ELECTROMAGNETIC MONITORING OF THREE DIMENSIONAL WATER FLOW AROUND A SEPTIC TRENCH

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Abstract

Nutrients, bacteria and viruses require a water transport system to move from the highly polluted septic tank discharge in a traditional drainfield to the outer perimeters where, before adequate treatment can occur, entry to groundwater or escape from surface discharge takes place. When water does not move large distances, contamination is constrained to those areas where water is present, hopefully in close proximity to the trench where nutrient uptake, microbial scavenging and mineralisation are the dominant factors. However, continual discharge of effluent into a saturated soil is likely to result in water surfacing along or adjacent to the trench. It is through this continuously saturated soil that excess nutrients and pathogenic microorganisms may move. An understanding of the dynamics and distribution of nutrient/organisms requires knowledge of the movement of water around a septic trench. Collection of such information, especially with sufficient detail to adequately represent actual conditions is time consuming and usually destructive.

Electromagnetic induction (EMI or EM) devices are proving increasingly useful for delineating three-dimensional relationships of soil with soil water, salinity and other discontinuities, such as clay type based, upon apparent electrical conductivity. This paper outlines the application of such technology to inferring the three-dimensional movement of domestic effluent around two subsurface discharge sites; a conventional trench system of three drainfields in series; and a sequentially dosed subsurface irrigation field. The detailed maps indicating 'soil wetness' were used to infer the movement patterns of water in the subsoil around the dispersal areas.

Keywords

non-destructive testing, electromagnetic (EM) induction, global positioning system

1 Introduction

The ability to track the movement of water around a conventional drainfield or subsurface irrigation area is difficult to accomplish without the installation of numerous piezometers, tensiometers or some electronic moisture sensors. Few, if any researchers have placed more than a dozen moisture devices over a dispersal field and iterated the intermediate readings. For example, van de Graaff and Brouwer (1999) inferred the movement of water through a yellow duplex soil (Yellow Chromosol) and calculated iso-potential lines from which direction of subsurface flow could be gauged using two standpipes and 26 tensiometers around a trench. Geary (2003) used tracers in domestic wastewater and then, using piezometers, determined the travel distance and route, and estimated the flow directions and speed of travel. Lesiker *et al.* (2004) excavated around a subsurface drip line to evaluate uniformity of wetting, a highly destructive method of testing. Owens *et al.,* (2004) used eight inspection wells in trenches and nine in background areas (0.4 to 2.0 m distant) to evaluate the performance of rested drainfield.

The ability to observe the movement of effluent from trenches or distribution lines without disrupting the soil profile, or without providing a void into a semi-saturated zone by conventional sample collection or installation of an inspection well, piezometer or tensiometer would be of considerable value in assessing actual on-site system performance. Moreover, periodic inspection of septic systems by regulatory authorities is often based on simply observing surface indicators of ‘wetness’. What happens below the soil surface is largely ignored because it requires considerable destructive testing to understand the moisture levels.

The need to measure and map spatial variations in soil characteristics, including texture, water content and salinity within agricultural fields has driven the development and application of electromagnetic (EM) induction soil survey instruments such as EM-38 and EM-31 (For example, see special edition of *Computers and Electronics in Agriculture*, **46** (2005)). EM soil survey technologies work on the principle that a small transmitter coil in contact with the soil produces a time-varying primary magnetic field in the sub soil. Where the primary field lines pass through an electrically conductive medium, in this case the soil, eddy currents are induced to flow. These eddy currents in turn generate their own secondary magnetic fields. A second, sensor coil in the EM unit measures the secondary field and the apparent soil conductivity (EC_a) in the vicinity of the transmitter coil is determined by the ratio of the secondary to primary magnetic fields (McNiell, 1980). Since soil ‘wetness’ will dramatically influence conductivity, EM sensors are potentially useful for inferring zones of differing hydraulic characteristics around septic trenches. This paper reports on a preliminary investigation into using a commercially-available EM sensor (EM-38) and global positioning system (GPS)/datalogger unit to generate maps of apparent conductivity around two septic trenches. Examples of the maps are presented as well as some basic interpretation of key features observed. A discussion of the scope of opportunities of using these technologies for regularly monitoring septic system performance is also presented.

