to identify values of the $x_i$, for *i* = 1 to 36 wells

$2^{36} = 7\text{x}10^{10}$ possible sampling plan designs

# Objective Functions for This Site

- **Minimize Cost (no. of wells):**

$$\text{Minimize} \sum_{i=1}^{n} x_i$$

- **Minimize maximum error between actual concentrations and those estimated with subset of K wells:**

$$\text{Minimize} \left[ \underset{K}{\text{Max}} \left\{ \text{Error} = \left| c_i^{actual} - c_i^{est}(K) \right| \right\} \right]$$

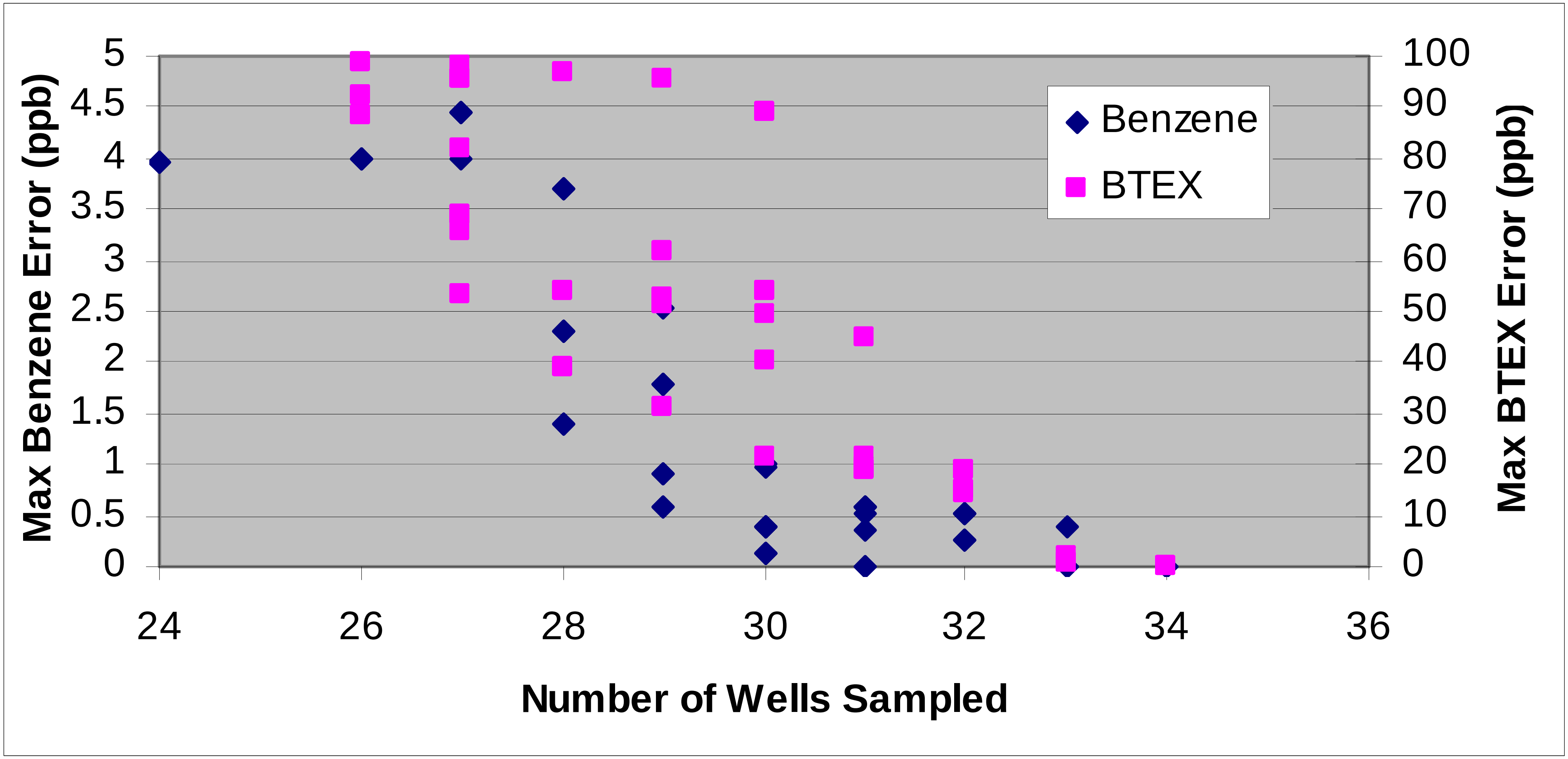
# Error Objective Functions for This Site

