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# Intensity of electric and magnetic fields from power lines within the business district of 60 Ontario communities

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**Abstract**

Electric and magnetic fields were measured during the summer of 1998 in south-central Ontario within the business district of 60 communities, ranging in size from 1000 to 2.3 million people. The mean magnetic flux density for the 60 communities was 5.8 mG. Communities with larger populations generally had higher magnetic flux densities than those with smaller populations. Communities with populations above 100 000, between 50 000 and 100 000, between 10 000 and 50 000, and less than 10 000 had mean magnetic flux densities of 14, 7, 4 and 2.4 mG, respectively. The city of Kingston, population 123 000, had the highest mean magnetic flux density (47 mG) while Burks Falls, population 1000, had the lowest (0.8 mG). More than 90% of the sites measured in Kingston, Toronto, Oshawa, London, Pickering Village and Bellville were above 2 mG, the lower limit associated with childhood cancers. In only one community (Burks Falls) were all of the measurements in the business district below 2 mG. Diurnal variations were detected in the magnetic field (but not in the electric field) with highest fields measured during business hours. For electric fields, the mean for the 60 communities was 3.2 V/m. Electric fields were generally low. Eight communities had maximum field strengths above 30 V/m and all of these were associated with overhead wires. In larger communities with underground distribution lines the electric fields were low or undetectable ($<0.1$ V/m) but the magnetic fields were often high. High electric fields were generally associated with low magnetic fields but the relationship was not sufficiently robust to enable prediction of one from the other. Data for the business district measured during business hours appear to be relatively consistent for both electric field and magnetic flux density over a two-year period. Two classification schemes that can be used independently or in combination are proposed to facilitate community comparisons. One is based on the average intensity of the fields (FI) and the other on the percentage of measurements that exceed a critical limit (CL) that has biological significance. The critical value of 5 V/m is proposed for electric fields and 2 mG for magnetic fields. Both classification schemes use the traffic light analogy for exposure (green-low, amber-medium, red-high exposure) with an additional category (black) for very high exposure. This classification system facilitates information transfer and can easily be understood and used by the public, public utilities, policy makers, and those wanting to practice prudent avoidance.
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*Keywords:* Power distribution; Electric field; Magnetic field; Magnetic flux density; Extremely low frequency; Electromagnetic field; Prudent avoidance; Business district; Urban centers; Ontario

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## 1. Introduction

In 1998, the National Institute of Environmental Health Sciences concluded that extremely low frequency (ELF) electromagnetic fields (EMF) can be classified as 'possibly carcinogenic'. They based this decision on an increased risk for childhood leukemias with residential exposure and an increased occurrence of chronic lymphocytic leukemia associated with occupation exposure (Portier and Wolfe, 1998).

Since 1998, the evidence that power frequency electromagnetic fields have adverse biological and health effects continues to mount for childhood cancers at residential exposure (Ahlbom et al., 2000; Schuz et al., 2001; Wartenburg, 2001); for childhood cancers following parental exposure (Feychting et al., 2000); and for occupational cancers including leukemia, brain cancer, and breast cancer (Savitz et al., 2000; Erren, 2001; Kheifets, 2001; Minder and Pfluger, 2001). Some of the evidence for electromagnetic field exposure also includes increased risk of miscarriage (Li et al., 2002); neurodegenerative diseases such as amyotrophic lateral sclerosis and Alzheimer's disease (Ahlbom, 2001); heart disease (Savitz et al., 1999); and suicides (van Wijngaarden et al., 2000).

In residential studies, the adverse health effects have been associated with magnetic field exposure, specifically, since the electric field generated by power lines does not penetrate buildings. People are exposed to electric fields from power lines and transformers only when they are outdoors. In occupational settings in the presence of high voltages, the electric field component is likely to be bioactive as demonstrated in an Ontario Hydro study of acute myeloid leukemia (Miller et al., 1996).

If EMFs are indeed 'possible carcinogens' and if they have other adverse biological and health effects, then all possible sources of exposure, including those both inside and outside the home and workplace, should be determined. While there has been progress in documenting fields associated with appliances (DeMatteo, 1986; EPA, 1992; Kaune et al., 2002), with fields within the home (EPRI, 1993) and with several types of occupations (Lea et al., 1989; Portier and Wolfe, 1998), only one study, so far, has measured field strengths on city streets (Lindgren et al., 2001).

The paucity of information about electromagnetic fields in urban centers prompted this study, the purpose of which is to document the strength of both electric and magnetic fields along the sidewalks in the business district of cities and towns in south-central Ontario and to classify the field strengths so that the information can be readily understood and used by the public, public utilities, and policy makers alike. This information is likely to be useful for those wanting to practice prudent avoidance and for studies of risk assessment for which even short-term high exposure is likely to be important.

## 2. Method

### *2.1. Measurement of electric and magnetic fields*

A total of 60 urban communities ranging in population size from 1000 to 2.3 million were selected for this study covering a total population of 5.7 million people (Table 1). All communities are within the area known as south-central Ontario and are bounded by Sudbury (north), Sarnia (west), Niagara Falls (south) and Cornwall (east) (Fig. 1). The magnetic[1] (mG) and electric (V/m) fields were measured at street intersections within the business district of each community on weekdays (Monday through Friday) during business hours (09.00h to 17.00h). Intersections were selected so that future studies in these communities can be compared. Time of monitoring corresponds to maximum power use for a business district and maximum human exposure in terms of workers in the downtown core as well as pedestrian traffic. Sites were measured from July to September 1998. Six communities (Norwood, Havelock, Hastings, Pickering Village, Peterborough, and Oshawa) were revisited in June 2000 to determine variability of the data over time (Table 2).

The magnetic flux density was measured using an omni-directional, handheld, battery operated

[1] Magnetic flux density and magnetic field are used interchangeably in this paper. Both refer to the scientifically appropriate term 'magnetic flux density'.

Table 1
The business district (as indicated by the main street and intersections) of 60 communities in south-central Ontario monitored for electric and magnetic fields. Communities are arranged by decreasing population size. The monitoring dates and number of corners monitored ($n$) are provided

| | City | Pop'n ('000) | Date 1998 | *N* | Main street (intersections) |
|---|---|---|---|---|---|
| | All | 5,700 | July to Sept | 1437 | |
| | **Pop'n > 100 000** | | | | |
| 1 | Toronto | 2,266 | 26-Aug | 108 | Yonge (Bloor to Front) |
| 2 | London | 331 | 01-Sep | 20 | Dundas (Talbot to Waterloo) |
| 3 | Ottawa | 325 | 13-Jul | 70 | Spark, Elgin, Laurier, Kent |
| 4 | Hamilton | 318 | 31-Aug | 24 | James (Wilson/York to Jackson) |
| 5 | Brampton | 283 | 28-Jul | 32 | Main (Market to Wellington) + Queen (George to Chapel) |
| 6 | Marham (old) | 154 | 28-Jul | 33 | Hwy 48 (Ramona to Hwy 7) |
| 7 | Oshawa | 139 | 03-Aug | 20 | Simcoe (Williams to Athol) |
| 8 | Burlington | 137 | 31-Aug | 28 | Brant (Caroline to Lakeshore) |
| 9 | St. Catharine | 130 | 31-Aug | 36 | St Paul (Geneva to West Chester) |
| 10 | Oakville | 127 | 31-Aug | 20 | Lakeshore (Navy to Trafalgar) |
| 11 | Kingston | 123 | 24-Jul | 36 | Princess (Division to Ontario) |
| | **Pop'n 50 000–100 000** | | | | |
| 12 | Barrie | 97 | 11-Aug | 24 | Dunlop (Maple to Mulcaster) |
| 13 | Guelph | 97 | 09-Sep | 24 | Wyndham (Woolwich to Carden) |
| 14 | Sudbury | 93 | 25-Aug | 32 | Elm (Elgin to Paris) + Durham (Massachussets to Elgin) |
| 15 | Cambridge | 93 | 09-Sep | 24 | Main (Grand to Wellington) |
| 16 | Sarnia | 87.9 | 01-Sep | 28 | Christina (London to Cromwell) |
| 17 | Pickering Village | 81 | 03-Aug | 16 | Old Kingston Rd (Elizabeth to Church) |
| 18 | Niagara Falls | 75.4 | 31-Aug | 28 | Queen (Victoria to Erie) |
| 19 | Whitby | 74 | 03-Aug | 18 | Brock (Mary to Dunlop) |
| 20 | Waterloo | 71 | 09-Sep | 28 | King (Water to Benton) |
| 21 | Peterborough | 67 | 15-Jul | 24 | George (Brock to Sherbrooke) |
| 22 | North Bay | 63.3 | 25-Aug | 24 | Main (Cassells to Sherbrooke) |
| | **Pop'n 10 000–50 000** | | | | |
| 23 | Newmarket | 45 | 11-Aug | 24 | Main (Water to Queen) |
| 24 | Chatham | 43.6 | 01-Sep | 28 | King (Third to William) |
| 25 | Cornwall | 42 | 20-Aug | 20 | Pitt (Fifth to First) |
| 26 | Bellville | 37 | 17-Aug | 20 | Front (Moira Bridge to Bridge) + Pinnacle & Bridge |
| 27 | Stratford | 28 | 09-Sep | 18 | Ontario (Huron to Waterloo) |
| 28 | Orillia | 27 | 11-Aug | 20 | Mississauga (Andrew to Front) |
| 29 | Brockville | 21 | 20-Aug | 32 | King (Perth to Market) |
| 30 | Lindsay | 21 | 27-Jul | 21 | Kent (Victoria to Lindsay) |
| 31 | Preston | 19 | 09-Sep | 20 | King (Waterloo to Lowther) |
| 32 | Stouffville | 18.4 | 27-Jul | 30 | Main (Albert to Park) |
| 33 | Bradford | 17.7 | 11-Aug | 13 | Holland (Simcoe to Holland Cres) |
| 34 | Trenton | 17 | 17-Aug | 20 | Dundas (Division to Front) + Front & Elgin |
| 35 | Cobourg | 15 | 23-Jul | 18 | King (Hibernia to Division) + Queen & Division |
| 36 | Huntsville | 15 | 24-Aug | 24 | King (Centre to John) |
| 37 | Pembroke | 14 | 11-Sep | 32 | Pembroke (Agnes to Mackay) |
| 38 | Port Hope | 12.5 | 23-Jul | 19 | Walton (Cavan to Queen) + Cavan & Maitland |
| 39 | Bracebridge | 12.3 | 24-Aug | 25 | Manitoba (McMurray to Entrance) |
| 40 | Wallaceburg | 11.8 | 01-Sep | 20 | James (Wellington to Nelson) |
| | **Pop'n < 10 000** | | | | |
| 41 | Gravenhurst | 9.5 | 24-Aug | 20 | Muskoka (Church to Sharpe) |
| 42 | Smith Falls | 9 | 20-Aug | 16 | Beckwith (Russell to Chambers) |

