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Subject: SOI – Electromagnetic Induction (EMI) Comparative Field Studies **Date:** 10 January 2002

To: Jane E. Hardisty
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Purpose:
The purpose of this investigation was to conduct comparative field studies using different electromagnetic induction instruments to delineate the locations of septic tanks, distribution boxes, and absorption field drains in soils with high clay and water contents. In addition, preliminary investigations were conduct to evaluate the potential of using EMI to locate buried field drains.

Participants:
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Activities:
Field activities were completed during the period of 3 to 5 December 2001.

Findings and Recommendations:

1. At each of the failed septic system site, results were similar for the Dualem-2 meter, EM38DD meter, and GEM300 sensor. Each instrument detected the septic tank and absorption field. Areas of higher apparent conductivity clearly defined these features. Each instrument detected areas of discharge emanating from the absorption fields. However, no instrument provides unambiguous images of the absorption fields' drain lines and trenches.

2. Each instrument failed to detect buried field drains within a cultivated area of Blount and Del Rey soils. However, the presence of buried field drains within the surveyed portion of the cultivated field was unconfirmed. Consequently, the use of EMI to detect buried field drains was not properly or adequately assessed. Additional studies are recommended on sites that have greater information on the presence and location of field drains. Studies should also be conducted in areas of different textured soil materials.

3. At the time of this investigation, soils were saturated and the water table was very close to the soil surface. Soil moisture can decrease electromagnetic gradients that exist between small drainage pipes or trenches and the surrounding soil matrix. This impairs the detection of these features with EMI. To fully assess the capacity of

EMI to detect buried absorption lines and field drains, this study should be continued during a drier time of the year when the electromagnetic difference between these features is greater.

4. The use of dual dipole meters (Dualem-2 and EM38DD) substantially reduced survey time and operator fatigue. All EMI instruments used in this study can be operated in the continuous mode to provide more comprehensive coverage of sites. Slight differences in spatial patterns were observed when between data collected in north-south and east-west walking directions over the same survey area. However, results from this study do not confirm the need to conduct surveys in two orthogonal directions across sites.

5. Training was provided to all participants on the operation of the Dualem-2 and EM38DD meters, and the GEM300 sensor. Participants completed comparative field tests that evaluated the suitability and reliability of these devices.

With kind regards,

James A. Doolittle
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cc:
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Background:

A recently completed survey by the Indiana Department of Health found an alarming increase in the number of reported septic system failures throughout the state (Purdue News Service, 1998). Many of these reported failures stem from older systems that send wastewater directly into tile lines or ditches. In one town near Fort Wayne, it was reported that nearly every septic tank tested passed raw sewage directly into ditches that eventually fed into the St. Joseph River (Kilbane, 2000). Soils with moderately slow to slow permeability or shallow to moderately deep depths to a seasonal high water table pose moderate to severe limitations for septic absorption fields. Because of the ubiquity of soils with high clay contents and water tables in many areas of Wells and Allen counties, Indiana, it is difficult to find sites that are suitable for standard septic tank absorption fields. Absorption fields that are improperly sited in these areas contribute contaminants to ground and surface waters. In Allen and Wells counties, towns are expanding sanitary sewage-treatment systems that will eventually eliminate the need for individual septic systems.

The locations and designs of older systems need to be determined in order to assess their performance and reduce system modification expenses. Finding an absorption field is not always an easy task. Records are often unavailable or lost, and some absorption fields provide little or no visible signs of their presence. The primary purpose of this investigation was to evaluate the use of EMI for locating septic tanks, distribution boxes, and absorption fields.

Electromagnetic Induction

Electromagnetic induction is a noninvasive geophysical tool that can be used for detailed site investigations. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This geophysical method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the type and concentration of ions in solution, volumetric water content, temperature and phase of the soil water, and amount and type of clays in the soil matrix (McNeill, 1980). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic induction measures vertical and lateral variations in apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves. However, relative values and lateral and vertical variations in apparent conductivity can be used to infer changes in soils and soil properties. Interpretations are based on the identification of spatial patterns within data sets. To assist interpretations, computer simulations of EMI data are normally used. To verify interpretations, ground-truth measurements are required.

Electromagnetic induction has been used to infer the relative concentration, extent, and movement of animal waste products in soils. Because of its sensitivity to soluble salts, EMI has been an effective tool for the assessment of surface and ground water contamination from animal wastes (Bowling et al., 1997; Brune and Doolittle, 1990; Drommerhausen, 1995; Eigenberg and Nienaber, 1998; Eigenberg et al., 1998; Radcliffe et al., 1994; Ranjan and Karthigesu, 1995; Siegrist and Hargett, 1989; Stierman and Ruedisili, 1988). In these studies, soils affected by wastes were found to have higher nutrient contents and apparent conductivity than adjoining, unaffected soils.

Electromagnetic induction does not provide a direct measurement of specific ions or compounds. However, measurements of apparent conductivity have been correlated with specific ions that are mobile in soils and associated with animal wastes. In soils that are affected by effluent from animal wastes, apparent conductivity has been correlated with concentrations of potassium, sodium, chloride, sulfate, ammonia, and nitrate-nitrogen (Brune and Doolittle, 1990; Eigenberg and Nienaber, 1998; Eigenberg et al., 1998; Ranjan and Karthigesu, 1995; Stevens et al., 1995).

While information exist on the use of EMI to assess surface and ground water contamination from animal wastes, few references exist on the use of EMI to detect buried septic tanks, absorption fields, or field drains. Geophysical Survey Systems Inc. (1998) mentions the use of EMI to locate buried utilities, detect leakage from buried pipes, and delineate septic systems. Allred and others (2000) are exploring the use of ground-penetrating radar, electromagnetic induction, and geomagnetic methods to locate buried agricultural tile lines in Ohio.