2 The Two On-site Systems

Two domestic effluent dispersal areas were selected on which to evaluate the EM methodology for defining the subsoil movement of effluent away from the drainage line. Each system was selected on the basis of involving single a household and the discharge of effluent from a septic tank to a soil absorption area.

The first system, hitherto referred to as ‘System-PH’, had a sequentially pump-dosed subsoil drainfield consisting of four soakage lines, each approximately 30 m long, receiving effluent from a new dual chamber septic tank (with outlet filter). Each soaking line was a small excavated trench 300 mm wide and 400 mm deep into which a 65 mm, geotextile wrapped agricultural drainage line was placed. A 25 mm polyethylene distribution line, drilled with 6 mm holes (one side only) at 1 m spacings was placed inside the drainage line. The trench was backfilled to a depth of 200 mm with 19 mm crushed rock and top-dressed with natural surface soil. Each soakage line was constructed parallel to the contour. With buffers of 1 m upslope and 6 m downslope, the dispersal area was about 700 m^2.

The second system, ‘System-JN’, was a reconstructed subsurface drainfield, consisting of three parallel serially dosed trenches, each 25 m long. Each trench was 600 mm wide and 400 mm deep into which a 230 mm RELN corrugated semi-circular arch trenching was placed, backfilled to the top of the arch trenching with 19 mm crushed rock, covered with geotextile and topdressed with topsoil from the site. At each end of each trench, a well with an inspection cap provided both visual and physical access to the internal trench. As the system had been recently reconstructed, surface vegetation had not had an opportunity to establish during the dry autumn and cold winter. System-JN had similar buffer distances to System PH, and a total area of 600 m^2 for dispersal.

3 The Equipment

Measurements of apparent soil electrical conductivity were completed using a Geonics® EM-38RT unit (Geonics Ontario, Canada) operated in vertical dipole mode. As the unit weighs approximately 3.1 kg, it is easily carried, suspended close to the ground on a hand sling. Prior to conducting each set of measurements the instrument was switched on and warmed up for a period of 15 minutes, and zeroed following the standard Geonics protocol. Immediately following the zeroing procedure, the unit was placed on the ground at a pre-designated calibration point and the EC_a measured and checked to ensure it was repeatable to within 5%.

Two-dimensional surveys were completed by carrying the EM-38 unit (Figure 1). The distance between the unit and the surface of the ground could be varied by simply varying the carrying height (via the length of the sling).

Figure 1 Author carrying EM-GPS over dispersal field, front and rear views

The EM-38 is designed to exhibit a depth-response function; that is the sensitivity of the EM unit to stimulating and then detecting the secondary magnetic fields varies with depth. A schematic of the EM-38 depth response function is given in Figure 2.

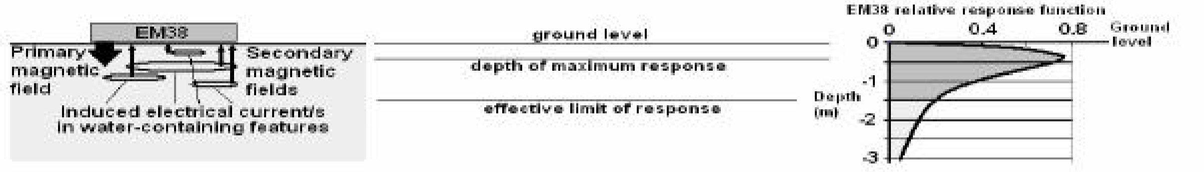

Figure 2. EM38 response characteristics: operating principle schematic and diagrammatic description of relative response with depth (sensitivity).

The continuous output data stream from the EM-38 unit was fed into a Trimble TSCe® datalogger along with the location information, every second, from a Trimble differential global positioning system (dGPS) (Trimble, Sunnyvale California, USA).

