Deep Groundwater Exploration Using Geophysics

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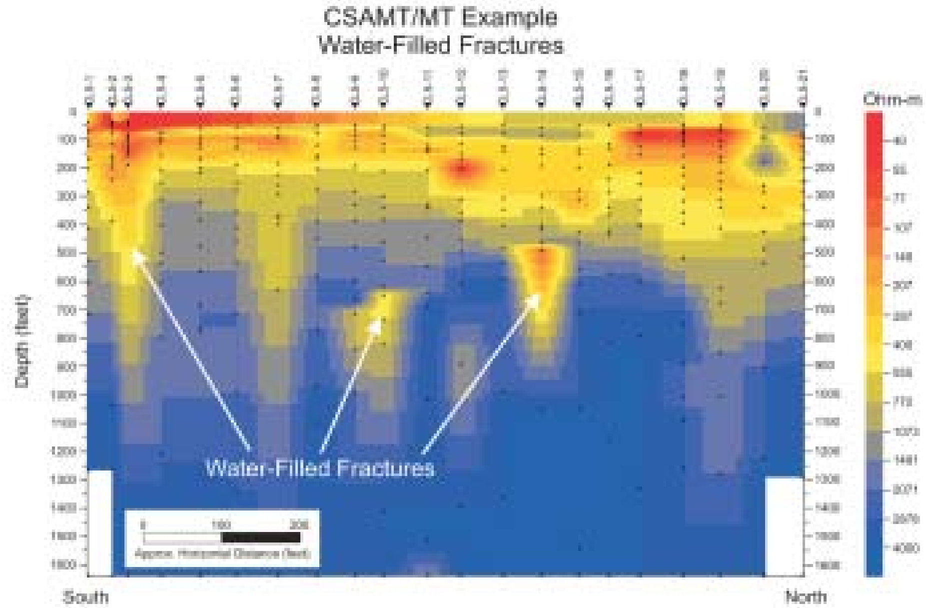
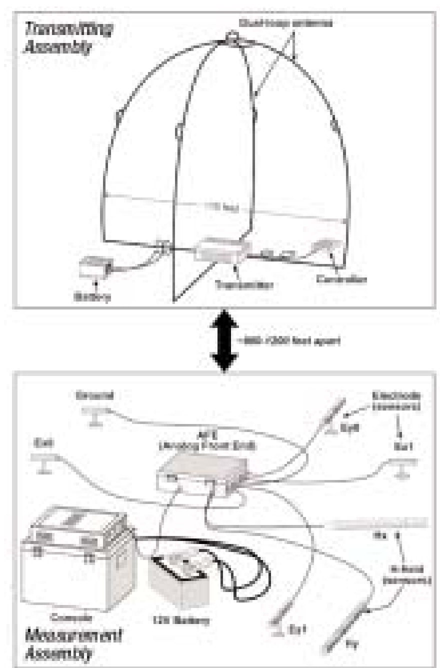
The current and continuing drought in many parts of the world, combined with ever-increasing demands from both traditional and new water users, including municipal, industrial, agricultural and environmental needs, has impacted groundwater resources. Consequently, many groundwater exploration programs are increasingly focusing on deep (1,500 to 2,500 feet below ground surface) production zones. The financial investment in a new 2,500-foot deep groundwater production well can often approach $1 million. Surface geophysical methods can reduce risk and unnecessary costs by assisting in the siting of wells in locations with the most potential to produce acceptable quantities of water.

Surface geophysical methods have been used for decades to successfully and economically explore for groundwater resources. For depths on the order of 200 feet or less, the electrical resistivity profiling and seismic refraction methods are generally useful and economic. For investigations to depths of about 500 feet, the time domain electromagnetic (TDEM) method has been successfully used; however, at greater depths TDEM becomes logistically difficult and less economic. For reconnaissance or regional basin-wide surveys, the gravity and/or magnetic methods have often been applied, but it is risky to select groundwater targets from those methods alone. For exploration depths of 1,500 to 2,500 feet, the seismic reflection and



controlled source audio magnetotellurics / magnetotellurics (CSAMT/MT) methods have proven to be successful. However, using high-resolution seismic at those depths is very expensive, and it is often difficult to interpret small faults or fractures zones within bedrock (typical groundwater targets) or to distinguish subtle changes in stratigraphy, such as the amount of clay. Therefore, in recent years, the CSAMT/MT method has become more widely used as it produces economic, structural, and stratigraphic detail to depths approaching 3,000 feet.

