ELECTRIC AND MAGNETIC FIELD EXPOSURE ASSESSMENT OF POWERLINE AND NON-POWERLINE SOURCES FOR CALIFORNIA PUBLIC SCHOOL ENVIRONMENTS

EXECUTIVE SUMMARY

The purpose of this project is to obtain accurate information about the degree to which California children are exposed to power system electric and magnetic fields (EMF) while attending schools, identify and characterize the sources of those fields, and assess the cost of reducing the fields. The study was conducted by Enertech Consultants and was managed by the California Department of Health Services.

The project was a three-year effort that started in January 1996. The project consisted of an EMF survey of a sample of California public schools, and of the day care centers associated with the schools. The survey covered several aspects of EMF, including power frequency (60 Hz) magnetic fields, harmonics of the 60 Hz magnetic fields, DC magnetic fields, transient magnetic fields, and power frequency electric fields. Most efforts, however, were spent to characterize power frequency magnetic fields.

Information about field values and field sources was obtained with a systematic survey of a sample of 89 schools. This school sample size was estimated to be sufficient to produce statistically stable estimates for the number of school areas in which the average 60 Hz magnetic field exceeds a given value. The school sampling strategy was designed to obtain unbiased estimates of EMF levels for the entire population of California public schools. In fact, the results of the survey were used to produce estimates and 5% to 95% confidence ranges of a variety of EMF quantities.

The cost of reducing magnetic fields was determined by studying the field reduction that could be achieved by modifying the field sources and assessing the cost of modification. Only the cost of reducing 60 Hz magnetic fields was assessed. In particular, this cost was assessed for "area sources" only. Area sources are the sources that affect an area, and are so named to distinguish them from “operator sources” which are electrical devices that, generally, affect only the magnetic field exposure of the operator of the device. Area sources include electric power transmission lines, overhead and underground electric power distribution lines, school power supply cables, net current in electrical conduits or conductive pipes, electrical panels, fluorescent lights, air conditioning or heating equipment, power transformers, and distributed office equipment or appliances. Operator sources included computer monitors, electric typewriters, pencil sharpeners, overhead projectors, aquarium pumps, and many others.

Data available prior to the start of the project indicated that sufficient accuracy could be obtained with a sample of about 80 randomly selected schools. Random selection of schools, however, conflicted with the goal of determining the total cost of field reduction with the greatest possible accuracy. It was expected that the cost of exposure reduction would be greater when the fields are caused by power lines. Therefore, schools were stratified by different types, corresponding to different estimated field reduction costs: schools in proximity to overhead transmission lines, schools in proximity to overhead three-phase distribution lines, and others. In order to obtain the most accurate magnetic field reduction cost estimate for the entire population of schools the first two types of schools required oversampling. A sampling strategy was developed that ultimately resulted in the selection of 25 schools close to transmission lines, 50 schools close to three-phase distribution lines, and 14 other schools.

The population of California public schools considered in the study is described in the "1995 California Public School Directory", issued by the California Department of Education. The number of public schools is 7859. The schools were selected using an elaborate process from two databases: 84 schools from the State School Directory, and 5 schools from the Utility School Database (a list of schools and distances to power lines provided by California Electric Utilities). The result of the selection was a probability sample, for which the probability of each school being selected could be calculated. In order to generate representative sample estimators of the EMF variables of the general population of California public schools, each school was assigned a weight inversely proportional to the school's selection probability. This weight can be interpreted as the number of schools that the selected school represents. Sample estimators computed using these weights are unbiased estimators of the California public schools. In addition, special procedures applicable to probability samples were used to calculate the standard error and the 5% to 95% confidence interval of the estimates.

An effective recruiting strategy was developed in order to perform the measurement program in a timely and efficient manner. This strategy included the development of an informative solicitation folder, a videotape showing the measurements to be performed, school meetings, and guidelines for assisting the schools in understanding and supporting the measurement program. The recruitment folder contained numerous informational items for the school district supervisor to review: a letter of introduction from the California Department of Health Services, a letter of introduction from Enertech Consultants, letters of endorsement from the California Department of Education and the California Parent-Teachers Association, a one-page Fact Sheet, a Question and Answer Sheet, a detailed description of the measurement protocol and a sample school measurement report.