- **One error objective for benzene and one for BTEX**
  - Scaled by maximum acceptable error (5 ppb for benzene, 100 ppb for BTEX)
- **Locations for measuring error are important**
  - At monitoring well locations only
  - Other locations in the interpolation grid have no data support, so could only compare predictions with modeled values that have errors themselves

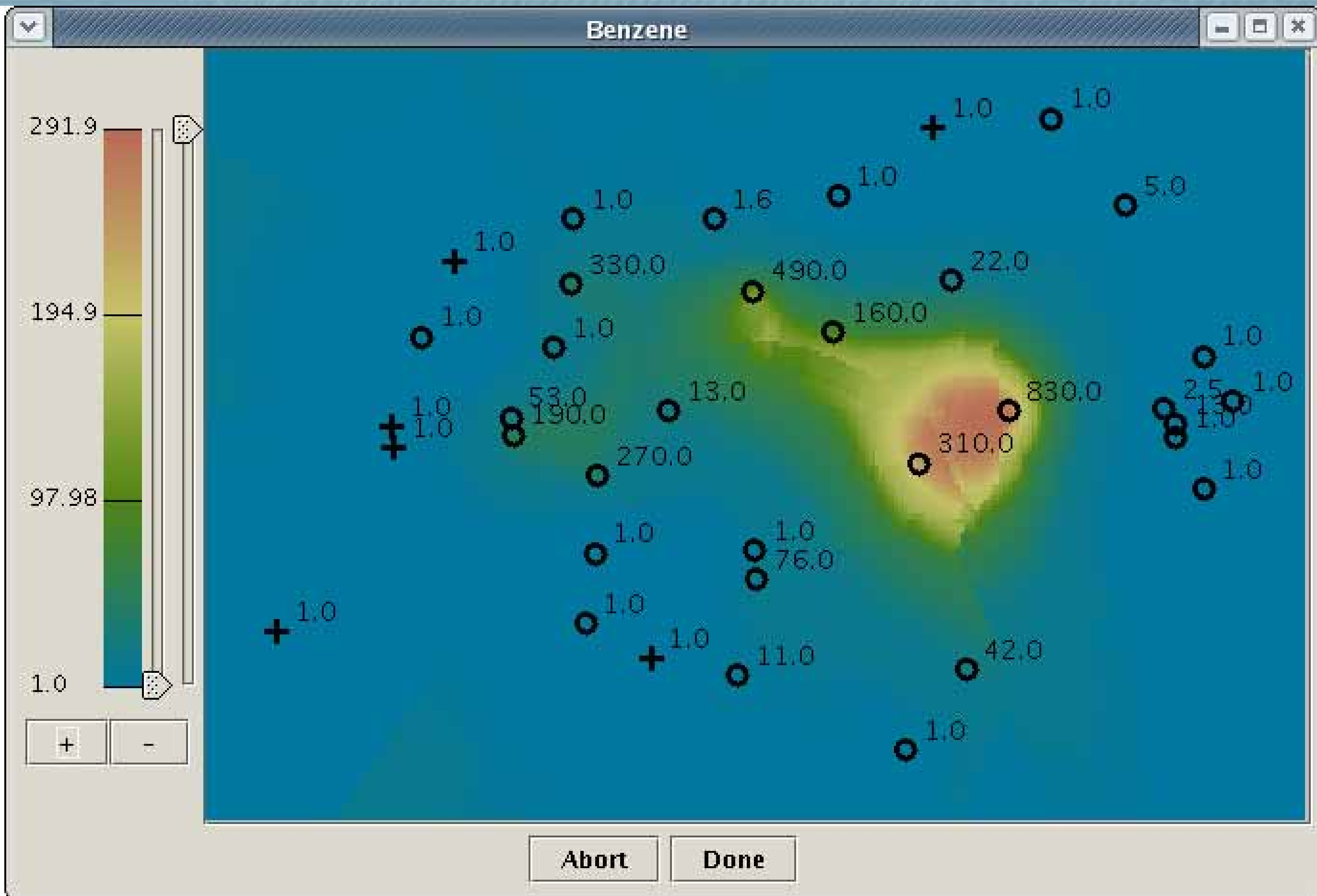
# M-LTMO Software

- **Optimization process was implemented in Multi-objective Long Term Monitoring Optimizer Software (M-LTMO) developed at University of Illinois and Moire**
  - Automated interpolation model fitting and selection
  - Multiobjective optimization to find monitoring designs that best meet objectives
- **For more information and a demonstration of the software, come to the Long-Term Monitoring Optimization Methods and Software Workshop Wednesday evening from 6:30-9 PM**

