APPLICATION OF FREQUENCY- AND TIME-DOMAIN ELECTROMAGNETIC SURVEYS TO CHARACTERIZE HYDROSTRATIGRAPHY AND LANDFILL CONSTRUCTION AT THE AMARGOSA DESERT RESEARCH SITE, BEATTY, NEVADA

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Abstract

In 2014 and 2015, the U.S. Geological Survey (USGS), conducted frequency-domain electromagnetic (FDEM) surveys at the USGS Amargosa Desert Research Site (ADRS), approximately 17 kilometers (km) south of Beatty, Nevada. The FDEM surveys were conducted within and adjacent to a closed low-level radioactive waste disposal site located at the ADRS. FDEM surveys were conducted on a grid of north-south and east-west profiles to assess the locations and boundaries of historically recorded waste-disposal trenches. In 2015, the USGS conducted time-domain (TDEM) soundings along a profile adjacent to the disposal site (landfill) in cooperation with the U.S. Environmental Protection Agency (USEPA), to assess the thickness and characteristics of the underlying deep unsaturated zone, and the hydrostratigraphy of the underlying saturated zone.

FDEM survey results indicate the general location and extent of the waste-disposal trenches and reveal potential differences in material properties and the type and concentration of waste in several areas of the landfill. The TDEM surveys provide information on the underlying hydrostratigraphy and characteristics of the unsaturated zone that inform the site conceptual model and support an improved understanding of the hydrostratigraphic framework. Additional work is needed to interpret the TDEM results in the context of the local and regional structural geology.

Introduction

Electromagnetic (EM) methods including frequency-domain electromagnetic (FDEM) conductivity surveys permit rapid, non-invasive mapping of the electrical conductivity of shallow earth materials, with particular sensitivity to electrically conductive soils, fluids, metals, and materials with high magnetic susceptibility (e.g. Brosten et al., 2011). FDEM methods are commonly used to map the location and extent of buried waste and to delineate groundwater leachate plumes emanating from landfills and other waste management facilities (e.g., Kachanoski et al., 1988; Sheets and Hendrickx, 1995; Reedy and Scanlon, 2003; Hezarjaribi and Sourell, 2007). Time-domain electromagnetic (TDEM) systems are useful for mapping deep subsurface electrical conductivity structure and lateral changes in hydrostratigraphy (e.g., Fitterman and Stewart, 1986). Used together, FDEM and TDEM surveys around waste management facilities provide complementary multi-scale information on the distribution of subsurface electrical conductivity that can reveal the distribution of buried waste and delineate hydrostratigraphic controls important for understanding contaminant fate and transport.

Research at the U.S. Geological Survey (USGS) Toxic Substances Hydrology Program Amargosa Desert Research Site (ADRS) focuses on the fate and transport of contaminants in arid environments. In support of this research, FDEM surveys were conducted to delineate the general location and extent of buried waste-trenches and map near-surface hydrogeologic structure within a closed low-level radioactive waste (LLRW) disposal site. TDEM methods were used to map the larger-scale hydrostratigraphy underlying the site.

Purpose and Scope

The purpose of this paper is to document mapping of subsurface electrical conductivity distributions at selected areas of the ADRS and adjacent LLRW facility. Although the location of the waste disposal trenches is generally known, historical construction activities may have displaced the trench boundary monuments. EM methods provide a non-invasive means of delineating trench boundaries to assess locations and geometry. Acquisition, processing, and interpretation of FDEM and TDEM surveys are described. FDEM and TDEM survey results are compared to available borehole data and waste-trench construction plans to inform the site conceptual model with an infrastructure map, and support an improved understanding of the hydrostratigraphic framework.

Site Description

ADRS is a field laboratory approximately 20 km east of Death Valley, California, 17 km south of Beatty, Nevada, and 170 km northwest of Las Vegas, Nevada (Figure 1). ADRS is located within a northwest-trending valley formed by normal faulting along the front of nearby mountain ranges. The site is underlain by a 175-meter (m)-thick unit of unconsolidated alluvial-fan, fluvial, and marsh deposits consisting of several sand and gravel sequences (Andraski, 1996). Depth to the water table is 85 to 115 m below land surface (BLS) (Fischer, 1992). ADRS serves as a field laboratory for the study of arid-land processes and associated hydrologic conditions within and adjacent to a LLRW site, including study of the fate and transport of contaminants through the unsaturated zone on a 160,000-km^2 area adjacent to a hazardous waste-burial facility. Since 1962, approximately 119,000 m^3 of LLRW has been buried in shallow trenches at the facility (Andraski, 1996). The trenches range from 1- to about 90-m wide, 90- to 250-m long, and 2- to 15-m deep (Mayers, 2003). Waste buried in the trenches was stacked in layers to a height of approximately 3 m and covered with about 0.5 m of native alluvium previously removed from the trenches (Andraski, 1996).

