

**FINDINGS OF MINNESOTA SCIENCE ADVISORS  
ON THE EFFECTS OF GROUND CURRENT  
ON THE HEALTH AND PRODUCTIVITY OF DAIRY COWS**

**by  
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**INTRODUCTION**

I served as one of the members of the Science Advisors to the Minnesota Public Utilities Commission (PUC). The final report of the Science Advisors to the PUC in August of 1998 contained some findings and recommendations which I felt should be shared with agricultural engineers and others who are interested in the electrical issues of ground currents affecting dairy animals.

All findings and recommendations in the final report are those of the Science Advisors who worked under contract to the Minnesota Public Utilities Commission, and do not necessarily reflect the views of the Commission. The findings and recommendations in the final report to the PUC are quoted here exactly as they were in the final Science Advisors Report. The remaining parts of this paper are excerpts from the final report or my explanation of material in the final report.

**BACKGROUND**

The Minnesota Legislature authorized the PUC to establish a committee of science advisors in response to claims by some dairy farmers that electric currents in the earth from electric utility distribution systems are somehow responsible for problems with animal behavior, health and production problems of dairy cows. These claims were advocated by The Electromagnetic Research Foundation (TERF), a group consisting mainly of dairy farmers from Minnesota and Wisconsin. While TERF produced a report including anecdotal evidence, they did not propose a specific mechanism for how currents in the earth might interact directly with dairy cows to cause the problems with dairy production. It is important to note that the issues associated with currents in the earth from grounded electric distribution systems are quite different from concerns raised in the 1970's about Minnesota's dc power line and from ongoing controversies related to low frequency fields from overhead ac power lines. The Science Advisors were a multidisciplinary group with expertise in the fields of agricultural engineering, animal physiology, biochemistry, electrical engineering, electrochemistry, epidemiology, physics, soil science and veterinary science.

The PUC also hired a Research Director and a Field Study Coordinator to assist, coordinate and conduct the meetings and projects of the Science Advisors. The Science Advisors and PUC staff are listed on the following page.

## **Minnesota PUC Science Advisors<sup>1</sup> 1994-1998**

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## **Minnesota Public Utilities Commission**

**Patricia J. Hoben, Ph.D.**  
Research Director  
Liaison, PUC/Science Advisors

**Riley C. Hendrickson**  
Field Study Coordinator

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<sup>1</sup>Alex Furo, Electrical Engineer and Consultant, was a Science Advisor from December 1994 until April 1998.

On November 23, 1994 the PUC authorized the Science Advisors to carry out the following tasks:

- (1) Review any evidence that might support the proposal that earth currents adversely affect dairy herd health and production.
- (2) Determine whether further research in this area is warranted.
- (3) Oversee any research proposed to resolve questions related to possible earth current effects.
- (4) Provide recommendations to the PUC based on available evidence and the results of any research conducted with funds appropriated under the legislation.

Numerous electrical and related technical terms were defined; information from interested parties was reviewed; possible mechanisms of earth and ground current interaction with dairy cattle were hypothesized; and a research plan to address unanswered questions was proposed. A Progress Report was issued in January 1996. It was noted then that currents in the earth can only interact with dairy cows through their associated electric fields, magnetic fields and voltages, and that these parameters should be the focus of our analysis, rather than earth currents per se. The Commission approved research plans in February 1996 and the Minnesota Legislature appropriated additional funding for some of the proposed work in April 1996 and again in April 1997.

The final report is based on all of the reviews and analyses conducted, and upon the results of a survey and a dairy farm field study. A survey of Minnesota and Wisconsin dairy operators was designed to obtain information on the specific types of herd health and production problems and to assess the extent to which owners of dairy herds attribute such problems to stray voltage or other causes. A field study was conducted to assess possible associations between selected electrical and non-electrical parameters and the presence or absence of persistent problems associated with dairy cow health and milk production. Follow-up laboratory research at the University of Wisconsin was funded by the PUC.

