

Low-Cost Apparatus for On-Site Monitoring of Methane in Ground Water

by Samuel S. Harrison

Abstract

An upsurge in oil- and gas-well drilling in northwestern Pennsylvania and western New York has been accompanied by several incidents of contamination of ground water by methane. Determining which well is causing the contamination is extremely difficult if more than one gas or oil well is present in the area.

The fact that the solubility of methane decreases as the pressure on ground water decreases provides a quantitative basis for monitoring changes in the amount of methane in the ground water. Quantitative measurements of the volume of methane given off by ground water pumped from a well as the water enters atmospheric pressure permit detection of temporal changes in the gas content which are too subtle to be detected visually. These gas volume changes may, in some cases, be correlated with variations in the pressure of methane in the annulus of nearby individual gas/oil wells and thus may provide a means of pinpointing the gas/oil well that is causing the methane contamination.

The basic principle of the gas-volume monitoring apparatus (GVMA) described in this paper is that as a measured amount of ground water enters atmospheric pressure the gas which comes out of solution is trapped and measured. The GVMA can be constructed of materials costing less than \$100 and requires no special skills to assemble or operate. In a recent study conducted in a western New York village, four homeowners were able to collect quantitative gas-volume data from their household water wells daily in about one-half hour. Unlike laboratory analyses for dissolved methane, there is no cost involved in monitoring with the GVMA beyond the initial instrument cost and operator time. Another advantage is that the data are available immediately.

Introduction

During the past decade hundreds of gas and oil wells have been drilled on the Glaciated Appalachian Plateau in northwestern Pennsylvania and western New York. Although the wells are constructed and

operated so that nearby fresh water aquifers are usually protected from the gas/oil well fluids and gases, there have been several instances of contamination of domestic water wells (Harrison 1983; Harrison 1985). Most of the reported cases of contamination of domestic water supplies involve the incursion of methane gas into the aquifers tapped by the water wells. In some cases, the methane is not only present within the aquifer, but also seeps out of the ground surface above the aquifer.

The contamination of an aquifer by methane usually first becomes apparent to a water well user when faucets begin "spitting" when turned on. Also, when a glass of water is drawn from the tap, small bubbles can be seen escaping from the water, giving it the appearance of soda water that has just been uncapped and poured into a glass. If a submersible pump is used in the water well, the gas may cause it to air lock and malfunction. For persons using water wells that contain large amounts of methane, there is the hazard that the methane might accumulate within their homes in a sufficient concentration (5 percent) to become potentially explosive.

In most instances the methane that is emitted from contaminated domestic water systems probably was not present in the gaseous phase as it entered the water well, but rather, the methane was dissolved in the ground water. The solubility of methane gas in water at normal temperature and atmospheric pressure has been reported in the literature to be from 21 to 30 mg/L. I will assume a solubility of 28 mg/L (equivalent to 40 cc/L) in this paper. Because the solubility of methane in water is directly proportional to pressure (Figure 1), ground water drawn into a pumping system at some depth below the water table may become supersaturated with methane as that water is discharged from the pumping system into atmospheric pressure. For instance, ground water saturated with methane at a depth of 100 feet below the static water level in a well would be under a pressure of 43 psig (100 ft x 0.43 psig/ft) and contain approximately 110 mg/L of methane. If this water were drawn into a pumping-system intake at that 100-foot depth, the solubility of the methane would decrease to approximately 28 mg/L when the water was discharged from a tap into the atmospheric pressure of a home. Thus,

