United States Department of Agriculture

Soil Conservation Service

Northeast NTC
160 E. 7th Street
Chester, PA 19013

Subject: SOI - Application of Ground-Penetrating Radar (GPR) to the Long-Term Wind Erosion Study; Big Spring, Texas; March 24-28, 1986.

Date: April 22, 1986

To:
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PURPOSE

Use GPR techniques to locate and determine the depth to pipelines and to use this data to make inferences on the amount and rates of wind erosion occurring on rangeland and cultivated areas.

PARTICIPANTS

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Equipment

The equipment used during this field trip was the SIR System-8, the ADTEK SR-8004H graphic recorder, and the ADTEK DT-6000 tape recorder. A microprocessor was available and used unsuccessfully to enhance the signal of a buried metallic pipe at a depth of about 4 feet in an area of fine textured Olton and Rowena soils. The use of the ADTEK DT-6000 tape recorder was discontinued after observing skips or breaks in the recorded data. These breaks resulted from small periodic drops in the voltage supplied to the system. The recorder has been subsequently returned to the manufacturer where a modification has been implemented to overcome this problem.

The 80, 120, 300, and 500 MHz antennas were field tested under different soil conditions. In all investigations, the antenna used is a compromise among several factors.

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Vertical and horizontal resolution, the ability to discriminate two or more closely spaced objects, varies directly with frequency. Higher frequency antennas have narrower bandwidths and therefore provide better resolution of subsurface features.

The probing depth of the GPR is limited by the rates of signal attenuation within the soil. The attenuation of electromagnetic energy in soils increases with increasing frequency and soil water, clay, and salt contents. Lower frequency antennas have higher average and peak powers of radiation and provide greater penetration through soils.

The investigated soils are relatively conductive and rapidly attenuate the radar signals. High rates of signal attenuation severely restrict the probing depths of the 500 and 300 MHz antennas. In fine-loamy soils, probing depths were restricted to the surface layer for the 500 MHz antenna and to the upper part of the argillic horizon for the 300 MHz antenna.

Although the 80 MHz antenna provided greater penetration, its broader bandwidth reduced the resolution of buried pipes and provided crude estimates of the depth to buried pipelines. In this study, its application was restricted.

The 120 MHz antenna provided the best balance of resolution and probing depth. In fine-loamy soils, the 120 MHz antenna descerned a 24 inch metallic pipe at 55 inches (the maximum observed depth at which the pipeline occurred within the study area). Both the 705DA and the 705DA2 transceivers were used interchangeably with the 120 MHz antenna. However, the 705DA transceiver was preferred as it provided the best resolution of the pipe at shallower depths.

DISCUSSION

Gas utility and transmission companies have used GPR techniques to determine the location and depth of pipelines. Recent research has indicated that GPR techniques can be used in some environments to locate leaks in gas pipelines. When crossed at right angles, pipelines are considered point objects and produce hyperbolic patterns. The apex of the hyperbola can be used to accurately locate the top-center of a pipe. Often, pipe routes have been located by laying lines on the ground surface through the interpreted location of the buried pipe which has been crossed at right angles by the GPR.

This study represents the first comprehensive attempt to measure soil erosion with the ground-penetrating radar. This discussion will not evaluate the quantitative results but will cover some of the recognized limitations and advantages of applied GPR techniques.

Representatives of the various pipeline companies were contacted and two pipelines with "good depth control" were selected for this study. The pipelines selected were the El Paso National Gas pipeline (a 16 inch line) and the Mesa Crude pipeline (a 24 inch line). Representatives assured the study group that the El Paso Natural Gas pipeline had been buried in 1950 beneath 48 and 30 inches of fill for farmland and rangeland, respectively. The Mesa Crude pipeline had been buried in 1951 beneath 24 inches of fill. Landowners were contacted along each pipeline in Howard County and access was granted to a large number of fields.

