AEM for Investigations of Natural and Managed Aquifer Recharge in the Indian Wells Valley Basin, California

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Introduction

Indian Wells Valley Water District (IWVWD), is a State classified high priority and critically overdrafted basin in the Upper Mojave Desert, California. Groundwater pumping in the basin exceeds natural recharge by four times and well levels have declined at a rate of about one to two foot per year. IWVWD mapped the area with airborne electromagnetics (AEM) and is using the data to develop an updated hydrogeological conceptual model (HCM) of the basin. In addition to providing insight into areas where natural groundwater recharge occurs, the study also focused on mapping potential water bearing strata and structure throughout the study area.

The airborne electromagnetic survey was flown across the basin using the SkyTEM system. The basin size required a relatively coarse flight line spacing in order to provide the needed coverage. Despite the wide spacing between the flight lines, the data set provides valuable new insight about where natural recharge to the deeper aquifers is occurring and can be used to identify possible sites for artificial recharge and water banking.

The Indian Wells Valley study area

The Basin, located at the southeast edge of the Sierra Nevada Mountain Range, is the home of the City of Ridgecrest, population roughly 30,000, and China Lake Naval Air Weapons Station (NAWS), the major employer in the Basin. The Basin has been subdivided into two areas: the El Paso area to the south, and China Lake area to the north. Land uses in the basin, from larger to smaller relative size, are dominantly open space federal lands (Navy and Bureau of Land Management), urban, agricultural production for alfalfa and pistachios, and rural residential. Average annual precipitation in the valley varies from 2 to 6 inches, although some years the basin receives no precipitation. The basin comprises roughly 600 square miles of land area and is filled largely with unconsolidated clays, sands, silts and gravels extending to depths of over 2,000 feet throughout most of the basin area.

Figure 1. Dry desert in the middle of the Indian Wells Valley. In the background Sierra Nevada mountain range.

Groundwater supplies over 95 percent of water use in Indian Wells Valley, and groundwater pumping has been the largest discharger from the basin for over 50 years. The main groundwater pumpers, from most to least water demand include, agriculture, a water district for urban supply, exported for mineral extraction, NAWS, and neighborhood and rural residential. Annual storage change is reflected in chronic groundwater level declines of 1 to 2 feet per year, documented in the basin for some +50 years. Associated with the groundwater level decline is degrading water quality, with the majority of wells showing slowly increasing concentrations of total dissolved solids.

The chronic declines in groundwater levels and storage are increasing pumping costs, and likely to cause more shallow wells to go dry. In addition, there is a risk of further degradation of water quality and potential land subsidence, although to date there is no evidence subsidence due to groundwater extraction.

The SkyTEM system employed in Indian Wells Valley

The airborne electromagnetic survey (AEM) survey, totalling 500 line-miles (800-line kilometers), was carried out November 8-12, 2017 with the SkyTEM 312M system.

The SkyTEM system is carried as an external sling load independent of the helicopter and acquires data at an average rate of 53 mph (85 kph). Flight line spacing was 4100 feet (1250 m) and 8200 feet (2500 m) and the flight lines were primarily of north-south, east-west and northeast-southwest orientation. They survey plan design was based on an evaluation of selected deeper wells, an understanding of the regional and basin-specific geology, ground based geophysical transient/time-domain electromagnetic (TEM) survey, seismic sections, and understanding of the regional structure and known faults within the basin. The line directions were chosen to cross the main geological structures with the objective to cover the entire basin and obtain the highest resolution by placing the majority of the flight lines in the primary areas of groundwater extraction, and within the project budget and constraints.

The airborne instrumentation includes a time domain electromagnetic system, a magnetic data acquisition system and an auxiliary data acquisition system containing two inclinometers, two altimeters and two DGPS (see Figure 2). All instruments are mounted on the frame suspended approximately 115 feet (35 m) below the helicopter, the generator used to power the transmitter is suspended between the frame and the helicopter at about 65 ft (20 m) below the helicopter.

