Conceptual Site Models*

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Search and Discovery Article #80037 (2008)
Posted December 15, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, TX, April 20-23, 2008

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Abstract

This paper will focus on uncertainties in the underlying conceptual framework on which all subsequent steps in a modeling effort depend. Every serious modeler recognizes the value of selecting an optimal from several competing site models, but the process of developing alternative models is sometimes hampered by poor access to site data and relevant nearby data. We will present case histories based on reported flow or transport modeling in which alternative site models are suggested or allowed by data that were not available to or not used by the modeler. We like a quote from Tukey (1962) that, we believe, places in perspective many issues in attempting to produce mathematical models and computer simulations of natural systems. “Far better an approximate answer to the right question, which is often vague, than the exact answer to the wrong question, which can always be made precise.”

Case histories are selected to provide food for thought for those attempting to approach model uncertainty and may include:

1. Charleston Navy site where seismic characterization data allowed significant revision of the CSM and subsequent contaminant transport modeling.

2. Hanford 300 area where river water momentum is suggested as an alternative component of the site model.

3. Savannah River C-Area where a characterization report for a waste site within the modeled area was not available to the modelers, but would have required changes to the underlying geologic and hydrogeologic models used.

4. Amargosa Desert Research Site (USGS) where re-interpretation of resistivity sounding data and water level data suggested an alternative geologic model. Simple 2-D spreadsheet modeling with the revised CSM provided an improved match to vapor-phase tritium migration.

Conceptual Site Models

(NUREG/CR-6948 Vols. 1 & 2)

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Overview

- Uncertainties in Conceptual Site Models
- Develop Alternative Conceptual Models
- Case Histories
- Integrate Modeling with Monitoring to Reduce Uncertainties
- Information Sources (NUREG/CR-6948 Vols. 1 & 2)

Conceptual Site Model

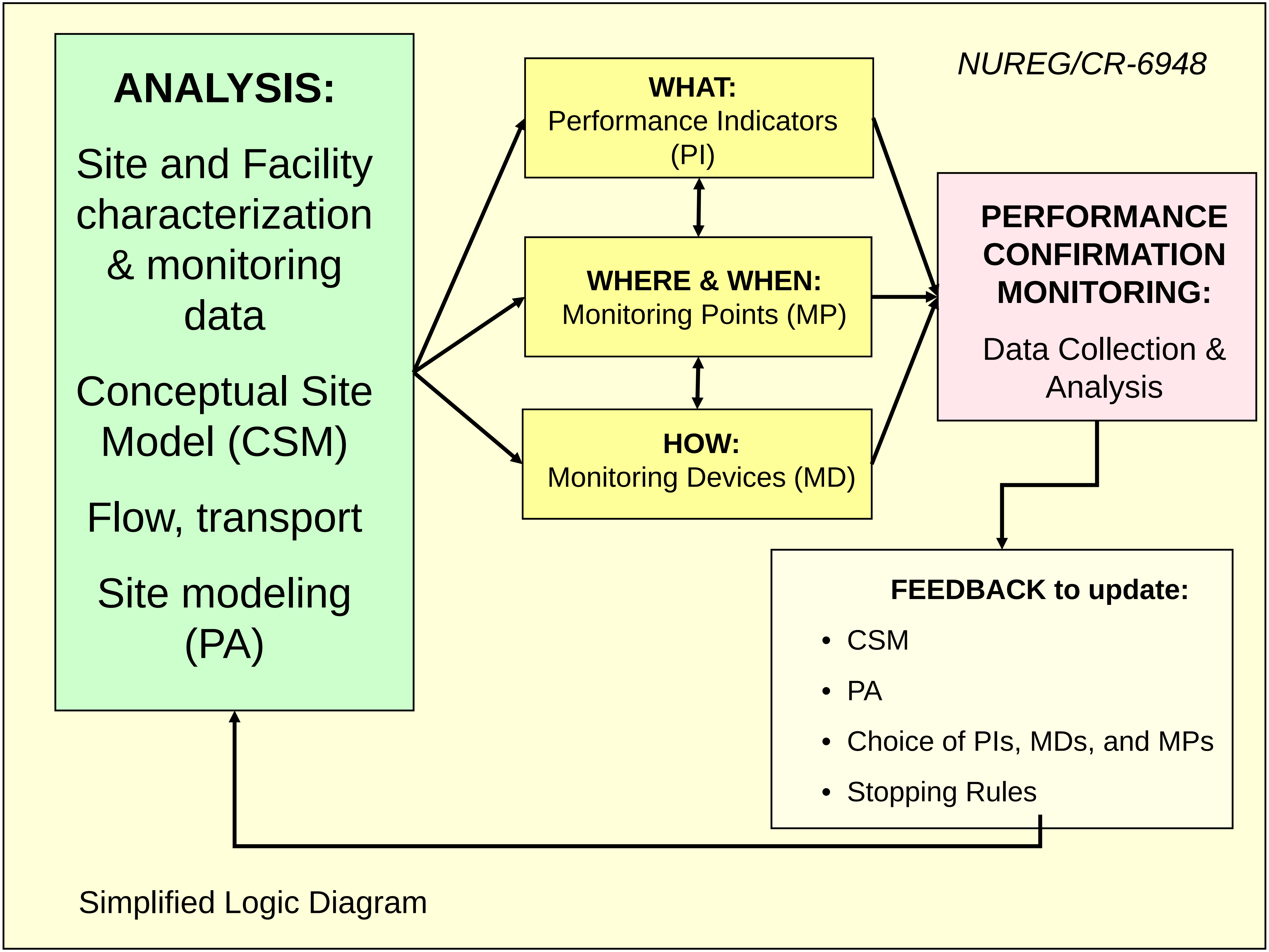
Starting Point for All Subsurface Investigations

- CSM is guide for where to drill
  - Mineral exploration
  - Contaminant investigations
  - Ground Water Wells
  - Oil and gas
- CSM constructed from geology/geophysics

CSM Development

- Characterization allows development of CSM
- CSM allows modeling / simulation
- Modeling allows prediction
- Monitoring allows refinement
- Refinement allows confidence

- Characterize (puzzle pieces) - Conceptualize – Simulate - Revise


NUREG/CR-6948
ANALYSIS:
Site and Facility characterization & monitoring data
Conceptual Site Model (CSM)
Flow, transport
Site modeling (PA)
WHAT:
Performance Indicators (PI)
WHERE & WHEN:
Monitoring Points (MP)
HOW:
Monitoring Devices (MD)
PERFORMANCE CONFIRMATION MONITORING:
Data Collection & Analysis
FEEDBACK to update:
• CSM
• PA
• Choice of PIs, MDs, and MPs
• Stopping Rules
Simplified Logic Diagram

Class 1 - Chemical

A. Regulated and Direct Drivers of Risk - U, Cs-134, Pu, Sr-90 these are Primary PIs

B. Surrogates and Indicators that a process is occurring –

- gross Alpha for Uranium
- Cl or NO3 from same source as risk drivers
- degradation products - Am241 for Pu, organic breakdown products for MNA

C. Process control chemical indicators needed to model transport

- pH, alkalinity, conductivity, major cations, major anions, redox indicators ...

Class 2 - Physical

- examples include water content, pressure distributions
- physical properties of rocks
- physical properties of subsurface fluids

Class 3 - Modeled or Derived from Data Analysis

A. Distribution of uncertainty

- This would be determined by examined the distribution of characterization data available to develop a site conceptual model and flow model. Areas of sparse or questionable data would have high uncertainty.

B. Lack of Congruity

Tests of site conceptual and flow / transport models -

- do actual plume maps match predicted plumes
- does site geology match regional geology
- does site geology match geology reported from adjacent areas

C. Outliers

Spatial - for example:

- bulls eyes around data points on contoured maps
- areas of high characterization uncertainty

Statistical (no spatial component) -

- univariate includes control chart anomaly,
- **multivariate would include single-sample cluster**

Conceptual Model many facets

- Site –
  - Physical - geology, hydrogeology
  - Chemical – controls on chemical transport
- Facility – for environmental CSMs
  - Inventory
  - Likely leaks (from safety analysis…)
    - Pathways – e.g. gravel fill around underground lines
- Characterize (puzzle pieces) - Conceptualize – Simulate - Revise

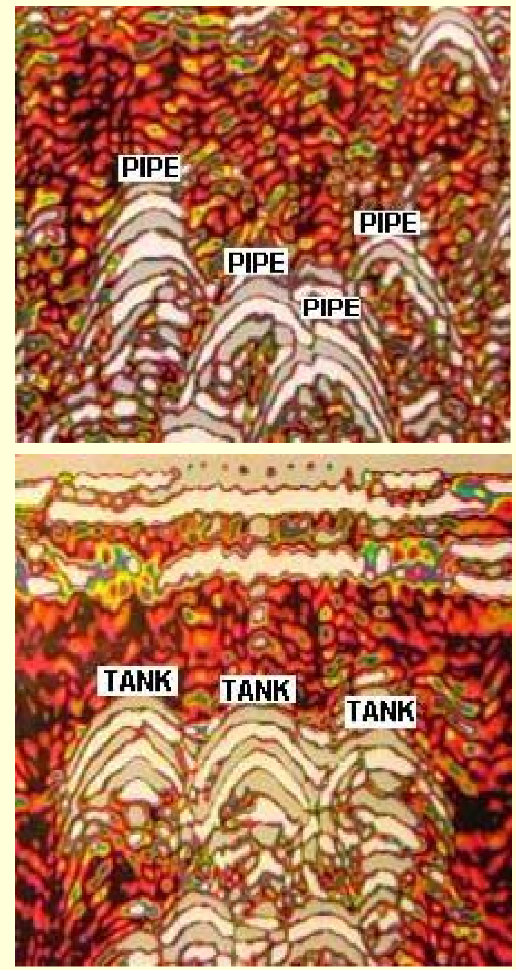
Conceptual Site Hydrologic Model for Environmental Projects

Important to consider the following:

- ✓ Natural and engineered features, structures, backfills and soil-rock interfaces
- ✓ Regional and site hydrologic setting (aquifers, surface-water bodies, springs, wetlands and drainage systems)
- ✓ Local drinking water sources (ground- and surface-water sources)
- ✓ Existing ground-water wells onsite and offsite
- ✓ Depth to the water table and surface-water body elevations
- ✓ Historical details on contaminant releases
- ✓ Ground-water flow directions and rates
- ✓ Remediation Approaches (e.g., MNA)

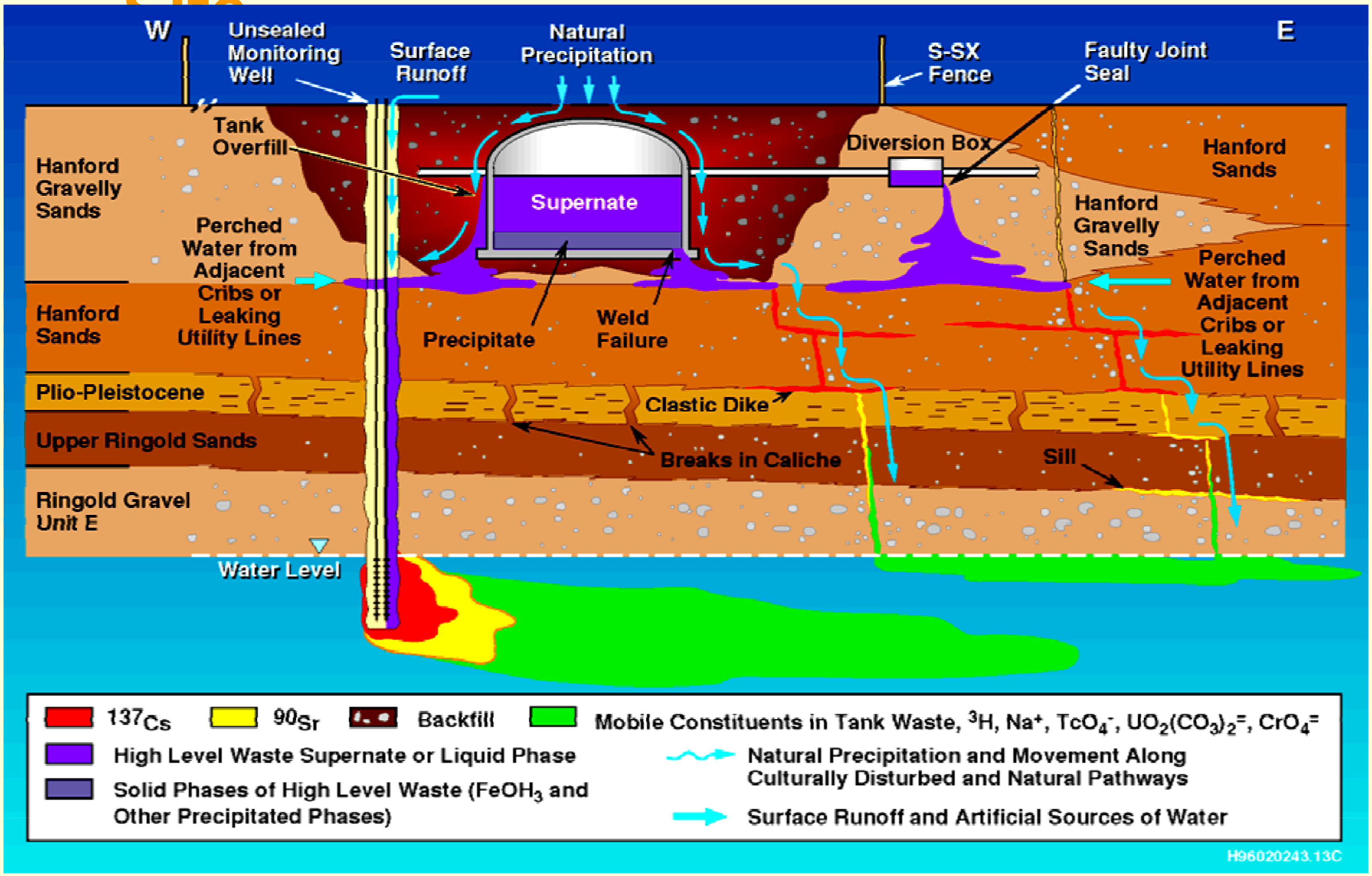
Site-Specific FEP's for Developing Alternative Conceptual Site Models