# Optimal Tradeoffs Between Errors and Sampling Levels

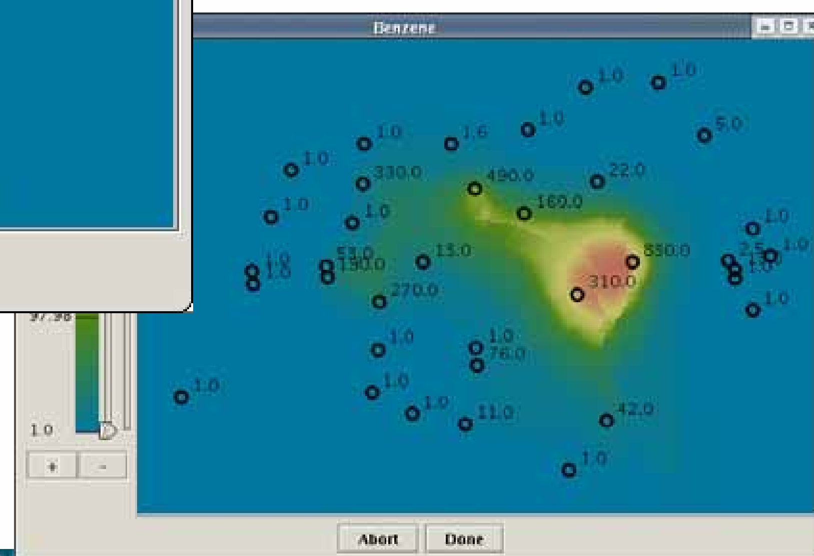


# Benzene Concentrations for 30-Well Design




## 30-Well Predictions

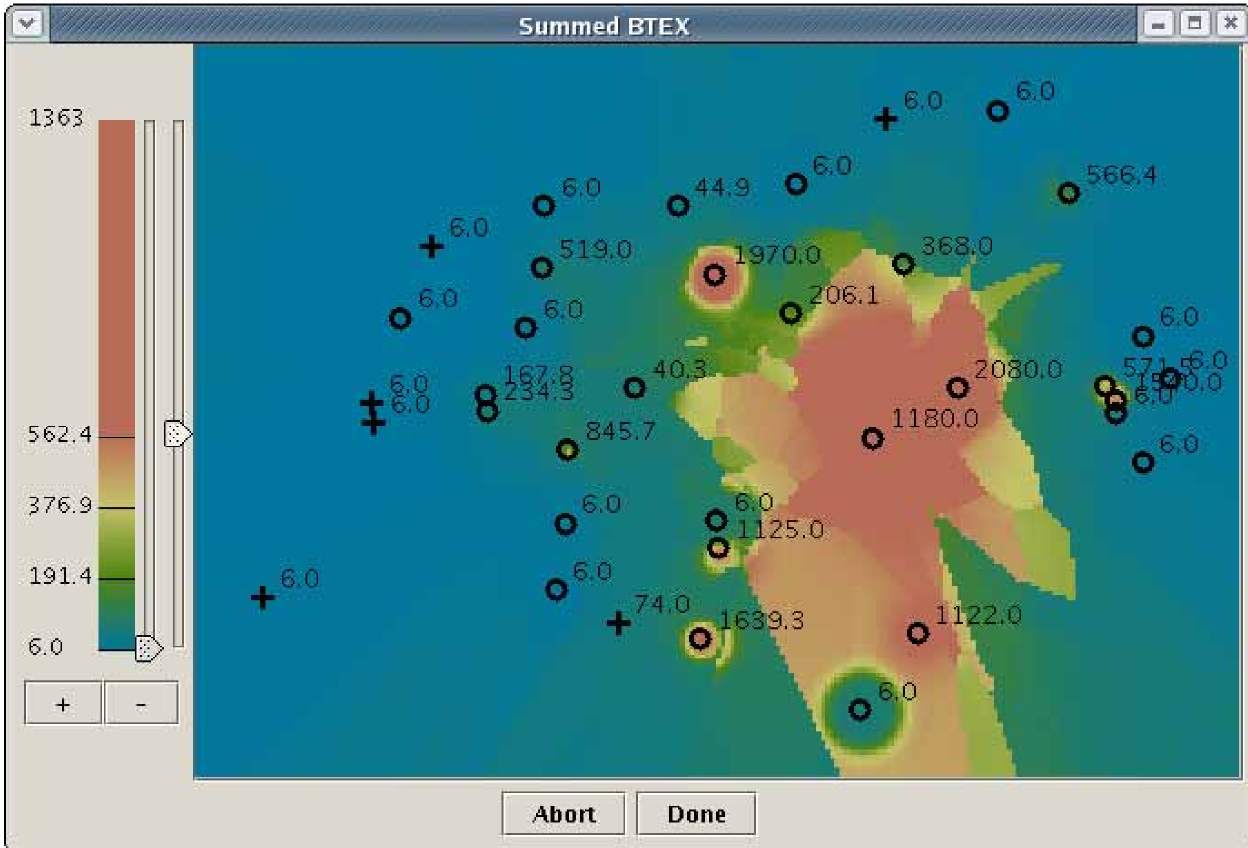
