Field Scale Dye Tracer Experiments
A Method for Delineating Vadose Zone Flow and Transport Processes

Subsurface Flow and Transport Processes Laboratory

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"Field Scale Dye Tracer Experiments: a Method for Delineating Vadose Zone Flow Processes"

Identification of site-specific vadose zone flow processes is fundamental to understanding transport mechanisms responsible for observed contaminant distributions, assessing the extent of contamination beyond sampled areas, and predicting the fate of the contaminants. Among the methods available for studying vadose zone flow processes, dye tracer studies stand out as one of the best methods for identifying flow and transport pathways by providing direct visual evidence. We have performed dye tracer studies in a variety of geologic materials ranging from a glacial till comprised of fractured clay deposits to stratified fluvial deposits. Results from these studies have provided critical insight required for the correct conceptualization of the flow processes in these environments.

Objective of the Fernald Infiltration Studies

Provide information on flow and transport pathways within near surface glacial deposits (Roepke et al, 1995)

Methods

Perform an infiltration experiment in glacial till deposits adjacent to known contaminant sources

Incorporate a salt tracer followed by a dye tracer to provide independent means of identifying transport pathways

Monitor the subsurface with multiplexed arrays of instruments and sampling lysimeters

Excavate site following the dye pulse, map location of dye tracer, and identify transport mechanisms

Site Location

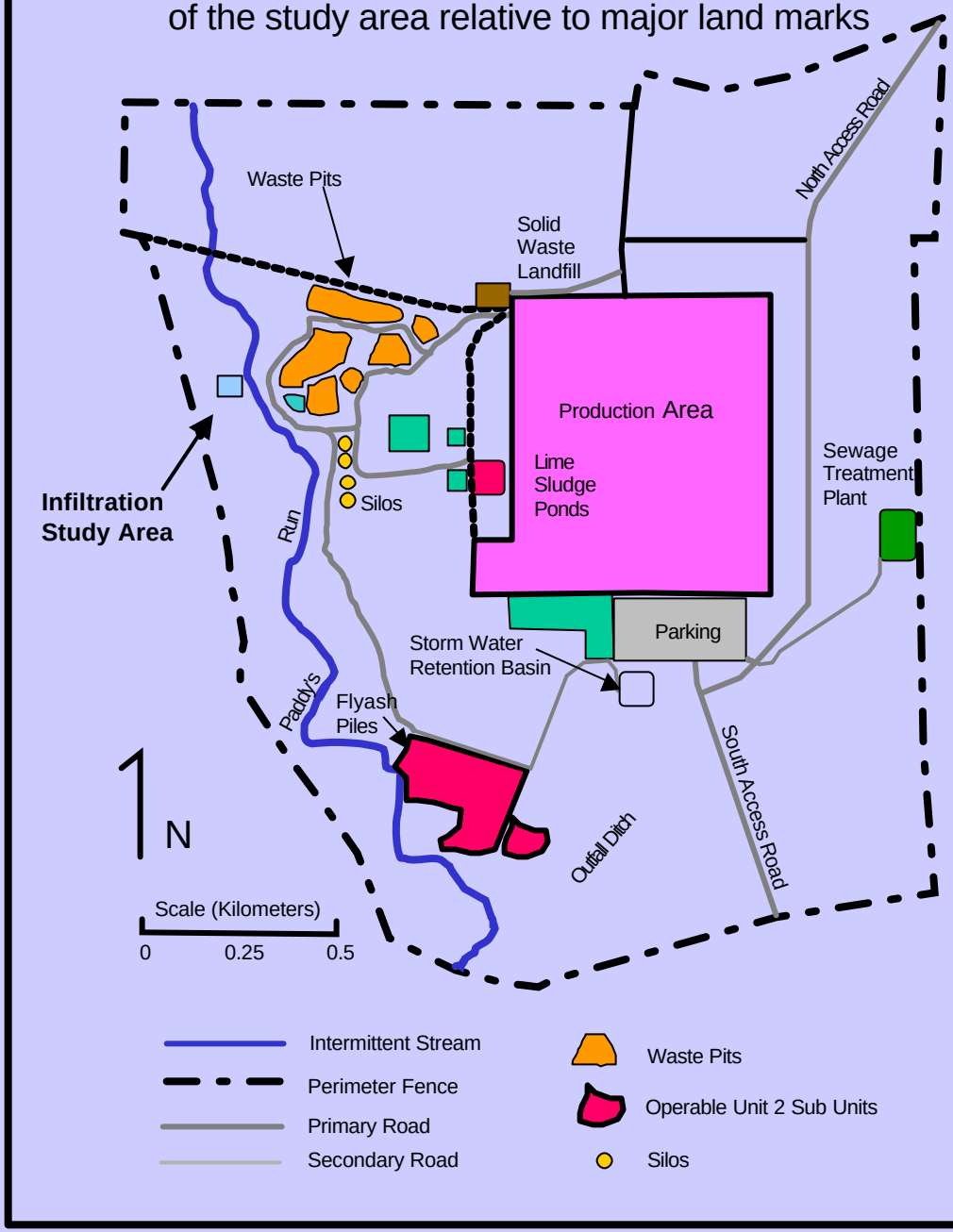
Fernald DOE facility located 20 miles NW of Cincinnati Ohio