If the district declined to participate, an alternate school district would then be selected according to well defined criteria and contacted for participation. If the district accepted, then similar recruitment folders were sent to the principals of the selected schools within that district. A Letter of Consent was sent to each principal to be signed and returned to Enertech.

After completion of the measurement survey at a particular school, the school district would receive a report for each participating school of that district. These reports followed a predefined, established format and included overall school statistics, individual area statistics, and identification of sources with suggested EMF exposure reduction strategies.

Participation in the project by a school district was strictly on a voluntary basis. During the course of the project, 51 school districts were asked to participate in the study. Of these 31 accepted and 20 declined to participate. There is no reason to believe that EMF exposure in the districts that refused to participate is different in some particular way from the exposure in the rest of the districts.

The geographical distribution of the participating schools is shown in Figure 1.

The measurement protocol used at each school was designed to provide a detailed record of magnetic field levels within all school areas and an identification of their sources. Measurements were conducted during normal school hours while school was in session. The protocol was designed to minimize intrusiveness while collecting complete, detailed, quality measurement data. The protocol included:

1. Systematic magnetic field measurements at a large number of points in each school area. The value measured was the rms magnetic field value in the 40 to 800 Hz frequency range. All school areas (classrooms, staff occupied indoor areas, other student occupied indoor areas, and outdoor areas) were individually surveyed. Measurements were performed at about 1 meter height above ground (or floor) at a large number of points uniformly distributed over each area.
2. Identification of up to three area sources responsible for the magnetic field in each area. Special measurements and documentation for each identified source.
3. DC, 60 Hz, and harmonic magnetic field at the center of all classrooms.
4. Measurements of the magnetic field for a 24-hour period at selected indoor locations, including five classrooms.
5. Measurements of the magnetic field lateral profile of all power lines adjacent to the school. Sketches and photos of the lines, including the details of the conductor attachment at each structure.
6. Identification of all operator sources in each area. Measurements of the magnetic field characteristics (60 Hz and 180 Hz dipole moments) of selected operator sources.
7. Measurements of the maximum electric field outdoors, generally near overhead power lines, and in five classrooms.
8. Documentation (sketches, photos, special measurements) of the area sources identified during the survey.

Measurements at each school were performed by a two-person measurement crew and required about two days to complete. In total, measurements were performed in 5,403 different school areas, of which 3,193 were classrooms.

If the school being measured had an associated daycare facility on the premises, then the daycare facility was also surveyed. All measurements at the daycare center used the same protocol as for the school. Most of the daycare facilities encountered were limited to a few indoor classrooms, with the outdoor areas shared by the school.