CSAMT/MT is a hybrid method that determines subsurface electrical resistivity distribution by measuring time-dependent variations of the earth's natural electric and magnetic fields (MT), as well as the electric and magnetic fields resulting from high-frequency, non-polarized, artificially transmitted electromagnetic waves (CSAMT). The method measures the resistivity of earth



materials in two directions with perpendicular electric dipoles (Ex and Ey) and magnetometers (Hx and Hy) in the field setup shown above. In general, electric and magnetic fields are measured both parallel and perpendicular to geologic strike, thus giving CSAMT/MT a two-dimensional capability that is not achieved by other electrical or electromagnetic methods.

CSAMT/MT field data consist of sounding curves that are logarithmic plots of apparent resistivity versus frequency. Subsurface resistivities can be calculated with forward and inverse computer modeling software by converting the sounding curve data to computer modeled resistivity structure or layering below a given CSAMT/MT sounding. The resulting computer models are used for interpretation of subsurface materials and geologic structures related to groundwater flow, and can be presented as cross sections consisting of several soundings. From these cross sections, data can be presented as individual contour maps from selected depths or combined into a movie showing several depths or other slices. In general, CSAMT/MT data have shown a 10 to 15 percent variation between the actual depths to the anomalies, as verified by test hole drilling, and the depth predicted by the models. The nearby presence of conductors, such as buried metal pipes or drill stem, metal fences or electrical transmission lines, will result in electromagnetic noise that may affect the quality of the data.

The true resistivity of earth material is dependent upon composition, grain size, water content, and other physical characteristics. In general, fine-grained materials have lower resistivities than coarse-grained materials. Unweathered and unfractured hard rocks such as lithified sedimentary rocks, volcanic rocks, plutonic rocks, and some metamorphic rocks generally have high resistivities. The presence of fracturing and weathering lowers the resistivity of these rocks. Additionally, the occurrence of groundwater will greatly reduce the resistivity of all rocks and sedimentary materials through electrolytic conduction. Because of this effect, groundwater is a good target for electrical and electromagnetic geophysical methods that measure resistivity.

The CSAMT/MT method has been used to identify groundwater exploration targets and to site wells in a variety of geologic conditions. A water-filled fracture example is shown in the figure at the top of page 6 from an area with clastics on the surface and weathered-to-unweathered carbonate bedrock at depth. Note that similar results would be obtained from an area with sediments over granitic or metamorphic bedrock. Station spacing for this example is 50 feet, which is considered a detailed survey. Calculated resistivities in ohm-meters are shown in a logarithmic range with colors ranging from red for conductive or low resistivity zones to blue for higher resistivity areas. Clastics in this area generally have lower resistivities and are interpreted with values of less than about 500 ohm-meters (primarily the red to yellow colors on the section). Hard, relatively unweathered and unfractured carbonates are interpreted as much higher resistivities with values from around 1,000 to more than 4,000 ohm-meters (darker blue colors). Resistivity values between about 500 and 1,000 ohm-meters are interpreted as weathered zones, fractures zones, or faults within the hard carbonates.

Clastics are interpreted to extend to about 200 to 400 feet depth in the example, weathered bedrock beneath the clastics is interpreted to have thicknesses on the order of 100 to perhaps 200 feet, while carbonate bedrock extends beyond 1600 feet depth. Within the high resistivity bedrock at depths ranging from about 400 to 900 feet, as identified on the figure, are low resistivity water-filled fractures that have been drilled and found to be good groundwater producers.

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