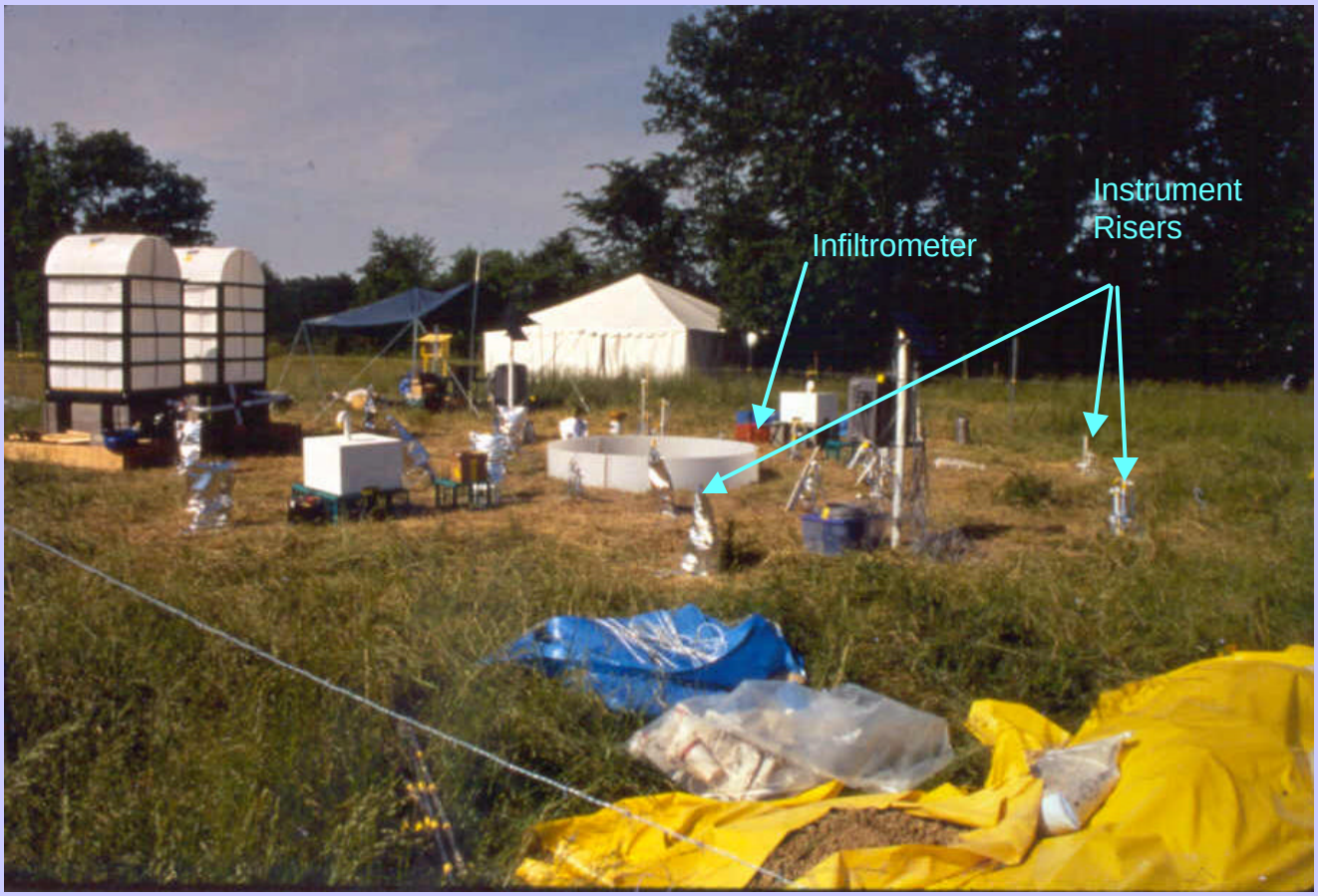
The Fernald facility produced uranium metal products for the nation's defense programs

Experimental site located adjacent to waste pits

Paddys Run - and intermittent entrenched stream- runs between the experimental site and the waste pits

Map of the Fernald Facility showing the location of the study area relative to major land marks

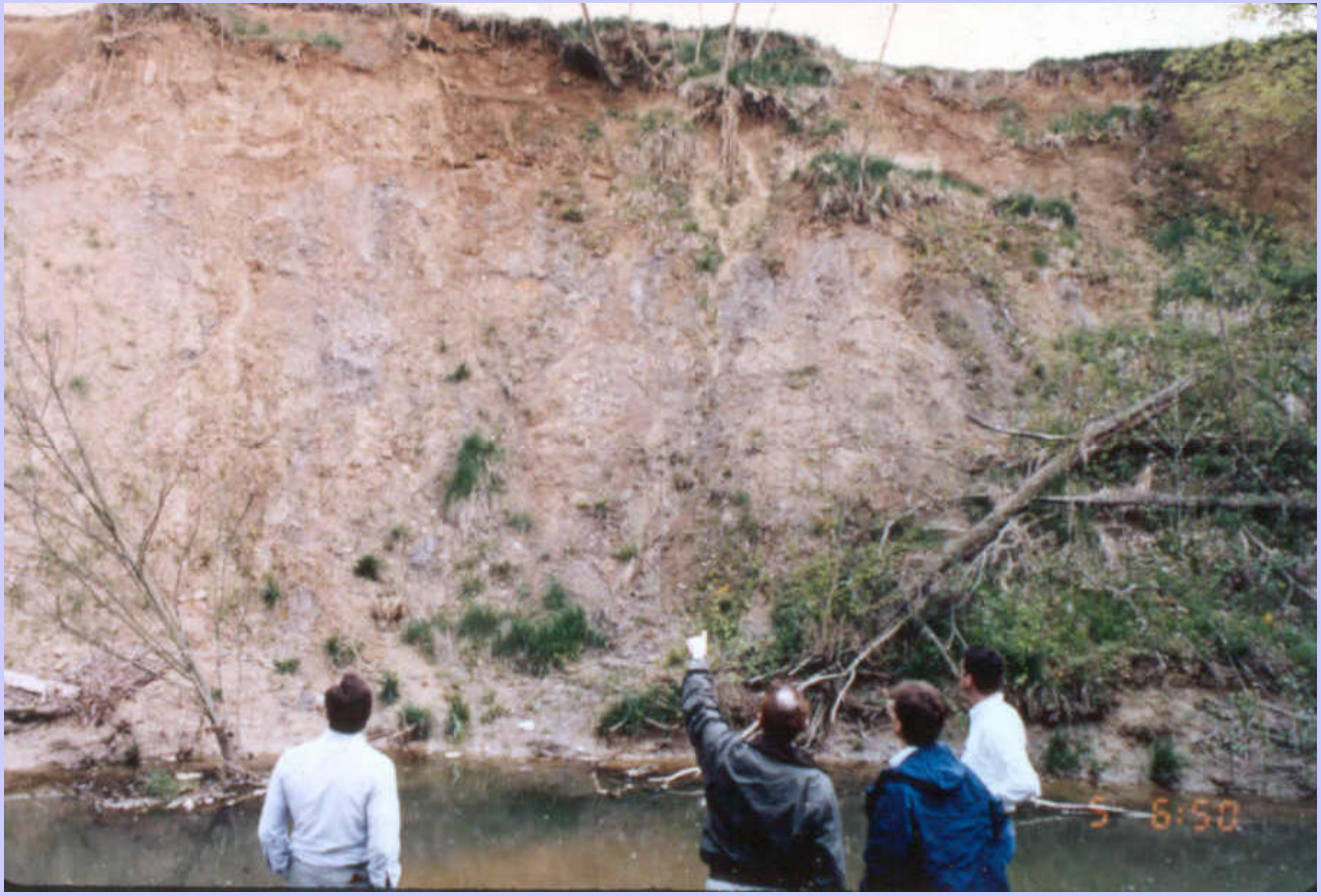




View of one of two experimental sites at the Fernald Facility

Two experiments were ran simultaneously, each experiment introduced water and salt tracer into different types of deposits. We chose to perform the dye tracer study and subsequent excavation where clay deposits predominated (clay site). The other experiment was sited above a shallow perched sandy aquifer (sand site).

