Sample Design Optimization and Identification of Contaminant Plumes and Subsurface Structures Through Use of Multi-tool Surface Geophysics

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Multi-tool surface geophysical surveys (resistivity, seismic refraction/reflection, gravity, magnetics) were employed at an experimental fire fighting training facility at a naval installation to determine (1) the presence and geometry of contaminant plumes and (2) subsurface characteristics of lacustrine fill and bedrock, including morphology, faulting, and potential pathways for contaminant migration. The geology at the site consists of fine-grained Pleistocene-Holocene playa deposits overlying Mesozoic granodiorite. The site is bounded by Mesozoic bedrock outcrop on the east and opens onto the playa (dry lake) to the north, west, and south. The site has one known and several suspected source areas of organic and inorganic contaminants in soil and groundwater, as well as an 800-foot long by 200-foot wide non-aqueous phase liquid (NAPL) and dissolved-phase contaminant plume. The objectives of the study were to identify potential sampling targets, optimize sampling depths, and eliminate the installation of unnecessary exploratory borings and wells. Results of the ground resistivity survey were used to identify isolated areas of NAPL within a larger dissolved-phase contaminant plume, model the underlying bedrock surface, and show that the bedrock was not intensely fractured. Seismic refraction/reflection results were used to map the underlying competent bedrock surface and show that weathered bedrock was not present. Results from both geophysical surveys were combined to develop a depth-to-bedrock map to help identify contaminant pathways, eliminate exploratory borings (>100 feet deep), and locate specific sampling locations.

The investigation site (Figure 1) is a concrete pad and associated areas. The concrete pad is constructed on artificial fill that overlies silt and clay playa deposits. Five shallow monitoring wells are located onsite. At one monitoring well near the concrete pad, layer of NAPL as much as 3-feet thick has been found floating on the groundwater. Shallow groundwater is approximately 10 feet below ground surface. Fuel and water mixtures were ignited and extinguished on the concrete pad for training activities to simulate fire fighting on an aircraft carrier deck. Unburned fuel and water were discharged into a nearby evaporation pond excavated 6 feet deep into the playa deposits. The evaporation pond and perimeter of the concrete pad are the principal sources of NAPL and dissolved-phase hydrocarbons in soil and shallow groundwater. Additional hydrocarbon contaminant sources include aboveground storage tanks, underground fuel piping, and pipe and valve manifolds.

The surface geophysical surveys were used to gain a better understanding of site conditions and to help identify sampling locations and sampling depths. Two magnetometer survey lines and one gravity survey line were used to identify gross bedrock anomalies and depth to bedrock in the playa area prior to conducting other geophysical work. Five seismic reflection surveys, one seismic refraction survey, and nine ground resistivity surveys were performed.

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Seismic reflection and refraction surveys were conducted using a 24-channel Bison 9024 portable seismograph with 24 geophones placed at 5- to 20-foot intervals. Each seismic line was run forward and back, with the data combined to yield the subsurface information. The seismic lines were up to 1,440 feet in length, with the work conducted in a series of six 240-foot long events. Depth of penetration was limited to about 80 feet using a hand-generated sound source.

The ground resistivity surveys were conducted using STING (Advanced Geosciences, Inc. STING R1-IP resistivity/induced polarization meter). The STING system consists of 56 electrodes linked by cable to a central computer-operated control and recording device. The maximum spacing of the electrodes was 26 feet, and the ground resistivity survey lines were 1,470 feet long. The typical depth of a ground resistivity survey is normally one-fourth of a given line length. Due to the high salt content of the soil and groundwater, the electrical conductivity of the soil was exceptional (low resistivity), and the depth of penetration was limited to a maximum depth of about 140 feet (about one-tenth of a line length). Ground resistivity surveys were conducted in three areas near the evaporation pond and along several lines trending from the bedrock outcrop and into the playa. The principal objective of the ground resistivity surveys was to identify the extent of the NAPL and dissolved-phase hydrocarbon plume in shallow groundwater. Plume definition was possible due to differences in the electrical properties of uncontaminated groundwater (low resistivity) and groundwater containing petroleum compounds (high resistivity due to the presence of nonpolar substances). Results from the ground resistivity surveys were also used to corroborate the seismic survey results.

The magnetometer surveys were conducted along two survey lines using a hand-held proton precession magnetometer. The gravity survey was conducted over a single line using a gravity accelerometer. Measuring stations were between 20 and 40 feet apart. The survey lines began at the bedrock outcrop and extended into the playa approximately 1,500 feet.