### **MAIL AND TELEPHONE SURVEYS**

Dairy herd owners in Minnesota and Wisconsin were surveyed in late November 1996 in a collaborative effort involving the Agricultural Statistics Services of Minnesota and Wisconsin, the University of Minnesota, the University of Wisconsin, the Department of Public Service of Wisconsin, the Minnesota Public Utilities Commission, the Minnesota Department of Agriculture, the Wisconsin Department of Agriculture, Trade and Consumer Protection, and various organizations representing dairy farmers and electric utilities in the two states. The objectives of the survey were: (1) to collect more comprehensive and valid information than had previously been available on the general health and milk production status of Minnesota and Wisconsin dairy herds and (2) to learn more about perceptions of dairy operators related to electrical and non-electrical causes of persistent problems associated with health and production. At the time of the survey (November 1996), there were about 11,000 dairy operations in Minnesota and 25,000 dairy operations in Wisconsin.

Surveys were mailed to a random sample of 2,500 dairy operators, 1,250 from each state's database. Post card reminders and follow-up telephone calls were used to encourage response. Thirty percent (752) of the surveys were completed and returned. The purpose of selecting a random sample of dairy operators was to obtain results that would be representative of the entire population of Minnesota and Wisconsin dairy operations. The random selection method and the number of completed surveys obtained from the initial mailing suggests that the results are representative of the opinions and perceptions of herd owners in the two states.

Each of the herd owners who had completed and returned a mailed survey was contacted by telephone to obtain more detailed information concerning their experience with on-farm investigations of stray voltage and related electrical phenomena. Ninety percent of those who completed and returned the mailed survey also participated in the telephone survey.

Detailed results of the survey have been reported (Marsh et al. 1997a, 1997b). The general results of the survey were:

### 1. Herd Information

Responses from dairy herd owners in Minnesota and Wisconsin were similar for almost every parameter addressed in the survey; thus all response data could be averaged for the two states. The average reported herd size (milking and dry cows) was 56, with a range of 10 to 385. Average daily milk production at the time the survey was taken was 52 pounds/cow/day for cows in milk and 42 pounds/cow/day when dry cows were included. From the dairy owners rough estimates, average annual mortality and culling rates for adult cows were calculated at 4.3 percent and 20.6 percent, respectively.

### 2. Clinical Signs of Herd Health Problems

Herd owners were asked how often each of 22 clinical signs of health or production problems were observed in their herds over the last 12 months. Respondents reported poor heat (estrus) expression, poor conception rate, and mastitis as the most frequently observed signs. Some of the least frequently observed signs were unhealed sores on cows' legs and bodies and various behavioral patterns (e.g., unusual behavior at the drinking cup, nose pressing, and excessive kicking).

Ten percent of all herd owners, at the time of the survey, thought that cows in their herds have persistent health and/or production problems. These dairy herds tended to have lower milk production, higher somatic cell counts, and more frequent adverse clinical signs than herds for which no such problems were reported.

### 3. Perceived causes of Herd Health and Production Problems

Herd owners were asked their opinions regarding importance of each of 26 factors in causing problems with animal health and/or production problems in their herds. Factors rated as most significant (top one-third) were forage quality, fresh cow performance, cow comfort, heat

detection, and animal housing or environment. Factors rated as least significant (bottom one third), were soil type, quality of outside experts' advice, stray voltage, and other electrical phenomena, and chemical contamination of feed or water.

Principal survey findings regarding electrical concerns:

- Thirty percent of the dairy herd owners reported that at some time they had a problem with herd health and/or production which they thought was caused mainly by stray voltage or some other electrical phenomena.
- Sixty percent of all dairy herd owners reported that their farms had been tested at least once for stray voltage; 15 percent reported testing for other electrical phenomena, such as magnetic fields, electric fields, EMF, ground currents or earth currents. Of these respondents, about one-half reported that the persons who conducted the tests informed them of stray voltage or other electrical conditions that should be corrected; eighty-seven percent of those with problematic conditions reported that corrective steps had been taken.
- Sixty percent of dairy operators reported that stray voltage testing was performed by employees of electric utilities. Thirty percent of dairy operators reported that electricians conducted such tests. Milk processing field representatives and dairy farm owners were also reported to have conducted stray voltage tests in 10-20 percent of the cases.
- Eighty-seven percent of dairy herd owners in Minnesota and Wisconsin who reported that electrical phenomena were investigated, also reported they were satisfied with both the investigations and attempts to correct stray voltage or other electrical conditions.
- Eight of the 679 owners in Minnesota and Wisconsin who both returned a completed mail survey and answered questions in the telephone survey, indicated that their herds presently had persistent problems with health and production and that they think uncorrected stray voltage or related electrical conditions are having negative effects on the health and production of their dairy herds.

