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Detection of Leaks in Buried Rural Water Pipelines Using Thermal Infrared Images

Many surface and subsurface leaks were detected during thermal infrared aerial surveys of a test site in eastern South Dakota.

Introduction

Since the mid-1970's an intensive effort has been made to provide a reliable source of high quality water for human and livestock consumption in rural areas. Over 30 locally operated rural water systems have been developed in South Dakota, and similar systems have been developed in the surrounding States.

Several wells and pumping stations are used to withdraw and distribute the water throughout a system. Main lines extend from pump sites with lateral lines serving customers in the peripheral areas. A typical system has from 640 to 2,400 km of pipeline.

The pipe, usually polyvinylchloride (PVC), varies from 3.8 to 30.5 cm in diameter, and is generally installed using either a wheel-type trencher or a pipeline plow. A trencher digs a 0.6-m wide trench in which the pipe is buried, whereas the pipeline plow lifts and spreads the soil, creating a groove wide enough to install the pipe. The pipe is buried 1.8- to 3.0-m deep.

Leakage is a major problem in many pipelines. Normal line water loss is 10 to 15 percent of the volume delivered, but many systems experience a 25 to 35 percent loss due to leaks (Pat Gilligan, Brookings Deuel County Rural Water System Manager, personal communication, 1980). Most leaks occur at joints in the pipeline. Major leaks, generally from 10 to 200 m^3 per day, are easy to identify because they usually result in ponding of water at the surface or in complete line failure. Minor leaks, called "seeper leaks," which generally range from 2 to 10 m^3 per day, are more common and are difficult to detect using conventional ground surveys.

The objective of this research was to determine whether airborne thermal-infrared remote sensing could be used in detecting leaks and monitoring rural water pipelines.

Background

Current procedures for detecting leaks in subsurface pipelines are neither efficient nor reliable. The leak can be located by surface ponding over the pipeline after the problem is severe, but detecting leaks prior to the water surfacing is difficult. Occasionally, a leaking length of pipeline can be identified simply by metering the water volume between two given points. A ground survey is then conducted by inserting a metal rod into the ground every 1.2 to 1.5 m along the pipeline route and checking the rod for excessive dampness when removed. This method of leak detection is tedious, and knowledge of the exact location of the pipeline is necessary.

Airborne thermal sensing, which measures apparent radiometric temperature of the ground surface, may provide a rapid survey method to locate zones of soil moisture saturation indicative of pipeline leaks. This technique is particularly useful for areas which are either too large for adequate ground survey or inaccessible.

When a leak occurs, the surrounding soil becomes saturated as the water percolates downward, laterally, or upward (Hillel, 1980). Although various types of soils react differently, generally the water commonly rises more slowly—but approaches the surface more closely—in clay soils than in coarser soils. In either case, the water may evaporate from the surface, be intercepted by plant roots and removed through increased transpiration, or be stored in the soil profile, thus changing the thermal properties of the soil. As the volume of the leak increases, the water may even saturate the soil profile near the surface.

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Diurnal variations of surface soil temperatures are affected by both soil thermal properties and meteorological conditions (Heilman and Moore, 1979). Because solar radiation heats the soil surface and profile, typically the highest soil surface temperature under clear skies occurs during midafternoon. Thus, the greatest contrast between surface and subsurface temperatures exists at that time (Rosenberg, 1974). Because thermal inertia increases with soil moisture, the range of surface temperatures decreases as soil moisture increases (Fairbridge and Finkl, 1979). Also, daytime surface radiometric temperatures tend to decrease with increases in evapotranspiration. Lastly, all the factors associated with increased soil moisture generally result in cooler radiative land surface temperatures.

Procedures

On 1 July 1981, low-altitude (458 m Above Ground Level), thermal infrared line scanner data and 1:1650-scale color infrared aerial photographs were collected over approximately 56 km of rural water pipeline within the Brookings-Deuel Rural Water System in eastern South Dakota (Figure 1). The study area included a segment of pipeline with a known existing leak in order to provide a benchmark from which to identify other possible leaks. The ground radiometric temperature was approximately 24° C. Widely scattered cumulus clouds did not prohibit significant soil surface heating. There had been only 0.8 cm of precipitation in the nine days prior to the flight and none for three days prior to the flight. Vegetative ground cover was sparse in cultivated fields of corn, soybeans, and sunflowers. Cover was dense in grassy road ditches and small-grain fields. Most small grains were headed but not senescent.

The thermal scanner used a trimetal 8.75- to 11.5-μm detector. The instantaneous field of view of the scanner was 1.6 milliradians, which, at an altitude of 458 m, corresponds to a 0.73-m diameter ground resolution element. The thermal resolution of the system was approximately 0.2° C with the stated accuracy of the blackbodies at ±0.5° C. The blackbody settings were determined in flight by viewing, on an oscilliscope, the range of signal for the terrain to be recorded. This required a preliminary aircraft pass over the area to be imaged. The resulting blackbody adjustments bracketed a temperature range of 12° to 33° C.