The effluent that is discharged from septic tanks into absorption fields carries organic matter and dissolved chemicals. Effluents from kitchens, laundry, and bath/showers contain high levels of nutrients (nitrogen, phosphorous, and potassium). These dissolved chemicals increase the apparent conductivity of gravel filled trenches and enclosing soil materials that make up absorption fields. Electromagnetic induction has been used to locate backfilled disposal trenches, buried landfills, storm sewers, and buried metallic and non-metallic containers and pipes, (Jordan and Costantini, 1995; Huang and Won, 2000; Lanz et al., 1998; Roberts et al., 1989; Won et al., 1996). However, these features (sewer line, stainless steel pipe, buried metallic containers, and filled trenches) were relatively large and/or electrically contrasting with surrounding undisturbed soil materials. Absorption field trenches and pipes are narrow and small. Individual absorption trenches and pipes are narrow and therefore more difficult to detect with EMI. Commonly, absorption trenches are 2 to 3 feet wide and deep. Near the base of the trench, gravel beds surround perforated pipes. These pipes are about 4 inches in diameter. Trenches are backfilled with the previously unearth soil materials. The backfilled soil materials are identical to the surrounding non-disturbed soil materials thus reducing the capacity of EMI to detect the trenches.

For buried pipes to be detectable with EMI, a substantial and measurable difference must exist between the soil and the buried pipe or between the pipe and the confined air or liquid. The electromagnetic response produced by a buried pipe will depend on its depth, diameter, orientation, and material properties. In addition, response will depend on whether the pipe is full, partially full, or empty. Furthermore, the electromagnetic contrast between a buried pipe and the surrounding soil matrix will depend on the clay and moisture contents of the soil. The electromagnetic response is moisture dependent and is therefore temporally variable.

Equipment:

The instruments used in this study included the Dualem-2 meter, EM38DD meter, and GEM300 sensor. No ground contact is required with these devices. Lateral resolution is approximately equal to the intercoil spacing. The Dualem-2 meter, EM38DD meter, and GEM300 sensor have 2, 1, and 1.3 m intercoil spacings, respectively. All of these devices are portable and require only one person to operate.

Dualem Inc. manufactures the Dualem-2 meter.[1] Taylor (2000) has described the principles of operation for this meter. The Dualem-2 meter consists of one transmitter and two receiver coils. One receiver coil and the transmitter coil provide a perpendicular (P) geometry. The other receiver coil provides a horizontal co-planar (HC) geometry with the transmitter coil. This dual system permits two depths to be measured simultaneously without rotating the coils. The depth of penetration is “geometry limited” and is dependent upon the intercoil spacing, coil geometry, and frequency. The Dualem-2 operates at a frequency of about 9800 Hz. It provides penetration depths of 1.3 and 3.0 m in the P and HC geometries, respectively. The meter is keypad operated and measurements can either be automatically or manually triggered.

Geonics Limited manufactures EM38DD meter.[1] Geonics Limited (2000) has described the principles of operation for this meter. The depth of penetration is “geometry limited” and is dependent upon the intercoil spacing, coil geometry, and frequency. The EM38DD operates at a frequency of 14,600 Hz. It has effective penetration depths

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[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000). The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One unit acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one unit acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). A Polycorder Series 600 Digital Data Recorder is used to record and store data. [1]

The GEM300 multifrequency sensor is manufactured by Geophysical Survey Systems, Inc. [1] Won and others (1996) have described the use and operation of this sensor. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 20,000 Hz with a fixed coil separation (1.3-m). With the GEM300 sensor, the penetration depth is considered “skin depth limited” rather than “geometry limited.” The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. Theoretical penetration depths of the GEM300 sensor are dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequencies. Multifrequency sounding with the GEM300 supposedly allows multiple depths to be profiled with one pass of the sensor.

Study Sites:

Three study sites were selected in Allen and Wells counties, Indiana. The two sites selected in Allen County were residential and contained failed septic systems. One site was located at 11030 Schwartz Road (SE1/4, Section 34, T. 32 N., R. 13 E). This site is located in areas that had been mapped as Pewamo silty clay loam and Blount silt loam, 0 to 2 percent slopes (Kirschner and Zachary, 1969). The very deep, very poorly drained Pewamo soil formed in tills on moraines and lake plains. Pewamo is a member of the fine, mixed, active, mesic Typic Argiaquolls family. The very deep, somewhat poorly drained Blount soil is moderately deep or deep to dense till. Blount is a member of the fine, illitic, mesic Aeric Epiaqualfs family.

The other site in Allen County was located at 6716 Hursh Road (SE1/4, Section 19, T. 32 N., R. 13 E). This site is located in an area that had been mapped as Morley silt loam, 2 to 6 percent slopes, moderately eroded (Kirschner and Zachary, 1969). The very deep, moderately well drained Morley soil formed in tills and is moderately deep to dense till. Morley is a member of the fine, illitic, mesic Oxyaquic Hapludalfs family.

The site selected in Wells County was believed to contain buried agricultural tile lines. This site was located in NE1/4 of Section 8, T. 27 N. and R. 12 E. The site was in a cultivated field that had been mapped as Blount-Del Rey silt loam, 0 to 1 percent slopes (Neely, 1992). The very deep, somewhat poorly drained Del Rey soil formed in lacustrine materials on lake plains. Del Rey series is a member of the fine, illitic, mesic Aeric Epiaqualfs family.

Field Procedures:

Survey procedures were simplified to expedite fieldwork. At each site, two parallel sets of orthogonal lines were laid out. These four lines defined the perimeter of a rectangular grid area. Dimensions of the grids were either 60 by 40 m (0.24 ha) or 24 by 33 m (0.08 ha). Along each of the four lines, survey flags were inserted in the ground at intervals of either 1.5 or 2 m. These flags served as grid line end points and provided ground control. Walking at a fairly uniform pace between similarly numbered flags on opposing sets of parallel lines in a back and forth pattern across each grid area completed a survey. Each EMI device was operated in the continuous mode with measurements recorded at 1-sec intervals. For each traverse line, the location of each measurement was adjusted to provide a uniform interval between observation points.