- Pathways for rapid spread of leaking contaminants
  - pipe or cable trenches
  - gravel backfill
- May drive contaminants in directions not predicted by contouring a few data points on a water-table map
- Local precipitation drainage (roof and storm drains)
- Water-sources of leaks
  - can inject large amounts of water into the vadose zone, sometimes creating perching
  - drive ground water and contaminants in directions not predicted based on water levels from scattered monitoring wells



GPR Images

Conceptual Model of a Complex Site



from Ward et al (1997) after Caggiano, et al. (1996)

A backwards look at Environmental Hydrology Transport Modeling

- History of subsurface modeling
  - Water resource studies
  - Mineral resource studies
- A matter of scale
- A matter of detail
- Mining and petroleum applications – **profit related**
  - Lots of software development -- just walk around at AAPG
- Environmental applications – **cost related**

So What is a (flow and transport) Model?

- State of practice 1990-
  - Commissioned like a work of art by a patron
  - Computer resource hog
  - Expensive
  - Once done, resting on a shelf
- State of art 2006
  - Database for all characterization data
  - Visualization for communication support (BNL data later)
  - Dynamic use of new site data
  - Desk-top computer adequate
- State of Practice 2010+ ?
  - Could be routine practice at every facility with an environmental program

A 1986 Environmental Flow/Transport Modeling Example

- Conceptual model
- Predictive results from computer simulation and forward projection in time
- Monitoring Observations

Layer Cake Conceptual Site Model

1986 model

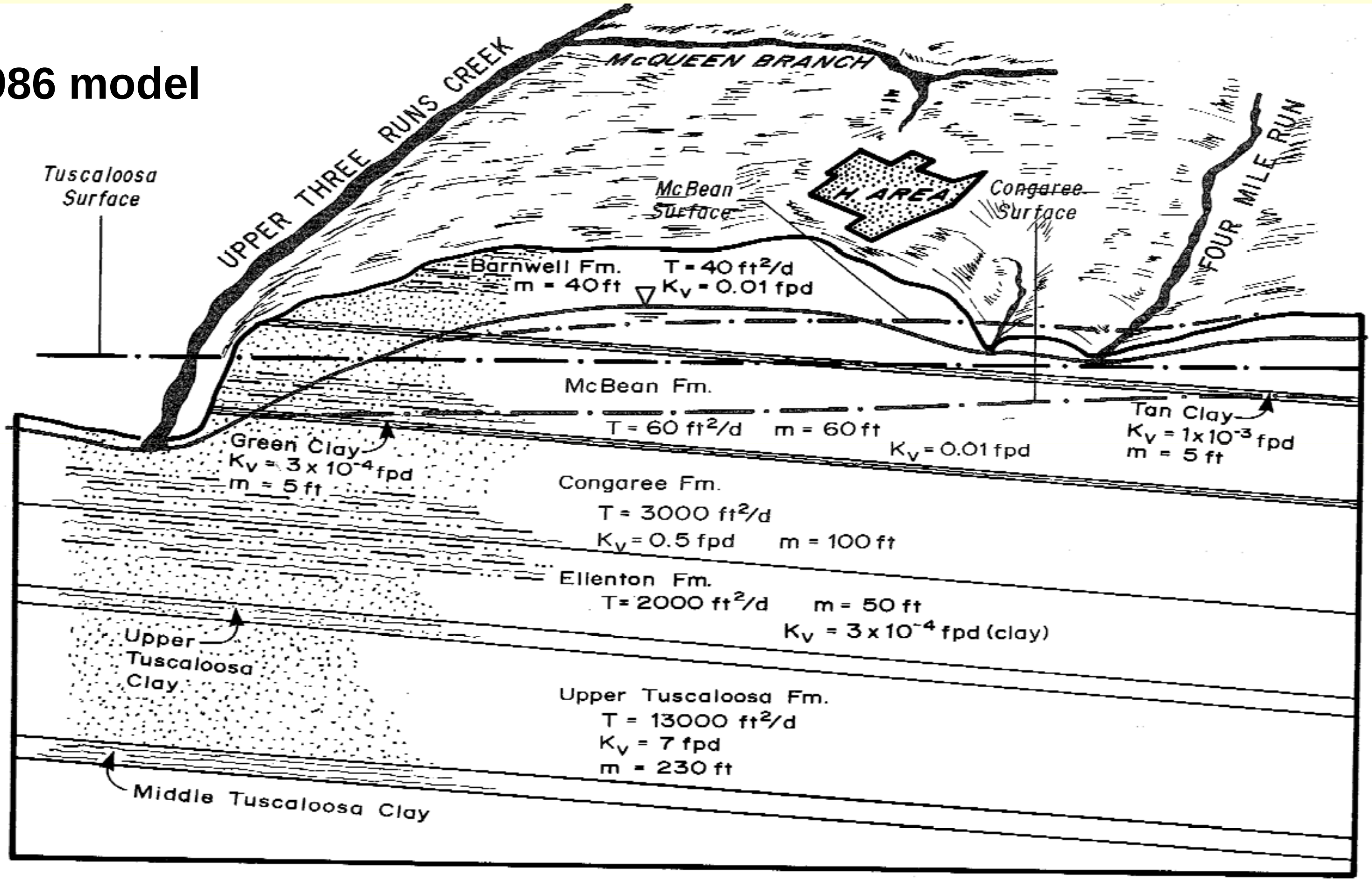


Figure 1.3 Summary of hydrogeologic conditions for the General Separations Area.

12

Prediction Made with Model

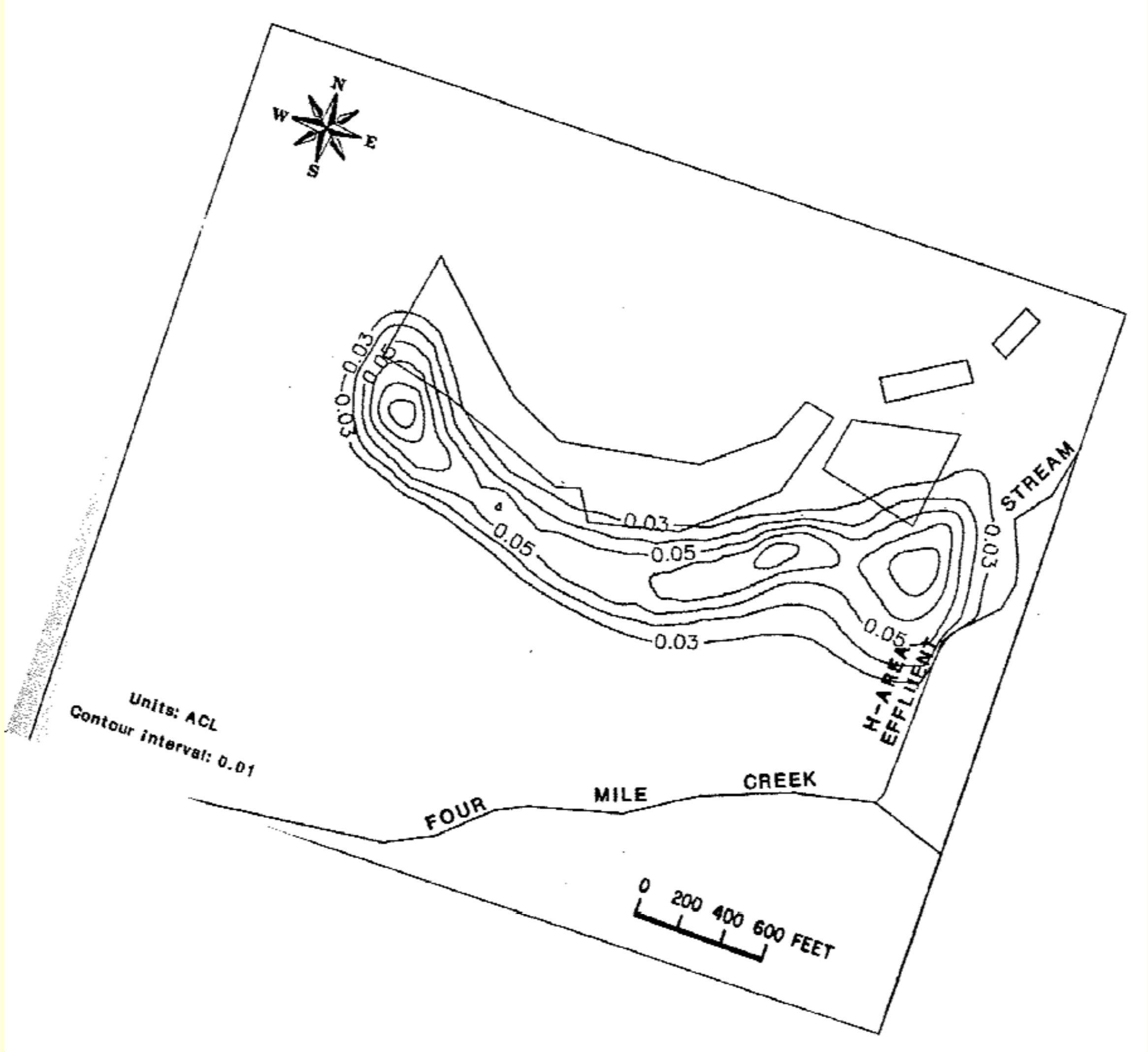
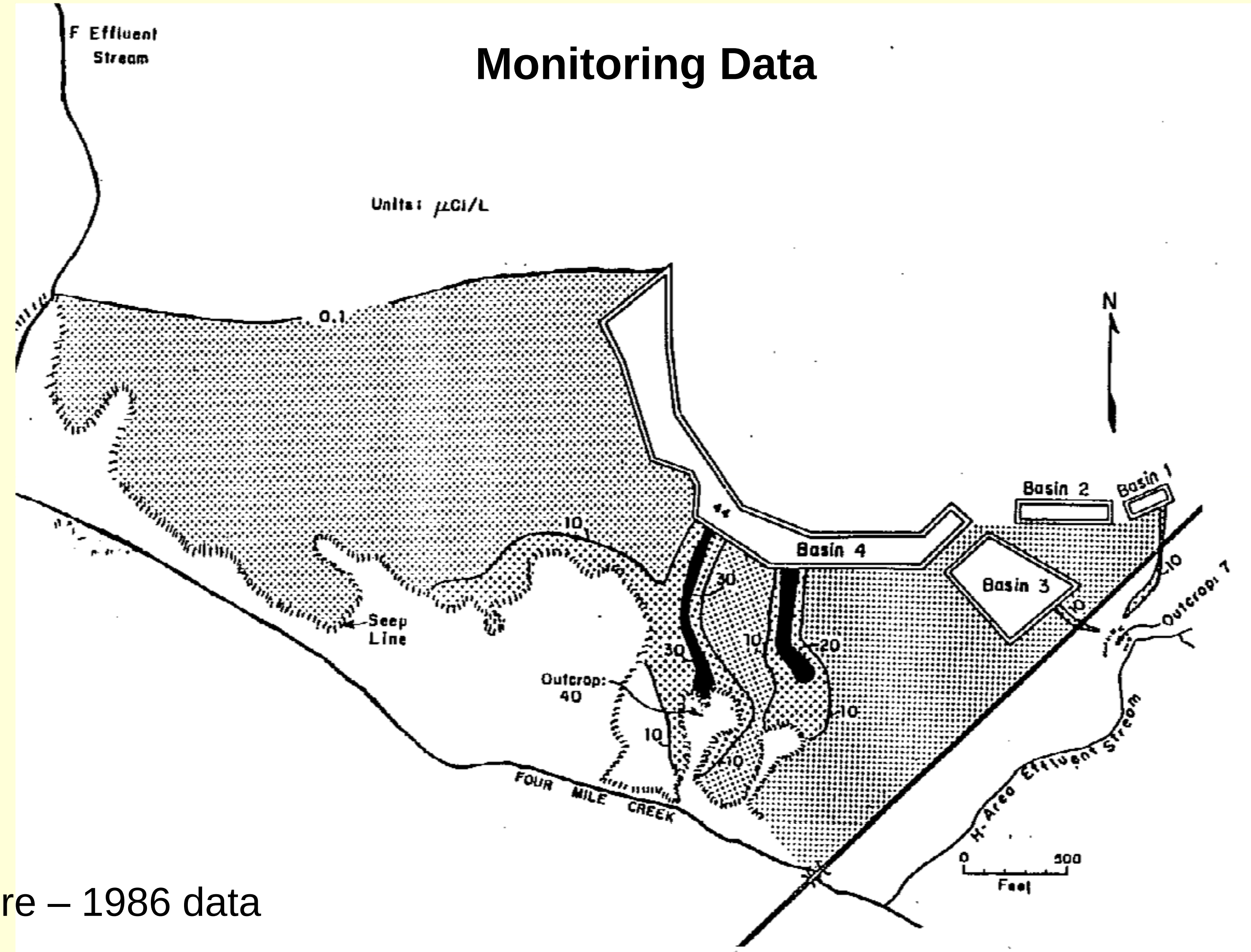


Figure 2.16 H Area Concentrations in the Barnwell aquifer at the end of 45 years of operation, R = 5.0.

