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Project Summary

Geophysical Methods for Locating Abandoned Wells

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Field measurements with spontaneous potential (SP), electromagnetics, and magnetometers indicated that a magnetometer could be used to locate steel-cased abandoned wells. A mathematical model using a set of magnetic pole pairs was developed to evaluate the applicability of an airborne magnetic survey to locate abandoned wells. The modeling indicated that airborne measurements made at a height of 200 feet above the ground with passes spaced at between 300 to 400 feet could detect with a high level of confidence the steel-cased wells within the search area. The aerial magnetic measurements permit a reduction in the noise from cultural and geological sources while the magnetic anomaly broadens; thus, fewer passes with an airplane are required than with a surface magnetometer.

This Project Summary was developed by EPA's Environmental Monitoring Systems Laboratory, Las Vegas, NV, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

A provision of the Underground Injection Control Regulations issued by the U.S. Environmental Protection Agency (EPA) establishes a radius of review for proposed injection wells. The hydrological properties of the subsurface are used to predict the area affected within an injection zone. Any abandoned wells within this calculated area could serve as possible conduits for the transmission of injected wastes into a potable water zone.

In the United States, it has been estimated that there are approximately 500,000 municipal, industrial, commercial, agricultural, and domestic wells injecting fluids below the surface and approximately 5,000 new injection wells are being constructed each year. Abandoned wells located near these injection wells must be located to prevent contamination of the potable water aquifer; however, records of the locations of these abandoned wells may be imprecise, incomplete, out-of-date, and difficult to locate. Record searches may prove to be time-consuming and expensive, and there is some chance that a record search will fail to show an abandoned well that falls within a radius of review for an injection well. Other means for locating abandoned wells are needed.

The EPA's Environmental Photographic Interpretation Center (EPIC) is investigating the use of historical photographic searches to locate abandoned wells. Aerial photographs of large areas of the country exist as far back as the early thirties and these photographic searches may either supplement or complement the record search as a means for locating abandoned wells. An advantage of this method is the ability to locate wells in which the casing was either nonmetallic or removed; however the method is limited to the quantity, quality, and timeliness of the photographs that cover an area.

Geophysical methods offer another means for locating abandoned wells. Although some geophysical methods may detect an abandoned well without steel-casing when the well is in close proximity to the instrument, for all practical purposes, geophysics offers little hope for detecting wells without casing. The magnetometer is the most practical geophysical method for locating steel-cased abandoned wells.

The magnetic method has been the focus of an EPA-funded U. S. Geological Survey (USGS) study of geophysical methods for locating abandoned wells. Two scenarios can be envisioned in which a magnetic well survey would be useful. First, an injection well operation may identify a proposed site for an injection well and all wells (including abandoned wells) in the vicinity of the proposed site would need to be located. The second scenario involves the characterization of large areas where injection wells could be permitted with little chance of harm occurring. While aircraft-based magnetometer surveys may be economical in the first scenario, the method appears to offer the greatest potential for the second scenario.

Procedure

Ground-based magnetic measurements were made in the vicinity of several steel-cased wells in Colorado to characterize the magnetic anomaly and to determine if the anomaly could be detected from an aircraft. To evaluate the spacings and altitudes required for a magnetic survey for abandoned wells, a mathematical model was developed for 18 wells in the Denver area. A finite number of magnetic dipoles were used in the model. Surface magnetometry measurements were made to adjust the models for the test wells to produce a map of the magnetic anomaly on the surface that was consistent with field measurements. The measurement of the magnetic anomaly at various heights and distances above the well could then be assessed to determine if actual field tests with an aircraft were practical and economical.

Electrical geophysical measurements were also made on the surface in the vicinity of the steel-cased wells; however, the emphasis was on the characterization of the magnetic anomaly.

Results and Discussion

Ground-based magnetic measurements made in the vicinity of the test wells in Denver yielded total field anomalies with peak values ranging from about 1,500 to 6,000 gammas. The anomalies measured on the ground were very narrow; and, considering noise due to other cultural and geologic sources, a line spacing on the order of 50 feet would be necessary to locate all casings in the test area.

By use of a nonlinear least squares curve-fitting (inversion) program, model parameters which characterize each test casing were determined. The position and strength of the upper-most pole was usually well resolved. The parameters of lower poles were not as well resolved, but it appears that the results are adequate for predicting the anomalies which would be observed at aircraft altitudes. Modeling based on the parameters determined from the ground data indicates that all of the test casings would be detected by airborne measurements made at heights of 150 to 200 feet above the ground, provided lines spaced as closely as 330 feet were used and provided noise due to other cultural and geological sources is not very large. Given the noise levels of currently available equipment and assuming very low magnetic gradients due to geological sources, the detection range for total field measurements is greater than that for measurements of the horizontal or vertical gradient of the total intensity.