approximately 82 mg of methane gas would evolve from each liter of water. Expressed as a volume, 117 cc of gas would theoretically escape from solution from each liter of water discharged from the tap. Under these conditions, enough gas could theoretically be emitted from the water to raise the concentration of gas to a potentially explosive level (5 percent) in a volume of air 2.3 times the volume of the water drawn. For instance, under the conditions just described, in order for the gas to reach potentially explosive levels in a small shower stall ($2\frac{1}{2}' \times 2\frac{1}{2}' \times 7'$), approximately 140 gallons of water would have to discharge from the shower head (assuming a "closed" system with no mixing of air outside the shower stall). Fortunately under the conditions just described, potentially explosive levels are not likely to be reached in the shower, but they could easily be exceeded in an automatic clothes washer or dishwasher using roughly 20 gallons of water containing 110 mg/L of methane. Actually, in the case of hot water, the amount of water required to reach a potentially explosive level would be somewhat less, as the concentration of methane that can theoretically remain in the water is decreased as water temperature is increased. The calculations cited here are based on the assumptions that (1) the ground water is saturated with methane gas as it enters the pumping system, (2) the pressure/solubility relationship of methane in water is as shown in Figure 1, (3) the pressure in the water column in the well increases 0.43 psi for each foot below the static level, (4) the temperature of the water remains constant, and (5) once the water containing the dissolved gas enters the pumping system the gas is not trapped or vented before exiting the system via the tap into the atmospheric pressure.

The fact that water in a methane-contaminated pumping system is often supersaturated with gas as it enters atmospheric pressure provides an opportunity to monitor the volume of gas coming out of solution. In the example previously cited, 117 cc of gas should theoretically come out of solution for each liter of water drawn from the system. Now suppose that over a period of time the concentration of methane dissolved in the ground water at the pump intake decreases to 80 mg/L. When this water discharges from a tap into atmospheric pressure, only 74 cc of gas will theoretically be emitted from each liter of water as the saturation level of 40 cc/L at atmospheric pressure is reached. It is very unlikely that this decrease in the volume of gas being emitted from the tap water would be apparent to an observer looking at the bubbles forming in a glass of water, especially if the decrease occurred gradually over a period of days or weeks. Careful quantitative monitoring of the change in the volume of gas being emitted from the water, however, might provide important clues for determining the source of the methane. For example, if the gas pressure within the annulus of a nearby gas well was known to have been reduced, and monitoring showed a subsequent decline in the volume of gas emitted from a nearby household water system, a cause-effect relationship would be suggested between the pressurized gas well and the contamination of the aquifer by methane.

Design and Operation of the Gas-Volume Monitoring Apparatus (GVMA)

In order to be able to monitor changes in the concentration of methane coming out of solution from

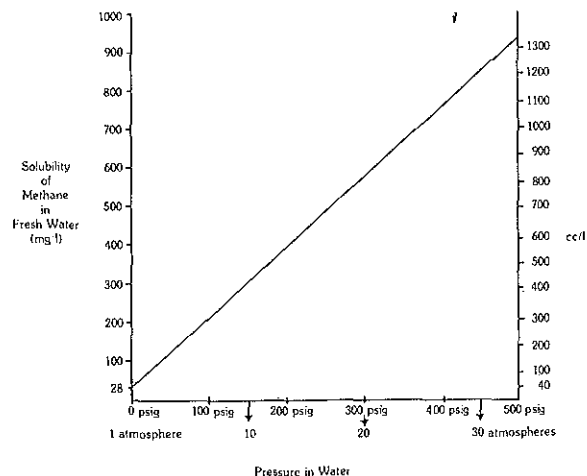


Figure 1. Graph showing the effect of pressure on the solubility of methane in ground water. Reports of the maximum solubility of methane in fresh water at normal temperatures varies somewhat in the literature. A value of 28 mg/L was used in the construction of this graph.

household water systems, a Gas-Volume Monitoring Apparatus (GVMA) was designed and constructed. The principle of the GVMA design is that it provides a means of capturing methane gas as it comes out of solution from household plumbing systems as the ground water enters atmospheric pressure and passes through a collection cylinder. Because both the volume of water and the volume of gas evolving from the water can be measured, the concentration of supersaturated gas in the water can be determined quantitatively.