For each instrument, surveys were completed along both north-south and east-west trending grid lines. The Dualem-2 meter was not available for the survey at the Schwartz Road site in Allen County. Two surveys were conducted with the EM38DD and the Dualem-2 meters at each site in which these instruments were used. One survey was conducted in north-south directions between similarly numbered flags on the two opposing east-west trending base lines. The other survey was conducted in east-west directions between similarly numbered flags on the two opposing north-south trending base lines. Surveys were conducted in the continuous mode with both the EM38DD and the Dualem-2 meters held about 1 to 2 inches above the ground surface with their long axis parallel to the direction of traverse.

When operated in the continuous mode, the GEM300 sensor cannot be rotated to simultaneously record measurements in both dipole orientations. As a consequence, four separate surveys were required with the GEM300 sensor at each site. Two surveys (one in the horizontal and one in the vertical dipole orientation) were conducted in north-south directions between similarly numbered flags on the two opposing east-west trending base lines. The other two surveys (one in the horizontal and one in the vertical dipole orientation) were conducted in east-west directions between similarly numbered flags on the two opposing north-south trending base lines. Surveys were completed with the GEM300 sensor held at hip height with its long axis parallel to the direction of traverse.

The required time to complete a survey with each instrument is dependent upon the walking speed of the operator and the ease of keying grid information into the instruments or data recorders at the end or beginning of each grid line. Compare with systems that can only be operated in the one-dipole orientation when recording measurements in the continuous mode (GEM300 sensor), the use of dual dipole meters (Dualem-2 and EM38DD) reduced survey time and operator fatigue. Although it was easier to key grid information into the GEM300 sensor, the two additional surveys required with this device increased the total survey time by a factor of about 1.3 to 1.4 at the site on Hursh Road in Allen County (see Table 1).

Table 1
Survey Times and Number of Observations recorded with each EMI Device at the Hursh Site in Allen County, Indiana.

Instrument	Direction	Dipole Orientation	Observations	Survey Time
DUALEM-2	NS	Dual	1225	26.1 min
DUALEM-2	EW	Dual	1105	36.5 min
EM38DD	NS	Dual	1127	27.4 min
EM38DD	EW	Dual	1150	38.3 min
GEM300	NS	Vertical	1083	22.7 min
GEM300	EW	Vertical	1083	22.2 min
GEM300	NS	Horizontal	1165	21.6 min
GEM300	EW	Horizontal	1018	21.4 min

Spatial Discrepancies

Because of the distance between the transmitting and receiving coils and the time delay in data logging, slight spatial discrepancies will exist in EMI data. These offsets and delays, as well as the gridding methods and contour intervals used in computer simulations, are responsible for the “herringbone” patterns that occur in the accompanying plots. In addition, susceptibility to subtle levels of signal interference is known to vary with changes in the orientation of the meter’s axis on succeeding survey lines. Frohlich and Lancaster (1986) observed differences in spatial patterns of apparent conductivity when comparing data collected in north-south with data collected in east-west walking directions over the same survey area.

Drift or instrument error can also occurs and may be responsible for some of the elongated patterns of apparent conductivity seen in some of the accompanying plots. Drift is caused by the effect of heating and cooling on the length or straightness of the instrument and on the conductivity of electrical components in the instrument (Rick Taylor, personal communication). Drift is often more noticeable on simulated plots that use narrow contour intervals.

Results:

***Site 1*- Schwartz Road, Allen County, Indiana.**

The site was located in the backyard of a residential home. A 33- by 24-m grid was established across the site. The grid interval was 1.5 m. The grid area was bordered on the south by a fairly large, above ground swimming pool with a deck. The grid area contained a metallic tetherball pole and several small trees. At the time of the survey the soil was saturated and seepage was observed on the soil surface in the northwest portion of the grid area.

Basic statistics for the EMI surveys that were completed with the EM38DD meter and the GEM300 sensor are shown in Table 2. Data collected in the two surveys completed with the EM38DD meter in the horizontal (H) and vertical (V) dipole orientations were similar. In general, apparent conductivity increased and became slightly more variable with increased soil depth. Negative values are believed to represent strong interference from cultural features that occurred within or near the survey area. Cultural features that occur within the meter's sphere of influence are averaged into measurements.

Table 2

Basic Statistics for the EMI Surveys of the Schwartz Road Site in Allen County, Indiana.

(All measurements are in mS/m)

Surveys conducted in East-West Directions

	EM38DD	**EM38DD**	**GEM300**	**GEM300**	**GEM300**	**GEM300**	**GEM300**	**GEM300**
	VDO	**HDO**	**6030Hz-VDO**	**9810Hz-VDO**	**14790Hz-VDO**	**6030Hz-HDO**	**9810Hz-HDO**	**14790Hz-HDO**
Number	655	655	656	656	656	630	630	630.0
Average	43.5	24.6	60.9	57.1	56.2	33.8	30.9	31.3
SD	8.3	7.2	44.9	27.0	17.1	18.8	11.5	8.0
Minimum	-17.8	-27.3	-15.5	20.9	27.1	-65.3	-48.6	-33.2
Maximum	67.8	39.1	892.2	517.1	366.5	267.5	164.6	109.5
First	37.5	19.9	52.3	50.2	50.4	27.7	26.0	27.2
Median	44.4	26.0	56.8	55.0	55.0	31.4	30.0	31.1
Third	48.9	29.3	60.9	59.0	59.2	34.5	32.9	34.1

