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CONCLUSIONS

This borehole-to-surface resistivity experiment successfully delineated background groundwater from zones whose relatively high conductivity is due to wastewater leakage from slurry ponds and pipes. On the basis of lithologic logs, the more conductive regions correlate well with sand-gravel layers, and the slightly more resistive overlying zones appear to correlate with interbedded silts, clays, and sands.

The downhole resistivity technique employed in this survey is capable of differentiating small resistivity changes. To do this we calculate from apparent resistivities the percent differences, which yield in an elegant and simple manner reasonable geoelectric sections. We collected far more data than were needed for a reasonable interpretation. As it turned out, only a few of the 10 curves would have yielded a 2-D model of the subsurface resistivities.

The apparent success of downhole resistivity for locating the waste water at the industrial site presents a strong case for continued use of this technique. As only a few wells are needed to determine the extent of a conductive contaminant, and because the technique gives good vertical and lateral resolution of boundaries and eliminates topographic effects, the downhole resistivity technique can be used for a great variety of hydrology problems.

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inated aquifer and compare the results of surveys taken before and after contamination. In addition, we consider four different types of contaminant boundaries to determine the sensitivity of measurements to variations in boundary geometry.

For the resistivity simulation we consider a simple five-layer resistivity model with an electrolytic contaminant present in a sandstone aquifer with a porosity of 15% and an initial in situ water salinity of 600 ppm (Fig. 1).

The contaminant mass is assumed to form a prism situated between the aquifer's upper and lower boundaries (at depths of 45 and 70 m). We consider three types of plume boundaries: (1) an abrupt boundary, (2) a diffused boundary, and (3) a stratified boundary. In each case, the total volume of contaminant remains fixed at 11,000 m³. For all of these cases we seek to measure the sensitivity of the resistivity measurements to the shape of the contaminant mass and its boundaries.

We also considered incorporating a regional groundwater gradient into the model. Choosing an abrupt-boundary model, we assumed that the downhole current electrode is located at progressively larger distances from the center of the plume, until it is eventually outside of the contaminant plume. This is equivalent to a contaminant mass being moved by the natural regional flow without changing shape.

Figure 2 shows anomalous responses for the abrupt-boundary case with the downhole current electrode at distances ranging from 0 to 67 m from the contaminant center. The amplitudes of the curves are expressed in terms of the percent difference by which the contaminant modifies the background apparent resistivity. The second current electrode is assumed to be far from the contaminant. For the case of zero offset an inverted bell-shaped curve is obtained, with a maximum apparent resistivity difference of about 20% observed for measurements directly over the current electrode. This compares with a maximum anomaly of about 2% if the entire array were confined to the surface (Wilt et al., 1983). The placement of the current electrode within the contaminated region can therefore improve sensitivity by an order of magnitude. We would expect a similar improvement if the potential measurements also were made downhole. As the electrode is moved from the center toward the edge of the contaminant, two changes become apparent in the anomaly. First, the peak magnitude of the anomaly is reduced from 20% when the offset is zero to about 3% when the offset is 67 m. Second, the shape of the anomaly changes from an inverted bell curve to an asymmetric bell curve with both negative and positive lobes. When the current electrode is placed outside the plume, the position of the near-side boundary is approximately where the anomaly changes shape, or about –40 m. The position of the negative lobe seems to remain fixed at about –10 m regardless of the position of the current electrode.

The asymmetric anomaly pattern is due to current redistribution into the zone of decreased resistivity. The potentials on the near-side boundary are anomalously small, because the current is being drawn into the conductive body at the expense of the surrounding medium. The increases in apparent resistivity on the far side of the contact are due to the increase in current caused by the contaminant body.

For the offset case a half-width calculation may be made by averaging the near-side and far-side apparent resistivity differences and adjusting the anomaly to the new level. The half-width calculation indicates a contaminant front 43 m from the center, which is in reasonable agreement with the true position.

Figure 1. Cross section of the resistivity distribution for the simulation. [XBL 851-10217]
Figure 2. Plots of total-field, percent-difference apparent-resistivity calculations for the offset downhole-current electrode. Model uses an abrupt boundary. Offsets are indicated in figure. [XBL 862-506]
Two-Dimensional Inversion of Resistivity Monitoring Data from the Cerro Prieto Geothermal Field, Mexico

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Repetitive dc resistivity measurements were made over the Cerro Prieto geothermal field at intervals of 6 to 24 months during the term of the first international agreement between the U.S. Department of Energy and the Comisión Federal de Electricidad (CFE) to study the Cerro Prieto reservoir (1978–1983). The method of data acquisition and the results of these repetitive measurements have been reported earlier (Goldstein et al., 1982; Wilt and Goldstein, 1984; Wilt et al., 1984). Most recently, Goldstein et al. (1985) have discussed a more rigorous numerical approach for interpreting the repetitive resistivity observations. Our initial impressions were that changes observed in the succession of dipole-dipole pseudosections showed (1) increasing resistivity associated with the production zone, (2) possible hot water recharge from a deeper source to the east, and (3) complex changes in near-surface resistivities due to a combination of factors such as changes in farming and irrigation patterns, infiltration of waste water from the evaporation pond and canals, variations in rainfall, and underflow from the nearby Colorado River. The impressions were based primarily on inspection of the percent changes in the apparent resistivity pseudosections relative to baseline data taken in 1979.

THE RESISTIVITY MODEL

Figure 1 shows the central portion of our control line (E–E′) over the well field. During the monitor-

Figure 1. Central part of the dipole-dipole resistivity line E–E' over the Cerro Prieto geothermal field. Wells are shown as dark circles, and those producing brine during the 1979–1983 period are mainly between electrode points 10 and 12. [XBL 811-2532D]