Above is a view of the clay site. Water was introduced into the subsurface through the infiltrometer located at the center of the picture. Surrounding the infiltrometer are surface expressions of the monitoring instrumentation (instrument risers). Instruments were installed in “packs”, each pack containing a time domain reflectometer (TDR) probe, tensiometer, and suction lysimeter. Thirty-two packs were installed at 3 and 5 meters below the ground surface in two concentric circles at a radial distance of 2.5 and 5 meters from the center of the infiltrometer. Another 8 packs were installed 3 and 5 meters below the infiltrometer. The infiltrometer diameter is 2 meters.



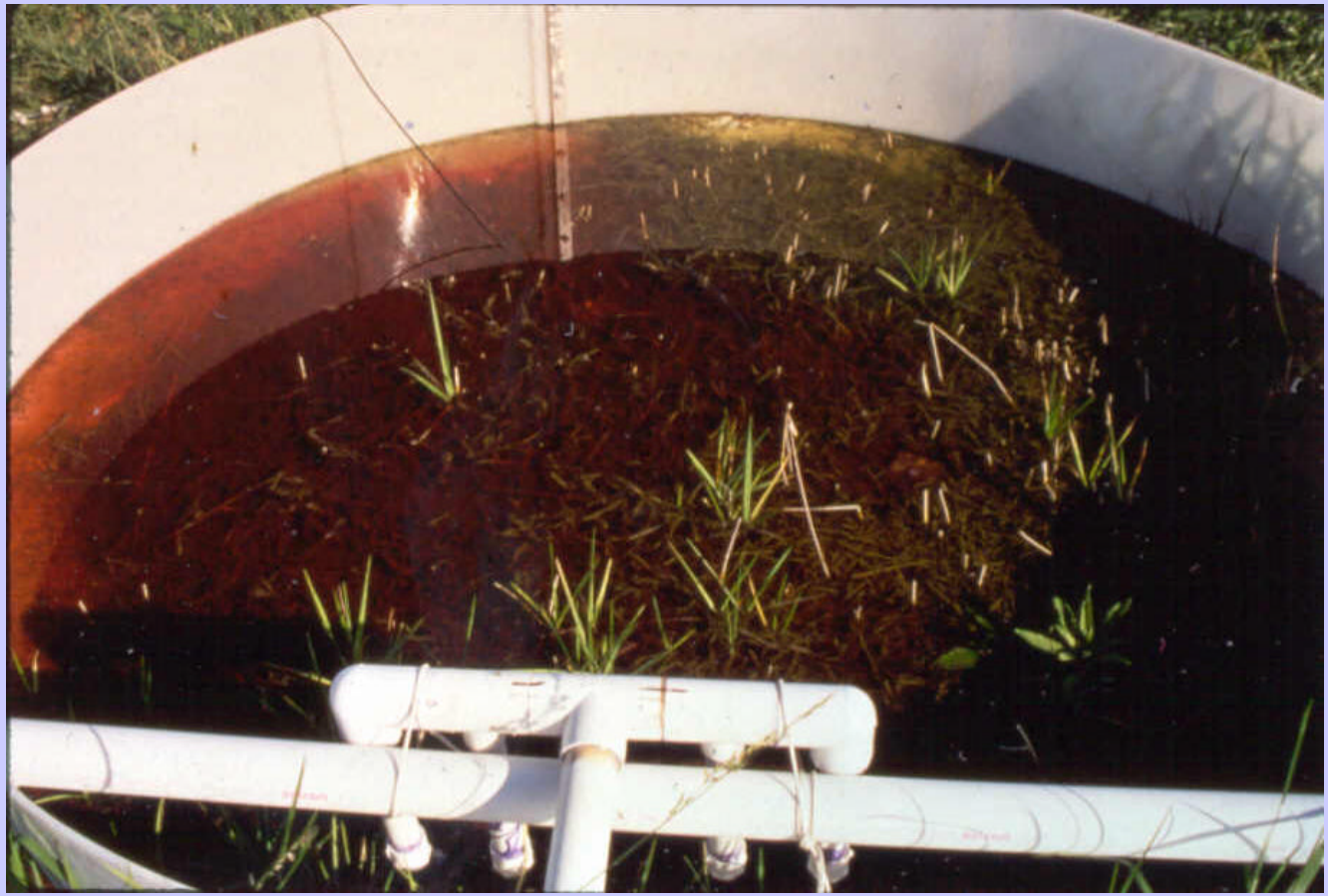
Nearby outcrops in Paddys run provided the opportunity to identify geologic units and potential transport pathways

Small excavations in the outcrops provided the opportunity to characterize the deposits in more detail

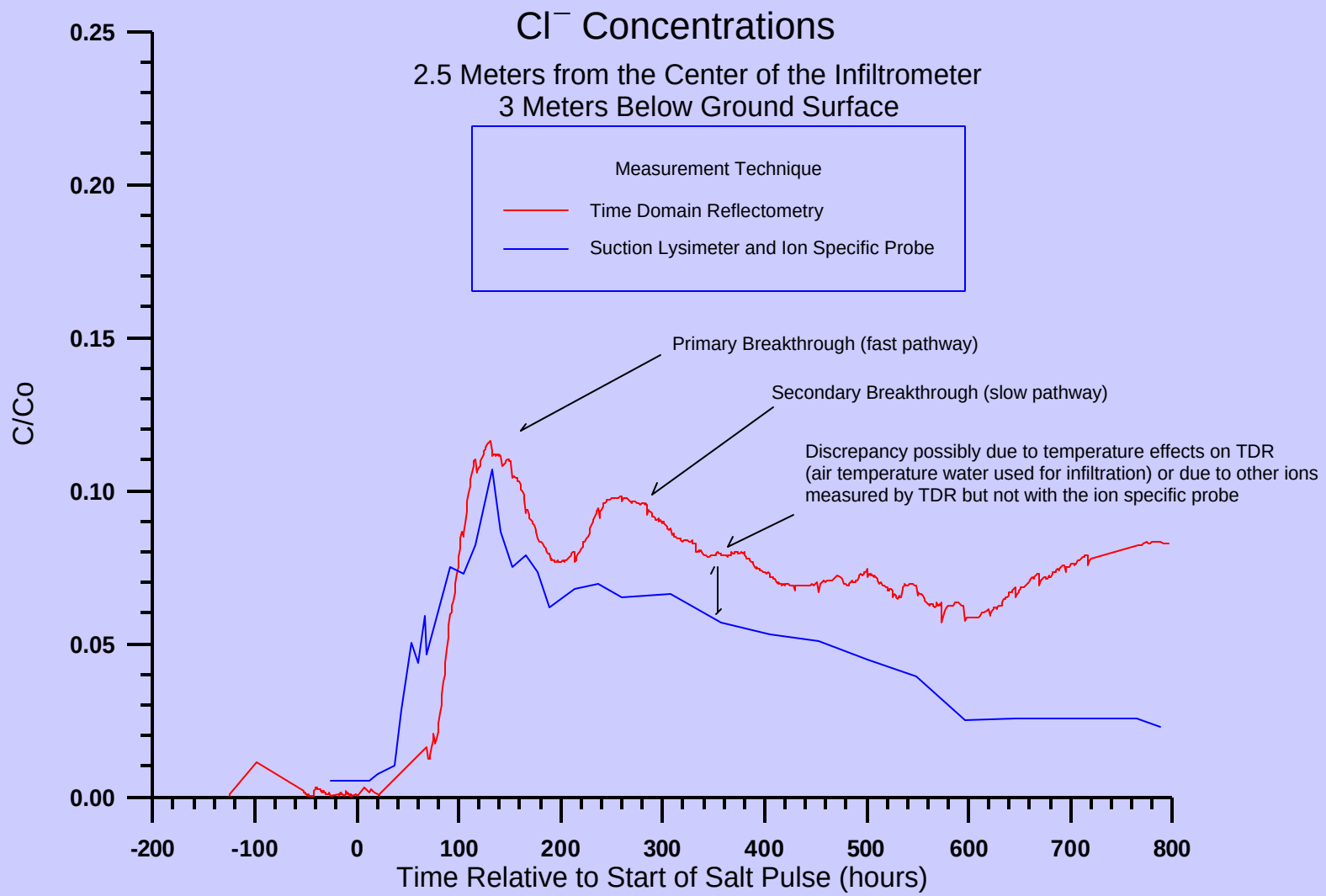
Note the 3 lb. sledge hammer head on the extreme right of the photograph for scale. Clay deposits were extremely fractured and exhibited bedding at several scales.