Surveys conducted in North-South Directions

	EM38DD	**EM38DD**	**GEM300**	**GEM300**	**GEM300**	**GEM300**	**GEM300**	**GEM300**
	VDO	**HDO**	**6030Hz-VDO**	**9810Hz-VDO**	**14790Hz-VDO**	**6030Hz-HDO**	**9810Hz-HDO**	**14790Hz-HDO**
Number	599	599	665	665	665	657	657	657
Average	43.4	25.0	59.1	55.9	55.9	34.8	31.1	30.7
SD	8.0	5.3	27.8	15.4	10.3	23.6	16.9	9.8
Minimum	-6.2	6.7	12.2	28.6	35.3	19.8	-4.7	-7.9
Maximum	71.7	40.0	547.9	275.7	190.4	374.4	306.6	163.9
First	38.0	21.0	51.2	49.7	50.3	28.1	26.0	26.6
Median	43.0	25.4	56.4	54.6	55.4	31.2	29.4	30.0
Third	49.2	29.1	60.8	59.7	60.3	34.0	31.8	32.5

Apparent conductivity averaged 24.6 mS/m with a range of –27.3 to 39.1 mS/m for measurements collected with the EM38DD meter in the horizontal dipole orientation along east-west trending grid lines. Half of these observations had values of apparent conductivity between 19.9 and 29.3 mS/m. For measurements collected along north-south trending grid lines in the horizontal dipole orientation, apparent conductivity averaged 25.0 mS/m with a range of 6.7 to 40.0 mS/m. Half of these observations had values of apparent conductivity between 21.0 and 29.1 mS/m.

Apparent conductivity averaged 43.5 mS/m with a range of –17.8 to 67.8 mS/m for measurements collected with the EM38DD meter in the vertical dipole orientation along east-west trending grid lines. Half of these observations had values of apparent conductivity between 37.5 and 48.9 mS/m. For measurements collected along north-south trending grid lines in the vertical dipole orientation, apparent conductivity averaged 43.4 mS/m with a range of –6.2 to 71.7 mS/m. Half of these observations had values of apparent conductivity between 38.0 and 49.2 mS/m.

Figure 1 contains plots of apparent conductivity measured with the EM38DD meter at the Schwartz Road site in Allen County. The upper two plots in Figure 1 show the spatial distribution of apparent conductivity collected with the EM38DD meter for survey that was conducted along north-south trending grid lines. The lower two plots show the spatial distribution of apparent conductivity measured with the EM38DD meter for survey that was conducted along east-west trending grid lines. For each survey, the spatial distributions of apparent conductivity collected in the horizontal and vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. In each plot, the isoline interval is 2 mS/m. The approximate locations of the septic tank and the distribution box are shown in the lower right-hand plot.

Regardless of the directions in which the data were collected, spatial patterns are similar. Because of the depth to the septic system, spatial patterns are perhaps more informative in the plots prepared from data collected with the EM38DD meter in the deeper-sensing, vertical dipole orientation. In Figure 1, the septic tank produces anomalous apparent conductivity values that are conspicuous and more readily identified in plots of the vertical dipole data. High levels of signal interference affect some of the data collected along east-west lines. The interference is caused by a closely adjoining swimming pool and deck (see lower boundary, between reference points 9 and 18 m). Above- and belowground metallic objects can interfere with electromagnetic fields. Metallic objects are good conductors and can produce anomalously high or low (negative) EMI responses. The distribution box did not produce a conspicuous and distinguishing response and its location is not definable from EMI data alone. Though unconfirmed, the area of higher apparent conductivity in the central portion of the survey area is believed to represent the absorption field. The presumed location of the absorption field is within a rather broad band of higher apparent conductivity that crosses the grid area in a northwest to southeast direction. This band could represent dissimilar soil materials (higher clay, moisture, and or soluble salt contents) or contaminants from the absorption field. If the latter, based on apparent conductivity, the flow and concentration of wastes appears to be greater to the east of the absorption field.

With the GEM300 sensor, apparent conductivity increased with increasing penetration depths (lower frequency). In addition, with each frequency, measurements obtained with the GEM300 sensor in the vertical dipole orientation were higher and generally more variable than those obtained in the horizontal dipole orientation. This trend suggests the presence of more conductive materials in the underlying subsoil and substratum than at the surface. Measurements obtained in the horizontal dipole orientation are more sensitive to changes in apparent conductivity that occur at or near the soil surface. Measurements obtained in the vertical dipole orientation are more sensitive to changes in apparent conductivity that occurred at greater soil depths. The more conductive materials may be layers of calcium carbonate enrichment, finer-textured materials, and/or contaminants from the absorption field.

Figures 2 and 3 show the results of the EMI survey conducted with the GEM300 sensor along north-south and east-west trending grid lines, respectively. In each figure, data collected at 14790 Hz, 9810 Hz, and 6030 Hz are shown in the upper, middle, and lower sets of plots, respectively. For each frequency, data collected in the horizontal and vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. In each plot, the color interval is 2 mS/m. The approximate locations of the septic tank, distribution box, and tetherball pole are shown in the lower right-hand plot.

Spatial patterns shown in these plots are closely similar to the spatial patterns of apparent conductivity that were simulated from data collected with the EM38DD meter (see Figure 1). Like the data acquired with the EM38DD meter, data collected with the GEM300 sensor is also affected by signal interference caused by a closely adjoining swimming pool and deck. However, because the GEM300 sensor was operated at hip height rather than near the soil surface, a larger zone of interference appears in both the north-south and east-west data sets.

In figures 2 and 3, a zone of relatively high apparent conductivity in the central portion of the survey area is believed to represent the approximate location of the absorption field. The absorption field is poorly defined and is situated within a broad band of comparatively high apparent conductivity that extends across the survey area. The poor definition of the absorption field in these plots may represent excessive discharge of contaminants into adjoining soils from a failed septic system. Areas of higher conductivity extend outwards from the absorption field to the east and west. Compared with the EM38DD meter, amplitudes are higher and contrasts between areas of higher and lower conductivities are greater with the GEM300 sensor. As a consequence, the band of higher apparent conductivity that crosses the survey area from near the northwest to southeast corners is more apparent.