The thermal infrared data, recorded on magnetic tape during the flight, were later processed to a black-and-white image. The full 21° C temperature range was level-sliced into six discrete gray levels representing 3.5 °C increments (Figure 2). Six levels was the limitation of the processing system.

Analysis of the full temperature range indicated that the benchmark leak was in the 15.5° to 19.0° C range, and a second known leak, detected along a flight line prior to data analysis, was within the 19.0° to 22.5° C temperature range. This information indicated that other leaks would most likely be detected by analyzing the lower temperature ranges. Therefore, the original raw data were reprocessed by expanding the three lowest temperature ranges to six levels, thus decreasing the temperature range of each level from 3.5° C to 1.75° C (Figure 3). It was expected that this would enhance the probability of detecting temperature differences in the lower ranges. After reprocessing, the known leaks were associated within the four temperature levels corresponding to the 13.75° to 20.75° C temperature range. The reprocessed images were then interpreted for potential leaks. Generally, the known leaks appeared as small circular to slightly linear features, so these patterns were used as a key for interpretation.

The interpreters of the thermal images also had low-altitude, 1:1650-scale, color infrared aerial photographs of the study area. The photographs were used to identify small trees and shrubs which often had apparent temperatures similar to those of possible leak sites.

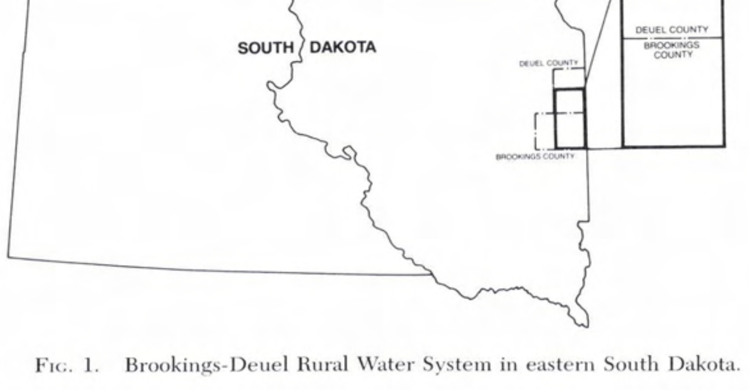

Fig. 1. Brookings-Deuel Rural Water System in eastern South Dakota.

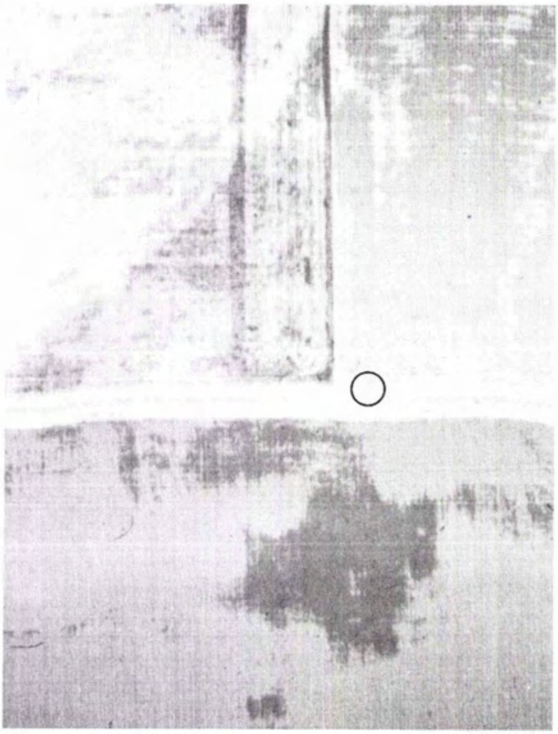

FIG. 2. Full temperature range (12.0° C to 33.0° C) thermal infrared image, with benchmark leak circled, for segment of pipeline in the Brookings Deuel Rural Water System in eastern South Dakota (cool is white).

