Optimization of Long-Term Groundwater Monitoring

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Outline

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- Task committee on the state of the art in long-term monitoring design
- Overview of methods for LTM design
- Summary of LTM design field studies
- Optimizing LTM designs
- Future needs to improve LTM design

Introduction to Long-Term Groundwater Monitoring

Motivation

- Long-term monitoring (LTM) is becoming increasingly important
  - More sites moving toward closure or completion of active cleanup
  - Changing regulatory environment is allowing more contaminants to remain in place
  - Realization that LTM costs will be significant in foreseeable future
- Many methods exist for optimizing LTM design that are not widely used
- New approaches are needed to address unmet LTM needs

Monitoring Stages: Stage 1

- **Numerous monitoring wells drilled to find extent of contamination & identify site characteristics**

- **Large sites may have dozens if not hundreds of wells**

- **In 1993 at the Savannah River Site in South Carolina, 1500+ groundwater monitoring wells had 10,000 samples taken at a cost of $10,000,000 (*Johnson et al. 1996)***

Monitoring Stages: Stage II

- Long-term monitoring (LTM)
  - Remediation is in place or completed
  - Tracking the progress of remediation or closure
    - May not require as many monitoring wells as for site characterization
    - Which wells can be eliminated?
  - Current approaches focus primarily on reducing sampling from monitoring wells
    - Sensor, indicator or other types of data not considered

Reducing the Burden of LTM

- Temporal redundancy analysis
  - Can sampling be done less frequently?
- Spatial redundancy analysis
  - Assumes the “best” picture of contamination plume is attained from sampling all available monitoring locations
  - Can fewer locations be used to attain acceptable pictures of the contaminant plume?

Task Committee on the State of the Art in Long-Term Monitoring Design

American Society of Civil Engineers (ASCE) Environmental and Water Resources Institute (EWRI)

LTM Task Committee

- ASCE/EWRI task committee to address these issues formed in Summer 2000
  - Formed by the standing Groundwater Management Committee (Current Chair: George Pinder)
- Volunteer partnership among 25 members from industry, academia, and government (EPA, DOE, DOD, and USGS)
  - Chair: Barbara Minsker, UIUC
  - Vice-chairs:
    - Ira May, Army Environmental Center
    - Donna Rizzo, Subterranean Research Inc.
    - Gus Williams, Argonne National Laboratory
  - Secretary: Hugo Loaiciga, UC Santa Barbara

Committee Objectives

- Facilitate communication between researchers and practitioners
- Disseminate state-of-the-art methods and future research and technology transfer needs

Committee Goals

- Organize special sessions, panel discussions, and training workshops at conferences
- Prepare a report on state-of-the-art methods and future needs for LTM design
  - Overview of methods and needs presented here came from the report
  - Extended abstract for this conference contains the report's executive summary
  - Watch http://web.ead.anl.gov/asceltm for news on its release this summer

Overview of Methods for LTM Design

Choosing the Right Approach

- **How much data are available?**
  - **Redundancy studies assume historical data are available**
    - **Other approaches exist for siting new wells (see report)**
      - Hydrogeologic method
      - Geostatistical approaches
  - **More complex methods require more data**

Data Requirements

	Amount of Data and Information Required		
Type of Method	**Few**	**Intermediate**	**Many**
Rule-based methods	X	X	
Statistical methods		X	X
Probabilistic methods		X	X
Mathematical optimization		X	X

Choosing the Right Approach

- **What are the monitoring objectives?**
  - **Background sampling**
  - **Release detection**
  - **Verify flow containment**
  - **Verify plume shrinkage**
  - **Verify plume stability**
  - **Compliance monitoring after closure**
  - **Verify or correct site models**
- **Different objectives require different approaches**

LTM Design Field Studies

Summary of New Field Studies

Authors	Optimization Method	Monitoring Objectives	Results and Savings
Hudak	Mathematical optimization	Release detection	Identified minimum number of borehole locations needed to detect contaminant plumes
Tomasko	Rule-based method	Verify plume stability or shrinkage	Reduced initial monitoring plan consisting of 80 wells and 15 springs to 6 wells and 7 springs
Tuckfield et al.	Statistical approach	Verify plume stability or shrinkage	Recommended eliminating 42 wells and up to 19 analytes from the sampling schedule
Aziz et al.	Rule-based method	Verify plume stability or shrinkage	Identify redundancy in existing monitoring well network, improved sampling frequency.