Small-scale infiltration experiments provided direct evidence of potential preferential flow mechanisms at the infiltration site

Small scale experiments and outcrop observations provided the means to identify several potential fast pathways in the near surface vadose zone.



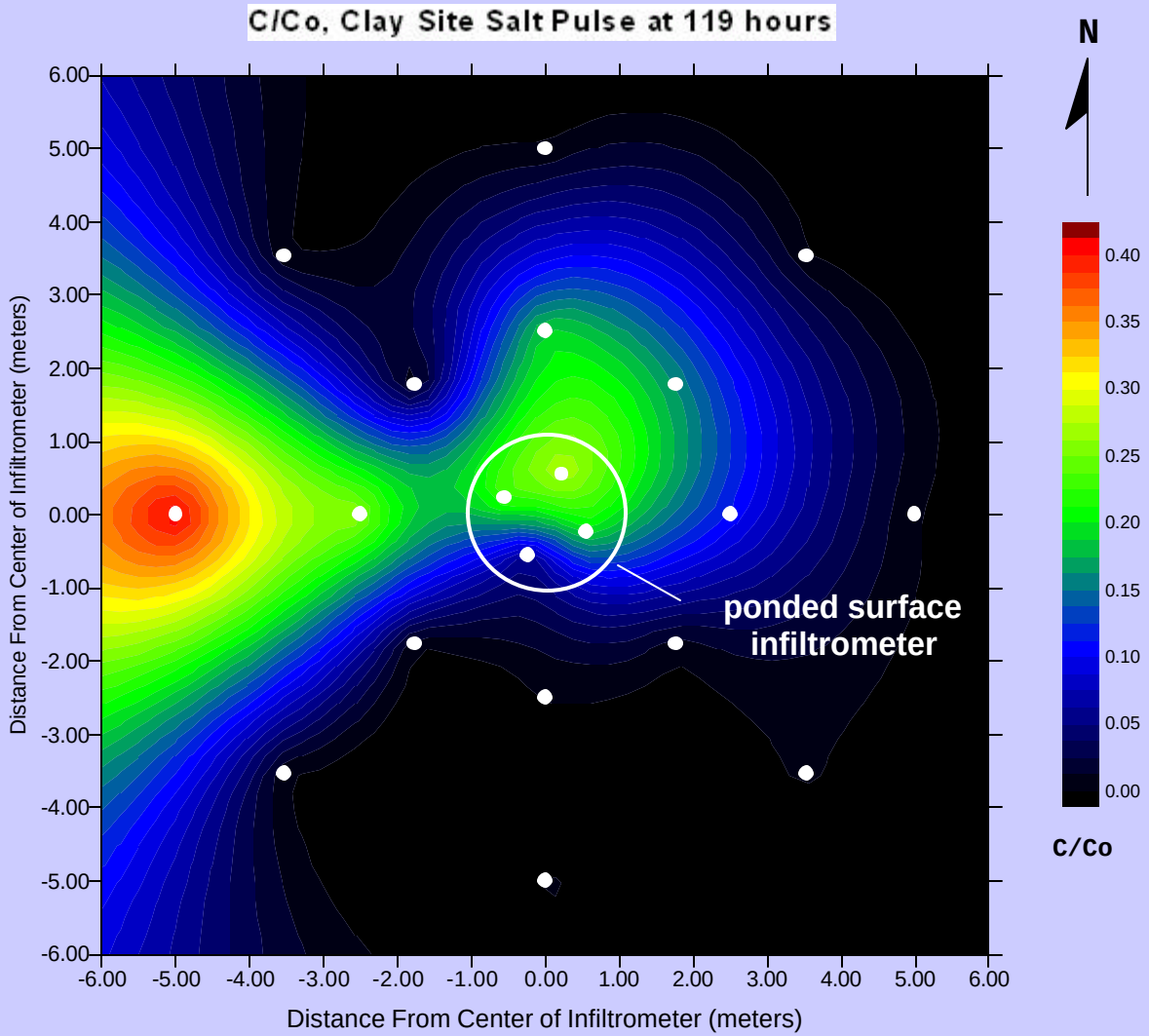
Infiltration continued for 66 days and consisted of a 2 day salt pulse early in the experiment and ended following a dye pulse lasting 4 days. The start of the dye pulse can be seen in the photograph above.



Breakthrough curves were obtained from both the TDR and samples collected from the suction lysimeters

Double peaks in the breakthrough curves were common. The discrepancy between the TDR and suction lysimeter sample data may indicate mobilization of additional ions which influenced the TDR, but was missed by the ion specific probe used to measure concentrations from the suction lysimeter samples. Another possibility is that TDR is temperature sensitive. We infiltrated water that was stored in large tanks at the site. Warm summer temperatures raised the temperature of the water above background subsurface temperatures. Warm water may have reached the TDR probes.

Solute Concentration at 3m Depth



Plots such as this were constructed from breakthrough curve data

The data presented above suggests that the majority of the salt tracer was transported to the west side of the site. During augering we located a sand body at the the western and northwestern outer instrument packs. This data suggests that the sand body was a major influence of the flow and transport pathways at the site.