The two dimensional EC_a data were post-processed according to the following steps:

1. Missing data values or spikes were identified and removed from the data string.
2. Data were then processed into ArcView® Gis 3.2a (Environmental Services Research Institute, California, USA) for final map presentation.

4 Method

The first step of each site survey is to define the site boundary. This task was completed simply by traversing the boundary with the dGPS/datalogger to record coordinates of the corners and other key positions. The triangles and firm line in Figure 3 shows that survey.

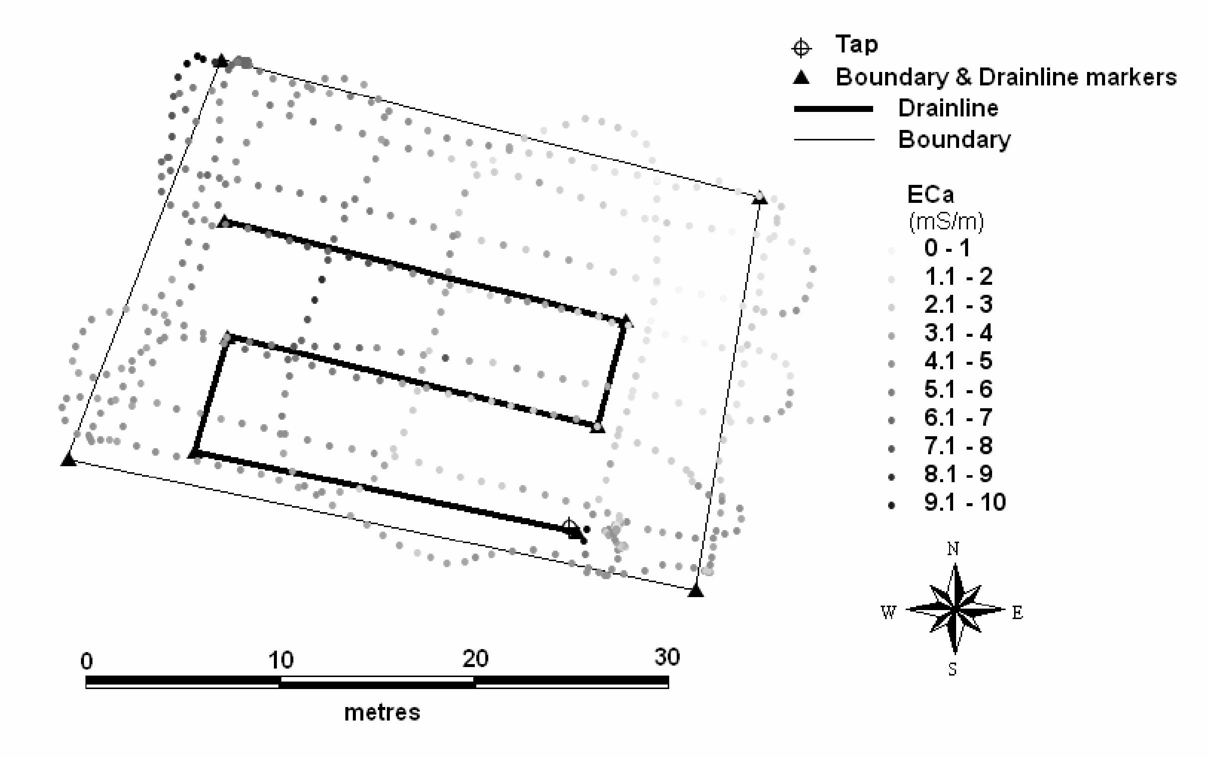

Figure 3. Site boundary and surveyed transects used to collect EC_a data at System-JN

The second task is to collect EC_a/dGPS data along transects inside the site boundary in such a pattern that Figure 3 shows the site identified at System-JN, the boundary set by corners, the centre line of each of three trenches and the weaving pattern used to collect the whole 'view' of the area.

The site was surveyed on 5 occasions between 17th July and 21st August, 2005 (at approximately 7-day intervals) holding the EM units at approximately 100 mm above the ground. On the final survey, conducted on the 21st August, two traverses were completed at heights above ground of 100 mm and 600 mm respectively.