Summary of New Field Studies

Authors	Optimization Method	Monitoring Objectives	Results and Savings
Lillys et al.	Statistical approach	Verify plume stability or shrinkage	Reduced existing network design by 60%, from 193 to 72 sampling locations
Cameron & Hunter	Statistical approach	Verify plume stability or shrinkage	Identified 20% of monitoring wells as spatially redundant and reduced sampling frequencies
Rizzo & Dougherty	Statistical and probabilistic approach	Verify plume stability or shrinkage; verify or correct site models	Identified 20% of wells as redundant and reduced frequencies. Would result in ~35-40% reduction in sampling and analytic budget
Herrera, Guarnaccia & Pinder	Probabilistic approach	Verify plume stability or shrinkage	Initial monitoring plan consisting of 322 samples from 62 wells was reduced to a plan consisting of 40 samples from 23 wells.

Optimizing LTM Designs

Research from the University of Illinois Environmental Management and Systems Analysis Laboratory

Mathematical Optimization

- Mathematical optimization can, e.g.
  - Systematically search for fewest wells necessary to
    - Minimize sampling costs while achieving acceptable errors
    - Minimize error subject to fixed sampling budget
  - Identify tradeoffs among multiple objectives

Why Optimize?

- A site with 10 wells and 3 possible constituents to measure at each well would have

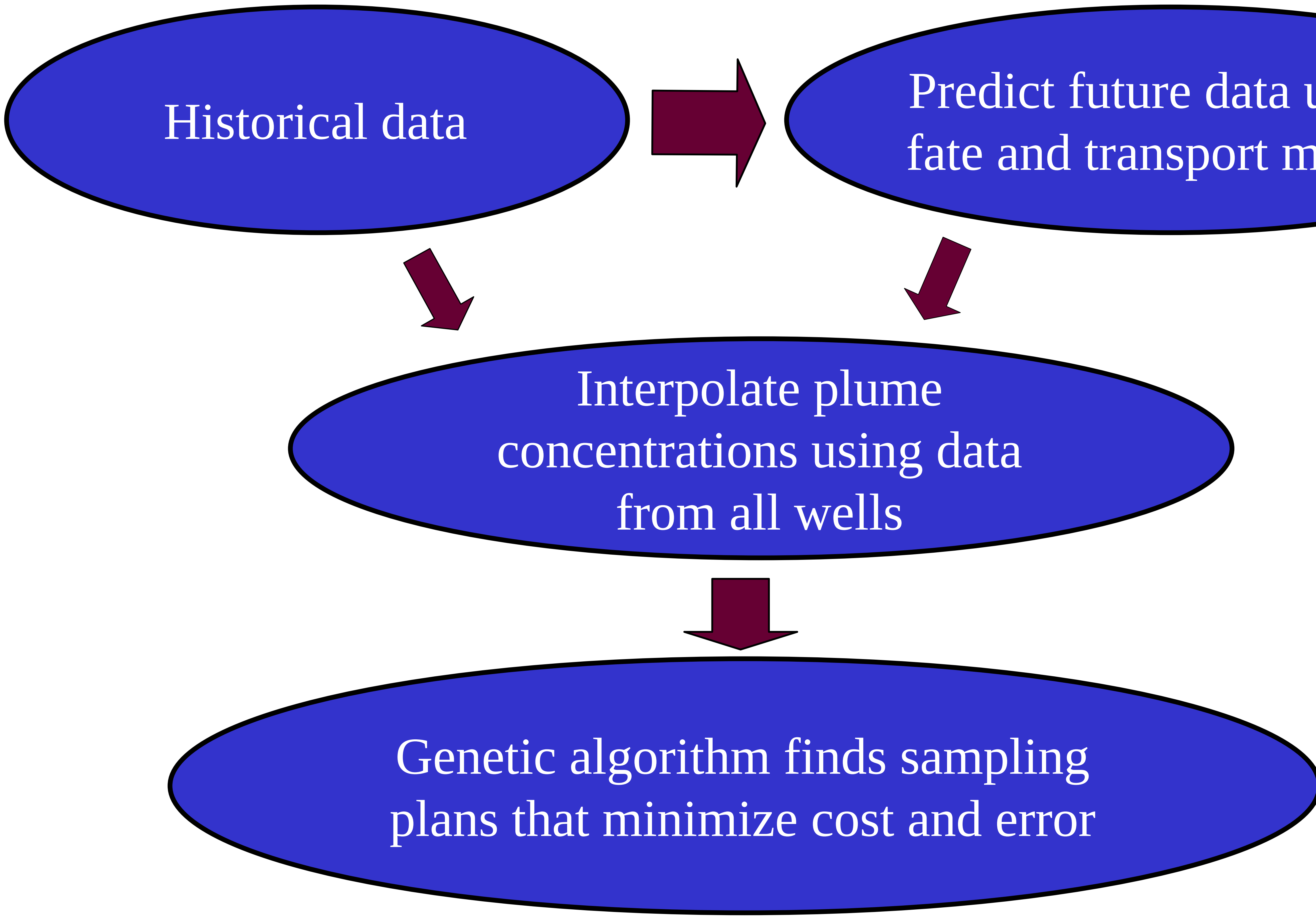
$$2^{30} \text{ or } 1 \text{ billion}$$

