Report for 2001AL4221B: Development of Geophysical Assessment Tools for a New In-Situ Groundwater Remediation Process

- Conference Proceedings:
    - Saunders, J. A., M-K. Lee, L. W. Wolf, S. Park, C. Rutherford, 2001, In situ groundwater remediation using sulfate-reducing bacteria at Sanders lead site, Troy, Alabama, AL Water Resources annual meeting, 5-7 Sept 2001, Orange Beach, AL.
    - Saunders, J.A., Lee, M.-K.,Whitmer, J.M., and Thomas, R.C., 2001, In situ bioremediation of metals-contaminated groundwater using sulfate reducing bacteria: A case study, Proceedings 6th International Symposium on In-Situ and On-Site Bioremediation, Battelle Press, v. 9, p. 105-112.

Report Follows:

a. Statement of Regional Water Problem and Research Objectives:

Groundwater is contaminated by a number of toxic heavy metals (e.g., Pb, Cd, Hg, Cr, Ag, Cu, Zn), and metalloids (As, Se) at thousands of sites in the U.S. These sites largely are associated with industries such as electroplating facilities, battery recycling plants, foundries, coal mines, and base and precious mines. Similar contamination problems occur at government (particularly DoD and DOE) sites. Bioremediation has largely been thought of as technique for treating *organic* contaminants; however, this technique appears to be well suited for both inorganic and organic contaminants, or mixtures of both. In 2000, researchers from Auburn University began a research endeavor using a new groundwater remediation process at a highly contaminated Alabama industrial site in southeastern Alabama. The company legally responsible for the site is Sanders Lead, Troy AL. The company contaminated groundwater at the site in their early days of operations, which involve the recycling of old car batteries to recover lead, sulfuric acid and plastic. Sanders Lead is the biggest employer in Pike County and produces ~15% of the U.S. lead supply. Groundwater at the site is acidic and contains high levels of lead, cadmium (primary contaminants of regulatory interest), zinc, copper, and sulfuric acid. Shallow contaminated groundwater discharges to a natural wetlands on the site and has caused extensive killing of natural vegetation. A large-scale conventional "pump-and-treat" remediation scheme has been ongoing for a decade at an estimated cost to date of $7 million. It has shown little success (with respect to EPA Maximum Contaminaents Levels) in improving water quality. In 1999, our research group approached Sanders Lead with the concept of a passive *in situ* bioremediation process at their site. The process involves the stimulation of naturally-occurring anaerobic bacteria to remediate, *in situ*, contaminated groundwater in an innovative way. Preliminary results indicate that the technique is very promising; however, the process of remediation is currently monitored only by direct measurements taken near the injection site. A realistic groundwater flow model that can be used to accurately predict the migration of the plume is lacking and cannot be tested without a better assessment of the actual flow and plume migration. The project supported through the Alabama Water Resources Research Institute (AWRRI) grant was aimed specifically at developing surface geophysical techniques (electromagnetic, electrical resistivity, and magnetic) to track the progress of bioremediation in the subsurface, in areas where monitoring wells are absent or are too far apart for proper assessment of remediation progress. The effort responded to AWRRI program focus 1A (Groundwater) in that the research was aimed at studying the fate and transport of contaminants and at developing improved methods for groundwater remediation using the bioremediation process. The real-time assessment techniques used in the project are based on well understood electrical, electromagnetic, and magnetic geophysical methods and the observation that the mineral phases produced in the zone of bioremediation are electrically conductive and potentially ferrimagnetic. The contaminated groundwater at the site is extremely conductive, containing >4000 ppm of divalent ions (sulfate, iron, calcium, magnesium, etc.). The project sought to determine whether the bioremediation process would decrease the electrical conductance of the groundwater by removing sulfate, iron, etc., or increase the electrical conductance of the aquifer minerals by precipitating metal-sulfide phases.

b. Methodology Used

To test the effectiveness of geophysical techniques to be used at the bioremediation site, we conducted several baseline geophysical surveys prior to the new injection test proposed under this contract. The surveys conducted were electromagnetic (EM-31 ground conductivity meter), magnetic (proton precession magnetometer), electrical resistivity (direct current). These baseline surveys were used to establish the natural background characteristics of sediments in the monitoring area, and later, post-injection surveys were used to track changes related to the plume movement and progress of bioremediation. Geochemical data from the injection well was collected prior to and during these baseline geophysical surveys. After groundwater geochemical data from the well indicated that the contaminant levels in the well had returned to the pre-injection amounts, a second injection was conducted at the site using the same injection well. Groundwater geochemistry was tracked at regular intervals following the injection. Once contaminant levels of Pb and Cd were significantly altered (indicating that the bacteria population was thriving and responding), we repeated the geophysical surveys, using identical methodology and measurement points. The surveys were conducted over a period of several months, and the geochemical sampling strategy was continued throughout this period. The repeated surveys were designed to (1) track the precipitation of magnetic minerals that form in conjunction with or as precursors to iron sulfide byproducts of the SRB activity, which, in turn, can be used to establish the rates of the various stages in the remediation process, and (2) characterize at small scales (~ 1 to 2 m) sediment properties of the aquifer and zones in which the SRB are active. .In addition to electrical resistivity, electromagnetic (EM-31), and magnetic surveys, we also collected additional electromagnetic data (using an EM-34 conductivity meter) and self-potential data. Finally, a detailed site map that included topography was constructed using both high-precision GPS unit and total station surveying instruments. Detailed topography is required for constructing future flow models at the site, and is also used for making static corrections to the geophysical data, if needed.

c. Principal findings and significance

According to Archie's Law, ground conductivity for partially saturated materials, σ_a,, is a function of the soil water conductivity, σ_w, the soil porosity, ϕ, and particle factor, m, which varies with particle shape and type:

$$\sigma_a = \sigma_w \phi^m$$

Using the strategy discussed above, we assume that ϕ^m remains constant during the course of the experiment because measurements are taken with each technique at the same location. Furthermore, we make the assumption that if the groundwater level at the site changes due to periods of heavy rain or drought, that the change in bulk ground conductivity would be uniformly affected over the entire site. From these assumptions, we conclude that any change in the relative conductivity of points within the site would be due to changes in the soil water conductivity related to the remediation process.

Figure X shows an example of the relative change in conductivity at specific measurement points through the experiment period. Our preliminary conclusions based on the repeated surveys at the sites are (1) the bioremediation process appears to lower electrical conductance, (2) rates of plume migration at the site are probably on the order of 10 meters per year, (3) flow paths at the site are effectively determined from the surface geophysical surveys. An intriguing result from the self-potential surveys suggests that the sulfate-reducing bacteria may be involved in creating streaming potentials. This possibility will be explored in future work by the PIs and their students.