

Time-lapse electrical resistivity monitoring of salt impacted soil and groundwater

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Summary

Time-lapse electrical geophysics is used to monitor the remediation of oilfield brines in soil and groundwater. Challenges with comparing geophysical surveys done during different seasons at different temperatures were overcome through temperature monitoring and geophysical processing techniques. The background electrical conductivity structure captured by the geophysics compared well with push tool conductivity logs collected and had strong correlation with salt samples taken. However the changes in electrical conductivity observed in the time-lapse geophysics provided information about the remediation effectiveness that was not available from the logs and point measurements. From the observed changes in the geophysics we interpret that depression focused recharge has a large impact on remediation effectiveness. This research indicates that time-lapse electrical geophysics is an effective and low cost remediation monitoring method at appropriate sites.

Introduction

Petroleum reservoirs typically produce a mixture of petroleum hydrocarbons (PHC) and saline water. Due to legacy contamination, accidental spills or pipeline breaks, salt-affected soils are perhaps the single most common environmental problem faced by the upstream hydrocarbon industry. Salt-affected soils can be remediated by flushing salt from the soil, but the remediation progress needs to be monitored. Traditional hydrogeological monitoring consists of sparse point measurements from expensive well installations. The addition of geophysical methods allows for spatially extensive mapping and monitoring. In the following, we present the results of three years of 3-D time-lapse electrical resistivity imaging (ERI) that has been used as part of a monitoring program over a salt-affected site with an underlying tile drain system.

Theory and/or Method

Inversion of ERI data produces an image of the subsurface electrical conductivity (EC) distribution. In a time-lapse survey, the images from repeated surveys can be subtracted from an image produced from an initial survey to produce difference images that show EC changes over time. These changes provide evidence of changing soil water saturation, temperature, or chemistry. The ERI survey was incorporated into a soil and groundwater monitoring program to evaluate the performance of a tile drainage network in removing salts from the subsurface. Multiple push tool conductivity (PTC) logs and direct push core samples were also collected.

Preliminary analysis of the ERI electrical conductivity (EC) changes indicated that temperature variations were responsible for the largest EC changes observed in the ERI difference images. Soil water saturation and temperature were monitored using nested tensiometers and soil and groundwater temperature sensors. The saturation and temperature data was used to isolate changes in EC due to salinity variations within the subsurface. A petrophysical model relating bulk EC to pore fluid EC, temperature, soil water saturation, porosity, and clay content, and a linear temperature/EC relationship were tested using laboratory measurements. The temperature EC relationship and in-situ soil and groundwater temperature measurements were used to compensate for variable temperatures in the ERI inversion images. The temperature variation compensation produced standard images which were equivalent to an image at a reference temperature. The soil at the study site was predominantly fine grain size resulting in relatively consistent high soil saturation across the site and during all of the surveys. Hence, the effect of soil saturation changes on the time-lapse ERI images could be ignored.

Examples

The results of the ERI inversions appeared to capture the main features observed in the PTC logs, and a linear correlation with collocated core sample salinity measurements had an R^2 of 0.71. Difference images using standard temperature equivalent images show a decrease in EC above the tile drain lines under an enclosed topography low (Figure 1). Although the difference images contain many distortions due to noise, the decrease in EC was interpreted to be due to enhanced effectiveness of the tile drainage remediation system. This heightened effectiveness under the topography low is likely due to depression focused recharge. In order to use time-lapse inversion techniques to reduce ambiguity due to noise in the difference images, a temperature correction method that acts directly on the ERI data, instead than the inversion model, was developed. By performing the temperature correction on the data, the temperature correction is less affected by the smoothing in the inversion procedure, and time-lapse inversion techniques can be used on the temperature corrected data. A time-lapse inversion technique was developed that maximized the resolution of EC changes in a numerical test. These results produce clear images showing decreases in EC above the tile drainage system concentrated under a topography low (Figure 2).

Conclusions

Based on the results of the time-lapse survey, surface recontouring and irrigation has the potential to increase the effectiveness of tile drainage systems. The findings of this research demonstrate the applicability of time-lapse ERI in remediation monitoring. The results of this time lapse survey provided information not available from a traditional hydrogeological monitoring program with point samples. Moreover this information was obtained from a low cost surface based survey not needing the extensive drilling required in a traditional monitoring program.

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Figures

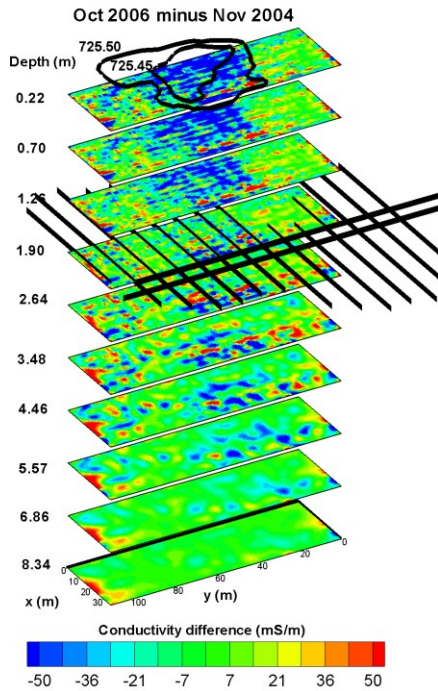


Figure 1: difference between October 2006 and November 2004 standard temperature equivalent images. Blue decrease in EC under the topography low and above the tile drains is interpreted to be due to flushing of salts.

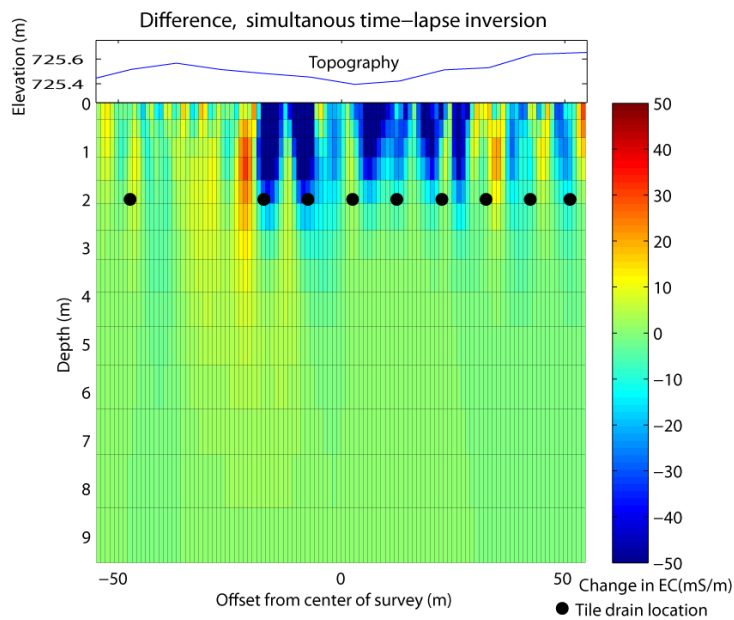


Figure 2: 2D time-lapse inversion of temperature compensated data from November 2004 and October 2006. EC decreases above the tile drains below the topography low are clearly present and interpreted to be due to enhanced salt flushing under the topography low due to depression focused recharge. The temperature correction on the data and the time-lapse inversion has reduced some of the noise present in figure.