In each plot appearing in figures 2 and 3, patterns of apparent conductivity are elongated in the direction of traverse. These patterns are a form of noise and may represent errors introduced by equipment drift, the alignment of the transmitter and receiver coils, and/or the offsets or delays in signal recording. These patterns also occur, but are less noticeable, in the plots of data collected with the EM38DD meter

Spatial patterns of apparent conductivity collected in the same dipole orientation are remarkably similar for data collected at different frequencies (see figures 2 and 3). For each of the four surveys conducted with the GEM300 sensor, strong (r = 0.844 to 1.000) and significant (0.001 level) correlations existed between data collected at different frequencies (6030, 9810, 14790 Hz) but in similar dipole orientations. It is therefore doubtful that the use of multiple frequencies provides multiple depths of observation or any additional information about this site. Won and others (1996) specifically designed the GEM300 sensor to detection of buried objects. They noted that each frequency and dipole orientation will provide a slightly different picture of a buried object. Buried objects may be more easily detected at a particular frequency. Each frequency and dipole orientation will provide slightly different visual presentations of the site. However, more information appears to be provided in data that are collected with one frequency and two dipole orientations than in data that are collected at multiple frequencies and only one dipole orientation. In addition, the use of multiple frequencies requires additional time and expenses to process and display the data.

The EM38DD and the GEM300 sensor produced similar results at the Schwartz Road site. Both instruments detected the septic tank and the absorption field. However, neither instrument defined the presence and location of the absorption field’s drain lines and trenches. An extended band of relatively high apparent conductivity extended across the site from northwest to southeast. This band included the probable location absorption field. The higher apparent conductivity within this band is assumed to be associated with waste products from the absorption field. However, soil borings are required to confirm this interpretation.

Site 2 - Hursh Road, Allen County, Indiana.

The site was located in a yard of a residential home. A 40- by 60-m grid was established across the site. The grid interval was 2 m. The grid area was located on the lawn to the west and southwest of the home. At the time of the survey the soil was saturated.

Basic statistics for the EMI surveys that were completed with the Dualem-2 meter, the EM38DD meter, and the GEM300 sensor are shown in Table 3. In general, apparent conductivity, as measured with the Dualem-2 meter, increased with increased soil depth (measurements obtained in the deeper-sensing, horizontal coplanar (HC) geometry were higher than those obtained in the shallower-sensing, perpendicular (P) geometry). A few anomalously high or negative measurements were recorded. These measurements are believed to principally reflect interference from cultural features that occurred within the survey area.

For the two surveys conducted with the Dualem-2 meter, data collected in the same geometry were similar. Apparent conductivity averaged 24.6 mS/m with a range of 5.9 to 93.2 mS/m for measurements collected with the Dualem-2 meter in the perpendicular geometry along east-west trending grid lines. Half of these observations had values of apparent conductivity between 20.7 and 27.2 mS/m. For measurements collected along north-south trending grid lines in the perpendicular geometry, apparent conductivity averaged 25.0 mS/m with a range of 14.8 to 226.5 mS/m. Half of these observations had values of apparent conductivity between 20.8 and 27.0 mS/m.

Apparent conductivity averaged 38.1 mS/m with a range of –7.5 to 59.0 mS/m for measurements collected with the Dualem-2 meter in the horizontal coplanar geometry along north-south trending grid lines. Half of these observations had values of apparent conductivity between 33.1 and 42.1 mS/m. For measurements collected along north-south trending grid lines in the horizontal coplanar geometry, apparent conductivity averaged 39.4 mS/m with a range of –1.2 to 234.6 mS/m. Half of these observations had values of apparent conductivity between 33.8 and 43.6 mS/m.

Figure 4 contains plots of apparent conductivity measured with the Dualem-2 meter at the Hursh Road site. The upper two plots in Figure 4 show the spatial distribution of apparent conductivity collected with the Dualem-2 meter for surveys that were conducted along north-south trending grid lines. The lower two plots show the spatial distribution of apparent conductivity measured with the Dualem-2 meter for surveys that were conducted along east-west trending grid lines. For each survey, the spatial distributions of apparent conductivity collected in the perpendicular and horizontal coplanar geometries are shown in the left-hand and right-hand plots, respectively. In each of the plots, the isoline interval is 1 mS/m. The approximate locations of the septic tank, distribution box, observation port, and perimeter drain are shown in the lower right-hand plot.

The Dualem-2 meter has clearly defined the locations of the septic tank, absorption field, and observation port. These features are apparent in each plot of Figure 4. In addition, portions of the perimeter drain are evident in all plots. However, this feature is best expressed in the plot of the data collected in the shallower-sensing, perpendicular coplanar geometry. The distribution box was not detected with the Dualem-2 meter. Spatial patterns in the data sets for the deeper-sensing horizontal coplanar geometry suggest the presence of linear features within the absorption field. The parallel, east-west trending, linear patterns within the absorption field suggest the locations of trenches and/or pipes. Two area of slightly higher apparent conductivity extends southwards from the south-central portion and the southwest corner of the absorption field. These patterns suggest possible discharge of waste products from the system. No interpretation is available for the anomaly that occurs in the central portion near the southern grid boundary.

Data collected with the EM38DD meter was slightly lower and less variable than the data collected with the Dualem-2 meter (see Table 3). In general, apparent conductivity, as measured with the EM38DD meter, increased and became slightly more variable with increased soil depth (measurements obtained in the vertical dipole orientation were higher than measurements obtained in the horizontal dipole orientation). High positive measurements are believed to represent interference from cultural features that occurred within the survey area.

For the two surveys conducted at this site with the EM38DD meter, data collected in the same dipole orientations were similar. Apparent conductivity averaged 12.8 mS/m with a range of –0.2 to 44.2 mS/m for measurements obtained in the horizontal dipole orientation along east-west trending grid lines. Half of these observations had values of apparent conductivity between 9.8 and 15.1 mS/m. Apparent conductivity averaged 11.8 mS/m with a range of –2.5 to 26.1 mS/m for measurements obtained in the horizontal dipole orientation along north-south trending grid lines. Half of these observations had values of apparent conductivity between 8.8 and 14.5 mS/m.

