Overview and Theory

The ET-DSPTM process is an in-situ electrical heating process that combines electrical heating with heat transfer by convection to achieve rapid and uniform heating of the soil. Electrical heat increases the temperature of the soil and groundwater by conducting current from electrodes through the water that fills the porosity of the soil. The heating is enhanced by convective heat transfer from potable water injected into the electrodes. This facilitates the transfer of electrical heat in the soil, creates a steam phase, and enhances the overall recovery process of contaminants.

The increase in temperature, whether brought about by steam injection or ET-DSPTM , causes a variation in the electrical properties of the soil. Additionally, changes in water saturation, Sw, resulting from the vaporization of the water phase and reduction of the contaminant also changes the electrical properties of the soil. The behavior of the electrical properties of the soil as a function of temperature and saturation is best described in Equation 1;

$$\sigma_s(S_w, \phi) = \sigma_w \frac{\phi^{\alpha_n}}{P_a} \cdot S_w^2 \cdot f(T) + (1-\phi)\sigma_r$$

$$f(T) = 1 + a_0 \cdot (T - T_0) + a_1 \cdot (T - T_0)^2 + a_2 \cdot (T - T_0)^3 \ldots \quad (1)$$

The function f(T) is a polynomial that is linearly dominated. Typically the conductivity increases by a factor of three times over a 100 C increase in temperature.

Using the Schumann and Gardner solution of the multilayered Laplace equation it should be possible to determine the vertical resistivity profile between any two electrode pairs if it is possible to constrain either the temperature or saturation effects A solution can be found for a loosely constrained system so long as the physics of the process are incorporated into the solution matrix (for example, based on volumes of steam injected we anticipate a certain temperature response and we constrain the temperature variable to be within a reasonable expectation of results).

The multilayered solution of the Laplace equation provides for the calculation of the resistance on the top surface of a nonuniform structure. The structure is planer and made up of a number of layers, each layer being of uniform resistivity. The fundamental assumption of the multilayer analysis is that Laplace's equation is satisfied in each layer of the material.

First, consider the case of a single uniform layer of resistivity. The solution to this problem provides a solution which describes the potential in each layer. The problem is set up in cylindrical coordinates to emulate the symmetry of an electrode. The principle of superposition will be heavily relied on in the multi-electrode system. The Laplace equation, assuming angular symmetry s:

$$\frac{\partial^2 V(r,z)}{\partial r^2} + \frac{1}{r}\frac{\partial V(r,z)}{\partial r} + \frac{\partial^2 V(r,z)}{\partial z^2} = 0 \quad (2)$$

The general solution to Equation 2 is straight forward and is

$$V(r,z) = \int_0^\infty \left[(1+\theta(\lambda))\exp(-\lambda r) + \psi(\lambda)\exp(+\lambda r) +\right] J_0(\lambda r) d\lambda = 0 \quad (3)$$

The weighting functions and $\theta(\lambda)$ and $\psi(\lambda)$ are determined from the z-dependent boundary conditions. For the case of an n-layer structure, Equation 3 is assumed to be valid in each layer. The solution in the i-th layer may then be written as;

$$V_i(r,z) = \int_0^\infty [(1+\theta_i(\lambda))\exp(-\lambda r) + \psi_i(\lambda)\exp(+\lambda r)+]\, J_0(\lambda r) d\lambda = 0 \qquad (4)$$

The boundary conditions used to solve the system of equations (i.e., determine $\theta_i(\lambda)$ and $\psi_i(\lambda)$ for i = 1, ..., n are provided by conditions on the surface of the ground, the interface between layers and, bottom surface. I have modified Schumann and Gardner approach so that a no flow current condition in the z-direction exists at the surface but a 1 / z_2 condition exists between the top of the electrode and ground surface. This is novel approach which has never been field tested i.e. it may not work.

The data that we need to solve the equations that we do not gather at the moment are $\Delta V_i(0, Z)$ where Z is the distance from the top of the electrode to ground surface and i is from 0 to the total number of electrodes. Once the boundary conditions are incorporated into the solution matrix and the field measured data is used to define the forcing matrix, the system of linear equations can be solved. The solution will be a 3D Map of the resistivity distribution. **This is not a unique solution**. The solution will have to be iterated against our understanding of the temperature and saturation distribution to target a unique solution that satisfies our confidence constraint.