5 Results

5.1 System-JN

Two dimensional EC_a maps of this site are shown in Figures 4a and 4b. Zones exhibiting greater or lesser degrees of “wetness” are clearly delineated in these maps on the basis that wetness is correlated to EC_a . The time sequence of maps illustrates that the relatively high and low EC_a zones remain fixed.

Water outflow was suggested only in the first 10 – 20 m of the first drainline (indicated in figure 4(a)), no discernable “wetting” pattern being obvious beyond this line. A zone of significant “wetting” was, however, observed at the extreme end of the third drainline (indicated in figure 4(a)), this coinciding with the location of a tap from a nearby water tank. It is not possible to definitely attribute the significant “wetting” to a leaking tap or water line, but this was the realistic interpretation given to the anomaly. Sampling of the ground water would be necessary to confirm this.

The EC_a profiles generated from surveys where the sensor was carried at different heights above ground are given in Figure 4(b). Due to the depth response function of the EM38, the two maps can, therefore, be a useful indicator of wetness in the depth ranges of 0 – 1.5 m and 0 – 0.9 m, respectively. The high and low ECa zones (west and east) were broadly similar to those in the full depth images (Figure 4a) but the highest ECa zones between the first and second drainlines were absent, indicating that these features were below approximately 0.9 m. The lower ECa responses for the 0 – 0.9 m depth surveys relative to the 0 – 1.5 m responses were corrected by applying a factor obtained as the ratio of the areas beneath the relative response curves for both depths (full vs shallow depths), this factor being estimated at 1.8.
Some of the apparent drying along the western edge of the survey could be attributed to the high rainfall received in the month immediately prior to the start of the survey. Heavy rain soaked the soil profile that was reflected in the higher EC_a of the earlier survey. The period between the first and the last survey received less than 10 mm of rain.

5.2 System-PH

Results similar to those from System-JN were obtained from System-PH, though with a greater ECa range, probably indicating greater water content but also possibly reflecting a higher or shallower clay content. The variations in “wetness” were able to be followed throughout the survey period. One zone did appear to exhibit an anomalous drying out but this was interpreted as a probable dilution of salt-laden drainage water with fresher water from an adjacent dam. Both of the above interpretation “problems”, though increasing the uncertainty of some aspects of this preliminary survey, did reinforce the stated need for the development of appropriate protocols of procedure.

