USING GROUND ELECTROMAGNETIC CONDUCTIVITY TO DETERMINE THE SOURCE OF NITRATE IN DAIRY WELLS

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Abstract. A recent study of dairies in a five-county area in north Georgia found a high incidence of nitrate nitrogen (NO_3-N) contaminated well water. We used a ground electromagnetic (EM) conductivity meter to survey nine dairies in the region to determine the source of contamination. Ground EM conductivities were highest in the loafing areas on most dairies. These are the corrals or small fields near the barn where the milking herd is kept when it is not in the barn or on pasture, and other areas near the barn where there is high animal traffic. Conductivities were typically in the range 15 - 20 mS m^{-1} in these areas, compared to less than 10 mS m^{-1} in the pastures away from barns. Water samples from groundwater observation wells installed in the loafing areas on three diaries had NO_3-N concentrations of 47-135 mg/L compared to 12-16 mg/L from a well in a pasture. There was evidence of seepage at four of the seven wastewater lagoons we surveyed, but the loafing areas appeared to be a greater threat to drinking water supplies because they were closer to the milking barn where the supply well was located and because they affected a larger area than the lagoons. Best management practices need to be developed that address nitrate leaching from loafing areas.

INTRODUCTION

Ground electromagnetic (EM) surveys have been used to detect different types of contaminant plumes. Ground conductivity is a function of the soil water and salt content and the dielectric properties of the soil and parent material. If the water content and soil and parent material are relatively uniform at a site, changes in EM conductivity can be interpreted as changes in salt content.

Eighty of Georgia's total of approximately 600 dairies are found in the five county area that comprises the Little River\Rooty Creek Hydrologic System (Anonymous, 1991). The University of Georgia Cooperative Extension Service sampled 138 farm wells from June 1991 to October 1992 in this area. Most of the wells supplied water to the barn. Thirteen percent of these wells exceeded the drinking water standard of 10 mg/L for NO_3-N (Gould, 1993).

The objective of this study was to determine the source of nitrate in the groundwater in this region.

MATERIALS AND METHODS

Nine dairies located approximately 40 miles east of Atlanta in Morgan and Putnam Counties (within the Little River\Rooty Creek Hydrologic System) were selected for EM surveying. Dairies were selected to represent a range in herd size (90-1,050 cows) and supply well NO_3-N concentrations (1-24 mg/L). Seven of the dairies were in Morgan County (designated MO-1 through MO-7) and two were in Putnam County (PU-1 and PU-2).

The dairies were surveyed with an EM 34-L3 conductivity meter which consists of a trasmitter and receiver coil (Geonics Ltd., Mississisauga, Ontario). Both coils are held at the soil surface separated by a distance of 10, 20, or 40 m (Anonymous, 1985). An alternating current is sent through the transmitter coil which produces a magnetic field below the ground near the transmitter. The magnetic field in the ground induces a current which in turn sets up a secondary magnetic field. The primary and secondary magnetic fields are sensed at the receiver coil and the ratio of the strength of the secondary magnetic field to the primary field is used to determine the ground conductivity. We used a 10 m spacing between the coils and took readings at each grid point in a horizontal and vertical dipole orientation which measured shallow (field strength greatest at 0-2 m) and deep (field strength greatest at 4.5 m depth) conductivity, respectively.

The surveys were conducted during the period of July 5-16, 1993. At each dairy, we ran transects (with measurements every 10 m) around the lagoon if one was present. We also ran transects from the source well through the loafing areas and pastures. We have used the term *loafing area* to describe any area near the barn where the milking herd gathers. In the more intensively managed dairies where grazing is controlled, this is a corral or small field where the herd is kept when it is not in the barn or on pasture. On the less intensively managed dairies, this is usually an area of a pasture near the barn where there is high traffic due to entering and exiting the barn, feeding hay bales, water troughs, etc. The USDA Soil Conservation Service uses the term *heavy use area*, instead of loafing area (Anonymous, 1992).

In November, 1993, we installed seven groundwater observation wells with a hollow stem auger. Five of the wells were located at MO-1 in and around the loafing area. The two other wells were installed in loafing areas at MO-6 and PU-2. The wells were installed to a depth approximately 1.5 m below the water table with a 3 m section of screen installed to extend 1.5 m above and below the water table. Samples were taken on 11/16/93, 12/7/93, 1/6/94, 1/28/94, 2/19/94, 3/9/94, 3/29/94, and 4/21/94 and refrigerated until nitrate analysis could be performed. Nitrate concentrations were measured using a DX-100 ion chromatograph (Dionex Corp., Sunnyvale, CA). Supply wells at all the dairies, except MO-1, were sampled for NO_3-N on 3/21/94.