Initial plans were to drive the radar unit and antenna along the center line of the pipeline. However, the centerline of the pipeline had not been located prior to the arrival of the radar unit. The approximate location of the pipeline was located and flagged at 50 or 100 foot intervals in each surveyed field with a Model GA-52 magnetic locator. As these locations were only close approximations and it was inconceivable that the antenna would remain exactly over the centerline of the pipeline for accurate depth measurements, parallel traverses along the pipeline were rejected in favor of perpendicular traverses across the pipeline at fixed intervals.

The potential of using GPR techniques to locate and determine the depth to pipelines was explored over a comprehensive range of soils and site conditions in Howard County, Texas. GPR surveys were conducted in areas of Acuff (fine-loamy, mixed, thermic Aridic Paleustolls), Amarillo (fine-loamy, mixed, thermic Aridic Paleustalfs), Brownfield (loamy, mixed, thermic Arenic Aridic Paleustalfs), Drake (fine-loamy, mixed (calcareous), thermic Typic Ustorthents), Gomez (coarse-loamy, mixed, thermic Aridic Ustochrepts), Mansker (fine-loamy, carbonatic, thermic Calciorthidic Paleustolls), Olton (fine, mixed, thermic Aridic Paleustolls), Potter (loamy, carbonatic, thermic, shallow Ustollic Calciorthids), Rowena (fine, mixed, thermic Vertic Calciustolls), Tivoli (mixed, thermic Typic Ustipsamments), and Zavala (coarse-loamy, mixed, nonacid, hyperthermic Typic Ustifluvents) soils.

With the exception of the fine-textured soils, the GPR consistently located the pipeline and provided useable subsurface soil information. It was learned from an earlier study (August 1982) that the soils of Texas are generally not the most conducive to GPR operations. Calcareous, moderately-fine and fine textured soils having appreciable amounts of smectitic clays are highly conductive and dispersive to electromagnetic energy and restrict the probing depth of the GPR. However, the GPR is capable of providing appreciable data for the upper meter of nonsaline soils having less than 35 percent clay. Subsurface information obtained with the GPR included the presence of, depth to, and lateral variations of argillic, calcic, and petrocalcic horizons. Petrocalcic horizons can be distinguished from calcic horizons on the basis of differences in their reflected signatures as impressed on the graphic profiles. Rapid, quantitative assessments of the distribution and the proportion of soils underlain by calcic and petrocalcic horizons can be made with the GPR to improve the quality of map unit design.

Pipelines were accurately located with the GPR in all but the fine-textured soils. A 16 inch pipe, buried between depths of 36 to 48 inches, represents a large, highly contrasting object which will reflect a significant portion of the available transmitted energy. However, electromagnetic energy is severely dissipated in fine-textured soils and the amount of energy reaching, let alone reflected from the pipeline is often less than the sensitivity of the radar's receivers. Even after amplification, reflected signals are often too faint or diffuse to be clearly identified on graphic profiles from areas of Olton and Rowena soils. For erosion assessment purposes the restriction imposed on GPR operations by fine-textured soils can be acknowledged and accepted.

As seen in Figure 1, the hyperbolic pattern of a pipe which has been traversed at right angles by the radar is usually readily apparent and identifiable. Variations in the shape of the hyperbola are caused by variations in: 1) the angle at which the pipe is crossed, 2) the speed of antenna advance across the pipe, and 3) the velocity of pulse propagation. As the speed of the electromagnetic pulse is decreased, the angle between the two tails of the hyperbola will decrease and the delay time will lengthen.

Closely spaced pipelines or a pipeline and a large coarse fragment produce superimposed images which are more difficult to resolve. Polarity highlightening (printing one signal component as a solid band, the other hatchured) helps to "sort-out" signals which have been superimposed and to identify the metallic pipe.

While the location of a pipeline was accurately detected with the 120 MHz antenna in most moderately-fine or coarse textured soils, the accuracy of the depth measurements scaled from the graphic profiles must be questioned. Generally, for radar investigations within areas of uniform soils and soil conditions, 80 percent of the scaled depths will be within $\pm$ 2 inches of the observed depth. This level of accuracy is acceptable for studies of the composition of soil map units, but may be unacceptable for a more exacting wind erosion study. Variations between the scaled radar data and the ground-truth auger observations are attributed to: 1) the imagery being a composite of signals averaged over a "foot-print" area beneath the antenna, 2) difference between what the human and the machine sense as the depth to a particular interface, 3) a mismatch between the site of auger measurement and the track of the radar, 4) nonvertical auger measurements and 5) the tendencey to questimate or round off auger measurements.