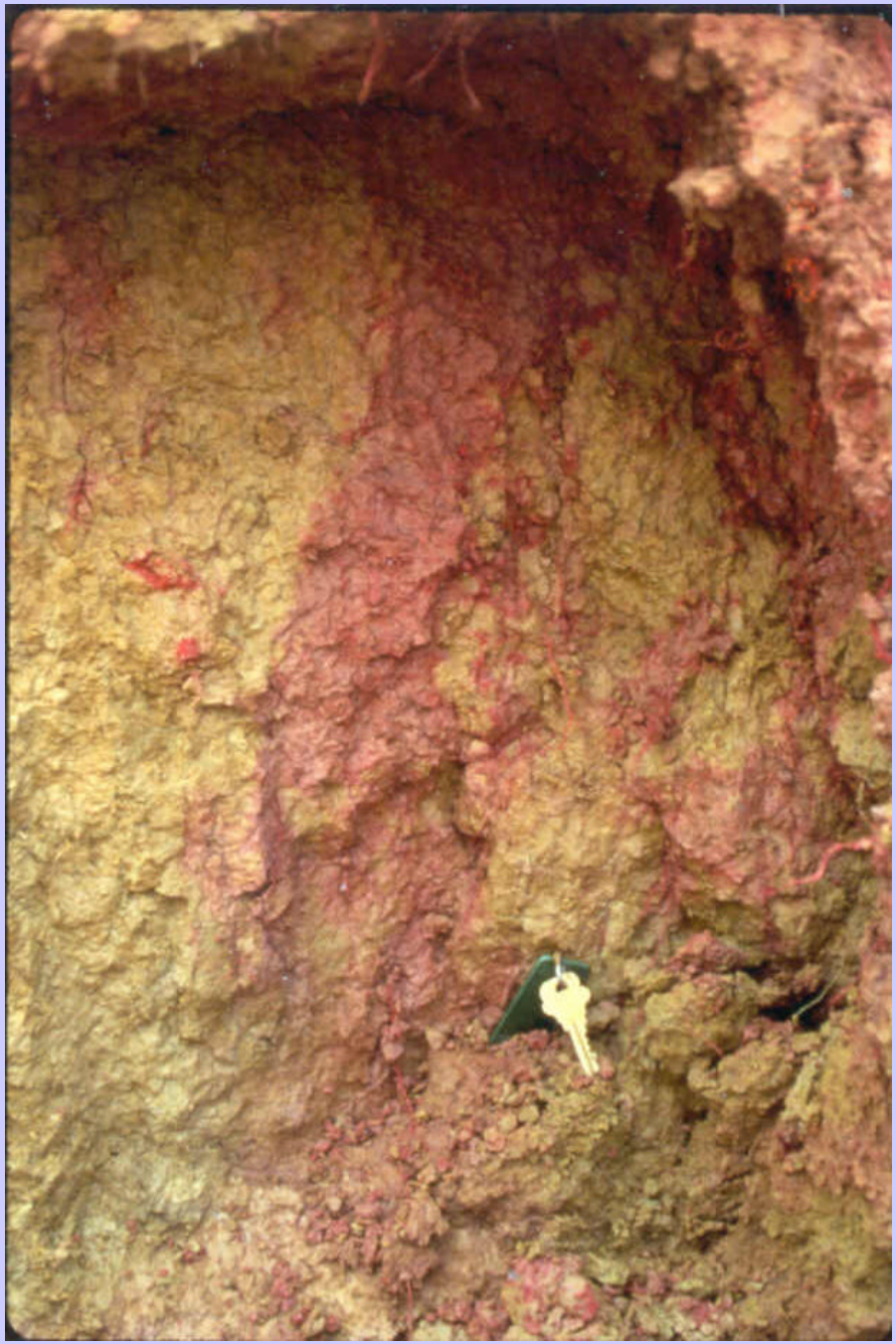
Excavation involved removal of material by hand to provide the ability to make detailed observations and (next slide)

And by shovel…(next slide)

And by track hoe to remove large quantities of material

Dye stained burrows indicated that preferential flow occurred through near-surface macro pores as we expected might be the case

Near surface fracture planes were stained with dye as expected



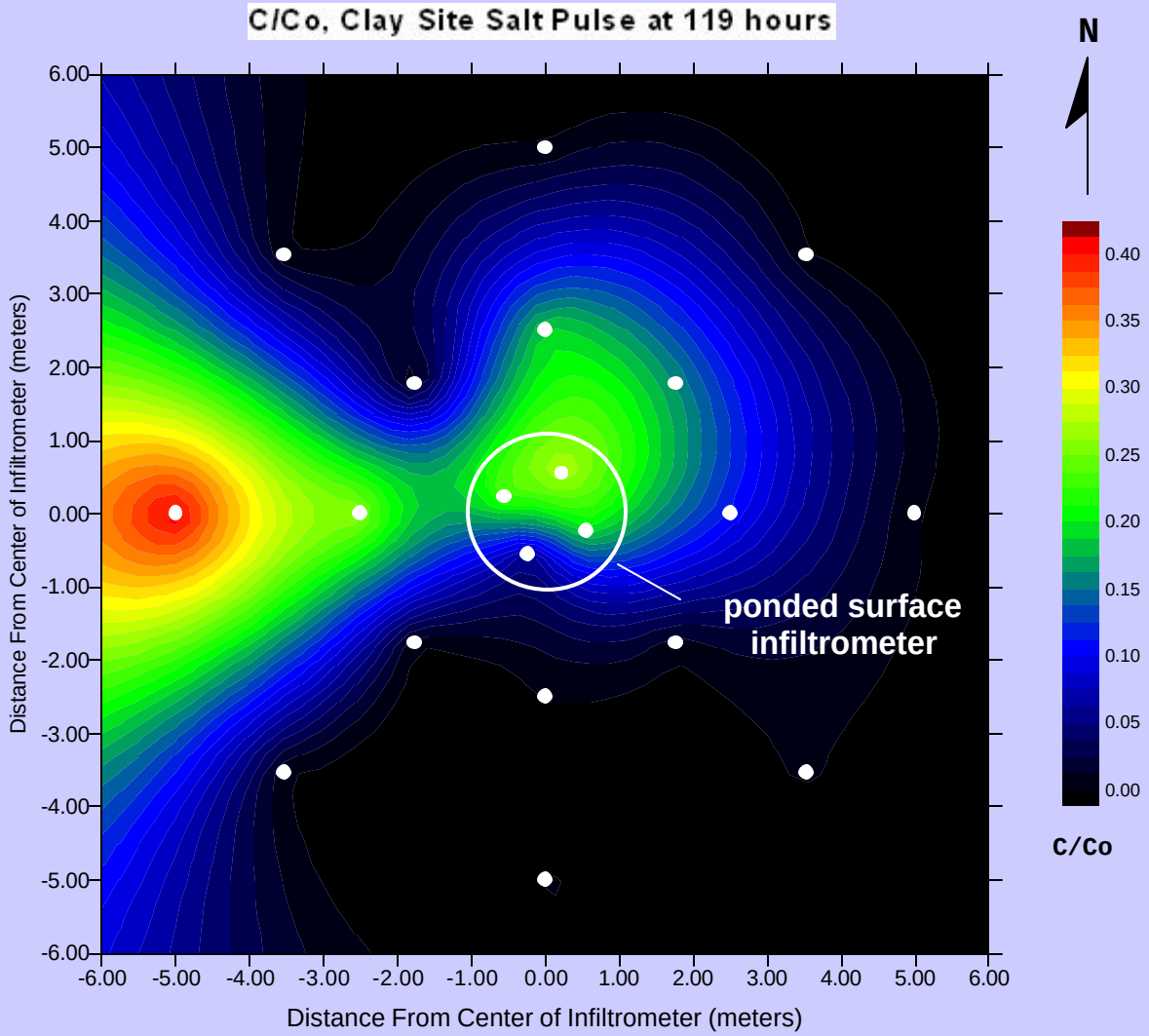
In deeper deposits, pink dye in sandy bedding planes confirmed our suspicions that these features may provide transport pathways

And we found a dye stained hole!