RESULTS

Dairies with High NO_3-N in Supply Wells

Four of the nine dairies we surveyed had NO_3-N concentrations above 10 mg/L in the supply well. Of these four, the contamination appeared to be caused by nitrate leaching from excessive manure deposition in nearby loafing areas in three dairies: MO-3, MO-4, and PU-1. The deep (veritcal dipole) EM survey of MO-4 was typical of these dairies and is shown in Fig. 1. The supply well was located at the south corner of the dairy barn and had a NO_3-N concentration of 12 mg/L. The loafing area consisted of a corral immediately to the west of the barn. Electromagnetic conductivities were highest in the loafing area and along the traffic lane to the east of the lagoon. Surface elevations decreased gradually from the southeast to northwest at this site so the presumed direction of groundwater flow was to the northwest (LeGrand, 1988). There was a small area of high EM conductivity at the northeast corner of the lagoon but this could have been due to heavy animal traffic where paths from the pastures converged. Beyond the loafing area, EM conductivities decreased to background levels near 5 mS/m. For the loafing area to be the source of contamination in the supply well, some of the nitrate would have had to move in the opposite direction of the presumed groundwater water flow. Heavy pumping of the shallow saprolite well during daily milking was probably sufficient to draw water from the loafing area which was less than 15 m away.

The EM patterns at MO-3 and PU-1 were very similar to that at MO-4 (data not shown). At MO-3 there was no lagoon and the loafing areas were heavily trafficed areas of the pasture adjacent to the barn where the herd entered and exited the barn, rather than a corral. The NO_3-N concentration in the well was 14 mg/L. The loafing areas were about 30 m upslope of the supply well so presumably groundwater flow carried nitrate from the loafing areas toward the supply well. At PU-1, the highest EM conductivities also occured in the loafing areas, which consisted of a corral and small field adjacent to the milking barn. There was no evidence of seepage from the lagoon at this site. The supply well was located within 15 m of the loafing areas and had a NO_3-N concentration of 20 mg/L. Although it was a deep well (90 m) that drew water from fractured bedrock, seepage from the loafing area was the likely source of the nitrate since the saprolite layer supplies water to the fractures (LeGrand, 1988).

At MO-2, the fourth dairy with NO_3-N concentrations above 10 mg/L in the supply well, our EM survey produced inconclusive results about the source of the contamination. A loafing area, consisting of a small corral, was located within 5 m of the well (NO_3-N concentration of 24 mg/L) but we were unable to take reliable EM readings in this area due to interference from nearby metal fences and electrical lines. Two lagoons were located within 30 m of the well and there were elevated EM readings toward the downslope end of these lagoons, but we could not get a complete survey of this area becauses it was heavily overgrown with brush. The well at this site was a deep drilled well (37 m) that penetrated bedrock. This type of well can draw water through fractures from as far away as 250 m (Bracket et al., 1991). As a result, the NO_3 in the supply well could have come from the loafing area, the lagoons, or both at this site.

Dairies with Low NO_3-N in Supply Wells

Of the five dairies with NO_3-N concentrations less than 10 mg/L in the supply well, the loafing area did not appear to be contributing to extensive groundwater contamination on only one dairy, MO-5. This was the smallest dairy with only 40 cows. The loafing area consisted of a small area where the cows entered the milking barn and the maximum EM readings in this area were 16 and 15 mS/m for the shallow and deep readings, respectively. The supply well probably wasn't contaminated (NO_3-N concentration of 1 mg/L) because it was deep (69 m) and such a small dairy was unlikely to require heavy pumping of the well that would draw contaminated water from the loafing area, which was about 30 m downslope and limited in areal extent.

At MO-7, the supply well NO_3-N concentration was 1 mg/L, but the EM survey indicated that there were elevated deep readings in the loafing areas and downslope of the lagoon. A dug stock well in the loafing area had a NO_3-N concentration of 16 mg/L when tested on 3/21/94, confirming that the high EM readings in the loafing area were due to nitrate leaching. Nitrate concentrations were probably low in the supply well because it was deep (60 m) and upgradient of the loafing areas.

