The Use of CSAMT and NSAMT in siting groundwater production wells: two case histories

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Summary

While the presence or absence of water in the subsurface obviously should have an effect on the electrical properties of the ground, in the exploration process, particularly in relatively unexplored basins, it is not always immediately clear whether groundwater is a low resistivity target relative to background, or a high resistivity target. Correlation with known or suspected geological structure, borehole geophysics, and down-hole lithology is often critical in the proper application of surface geophysics to groundwater exploration. We present two case histories in which controlled source and natural source audio-frequency magnetotelluric surveys (CSAMT and NSAMT) were used to successfully site groundwater production wells, though in one case, groundwater was a low resistivity target, while in the other, the successful groundwater well was drilled into a locally resistive area.

Introduction

The magnetotelluric (MT) method is a well-established subsurface imaging technique that is most often used in geothermal, minerals, and hydrocarbon exploration, as well as deep crustal studies. This surface-based method involves measuring the electric field (usually referred to as the E-field) and magnetic field (H-field) components of naturally occurring electromagnetic fields in order to calculate an apparent resistivity value of the subsurface from the ratio of these measurements. There are several variations of this method, including audio-frequency magnetotellurics (AMT or NSAMT), and CSAMT (controlled source audio-frequency magnetotellurics), both of which concentrate on the higher frequencies (1 Hz to 10s of KHz) for shallower investigations. The theory and background for these methods are well documented in Cagniard, 1953, Goldstein and Strangway, 1975, Vozoff, 1991, Zonge and Hughes, 1991, and others.

These methods are well-suited to groundwater exploration, since the presence or absence of water in the subsurface affects the resistivity: dry, tight bedrock is usually high resistivity relative to saturated alluvial layers, for example, and fracture zones containing groundwater are usually low resistivity relative to surrounding un-fractured impermeable material. Additionally, brines with high total dissolved solids (TDS) are low resistivity relative to good quality, low TDS water. In our experience, we have found that CSAMT and NSAMT usually provide better lateral resolution at moderate and large depths than galvanic electrical resistivity methods, since the depth of investigation of CSAMT and NSAMT is determined by frequency of the signal and background resistivity, rather than dipole size and array geometry, as is the case in the galvanic methods.

The two case histories we describe here highlight the need for proper integration of background geological and hydrological information in the interpretation of the geophysical data.

Tule Desert Project, Nevada, USA

In the Tule Desert in Nevada, USA, the geophysical program was initiated after unexpected results were encountered in drilling two exploratory test holes (called MW-1 and MW-2). The geophysical CSAMT and NSAMT surveys were done in phases, and eventually included more than 2000 stations at 76 m intervals (250 ft.) on 11 lines, covering approximately 158 km (98 miles) in this previously unexplored basin. Prior to this project, only one drill-hole existed in the entire groundwater basin. Interpretation of the data included both 1D and 2D smooth model inversion; the 2D inversions tend to be more geologically reasonable, but also often tend to smooth out narrow features that may indicate productive fracture zones. On the assumption that saturated basin fill would be

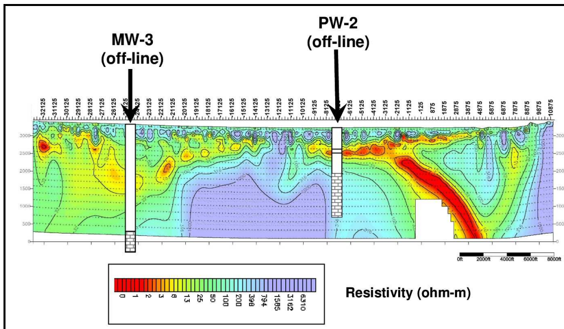

Figure 1: Smooth-model inversion cross section from 1D models of resistivity for a segment of Line 4 from the Tule Desert project, showing the relative locations of wells MW-3 and PW-2 to the resistive basement feature in the middle of the basin.

characterized as low resistivity material relative to less permeable basement rock, drilling originally targeted low resistivity features; MW-3, for example, targeted a very thick section of almost 1000 meters of moderately low resistivities. While MW-3 did encounter significant moist material, the thick section of volcanics and clays was not capable of any significant production.