Apparent conductivity averaged 33.1 mS/m with a range of 11.7 to 68.5 mS/m for measurements collected with the EM38DD meter in the vertical dipole orientation along east-west trending grid lines. Half of these observations had values of apparent conductivity between 28.2 and 36.7 mS/m. For measurements collected along north-south trending grid lines in the vertical dipole orientation, apparent conductivity averaged 31.7 mS/m with a range of 20.1 to 81.4 mS/m. Half of these observations had values of apparent conductivity between 27.0 and 34.8 mS/m.

Table 3
Basic Statistics for the EMI Surveys of the Hursh Road Site in Allen County, Indiana.
(All measurements are in mS/m)
Surveys conducted in East-West Directions

	DUALEM2	DUALEM2	EM38DD	EM38DD	GEM300	GEM300	GEM300	GEM300	GEM300	GEM300
	HC	**P**	**V**	**H**	**6030Hz-V**	**9810Hz-V**	**14790Hz-V**	**6030Hz-H**	**9810Hz-H**	**14790Hz-H**
Number	1105	1105	1150	1151	1083	1083	1083	1018	1018	1018
Average	38.1	24.6	33.1	12.8	40.0	38.9	42.0	20.1	16.7	19.3
SD	6.7	6.2	7.2	5.0	12.8	8.9	7.7	7.4	5.8	5.2
Minimum	-7.5	5.9	11.7	-0.2	7.2	25.8	29.6	-2.7	1.0	7.3
Maximum	59.0	93.2	68.5	44.2	367.7	193.4	108.5	67.6	44.3	38.4
First	33.1	20.7	28.2	9.8	33.3	32.4	35.7	17.1	13.2	15.8
Median	36.8	22.1	30.4	11.5	38.4	37.5	40.6	19.6	15.7	18.1
Third	42.1	27.2	36.7	15.1	45.5	44.4	47.7	24.8	21.0	23.3

Surveys conducted in North-South Directions

	DUALEM2	DUALEM2	EM38DD	EM38DD	GEM300	GEM300	GEM300	GEM300	GEM300	GEM300
	HC	**P**	**V**	**H**	**6030Hz-V**	**9810Hz-V**	**14790Hz-V**	**6030Hz-H**	**9810Hz-H**	**14790Hz-H**
Number	1226	1226	1127	1127	1083	1083	1083	1165	1165	1165
Average	39.4	25.0	31.7	11.8	39.5	36.3	39.0	25.4	21.0	23.3
SD	8.8	9.0	6.8	4.6	17.0	11.1	8.5	6.7	5.4	4.9
Minimum	-1.2	14.8	20.1	-2.5	27.9	24.9	28.0	16.1	12.5	15.1
Maximum	234.6	226.5	81.4	26.1	488.1	290.5	184.0	96.5	63.0	50.4
First	33.8	20.8	27.0	8.8	32.8	30.0	33.0	21.3	17.2	19.6
Median	37.7	22.2	29.0	10.8	37.4	34.6	37.4	24.0	19.8	22.2
Third	43.6	27.0	34.8	14.5	43.9	41.2	44.0	29.0	24.6	26.9

Figure 5 contains plots of apparent conductivity measured with the EM38DD meter at the Hursh Road site. All plots contain herringbone patterns caused by the reorientation of the transmitter and receiver coils along succeeding traverse lines. The upper two plots in Figure 5 show the spatial distribution of apparent conductivity for surveys that were conducted along north-south trending grid lines. The lower two plots show the spatial distribution of apparent conductivity for surveys that were conducted along east-west trending grid lines. For each survey, the spatial distributions of apparent conductivity collected in the horizontal and vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. In each of the plots, the isoline interval is 1 mS/m. The approximate locations of the septic tank, distribution box, observation port, and perimeter drain are shown in the lower right-hand plot.

The EM38DD meter clearly defined the locations of the septic tank and the absorption field. These features are apparent in each plot of Figure 5. However, the EM38DD meter did not discern the observation port, perimeter drain or distribution box. Spatial patterns in the data sets for the deeper-sensing, vertical dipole orientation suggest the presence of linear features within the absorption field. These patterns may reflect the locations of absorption field trenches and/or pipes. However, compared with the data collected with the Dualem-2 meter, these patterns are broader and more ambiguous. The area of slightly higher apparent conductivity that extends southwards from the southwest corner of the absorption field is well expressed in all plots of Figure 5. This pattern of higher apparent conductivity suggests possible discharge of waste products from the absorption field.

Table 3 also summarizes the data collected with the GEM300 sensor at the Hursh Road site. For each frequency, measurements obtained with the GEM300 sensor in the vertical dipole orientation were higher and more variable than those obtained in the horizontal dipole orientation. Basic statistics for the GEM300 sensor and the Dualem-2 meter were similar and slightly higher than data collected with the EM38DD meter at this site.

For each of the four surveys completed with the GEM300 sensor, strong (r = 0.774 to 0.994) and significant (0.001 level) correlations existed between data collected at different frequencies (6030, 9810, 14790 Hz) but in the same dipole orientation. In general, lower correlations (r = 0.774 to 0.896) were found to exits between data collected at 6030 Hz and 14790 Hz. As noted for the data collected with the GEM300 sensor at the Schwartz Road site, these high and significant correlations suggest that the sensor is responding to similar soil layers and makes it difficult to believe that the use of multiple frequencies is providing multiple depths of observation.

