Quality Assurance Plan

Evaluation of a new surface nuclear magnetic resonance sounding geophysical instrument

Approvals:

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Evaluation of a new surface nuclear magnetic resonance sounding geophysical instrument

This project fall into the basic research and development quality assurance (QA) category consisting of a QA narrative. It is not intended to be a full validation of the instrument and method, but an evaluation of its capabilities and limitations.

Project Description/QA Approach

In the summer of 2002, the U.S. Department of Interior, Geological Survey (DOI/USGS), in cooperation with the U.S. Environmental Protection Agency (EPA), will conduct a series of field tests of a magnetic resonance sounding (MRS) instrument invented in the former Soviet Union that has been upgraded and developed for commercial use.

The purpose of the testing is to determine if the technology can be used to reliably detect ground water and estimate aquifer free water content and effective permeability using surface nuclear MRS measurements. The system will be tested at a number of sites in the Central, Western, and Southeast regions of the United States. The selection of the sites is based upon accessibility of the areas for the MRS and other geophysical surveys, the presence of existing water wells, different geological formations, depth to the water table, and where possible, locations to compare the current results with data from previous prototype MRS surveys conducted in 1993 and 1996. This is the only method that can determine the "free water content" in the subsurface formations. The "free water content" is that water in the pore spaces that is not held by surface tension forces and would be free to move as groundwater flow or pumping. There is no other single direct method to ground truth the results. However, changes in the "free water" content will exhibit changes in other physical properties that can be measured with other geophysical methods. Therefore, concurrent or subsequent to the MRS surveys, several surface and borehole geophysical methods will be used to independently measure aquifer physical properties that effect MRS measurements or interpretations, including subsurface electrical conductivity structure and porosity. Where available, lithologic logs and the results of pumping tests will be compared with the results of the MRS data.

Geophysical surveys:

In addition to MRS, surface, borehole, and cross-hole geophysical surveys will be performed to provide supplemental and constraining information needed to evaluate the performance of the technology. Basic data will also be collected at each site to document the survey stations and well locations with a Global Positioning System (GPS), measurements of the total earth's magnetic field to determine the Larmour frequency for the MRS instrument, measurements of the depth to the water table for correlation to the MRS data, and local (60 Hz) noise levels to evaluate signal strength to noise levels.

a. Surface Geophysics: At all sites, MRS and Time-Domain Electromagnetic (TDEM) sounding will be conducted. The TDEM data will be used to estimate aquifer electrical conductivity, a parameter known to affect MRS measurements. The total number of stations surveyed at each field site will be determined on a site by site basis, depending upon accessibility, ability to ground truth the MRS results, and the noise levels. Since the data is processed in the field in real time, the signal to noise data quality can be determined at any point during acquisition. The signal to noise level can be improved with additional stacking. The time for data acquisition at each station will depend upon the local noise level and it is expected will vary from about 2 hours at low noise levels to about 4 hours in high noise environments. Data will be stacked and monitored until little change or improvement is observed in the results. If a particular station appears to be very noisy on initial evaluation (~36 stacks), re-location to a nearby area with lower noise may be considered. In very high noise areas, the use of a figure "8" configuration, instead of a loop, will be considered. If significant improvement in the signal to noise level has not been obtained in the 4 hour period, the station location may be deemed too noisy and terminated. In all cases, quality will be emphasized over quantity. Where cultural noise (metal fences, metal pipelines) is present and if access is possible, additional d.c. resistivity soundings will be conducted and interpreted for comparison with the TDEM results. Each of these techniques responds differently to cultural noise. The TDEM and dc resistivity sounds will be interpreted with at least one dimensional inversion programs. Where access is possible, sufficient TDEM and dc resistivity soundings will be conducted around the MRS station to determine 2 and 3 dimensional effects.

b. Borehole Geophysics: At all sites where wells exist, are accessible, have been completed with compatible well casings (non metallic), and permits can be obtained for access or use of the various borehole tools (in particular, a neutron source), a basic suite of borehole logs will be collected including EM-induction, magnetic susceptibility, and natural gamma. Where permits can be obtained from the various State regulatory Agencies, active-source neutron logging will be conducted. The borehole logs will be used to provide insight into aquifer structure and to provide in situ measurements of aquifer electrical and magnetic susceptibility needed to verify both TDEM and MRS results.
c. Cross-hole radar: Where suitable boreholes are present as determined from their location, distance they are apart, and well completion materials, cross-hole radar surveys (zero-offset gathers and/or full tomography) will be conducted. These data sets will provide additional insight into aquifer structure, porosity, and electrical conductivity needed to verify the MRS results.

All the USGS geophysical equipment will undergo standard calibration and testing procedures at the USGS field test area before the surveys are initiated and after they have all been completed.

Data Analysis:

Analysis of the MRS data will be conducted in several phases. Results of each phase will be recorded and archived before proceeding to the next phase.

(1) Inversion of the MRS data without any additionalinformation, such as depth to the water table. The analysis should include estimates of free-water with depth, and aquifer permeability.

(2) Inversion of the MRS data using electrical conductivity information supplied by EM induction logs, TDEM and/or dc resistivity soundings (if dc resistivity soundings are available from other previous conducted surveys) to account for electromagnetic signal attenuation due the electrical conductivity of the formations

(3) Additional analysis as deemed necessary by the research team, such as the effect of 2 or 3 dimensional lateral variations, or the presence of high magnetic susceptibility in the formations on the MRS results.

Comparison of MRS results to other sources of information:

After the completion of MRS analysis, the results will be compared to other sources of information including estimates of aquifer structure from lithologic and borehole logging, estimates of porosity provided by neutron logs and interpretation of cross-hole EM (radar) wave velocity using petrophysical constitutive relationships (such as CRIM), and estimates of hydraulic conductivity provided by pumping tests if available from other previously conducted studies. Emphasis on this stage will be on developing both qualitative and quantitative comparisons of the MRS results against the benchmark data.
There are different aspects of the MRS data that can be evaluated independently. The first is the depth to the water table as compared to the measured and interpolated depth between wells. Since the sensitivity of the MRS data decreases with depth, the MRS results would be deemed successful or acceptable if the well measured water table falls within the MRS depth range associated with a significant increase in water content (10% or more). The MRS results will also be compared to the TDEM and d.c. resistivity results for evaluation of the water content of the capillary zone and zones of increase moisture content in the vadose zone. These results will be deemed successful if increases in the electrical conductivity are observed associated with zones of increase water content from the MRS data. Any increases in electrical conductivity due the presence of clay will be evaluated by comparison with borehole gamma logs. The structure detail of the aquifer of fine, medium and coarse grain from the MRS data will be compared to lithologic logs, borehole geophysical logs, TDEM and d.c. resistivity data. Each of these methods provides different information for evaluation of the different grain sizes. The MRS results on grain size distribution would be deemed successful if there is general agreement with the other data, such as estimates of changes in the porosity.

Reporting Study Results:

The results of the study will be reported in a manner consistent with the requirements of the USGS and the EPA. At least one article will be submitted to a peer reviewed journal within eight (8) months after completion of all the field work and analysis, with authorship shared by the research participants.