## **Survey Conclusions**

The survey results place dairy farmers' perceptions about stray voltage and related electrical conditions into context with the variety of non-electrical factors that have long been known to be associated with poor herd health and low milk production. From their answers to several of the questions in both the mail and follow-up telephone surveys, it is clear that most owners of dairy herds in Minnesota and Wisconsin are much less concerned about stray voltage and other electrical conditions as the source of their unresolved health and production problems than claimed by TERF and by individual dairy farmers who reported in public hearings during meetings at the PUC. Most dairy farmers who have had potentially problematic electrical conditions on their farms appear to follow-up on them and are generally satisfied with the corrections recommended by electric utility representatives or other farm consultants.

## FIELD STUDY

The charge from the PUC was to examine the effects, if any, of currents in the earth and related parameters on dairy cows. However, such a mandate could not be fulfilled without also assessing non-electrical factors. It has long been known that certain non-electrical factors can significantly increase problems with cow health and production. Of all the complaints brought to the PUC or directly by farmers where electric currents in the earth were said to be involved, none showed convincing evidence that non-electrical factors could be ruled out. The survey results supported this decision.

In addition, there is little information on the electrical conditions on farms *that do not have* persistent problems with health and production. Further, no study was found in which electrical measurement protocols had been used uniformly such that results could be compared from farm to farm. For these reasons, a small field study was designed to assess the effects of both electrical and non-electrical factors on the health and productivity of dairy herds. The study included two different kinds of dairy operations, those with persistent and unresolved health and productivity problems, and those without such problems.

The primary objectives of the field study were:

- (1) To test the feasibility of implementing protocols in relatively short visits to dairy farms that would measure electrical factors, inspect electrical wiring conditions, and assess herd health and productivity.
- (2) To determine whether it is possible in a small field study to document associations among specific electrical or non-electrical factors and the health and productivity of dairy herds.
- (3) To assess the need for and approach to a larger scale study of potential factors that contribute to poor health and production of dairy herds.

The study did not evaluate on-farm or off-farm sources of electric and magnetic fields and voltages since the first step should be to establish whether the fields or voltages associated with earth and ground currents interact with the cow in the barn to induce health and production problems. Only if such an effect is found would it be appropriate to examine the sources and undertake some kind of mitigation.

The field study was carried out under contract to the PUC by Dr. Ashley Robinson and Dr. Will Marsh, both with the Department of Clinical and Population Sciences at the College of Veterinary Medicine, University of Minnesota, at the time of the study. Dr. Robinson was selected for his expertise in veterinary epidemiology; Dr. Marsh was selected for his expertise in agricultural statistics.

## Field Study Process

Actual field tests were conducted by a research team under contract to the PUC. The team consisted of a veterinarian, a specialist in electrical measurements, an electrical inspector, and two research assistants. One research assistant was responsible for pre-visit interviews and collection of available farm records. The other assisted both the veterinarian and the electrical measurement specialist. Three detailed protocols for the 3-4 day site visits by the team were developed: one for the evaluation of herd health, production and management; one for inspection of the farm wiring; and another for measurements of the electrical environment. The protocols were developed with Science Advisor advice as well as input of staff from the PUC, the Public Service Commission of Wisconsin, the Minnesota Department of Agriculture, and the Wisconsin Department of Agriculture, Trade and Consumer Protection; and representatives of special interest groups including various farm and dairy producer organizations, electric utilities, research universities and others. The field study data was analyzed by Dr. Marsh, with assistance from Ms. Doris Mold, also of the College of Veterinary Medicine of the University of Minnesota, and members of the field study research team.