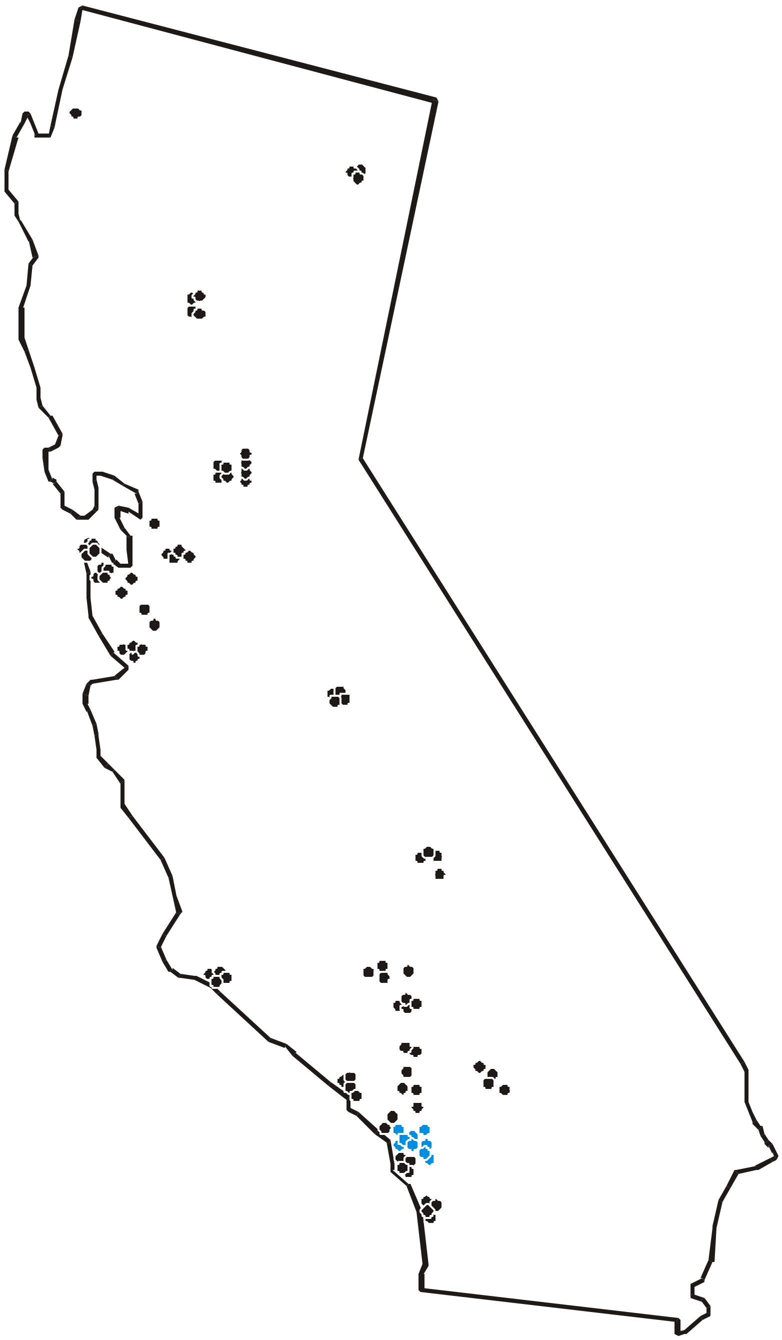

Figure 1. Diagram of the Participating Schools within the State of California

Survey Results

The data collected during the EMF survey were entered in a comprehensive database. The "California Public School EMF Survey Database" was constructed using Microsoft Access version 7.0 for Microsoft Windows 95. This database consists of a number of related tables.

The central table of the database is the "Area and source data" table. This table contains one record (line of data) for each school area and for each magnetic field source, up to a maximum of 3 sources per area.

The "Area and Source Data" table is related to three main groups of tables:

- tables that describe the measured field in each area (spatial distribution, temporal variations, DC and harmonics, transient count, operator sources, operator source field),
- tables that describe the characteristics of the "area sources" (power line, net current, electrical panel, fluorescent lights, power transformer, office equipment, power cable, water main, other sources),
- a "School" table that contains general information about each school. Related to this table are the "Electric Field" and the "Wire Code" tables that contain information applicable to each school, and the “Weights” table that contains the weight to apply to each school when the data are used to make estimates applicable to the whole population of California public schools.

Several magnetic field quantities were analyzed. The most significant results are shown in the following.

The average magnetic field in a California public school area (classroom, other indoor student occupied areas, offices, outdoor areas) is a statistical quantity described in Figure 2. The figure shows, for example, that about 20% of school areas have average field greater than 1 mG. The 95% confidence interval of the estimated percentage is from 17% to 23.6%. Since the results corresponding to the lowest percentages are of greatest interest, the same data are plotted with an expanded vertical scale in Figure 3. From this figure it is possible to read, for instance, that 1.1% (95% C.I. from 0.6% to 1.8%) of school areas have average fields greater than 5 mG. Table 1 shows the estimated number of California public school areas with fields exceeding a given value.