Table 1 *(Continued)*

| | City | Pop'n ('000) | Date 1998 | *N* | Main street (intersections) |
|---|---|---|---|---|---|
| 43 | Parry Sound | 6 | 25-Aug | 26 | James (Sequin to McMurray) + Seguin (Gibson to Great North) |
| 44 | Port Perry | 6 | 27-Jul | 17 | Queen (Simcoe to Water) |
| 45 | Perth | 6 | 20-Aug | 16 | Gore (Foster to Basin) |
| 46 | Sturgeon Falls | 5.8 | 25-Aug | 16 | King (John to Hwy 17) |
| 47 | Napanee | 5.2 | 17-Aug | 20 | Dundas (Centre to Bridge) |
| 48 | Picton | 4.6 | 17-Aug | 20 | Main (Chapel to Bridge) |
| 49 | Brighton | 4 | 17-Aug | 16 | Main (Kingsley to Young) |
| 50 | Uxbridge | 4 | 27-Jul | 14 | Brock (Spruce to Main) |
| 51 | Bowmanville | 4 | 03-Aug | 16 | King (Scugog to Division) |
| 52 | Campbellford | 3.4 | 15-Jul | 14 | Bridge (Queen to Town Hall) |
| 53 | Lakefield | 2.6 | 15-Jul | 10 | Queen (Reid to Water) + Water & Bridge |
| 54 | Bancroft | 2.4 | 11-Sep | 20 | Hastings (Madawaska to Bridge) |
| 55 | Madoc | 1.8 | 20-Aug | 12 | Durham (St. Lawrence to Elgin) + St. Lawrence & Davidson |
| 56 | Havelock | 1.4 | 15-Jul | 15 | George (Quebec to Orange) + Hwy 7 & Concession |
| 57 | Norwood | 1.3 | 15-Jul | 16 | Colbourne (Hwy 7 to Spring) + Hwy 7 & Pine + Victoria & Alma |
| 58 | Barry's Bay | 1.2 | 11-Sep | 20 | Opeongo (Martin to Stafford) |
| 59 | Hastings | 1.2 | 15-Jul | 16 | Front (Trent to Victoria) + Bridge & Albert |
| 60 | Burks Falls | 1.0 | 24-Aug | 16 | Ontario (Yonge to Queen) |

Trifield™ meter that was calibrated by the manufacturer. It has a sensitive range for magnetic flux density from 0.2 to 3 mG with a resolution of 0.2 mG. In the high range, it can measure magnetic flux densities from 1 to 100 mG with an accuracy of +20% at mid-range. The Trifield meter measures frequencies of 60 Hz and from 30 to 500 Hz in the sensitive and high ranges respectively. Thus harmonics associated with 60-Hz power distribution are detected in the high range.

The electric field was measured with a Magnetic Sciences International™ (MSI) digital multimeter equipped with a 9-cm vertical antenna. This meter can detect electric fields from 0.1 V/m to 750 kV/m with a precision of ±15%. It is calibrated for electric fields at 60 Hz so accuracy degrades at higher and lower frequencies. The meter was held at a height of approximately 100 cm above the ground and 30 cm from the body. The author measured all the fields and wore rubber-soled shoes throughout the study. All readings were taken during dry weather. Despite these precautions, the electric field readings were taken within 30 cm of the researcher and cannot be considered 'unperturbed' fields. For this reason they should be considered relative rather than absolute since so many factors can alter them. During June 2000 the values obtained by the MSI meter were compared with an extended range Trifield Meter (Model 100XE, range 1–100 V/m) for 6 communities. Results are shown in Fig. 2.

To determine site variability for magnetic flux density, multiple readings were taken within a 30-min period at the intersection of George and Brock in Peterborough. This is a corner where the magnetic field oscillates slightly and should thus produce high variability. A total of 10 readings at each corner ($n=40$) gave a mean and S.D. of $17\pm1.6$ mG and a S.E. of 0.5 mG.

To determine diurnal changes, one community (Peterborough) was selected for 24-h monitoring at 4-h internals for magnetic flux density and electric field strength (Fig. 3).

Measurements were taken at all corners of an intersection (NE, NW, SE, SW) where people normally stand to cross the street. Traffic lights, overhead wires, and pole-mounted step-down transformers within a few meters of the corner were noted since these are likely sources of electromagnetic fields. Trees or metal poles that may block the electric field coming from overhead wiring were also noted. Time of monitoring was

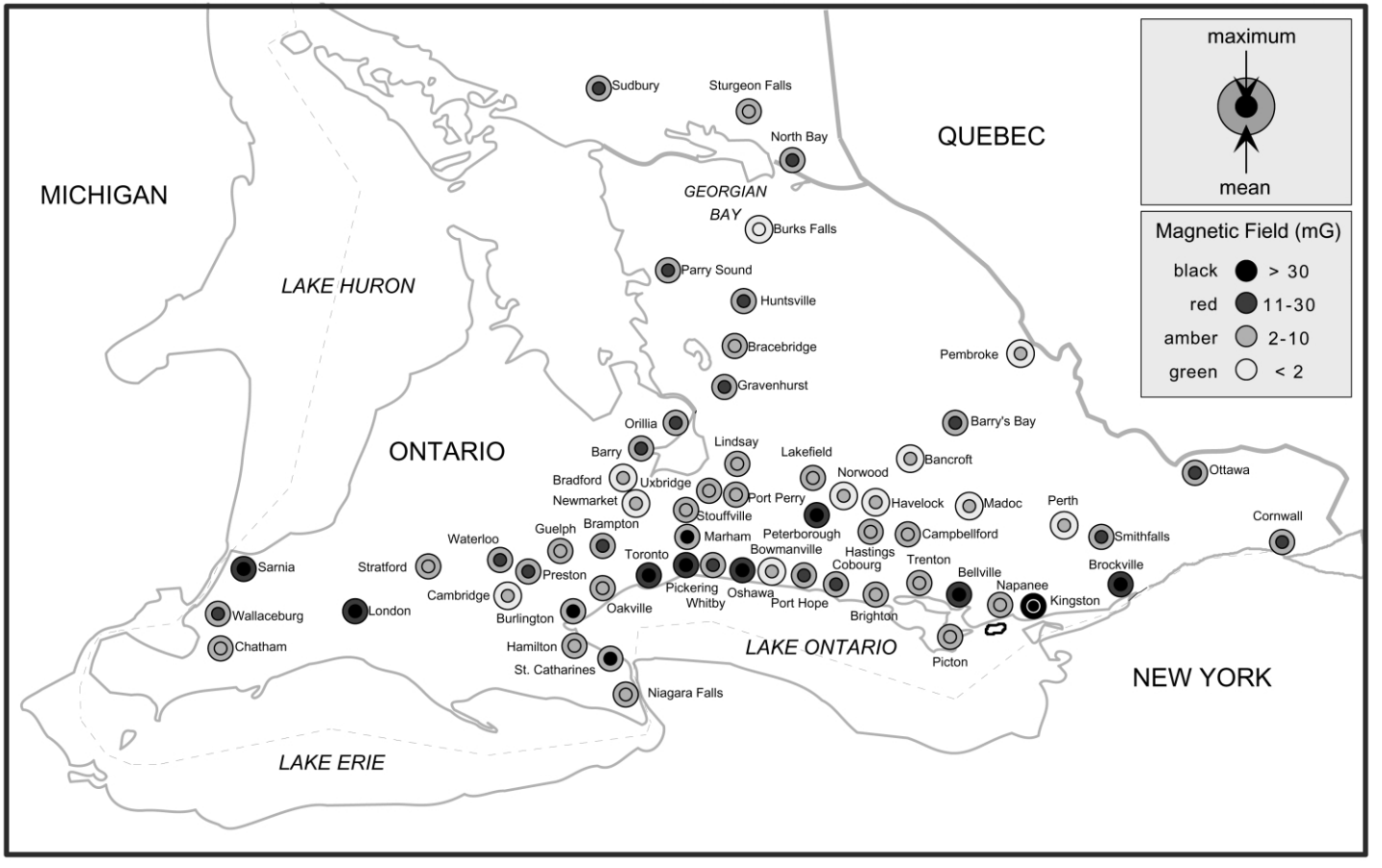



Fig. 1. Power frequency magnetic fields for 60 communities in south-central Ontario. Concentric circles represent the mean and maximum values for the business district during business hours. Color code is based on traffic light analogy for exposure, as follows: low (green), medium (amber), high (red) and very high (black) exposure.

recorded for each measurement since magnetic field strength is a function of current and current can change with time.

Intersection values are based on the mean corner values. The intersection values may not necessarily represent the values along a street and hence the maximum field strength between intersections on both sides of the street was also recorded (see results for Toronto, Fig. 4).

The number of measurements needed to determine the field strengths of the 'business district' depends on the size of the community. In small communities, the business district may consist of the 'four corners' and for these communities measuring the intersection at the four corners and in either direction (for a total of 5 intersections) may be enough to represent that community. In larger communities, the main street running through town with 4 or more intersections may be most representative of the business district. In even larger communities, several streets running in both directions may be used to represent the business district, although a survey of one street may be sufficient for an initial assessment.

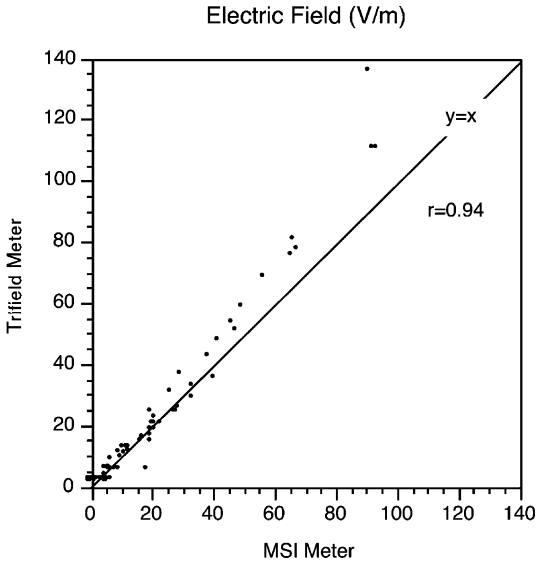



Fig. 2. Comparison of electric fields as measured by the Trifield meter and the MSI meter for six communities in south-central Ontario (Hastings, Havelock, Norwood, Oshawa, Peterborough, and Pickering Village). The electric fields were measured on street corners within the business district during business hours in June 2000 ($n=99$ corners).

### 2.2. Proposed classification scheme for electric and magnetic fields

An attempt was made to establish a classification scheme for both electric and magnetic fields that would facilitate community comparisons or comparisons of one community over time. Two classification schemes are proposed which can be used independently (Table 3) or in combination

Table 2
Comparison of magnetic and electric fields measured in 1998 and 2000 in 6 communities in south-central Ontario

| Community (pop'n) | Year | Magnetic flux density (mG) | | | | Electric field (V/m) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Min | Mean | Max | *n* | Min | Mean | Max | *n* |
| Oshawa | 1998 | 1 | 30 | 90 | 20 | 0.2 | 0.3 | 0.6 | 20 |
| (139 000) | 2000 | 0.9 | 33 | 101 | 19 | 0 | 0.3 | 0.7 | 20 |
| Pickering | 1998 | 2 | 11 | 48 | 16 | 3 | 16 | 44 | 16 |
| (81 000) | 2000 | 1.2 | 8.2 | 52 | 16 | 7 | 41 | 94 | 16 |
| Peterborough | 1998 | 0.4 | 21 | 110 | 24 | 0.2 | 2 | 15 | 24 |
| (67 000) | 2000 | 1.4 | 16 | 90 | 24 | 0.3 | 6 | 48 | 24 |
| Havelock | 1998 | 0.2 | 1.9 | 6 | 19 | 1.6 | 20 | 68 | 19 |
| (1400) | 2000 | 0.3 | 1.5 | 5 | 19 | 1.6 | 24 | 93 | 19 |
| Norwood | 1998 | 0.5 | 1.7 | 2.8 | 12 | 0.3 | 14 | 56 | 12 |
| (1300) | 2000 | 0.4 | 1.3 | 1.8 | 12 | 0.3 | 15 | 57 | 12 |
| Hastings | 1998 | 1.3 | 2.6 | 8 | 16 | 0.2 | 8 | 50 | 16 |
| (1200) | 2000 | 0.5 | 1.6 | 5 | 16 | 1 | 12 | 68 | 16 |