The 1996 Progress Report of the Science Advisors identified five possible mechanisms by which the various electrical parameters associated with the electrical distribution system that supplies power to dairy farms could conceivably affect dairy cows' behavior, health or milk production (Minnesota PUC, 1996).

The hypotheses were:

1. AC Voltage: Continuous or frequently repeated contact of confined cows to sources of low level stray voltage may result in electric fields inside the cow at levels high enough to produce biological effects without producing observable or measurable behavior modifications.
2. Transient Voltage: Current transients may affect a cow through the associated transient stray voltage or through magnetic induction. Examples include 60 Hz transients from motor starting events, and high frequency transients from electrical switching events and from malfunctioning cow trainers and electric fences. The sources of these transients can originate on or off the farm.
3. AC Magnetic Fields: Magnetic fields from ac ground current on water lines in the barn may be large enough at the head of a cow to induce biological effects.
4. Interaction of ac and dc Magnetic Fields: Exposure of cows to ac magnetic fields from all sources in the barn combined with particular levels of the geomagnetic field may conceivably produce biological effects.
5. Pulsed Electric Fields: Pulsed electric fields from sources such as cow trainers may be locally large enough at the cow's back to be sensed by cows.

## **Electrical Measurement Conclusions:**

Data from the 1997 field study was reported by Hendrickson at the 1998 ASAE Annual Meeting, (Hendrickson & Patoch 1998a, 1998b). For each of the five electrical hypotheses posed, the following was concluded:

### 1. AC Voltage

The range of average front-to-rear hoof step potentials of dairy cows in stalls on the 17 farms where the measurement was made was 0.001 volts to 0.047 volts. Using data from published studies on animals other than dairy cows, it was estimated that voltages as low as 0.002 volts could conceivably cause internal electric fields in the cow that are high enough to produce a physiological response. If a physiological response is to occur in dairy cows, it is more likely to be produced by step potential exposures in the stalls rather than outside because (1) step potentials in the stall are larger than outside and (2) step potentials in the stall last longer because of longer periods of cow confinement.

No one has proposed a specific physiological response in dairy cows that are exposed to low level voltages (i.e., 1-100 millivolts range). It is not possible to extrapolate directly the research findings from other animal species directly to dairy cows. The various types of physiological responses (e.g., circulating hormones or their metabolites) to electric and magnetic field exposures that have been shown in the published literature to occur in various animals other than dairy cows, are neither equivalent to nor indicative of pathological effects that cause poor health and production in dairy cows. Since it is not possible to extrapolate to dairy cows, further studies that specifically examine exposure of dairy cows to step potentials lower than those threshold levels already known to elicit behavioral responses were recommended.

### 2. Transient Voltage

Measured magnitudes of transient voltages are lower than would be necessary to elicit a behavioral response in dairy cows according to the most recent laboratory research. Further, data from the field study demonstrate that transient voltages in a dairy barn are most often from nearby sources, a finding which supports previous research.

### 3. AC Magnetic Fields

Adverse physiological or biological effects of ac magnetic fields at levels in the range of those found in the field study have not been documented in the laboratory (Reinemann et al., 1995; and Burchard et al., 1996). Laboratory research on other animals has demonstrated effects caused by ac magnetic fields, but these results involve field strengths generally well above the 10 milligauss measured in this study. No ac magnetic fields were detected away from outside distribution lines; thus, there were no measurable ac magnetic fields associated with electric currents in the earth. These findings indicate that, at this time, further research on effects of ac magnetic fields on dairy cows is not a priority.

#### 4. Interaction of ac and dc Magnetic Fields

Some magnetic resonance conditions were found in the test stall at each of the farms studied. However, even the largest, single ac magnetic flux density measured in the field study was not as large as those used in published laboratory studies where effects have been observed. Because of this large difference, the likelihood is low that cyclotron or ion parametric resonance has affected cows under normal circumstances. Thus, further research on the interaction of ac and dc magnetic fields in dairy cows is not a priority at the present time.