Vertical resolutions of images to within 0.5 inch of their actual depths can only be consistently achieved through radar systems operating at a frequency range of about 1 GHz or higher. Unfortunately, radar systems operating at these frequencies are restricted to the surface layers of most earthen materials as a result of their higher rates of signal attenuation.

Soils are layered mediums, often with each layer having differring physical, chemical, and electromagnetic properties. Variations in these properties influence the travel time of the radar's electromagnetic pulses and produce horizontal and vertical variations in the depth scale. Variations in soil moisture, particle-size fractions, density, temperature, and horizonation have been related to variations in the travel time of the electromagnetic energy. Slight variations in these properties within even the most homogeneous and uniform of soil map units can cause slight discrepancies in the accuracy of the depth measurements.

Prior to field work, assurances were given by company representatives of the "good depth control" along two pipelines. After reviewing the graphic profiles of successive cross sections of the pipeline, it is felt that the pipes were buried at controlled but not invariable depths. Is a variation of $\pm$ 6 inches per hundred feet (which seems highly probable) considered "good depth control"? Would this degree of control be acceptable for this study?

Recognizing the limitations imposed by the medium, the artifact, and the system; the significance of this study may well rest with the generalities which can be made after considering that the errors will cancel each other out.

RESULTS

A total of 140 acceptable observations were made of the pipelines. These observations have been summarized in Table 1. While not corrected for original burial depths, variations in the depth to the pipeline are evident within and between soil types in similar and contrasting management units. If all of the pipes had been buried at a constant depth or assured to be equally variable in depth, this data would support the premise that erosion has been significantly greater on cropland than on rangeland.

Much has been learned from this, the first comprehensive attempt to use radar to measure soil erosion. Our methodology and interpretative skills have been refined as the limitations of the GPR have been better defined. The results appear to be promising.

All copies of the graphic profiles have been returned to Dr. Ted Zobeck. If I can be of any further assistance to members of your staff or to Dr. Zobeck in preparing his report, please do not hesitate to call or write.

With kind regards,

J. A. Doolittle
Soil Scientist (GPR)

cc:
A. Holland
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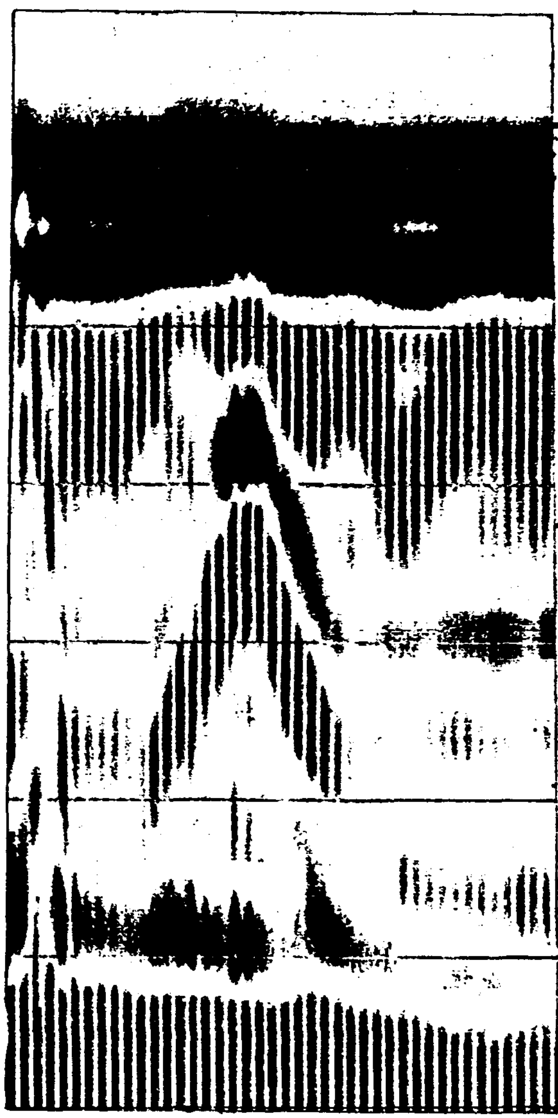
JADoolittle/ef