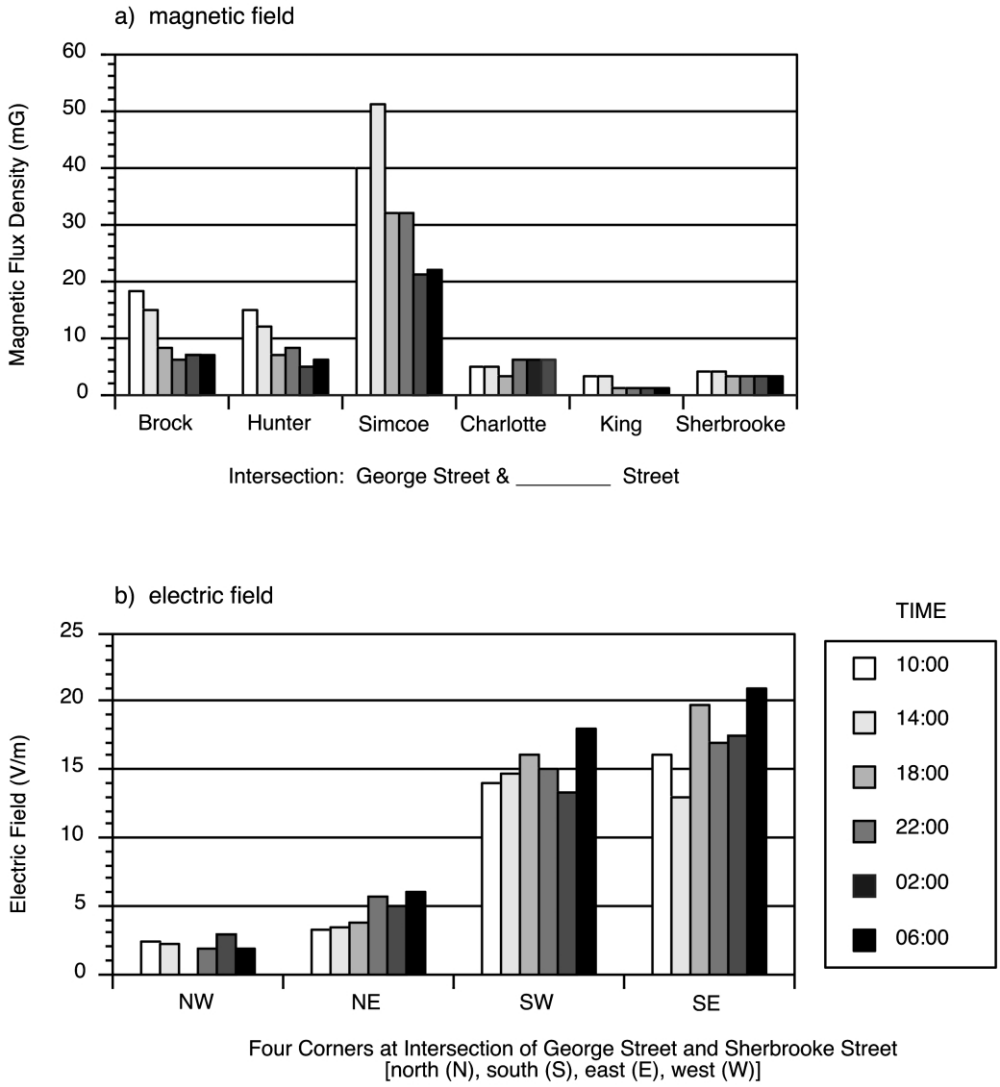



Fig. 3. Diurnal measurements of the (a) magnetic field and (b) electric fields at major intersections along George Street in Peterborough on September 21 and 22, 1998. An appreciable electric field was detected on the only corner with overhead distribution lines (George and Sherbrooke). All other intersections had buried power lines.

(Table 4 ). One is based on average intensity of the fields (FI) for the community and the other on the percentage of readings above a critical limit that has biological significance. The critical limit for the classification system is based on the lowest intensity of the electric and magnetic fields that is likely to have biological significance to the more sensitive individuals in the population. In this regard it reflects setting of drinking water standards for sodium and nitrate concentrations.

### *2.3. Magnetic flux density*

For magnetic fields, four biologically important end points have been documented in the literature. One of these has been linked to childhood leukemia and is between 1.4 and 4 mG (Wertheimer and Leeper, 1982; Savitz et al., 1988; Green et al., 1999; Ahlbom et al., 2000). For this classification scheme a value of 2 mG has been selected and this will be referred to henceforth as the lower

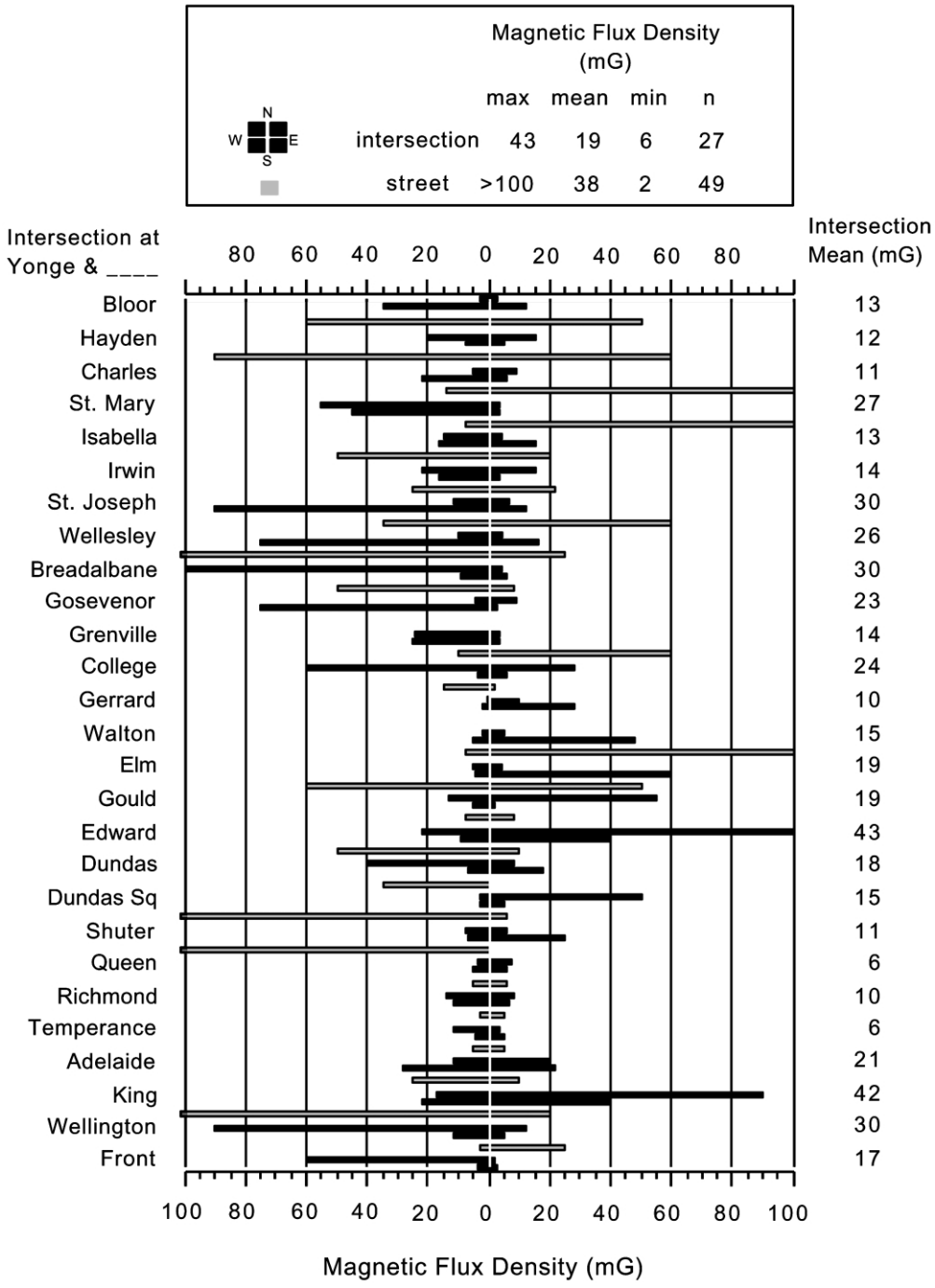



Fig. 4. Magnetic flux density along Yonge Street in Toronto, Canada. Measurements were taken on August 26, 1998 between 12:10 and 14:30 local time. Values are provided for each corner at each intersection (black bar) and for maximum values between intersections (gray bar).

Table 3
Classification scheme proposed for electric and magnetic fields based on field intensity (FI) and percentage of readings that exceed a biologically established critical limit (CL). Both classifications are modeled on traffic lights (green, amber, red) for low, medium and high exposure with an additional category (black) for very high exposure. Categories can be converted into a numeric code for statistical manipulation

| Number Code | Colour code (exposure) | FI: Mean field intensity categories | | CL: Critcal limit (% of readings above CL[a] | |
|---|---|---|---|---|---|
| | | Electric | Magnetic | Electric | Magnetic |
| 1 | Green (low) | <5 V/m | <2 mG | 0% | 0% |
| 2 | Amber (medium) | 5–10 V/m | 2–10 mG | 1–20% | 1–20% |
| 3 | Red (high) | 10–30 V/m | 10–30 mG | 21–50% | 21–50% |
| 4 | Black (very high) | >30 V/m | >30 mG | 51–100% | 51–100% |

[a] Critical limit (CL): 5 V/m electric field; 2 mG magnetic flux density.

limit for childhood cancers (LLCC). A second end point is 12 mG, which has been associated with increased growth of human breast cancer cells in vitro (Liburdy et al., 1993; Harland and Liburdy, 1997; Blackman et al., 2001; Ishido et al., 2001). The third is for spontaneous abortions associated with a maximum exposure above 16 mG (Li et al., 2002), and the fourth is for chromosomal aberrations in peripheral lymphocytes between 20 and 150 mG (Nordenson et al., 2001).

### 2.4. Electric field

For electric fields, the critical value of 5 V/m has been selected based on a paper by Kulczycki (1989) who claims that biologically significant strengths (for continuous exposure) are considered to start at 6 V/m.

Shandala et al. (1988) report that electric fields, even at low intensities, are biologically active and elicit measurable responses in the form of pathological changes (between 1 and 5 kV/m) or functional changes (7–100 V/m) in a variety of organisms. Effects include altered rate of mitochondrial metabolism in the brain cortex, altered thyroid function, and ECG and histopathological changes in the myocardium. Effects on reproduction, based on experiments with rats, include increased estrous and gestation time, decreased spermatogenesis with more atypical sperms, increased fetal and post-fetal mortality and decreased growth of young. Changes in reaction time among primates were found at 7–100 V/m (as cited in Shandala et al., 1988).

Blackman et al. (1988a,b) reported statistically significant changes in calcium flux in chick brain when the eggs were incubated in a 10-V/m electric field, 0.73-mG (0.073-uT) magnetic field, and at a frequency of 50 Hz and 60 Hz.

Villeneuve et al. (2000) reported an increased risk of developing leukemia among electric utility workers employed for at least 20 years and working in the highest tertile of percentage of time spent above 10 V/m (OR 10, 95% CL 1.58–65.3). In this study they did not observe an increased risk with magnetic field exposure and leukemia.

A value of 5 V/m is at the low end of the electric field and while pathological effects are unlikely at this intensity, functional changes are possible.