The principle part of the CBMA is a vertical, clear acrylic separation/collection cylinder 2 inches in diameter and 5 feet long (part A in Figure 2). This cylinder is sealed at the top and bottom by solid rubber stoppers into which holes have been drilled for the required inlet and outlet pipes. As water enters the filled cylinder from the pressurized water systems through inlet pipe B, it flows down to the outlet of pipe C near the bottom of the cylinder (both pipes are $\frac{1}{2}$ -inch diameter copper). Upon entering the cylinder, the pressure is essentially atmospheric, so the supersaturated gas comes out of solution and forms bubbles (similar to the bubbles that form in a carbonated beverage when it is uncapped), which rise to the top of the cylinder where they are trapped. As the trapped gas displaces the water at the top of the cylinder, the time required for a given volume of gas to accumulate is measured. Graduations on the side of the cylinder facilitate this measurement. Once the desired volume of gas is collected, a pinch clamp on a tube connected to a $\frac{1}{4}$ -inch diameter copper tube inserted in the upper rubber stopper is opened to release the gas (part D in Figure 2).

Both the pressure within the water before it enters the GVMA and the rate at which water enters the cylinder are controlled by a $\frac{1}{2}$ -inch globe valve (E). The rate of flow through the cylinder is adjusted so that the pressure drop in the water before it enters the GVMA (measured by gauge F) is no more than a couple psi less when the device is running than the static pressure in the plumbing system when valve E is closed.

Also, the rate of flow through the cylinder must be kept low in order to maximize the collection of gas evolving from the water before it exits out the bottom outlet pipe (C).

The volume of flow through the collection cylinder is measured by the bucket-and-stopwatch method. My experience indicates that a flow rate of about ½-gallon per minute works well. Average values for water discharge and gas volume are calculated from readings taken from three consecutive trials (Table 1). In an attempt to purge the pipes leading to the measuring site of any gas that may have accumulated in the water as the temperature of the water increased while sitting in the pipes, several gallons of water are purged from the line through a bypass valve before the test is run. The bypass valve is located just ahead of the GVMA. Also, prior to beginning the tests, water is allowed to flow through the GVMA for several minutes at the prescribed flow rate.

Operation of the GVMA is simple enough that most homeowners can be trained to operate it, making the daily collection of data both feasible and inexpensive. A homeowner can collect a set of data (three trials such as those depicted in Table 1) in about one-half hour. Written instructions and data sheets enhance consistency and accuracy in the collection of the data.

The total cost of materials for a GVMA is less than \$100. No special skills or equipment are needed to construct it.

Example of Gas-Volume Data Collected with a GVMA

Actual gas-volume data collected by a homeowner from his household plumbing system are shown in Figure 3. The volume of gas he measured in his well water was plotted against average outdoor air temperature for that day. The correlation between the volume of supersaturated gas in the water and the average air temperature on the day the gas volume was measured is 0.82 (Figure 3). The hypothesis in this case is that pressure variations in the annulus of a nearby gas well caused variations in the rate of which gas-saturated water was being forced into the aquifer tapped by the homeowner's well. Because gas from this particular gas well annulus was used for heating some homes adjacent to the gas well, cooler air temperatures necessitated increased gas consumption from the annulus, which thereby reduced the gas pressure in