GPR PROFILE OF A BURIED PIPE

TABLE 1
Comparison of Pipeline Depths Under Cropland/Rangeland Conditions

Cropland				Rangeland			
Soil	# of Observations	Mean (cm)	Standard Deviation (cm)	Soil	# of Observations	Mean (cm)	Standard Deviation (cm)
Amarillo	24	93.2	8.96	Amarillo	16	110.6	20.8
Amarillo	21	75.0	9.9				
Drake	10	95.2	9.87	Drake	9	96.9	12.5
Gomez	20	80.0	13.9	Gomez	9	107.2	11.35
Gomez	11	83.6	8.2				
Zavala	4	98.2	11.06	Brownfield	16	82.2	12.0
	90	84.4	15.67		34*	106.08	17.2

* Brownfield represents a sandy range site and was not included in this tabulation.

Table 2
Depth to pipeline

#	Depth (cm)	Soil-Management	#	Depth (cm)	Soil-Management
1	86.0	Gomez - Cropland	43	79.5	
2	82.5		44	66.7	
3	71.0		45	65.3	
4	75.00		46	67.4	
5	78.6		47	76.7	
6	98.2		48	66.7	
7	92.3		49	79.5	
8	78.6		50	73.8	
9	78.6		51	63.9	
10	87.4		52	68.2	
11	91.7		53	75.3	
12	88.0	Zavala - Cropland	54	80.9	
13	90.0		55	89.5	
14	103.4		56	102.2	
15	111.2		57	108.5	Amarillo - Cultivated
16	106.1	Gomez - Cropland	58	81.9	
17	96.0		59	110.4	
18	91.0		60	118.1	
19	83.2		61	113.2	
20	66.2		62	101.2	
21	64.3		63	108.4	
22	68.0		64	103.6	
23	64.3		65	120.2	
24	71.8		66	105.6	Drake - Cultivated
25	70.9		67	84.5	
26	60.5		68	81.2	
27	65.2		69	99.1	
28	94.5		70	107.2	
29	100.2	Gomez - Cropland	71	86.1	
30	90.7		72	107.3	
31	96.4		73	99.1	
32	79.5		74	94.2	
33	78.1		75	87.8	
34	75.2		76	104.0	Drake - Pasture
35	78.1		77	91.0	
36	83.5	Amarillo - Cropland	78	105.5	
37	75.3		79	86.7	
38	78.1		80	85.1	
39	69.6		81	93.0	
40	71.0		82	111.8	
41	71.0		83	115.0	
42	70.3		84	80.3	

#	Depth (cm)	Soil-Management	#	Depth (cm)	Soil-Management
85	104.2	Amarillo - Cultivated	131	118.8	
86	100.0		132	139.4	
87	85.9		133	137.1	
88	102.8		134	-----	
89	104.2		135	116.6	
90	100.0		136	123.4	
91	70.4		137	112.0	
92	98.6		138	121.1	
93	92.9		139	114.3	
94	94.4		140	82.2	
95	93.9		141	80.0	Amarillo - range
96	85.9		142	80.0	
97	98.6				
98	73.3				
99	91.5				
100	98.6				
101	92.9				
102	78.9				
103	94.4				
104	94.4				
105	93.7				
106	100.0				
107	98.6				
108	88.7				
109	77.6	Brownfield - range			
110	----				
111	92.8				
112	96.3				
113	110.4	Brownfield - range			
114	82.3				
115	62.3				
116	61.1				
117	75.2				
118	77.6				
119	79.9				
120	89.3				
121	79.9				
122	77.6				
123	80.0				
124	88.0				
125	84.5				
126	132.6	Amarillo - range			
127	102.8				
128	75.4				
129	112.0				
130	121.1				