### 2.5. Classification schemes: critical limit and field intensity

Both the critical limit (CL) and field intensity (FI) classification schemes use the traffic light analogy for exposure (green = low, amber = medium, red = high; with an additional category, black, for very high exposure). The CL classification

TABLE 4. Combination of the two classification schemes (Field Intensity and Critical Limit) for electric or magnetic fields gives numerical categories ranging from 2 to 8. As an example, for magnetic flux density a combined value of 3 are for communities with 1-20% of the readings above 2 mG and with an average field below 2 mG. Seven of the 60 communities fall into that category. Refer to Table 3 for description of colour codes and classification systems.

## MAGNETIC FLUX DENSITY

**CLASSIFICATION** — **FI: Mean Field Intensity (mG)**

| | % of readings > CL of 2 mG | code | < 2 | 2-10 | 11-30 | > 30 |
|---|---|---|---|---|---|---|
| | | | green=1 | amber=2 | red=3 | black=4 |
| | 0 | green=1 | 2 | 3 | 4 | 5 |
| CL: | 1-20% | amber=2 | 3 | 4 | 5 | 6 |
| Critical | 21-50% | red=3 | 4 | 5 | 6 | 7 |
| Limit | 51-100% | black=4 | 5 | 6 | 7 | 8 |

**NUMBER OF COMMUNITIES PER CATEGORY** — **FI: Field Intensity (mG)**

| | % of readings > CL of 2 mG | # communities | < 2 | 2-10 | 11-30 | > 30 |
|---|---|---|---|---|---|---|
| | | | green | amber | red | black |
| | 0 | green | 4 | 0 | 0 | 0 |
| CL: | 1-20% | amber | 7 | 4 | 0 | 0 |
| Critical | 21-50% | red | 0 | 27 | 0 | 0 |
| Limit | 51-100% | black | 0 | 9 | 8 | 1 |

impossible combination

unlikely combination

**COMMUNITY RANKING**

| code | # communities | community names |
|---|---|---|
| 2 | 4 | Burks Falls, Cambridge, Norwood, Pembroke |
| 3 | 7 | Bancroft, Bowmanville, Bradford, Havelock, Madoc, Newmarket, Perth |
| 4 | 4 | Guelph, Hastings, Port Perry, Trenton |
| 5 | 27 | Barrie, Barry's Bay, Bracebridge, Brighton, Burlington, Campbellford, Chatham, Cornwall, Gravenhurst, Hamilton, Huntsville, Lakefield, Lindsay, Napanee, Niagara Falls, Oakville, Orillia, Ottawa, Picton, Preston, Smith Falls, Stouffville, Stratford, Sturgeon Falls, Uxbridge, Wallaceburg, Waterloo |
| 6 | 9 | Brampton, Cobourg, Markham, North Bay, Parry Sound, Port Hope, St. Catharine, Sudbury, Whitby |
| 7 | 8 | Bellville, Brockville, London, Oshawa, Peterborough, Pickering Villiage, Sarnia, Toronto |
| 8 | 1 | Kingston |

## ELECTRIC FIELD

**CLASSIFICATION** — **FI: Mean Field Intensity (V/m)**

| | % of readings > CL of 2 mG | code | < 5 | 5-10 | 11-30 | > 30 |
|---|---|---|---|---|---|---|
| | | | green=1 | amber=2 | red=3 | black=4 |
| | 0 | green=1 | 2 | 3 | 4 | 5 |
| CL: | 1-20% | amber=2 | 3 | 4 | 5 | 6 |
| Critical | 21-50% | red=3 | 4 | 5 | 6 | 7 |
| Limit | 51-100% | black=4 | 5 | 6 | 7 | 8 |

**NUMBER OF COMMUNITIES PER CATEGORY** — **FI: Field Intensity (V/m)**

| | % of readings > CL of 2 mG | # communities | < 5 | 5-10 | 11-30 | > 30 |
|---|---|---|---|---|---|---|
| | | | green | amber | red | black |
| | 0 | green | 14 | 0 | 0 | 0 |
| CL: | 1-20% | amber | 21 | 0 | 0 | 0 |
| Critical | 21-50% | red | 10 | 3 | 0 | 0 |
| Limit | 51-100% | black | 0 | 3 | 5 | 0 |

**COMMUNITY RANKING**

| code | # communities | community names |
|---|---|---|
| 2 | 14 | Barrie, Bellville, Chatham, Lakefield, Oakville, Oshawa, Ottawa, Pembroke, Perth, Stratford, Sudbury, Trenton, Wallaceburg, Waterloo. |
| 3 | 21 | Brighton, Brockville, Cambridge, Campbellford, Gravenhurst, Kingston, Lindsay, London, Napanee, Newmarket, Orillia,Parry Sound, Peterborough, Picton, Port Hope, Port Perry, Preston, Sarnia, Toronto, Uxbridge, Whitby |
| 4 | 10 | Bancroft, Bracebridge, Bradford, Brampton, Cobourg, Cornwall, Guelph, Huntsville, North Bay, Sturgeon Falls |
| 5 | 3 | Bowmanville, Burks Falls, Smith Falls |
| 6 | 3 | Barry's Bay, Hastings, Madoc |
| 7 | 5 | Havelock, Markham, Norwood, Pickering Villiage, Stouffville |
| 8 | 0 | no communities |

scheme is based on the percentage of readings within a community at or above a critical limit of 2 mG for magnetic field and 5 V/m for electric field (Table 3). These critical limits are first approximations that may change as we learn more about the mechanism of EMF exposure.

The FI classification scheme is based on the intensity of the field as measured by the mean for a community, also shown in Table 3. In this scheme the 12 mG value associated with enhanced growth of breast cancer cells and the 16 mG associated with miscarriages both fall within the red category (11–30 mG). The increase in chromosomal aberrations reported for train engine drivers between 20 and 150 mG (Nordenson et al., 2001) span the red and black categories.

Based on FI, any measurement of magnetic flux density or electric field can be classified into one of 4 categories. Hence, street corners, intersections, streets, and entire communities can be thus classified. Information can be displayed visually as shown in Fig. 1. The color code can be converted into a numeric code (green = 1, amber = 2, red = 3, black = 4) and manipulated statistically. But, most importantly, this classification system facilitates rapid comparisons and can be easily understood and used by those lacking technical expertise.

For some biological responses there appear to be intensity windows, which means that higher field strengths may not necessarily be more harmful (Takahashi et al., 1986; Blackman et al., 1982; Delgado et al., 1982). If this is the case, then the CL classification system is likely to be more useful than that of FI. While the two classification schemes can be used independently, they can also be combined and converted into a numerical classification system ranging from 2 to 8 (Table 4).

## 3. Results

### *3.1. Magnetic flux density*

The mean magnetic flux density exposure, based on the 60 communities assessed in Ontario, is 5.8 mG (amber). The mean magnetic flux density for communities with populations above 100 000 is 14 mG (red), for those between 50 000 and 100 000 it is 6.8 mG (amber), and for those between 10 000 and 50 000 it is 4 mG (amber). For the smallest communities, i.e. with less than 10 000, the average is 2.4 mG (amber) (Table 5, Fig. 5). The larger the community the greater is the exposure to magnetic fields in the business area, with a few exceptions.

The city of Kingston is the only community among the 60 monitored that has an average community magnetic flux density above 30 mG, category black (mean 47 mG for Princess Street from Division to Ontario Street, Fig. 1, Table 5). Only 3% of the readings along Princess Street in Kingston were below 2 mG (green) (Fig. 5).

The larger urban centers of Oshawa, London, and Toronto all have average magnetic flux densities above 10 mG (category red). Toronto, which is by far the largest city, is ranked 8th in this grouping of 11 communities (>100 000) and 56th for mean magnetic flux density. The rest of the communities in this population grouping fall in the range of 2–10 mG (amber) (Table 5). None of the communities have mean magnetic flux density below 2 mG (green)

In the population range of 50 000–100 000, Peterborough, Pickering Village, and Sarnia are within the red category (10–30 mG) for magnetic flux density. Seven communities fall within the amber category (2–10 mG) and one community (Cambridge) falls within the green category (<2 mG) (Table 5).

For the 18 communities with populations ranging in size from 10 000 to 50 000, two (Brockville and Bellville) are red (10–30 mG) while most are amber (2–10 mG). In this population grouping, 3 communities, Pembroke, Bradford, and the old centre of Newmarket, have averages below 2 mG (green) (Table 5).

For the 20 communities with populations less than 10 000, 65% are amber and the rest (35%) are green. Parry Sound and Gravenhurst top the list with average magnetic flux densities of 4.6 and 3.8 mG, respectively (Table 5). Of all 60 communities, only the village of Burks Falls, population 1000, has no readings above 2 mG on the streets monitored (Table 5, Figs. 1 and 5).

Interestingly, some of the higher magnetic fields were observed outside of banks in several of the communities tested. And, in Peterborough, closure

Table 5
Summary of magnetic flux density readings in the business district of 60 communities in south-central Ontario. Data are arranged and ranked ($RR_{M\text{-}Pop'n}$) by decreasing mean magnetic flux density within each population grouping ($RR_{Pop'n}$) and are also ranked for all 60 communities monitored ($RR_{all}$). Low relative rankings refer to low magnetic flux densities. The absolute ranking (AR) using colour codes is based on the mean magnetic flux density of each community ($AR_{FI}$) and on percentage of sites with readings above the critical limit (CL) of 2 mG ($AR_{CL}$). These two classification schemes are described in the text.