Monitoring Data



Pre – 1986 data

FIGURE 3. Isoconcentration Contours of Tritium in Ground Water at H-Area Seepage Basins

Lesson Learned

- Find and use ALL the data
- If you don't find all the data, someone will later.

The Modeling-Monitoring Connection

Wang and Anderson, 1981, Introduction to Groundwater Modeling, Chapter 1, Page 1

- “Good field data are essential when using a model for predictive purposes
- An attempt to model a system with inadequate field data can also be instructive as it may serve to identify areas where detailed field data are critical to the success of the model.
- In this way, a model can help to guide data collection activities.”

GIS

- Quickly access site data within a spatial framework
- Combines easily with database and spreadsheet programs
- Example >> concentration information BNL tritium Plume

BNL--HFBR

- 6 – 9 gallons / day of tritiated water to a “dry” vadose zone

- Installed **up-gradient and down-gradient horizontal wells** to confirm (0.6 – 1.6 meters below WT)--- (but < 5000 pCi/L when sampled)

- Relatively **fast moving aquifer** (0.3 m/day) created thin plume beneath HFBR (estimated to be about 0.3 m)

- The plume spreads downward **after emerging** from beneath the HFBR

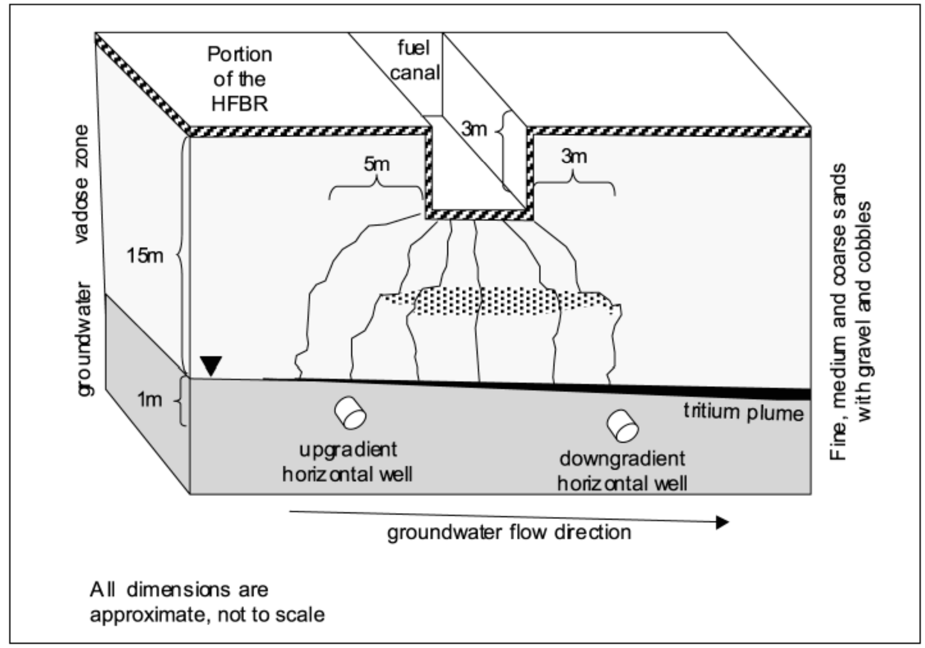


Figure 2. Detail schematic of vadose zone and shallow groundwater beneath the HFBR. Flow lines from a small continuous leak in a dry vadose zone spread out widely, especially when they encounter gravel and cobble zones.

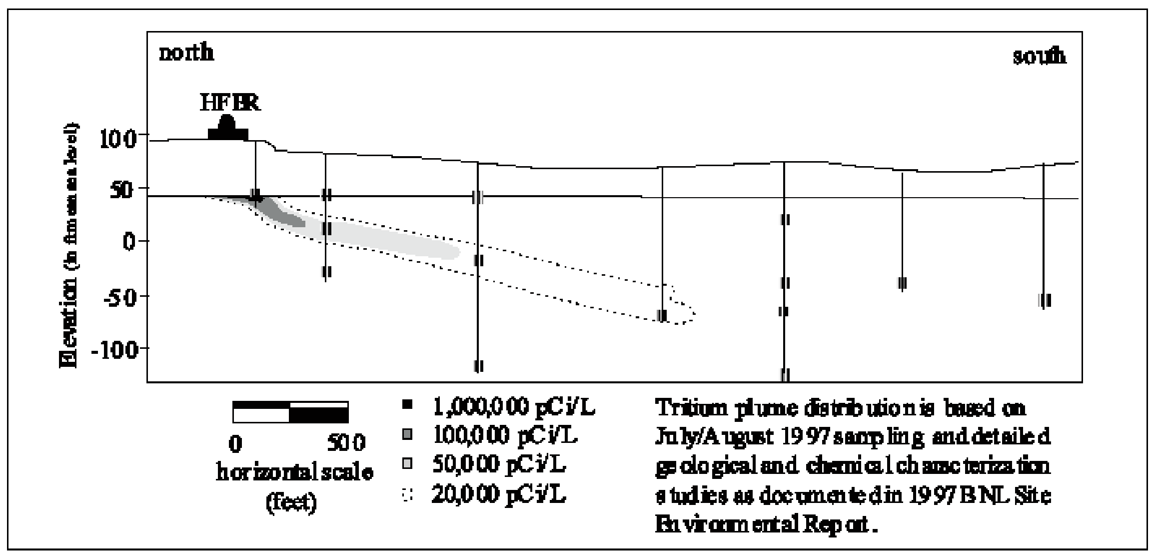
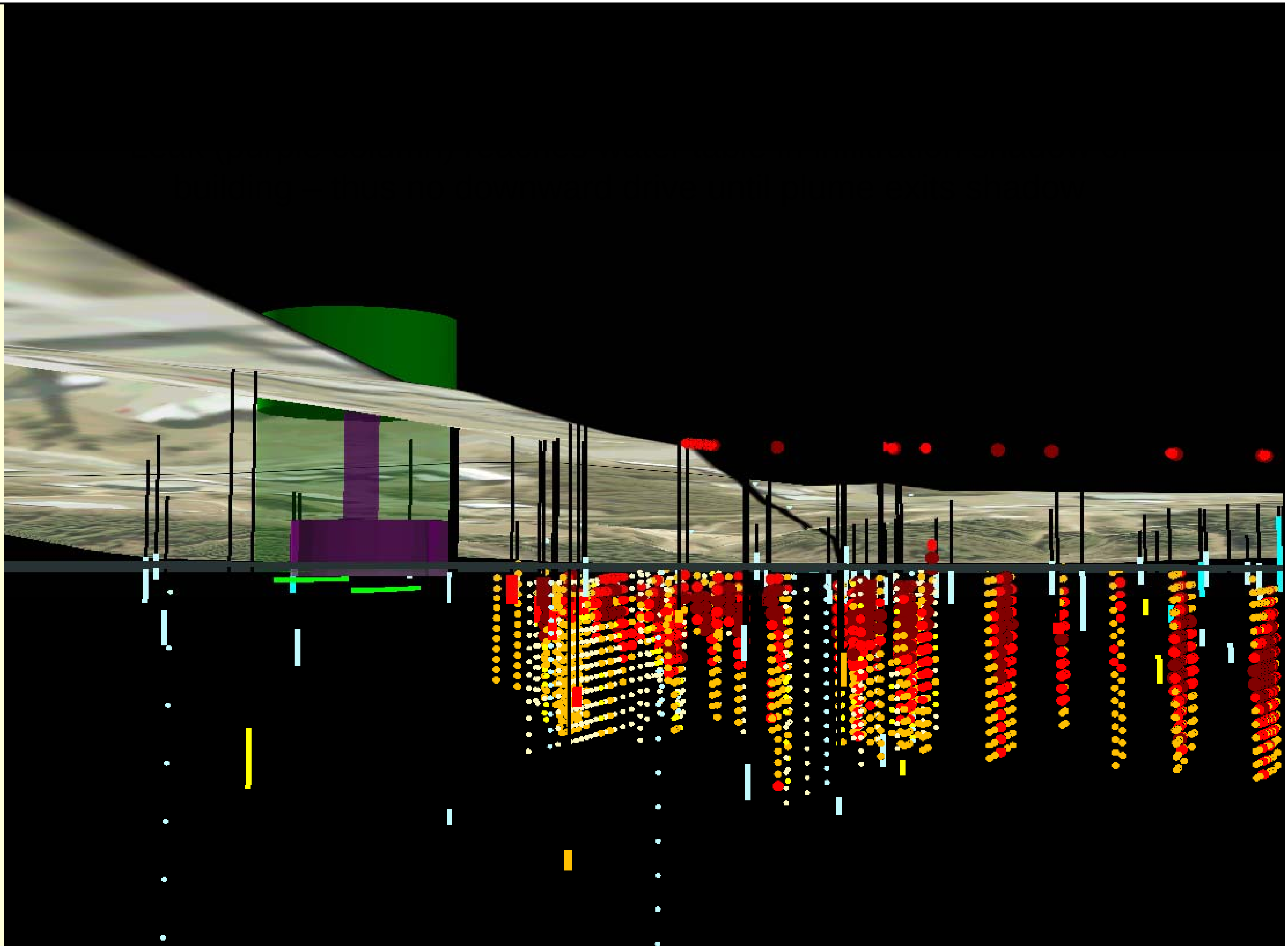
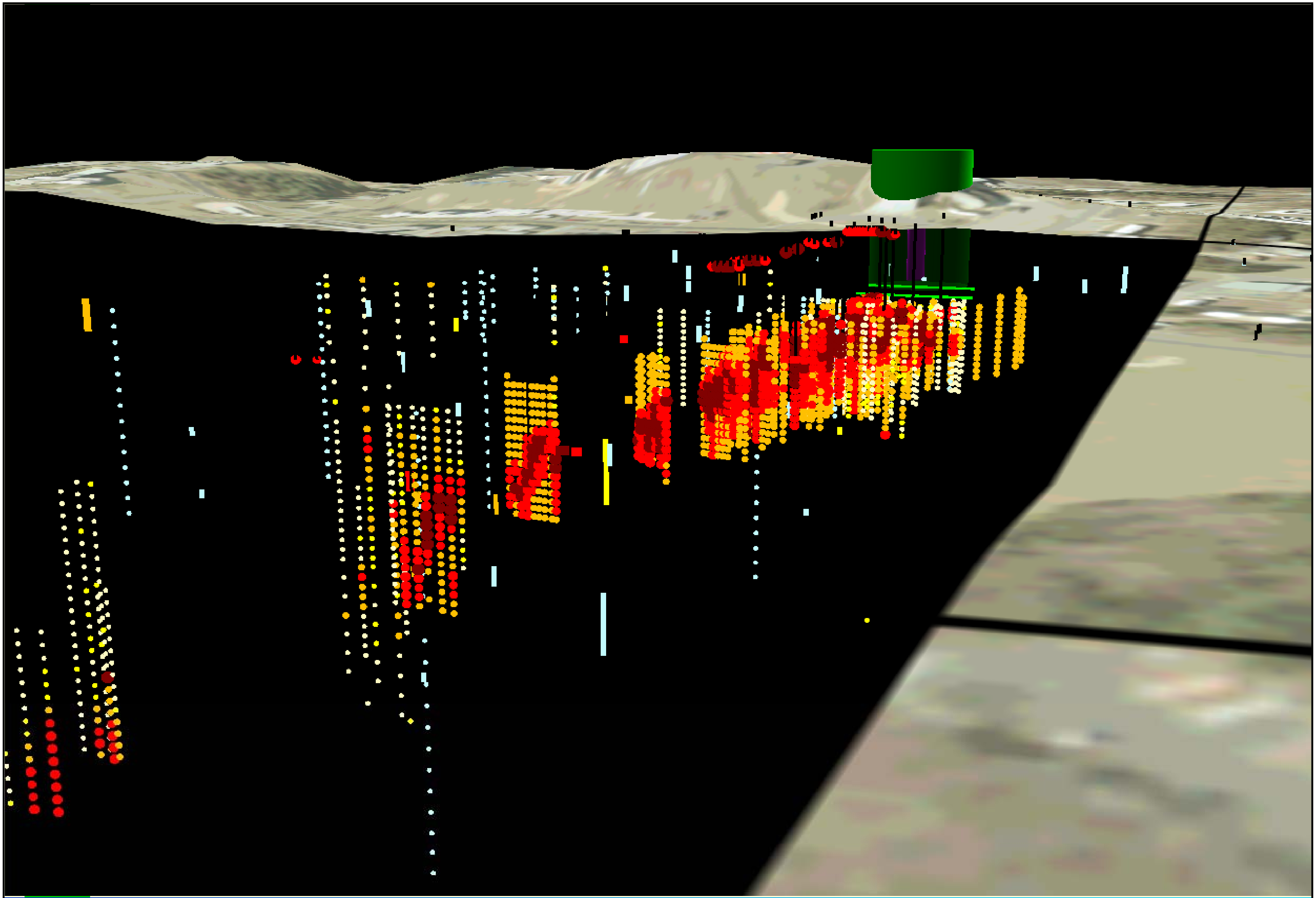