The z-component receiver loop is placed approximately 6.5 ft (2 m) above the frame in what is practically a central loop configuration with a vertical offset. Two lasers placed on the frame measure the distance to terrain continuously and an inclinometer measures the tilt of the frame. Power is supplied by a generator placed between the helicopter and the frame. Measurements are carried out continuously while flying. Every single transient is stored in a binary format, and pre-stacked. Measurements cover the time span of 16.2 µs to approx. 10.7 ms from beginning of ramp down

The transmitter loop for this survey was a twelve-turn 4000 ft^2 (340.8 m^2) eight-sided loop divided into two segments allowing transmittance of a super low moment (LM) in two turns and a high moment (HM) in all twelve turns. The LM current is about 6.0 A with a peak moment of ~4,000 NIA and turn-off time of about 14.6 µs; the HM transmits approximately 119.2 A with a with a peak moment of ~ 500,000 NIA. and has a turn-off time of about 319 µs.

A dual moment system provides a major advantage over single moment systems in that it is possible to measure a wider range of time gates. In LM mode early time gates can be measured allowing more accurately resolution in the near surface while in the HM mode, deep penetration can be achieved.

The measured data are averaged, reduced to data subsets (soundings) and stored together with GPS coordinates, altitude and inclination of the transmitter/receiver coils and transmitter waveform. Transmitter waveform information and other controlling parameters of the acquisition process are recorded for each data subset, thereby ensuring high data-quality control.

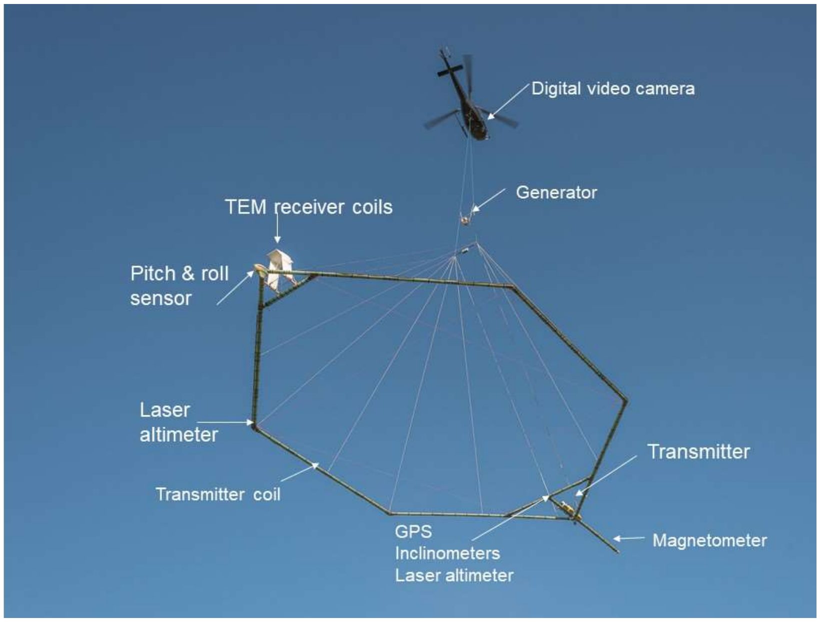

Figure 2. The SkyTEM system and instrumentation

Data from two DGPS receivers are recorded by the EM data acquisition system while a third DGPS is recorded by the magnetic data acquisition system. The DGPS systems are used for time stamping, positioning, and correlation of the EM and magnetic datasets. All recorded data are marked with a time stamp used to link the different data types.

All SkyTEM systems are calibrated at the Danish National Reference site. Calibration includes measurements of the transmitter survey data repeated at a range of altitudes at the reference site. Hereby, it is documented that the instrumentation can reproduce the reference site with the same set of calibration parameters independent of the flight altitude. All processed data are corrected according to the calibration parameters.

The data were inverted in Aarhus Workbench, using a 30-layer Spatially-Constrained Inversion (SCI) providing information to a depth of 500m in the more resistive areas.