| RANKING ABSOLUTE CL | RANKING ABSOLUTE FI | RANKING RELATIVE all | RANKING RELATIVE pop'n | COMMUNITY | n | MAGNETIC FIELD (mG) mean | median | max | min |
|---|---|---|---|---|---|---|---|---|---|
| b | A | | | **ALL COMMUNITIES** | **1437** | **5.8** | **2.4** | **>100** | **0.2** |
| b | R | | | **Population: > 100 k** | **427** | **13.9** | **3.8** | **>100** | **0.2** |
| r | A | 14 | 1 | Hamilton | 24 | 2.2 | 1.7 | 6.5 | 0.2 |
| r | A | 15 | 2 | Ottawa | 70 | 2.2 | 1.7 | 12 | 0.2 |
| r | A | 22 | 3 | Oakville | 20 | 2.5 | 2.4 | 8.0 | 0.2 |
| r | A | 46 | 4 | Burlington | 28 | 5.4 | 2.9 | 50 | 0.2 |
| b | A | 48 | 5 | Brampton | 32 | 6.6 | 3.8 | 20 | 0.3 |
| b | A | 49 | 6 | St. Catharine | 36 | 6.7 | 3.5 | 80 | 0.4 |
| b | A | 50 | 7 | Marham (old) | 33 | 8.2 | 7.5 | 35 | 1.5 |
| b | R | 56 | 8 | Toronto | 108 | 19.2 | 9.1 | 100 | 0.5 |
| b | R | 58 | 9 | London | 20 | 22.9 | 14.5 | 100 | 1.5 |
| b | R | 59 | 10 | Oshawa | 20 | 29.5 | 22.5 | 90 | 1.0 |
| b | B | 60 | 11 | Kingston | 36 | 47.0 | 42.5 | >100 | 1.8 |
| b | A | | | **Population: 10-50 k** | **404** | **4.0** | **2.4** | **100** | **0.2** |
| a | G | 2 | 1 | Newmarket | 24 | 0.9 | 0.6 | 3 | 0.2 |
| a | G | 5 | 2 | Bradford | 13 | 1.2 | 0.8 | 3.5 | 0.4 |
| g | G | 7 | 3 | Pembroke | 32 | 1.3 | 1.1 | 2.8 | 0.2 |
| a | A | 13 | 4 | Trenton | 20 | 2.0 | 1.8 | 9 | 0.3 |
| r | A | 19 | 5 | Wallaceburg | 20 | 2.5 | 1.1 | 12 | 0.3 |
| r | A | 20 | 6 | Stratford | 18 | 2.5 | 1.6 | 9 | 0.4 |
| r | A | 25 | 7 | Lindsay | 21 | 2.6 | 2.8 | 4.8 | 1.2 |
| r | A | 27 | 8 | Bracebridge | 25 | 2.7 | 2.8 | 6.2 | 1.0 |
| r | A | 26 | 9 | Chatham | 28 | 2.7 | 2.2 | 8.2 | 0.4 |
| r | A | 31 | 10 | Stouffville | 30 | 3.0 | 2.6 | 9 | 1.0 |
| r | A | 32 | 11 | Orillia | 20 | 3.1 | 2.0 | 15 | 0.2 |
| r | A | 33 | 12 | Huntsville | 24 | 3.2 | 0.9 | 24 | 0.2 |
| r | A | 38 | 13 | Preston | 20 | 3.5 | 2.5 | 12 | 0.4 |
| r | A | 39 | 14 | Cornwall | 20 | 3.5 | 2.7 | 12 | 0.3 |
| b | A | 45 | 15 | Port Hope | 19 | 5.1 | 4.5 | 12 | 1.2 |
| b | A | 47 | 16 | Cobourg | 18 | 5.7 | 4.3 | 25 | 1.0 |
| b | R | 54 | 17 | Bellville | 20 | 12.1 | 9.8 | 50 | 1.3 |
| b | R | 55 | 18 | Brockville | 32 | 14.8 | 4.4 | 100 | 1.0 |
| b | A | | | **Population: 50-100 k** | **270** | **6.8** | **3.4** | **>100** | **0.2** |
| g | G | 3 | 1 | Cambridge | 24 | 1.0 | 0.9 | 2.4 | 0.3 |
| r | A | 17 | 2 | Niagara Falls | 28 | 2.4 | 1.9 | 8.5 | 0.3 |
| a | A | 18 | 3 | Guelph | 24 | 2.4 | 2.2 | 6.2 | 0.4 |
| r | A | 36 | 4 | Waterloo | 28 | 3.3 | 1.0 | 25 | 0.3 |
| r | A | 42 | 5 | Barrie | 24 | 4.8 | 2.1 | 20 | 0.5 |
| b | A | 43 | 6 | Sudbury | 32 | 4.9 | 3.5 | 22 | 0.2 |
| b | A | 44 | 7 | Whitby | 18 | 5.1 | 3.6 | 18 | 0.6 |
| b | A | 51 | 8 | North Bay | 24 | 8.3 | 6.0 | 25 | 1.2 |
| b | R | 52 | 9 | Sarnia | 28 | 10.8 | 3.4 | >100 | 1.0 |
| b | R | 53 | 10 | Pickering Villiage | 16 | 11.3 | 5.9 | 48 | 2.0 |
| b | R | 57 | 11 | Peterborough | 24 | 20.8 | 5.1 | >100 | 0.4 |
| b | A | | | **Population: < 10 k** | **336** | **2.4** | **2.0** | **14.0** | **0.2** |
| g | G | 1 | 1 | Burks Falls | 16 | 0.8 | 0.7 | 1.5 | 0.3 |
| a | G | 4 | 2 | Madoc | 12 | 1.0 | 1.1 | 2.0 | 0.2 |
| a | G | 6 | 3 | Perth | 16 | 1.2 | 0.9 | 4.5 | 0.3 |
| a | G | 8 | 4 | Bowmanville | 16 | 1.3 | 1.2 | 3.3 | 0.3 |
| a | G | 9 | 5 | Bancroft | 20 | 1.4 | 1.4 | 4.8 | 0.2 |
| g | G | 10 | 6 | Norwood | 16 | 1.5 | 1.5 | 2.8 | 0.4 |
| a | G | 11 | 7 | Havelock | 15 | 1.9 | 1.1 | 5.5 | 0.2 |
| a | A | 12 | 8 | Port Perry | 17 | 2.0 | 1.2 | 7.0 | 0.8 |
| r | A | 16 | 9 | Uxbridge | 14 | 2.3 | 2.7 | 4.2 | 0.4 |
| r | A | 21 | 10 | Picton | 20 | 2.5 | 1.9 | 6.0 | 1.3 |
| a | A | 23 | 11 | Hastings | 16 | 2.6 | 2.1 | 8.0 | 1.3 |
| r | A | 24 | 12 | Napanee | 20 | 2.6 | 2.4 | 7.0 | 0.3 |
| r | A | 28 | 13 | Lakefield | 10 | 2.8 | 2.5 | 7.0 | 0.2 |
| r | A | 29 | 14 | Barry's Bay | 20 | 2.9 | 1.8 | 11.0 | 0.3 |
| r | A | 30 | 15 | Sturgeon Falls | 16 | 2.9 | 2.1 | 10.0 | 0.4 |
| r | A | 34 | 16 | Campbellford | 14 | 3.2 | 2.7 | 9.0 | 1.2 |
| r | A | 35 | 17 | Brighton | 16 | 3.2 | 2.9 | 7.8 | 0.8 |
| r | A | 37 | 18 | Smith Falls | 16 | 3.4 | 2.4 | 14.0 | 1.4 |
| r | A | 40 | 19 | Gravenhurst | 20 | 3.8 | 2.7 | 14.0 | 0.4 |
| b | A | 41 | 20 | Parry Sound | 26 | 4.6 | 4.5 | 11.0 | 1.1 |

n: number of measurements

**Absolute Ranking based on intensity and critical limit**

| | green | amber | red | black | |
|---|---|---|---|---|---|
| **Critical Limit** | g | a | r | b | |
| % values ≥2 mG | 0 | 1-20 | 21-50 | 51-100 | % |
| **Field Intensity** | G | A | R | B | |
| mean magnetic flux density | < 2 | 2-10 | 11-30 | >30 | mG |

**Number of communities per category**

| | green | amber | red | black | |
|---|---|---|---|---|---|
| **Critical Limit** | 4 | 11 | 27 | 18 | |
| % values ≥2 mG | 0 | 1-20 | 21-50 | 51-100 | % |
| **Field Intensity** | 11 | 40 | 8 | 1 | |
| mean magnetic flux density | < 2 | 2-10 | 11-30 | >30 | mG |

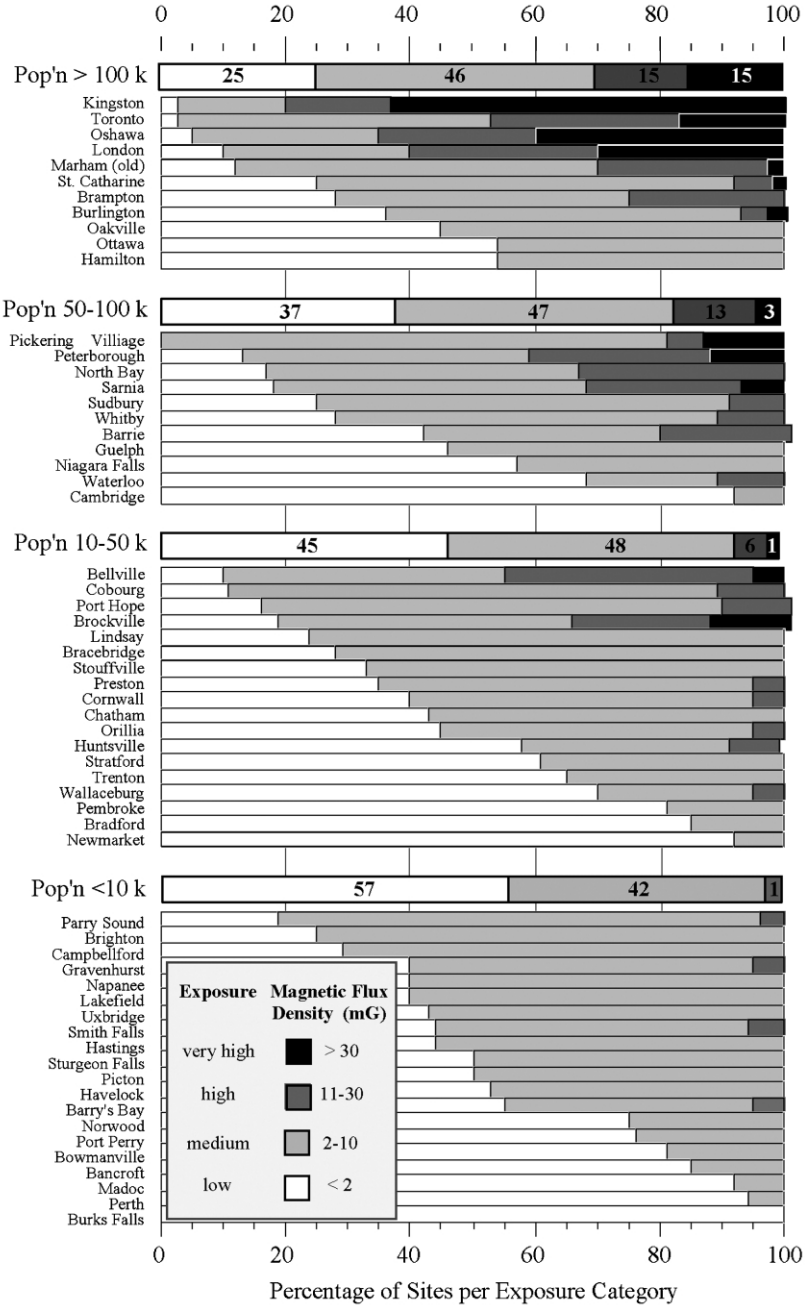



Fig. 5. Percentage of sites within the business district at each community that correspond to exposure categories for magnetic flux density (low, medium, high, and very high exposure). Means for population groupings are also provided.

of a street-corner bank resulted in lower magnetic fields on that corner when measured 2 years later (Fig. 2).

### 3.2. Electric fields

The pattern for electric fields differs considerably from those of magnetic fields. The overall average for all 60 communities in Ontario is 3.2 V/m (green) but with a wide range of community readings from less than 0.1 to 68 V/m (Table 6 ). The highest electric field exposure (community mean 19.4 V/m, red) was measured in Havelock, a community of 1400. There are only 5 communities with mean electric fields that exceed 10 V/m (red) (Fig. 6). In addition to Havelock, these include Old Markham, Pickering Village, Stouffville and Norwood. In all cases, the electric field could be traced to overhead wires, some of which have voltages higher than normally appear on residential streets.

### 3.3. Comparison of classification systems

The classification based on critical limits (CL) gives a higher exposure ranking than does the one based on average field intensity (FI) as shown in Table 5 for magnetic fields and Table 6 for electric fields. For example, the number of communities classified as 'black' (highest exposure) for FI:CL was 1:18 for magnetic fields (Table 5) and 0:8 for electric fields (Table 6).

When both systems are combined, as shown in Table 4, the overall score for all 60 communities is black:amber (CL:FI) for magnetic flux density which gives a numerical score of 6 and amber:green for electric fields with a score of 3. Possible range of values is 2 for low fields to 8 for high field strengths.

### 3.4. Electric vs. magnetic field

There appears to be an inverse relationship between the electric field and the magnetic field (Fig. 7). The high magnetic flux densities are often generated by underground cables or buried water and gas pipes. In these situations, the electric field is blocked by the earth. Values seldom exceed 3 V/m.

