

Feasibility Study of Using the Electromagnetic Method and High-Resolution Magnetic Method to Locate Abandoned Brine Wells in Hutchinson, Kansas

Objective

On January 17, 2001, a natural gas explosion and fire destroyed two downtown Hutchinson businesses. The next day another explosion occurred at a mobile home park 3 miles away. Two residents died of injuries from the explosion, which forced the evacuation of hundreds of people as gas geysers began erupting in the area. The geysers spewed a mixture of natural gas and saltwater. The pathways to the land surface at both the explosion sites and the geysers were abandoned brine wells used for solution mining of salt (<http://www.kgs.ukans.edu/Hydro/Hutch/Background/index.html>). To find these abandoned brine wells is a part of the Hutchinson Response Project. This proposal is to evaluate the feasibility of the electromagnetic and high-resolution magnetic methods to locate abandoned brine wells.

Introduction

Some known wells in the mobile home park had steel cased pipes. One uncapped abandoned brine well 4 inches in diameter and buried at a depth of 5 ft was located by the electromagnetic (EM) method (Xia, 2001). A GEM-2, owned by the Kansas Geological Survey, was used in this survey. The GEM-2 is a portable, digital, broadband electromagnetic sensor (Won, 1980). Multi-frequency data are acquired simultaneously with a maximum sampling rate of 30 Hz when an instrument operator walks along a survey line. For each frequency, both in-phase and quadrature components of the induced EM field were recorded in ppm (parts per million relative to the primary field). Data can be transferred onto a notebook computer and maps generated within a few minutes after surveying is completed.

Quadrature data are proportional to the ground conductivity in the low to middle induction numbers, but are inversely proportional to the conductivity at middle to high induction numbers. Thus, a moderate conductor may produce a strong quadrature anomaly, whereas a good conductor may produce a weak anomaly or no anomaly at all. In either case, in-phase data have to be used for further analysis (Huang and Won, 2001). The investigation depth is dependent on the frequency of the instrument used in the survey, conductivity and magnetic susceptibility of a target, and surrounding materials. There is no exact relation between instrument frequencies and the investigation depth. A skin depth concept (Won, 1980) may be used to obtain rough estimates of the investigation depth in a specific survey area.

The Kansas Geological Survey has a long history of using gravity and magnetic method to solve regional geological problems (Yarger, 1983, 1989; Lam and Yarger, 1989; Xia et al., 1992b, 1995a, 1995b, 1995c, 1996). Algorithms related to data processing and interpretation were developed (Yarger et al., 1978; Xia et al., 1991, 1992a, 1993). Although this research was focused on deep (> 200 m) geology, the fundament of anomalies induced by the geomagnetic field in near-surface (< 5 m) materials remains the same. A magnetic anomaly due to a buried brine well with a steel-case pipe at a depth of ~2 meters could be in the order of 10 – 100 nT. A

G-858 portable cesium magnetometer has resolution of 0.1 nT and accuracy of 0.5 nT. Based on these numbers, the high-resolution magnetic method, surveying on a grid with a 2-ft station spacing, could be a proper method to locate abandoned brine wells.

A microgravity survey was not suitable to locate abandoned brine wells because anomalies due to brine wells or salt voids are too weak to be detected by this method. The vertical steel pipe is normally 400 – 700 ft in length. The predicted maximum gravity signal caused by this pipe is only 4 – 6 μGal (microgal). The sensitivity of the most advanced gravimeter is at a 1 μGal level, so this anomaly is too weak to find using a microgravity survey. I also calculated the gravity anomaly caused by a salt cavern with a volume of 100 ft \times 100 ft \times 100 ft buried at a depth of 400 ft, a typical depth of salt voids in the Hutchinson area. The maximum anomaly from the cavern is approximately 25 μGal , assuming that the cavern is completely empty. In actuality, the maximum anomaly due to the cavern will be much less than 25 μGal because caverns are always filled with water, soil, and/or rocks, which makes a density contrast considerably smaller. To detect this 25- μGal anomaly, the sensitivity of the gravimeter and accuracy of elevation measurements are critical. The sensitivity of the most advanced gravimeters available in the market is 1 to 10 μGal . It takes much longer (normally more than 15 minutes/station) to acquire a microgravity data than a normal exploration gravity survey in order to achieve the 1- μGal sensitivity level. Elevation measurements are the other main challenge in the microgravity survey. The error associated with elevation measurements is 5 μGal per inch. In practice, one inch accuracy could be achieved by the most advanced Trimble GPS system.

To confidently identify a gravity anomaly, the maximum anomaly should be at least three times higher than possible errors. Therefore, to see an anomaly with an amplitude less than 25 μGal the sensitivity of gravimeter should not be less than 4 μGal (in the range of 1 – 4 μGal) and the accuracy of elevation measurements should be within one inch. It is very difficult to achieve an accurate of elevation survey with a one-inch range. In addition, to detect this 25- μGal anomaly in an urban area, culture noise will become a serious problem.

A 3-D ground penetrating radar (GPR) survey may be useful to locate these wells. The ground is dirt fill, however, and there could be a lot of reflected/diffracted events caused by objects other than the brine wells. Furthermore, time spent on 3-D GPR data acquisition and processing could be much longer than might be expected.

Proposed Project

An EM survey with a newly calibrated GEM-2 instrument and a high-resolution magnetic survey with a G-858 are proposed to locate abandoned brine wells. The project consists of two phases. Phase one will focus on 1) signature analysis of brine wells and 2) necessary data processing steps and filtering techniques to enhance signature of brine wells. In addition to the data acquired in the past five months by personnel of Kansas Geological Survey and the City of Hutchinson, in phase one both EM (1 reading/ft²) and high-resolution magnetic data (1 reading/ft²) will be acquired on three or four areas where a wells are expected to be located. Each area covers about 40 ft \times 40 ft. Analysis results will be a basis for research in phase two. Phase two will cover areas about 500,000 ft² to locate abandoned brine wells. Phase two will proceed only on the mutual agreement between the representative from the City of Hutchinson

and the researchers of the Kansas Geological Survey. We propose to purchase a continuously recording magnetometer G-858 in phase two.

Xia (2001a and 2001b) used three frequencies, 2,430 Hz, 7,290 Hz, and 18,270 Hz, in his previous EM study. To increase an investigation depth, lower frequencies are required. Two additional frequencies, 510 Hz and 1050 Hz, will be added in the proposed project. For each frequency, both in-phase and quadrature components of the induced EM field in ppm will be recorded. The data density will be about one multi-frequency reading (ten values) per square foot.

A high-resolution magnetic survey will require more field time than the EM survey. Data density of the magnetic survey will be chosen as one reading per four square feet, which is one reading in every 2 ft by 2 ft area. This design may be modified after phase one is completed. A base station is required to correct meter drifting. To control the accuracy of a high-resolution magnetic survey, a base station reading is required at one-hour intervals.

Space locations are critical in locating anomalous spots based on EM and/or high-resolution magnetic results. The Trimble system, a global position system (GPS) instrument available at the Kansas Geological Survey, will be used to lay out grids in phase two. The Trimble system has accuracy in the order of centimeters.

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