## All-Well Predictions




*+ = locations that are not sampled*

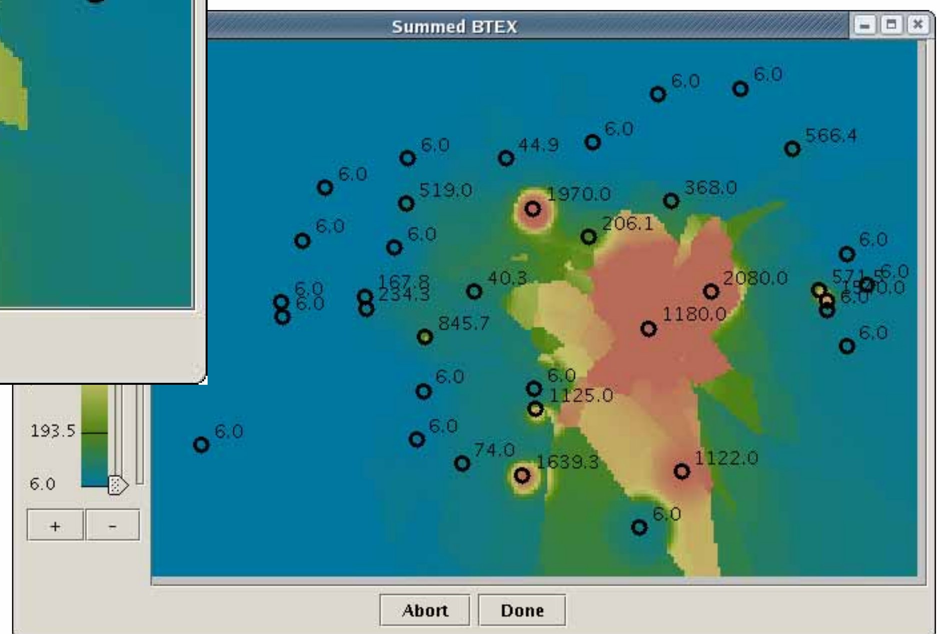
*O = locations that are sampled*

# BTEX Concentrations for 30-Well Design




**30-Well Predictions**

**All-Well Predictions**