#### 5. Pulsed Electric Fields from Cow Trainers

There does not seem to be a practical need to further study pulses of electric fields from cow trainers. As more farmers expand herd size and adopt loose housing for dairy cattle, the need for these devices will be reduced. The likelihood of electrical problems associated with improperly installed or malfunctioning cow trainer systems is high, and the pulsed electric fields from normally operating cow trainers may be large enough to be sensed by the cow. If trainers are perceived to cause problems, farmers can work to improve installation practices or discontinue using them altogether. There are many reasons why even the best installation and maintenance practices can lead to new problems over time.

#### 6. Conclusions Regarding Sources of Earth Currents

An extensive evaluation of the relative importance of on-farm and off-farm sources of earth currents and related step potentials or magnetic fields was not an objective of the field study, because it was to be established first whether such potentials or fields at the small expected amplitudes could be related to milk production or animal health. Furthermore, the measurements necessary to establish conclusively the sources of currents on the farm would have made the measurement protocol prohibitively time consuming and expensive.

### **Electrical Inspection Conclusions:**

The field study electrical inspections indicate that farm wiring is likely to result in hazardous conditions on many Minnesota farms. In many cases farm wiring resulted in elevated neutral-to-earth voltages in the barn. These hazardous conditions appear to be caused by the following factors:

- A substantial amount of wiring was done by the owner, operator, or other persons without electrical training.
- Many code violations were present in work done by electrical contractors.
- Electrical inspectors failed to note or did not require correction of some code violations.
- The wiring in general was not properly maintained or replaced when it became defective.

This situation could be improved by providing information to the users, improving the training of electricians, and by more effective administration of electrical inspection statutes in the state. Also, a re-inspection program, if implemented, could be effective.

### **Veterinary Analysis Conclusions**

The herds with persistent unresolved health and productivity problems differed from those without such problems by milk production, cow height, weight, body conditions, age and calving interval. Several non-electrical risk factors measured were associated with the lower productivity herds with persistent unresolved health problems. Those factors of greatest importance were lower standards for nutrition and cow comfort and use of vaccination to prevent infectious disease.

### **Author's Summary Comments**

Research recommended on low-level step potentials was funded at the University of Wisconsin. That research project was completed and a final report submitted to the Minnesota PUC by July 1 of 1999. The principal investigator, Doug Reinemann, has a report on that research at this meeting.

Concerns with earth currents instigated the formation of Science Advisors by the Minnesota PUC. Over a million dollars in State funds and four years of effort by many people were expended. No credible scientific links between earth currents and the health and production of dairy cows were found. The findings and recommendations of the Science Advisors is presented in the concluding section of this paper.

There are still those who propose removing electrical system grounding to prevent earth currents. The grounding of electrical systems has been studied extensively and has evolved over many years in order to improve the safety of those who use or supply electric equipment. Modifying the grounding systems will most often allow the electrical system to work. Yet, when a failure occurs, the system will not fail in a safe manner and loss of life or property will result.

As an agricultural engineer involved in electrical safety, I am very concerned if grounding is removed. The grounding systems that are in present codes and standards must be adhered to. If not, electrocution or property loss will certainly happen.

## **Findings and Recommendations from the Science Advisors Final Report to the Minnesota PUC on August 1, 1998.**

The findings and recommendations given below take into account our review and analysis of many different sources of information acquired by or provided to us over the four years of our term as advisors to the Minnesota Public Utilities Commission. The primary information sources we have used include:

- Research studies published in the peer-reviewed literature.
- Oral and written reports by concerned dairy farmers.
- Oral and written reports by electric utility company representatives.
- Oral and written reports by other citizens or scientists.
- Information provided by government agency staff with responsibility for matters pertaining to stray voltage and/or dairy cow health and production in Minnesota and Wisconsin.
- Information provided by groups that represent large numbers of dairy farmers such as the Minnesota Farmers Union and the Minnesota Milk Producers Association.
- The 1994 report of the Electromagnetics Research Foundation (TERF) written under contract to the Minnesota Department of Public Service with funds provided under the same legislation that authorized our own work.
- Site visits to Minnesota dairy farms with persistent, unresolved herd behavior, health and/or milk production problems.
- Results of the mailed and telephone surveys of Minnesota and Wisconsin dairy farmers.
- Results of the field study described in this report.