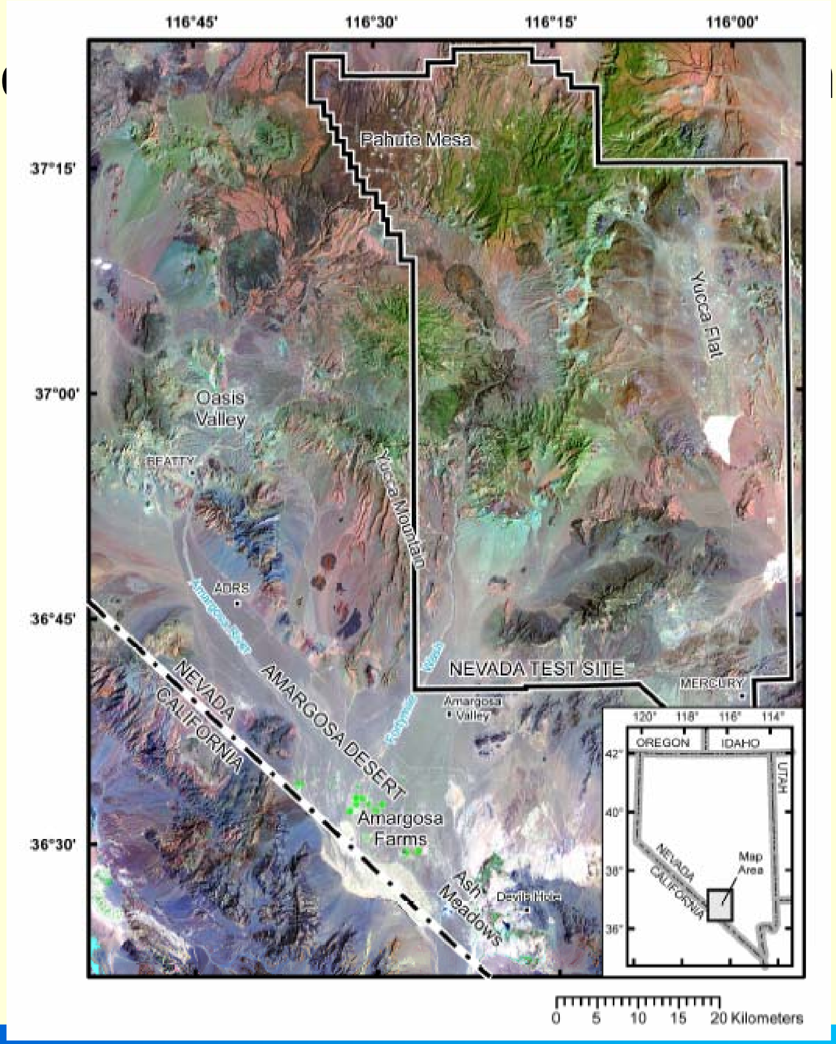
Figure 5. Observed tritium plume geometry at the HFBR.





USGS Amargosa Desert Research Site

(Data Court ers, USGS)



Resistivity Sounding Locations at ADRS

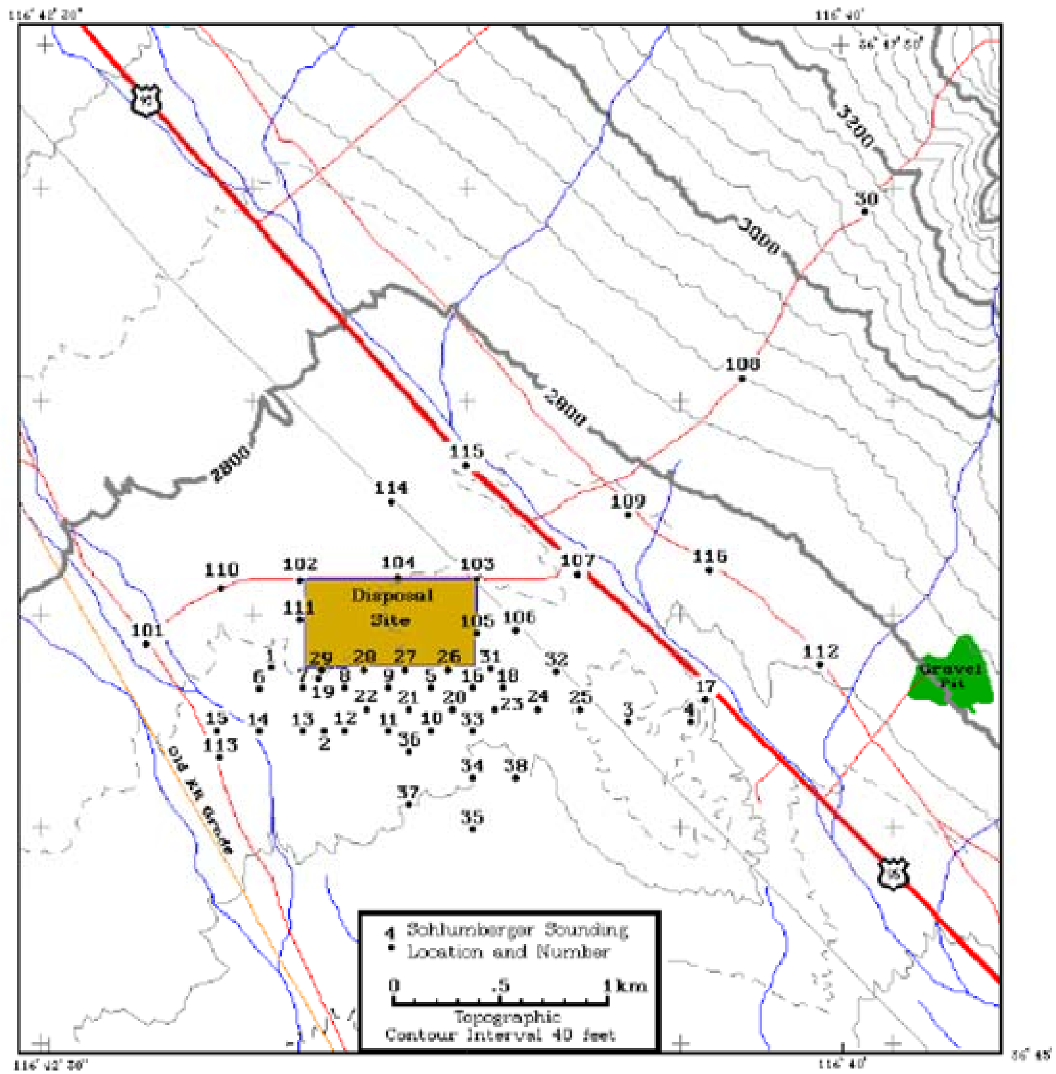
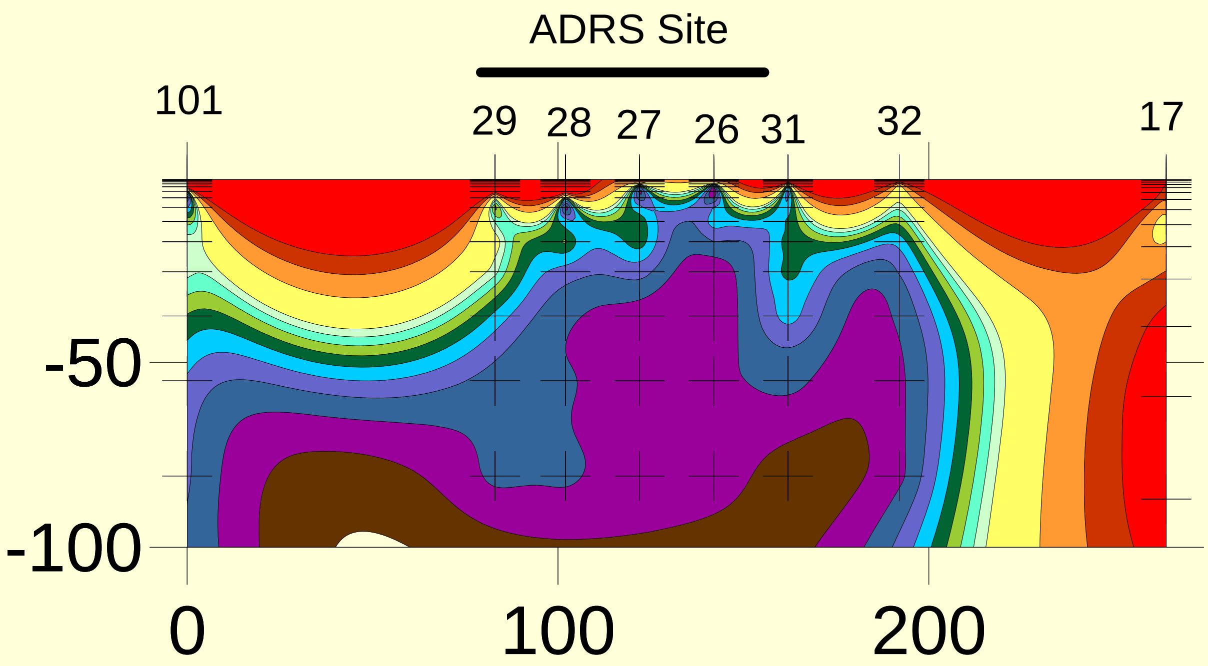


Figure 2. Map showing the number and location of the Schlumberger soundings.

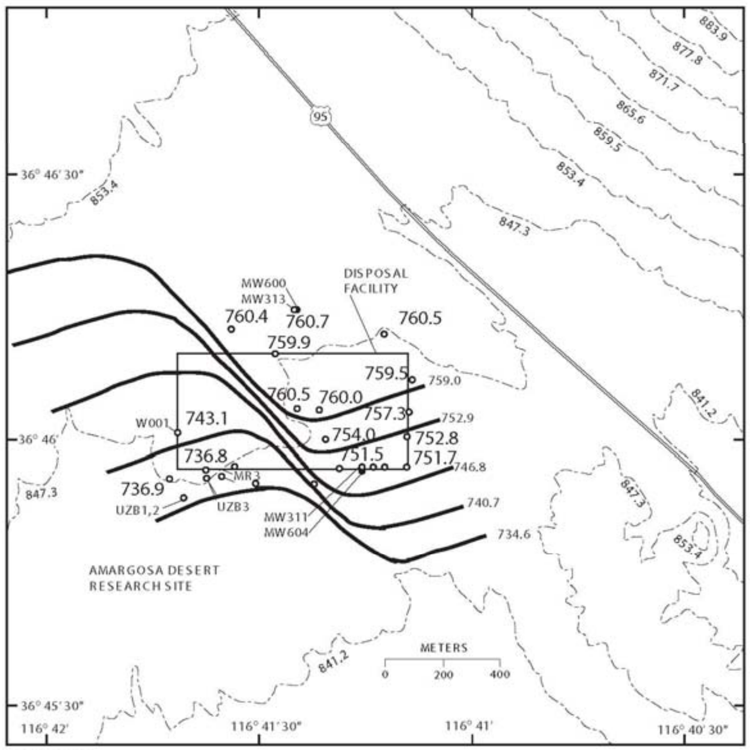
ADRS Resistivity Cross-Section

Cross section 3

Looking North



ADRS Water Table (Walvoord et al., 2005)



MR3 734.3
UZB3 736.8
MW302 736.9
MW311 751.6
MW317 751.0
Site Well 760.5

MR1 near Amargosa River 3,200 m west of northwest corner; Water table 757.82 m.