Figures 6 and 7 show the results of the EMI survey conducted with the GEM300 sensor along north-south and east-west trending grid lines, respectively. In each figure, data collected in the horizontal and vertical dipole orientations are shown in the upper and lower set of plots respectively. Simulations of data that were collect at frequencies of 14790 Hz, 9810 Hz, and 6030 Hz are shown in the left-hand, middle, and right-hand sets of plots, respectively. In each plot, the isoline interval is 1 mS/m. The approximate locations of the septic tank, distribution box, observation port, and perimeter drain are shown in the lower right-hand plot. All plots contain herringbone patterns caused by the reorientation of the transmitter and receiver coils along succeeding traverse lines.

As with the other instruments, the GEM300 sensor clearly defined the locations of the septic tank and the absorption field. These features are apparent in all plots of figures 6 and 7. The GEM300 sensor failed to detect the observation port, perimeter drain or distribution box. Broad spatial patterns in the data sets for the deeper-sensing, vertical dipole orientation suggest the presence of linear features within the absorption field. These blurred linear features have higher apparent conductivity and may reflect the presence of absorption field trenches and/or pipes. However, compared with the data collected with the Dualem-2 meter, these patterns are more blurred and ambiguous. In plots of the data collected in the vertical dipole orientation, areas of slightly higher apparent conductivity extend southwards from the south-central portion, and the southeast and southwest corners of the absorption field. These patterns of higher apparent conductivity suggest possible discharge of waste products from the absorption field. Spatial patterns of apparent conductivity collected in the same dipole orientation are remarkably similar for data collected at different frequencies (see figures 6 and 7). As reported for the Schwartz Road site, the use of multiple frequencies does not appear to provide any additional information about the site.

In each of the plots in figures 6 and 7, patterns of apparent conductivity are elongated in the direction of traverse. These patterns are a form of noise and may represent equipment drift, the alignment of the transmitter and receiver coils, and/or the offsets or delays in signal recording.

All three instruments clearly detected the septic tank and the absorption field at the Hursh Road site in Allen County, Indiana. Each instrument detected an area of discharge emanating from the southwest corner of the absorption field. In addition, each instrument provided indistinct images suggesting the presence of drain lines or trenches within the absorption field. The Dualem-2 meter provided the least obscure images of these features as well as the perimeter drain line.

Site 3 - Area of Blount and Del Rey Soils, Wells County, Indiana.

The study site was located in a cultivated field with corn stubble. A 40- by 60-m grid was established across the site. The grid interval was 2 m. Power transmission lines passed near to the northern boundary of the study site, but did not cause noticeable interference.

Basic statistics for the EMI surveys completed with the Dualem-2 meter, the EM38DD meter, and the GEM300 sensor at this site are shown in Table 4. In general, apparent conductivity, as measured with each EMI instrument, increased with increased soil depth (measurements obtained in the deeper-sensing, horizontal coplanar geometry or vertical dipole orientation were higher than those obtained in the shallower-sensing, perpendicular geometry or horizontal dipole orientation). A few negative measurements were recorded with the GEM300 sensor at this site. These measurements were attributed to interference from buried cultural features, momentary malfunctioning of the equipment, or external noise sources.

Table 4
Basic Statistics for the EMI Surveys of an area of Blount and Del Rey Soils in Wells County, Indiana.
(All measurements are in mS/m)

Surveys conducted in East-West Directions

		DUALEM2	DUALEM2	EM38DD	EM38DD	GEM300	GEM300	GEM300	GEM300	GEM300
	HC	P	V	H	6030Hz-V	9810Hz-V	14790Hz-V	6030Hz-H	9810Hz-H	14790Hz-H
Number	1189	1189	1206	1206	1030	1030	1030	990	990	990
Average	62.7	35.6	44.3	23.8	46.2	45.9	45.7	32.4	34.9	37.9
SD	8.7	5.2	7.7	3.6	9.2	8.8	8.7	6.3	6.4	6.5
Minimum	42.8	21.4	11.3	12.8	21.4	23.5	23.9	7.2	5.4	18.2
Maximum	83.9	48.1	61.0	34.8	70.0	68.0	65.2	49.2	52.6	57.2
First	56.1	31.6	39.9	21.2	39.3	38.9	38.3	28.4	30.6	33.6
Median	62.9	36.1	44.7	23.9	46.1	45.9	45.7	32.5	34.8	37.8
Third	67.8	38.9	49.1	26.3	52.1	51.8	52.1	36.5	38.9	42.0

Surveys conducted in North-South Directions

	DUALEM2	DUALEM2	EM38DD	EM38DD	GEM300	GEM300	GEM300	GEM300	GEM300	GEM300
	HC	P	V	H	6030Hz-V	9810Hz-V	14790Hz-V	6030Hz-H	9810Hz-H	14790Hz-H
Number	1086	1086	1261	1261	1079	1079	1079	1014	1014	1014
Average	63.5	35.9	46.6	23.3	47.5	44.5	44.9	34.8	38.1	41.7
SD	8.3	5.2	7.2	4.0	8.5	8.2	8.2	8.4	8.6	8.8
Minimum	44.9	22.1	11.4	4.7	20.6	14.9	-6.3	13.9	16.6	19.5
Maximum	81.9	48.1	62.9	34.0	68.8	66.9	68.2	56.7	58.5	64.2
First	57.6	31.8	42.5	20.9	41.7	38.9	39.3	28.2	31.7	35.2
Median	64.0	36.5	47.5	23.6	47.6	44.3	44.7	35.2	38.5	43.0
Third	68.5	39.5	51.1	26.2	52.5	49.3	49.6	41.0	45.0	48.7

In general, apparent conductivity measured with the Dualem-2 meter was higher at this site than measurements obtained with the EM38DD meter or the GEM300 sensor. For the two surveys, data collected in the same geometry with the Dualem-2 meter were similar. Apparent conductivity averaged 35.6 mS/m with a range of 21.4 to 48.1 mS/m for measurements collected in the perpendicular geometry along east-west trending grid lines. Half of these observations had values of apparent conductivity between 31.6 and 38.9 mS/m. For measurements collected along north-south trending grid lines in the perpendicular geometry, apparent conductivity averaged 35.9

mS/m with a range of 22.1 to 48.1 mS/m. Half of these observations had values of apparent conductivity between 31.8 and 39.5 mS/m.