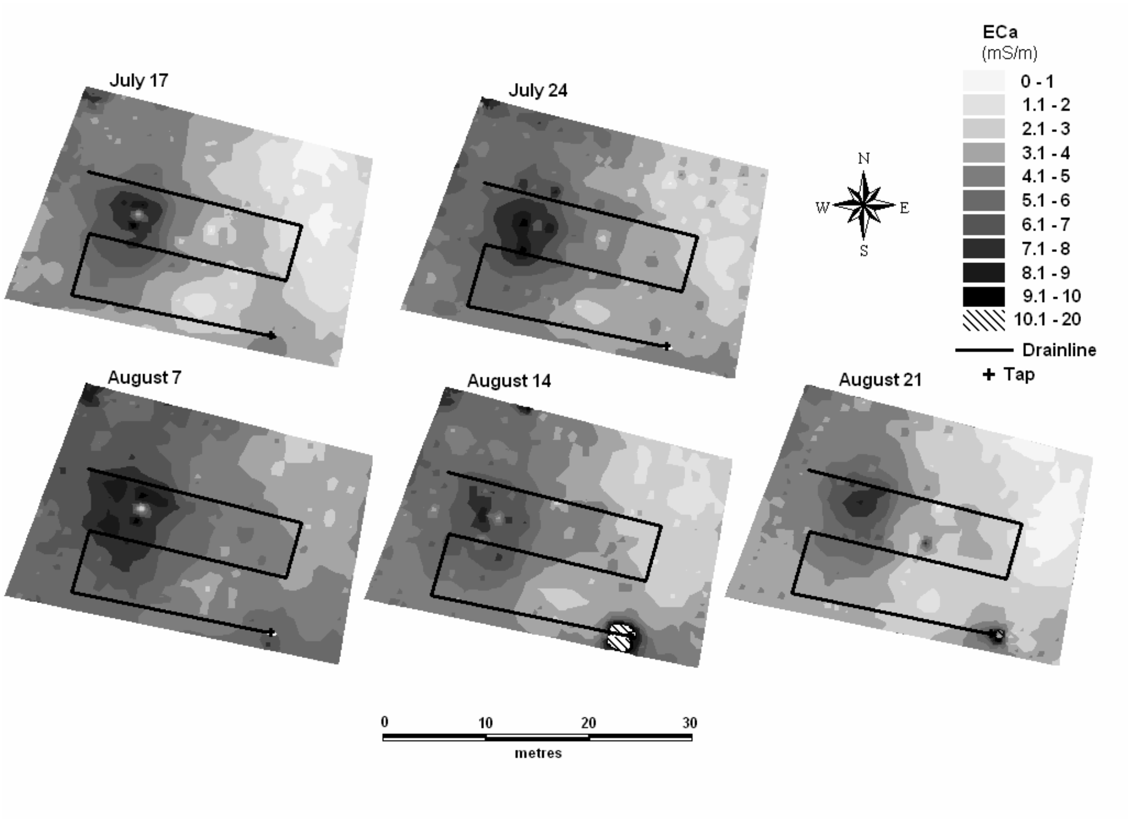

Figure 4a. Sequential EM plots for System-JN for the period July 17 – August 21, 2005) (for layer 0 – 1.5 m)