Table 1. Number of School Areas with Magnetic Fields Exceeding Given Values

Ave. field	% of areas	Number of areas	95% C.I.	Ave. field	% of areas	Number of areas	95% C.I.
1 mG	20.1	91,600	77,700-108,000	5 mG	1.1	4,900	2,900-

							8,400
2 mG	6.9	31,500	24,700-40,100	7 mG	0.43	1,900	1,200-3,200
3 mG	3.0	13,600	9,900-18,800	10 mG	0.15	680	260-1,800

The average magnetic field in California public school classrooms is a statistical quantity described in Figure 4. The figure shows, for example, that 17% of California classrooms have average field greater than 1 mG. The 95% confidence interval of the estimated percentage is from 13% to 21%. Since the results corresponding to the lowest percentages are of greatest interest, the same data are plotted with an expanded vertical scale in Figure 5. From this figure it is possible to read, for instance, that 0.6% (95% C.I. from 0.2% to 1.6%) of classrooms have average fields greater than 5 mG. Table 2 shows the estimated number of California public school classrooms with fields exceeding a given value.

Table 2. Number of Classrooms with Magnetic Fields Exceeding Given Values

Ave. field	% of class rooms	Number of classrooms	95% C.I.	Ave. field	% of class rooms	Number of classrooms	95% C.I.
0.5 mG	39.4 %	105,700	92,000 - 122,000	2 mG	5.7 %	15,300	11,300 - 20,000
1 mG	16.9 %	45,300	36,000 - 57,000	3 mG	2.13 %	5,700	3,700 - 8,700
1.5 mG	9.8 %	26,300	20,000 - 34,000	5 mG	0.63 %	1,700	700 - 4,200