Methods

Electrical conductivity of earth materials is affected by various factors including mineralogy, porosity, water saturation, fluid salinity, temperature, and cementation. FDEM instruments measure subsurface apparent electrical conductivity utilizing time-varying EM fields (in the kilohertz range) to induce subsurface eddy currents (Ward and Hohmann, 1988). This non-invasive approach enables the rapid mapping of conductive subsurface structures and has been widely used in groundwater studies (Johnson et al., 2002; Ong et al., 2010). FDEM instruments, simultaneously transmit and receive signals at one or more frequencies in a ‘continuous’ transmission mode. The FDEM instrument used at ADRS has a depth of investigation (DOI) in the range of 10 m. In contrast to FDEM methods, TDEM systems utilize an ‘on-off’ transmission mode whereby a transient current passed through a large transmitting coil is used to induce subsurface eddy currents. The decay-rate of secondary magnetic fields induced by the eddy currents penetrating into the subsurface is measured by a small receiver coil and inverted to determine subsurface electrical conductivity. The TDEM instrument used at ADRS has a DOI of hundreds of meters.

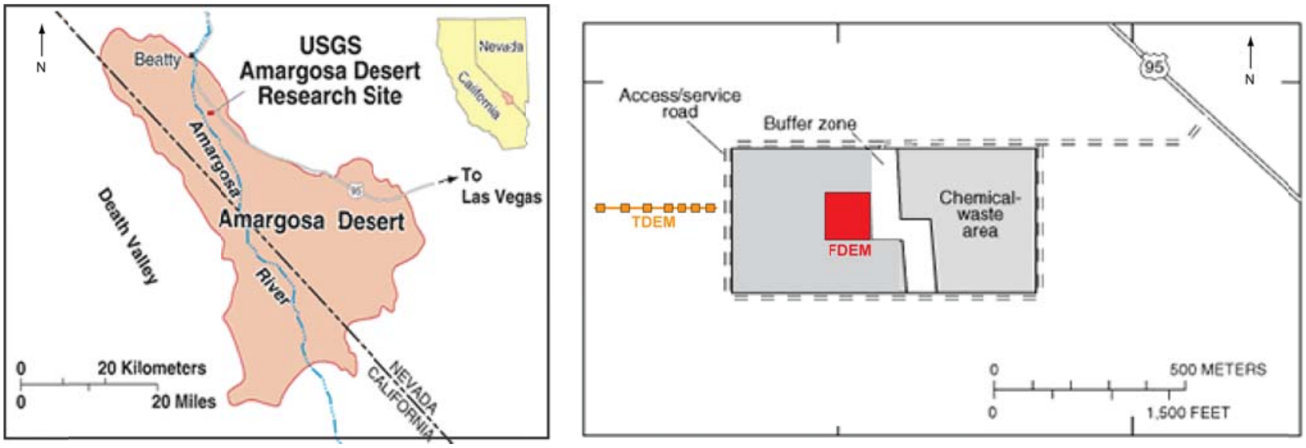

Figure 1. Locations of the (left) Amargosa Desert Research Site (ADRS) and (right) low-level radioactive and chemical waste disposal areas (grey-zone) and FDEM and TDEM surveys. (After http://nevada.usgs.gov/water/adrs/site.htm).

Data Collection

The FDEM surveys were acquired using a Geophex GEM-2 multi-frequency instrument to delineate the general location and extent of waste trenches within the hazardous LLRW facility (Figure 2A). An ABEM WalkTEM system was used to collect TDEM surveys outside the western boundary of the LLRW at the ADRS facility to collect information about the electrical conductivity of the unsaturated zone and the hydrostratigraphy beneath the site. Locations of the FDEM and TDEM measurement profiles are shown in Figure 1.

FDEM Data Collection

FDEM data were acquired by hand-carrying the instrument in the vertical-dipole orientation approximately 1 m above the land surface. FDEM profiles were collected in a grid pattern along north-south and west-east transects over approximately 60,000 m^2 of the LLRW trench area. Seven logarithmically spaced frequencies ranging from 1.5 to 93 kHz were used to ensure an adequate depth of investigation (~10 m) and near-surface resolution. Prior to data collection, the instrument was powered on and set to transmit for approximately 5 minutes to allow the coils and internal electronics to equilibrate to the operating temperature. After system warm-up, a baseline reference, or ‘drift’ station, was occupied for 5 minutes with the instrument actively transmitting and receiving. Occupying the drift reference station before and after each survey permitted removal of FDEM instrument drift during data processing.