  possible sampling plans
- Assume
  - 99% of plans can be eliminated using professional judgment
  - Each plan can be evaluated in one second
- Still 115 days to evaluate the remaining plans!
- Mathematical optimization efficiently identifies the best designs to satisfy most objectives

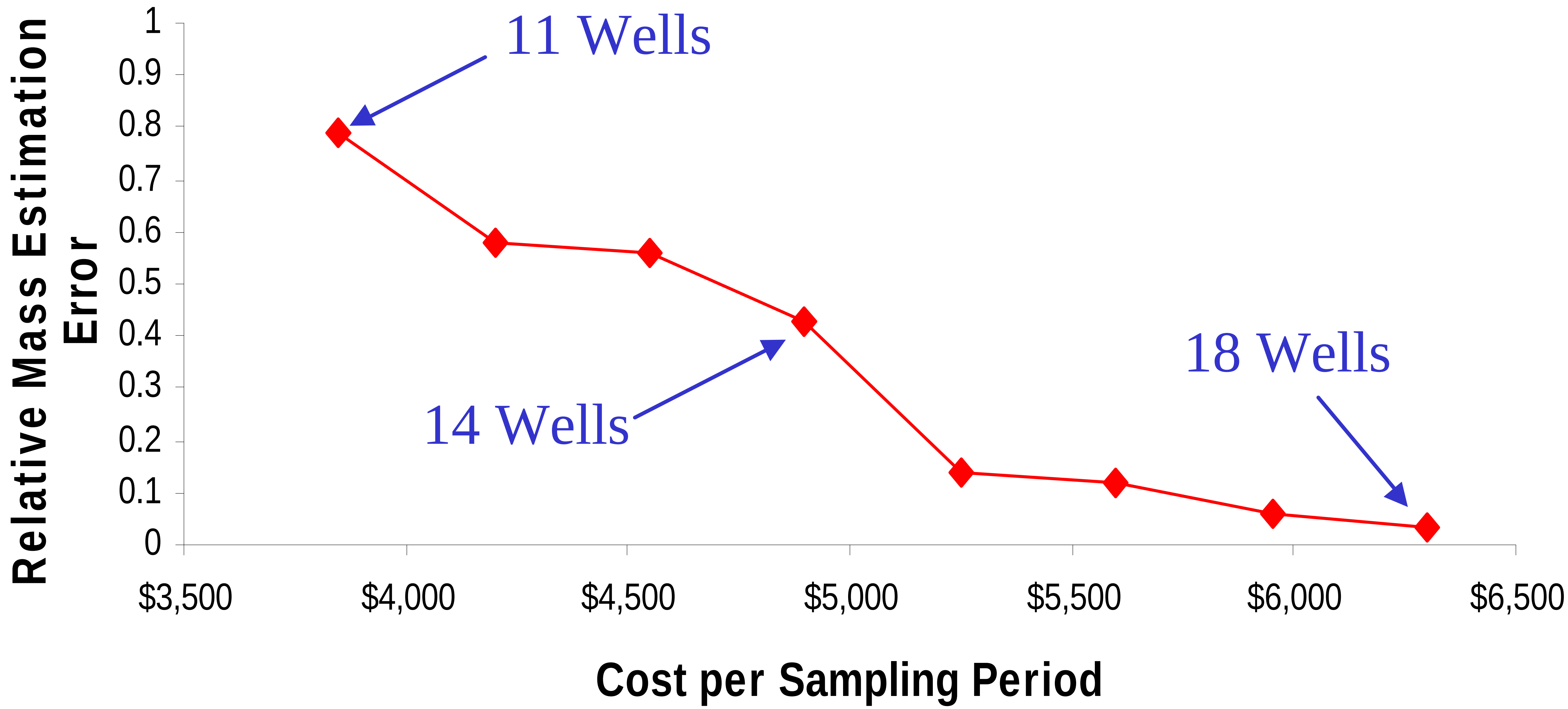
LTM Optimization Example

- **Case study based on published Hill AFB data (Weidemeier et al. 1995 and Lu et al. 1999)**
- **Analysis of spatial well redundancy among 30 existing wells**
  - **All constituents assumed to be sampled at each well**
  - **Over 1 billion possible sampling plans**
- **Monitoring objectives:**
  - **Minimize total mass estimation error**
  - **Minimize cost**

LTM Optimization Methodology



Optimal Cost-Accuracy Tradeoff



- Each point represents a design with the lowest mass estimation error possible for a given level of cost

Future Needs to Improve LTM Design

Recommendations of ASCE/EWRI Task Committee

LTM Research Needs

- Improved electronic management of and access to data
- Well-tested & documented public datasets
- Methods for integration and use of non-traditional data (e.g., sensor or screening technologies)
- Methods to better assess:
  - Linkages between LTM and remediation
  - Spatial redundancy in fractured media
  - Uncertainty in LTM design process

LTM Research Needs

- Improved decision rules and protocols for long-term management
  - Current practice: Location and frequency of a single constituent
  - Need to address:
    - Which constituents and indicator parameters should be measured and at what locations and frequencies
    - What data collection, validation, and analysis procedures should be followed to collect that data
    - Procedures to be followed when collected data indicate a problem
    - When the underlying conceptual model and monitoring system need to be re-evaluated

Research Needs (Cont'd.)

- "Living" models for performance assessment that can
  - Analyze current conditions and changes in system behaviors, in both space & time
  - Continually or periodically re-evaluate assumptions and goals used in initial LTM and remediation system design
  - Be updated in a low cost and accessible way
  - Optimize data collection and remediation
  - Integrate all available information at all scales

Technology Transfer Needs

- Types of data analysis needed
  - To assess remediation performance
  - To identify appropriate LTM designs
    - Approval of dynamic vs. fixed plans
- Combining LTM and remediation process optimization

Technology Transfer Needs (Contd.)

- Professional guidelines and education
  - Special problems associated with LTM and methods available
  - Extent of site characterization needed before undertaking LTM design
  - Incorporating sensor and screening data
  - Criteria for:
    - Eliminating sampling of particular constituents
    - Halting LTM
  - Public involvement in LTM optimization
  - Fate of wells that are no longer being sampled