

This is a report on the progress we have made on the Grant “Application of Geophysical Tomographic Imagery to the Development of Subsurface Flow and Transport Models”, No. DE-FG02ER15286. One graduate student worked full-time on the project from September 2001 until June 2003, and his work has been supervised by three members of the faculty. A second student has worked part time since last summer. Additional faculty time has been devoted to planning further scientific advances, and reporting on our experimental results.

Our first goal was to produce laboratory-scale test beds with a four-probe electrical impedance instrument having 32 current sources. The first test bed, filled with saline, resembles a larger lab-sized test bed at Lawrence Livermore National Lab. We studied arrays of four rods, each with 8 electrodes in this saline-filled tank. We then placed these rods in a test bed of Ottawa sand, and studied the conductivity of a saturated and unsaturated saline/sand bed. This test bed resembles the field test site in the ground at LLNL. The LLNL lab and the field site have only a single current source. Using our existing 32-source instrument, we studied an array of four 8-electrode probes in both the saline and sand tanks. The results were include in our report to you last year, and are summarized below. Figure 1 is a diagram of the four electrode rods, as seen from above, showing seven positions at which a small conductive target was placed, at the level of the middle of the rods. Figure 2 shows the sensitivity of the system to the target presence, as measured by norm distinguishability, at each of these seven positions. The distinguishability was substantially higher when the optimal, 32-source currents were used, compared to that available from only one current source [1], at all distances from the electrode array. Highest distinguishability was seen closest to the array, as expected, and the lowest distinguishability was seen at point 3, at the side of the array half way between two rods. Distinguishability was slightly higher than this at point 5 at the center of the four arrays.

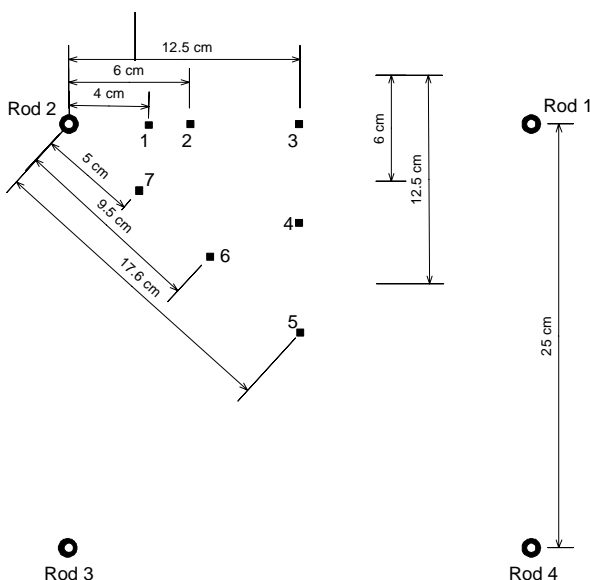
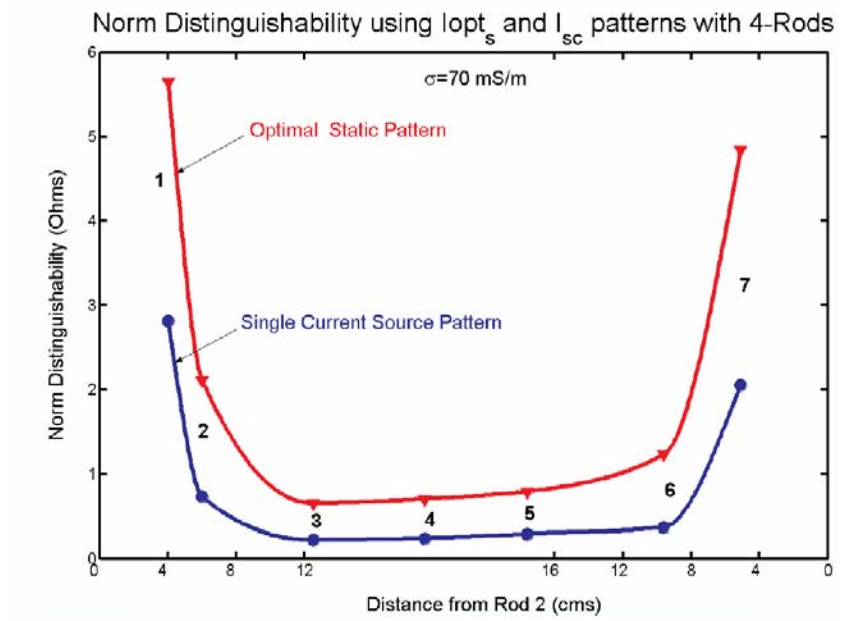


Figure 1. The seven target positions studied using four rods of electrodes as seen from the top.