TDEM Data Collection

A TDEM profile consisting of seven TDEM soundings was acquired along an east-west transect west of the ADRS LLRW landfill (Figure 1). The transmitter (Tx) loop was a single-turn square with side length of 40 m. A dual-moment measurement configuration was used for each sounding consisting of a low-moment ~1 Ampere (A) Tx current to obtain a high-resolution early-time earth response to image the shallow subsurface, and a high-moment (~7.5 A) Tx current to obtain the late-time earth response for deeper subsurface imaging. Two receiver loops centered within the transmitter-loop were used to record signals from the low- and high-moment transmissions.

Data Processing and Interpretation

FDEM Data Processing and Interpretation

FDEM data were pre-processed to remove instrument drift and filtered to remove transient spikes and other high-frequency noise. After filtering, the data were inverted to develop earth-conductivity models beneath each FDEM measurement location using EM1DFM, a one-dimensional (1D), non-linear least-squares, frequency-domain inversion code (Farquharson et al., 2003). Maximum depth of investigation from FDEM surveys is estimated to be 10 m.

A three-dimensional (3D) rendering of the inverted FDEM models is shown in Figure 2B. In the figure, the north-south orientation and the base of the trenches at approximately 5 to 6 m below land surface can be seen. Resistivity changes within and between waste trenches are interpreted as differences in the type and concentration of buried waste and could also indicate differences in waste-cell moisture content.

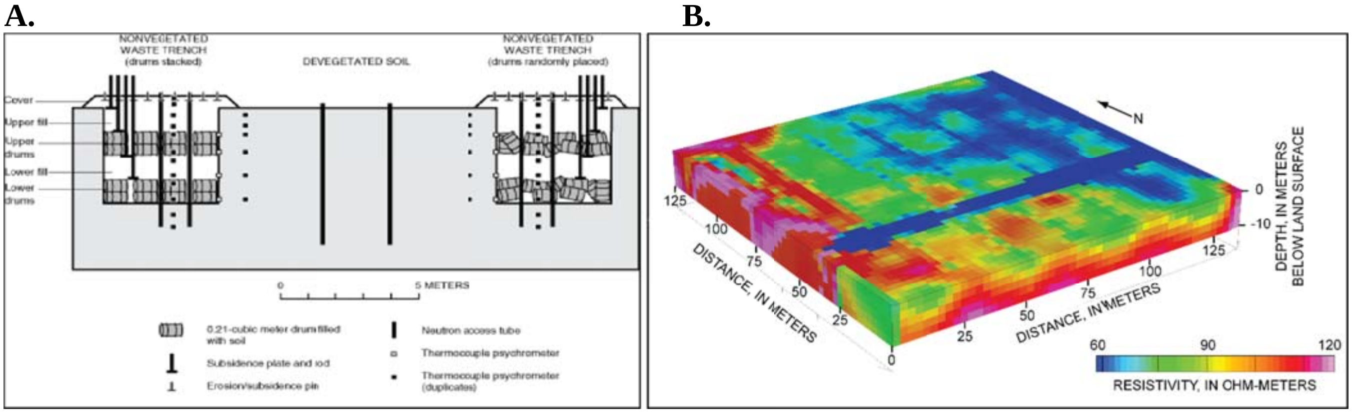

Figure 2. (A) Conceptual waste-trench construction drawing plan showing drum and backfill waste placement (after http://nevada.usgs.gov/water/adrs/site.htm). (B) A 3D FDEM model from inversion of data collected over the low level radioactive waste disposal trenches.

TDEM Data Processing and Interpretation

The TDEM data at each sounding location were stacked to reduce transients and high-frequency noise (average of 3 to 5 decay-curves per sounding); data from late-time responses were removed where significant differences between neighboring time-windows were observed. The filtered TDEM data were inverted using ViewTEM version 2.0.2. The depth of investigation (DOI) calculated from the inverted models using the method of Christiansen and Auken (2012) is greater than 225 m at each sounding location.

In Figure 3A, results from 20-layer fixed-thickness 'smooth model' inversions are shown plotted in cross section. A lithologic interpretation of the TDEM models is shown in Figure 3B. The lower-resistivity layer at about 50 to 75 m below land surface is interpreted as the transition from coarse- to fine- grained materials. The higher-resistivity zone between about 75 to 125 m is interpreted as a deposit of partially saturated coarse-grained material. Decreases in resistivity below 125 m are attributed to a transition to fine-grained materials, underlain by saturated fine-grained materials at about 150 m. The

TDEM model interpretations are consistent with the findings of Nichols (1987) who identified a fine-coarse-fine sequence consisting of upper and lower clay-rich units bounding partially saturated, coarse-grained materials from approximately 50 to 150 m below land surface. Appendix 1 in Taylor (2010) provides lithologic descriptions from deep wells in the vicinity of the ADRS that support interpretation of sediments below 175 m as saturated fine-grained materials. Additional work is needed to interpret the TDEM results in the context of the local and regional structural geology.