In fact, we found a network of dye stained holes!

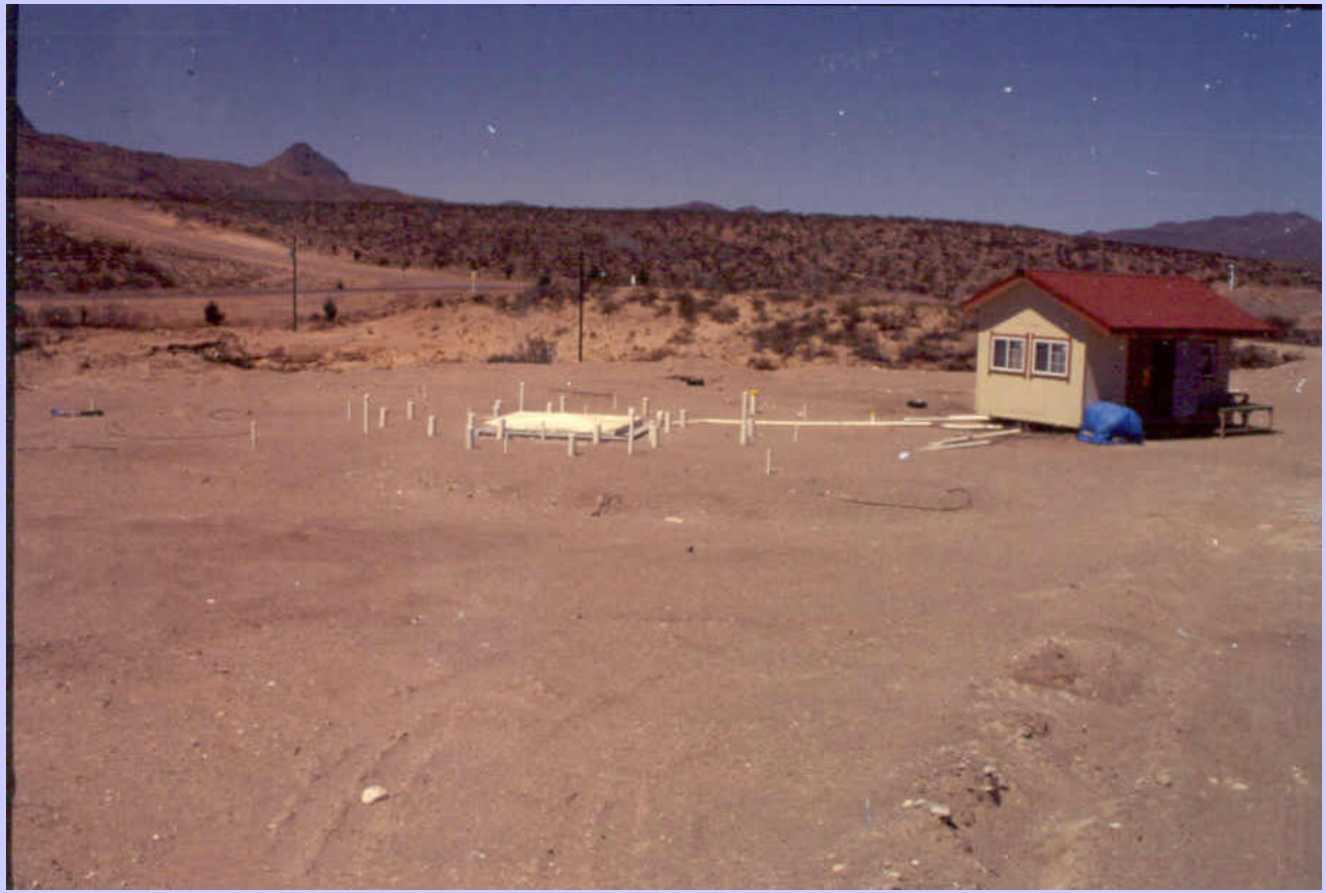
This unexpected result forced us to reevaluate our conclusions based on the breakthrough curve data.
Crawdad/Crayfish burrows!

Solute Concentration at 3m Depth



Had we not performed the dye experiment, we would have concluded that the burrows and fractures in the clay provided a fast pathway to sand bodies and that these features exert a major influence on flow and transport at the site. As it turns out, simple calculations of the potential volumetric flow rate through the burrows indicate that a single burrow could have diverted the entire flow from the infiltrometer.