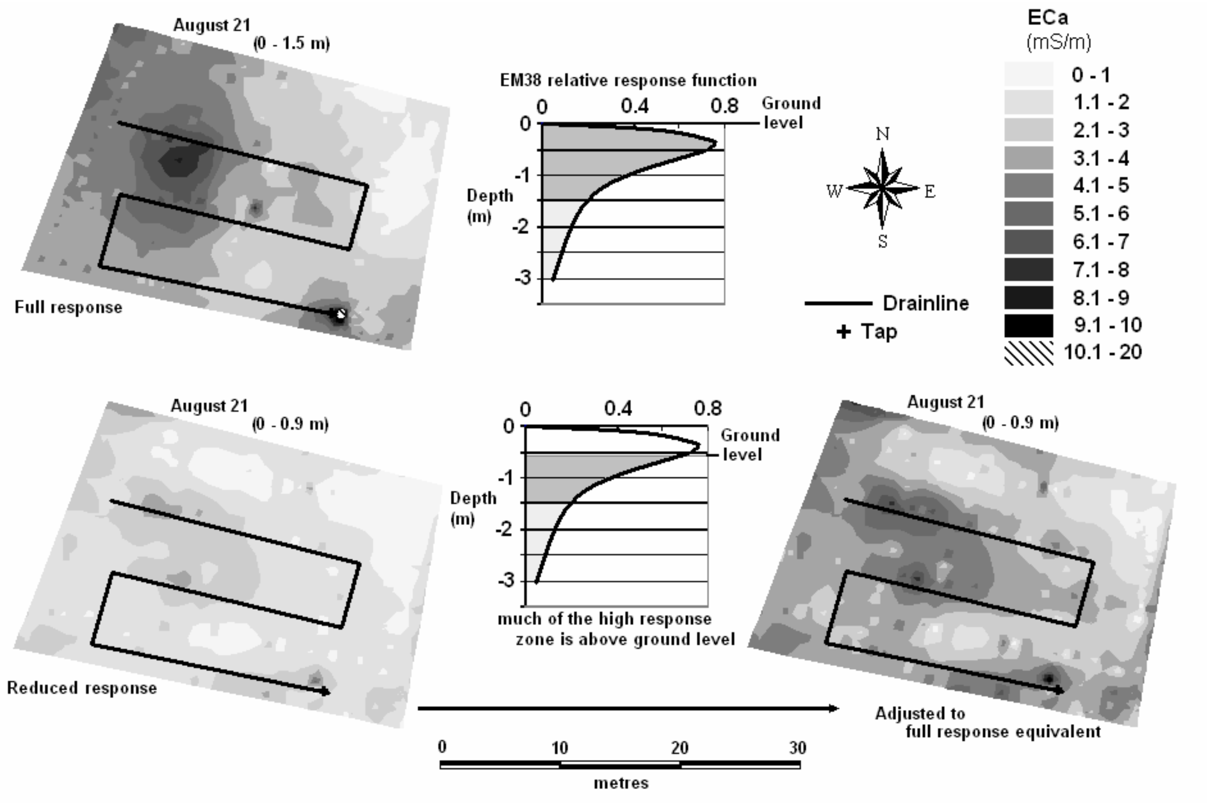

Figure 4b. Detail of EM layered plots for System-JN for August 21, 2005 (for layers 0 – 1.5 m and 0 – 0.9 m) with adjustment for relative response function.

6 Discussion

The purpose of the survey was to investigate the potential application of EM technology to understanding subsurface water movement around effluent dispersal fields. The preliminary results obtained have been very encouraging, though they have also indicated the need for some refinement of procedures and the inclusion of depth profiling and feature identification methods. The system is simple to use, non-destructive and rapid. The survey on each day took not more than 30 minutes including instrument calibration.

It is envisaged that a protocol for septic-tank drain-field surveys will ultimately be produced to enable non-invasive and relatively rapid evaluation of performance at existing sites and to assist in the optimisation of drainfield designs via the provision of substantially more and better data for generic designs. In addition, the technique will aid in the pin-pointing of zones of failure, thus assisting in reducing the time and effort required by trial and error methods for which inspection pits are now necessary but often not very meaningful.

Subtraction of successive composite EM layer images from a full-depth image and other composite images will enable EM plots of discrete soil layers to be displayed for depth profiling. Software for this application is available and will be applied in future surveys and will further assist in the above-mentioned site evaluations.

Physical calibration techniques for relating ECa to water content or other parameter are quite well established and would be included as a matter of course in more-intensive follow-up studies. The next step in correlating the EC_a readings to the site conditions and the possible movement path of the effluent is to take soil samples in the various areas identified in Figures 4(a) and 4(b) as either ‘hot spots’ or ‘cold spots’. Soil samples at various depth, consistent with the depths taken in the survey, in this case down to 1.5 m, could be measured for moisture, texture and salinity at very little cost.

The pre-construction survey of a proposed effluent dispersal site could be beneficial in understanding the soil subsoil conditions (clays, moisture paths and salinity) while a survey some time after system operation could be used to evaluate the system in a more meaningful way. Such actions could be developed as part of the protocols for new systems.

In System-JN, other than the possible leaking pipe in the south east corner, it is also possible that a large 100 kL rainwater tank and drainage from around the house could be responsible for the higher EC_a readings in the north-west corner. Both these possibilities need to be investigated.

Since the GPS component is accurate to within 100 mm, and each survey is accurately referenced to the same location, the areas shown in each of the maps in Figure 4 could be accurately measured and statistical examined for changes in EC_a.

7 Conclusions

This preliminary project has demonstrated the usefulness of the electromagnetic induction method for the evaluation of water movement through, from and around septic-tank drain-fields. It is necessary to point out that the technique is not selectively sensitive to water but to any underlying material’s ability to support an electrical current. This said, it is also important to note that water bodies and their dissolved salts are the only EM-detectable materials likely to shift their positions and concentrations below ground, clays deposits being static bodies. Where such water bodies are detected, their changing positions can be mapped over time while their changing ECa values can indicate drying, wetting or change in salinity of a drainage zone within the overall drainfield. The technique, once fully developed, will provide information of greater quantity, quality and timeliness for the management of systems under examination and could provide critical performance-based assessments of different drainfield designs for different ground characteristics such as soil textural class and drainage slope.

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