Optimization of Groundwater Monitoring Strategy at the Savannah River Site F-area using ASCEM

Subtitle of the presentation subtitle of the presentation (Arial Narrow 16 italic)

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Advanced Simulation Capability for Environmental Management

ASCEM in ongoing software project focused on next-generation, science-based reactive flow and transport simulation and supporting modeling toolsets within a high-performance computing framework to address DOE-EM’s environmental cleanup challenges

- Platform and Integrated Toolsets: model development and analysis, visualization, and management of data and simulation results.
- Multi-Process HPC Simulator: state-of-the-art flexible and extensible simulation capabilities for a range of modern computer architectures.
- Site Application: Provides the ASCEM developers and users with the expertise needed to address DOE-EM’s environmental cleanup challenges
  - Complex groundwater plume (metals, anionic/cationic rads, tritium)
  - Decade long project to develop reactive transport model for uranium funded by Office of Science and DOE-EM
  - Current challenge is Long Term Monitoring (LTM) of residual contaminants
Innovative approaches that account for the large volume and low groundwater concentrations.

Effective clean-up will require self sustainable low-energy concepts.

Baseline investigative and treatment methods or moderately aggressive alternatives.

Investigative approaches at the scale of the contaminant. Aggressive clean-up technologies are required to limit long term damage.

Multiple phases
High contaminant concentrations
Generally smallest volume.

Moderate to high concentrations
Residual phase effects
Modest volume.

Low concentrations above regulatory criteria.
Largest contaminant volume.

**Source Zone** ➔ **Primary Contaminant Zone** ➔ **Dilute/Distal Fringe**

**Principle Direction of Bulk Fluid Flow**
Well Characterized Plume
Deviations from predicted behavior
Cost effective methods that inform
changes from predicted behavior.

Delineate Internal Structure of the Plume
Optimization of Treatment Strategies

Principle Direction of Bulk Fluid Flow

Dense Depth Discrete Information
Nature/Extent for Design

Dense spaced, depth discrete methods such as cone penetrometer, multi-level sampling etc.

Groundwater sampling over areal extent of plume

Source Zone → Primary Contaminant Zone → Dilute/Distal Fringe
Long Term Monitoring

Better monitoring strategies to support site closure

– Monitoring should focus on identification of significant changes in plume behavior at a low cost
  • Identify controlling variables that will predict plume migration

– Shift focus from nature and extent of contamination to monitoring approaches that integrate over large areas
  • Verify that closure strategy is protective
Proposed Strategy

• Small number of required groundwater samples/lab analysis
• Add measurement of controlling groundwater processes
  – Boundary Conditions -- Overall physical and hydrological driving forces such as water level, evapotranspiration, stream flow
  – Controlling Variables -- Key geochemical controls on migration in the groundwater system such as pH, redox, ORP, specific conductivity etc.
• Incorporate spatial monitoring to increase confidence
• Methods are cheaper and provide early warning to changes in contaminant behavior
Sensors to Measure Controlling Processes

Installed commercial sensor packages at several locations to monitor water level and selected geochemical controlling variables

- **LTM Sensors**
  - Provide data for geochemical controlling variables & boundary conditions
  - Inexpensive (eliminates labor & analytical costs associated with sampling)
  - Wireless data transfer and access

Examples of Physical/Hydrological Forces Affecting Boundary Conditions of a Plume

<table>
<thead>
<tr>
<th>Precipitation</th>
<th>Evapotranspiration</th>
<th>Stream/River Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Water Ponds, lakes, trenches</td>
<td>Pumping Wells including Industrial and Water Supply</td>
<td>Discharges/ Industry Outfalls</td>
</tr>
<tr>
<td>New Infrastructure/ Construction</td>
<td>Discontinuation of Industrial Activities</td>
<td>Major Storm Events</td>
</tr>
</tbody>
</table>

Examples of Master Variables: Control Geochemistry of a Plume

<table>
<thead>
<tr>
<th>pH</th>
<th>Redox</th>
<th>Specific Conductance</th>
<th>Biological Community</th>
<th>Alkalinity (calcareous aquifers)</th>
</tr>
</thead>
</table>
Scales of Environmental Monitoring

- Original data
  - Pressure transducer data to measure water levels
  - Temperature data in vadose zone and groundwater
  - Meteorological data

- QC flagging method to identify and correct erroneous data outside a reasonable range and occurrence of anomalous spikes (due to perturbations during water sampling events from monitoring wells).

- QA/QC of location coordinates, elevations and top of casings.
Remote Sensing Technologies

Soil Moisture/Surface Drainage Mapping

Fukushima Gamma Source Mapping

- Microtopography
- Surface deformation
- Vegetation dynamics/characteristics
- Surface temperature
- Radioactive contamination

Courtesy to Kai Vetter et al.

Courtesy to Dafflon et al.
Fiber Optic Technologies

- Autonomous Distributed sensing
  - Temperature
  - Soil moisture
  - Acoustic properties
  - Chemistry (e.g., pH)

Permafrost Thaw Detection

[Image of permafrost detection setup]

Ajo-Franklin et al.
Geophysical Subsurface Imaging

- Electrical Resistivity Tomography
- Autonomous data collection and streaming
- Bulk electrical conductivity → Plume migration etc
Virtual Testbed

How do you test a new paradigm for long term monitoring without doing years of monitoring?

- Use historical monitoring data from a waste site with a long history and documented changes to boundary conditions.

- Virtual test bed using 3D reactive flow and transport mode to evaluate trigger levels and plume migration through time.
Use of Data Analysis/Modeling to Validate New Approach

**Big Data methods** for real-time data analysis and early warning systems
- Data mining, machine learning (Kalman filters, artificial neural network)

**Virtual Test Bed**: ASCEM modeling tool for predicting long-term performance

**Incorporation of new sensing technologies** for automated remote monitoring
- In situ sensors, geophysics, fiber optics, UAVs
• Field Test Bed
  – Historical datasets
    → Advanced statistical analysis
  – Data mining, Machine learning
    → Select controlling variables

• Virtual Test Bed
  – 3D reactive transport simulations
  – Super computers
    → System understanding, long-term predictions, testing different methods
Automated QA/QC

- Remove outliers or noise using smoothing
- Gap filling
- Detect significant changes

Well FSB 79, Groundwater level (additive outliers removed)
In situ Variables vs Contaminants

Controlling Variables
Prediction Capability: ASCEM

Advanced Simulation Capability for Environmental Management
3D Mesh Development

Surface Seismic Method

Wainwright et al. (2014)
Metals/Nitrate and Uranium

Top – Metals plume
Bottom -- Uranium Plume
Vertical exaggeration=15X
Summary

Real/Virtual Test Bed at SRS F-Area

- Data analysis confirmed the feasibility of in situ monitoring
- ASCEM 3D flow and transport simulations quantified the correlations (spatially and temporally variable) but also the future plume trajectory
- UQ/sensitivity analysis: the long-term feasibility of monitoring

Cost-effective strategies for long-term monitoring of contaminants

- **In situ sensors, data streaming and data analytics** for automated continuous monitoring
- **Advanced technologies**: geophysics, fiber optics, UAV’s
- **Data Analytics: QA/QC, correlations** between master variables and contaminant concentrations
- **Integrated approach** (data + modeling) for system understanding/estimation