Electrical self-potential anomalies were found to be associated with most of the casings where measurements were made. However, the anomalies tend to be very narrow and, in several cases, they are comparable in magnitude to other small anomalies which are not directly associated with casings. Measurements made with a terrain conductivity meter and slingram system were negative.

The principal effect of varying the aircraft altitude is to decrease the peak amplitude and to broaden the anomaly. By magnetic compensation of the aircraft and by recording and correcting for the motions of the aircraft, the noise level of an airborne system can be reduced to about 0.2 gamma or better for the total field as measured by sensors mounted in wing-tip pods or tail stingers. Total field anomalies are slightly broader in the east-west direction than in the north-south direction. Also, magnetometer system noise is likely to be slightly less on north-south lines than on east-west lines. Therefore, there is a small advantage in flying total field surveys in a north-south rather than east-west direction. If the smallest identifiable total field anomaly is assumed to be five times the expected noise level, or 1 gamma, then the data from the test wells near Denver indicate a line spacing of 330 feet will detect all the steel-cased wells in a rural area.

If the density of wells in an area is very high, it may be difficult to identify individual wells using airborne surveys. Use of small spacings between lines will of course help to resolve anomalies due to individual wells. If, for instance, the density of wells were 2000 per square mile as exists in the vicinity of Oklahoma City, the average spacing between wells would be only about 118 feet. In such an area, an airborne survey would have to be made at a height of 50 feet or less with a line spacing on the order of 50 feet or less to be able to resolve most of the individual anomalies. If the density of wells is extremely high and all wells must be identified and located, it might be more practical to use ground measurements rather than airborne measurements. Of course, if the density of wells is extremely high, it may not be necessary to identify separately all of the wells in a cluster.

The cost for a ground magnetic survey using two-person crew (including salaries, living expenses, vehicle, equipment rental, supplies, and overhead, but not including mobilization to the field site) has been estimated to be at least $10,000/4 weeks (1983 costs). By working a reasonable amount of overtime, this crew might survey, process, and plot a maximum of 160 line-miles in 4 weeks. If a line spacing of 50 feet (15.2 m) were used, this would cover an area of 1.52 square miles (3.94 km^2). This represents a cost of $6000/square mile (2.59 km^2) covered and $62.50/line-mile ($38.84/line-km). This is less than one-half the line-mile costs for mineral exploration, but much mineral exploration is done in heavily vegetated terrain. Rates of production would be less, and costs greater, if the crew had to spend time in obtaining landowner's authorization for access to the land or if the crew interpreted the results and did additional detailed work to "pinpoint" the location of suspected casings or investigate questionable anomalies.

For areas larger than a few square miles, airborne surveys are likely to be considerably less expensive than ground surveys. Airborne surveys are not practical for very small areas due to the high costs of mobilization.

Costs for routine aeromagnetic surveys using small fixed-wing aircraft are on the order of $8-14/line mile ($5-9/line-km) including data processing, provided: (1) several thousand line miles are flown in one block, (2) the lines are at least 10-20 miles (16-32 km) long, and (3) Doppler radar and photographic methods are used for flight path recovery. The costs for similar work done with rotary-wing aircraft are about $25-30/line mile ($16-19/line-km). Costs per line mile are much greater if the lines are short and the areas small, and if a microwave navigation system is required.

Conclusions and Future Actions

The mathematical model of a magnetic anomaly, developed by the USGS, for a steel-cased well indicates that an airborne magnetic survey can theoretically locate abandoned wells. Several areas near Oklahoma City, will be surveyed in 1983 to test the theory. The University of Oklahoma's Environmental and Groundwater Institute will select the test areas from a search of well drilling records. The EPIC will examine the same test areas with historical photographs to further substantiate the location of wells in the areas.

The cooperative effort between the EPA and the USGS is aimed at providing local, state and federal agencies with the methodology to determine if abandoned wells exist in an area where the underground injection of wastes is contemplated. Magnetometer surveys will likely be just one of several methods that can be utilized in locating abandoned wells. The record searches conducted by the Environmental and Groundwater Institute and the historical photographic searches conducted by the EPA's EPIC may provide alternative approaches to the problem of locating abandoned wells in other areas.The costs of conducting an airborne magnetic survey have been estimated but the costs must be weighed against the alternative approaches. An assessment of the costs and the benefits of the various approaches will be possible after the USGS has completed overflights of those areas near Oklahoma City that have been examined through record and historical photographic searches.

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The complete report, entitled "Geophysical Methods for Locating Abandoned Wells," (Order No. PB 84-212 711; Cost: $20.50, subject to change) will be available only from:
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