Figure 2. The optimal current pattern using 32 sources has higher norm distinguishability at all distances compared to that of the single source current pattern.



With these results in the saline tank in hand, we embedded the electrode rods in a 66 cm. diameter steel tank with an electrically insulated interior surface, filled to a depth of 48 cm. with Ottawa F-35 Grade sand. Experiments were conducted to verify the ability of this system to detect changes in the fluid level as saline was used to saturate the sand, and then drain out the bottom of the tank. Using simple current patterns to assess electrical resistance at the eight levels of electrodes, we found that after 5 days of draining, there was a gradient in local resistance of from 50-200 ohms at the bottom of the tank to 3000-4000 ohms at the top of the electrode array. When sufficient saline was added to saturate the field, local resistance fell to 70-110 ohms at all levels. When this saturating saline was allowed to drain, resistance began to rise at the topmost electrode level within 2 minutes, and continued to rise for at least the next two days, reaching 2000-4000 ohms at the top layers.

We then studied the ability of the system to detect a plume of saline in an otherwise drained tank. Saline was introduced at the midpoint between rods 1 and 2 at rate of 200 ml/min, and allowed to drain freely at the bottom of the tank. No change was seen at 2 min, but by 6 min there was a substantial fall in the resistance at the top of rods 1 and 2, but not in 3 or 4. After 30 minutes of plume flow, the resistance at rods 1 and 2 had fallen below 1000 ohms at all levels, but that of rods 3 and 4 was 1500-4000 ohms at the top levels, remaining below 500 ohms at the lowest electrode levels.

These results were qualitatively just as we would have expected. In making a detailed analysis of these data, however, we discovered a puzzling and unexpected finding: there was hysteresis of the complex impedance. That is, the sand bed behaved differently when being filled with saline than when being drained. This phenomenon had been observed previously in a study

of the hydration of sandstone published by Knight et al. in 1991. The hypothesized explanation is based on surface tension phenomena at the scale of pores in the medium.

We have also studied both the real and reactive components of electrical impedance in this system, and we found them to behave differently. This finding allows further data to be extracted from impedance measurements, compared to resistance measurements alone. Details of all these findings are reported in the enclosed manuscript. We have been working closely with Dr. Carrigan at LLNL to interpret them both in terms of their agreement with reasonable hypotheses about soil and water behavior, and in terms of their support for the use of multiple current sources in field-scale experiments.

There have been two publications resulting from this grant so far, and a third has been submitted for publication but has not been reviewed, despite having been submitted last March. I have written twice to the Editor requesting some decision, and been deferred both times. The NSF Engineering Center with which we collaborate, the Center for Sub-surface Sensing and Imaging Systems, held an Industrial Research Conference in December 2002 at which we presented a poster showing the saline results described above [1]. A more complete exposition was published as the Masters Thesis of Nirav Parekh [2]. In March 2003, we submitted a manuscript based on this thesis for publication in the Journal of Applied Geoscience. The editorial office has told us the reviews are complete, and the Editor's decision is awaited. This was six weeks ago. A copy of the preprint is available through Dr. Nicholas Woodward at DOE, (301) 903-4061.

[1] Parekh, N.H., J.C. Newell, D. Isaacson, G.J. Saulnier and C.R. Carrigan. Distinguishability of underground contaminant plumes by multi-source electrical impedance measurements. Proc. Research and Industrial Collaboration Conf. Center for Subsurface Sensing and Imaging Systems, Boston, MA Dec. 2002.

[2] Parekh, N.H. Distinguishability of Underground Contaminant Plumes Using Electrical Impedance Tomography. M.S. Thesis Rensselaer Polytechnic Institute, April, 2003