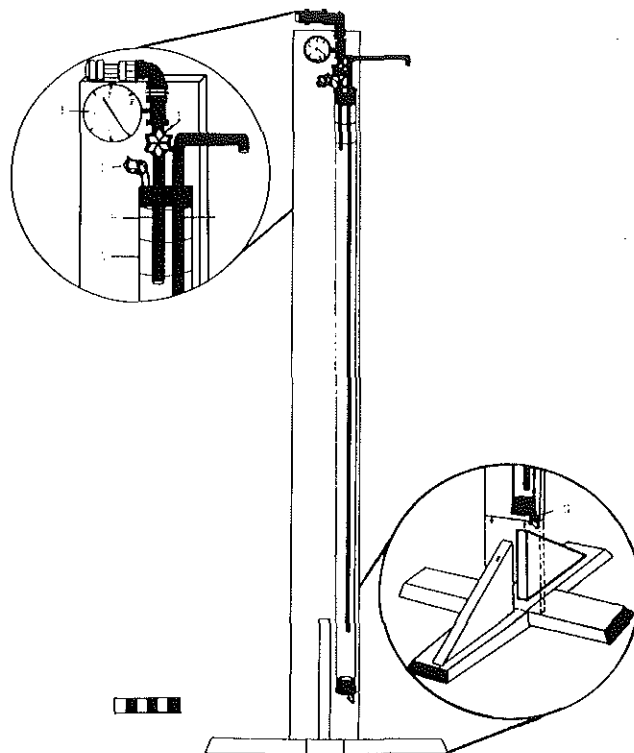


Figure 2. Sketch showing design of the Gas-Volume Monitoring Apparatus (GVMA). Part A = separation/collection cylinder; B = inlet pipe; C = outlet pipe; D = gas-release tube; E = pressure/flow control valve; F = water pressure gauge; G = drain tube.

the annulus. This in turn decreased the hydraulic gradient between the pressurized gas well annulus and the aquifer, thereby decreasing the rate at which gas-contaminated water entered the aquifer tapped by the homeowner's well. Figure 4 shows that after the gas pressure in the annulus of the suspect well was reduced to atmospheric, the correlation between the volume of gas in the ground water and the average air temperature dropped to 0.38, thus providing support for the hypothesis.

There are other minor variables that can affect the volume of gas measured by a GVMA. For instance, gas solubility is inversely related to water temperature. Although water temperature did change seasonally by 10 degrees F over a period of 10 months during the

Table 1
Example of One Set of Data Collected from a Water System Using the GVMA

	1 Water flow rate (liter/sec.)	2 Time to collect 100 cc gas (seconds)	3 Water discharged to collect 100 cc gas (col. 1 x col. 3 = liters)	4 Gas discharge rate (cc gas/ liter H ₂ O)	5 Ave. gas discharge rate (cc gas/liter H ₂ O)	6 Water temperature (F)
Trial 1	.031	120	3.72	26.9	26.9	54
Trial 2	.032	118	3.78	26.5		
Trial 3	.031	118	3.66	27.3		

Date: June 27, 1985

Data in columns 1, 2 and 5 are collected by the GVMA operator. Calculations provide the data in columns 3, 4 and 5.

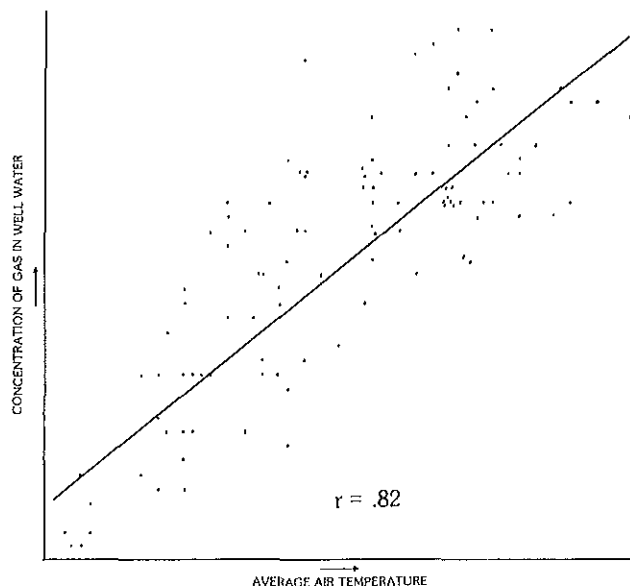


Figure 3. Graph of data collected by a homeowner using a GVMA. The correlation of .82 between the average daily air temperature and the volume of gas in the homeowner's well water indicate that as air temperature increased, gas withdrawn from the pressurized annulus of a nearby gas well decreased the rate at which gas entered the aquifer tapped by the homeowner.

collection of the data shown in Figures 3 and 4, these changes in water temperature appear to account for less than a 5 percent decrease in methane solubility between the lowest and the highest water temperatures measured. Another factor that directly affects the solubility of gas in water is fluctuations in atmospheric pressure. This appears to be a minor factor, however, since a change in barometric pressure of one inch of mercury theoretically results in only a .49 psi change in pressure (0.03 atmospheres).