### **General Findings**

Based on our analysis of information from the above sources, we have reached the following conclusions:

1. We have not found credible scientific evidence to verify the specific claim that currents in the earth or associated electrical parameters such as voltages, magnetic fields and electric fields, are causes of poor health and milk production in dairy herds.
2. At the present time, there is no basis for altering the PUC-approved standards by which electric utilities distribute power onto or in the vicinity of individual dairy farms.
3. There are many well-documented non-electrical factors that are known and accepted by the scientific community, and by most farmers as well, to cause dairy cow health and production problems. Among the most noteworthy stressors are poor nutrition, poor cow comfort and hygiene, and low or no use of vaccinations and related preventive veterinary practices. Those who want to improve performance of dairy herds should always address these factors.

At the present time, there is only one electrical condition that is well documented in the peer-reviewed, published literature to influence adversely cow behavior, health or milk production under specific circumstances. That is cow contact stray voltage. The 19-farm field study did find significant differences between high and low producing herds in the levels of electrical step potentials and soil resistivity in the field. Findings from epidemiological studies (i.e., those that employ field data to examine risks associated with specific factors) and laboratory research are important in uncovering and exploring new ideas about possible biological or physiological effects resulting from the various electrical parameters associated with electric distribution systems. In studies where effects have been established, they have either been potentially adverse, potentially beneficial or potentially neutral to the cell, animal or human system under study. Indeed, the scope and direction of current research in this area is in flux and we encourage additional basic research.

There has been some confusion among the general public, politicians and government decision makers about the relationships between currents in the earth and their *possible* effects on dairy cows versus the possible effects of overhead ac power lines or the high voltage DC power line built in Minnesota and widely debated in the late 1970's. Our analysis has focused only on the question of currents in the earth arising from the grounded ac electric distribution system. This report excludes other types of electrical power distribution systems, such as the DC power line. The 60 Hz magnetic fields that arise from overhead power lines were recently addressed in the report of an advisory committee to the National Institute of Environmental Health Sciences (NIEHS) that met in June 1998. The NIEHS committee found a possible relationship between low frequency magnetic fields from overhead ac power lines and certain forms of cancer in humans. However, the NIEHS committee findings should not be used to draw conclusions about possible effects on dairy cows from currents in the earth from electric distribution systems.

It is important to note here that there is a difference between what is conceivable or possible and what is likely or probable. For example, the Niehs committee concluded that there is a "possible" not a "probable" association between the presence of 60 Hz magnetic fields of 2-3 milligauss or higher and childhood leukemia. In the 19-farm field study described in this report, the average ac magnetic fields measured inside the dairy barns were on the order of 0.5 milligauss. Thus with the present body of evidence, it is our best judgement that magnetic fields from earth currents or any other contributory sources in the dairy barn are not of sufficient levels to cause any health or production problems in dairy cows.

## **Recommendations**

- The Minnesota Public Utilities Commission should advise the Minnesota Departments of Agricultural and Public Service, the Minnesota Board on Electricity, the University of Minnesota, and other agencies with appropriate missions on the need to support training of dairy farmers, utility electric engineers, government agency staff, electrical inspectors, veterinarians, insurers, milk processors and other consultants to dairy farmers. This training should address the importance of collaboration, discussion and evaluation by consultants with varying expertise in simultaneously assessing the potential for both electrical and non-electrical causes of health and production problems.
- The protocols developed for the field study and appended to this report should be given to the Minnesota Department of Agriculture so they can make them available for use by the dairy diagnostic team grants program in the state of Minnesota, as needed.
- Depending on the results of the research on low level step potentials that is now underway in Dr. Reinemann's laboratory, the Minnesota Public Utilities Commission should encourage investigators, including Dr. Reinemann, to pursue additional funds for extending that research, as appropriate.
- Although research on low level step potentials is the priority at this time, if more funds become available for research, attention should be paid to possible effects of magnetic fields on farm animals.

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