*+ = locations that are not sampled*

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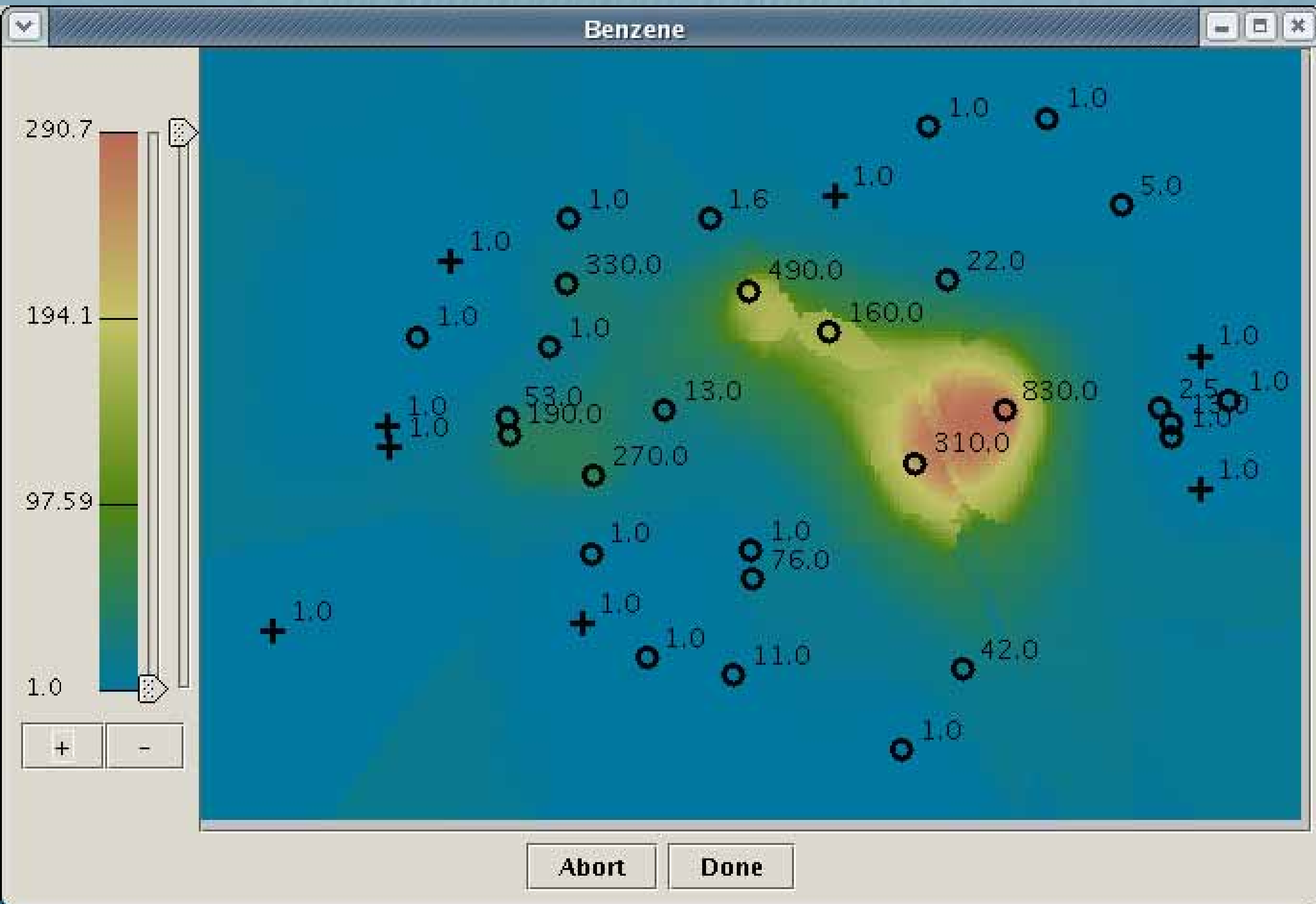
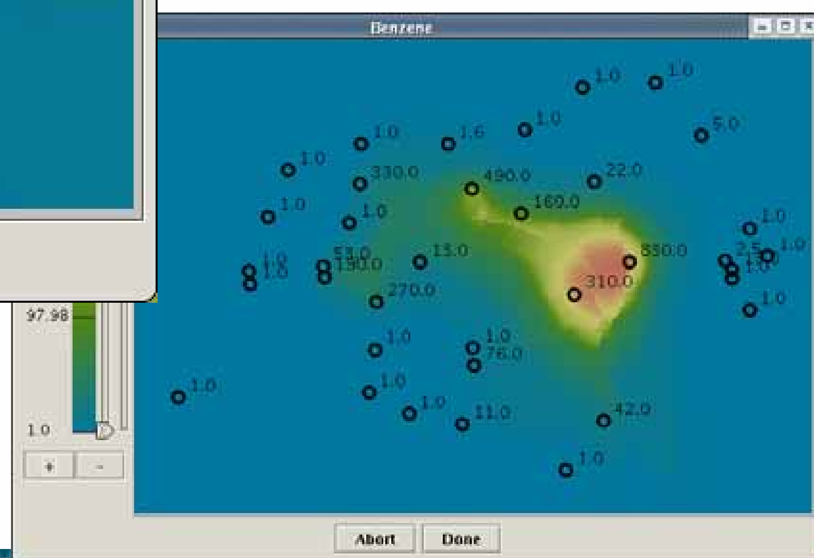
# Benzene Concentrations for 28-Well Design