The results of the gravity survey indicate that the bedrock slopes from the bedrock outcrop east of the evaporation pond northwestward into the playa. The increase in depth to bedrock northwest of the site is corroborated by the results of the other surface geophysical survey methods. Results from the magnetometer survey indicate similar conditions trending into the playa from the site.

Seismic data show that unsaturated sediment is limited to the upper 10 feet. Saturated sediment is found between 10 and 60 feet deep. These depths are consistent with data from monitoring well installation records. Below the saturated interval, the velocity of the seismic waves in the bedrock indicated that relatively sound unweathered bedrock was present at depth throughout the investigation area. The results of the seismic reflection surveys indicate that bedrock is between 20 and 60 feet below ground surface in areas of the playa and beneath the site. A steepened slope of the bedrock occurs northwest of the evaporation pond with unconsolidated saturated sediments greater than 40 feet thick and likely representing a buried channel in bedrock. A bedrock spur northeast of the evaporation pond appears to continue under the playa sediments and forms a bedrock ridge at depth. A southwest-northeast trending lineament parallel to the bedrock exposure is found approximately 500 feet west of the site. The lineament is greater than 100 feet deep and is interpreted as a downdropped normal fault block. Gravity survey results suggest that the fault block may be downdropped by as much as 400 feet.

The ground resistivity surveys provided information for use in determining the plume extent and corroborating the seismic data used to determine depth to bedrock. Three of the ground resistivity surveys conducted in the area of the evaporation pond and two of the ground resistivity surveys conducted in the playa showed good results in identifying the presence of NAPL and the dissolved-phase hydrocarbon plume. Zones of high resistivity in shallow soil and groundwater are NAPL. Similar less-intense high resistivity zones are found due to the presence of dissolved-phase petroleum compounds in groundwater (Figure 2).

Seismic and ground resistivity survey results indicated that the bedrock is relatively unweathered and likely is not intensely fractured and therefore not creating secondary porosity. A buried subsurface bedrock-bounded channel extends northwest from the area of the evaporation pond. This channel appears to affect groundwater and contaminant flow and appears to help confine the lateral extent of the dissolved-phase hydrocarbon contamination. The results of the ground resistivity surveys indicate areas of highest concentrations of NAPL and dissolved-phase hydrocarbons in soil and groundwater. Depth to bedrock information will be used to limit the depths of exploratory borings, such that no exploratory borings will be drilled greater than about 50 feet deep. Results from the ground resistivity surveys will be used to locate drilling and sampling points to further define the extent of NAPL and dissolved-phase hydrocarbons in soil and groundwater.

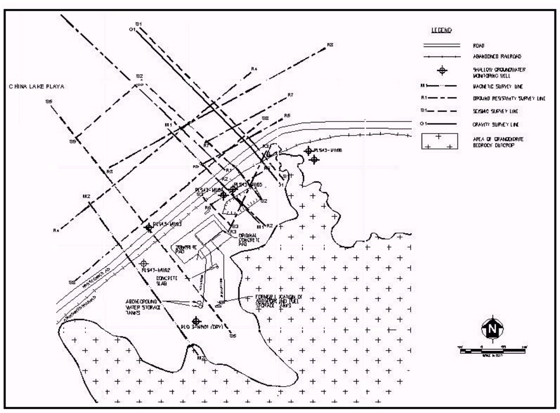

Figure 1. Geophysical survey lines.

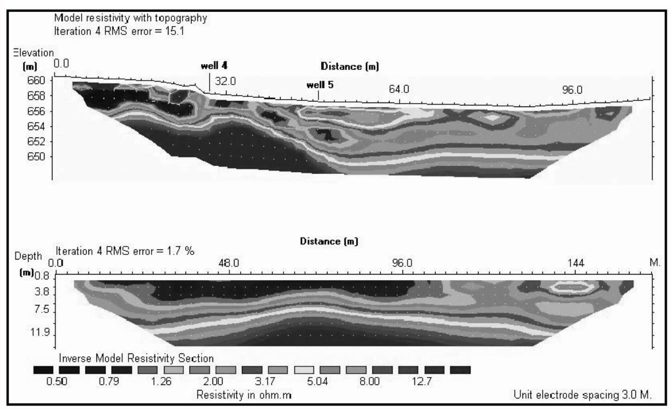

Figure 2. Examples of ground resistivity results. Darker shades are high resistivity zones.

Biography

Katherine Monks is a senior hydrogeologist with Tetra Tech EM Inc. She has over 15 years of experience in groundwater modeling and hydrogeochemistry and holds an M.S. in Geology/Hydrogeology from Wright State University.

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