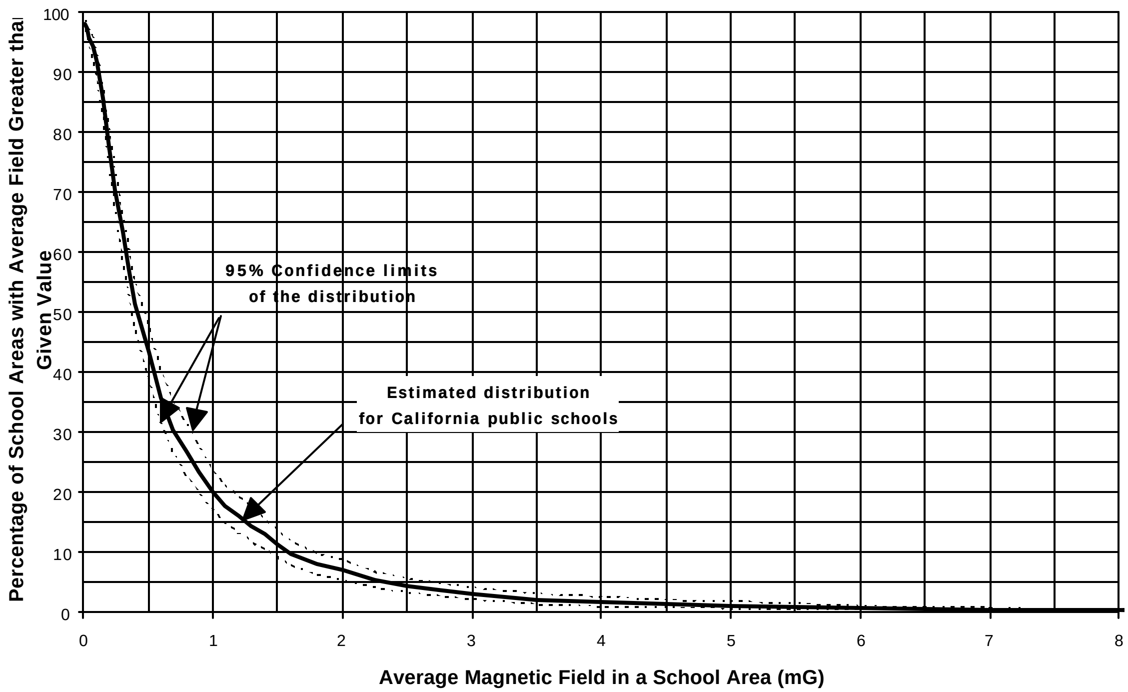

Figure 2. Distribution of School Area Average Magnetic Fields

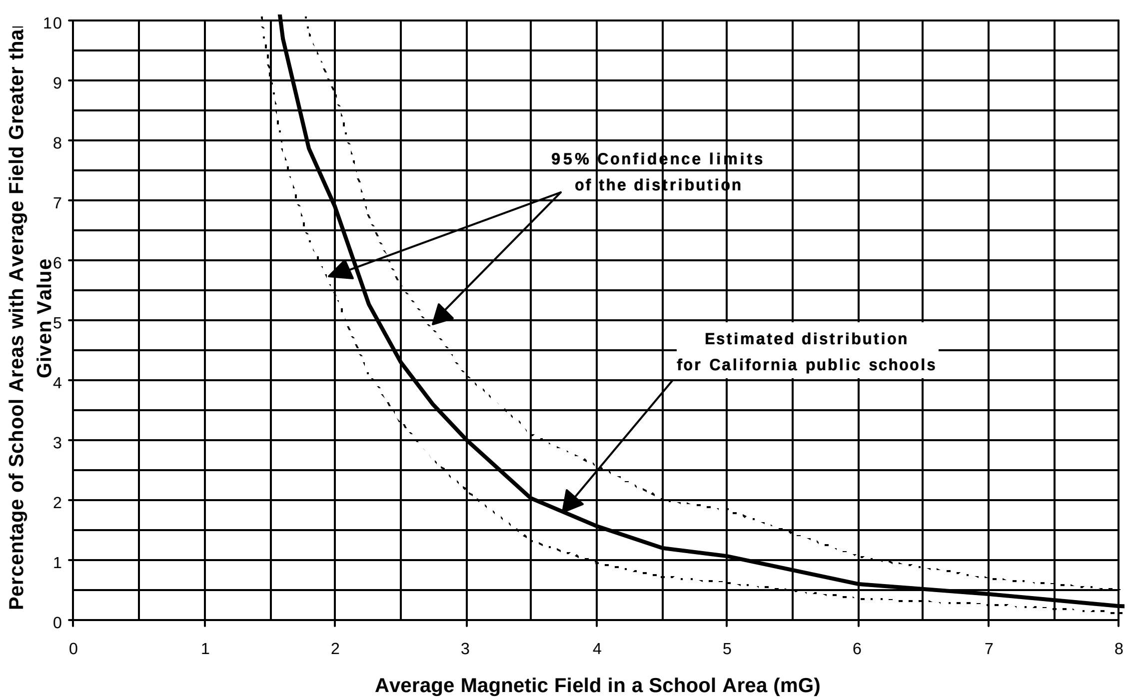

Figure 3. Distribution of School Area Average Magnetic Fields. Same data as Figure 2, but with an expanded vertical scale.