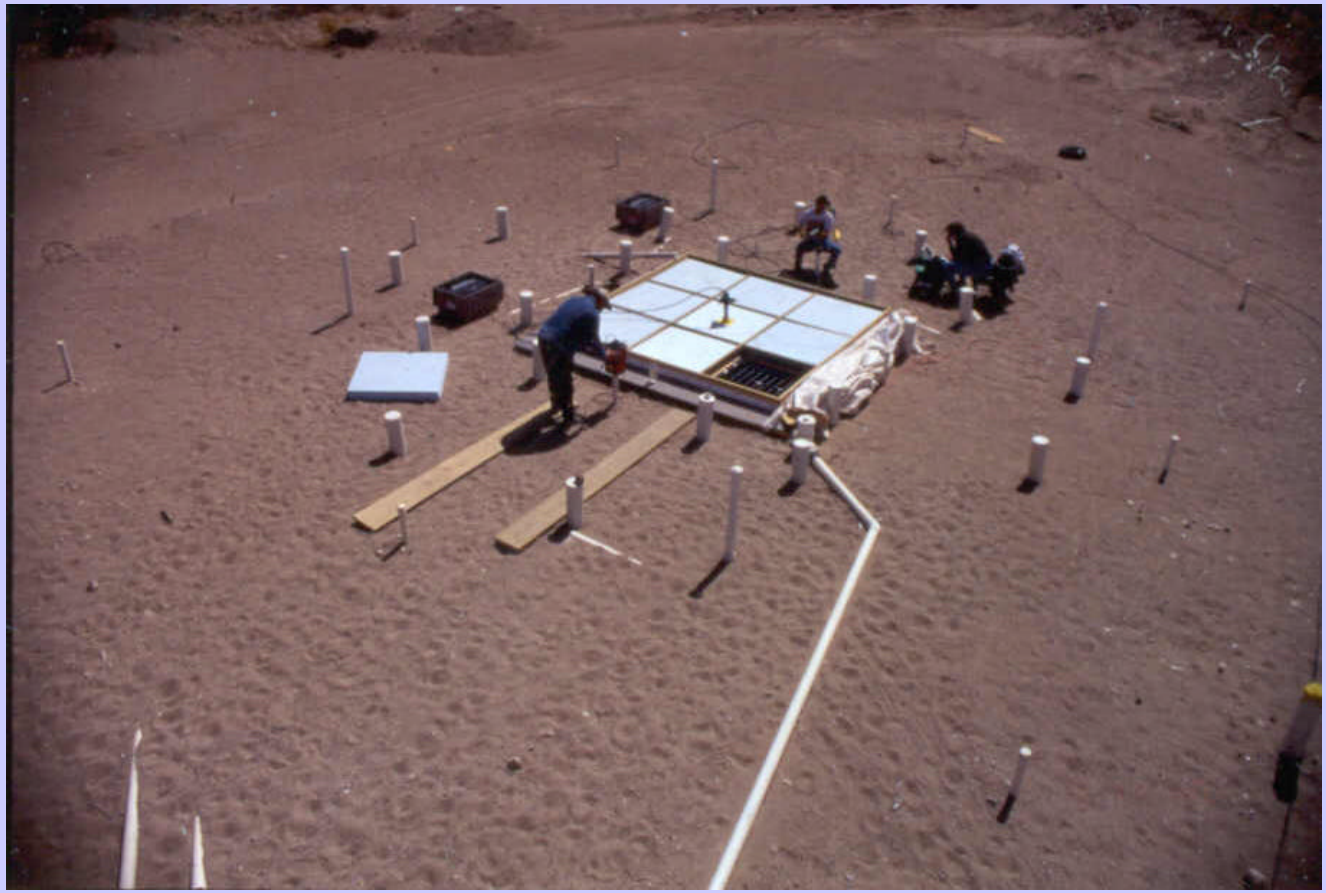
How is this relevant to Hanford? Incorporating dye tracer experiments into the proposed infiltration experiments would provide assurance that critical flow and transport mechanisms are not overlooked.



View of the Sandia-Tech Vadose Zone (STVZ) Facility looking to the northwest.

An infiltration experiment underway at the STVZ is part of an ongoing EMSP funded project to evaluate the ability of cross borehole ground penetrating radar (XBGPR) and electrical resistivity tomography (ERT) to provide useful vadose zone flow and transport information.

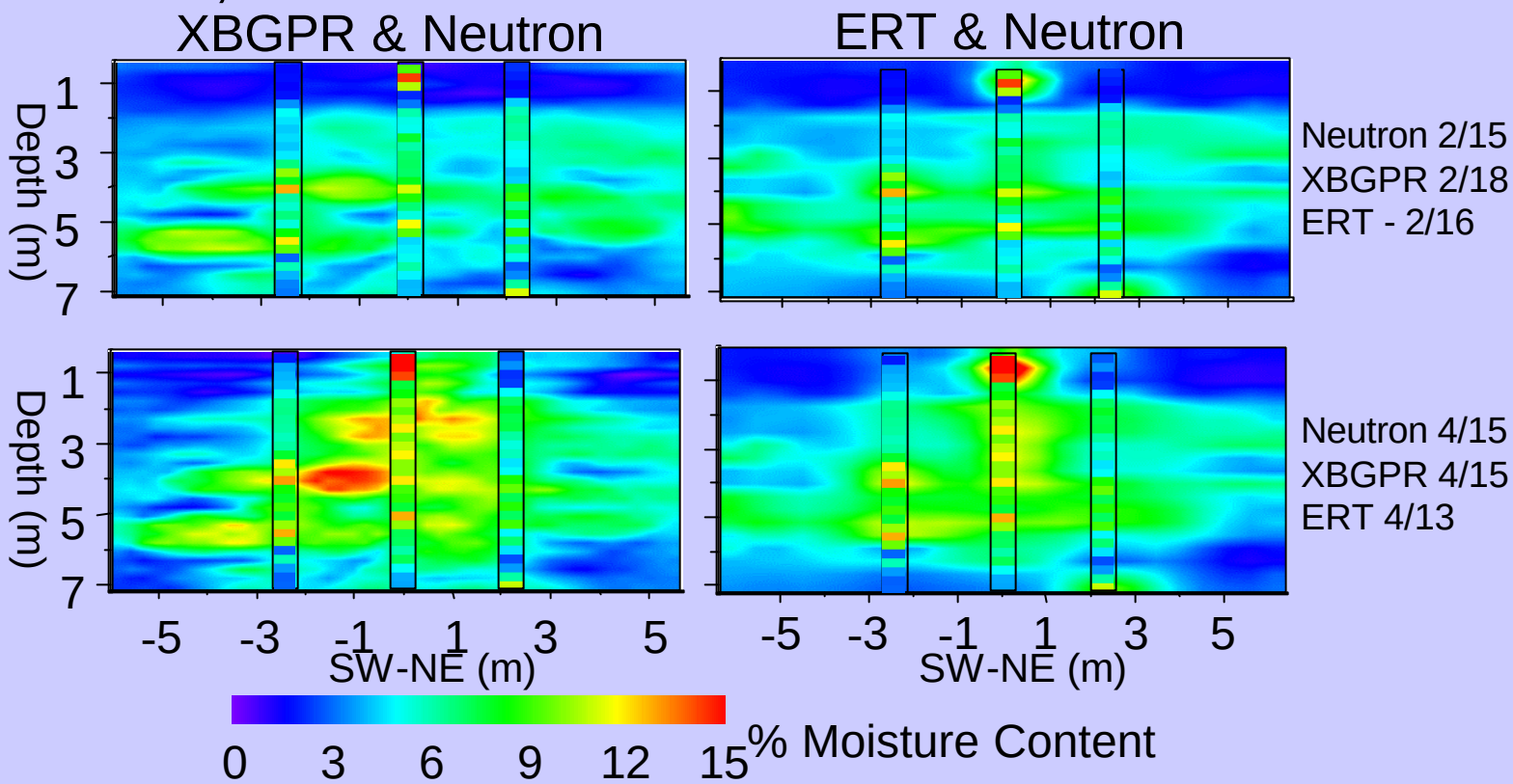
The STVZ is located adjacent to the New Mexico Tech campus. The infiltrometer can be seen in the center of the picture with risers from PVC access tubes protruding vertically from the ground. The data acquisition shed provides shelter for automated data acquisition systems and water supply equipment, as well as for researchers while uploading and processing data.