Overhead distribution lines produce a range of electric fields depending on line voltage, and a range of magnetic fields depending on current flow. The high electric fields in Fig. 7 are likely due to higher voltage distribution lines that may have lower currents resulting in a lower magnetic field. These higher voltage lines also tend to be placed on taller poles, which would further reduce magnetic field exposure for pedestrians.

### 3.5. Intersection mean vs. street maxima

The magnetic flux density at the intersection may or may not be the same as that along the street. The example with the most measurements is Yonge Street in Toronto (Fig. 4). In Fig. 4, each corner, at a particular intersection, is shown, as is the maximum value between intersections on both the east and west side of the street. Hence, the intersection at Yonge Street and Bloor Street has an average magnetic flux density of 13 mG with the highest reading of 35 mG on the south-west corner. Between Bloor Street and Hayden Street, the magnetic field increases to 60 mG on the west side of Yonge Street and up to 50 mG on the east side. This figure shows that intersection readings may be the same, lower, or higher than street maxima.

### 3.6. Diurnal variations in the electromagnetic fields

All readings were taken during business hours (weekdays 09.00 to 17.00h) in the business district of each community. Once businesses close for the evening, the magnetic flux density decreases. This is shown in Fig. 3a for Peterborough along George Street between Brock and Sherbrooke for a 24-h period starting at 10.00h September 21, 1998 and ending at 18.00h the following day. The highest magnetic fields were recorded during business hours (at 10.00h and 14.00h) for 5 of the 6 intersections. For some of the intersections (Brock, Hunter, Simcoe) readings at night were 60% lower than those measured during business hours.

Table 6
Summary of electric field readings in the business district of 60 communities in south-central Ontario. Data are arranged and ranked ($RR_{M\text{-}Pop'n}$) by decreasing mean electric field within each population grouping ($RR_{Pop'n}$) and are also ranked for all 60 communities monitored ($RR_{all}$). Low relative rankings refer to low field strength. The absolute ranking (AR) using colour codes is based on the mean electric field of each community ($AR_{FI}$) and on percentage of sites with readings above the critical limit (CL) of 5 V/m ($AR_{CL}$). These two classification schemes are described in the text.

| RANKING ABSOLUTE CL | RANKING ABSOLUTE int | RANKING RELATIVE all | RANKING RELATIVE pop'n | COMMUNITY | n | ELECTRIC FIELD (V/m) mean | median | max | min |
|---|---|---|---|---|---|---|---|---|---|
| a | G | | | **ALL** | **1301** | **3.2** | **0.4** | **68.0** | **0.0** |
| a | G | | | **Population: > 100 k** | **319** | **2.5** | **0.4** | **65** | **0.1** |
| g | G | 4 | 1 | Oshawa | 20 | 0.3 | 0.3 | 0.6 | 0.2 |
| g | G | 8 | 2 | Oakville | 20 | 0.4 | 0.3 | 0.9 | 0.2 |
| g | G | 13 | 3 | Ottawa | 70 | 0.4 | 0.4 | 2.0 | 0.4 |
| a | G | 14 | 4 | Toronto | 108 | 0.5 | 0.3 | 4.4 | 0.1 |
| a | G | 16 | 5 | Kingston | 36 | 0.6 | 0.4 | 9.6 | 0.2 |
| a | G | 22 | 6 | London | 20 | 1.2 | 0.3 | 6.5 | 0.2 |
| r | G | 45 | 7 | Brampton | 32 | 4.0 | 0.5 | 28 | 0.2 |
| b | R | 52 | 8 | Marham (old) | 33 | 10.6 | 2.3 | 65 | 0.2 |
| nd | nd | nd | nd | Burlington | 0 | nd | nd | nd | nd |
| nd | nd | nd | nd | Hamilton | 0 | nd | nd | nd | nd |
| nd | nd | nd | nd | St. Catharine | 0 | nd | nd | nd | nd |
| a | G | | | **Population: 10-50 k** | **404** | **1.9** | **0.9** | **44** | **0.1** |
| g | G | 2 | 1 | Chatham | 28 | 0.3 | 0.2 | 1.2 | 0.1 |
| g | G | 3 | 2 | Wallaceburg | 20 | 0.3 | 0.3 | 0.4 | 0.1 |
| g | G | 5 | 3 | Stratford | 18 | 0.3 | 0.3 | 0.6 | 0.1 |
| g | G | 7 | 4 | Bellville | 20 | 0.4 | 0.3 | 0.9 | 0.2 |
| g | G | 9 | 5 | Trenton | 20 | 0.4 | 0.3 | 1.1 | 0.2 |
| r | G | 11 | 6 | Huntsville | 24 | 0.4 | 0.4 | 0.6 | 0.3 |
| g | G | 12 | 7 | Pembroke | 32 | 0.4 | 0.4 | 1.1 | 0.1 |
| a | G | 21 | 8 | Preston | 20 | 1.1 | 0.7 | 4.9 | 0.3 |
| a | G | 24 | 9 | Port Hope | 19 | 1.3 | 0.6 | 4.4 | 0.3 |
| a | G | 27 | 10 | Brockville | 32 | 1.5 | 0.4 | 9.0 | 0.1 |
| a | G | 29 | 11 | Lindsay | 21 | 1.6 | 0.4 | 12 | 0.3 |
| a | G | 31 | 12 | Newmarket | 24 | 1.7 | 0.4 | 13 | 0.3 |
| r | G | 36 | 13 | Cornwall | 20 | 2.5 | 0.4 | 12 | 0.2 |
| r | G | 38 | 14 | Bradford | 13 | 2.5 | 0.8 | 6.3 | 0.3 |
| r | G | 39 | 15 | Bracebridge | 25 | 2.5 | 0.8 | 9.4 | 0.2 |
| a | G | 42 | 16 | Orillia | 20 | 3.2 | 0.3 | 19 | 0.2 |
| r | G | 44 | 17 | Cobourg | 18 | 3.7 | 0.4 | 26 | 0.2 |
| b | R | 53 | 18 | Stouffville | 30 | 10.7 | 8.2 | 44 | 0.3 |
| a | G | | | **Population: 50-100 k** | **242** | **2.9** | **0.4** | **44** | **0.1** |
| g | G | 6 | 1 | Barrie | 24 | 0.4 | 0.3 | 0.8 | 0.3 |
| g | G | 10 | 2 | Waterloo | 28 | 0.4 | 0.3 | 1.9 | 0.1 |
| g | G | 15 | 3 | Sudbury | 32 | 0.6 | 0.3 | 2.5 | 0.2 |
| a | G | 25 | 4 | Whitby | 18 | 1.3 | 0.6 | 5.6 | 0.3 |
| r | G | 30 | 5 | North Bay | 24 | 1.6 | 1.1 | 4.9 | 0.3 |
| a | G | 32 | 6 | Peterborough | 24 | 1.8 | 0.3 | 15 | 0.2 |
| a | G | 34 | 7 | Cambridge | 24 | 2.1 | 0.4 | 26 | 0.1 |
| r | G | 37 | 8 | Guelph | 24 | 2.5 | 0.5 | 24 | 0.2 |
| a | G | 41 | 9 | Sarnia | 28 | 2.9 | 0.4 | 35 | 0.1 |
| b | R | 55 | 10 | Pickering Villiage | 16 | 15.7 | 13.1 | 44 | 3.0 |
| nd | nd | nd | nd | Niagara Falls | 0 | nd | nd | nd | nd |
| r | G | | | **Population: < 10 k** | **336** | **4.8** | **0.7** | **68** | **0.0** |
| g | G | 1 | 1 | Perth | 16 | 0.2 | 0.2 | 0.4 | 0.2 |
| a | G | 17 | 2 | Uxbridge | 14 | 0.7 | 0.3 | 3.3 | 0.0 |
| a | G | 18 | 3 | Campbellford | 14 | 0.9 | 0.3 | 3.7 | 0.2 |
| g | G | 19 | 4 | Lakefield | 10 | 1.0 | 0.6 | 2.2 | 0.1 |
| a | G | 20 | 5 | Parry Sound | 26 | 1.1 | 0.6 | 3.1 | 0.2 |
| a | G | 23 | 6 | Brighton | 16 | 1.2 | 0.7 | 6.4 | 0.3 |
| a | G | 26 | 7 | Picton | 20 | 1.5 | 0.3 | 12 | 0.2 |
| a | G | 28 | 8 | Port Perry | 17 | 1.6 | 0.4 | 7.2 | 0.1 |
| a | G | 33 | 9 | Napanee | 20 | 1.8 | 0.9 | 8.5 | 0.3 |
| r | G | 35 | 10 | Bancroft | 20 | 2.4 | 0.7 | 11 | 0.3 |
| r | G | 40 | 11 | Sturgeon Falls | 16 | 2.6 | 0.6 | 16 | 0.3 |
| a | G | 43 | 12 | Gravenhurst | 20 | 3.3 | 0.3 | 16 | 0.3 |
| r | A | 46 | 13 | Smith Falls | 16 | 5.0 | 0.4 | 28 | 0.2 |
| r | A | 47 | 14 | Bowmanville | 16 | 5.3 | 0.8 | 30 | 0.4 |
| r | A | 48 | 15 | Burks Falls | 16 | 8.1 | 2.3 | 40 | 0.1 |
| b | A | 49 | 16 | Barry's Bay | 20 | 8.3 | 7.0 | 22 | 2.2 |
| b | A | 50 | 17 | Hastings | 16 | 8.9 | 5.9 | 50 | 0.2 |
| b | A | 51 | 18 | Madoc | 12 | 9.1 | 5.4 | 30 | 0.6 |
| b | R | 54 | 19 | Norwood | 16 | 13.1 | 7.6 | 56 | 0.3 |
| b | R | 56 | 20 | Havelock | 15 | 19.4 | 16.0 | 68 | 1.6 |

nd: no data
n: number of readings

**Absolute Ranking based on intensity and critical limit**

| | green | amber | red | black | |
|---|---|---|---|---|---|
| **Critical Limit** | g | a | r | b | |
| % readings ≥ 5 V/m | 0 | 1-20 | 21-50 | 51-100 | % |
| **Average Intensity** | G | A | R | B | |
| mean V/m | < 5 | 5-10 | 11-30 | >30 | V/m |

**Number of communitiees per category**

| | green | amber | red | black | |
|---|---|---|---|---|---|
| **Critical Limit** | 14 | 21 | 13 | 8 | |
| % readings ≥ 5 V/m | 0 | 1-20 | 21-50 | 51-100 | % |
| **Average Intensity** | 46 | 6 | 5 | 0 | |
| mean V/m | < 5 | 5-10 | 11-30 | >30 | V/m |