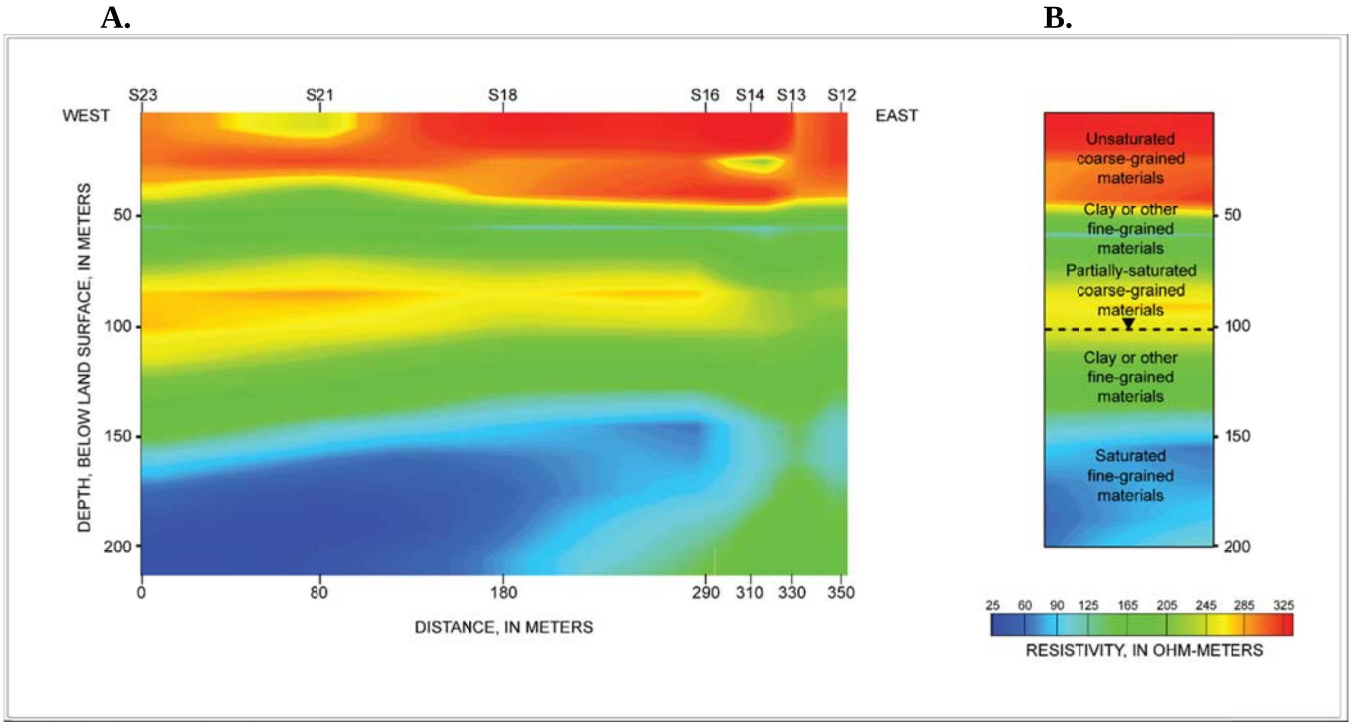

Figure 3. (A) Resistivity-depth profile assembled from seven TDEM soundings along an east-west transect adjacent to the low-level radioactive waste disposal area at the Amargosa Desert Research Site near Beatty, Nevada. (B) Lithologic interpretation of TDEM inversion results and a median depth to groundwater from Fischer (1992).

Conclusions

Integrated use of FDEM and TDEM surveys conducted within and adjacent to a LLRW disposal site at ADRS provided useful information about the electrical properties of the subsurface at different scales of investigation. The FDEM surveys were able to delineate the lateral boundaries and depths of the buried waste-disposal trenches and to provide information regarding the distribution of buried metallic waste. These results provide information useful for current and long-term management and monitoring of the LLRW site. This baseline information on subsurface electrical properties can be compared to the results of future FDEM surveys to assess potential effects of recharge events on the buried waste deposits and the impacts of future construction or landfill cap maintenance activities. The TDEM profile clearly identifies the underlying hydrostratigraphy including two clay layers that (1) bound a layer of unsaturated coarse-grained materials approximately 75 to 125 m below land surface, and (2) overlie saturated materials below 150 m. The TDEM results provide information on the underlying hydrostratigraphy and characteristics of the unsaturated zone that inform the site conceptual model and improve understanding of the hydrogeologic framework.

Acknowledgments

The authors acknowledge funding support provided by the USGS Toxic Substances Hydrology Program. Additional support for this research was provided by the USEPA, through its Office of Research and Development. It has been subjected to Agency review and approved for publication. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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