View from the top of the data acquisition building showing the infiltrometer with the rain tarp removed and with XBGPR and neutron logging under way

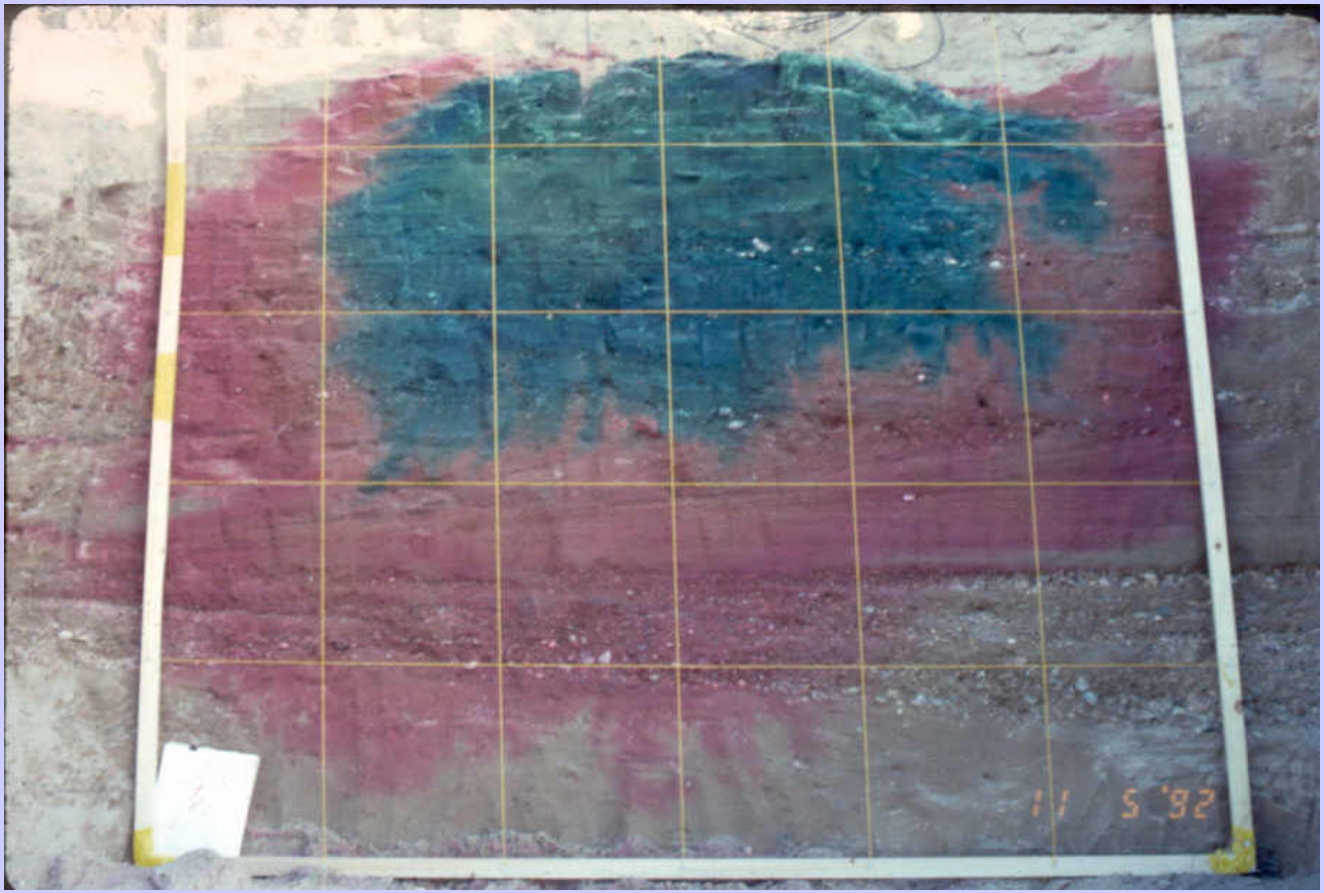
The infiltration experiment has been under way since March 11, 1999 at a constant flux of 2.7 cm/day. A salt tracer will be infiltrated into the steady state flow field in the fall of 2000. This data will be used to develop techniques for measuring solute concentrations with XBGPR and ERT and to evaluate the ability to gain useful transport information with these geophysical techniques.

ERT, XBGPR and Neutron Moisture Profiles



The moisture content profiles above show preinfiltration moisture contents at the STVZ) as determined from ERT and XBGPR (top left and top right respectively) and post infiltration conditions (bottom)

Moisture contents from neutron logging are superimposed on the geophysical images to allow direct comparison of results (see Labrecque et al. 1999 for details concerning converting ERT and XBGPR data to water contents) Both the XBGPR and the ERT correspond fairly well, but some discrepancies can be seen. Each of the three measurement techniques (ERT, XBGPR, and Neutron) are measuring some unique aspect of the subsurface and provide independent measures of the moisture content. Because of this, discrepancies are expected and might be useful in gleaming additional information about the flow and transport processes.



This colorful bulb is the result of a low budget infiltration experiment performed during a vadose zone hydrology class at the University of New Mexico in Albuquerque

A red, blue, and green dye were infiltrated in sequence for 3 days through a ponded source measuring 0.75 meters on a side. Following infiltration the outcrop face was excavated until the center of the ponded source was reached revealing the dye pattern above. The grid squares are 0.33 meters on a side. Streamers can be seen protruding from the blue dye front into the red dye. Beyond the grid on the left is some indication that the stratified deposits influenced dye transport. Because these deposits are very similar to the deposits at the STVZ, we are going to be looking for evidence of similar behavior of the salt tracer at the STVZ in the ERT and XBGPR images. A subsequent dye tracer study at the STVZ would provide additional information on the ability of ERT and XBGPR to capture similar features.

Summary and Recommendations

- Recommendations for the Advanced Characterization of the Vadose Zone at Hanford
  - Incorporate dye tracers in the planned infiltration experiments
    - provide visual evidence of flow and transport mechanisms
      - minimize the likelihood of overlooking significant fast pathway mechanisms
    - may provide a basis for evaluation of ERT and XBGPR imaging
  - Consider a pre experiment dye property study to obtain adsorption properties of different dyes
    - consider infiltrating strongly absorbed dyes first followed by weekly adsorbed dyes to provide the ability to differentiate between fast and slow pathways
  - Instrument the site with a variety of instruments to obtain independent measures of subsurface conditions
    - independent measurements will provide more information than what could be obtained with out what might seem to be at first glance duplicate measurements

References

LaBrecque, D., Yang, X., Alumbaugh, D., and Paprocki, 1999, Three-Dimensional Monitoring of Vadose Zone Infiltration using Electrical Resistivity Tomography and Cross-Borehole Ground Penetrating Radar, Proceedings of the Second International Symposium of Three-Dimensional Electromagnetics, Salt Lake City, Utah, 329-332.

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