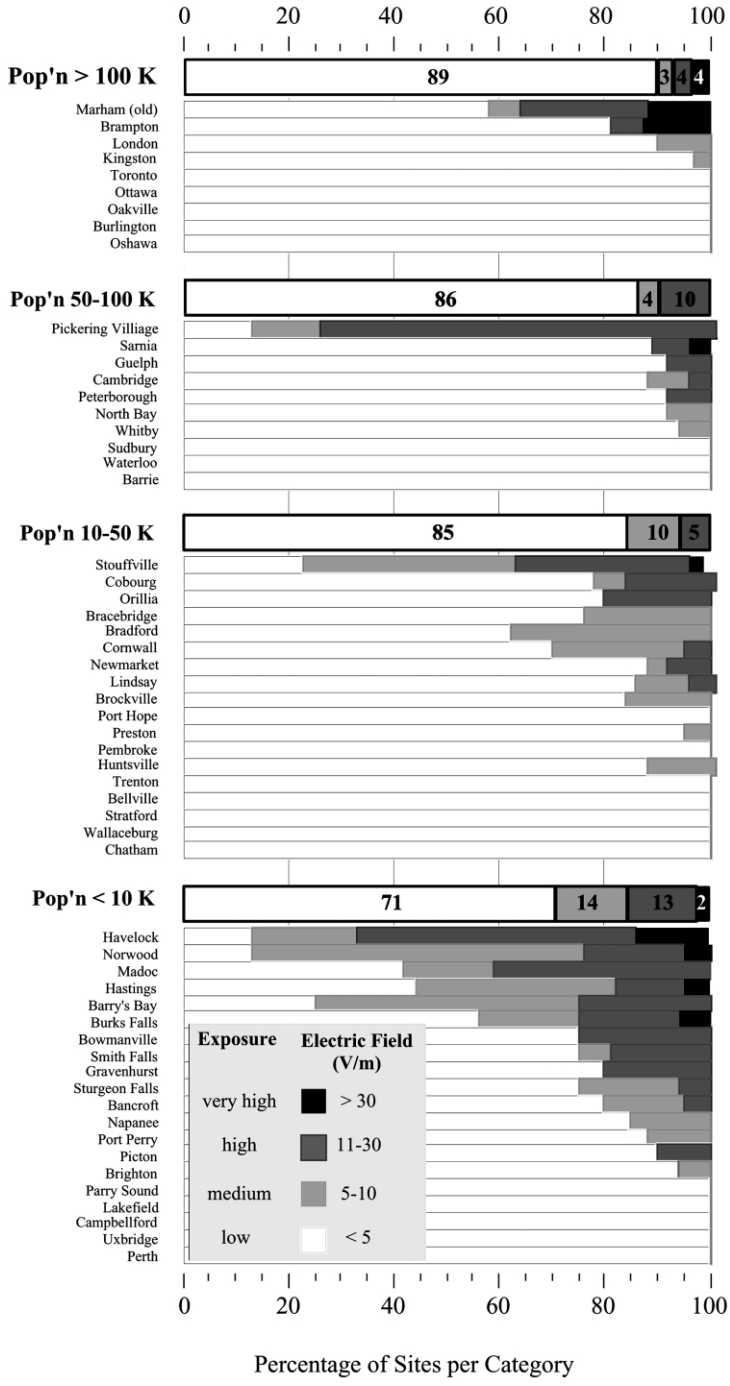



Fig. 6. Percentage of sites within the business district at each community that correspond to exposure categories for electric fields (low, medium, high, and very high exposure). Means for population groupings are also provided.

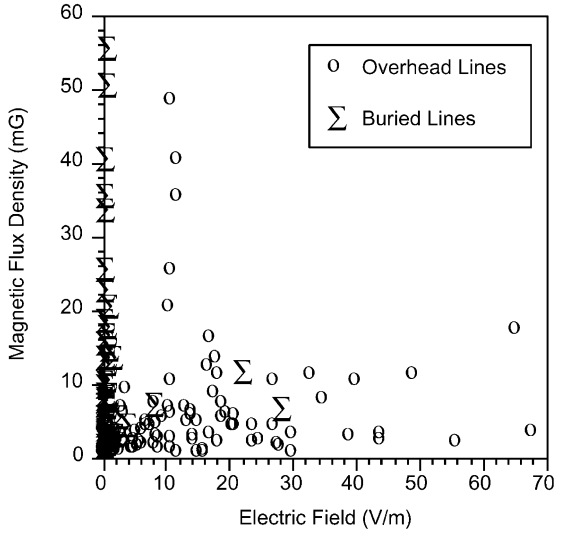



Fig. 7. Relationship between electric and magnetic fields for overhead and buried power distribution lines for 12 communities in south-central Ontario. The top three communities with measurable electric fields were selected from each population grouping (refer to Table 6). Measurements traced to multiple sources and unidentified sources are not included ($n=165$ corners).

The electric field, detected only at the intersection of Sherbrooke and George Street, did not fluctuate diurnally (Fig. 3b).

### *3.7. Data robustness: 1999 vs. 2000 for six communities*

Since the communities were measured only once, it seemed useful to determine the reproducibility of this measurement as a community feature. Accordingly, 6 of the communities were revisited in June 2000 and the same sites remeasured. The values over this 2-year period are relatively stable (Table 2). The largest difference in community means for magnetic field was 5 mG (Peterborough) and for electric field it was 25 V/m (Pickering Village). Part of this difference in Peterborough can be explained by the replacement of a bank by a coffee shop on the corner of George and Simcoe Street, which resulted in a much lower magnetic field at this corner and produced a lower average for this street. The higher electric field in Pickering Village suggests that the line voltage may have been increased since the magnetic field also decreased slightly in 2000. No obvious physical changes to the overhead lines were observed. Apart from major changes in hydro lines (rewiring, rephrasing, balancing) or in the use of electricity (altered current flow), the fields recorded in Table 5 and 6 should remain relatively constant.

### *3.8. Electric field: two meters*

Of the two fields, the electric field is by far the most difficult to measure. Hence, in June 2000, the electric field as measured by the MSI meter was compared with the electric field measured by an extended range Trifield meter. The results, shown in Fig. 2, indicate good agreement for fields at or below 40 V/m. At values above 40 V/m, the Trifield meter gave slightly higher readings than did the MSI meter. Only 5 communities in 1998 had electric fields above 40 V/m.

## 4. Discussion

Our collective understanding of the electromagnetic environment generated by human activity (technology), as opposed to naturally occurring fields, is still limited. While considerable progress has been made documenting electromagnetic fields (EMF) found near high voltage transmission lines (Lea et al., 1989), household appliances (EPA, 1992; Kaune et al., 2002), in the home (EPRI, 1993), and workplace (see Hitchcock and Patterson, 1995; Portier and Wolfe, 1998; Kheifet et al., 1997), we know virtually nothing about the EMFs found on city streets.

Primary interest in EMF exposure relates to possible consequences to human health. This topic is controversial for power frequency fields (50 or 60 Hz) but the evidence is mounting that extremely low frequency EMF are associated with various forms of cancers in exposed individuals as reviewed by the NIEHS report (Portier and Wolfe, 1998) and more recently by a variety of authors (Savitz et al., 2000; Erren, 2001; Kheifets, 2001; Minder and Pfluger, 2001; Schuz et al., 2001). The effects seem to be small when compared with known carcinogens such as cigarettes and asbestos. However, in urban centers where large human

populations are exposed, the number of people potentially affected is great and hence this possible health threat has to be taken seriously. This is especially so in the light of recent studies indicating an increased risk of miscarriages, heart disease, chromosomal aberrations, amyotrophic lateral sclerosis (ALS), and possibly Alzheimer's disease (Savitz et al., 1999; van Wijngaarden et al., 2000; Ahlbom, 2001; Li et al., 2002).

Unfortunately, we still do not know which aspects of electromagnetic exposure are linked directly to the biological and/or health effects. Exposure metrics are complex, variable and, in some cases, incompletely documented (transients for example). In some studies, the biological effects have been associated with electric field exposure (Blackman et al., 1988a; Villeneuve et al., 2000) in others with magnetic field exposure (Wertheimer and Leeper, 1979; Savitz et al., 1988), and in some with the combination of both fields (Miller et al., 1996). In some studies, there is evidence of greater risk at higher field intensities (Floderus et al., 1993) and in others of intensity windows (Blackman et al., 1982). We have yet to understand the importance of frequency windows, intensity windows, time-weighted fields, cumulative exposure, switching, transients, harmonics (refer to discussion by Morgan and Nair, 1992). Also, there is the question of the local geomagnetic field and of environmental variables such as temperature and time of exposure (night vs. day) (Blackman and Most, 1993; Schuz et al., 2001). Since we do not know which aspects of the electromagnetic field are biologically active and since human exposure is constantly changing as we move around, it is difficult to document exposure in a way that has biological significance. Until we have a better understanding of the key metrics involved in the observed effects, we can use the cut-off values for electric and magnetic fields identified by epidemiological and laboratory studies.

### *4.1. Classification system proposed*

Four biological end points have been identified for magnetic fields, 2 mG (range 1.4–4 mG) associated with childhood leukemias; 12 mG associated with breast cancer; 16 mG associated with increased risk of spontaneous abortion; and 20 mG for chromosomal aberrations (Harland and Liburdy, 1997; Nordenson et al., 2001; Wartenburg, 2001; Li et al., 2002). All except the breast cancer are based on epidemiological studies.

Biological end points for electric fields are more difficult to measure since electric fields themselves are more difficult to measure. Also, studies on the biological effects of electric fields have not kept pace with studies of magnetic fields. Most biological effects seem to occur at electric fields at or above 500 V/m, although effects have been documented between 7–100 V/m (cited in Shandala et al., 1988) and at and above 10 V/m (Blackman et al., 1988a; Villeneuve et al., 2000). A critical limit of 6 V/m is suggested by Kulczycki (1989) as having biological effects with continuous exposure and a critical limit of 5 V/m was selected for this study.

These biological end points (2 mG and 5 V/m) are the basis for the classification system proposed in this paper for both electric and magnetic fields. The system is intended to simplify information exchange and is designed to facilitate prudent avoidance. Two systems are proposed, both of which rely on the traffic light model: green for low exposure, amber for medium exposure, and red for high exposure with an additional category, black, for very high exposure. One system is based on average field intensity (FI) and the other on the percentage of sites within a given area that exceed the biologically critical limit (CL). Although the author prefers the FI classification scheme since individual sites can be classified (a corner, an intersection, a street, a school, a home, etc.), the CL classification scheme is also provided because of the literature on intensity windows, which suggest that some biological effects are intensity specific and neither lower nor higher intensities evoke the same biological response (Blackman et al., 1982; Delgado et al., 1982).

### *4.2. Electric fields*

In the present study, electric fields were low in the business district of most communities. This is particularly true in larger communities that have

buried distribution lines. In 22 of the communities (37%) the electric field did not exceed 5 V/m (green) at any of the locations measured (Table 6, Fig. 6). A total of 45 communities (75%) had averages within code green (less than 5 V/m). An additional 6 communities (10%) were within code amber (5–10 V/m) and all of these had populations less than 10 0000. Only 5 communities (8%) had average electric fields between 11 and 30 V/m (code red) and none had average fields above 30 V/m (black). The highest electric field detected in this study was 68 V/m and this was associated with overhead distribution lines in a small community of 1400 people. This community also had the highest average field for the business district of 19 V/m (red).

These values are considerably lower than those experienced by high voltage linemen or substation maintenance workers, who may be exposed to electric fields of several thousand V/m, and are more in line with values found in an office environment (mean 15.6 V/m, range 2.1–56.7 V/m) (cited in Hitchcock and Patterson, 1995). Deadman et al. (1988) reported that workers who wore personal monitors for a week were exposed to an average of 48 V/m in 'electrical' occupations and 4.9 V/m in an office environment. The highest value was 400 V/m and is much higher than the fields recorded on city streets. Household values may range from 2 to 40 V/m and may be as high as 250 V/m near appliances (Deadman et al., 1988). Hence, exposure to the electric field is unlikely to be a serious biological concern along the sidewalk within the downtown core of most communities. However, if public utilities continue to convert lower voltage lines (4 kV) to higher voltages (44 kV) then the electric field would have to be reassessed, since electric field strength increases with line voltage.