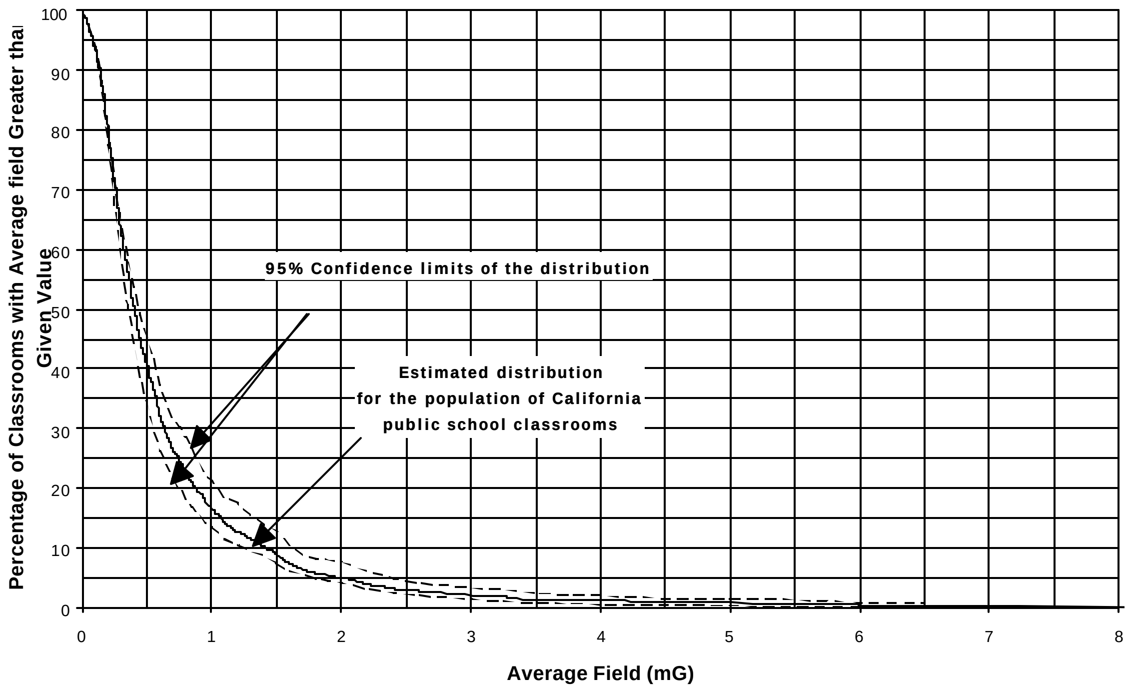

Figure 4. Distribution of Classroom Average Magnetic Fields

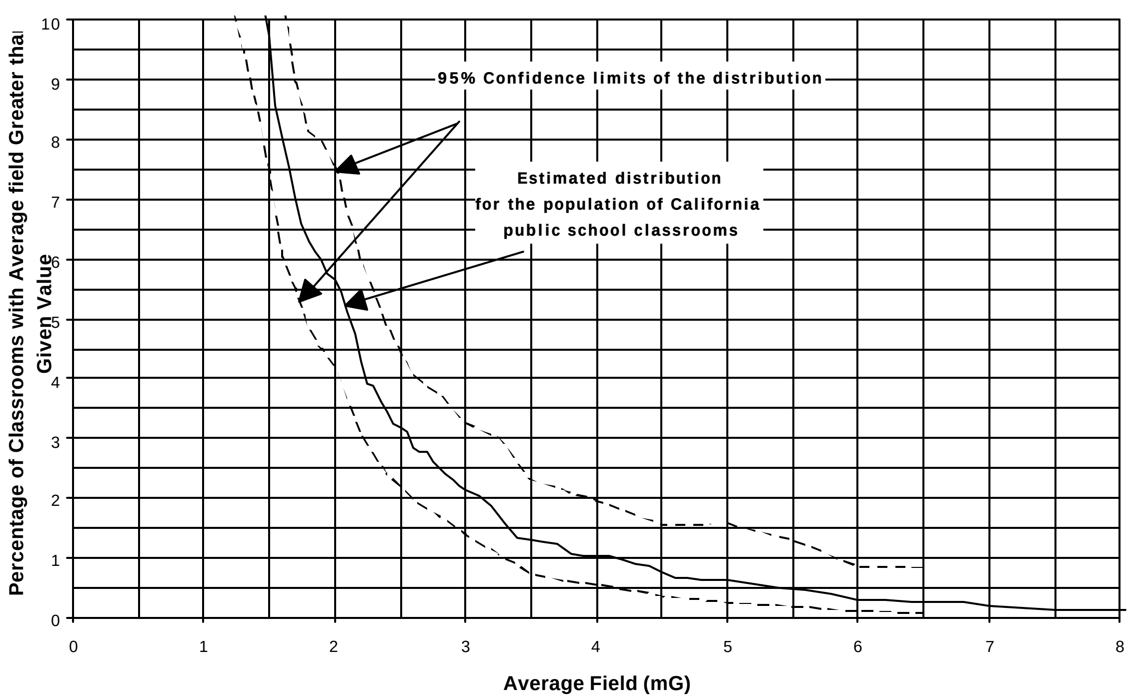

Figure 5. Distribution of Classroom Average Magnetic Fields. Expanded scale.