Well MW319 76.2 meters north; 181.92 m east of northwest corner
Elevation of water table is 760.4 m; May 6, 2004

Well MW318 71.4 meters north; 705.46 m east of northwest corner
Elevation of water table is 760.5 m; May 6, 2004.

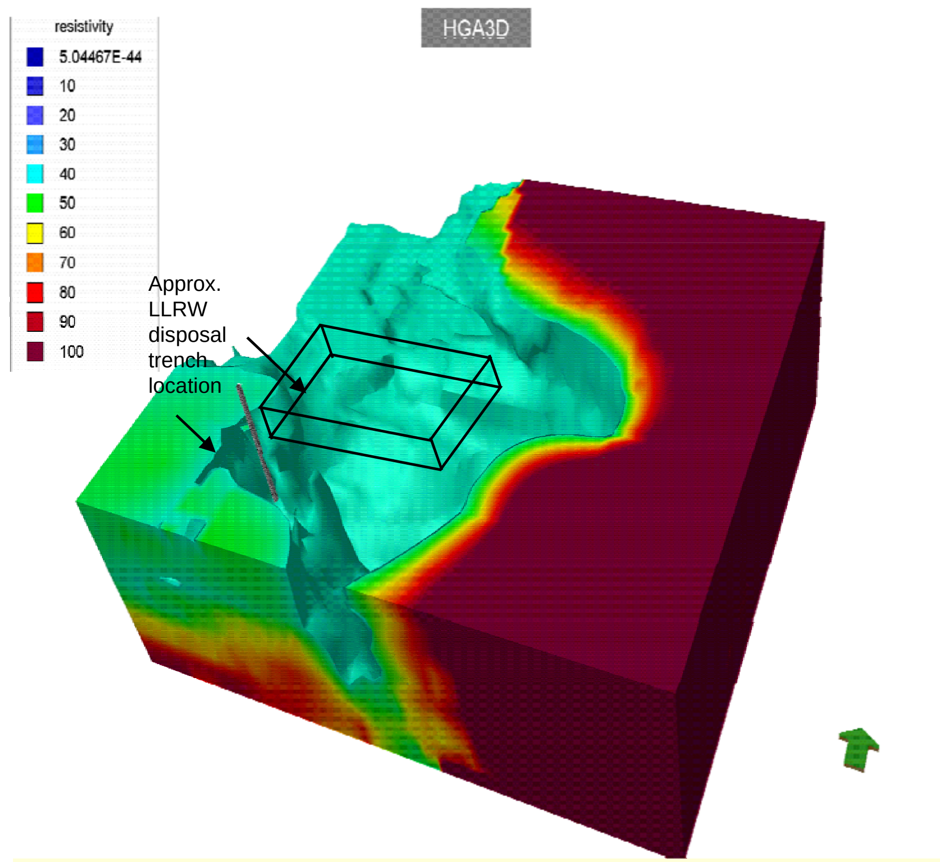
Well MW325 449.53 meters south; 28.91 m west of northwest corner
Elevation of water table is 736.9 m; May 6, 2004

Well MW326 447,22 meters south; 266.39 m east of northwest corner
Elevation of water table is 737.7 m; May 6, 2004

Well MW327 446.5 meters south; 472.33 m east of northwest corner
Elevation of water table is 741.6 m; May 6, 2004

ADRS Conceptual Site Model developed with 3-D contouring of resistivity data

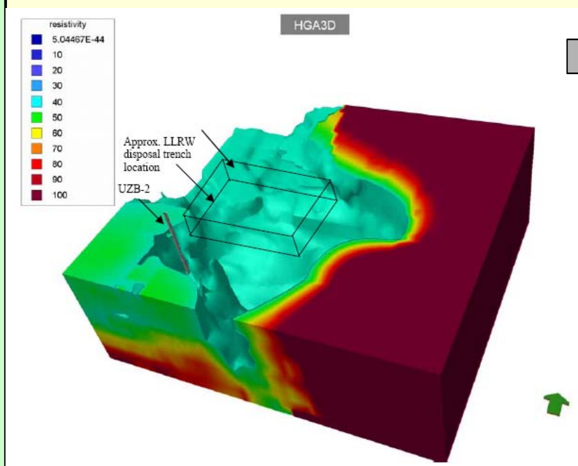
- Basis for the CSM:
  - Geology
  - Ground-water flow
  - Contaminant transport

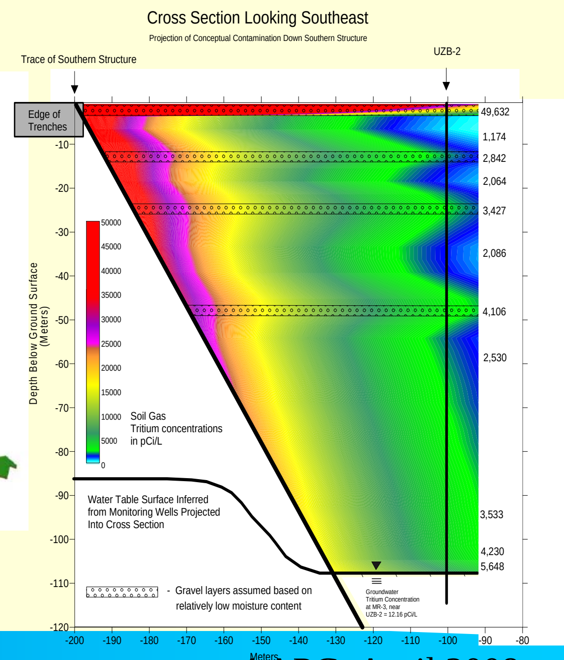


Synthesis of CSM & Flow and Transport Models

- USGS had an existing CSM; however tritium modeling results did not match observed contaminant distributions.
- AES developed an alternative CSM that included this fault. Observed data matched flow and transport simulations
- Modeled resistivity data in 3-D using kriging through HydroGeo Analyst 2.0 Simple Excel spreadsheet model to simulate movement of tritium in vadose zone both laterally and vertically in response to proposed fault
- Contoured tritium in ground water and vadose zone using Surfer code

- Current CSM did not match movement of tritium in vadose zone
- Revising CSM
  - An alternative CSM was proposed
  - Subsequent flow and transport modeling of the vadose zone produced results that more closely matched observed data





Analysis of Site and Facility Characterization & Monitoring Data

- Geophysical borehole log data (neutron-moisture, natural gamma, and gamma-gamma)
  Monitoring well data from existing wells
- Schlumberger resistivity soundings
- Soil gas data
- Thermocouple psychrometer data
- Neutron probe data
- Vegetation tritium analytical data

Analysis of this data suggested a fault which acted as a preferential transport path

Synthesis of CSM & Flow and Transport Models

USGS had an existing CSM; however tritium modeling results did not match observed contaminant distributions.

- AES developed an alternative CSM that included this fault. Observed data matched flow and transport simulations

•Modeled resistivity data in 3-D using kriging through HydroGeo Analyst 2.0 Simple Excel spreadsheet model to simulate movement of tritium in vadose zone both laterally and vertically in response to proposed fault

- Used Surfer for contouring tritium in ground water and vadose zone

WHAT:
PI Recommendations

- Class 1: tritium concentrations in ground water, soil gas, and plants
- Class 2: vadose zone water flux
- Class 3: incongruous water table shape, modeling congruity, tritium as outliers in ground water

WHERE & WHEN:
Monitoring Points (MP) Recommendations:

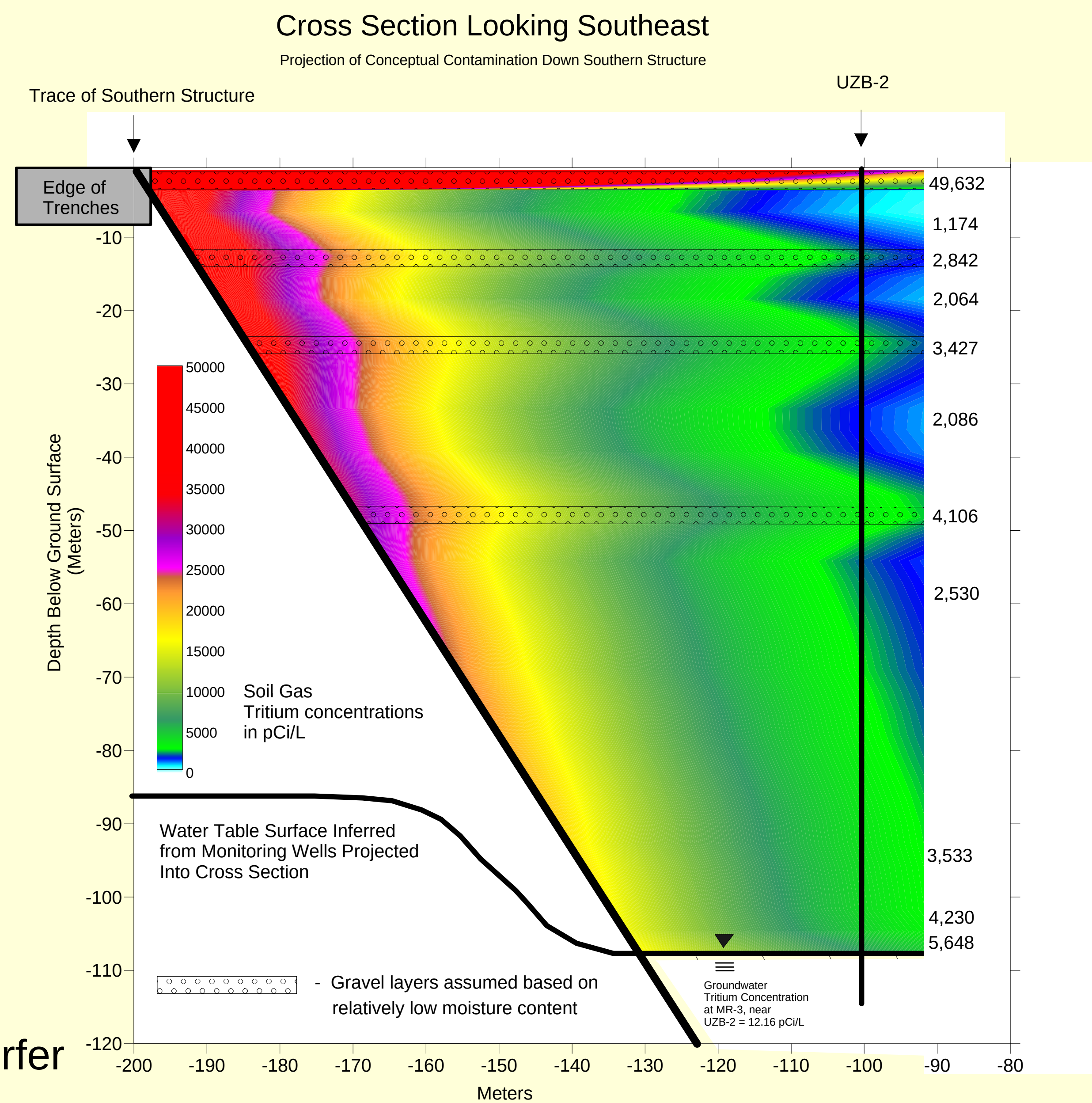
- Add vadose zone wells or CPTs near proposed fault to evaluate tritium and barometric pressure
- Ensure site monitoring system is integrated and comprehensive

HOW:
Monitoring Devices (MD)