If gas-volume data are collected from more than one household water system in an area, qualitative comparisons can be made between monitoring sites in an effort to determine if any of the sites show simultaneous changes in gas content, thus suggesting a similar contaminant source. But quantitative comparisons between sites can't readily be made. The reasons for this are that for water containing concentrations of gas that are near the saturation limit, the amount of gas dissolved in the water drawn into the household system is dependent on the depth of the pump intake below the static water level in the well. Thus, if household A has a pump intake 100 feet below the static water level in the well, where pressure is 3.9 atmospheres, water drawn into this intake would theoretically contain approximately 110 mg/L of methane if it is saturated, whereas a neighbor's well (B) with a pump intake 50 feet below the static level could theoretically contain only 68 mg/L methane if saturated at the intake. Under these conditions obviously more gas will be detected in the water from well A than well B. However, if the readings from both wells A and B show simultaneous increases and decreases, then it can be assumed that both are responding to the same variable.

Summary

The Gas-Volume Monitoring Apparatus (GVMA)

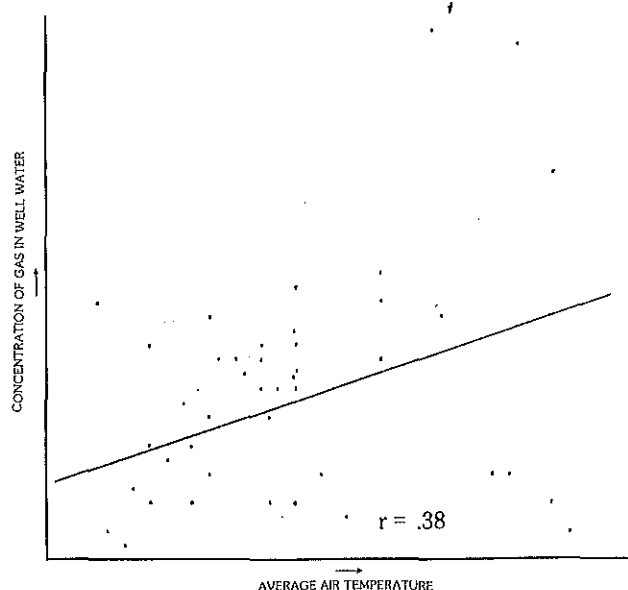


Figure 4. The sharp decline in the correlation between the average air temperature and the volume of gas in the homeowner's water well after the annulus of the nearby gas well was depressurized supports the hypothesis that the gas well was the source of gas that contaminated the aquifer.

provides a means of quantitatively monitoring the volume of supersaturated methane gas in a household plumbing system which taps an aquifer that contains methane. The GVMA is inexpensive and relatively easy to construct. Using the GVMA, a properly instructed homeowner can monitor daily fluctuations in the concentration of supersaturated gas in his/her water system in about one-half hour of time. Records of both short-term and long-term fluctuations in the gas concentration will indicate if the gas problem is increasing or decreasing. These data may also provide a means of determining the source of the gas in the aquifer. The cost of collecting the data, aside from the homeowner's time, is negligible.

Acknowledgments

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References

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Biographical Sketch

Samuel S. Harrison (Department of Geology, Allegheny College, Meadville, PA 16335) is a professor of geology and chairperson of the Environmental Science Department of Allegheny College. A graduate of Allegheny, he earned his M.S. and Ph.D. in geology from the University of North Dakota. In addition to teaching hydrogeology, he is a private consultant, with most of his work focusing on ground water contaminated by landfills and gas well drilling and operation. He is also active in the development of new methods and equipment for monitoring ground water.