The geophysical survey also identified a previously unknown, unexpected, large resistive feature extending from the south boundary of the basin out into the center of the basin. After additional drilling and revised correlation of the geophysics to the drilling results, a drill hole was sited to test this central resistive block (Figure 1). That well, PW-2, encountered the regional Paleozoic carbonate aquifer at a depth of only 300 m (1000 ft.), and has been pump tested at 4540 liters per minute (1200 gpm), producing very good quality, low TDS water in arid desert environment. Based on a re-evaluation of the geophysics with the drilling results, future drilling efforts can now be safely targeted on the resistive basin block that was originally avoided.

Dry Lake Valley Project, Nevada, USA

The Dry Lake Valley Project was more limited in size and scope than the Tule Desert Project, but was again in a relatively unexplored valley in the Basin and Range province of Nevada. Since the central part of the basin was expected to be relatively deep, and likely to have high TDS water, the project goal was to drill near inferred faults bounding the deep part of the basin. Given the relative simplicity of the geologic environment and survey budget, the survey was run as a scalar CSAMT survey, using 61 m electric field dipoles (200 ft.), measuring one magnetic field per five electric fields.

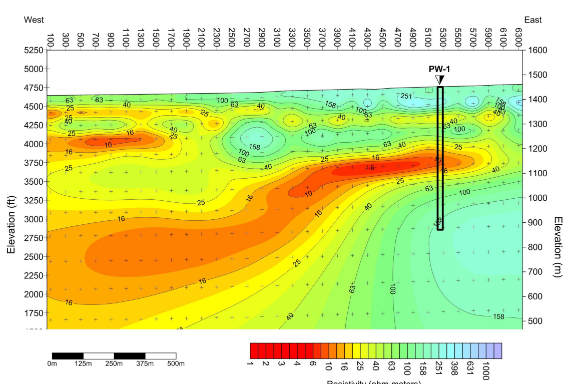

Figure 2: 2D Smooth-model inversion cross section of resistivity for Line 1 from the Dry Lake project, showing the location where the production well PW-1 was drilled after the CSAMT survey.

Figure 2 shows the 2D smooth model inversion results for one line of data. The center of the valley is off the west (left side) of the cross section, and it is clear that low resistivity basin fill material thickens dramatically to the west. Based on this data, drill site PW-1 was chosen in order to intersect bedrock material near, but east of the bounding fault.

During drilling a shallow alluvial aquifer was encountered which correlated well with a weak, thin low resistivity layer (shaded light yellow in the cross section) at an elevation of approximately 1325 m (4350 ft). However, this region also correlated with an increase in clay content, and it is not clear yet whether the low resistivity is the result of the shallow alluvial aquifer, the increased clay amounts, or both. After drilling through an extremely hard quartzite layer, fractured sandstone and limestone were encountered, with significant water production, correlating with the thicker, lower resistivity layer (shaded orange-red in the cross section) in the CSAMT data. This well is now producing over 6800 liters per minute (1800 gpm) of good quality water for agricultural fields.

Conclusions

These two groundwater exploration projects highlight the economic utility of the CSAMT and NSAMT methods in groundwater exploration; the survey data in Figure 2, for example, took slightly more than one day to acquire for a four person field crew, and led to a very successful groundwater production well. These projects also emphasize the need for integration, and sometimes iteration, between the geophysical results and background hydrological and geological information, both surface-based and down-hole. In one project, low resistivities appear well correlated to subsurface water, but in the case of the Tule Desert, the very low TDS water in the regional carbonate aquifer is actually manifested as a high resistivity target relative to surrounding clay-rich, lower resistivity material.

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