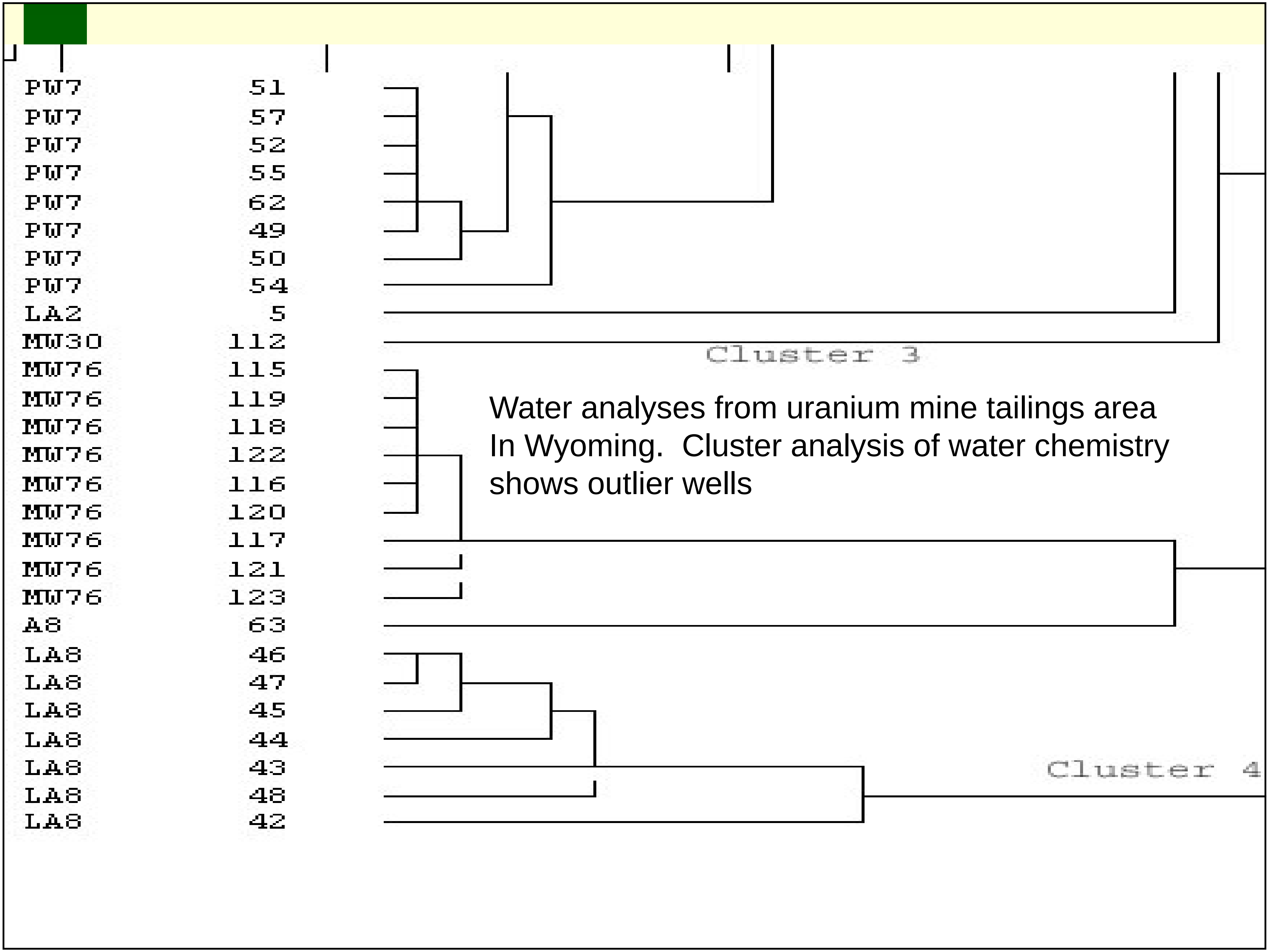
- Soil vapor, ground water sampling

PERFORMANCE CONFIRMATION MONITORING:
Data Collection & Analysis

FEEDBACK based on analysis of PCM data will be used to update CSM



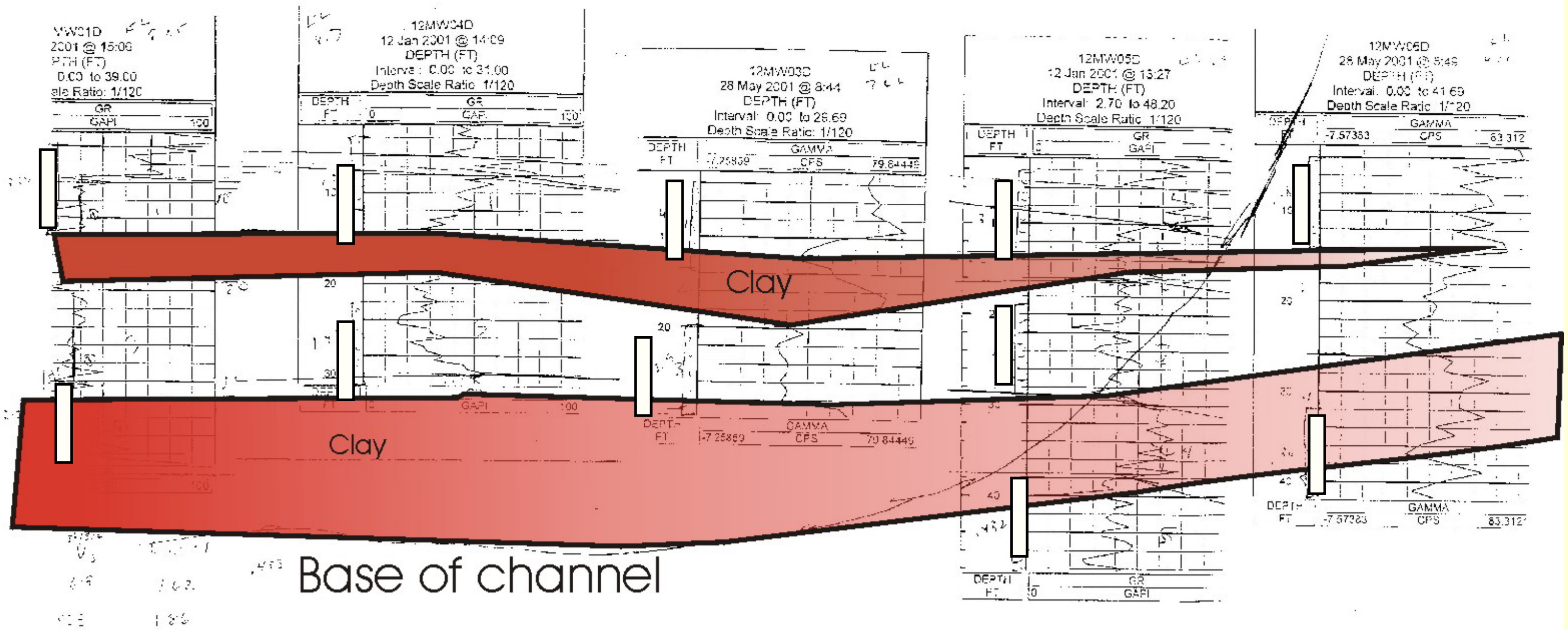
Excel then Surfer



Water analyses from uranium mine tailings area In Wyoming. Cluster analysis of water chemistry shows outlier wells

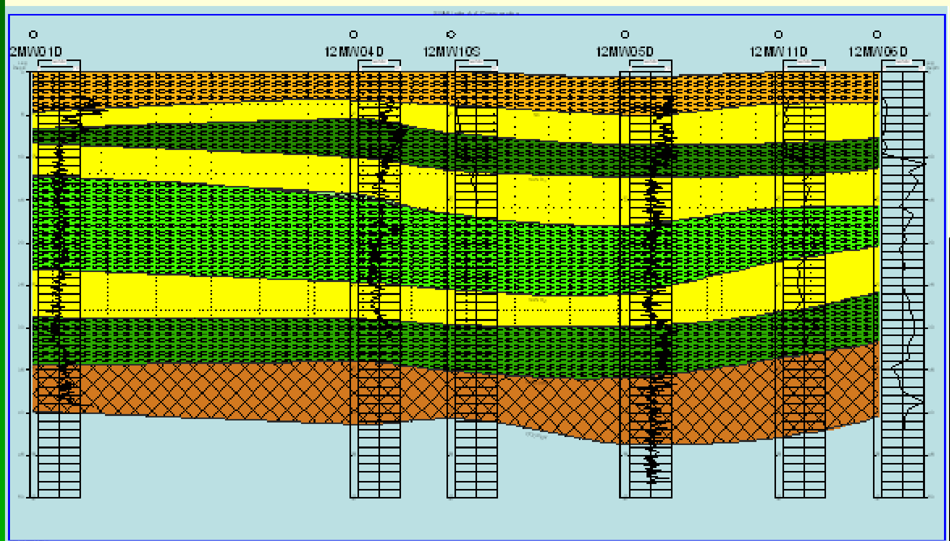
Charleston Naval Weapons Station (Site-12)