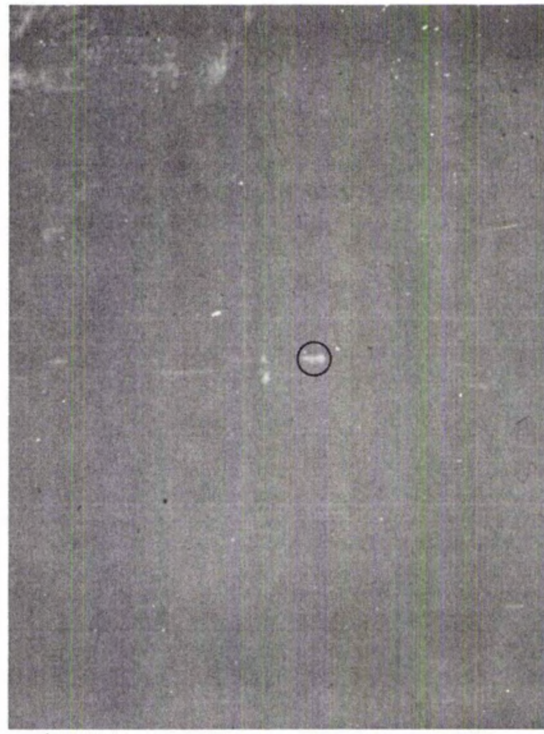

FIG. 3. Thermal infrared image for temperature range 13.25° to 20.75° C, with benchmark leak circled, for segment of pipeline in the Brookings-Deuel Rural Water System in eastern South Dakota (cool is white).

RESULTS

Fifteen possible leaks were identified from the thermal images. Five of these sites were eventually confirmed as leaks. Two were identified as leaks by the system operator prior to field verification of the imagery interpretation, but they were clearly evident on the thermal images and noted as possible leaks. Three more leaks were confirmed during field verification using the metal rod probes and excavation.

Four of the verified leaks were located in coarse sandy soils and the other was in tight clayey soil. Two were located in heavily vegetated road ditches, and the other three were in grazed pastures having very little vegetative cover. No leaks were detected in cultivated areas.

At the time of this writing, no leaks had been detected which were not delineated on the thermography. Hence, no error of omission is known to have taken place. On the other hand, only five of the 15 sites delineated as having potential leaks were verified as having actual leaks. There was, therefore, a commission error of ten. However, this level of commission may be acceptable, because the study technique offered a vast improvement over existing methods by targeting the inspection to 15 sites as opposed to an entire section of pipeline.

Only two of the ten sites which were not verified as containing leaks could be directly explained. One site was a metal electrical power transformer, another, a shadow cast by a billboard. The reasons some sites appeared cool were because of surface drainage patterns and related vegetation variations. One site in particular was in clayey soil in a soybean field, and no surface conditions could explain the cool spot. It is possible a leak could have existed, but it was not detected by a metal rod test. Because the soil was clayey, the water may have moved downward beyond the reach of the metal rod. No excavation was made for verification because of excavation costs and certain destruction of the soybeans.

It is impossible to determine exactly how long the five leaks in the study area had existed; however, based on the time span between data collection and the leak verification, one leak existed for at least four weeks, another for at least nine weeks, and two more for at least ten weeks. The fifth leak was the benchmark leak which was repaired immediately after data collection.

Moderate leakage is 6 m^3 per day. Thus, the four leaks could account for a total loss of up to 1,386 m^3 of water over the period of suspected existence. The cost of water ranges from \$0.28 to \$1.08 per cubic metre (Leonard Heideman, Big Sioux Rural Water

System Manager, personal communication, 1982). The total cost for water loss during the period of known existence was between $388 and $1,497.

These costs were computed from information pertaining to the 56-km long study area. Water loss costs over an entire system of several hundred kilometres could be very high, thus reinforcing the need for a feasible leak identification method.

Conclusion

The results of this study indicate that leaks in buried rural water pipeline can be detected using low-altitude 8.7- to 11.5-μm wavelength, thermal infrared images collected under proper conditions. The empirical determination of the cost effectiveness of this technique was not conducted. The cost effectiveness depends on several variables. These include cost of long-term water loss, the effects of deterioration of the pipeline at the point of the leak and how it effects maintenance costs, costs of conventional ground surveys, size of the area, and the cost and availability of thermal infrared remote sensing services.

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40th Photogrammetric Week

Stuttgart, Federal Republic of Germany
30 September-5 October 1985

The 40th Photogrammetric Week is sponsored by the Institute of Photogrammetry of Stuttgart University and the Division for Surveying and Photogrammetry of Carl Zeiss, Oberkochen. This regular event was initiated by Carl Pulfrich as a "vacation course in photogrammetry" in 1909. This is its seventh time in Stuttgart since 1973.

As in previous years, Prof. F. Ackermann, Stuttgart, and Prof. H.-K. Meier, Oberkochen, are responsible for the scientific direction. The lecturers, from Germany and abroad, will put special emphasis on

- Digital image processing in analytical plotters
- Digital mapping and topographical data bases
- Aerial photography

As most presentations will be in German, experienced technical interpreters will simultaneously translate into English. The contents of the lecturers will be presented unabridged. Sufficient time has been allocated for discussions. The program will be supplemented with demonstrations and practical exercises on three afternoons.

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