Natural infiltration

An area approximately 10-mile-long (16 kms) along the northwestern boundary of the groundwater basin comprised primarily of alluvial materials from the Sierra Nevada mountain range was mapped. Runoff from the High Sierras reaches the basin here, after crossing the Sierra Nevada Frontal Fault. The IWV groundwater basin has two defined aquifers: a shallow unconfined aquifer and a deeper confined aquifer. The aquifers are separated by a hydrogeologic zone (aquitard) containing more clayey deposits. Based upon well data in the valley, it was suggested that there are areas along the Sierra Nevada front where there is a more direct contact between the shallow and deeper aquifer. It was suspected that this zone was the primary recharge area for the deeper aquifer, however, there are very few deeper wells which can confirm this. Thus, one objective of the study was to confirm the contact between the shallow and deeper aquifer and that the very coarse alluvial material at the base of the Sierra provides a natural infiltration zone to the deeper aquifer in the basin.

The SkyTEM lines conducted across the Sierra Nevada Frontal Fault showed relatively high resistivity as deep as the survey penetrated (over 1200 ft). The shallower wells in the area also show predominately sand and gravel with the same resistivity. Thus, it can be seen from the SkyTEM data that the coarser sediments extend at depth without the presence of clayey materials which are seen between the two aquifers to the east and south in Basin. Finally, the SkyTEM data indicate there is connection between the shallow and deeper aquifer along the frontal fault, and that this also appears to be a potential area of natural recharge to the deeper aquifer from High Sierra runoff.

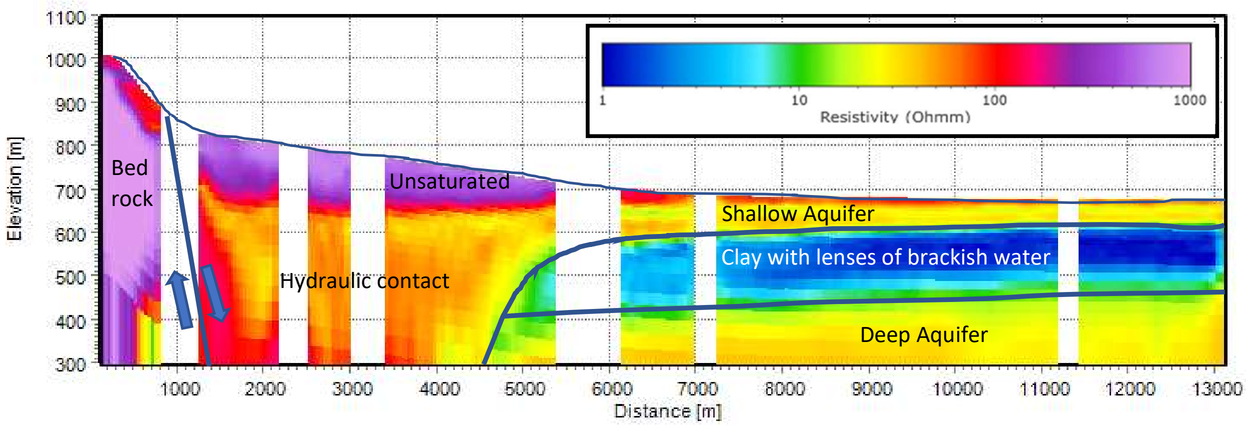

Figure 3. West – East oriented Vertical section from the sierra Nevada foothills towards east.

Figure 3 shows a vertical section from the basin boundary from the Sierra Nevada mountains to the east, towards the central part of the groundwater basin (China Lake). The purple and red colors show the unsaturated zone, where as the orange and yellow colors show sand and gravel deposits. The green to light blue colors show increasing clay content in the sediments. The dark blue colors show the clay units with high salinity.

Managed Aquifer Recharge

The AEM survey also included the El Paso area to the south. One of the purposes for mapping this area was to investigate the connectivity to the China Lake area and to obtain some initial evidence for the possible existence of currently unmapped aquifers that could lie beneath or between the existing wells.