On the three remaining dairies (MO-1, MO-6, and PU-2) we found extensive areas of high EM conductivities in the loafing areas, despite low NO_3-N concentrations in the supply wells (1-7 mg/L). To determine if the groundwater beneath the loafing areas was contaminated with NO_3-N, we installed observation wells in the loafing areas. The shallow EM

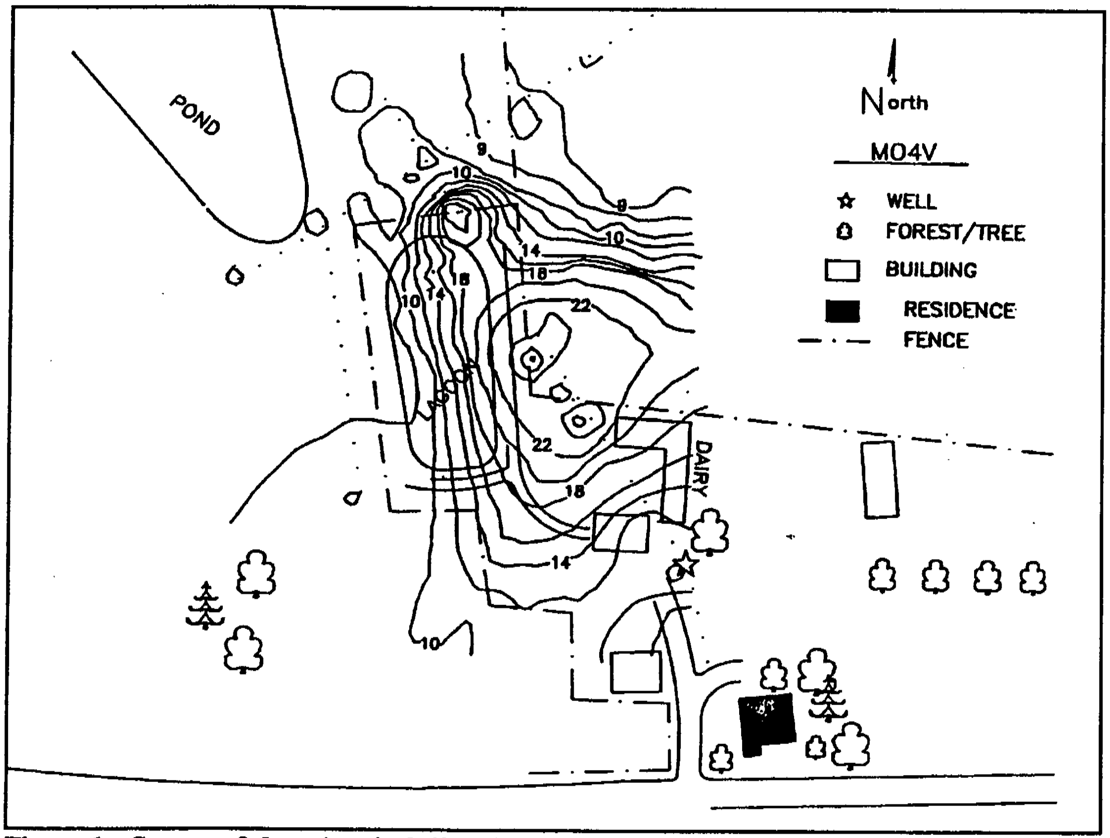

Figure 1. Survey of deep (vertical dipole) EM conductivities in mS/m at MO-4.