## 28-Well Predictions

## All-Well Predictions

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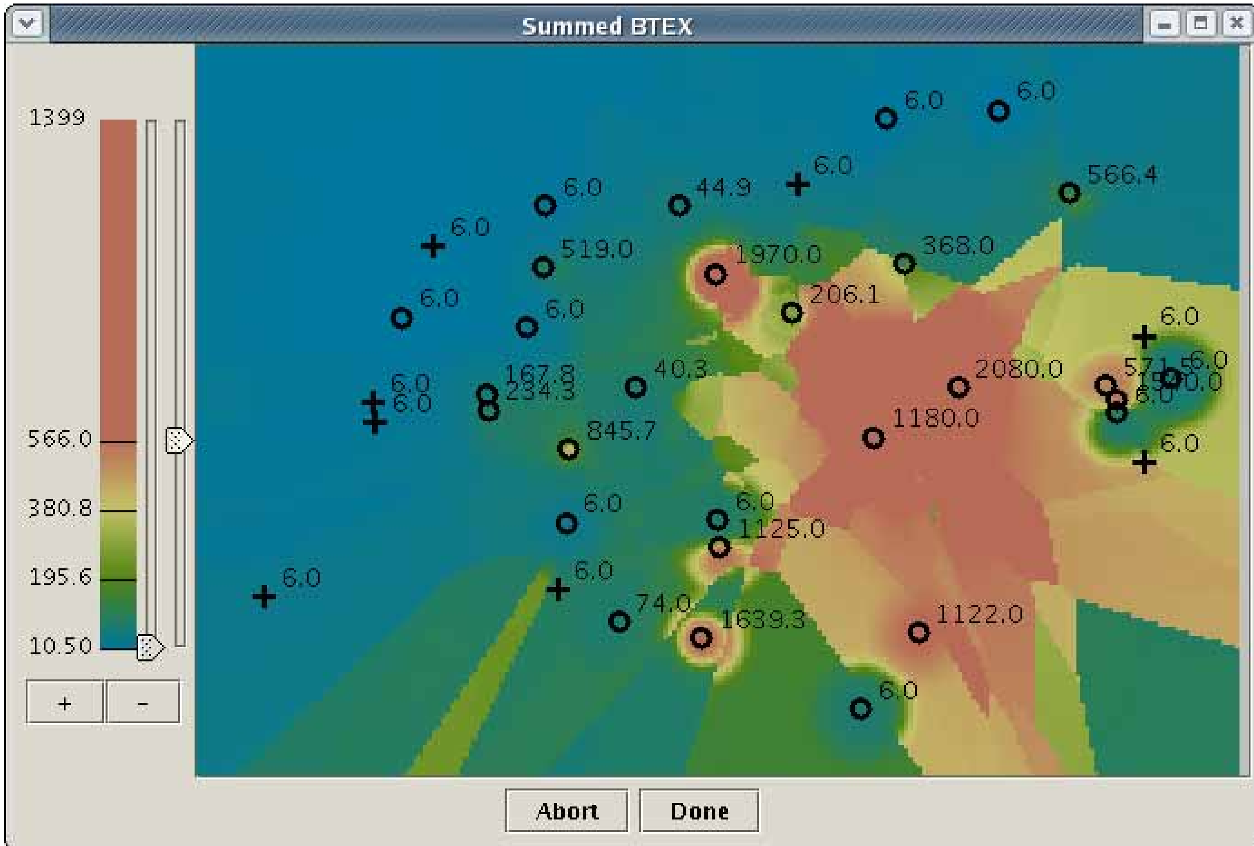
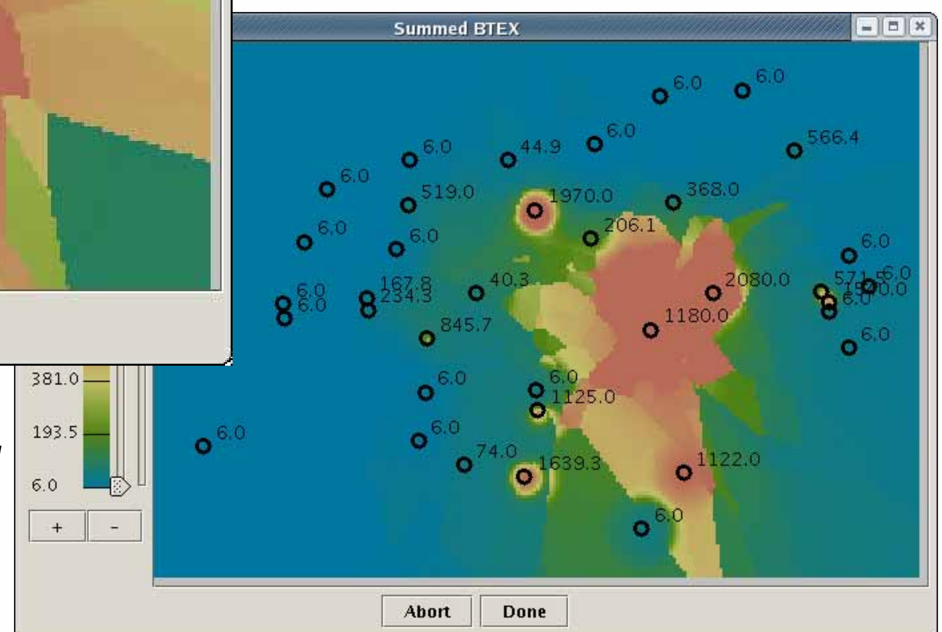
# BTEX Concentrations for 28-Well Design