Since the majority of the flight lines were flown over the central portions of basin and not the extremities of the survey area, only a few reconnaissance flight lines were planned in the El Paso area. The shortage of data made it difficult to interpret the AEM data from flight line to flight line. Adding to the challenge was that there are very few boreholes in the area to aid in the interpretation.

The reconnaissance lines were nonetheless beneficial as they identified areas with relatively thick deposits of coarser material near the surface, likely deposited in older alluvial fans coming out of the

Sierra Nevada mountains. The units with higher resistivity were seen to be as much as 250 ft thick, with a relatively thick unsaturated zone. At the end of the thicker deposits there is seen an area where lower resistive sediments occur shallower. Based on the geometry of the lower resistivity clayey sediments, they may form potential hydraulic barriers in the basin, which is also seen in wells and groundwater potential measurements. This area could be a prospective location for managed aquifer recharge, considering the potentially high infiltration rates, good storage capacity and a flow barrier that restricts flow out of the El Paso area(see Figure 4 and 5). AEM interpretation provides an initial estimate of the geometry and total size/volume of the area that could be used to store water and approximate storage capacity.

Based on the AEM data, plans are currently being developed to conduct further investigations throughout the area. A good understanding of the static water level is required for further interpretation of the AEM data and for evaluation of dipping clay layers and their effect on flow of infiltrating water in area. Future study may also include another AEM survey with denser flight lines and a survey configuration aimed at obtaining the highest possible resolution of the shallow resistive sediments.

Ground access is a challenge due to the sensitive nature of the desert ecosystem in the area making an AEM survey particularly appropriate.