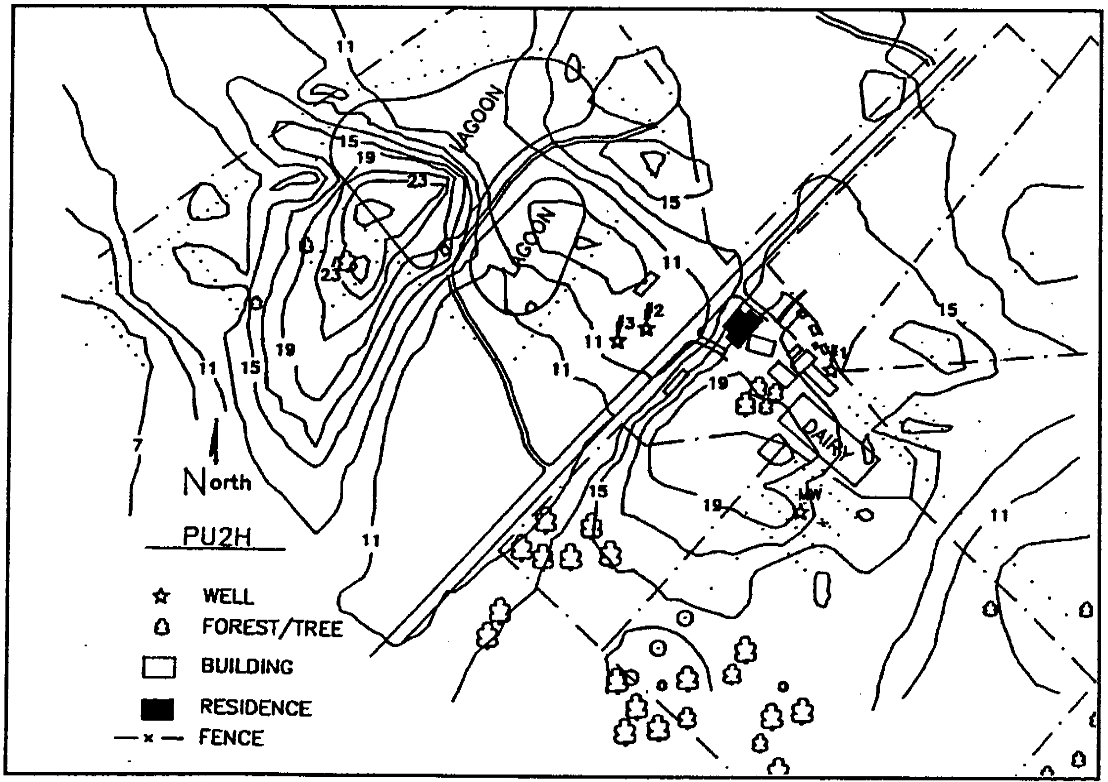

Figure 2. Survey of shallow (horizontal dipole) EM conductivities in mS/m at PU-2.

survey of one of these dairies (PU-2) is shown in Fig. 2. This was the largest dairy in our study with approximately 1,050 cows, about 600 of which are now in total confinement. We found elevated EM conductivites in the fields on all three sides of the dairy barn, with especially high readings in the field to the southwest of the barn. This field was used as the loafing area before the confined system was built. Conductivities were also high in an extensive area southwest of the second stage (larger) lagoon, which was in the presumed direction of groundwater flow. This may have been due to seepage or overflow from the large lagoon. We installed a monitoring well in the old loafing area to the southwest of the dairy barn (MW in Fig. 2). Nitrate concentrations in this well were the highest we observed in the study, varying between 93 and 135 mg/L. Because of the high demand for water at this dairy, three supply wells (1-3 in Fig. 2) were connected together. Nitrate concentrations were low in these wells (1-4 mg/L), despite the high NO_3-N concentrations in the shallow groundwater in the loafing area and the extensive area of elevated EM conductivities (Fig. 2). This was probably because the wells were among the deepest in this study (90-152 m).

At MO-1 the highest EM readings were also found in the loafing area. There was no evidence of a seepage plume downslope of the lagoon. We installed five groundwater monitoring wells in a rough transect that ran from the supply well at the barn out through the loafing area to a pasture. Nitrate concentrations in the three wells in the loafing area were the highest and varied between 60 and 120 mg/L. Nitrate concentrations in the well in the pasture varied between 12 and 16 mg/L. The direction of groundwater flow (determined from water elevations in the wells) would carry contamination from the loafing area away from the barn at this site. This probably accounted for the relatively low NO_3-N concentrations in the supply well at this dairy (7 mg/L).

At MO-6, EM readings were highest in the loafing area and downslope of the lagoon. We installed a monitoring well in the center of the loafing area and concentrations in this well varied between 47 and 83 mg/L . The high NO_3 levels in the groundwater beneath the loafing area may have been due in part to seepage from the lagoon, but groundwater flow would presumably carry the lagoon seepage south of the loafing area. Nitrate levels in the supply well next to the dairy barn were probably low because the well was deep (61 m) and located upslope of the loafing area and lagoon.

CONCLUSIONS

Of the nine dairies we surveyed for ground EM conductivity, loafing areas appeared to be contributing to groundwater contamination in at least eight dairies. Stocking rates were probably high enough in these areas to result in excessive N deposition from manure, but not high enough to cause anerobic conditions that seem to inhibit mineralization and promote denitrification in western feedlots. We found evidence of seepage or overflow at four of the seven lagoons surveyed, but the loafing areas appeared to be a greater threat to drinking water supplies because they were closer to the dairy barn and supply well and affect a larger area than do the lagoons.

Best management practices need to be developed that address nitrate leaching from loafing areas.

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