**28-Well Predictions**

**All-Well Predictions**




*+ = locations that are not sampled*

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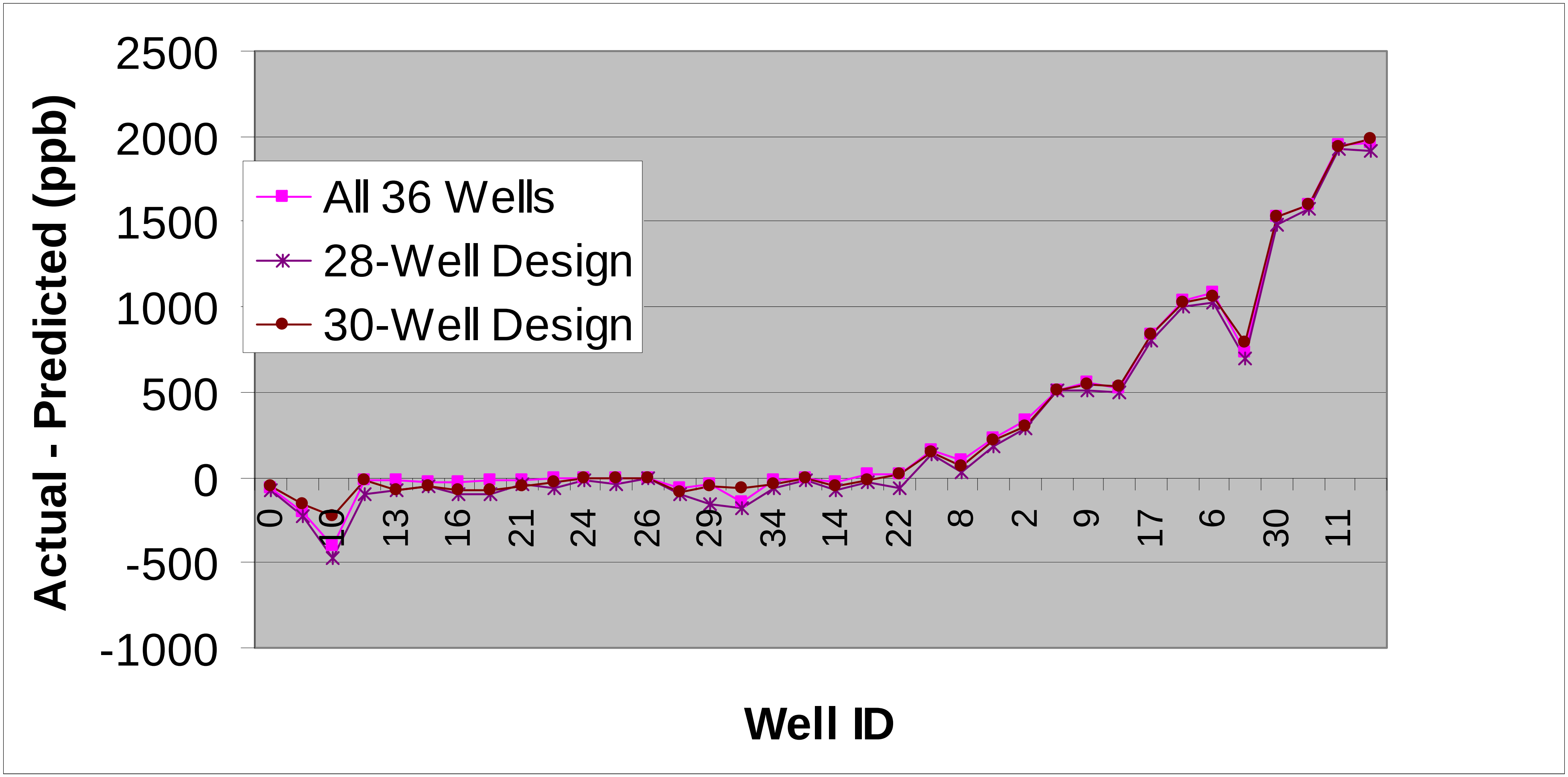
# BTEX Cross-Validation Comparisons



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# Optimization Findings

- **Found good predictions at all well locations using 28-30 wells**
  - 17 to 22% reduction in sampling costs possible
- **28-well solution has more difficulty interpolating correctly in the southeast corner, although this area is of much less concern than the leading edge of the plume**
- **M-LTMO software is useful tool for identifying data redundancies**
- **Further testing at a New Jersey terminal site with more wells is underway**