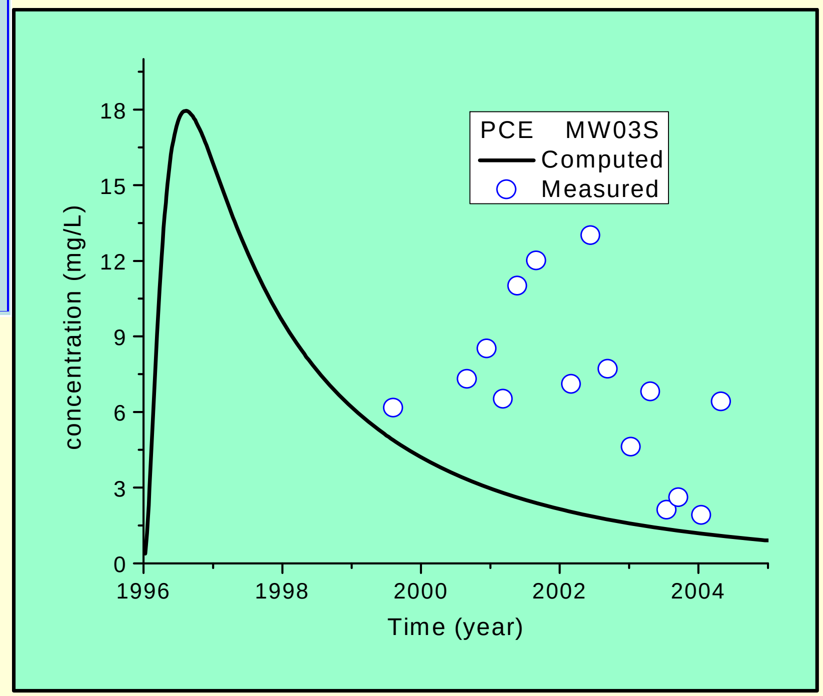
Original Interpretation



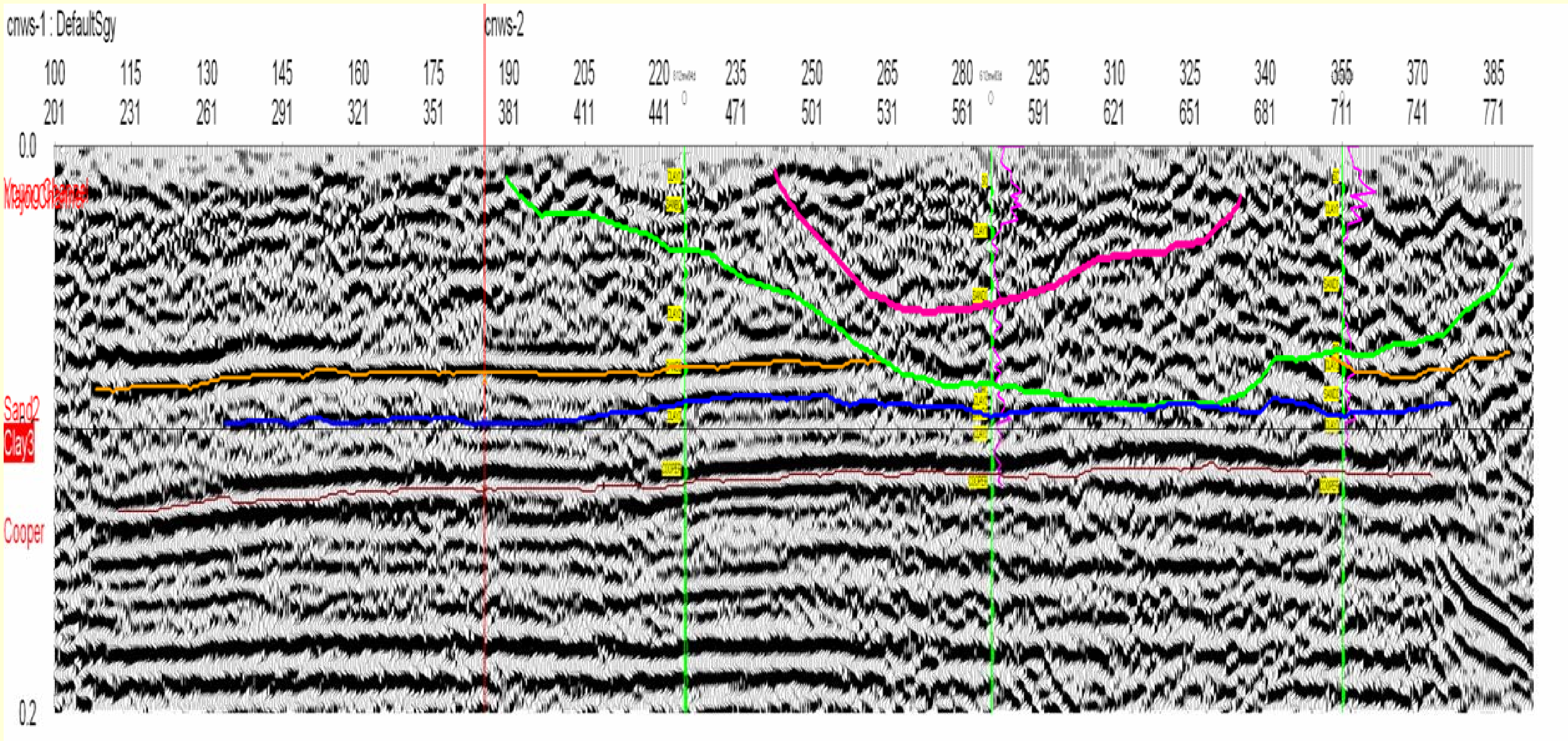
Layer-Cake model based on well data

Very poor match to observed contaminant timing

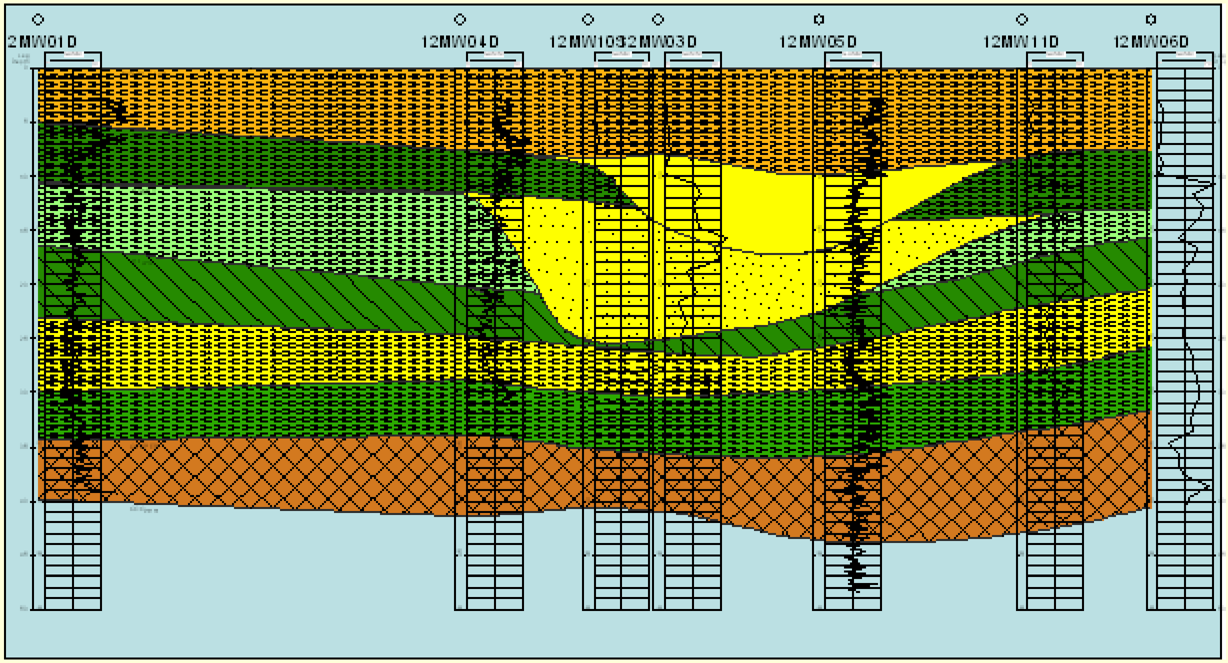




Seismic line shows shallow channels

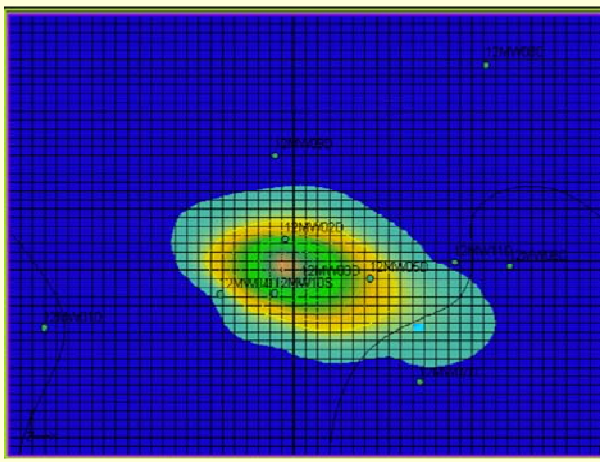


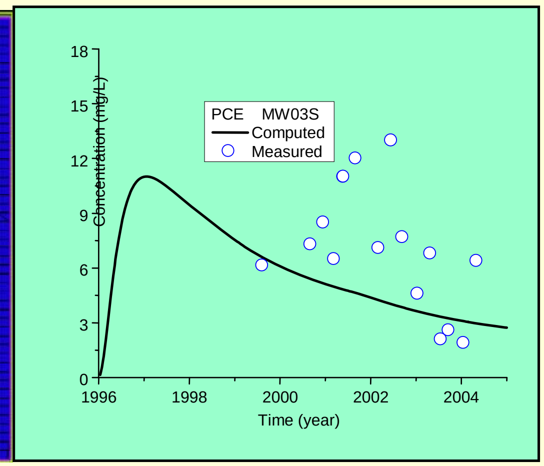
Revised CSM with channel sands



Petra then GMS

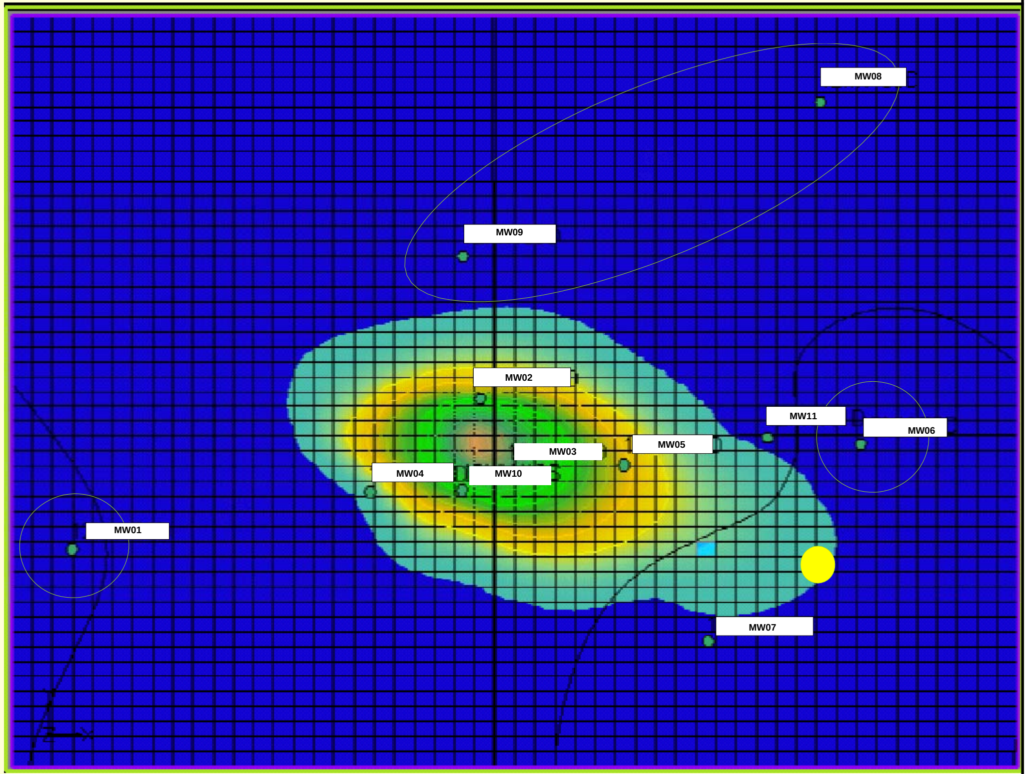
Improved history match to well data





Monitoring Frequency

- Volume II presents examples to illustrate:
  - pitfalls of premature reduction or termination of sampling (Ch 8)
  - when monitoring points may be abandoned (Ch 2)



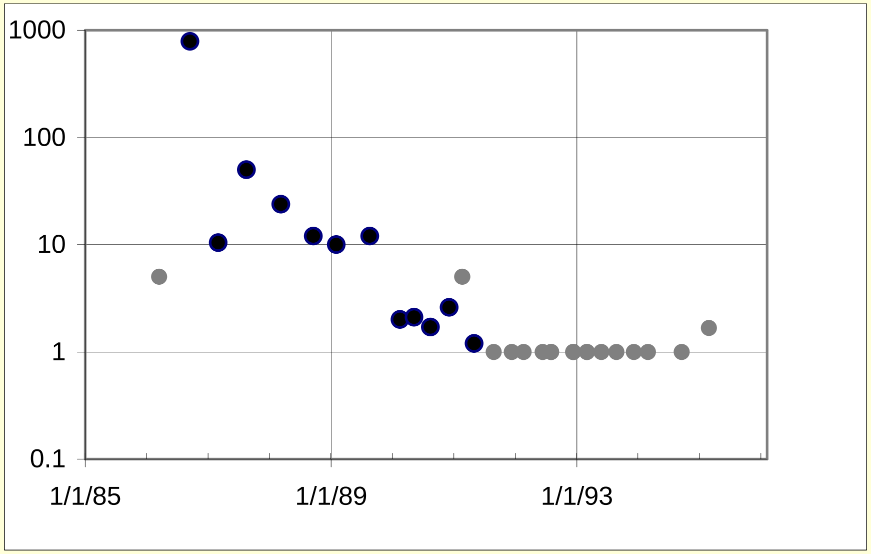
Vol. II, Figure 2-12. The predicted PCE plume in five years. Circled wells are suggested to be removed from the monitoring program, while a new point is suggested to be added at the yellow dot to test the CSM and simulation results

Characterization vs Monitoring

- Characterization allows development of CSM
- CSM allows modeling / simulation
- Modeling allows prediction
- Monitoring allows refinement
- Refinement allows confidence

Confirmation Monitoring

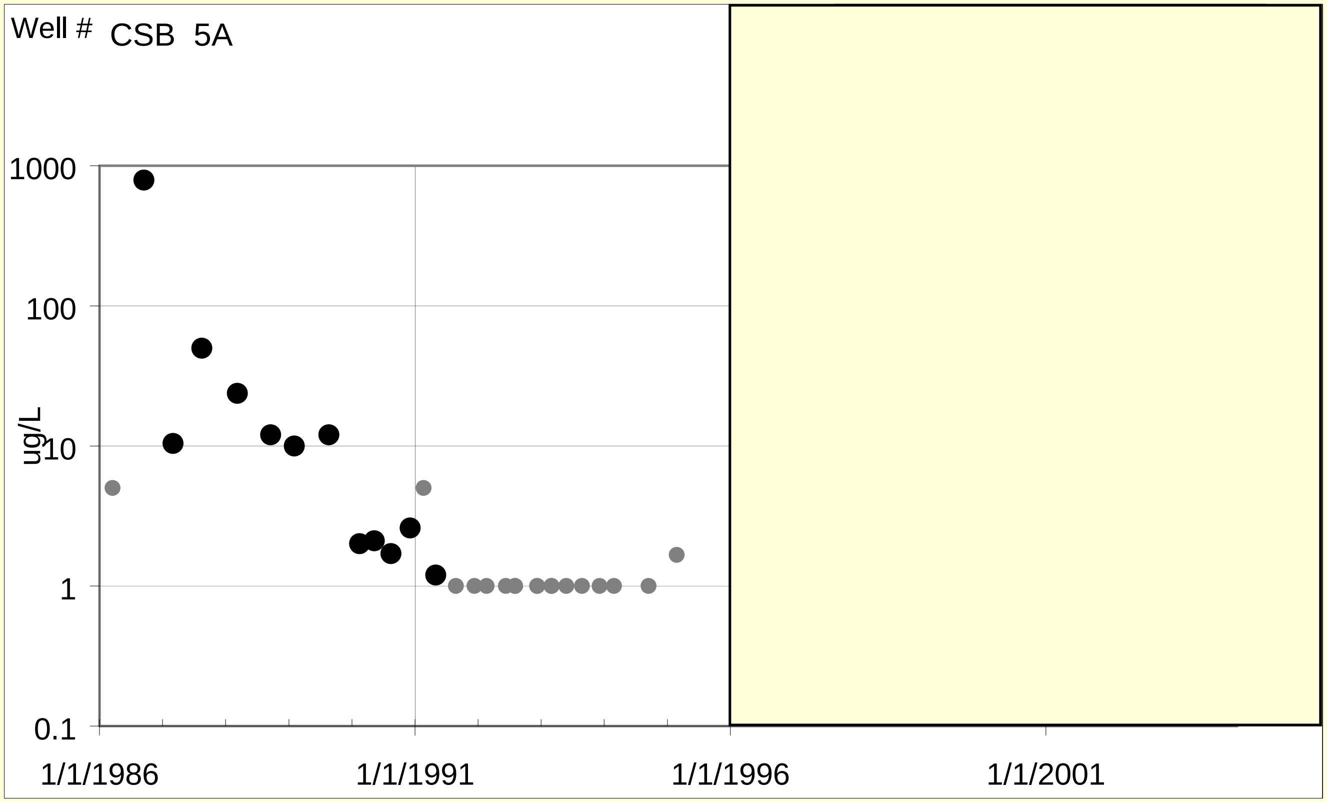
- Statistical methods useful in these evaluations include:
  - analyses of temporal trends in contaminant concentrations
  - comparisons with the specified concentration standard
- EPA guidance regarding verification of compliance with cleanup objectives is provided in Cohen *et al.* (1994) and EPA (1992a)