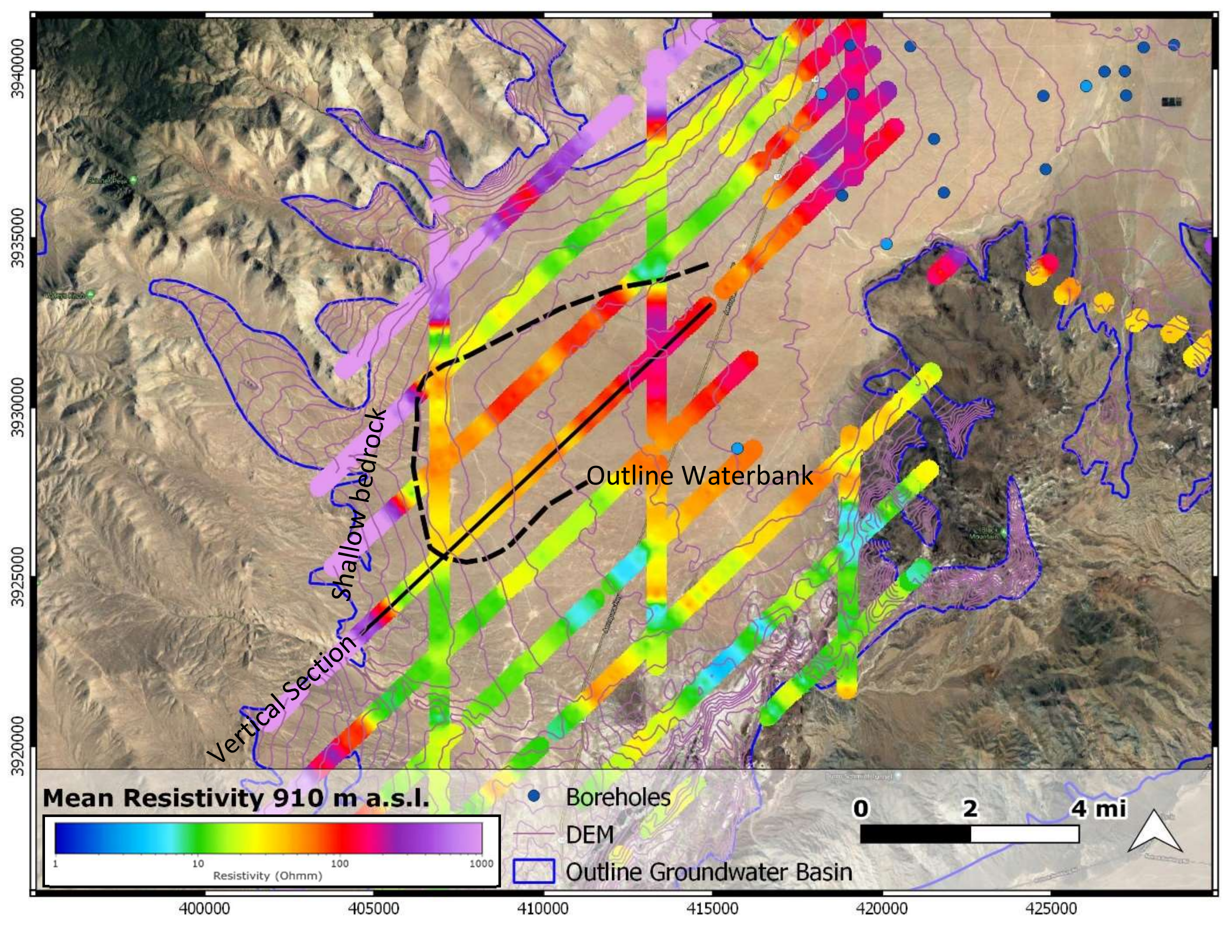

Figure 4. El Paso Subbasin

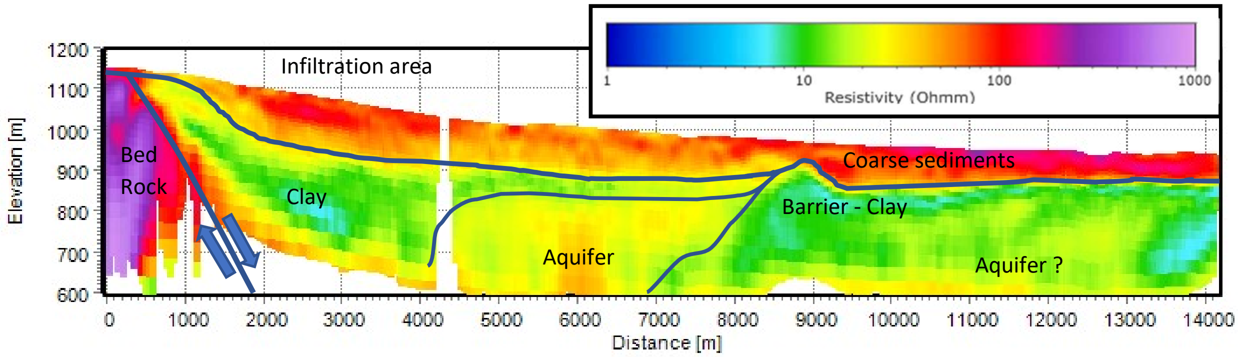

Figure 5. A 14 km long Vertical section showing the SkyTEM results. The section is located as can be seen on figure 4

CONCLUSIONS

Groundwater pumping in the Indian Wells Valley exceeds natural recharge by roughly four times and well levels have declined about one to two foot each year. Due to the lack of and short-lived nature of surface water, groundwater extraction is often the only realistic and affordable means of providing reliable water supply for much of the Basin demands. However, the large variability in geological and hydrological conditions have a profound influence on the availability of groundwater, and the sustainable development of the resource depends on an accurate understanding of the hydrogeology.

The AEM data set provides valuable new insight about natural recharge and possible sites for managed aquifer recharge and water banking. Delineating potential groundwater zones and prospective areas for managed aquifer storage using AEM is cost effective and efficient to minimize time and assists in quick decision making for sustainable water resource management. The AEM survey showed that aquifer and aquitard materials in the near surface can be readily mapped and delineated and that even a few reconnaissance lines to quickly explore outlying areas can deliver enough information for improving geological understanding interpretations. The results of the present study can serve as guidelines for planning future managed aquifer recharge projects in the Basin in order to ensure sustainable groundwater utilization and management. AEM succeeds in identifying potential groundwater zones and areas for management aquifer recharge in the future.