### *4.3. Magnetic fields*

Of the 60 communities tested in south-central Ontario, 49 communities (82%) had average magnetic flux densities above 2 mG (green), the lower limit associated with childhood cancers (LLCC) (range 1.4–4; Green et al., 1999; Ahlbom et al., 2000; Wartenburg, 2001) (Fig. 5). Within the business district of some of the larger communities, it is virtually impossible to avoid exposure to field strengths above 2 mG. In Toronto, Kingston, Oshawa and Pickering Village, for example, more than 90% of the sites measured exceeded 2 mG. All of these communities had mean magnetic flux densities above 10 mG (which is five times the lower limit for childhood cancers) and were within the red (11–30 mG) or black (>30 mG) categories that have been associated with increased growth of breast cancer cells at 12 mG, increased risk of spontaneous miscarriages at 16 mG, and increased incidence of chromosomal aberrations in peripheral lymphocytes at 20 mG (Liburdy et al., 1993; Nordenson et al., 2001; Li et al., 2002).

A number of the urban centers, particularly in their downtown core, have buried electrical cables rather than overhead distribution lines. This study found that some of the highest magnetic fields (and the lowest electric fields) were generated by these buried lines and/or by buried water and gas pipes that are connected to the electrical distribution system and carry a current (Fig. 7). This is contrary to many of the childhood epidemiological studies that reported low magnetic fields with buried lines (see Wartenburg, 2001). The major difference between those studies and this one is that the magnetic flux density decreases exponentially from a buried line, hence, while fields might be high close to the line, on the sidewalk for example, they are likely to decrease rapidly with distance since the lines are close together (at front door of residence). Underground sources are particularly difficult to avoid and must be checked by the public utility to ensure that field strengths are low.

Magnetic fields in the business districts are fairly consistent over time provided that they are measured during business hours (Table 2). After hours, these fields can decrease by more than 50% (Fig. 3a). In communities that have residences above businesses, the magnetic flux densities are likely to be higher than those on the sidewalk during the day since the front of the residence is closer to the overhead wires, but these would decrease at night due to the reduced current.

Many of the childhood epidemiological studies used wire codes as one of the estimates of exposure

to electromagnetic fields. Wire code configurations are based on a combination of distance from the power distribution line and the number and type of conductors. Magnetic flux densities associated with very high current configuration (VHCC) vary among studies but range between 1.1 and 2.5 mG (based on median values) (Wertheimer and Leeper, 1982; Savitz et al., 1988; Preston-Martin et al., 1996; Tarone et al., 1988; Severson et al., 1988; London et al., 1991). Based on community medians in Table 5, 53 communities (88%) fall within or exceed this range for VHCC, which means that an alternative classification for the downtown core of most of the communities measured is VHCC.

In the 1000 home survey (cited in Portier and Wolfe, 1998), the median spot measurement for all rooms was 0.5 mG while the median value for this study was 2.4 mG. Also, at least 5% of the homes exceeded values of 2.6 mG and 1% exceeded 5.8 mG. In the current study, 45% of the communities exceeded 2.6 mG and 13% of the communities exceeded 5.8 mG. Magnetic fields are much higher along the sidewalk within the business district of cities and towns than in most homes.

Deadman et al. (1988) reported a mean magnetic flux density of 0.16 mG for office workers, 1.66 mG for electrical workers with a maximum of 3.4 mG for one individual based on personal monitors worn for one week. Exposure in electrical occupations based on the time-weighted average magnetic field is estimated to be 1.7 mG on average (Portier and Wolfe, 1998) for occupations that include the textile industry, utilities, transportation, metal work, small equipment repair, electricians, telecommunications, office, sales and various miscellaneous occupations. According to these data, above average exposure (75th%) occurs at 2.7 mG and very high exposure at 6.6 mG (95th%). Hence, a hot-dog vendor on the northeast corner of Yonge and Edward Street in Toronto, exposed to 100 mG, would fall into the very high category for occupational exposure. Twenty-five of the 27 intersections (93%) measured on Yonge Street between Bloor and Front had values above 6.6 mG. The business district of 13 communities had mean magnetic flux densities of 6.6 mG or greater and hence would be classified in the 95th% of electrical occupations. Interestingly mail carriers fall above the average category for occupational exposure with a daily mean of 3.1 mG (cited in Lindgren et al., 2001).

In addition to the lower exposure limit associated with childhood leukemia (2 mG) another critical limit for biological effects is 12 mG, which has been associated with the growth of breast cancer cells. Laboratory studies have shown that a 60-Hz, 12-mG magnetic field reduces the inhibitory action on human breast cancer cells (MCF-7) of melatonin, a naturally occurring hormone, and tamoxifen, a drug used for the treatment of breast cancer (Liburdy et al., 1993; Harland and Liburdy, 1997; Blackman et al., 2001; Ishido et al., 2001). This is the first example of a 60-Hz field at intensities found in residential environments affecting cancer cells via inactivation of a cancer drug, tamoxifen, at pharmacological levels and it has potentially wide-reaching consequences. If we extend this to the present study, in those communities that have average magnetic flux densities at or above 12 mG, growth of breast cancer may be promoted by inactivating the drug used in chemotherapy (tamoxifen) and by reducing levels of the body's natural defense against cancer (melatonin). These communities (based on mean magnetic flux density) include Kingston, Oshawa, London, Toronto, Peterborough, Brockville, and Bellville. In the remaining communities, an additional 23 (38%) have sites within the community that exceed 12 mG (Fig. 5).

Li et al. (2002) conducted a population-based prospective cohort study of women within their first 10 weeks of gestation who lived in the San Francisco area. Women wore a personal monitoring device that measured magnetic fields for a 24-h period. Although they did not observe an association between average miscarriage risk and the average magnetic field, miscarriage risk increased with an increasing level of maximum magnetic field exposure. The threshold was around 16 mG. The association for women whose 24-h monitoring was representative of their daily activity had a statistically significant rate ratio of 2.9. The highest risk was for early miscarriages (RR 5.7, 95%CI 2.1–15.7) and for susceptible women (RR 4.0, 95%CI 1.4–11.5). They concluded that prenatal

exposure to a maximum magnetic field above 16 mG may be associated with an increase risk of spontaneous miscarriages and that this result is unlikely to be due to uncontrolled biases or unmeasured confounders. Of the 60 communities, 20 (33%) had sites with magnetic flux densities above 16 mG on city streets and 2 of these (Oshawa and Kingston) had median values above 16 mG.

The magnetic fields measured in the business centers of 60 communities in Ontario are higher than those found in most homes and in many electrical occupations. Based on the arithmetic mean, 48 communities (80%) exceed the lower limit for childhood cancer (2 mG); 7 communities (12%) exceed the limit associated with breast cancer (12 mG); 5 communities (8%) exceed the limit associated with spontaneous miscarriages; and 3 communities (5%) exceed the limit associated with chromosomal aberrations (20 mG).

While this paper was in review, Lindgren et al. (2001) documented extremely low frequency magnetic fields within a 1-km$^2$ section of Goteborg, Sweden, frequented by pedestrian traffic. They measured magnetic fields during business hours at a height of 1 m, every 2 m along 12 km of sidewalk. Interestingly, they also used the traffic light analogy and ranked fields into green (less than 2 mG), amber (2 to 10 mG), and red (greater than 10 mG). Fifty percent of the readings were above 2 mG and values above 10 mG were recorded near distribution pillars, substations, shoplifting alarms and other electrical devices. The peak value recorded was 97 mG, which is in the same range as the maximum values found in this study. Using the classification scheme proposed in the current study, Goteborg would be classified as black:amber (CL:FI) since more than 51% of the measurements were above 2 mG (black) and since the average magnetic flux density was 3.4 mG (amber).

### *4.4. Guidelines and policy of prudent avoidance*

Guidelines regarding extremely low frequency EMF exposure differ considerably. According to the International Radiation Protection Agency, public exposure for a 24-h period should not exceed 1000 mG. The magnetic field along the right-of-way (ROW) of power lines is 150–250 mG in Florida, 200 mG in New York, 4 mG as recommended by the City of Brentwood in Tennessee, and 1.5 mG as recommended by the Town of Lincolnwood near Chicago, Illinois (Milburn and Oelbermann, 1994). In Montana, the guidelines range from 150 to 250 mG depending on line voltage and configuration with the lower limit for lines at or below 230 kV (www.microwavenews.com/ncrp1.html). In Sweden, the National Energy Administration (NEA) has recommended that care be taken not to locate schools, daycare centres and playgrounds near powerlines. In 1990, the head of the Electrical Safety Division of NEA recommended that magnetic fields above 2 to 3 mG should be avoided in such locations and encouraged caution in the siting of new housing developments (Milburn and Oelbermann, 1994). Hence, we have a range from 2 to 1000 mG as a guideline for magnetic flux density depending on jurisdiction. The lower end of this range (2–3 mG) corresponds to threshold values associated with cancers in residential and occupational settings and is a more realistic guideline.

Guidelines for public exposure to 50/60 Hz electric fields range from 0.5 kV/m inside homes in the former Soviet Union to 10 kV/m, the value below which 'access need not be limited' according to the World Health Organization (in Deadman et al., 1988). At the edge of right-of-way the electric field guideline ranges from 1 (former Czechoslovakia) to 8 (Minnesota) (Deadman et al., 1988). In the Russian Republic, switchyard workers can be exposed to 5 kV/m but have time restrictions at higher electric fields as follows: 180 min per 24-h period at 10 kV/m, 90 min at 15 kV/m, 10 min at 20 kV/m, and 5 min at 25 kV/m (Korobkova et al., 1972). Existing State standards for electric fields along power line right-of-ways range from 1 kV/m in Montana for residential areas to 10 kV/m for 500-kV lines in Florida (Levitt, 1995). Sweden has some of the lowest electric field guidelines. The Swedish standard for video display terminal is 25 V/m for ELF fields and 2.5 V/m for VLF fields (Pinsky, 1995).

An alternative approach to standards and guidelines is a policy of prudent avoidance. This term was first used by Nair et al. (1989) and was

highlighted by Abelson (1989). Most documents that review the health effects of electromagnetic fields advocate a policy of prudent avoidance (Portier and Wolfe, 1998; NRC, 1997), which refers to a 'low- or no-cost' way of reducing one's exposure to electromagnetic fields. In both California and Colorado, the Public Utility Commission instructed utilities to practice prudent avoidance and to take 'responsible low cost steps to avoid exposing people unnecessarily to these fields' (Milburn and Oelbermann, 1994).

Prudent avoidance can be practiced by electrical utilities and by individuals. Two essential elements must be met if one is to practice prudent avoidance. Individuals must know what field strengths are present in a particular environment and they must have options that enable them either to decrease field strength or to avoid high fields. Practicing prudent avoidance in the downtown core of some communities (Kingston for example) may not be possible for the individual. In this case it becomes the responsibility of the electricity provider.

The public utility can reduce magnetic fields in a number of ways. They can properly balance the currents, rephase for maximum cancellation of the magnetic field, minimize the distances between lines with spacers, use a delta configuration for additional cancellation, and place overhead wires on taller poles, or bury them underground. Hence, magnetic fields generated by overhead or underground power distribution lines can be reduced.

Outdoor magnetic fields in built-up urban centers are not inconsequential and may be higher than in some occupational settings and in most homes. Hence, electric and magnetic fields need to be more widely measured in other communities so we can generate a more comprehensive understanding of our electromagnetic environment. This information, combined with field strengths in residential and occupational environments, would enable us to more accurately calculate individual exposure to both electric and magnetic fields and better access risk in various environments. This information should be made available to the public, public utilities, policy makers, and to anyone wishing to practice prudent avoidance. The proposed classification scheme provides one way of facilitating this information transfer.

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