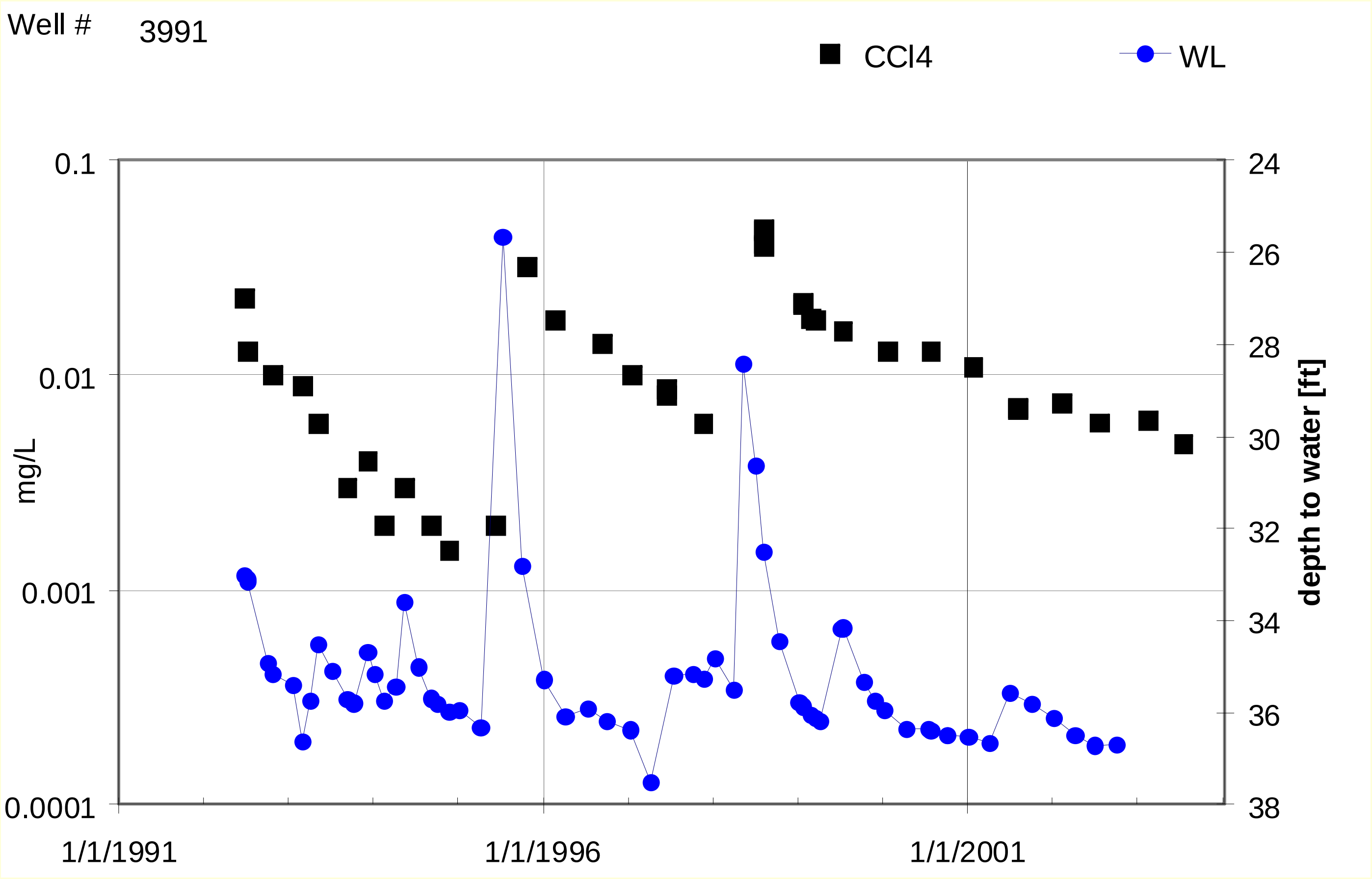
Modified from NUREG/CR-6948, V-2, Figure 5-6

When can you stop sampling?

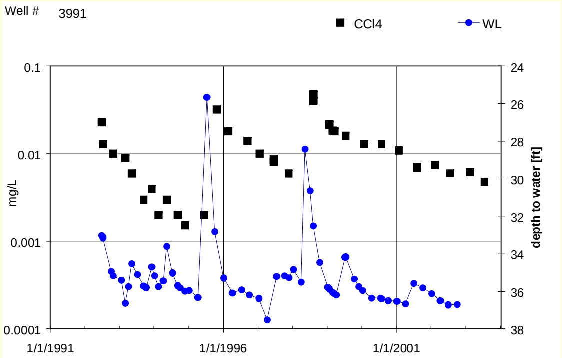
Water levels as a secondary indicator to guide sampling frequency.

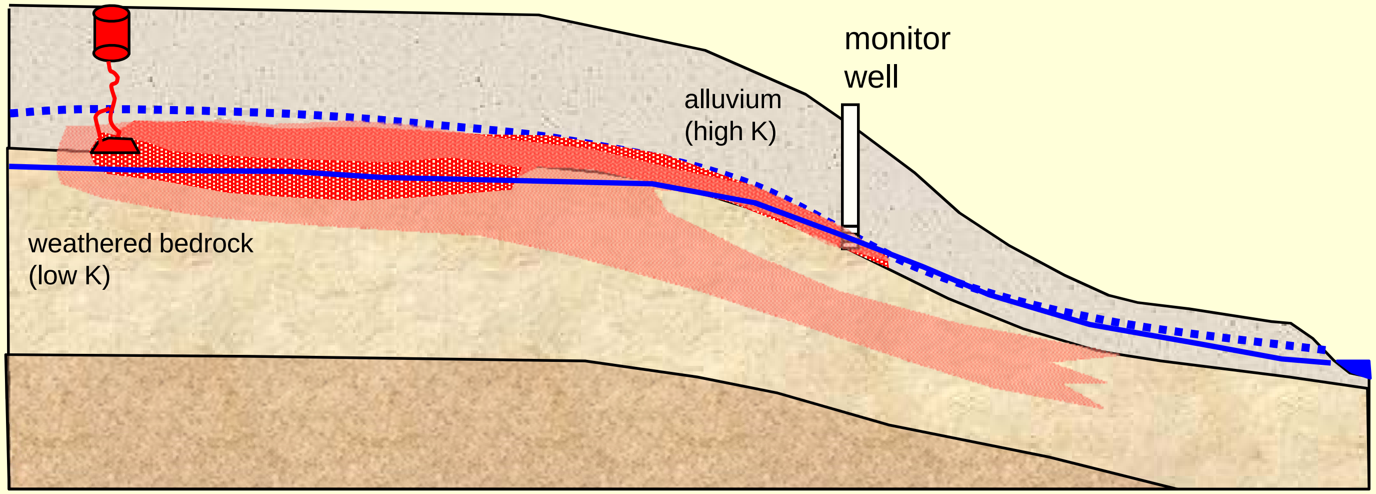


Multi-year variability



Conceptual Model of Transport





Lesson Learned

- You cannot use statistics to justify an end to sampling –
- Unless you have a clear understanding of how the subsurface system is working – a good CSM

Information Source – NUREG/CR-6948

- Technical bases for developing guidance on ground-water monitoring for NRC-licensed sites
- Systematic methodology to integrate monitoring with modeling

- **http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6948/v1/index.html**

NUREG/CR-6948, Vol. 1

Integrated Ground-Water Monitoring Strategy for NRC-Licensed Facilities and Sites: Logic, Strategic Approach and Discussion

Manuscript Completed: July 2007
Date Published: September 2007

Prepared by
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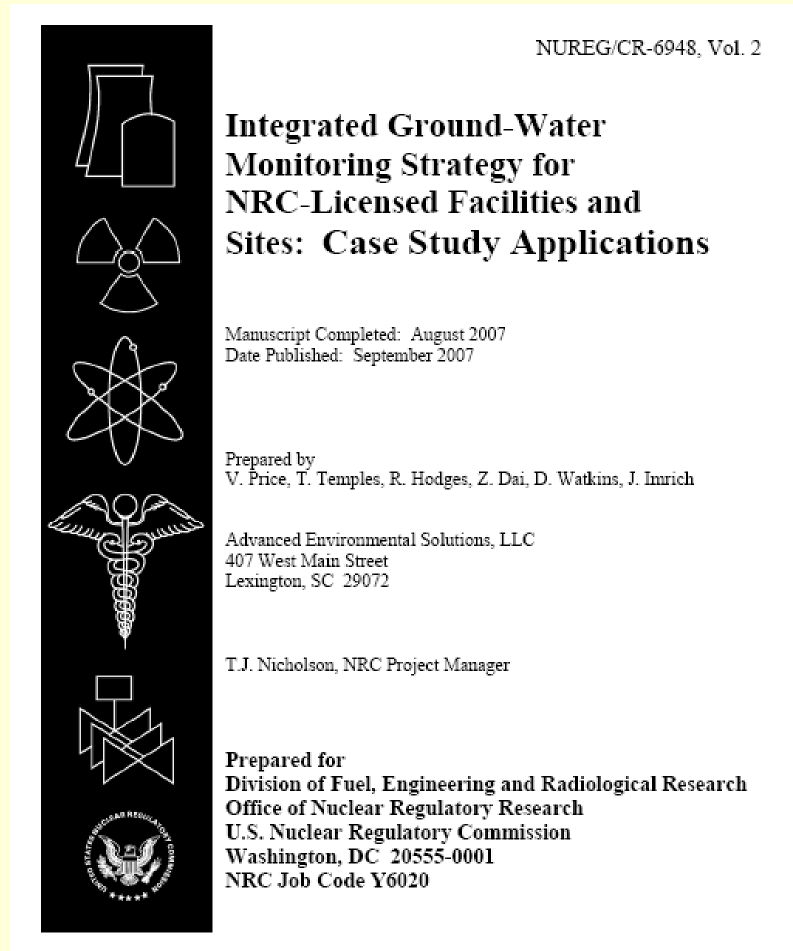
Division of Fuel, Engineering and Radiological Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6020

Information Source – NUREG/CR-6948

- Lessons-Learned for developing guidance on ground-water monitoring for NRC-licensed sites
- Case Studies which includes Brookhaven radionuclide plume remediation and monitoring
- **http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6948/v2/index.html**



NUREG/CR-6948, Vol. 2

Integrated Ground-Water Monitoring Strategy for NRC-Licensed Facilities and Sites: Case Study Applications

Manuscript Completed: August 2007
Date Published: September 2007

Prepared by
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Prepared for
Division of Fuel, Engineering and Radiological Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6020

References

Caggiano, J.A., 1996, Assessment groundwater monitoring plan for single shell tank waste management area B-BX-BY: DOE Technical Report WHC-SD-EN-AP-002-Rev. 2, Web accessed 21 November 2008, doi: 10.2172/326402.

Cohen, S., 1994, Apparent shift in EPA's ground water policy: Ground Water Monitoring and Remediation, v. 14/3, p. 97-98.

Tukey, J., 1962, The future of data analysis: Annals of Mathematical Statistics, v. 33, p. 1-67.

Walvoord, M.A., R.G. Striegl, D.E. Prudic, and D.A. Stonestrom, 2005, CO2 dynamics in the Amargosa Desert; fluxes and isotopic speciation in a deep unsaturated zone: Water Resources Research, v. 41/2, 15 p., Web accessed 21 November 2008, doi: 10.1029/2004WR003599.

Wang, H.R., and M.P. Anderson, 1982, Introduction to groundwater modeling; finite difference and finite element methods: 237 p.

Ward, C.H., J.A. Cherry, and M.R. Scalf, 1997, Subsurface restoration, 462 p.