Apparent conductivity averaged 62.7 mS/m with a range of 42.8 to 83.9 mS/m for measurements collected with the Dualem-2 meter in the horizontal coplanar geometry along north-south trending grid lines. Half of these observations had values of apparent conductivity between 56.1 and 67.8 mS/m. For measurements collected along north-south trending grid lines in the horizontal coplanar geometry, apparent conductivity averaged 63.5 mS/m with a range of 44.9 to 81.9 mS/m. Half of these observations had values of apparent conductivity between 57.6 and 68.5 mS/m.

Figure 8 contains plots of apparent conductivity measured with the Dualem-2 meter in the area of Blount and Del Rey soils. All plots contain herringbone patterns caused by the reorientation of the transmitter and receiver coils along succeeding traverse lines. The upper two plots in Figure 8 show the spatial distribution of apparent conductivity for surveys that were conducted along north-south trending grid lines. The lower two plots show the spatial distribution of apparent conductivity for surveys that were conducted along east-west trending grid lines. For each survey, the spatial distributions of apparent conductivity collected in the perpendicular and horizontal coplanar geometries are shown in the left-hand and right-hand plots, respectively. In each of the plots, the isoline interval is 2 mS/m.

Each plot in Figure 8 show similar spatial patterns but have different amplitudes. The patterns are believed to represent differences in soil properties. The lowest-lying and wettest portion of the survey area is in the southwest corner (upper right-hand corner of each plot). As this portion of the survey area is characterized by comparatively lower apparent conductivity values, soil water content is not believed to be the principal factor causing the spatial patterns. Changes in clay content or the depth to the finer-textured subsoil are believed to be responsible for these patterns.

Data collected with the EM38DD meter were slightly lower and less variable than the data collected with the Dualem-2 meter (see Table 3). For the two surveys, data collected in the same dipole orientations with the EM38DD meter were similar. Apparent conductivity averaged 23.8 mS/m with a range of 12.8 to 34.8 mS/m for measurements collected in the horizontal dipole orientation along east-west trending grid lines. Half of these observations had values of apparent conductivity between 21.2 and 26.3 mS/m. Apparent conductivity averaged 23.3 mS/m with a range of 4.7 to 34.0 mS/m for measurements collected in the horizontal dipole orientation along north-south trending grid lines. Half of these observations had values of apparent conductivity between 20.9 and 26.2 mS/m.

Apparent conductivity averaged 44.3 mS/m with a range of 11.3 to 61.0 mS/m for measurements collected with the EM38DD meter in the vertical dipole orientation along east-west trending grid lines. Half of these observations had values of apparent conductivity between 39.9 and 49.1 mS/m. For measurements collected along north-south trending grid lines in the vertical dipole orientation, apparent conductivity averaged 46.6 mS/m with a range of 11.4 to 62.9 mS/m. Half of these observations had values of apparent conductivity between 42.5 and 51.1 mS/m.

Figure 9 contains plots of apparent conductivity measured with the EM38DD meter in the area of area of Blount and Del Rey soils. All plots contain herringbone patterns caused by the reorientation of the transmitter and receiver coils along succeeding traverse lines. The upper two plots in Figure 9 show the spatial distribution of apparent conductivity for surveys that were conducted along north-south trending grid lines. The lower two plots show the spatial distribution of apparent conductivity for surveys that were conducted along east-west trending grid lines. For each survey, the spatial distributions of apparent conductivity collected in the horizontal and vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. In each of the plots, the isoline interval is 2 mS/m.

Spatial patterns of apparent conductivity measured with the EM38DD meter (Figure 9) are similar to, but of lower amplitude, than those obtained with the Dualem-2 meter at this site. Major spatial patterns shown in Figure 9 are believed to represent differences in soil properties. These patterns are believed to principally reflect changes in clay content or the depth to the finer-textured subsoil are believed to be responsible for these patterns. Numerous anomalies are evident in the data collected with the EM38DD meter in the vertical dipole orientation. As these features are not apparent in the plots of data collected with the Dualem-2 or GEM300, equipment malfunctioning or signal interference is suspected.

Table 4 summarizes the GEM300 data collected within the cultivated field of Blount and Del Rey soils. For each frequency, measurements obtained with the GEM300 sensor in the vertical dipole orientation were higher and more variable than those obtained in the horizontal dipole orientation. For each of the four surveys conducted with the GEM300 sensor, strong (r = 0.946 to 0.989) and significant (0.001 level) correlations existed between data collected at different frequencies (6030, 9810, 14790 Hz) but in one dipole orientation. Once again the close similarity in measurements suggests that regardless of frequency, the GEM300 sensor is responding to similar observation depths. The use of one frequency and two dipole orientation appears to provide as much information as multiple frequencies.

Figures 10 and 11 show the results of the EMI survey conducted with the GEM300 sensor along north-south and east-west trending grid lines, respectively. In each figure, data collected at 14790 Hz, 9810 Hz, and 6030 Hz are shown in the upper, middle, and lower sets of plots, respectively. For each frequency, data collected in the horizontal and vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. In each plot, the color interval is 2 mS/m. Spatial patterns shown in these plots are closely similar to the spatial patterns of apparent conductivity that were simulated from data collected with the Dualem-2 and EM38DD meters (see figure 8 and 9). All plots contain herringbone patterns caused by the reorientation of the transmitter and receiver coils along succeeding traverse lines

It was hoped that EMI could be used to located buried field drains. In the plots of the data collected with the Dualem-2 meter, EM38DD meter, and GEM300 sensor, no indications of buried field drains are apparent. However, it was unclear if buried field drains occurred within this field. To evaluate the potential of EMI to detect buried tile drains better knowledge and control is required.

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