The distribution of average fields was calculated separately for all types of school areas. The results are given graphically in the form of box and whiskers plots in Figures 6.

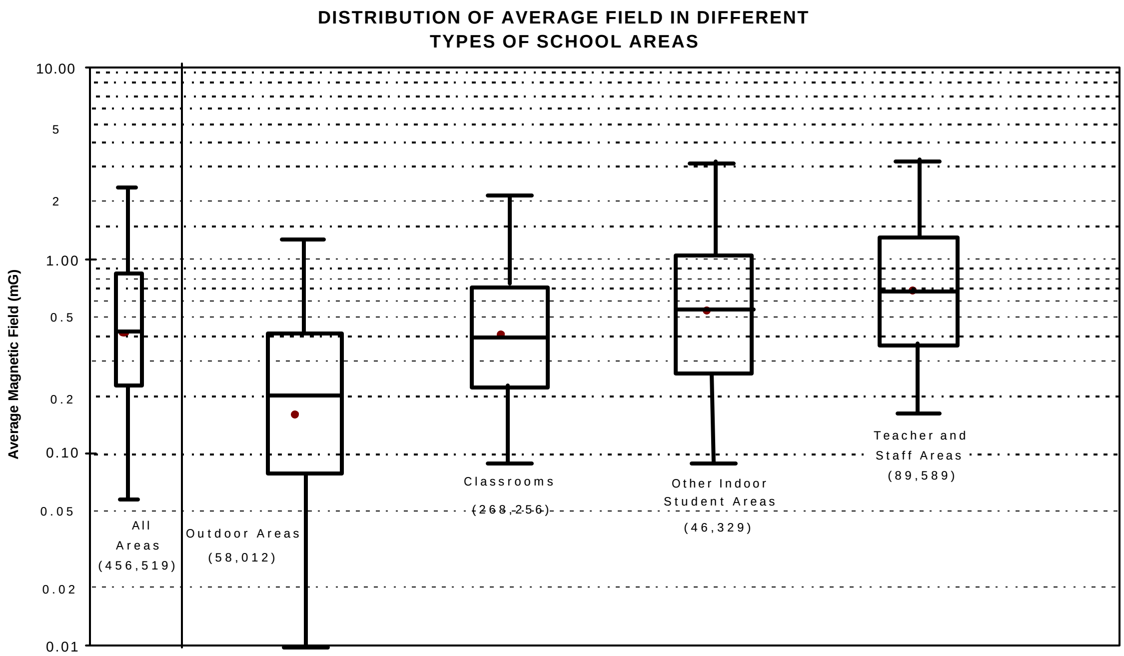

Figure 6. Box and Whiskers Plots of the Distribution of Average Fields in Different Types of School Areas

The EMF survey included not only the measurements of the spatial distribution of the magnetic field in all school areas, but also the identification and characterization of the sources of magnetic field. The distribution of school area magnetic field values was analyzed separately for each source. The measurements and the source information collected made it possible to attribute to each source the field that that source, if acting alone, would have produced in each area. The sources analyzed were: net currents, transmission and distribution lines, fluorescent lights, electrical panels, office equipment, power cables, power transformers, air conditioners, and currents in water mains. Table 3 shows the estimated number of classrooms in which a source produces an average field above a given value. Table 4 is for the 95th percentile field (exceeded in 5% of the room).

Tables 3 and 4 show that net currents are the most widespread source of magnetic field. For instance, the estimated number of California classrooms with average net current fields greater than 2 mG is 11,000. In contrast, it is estimated that only 140 California classrooms have average field exceeding 2 mG because of transmission lines.

Table 3. Number of Classrooms in Which Different Sources Cause an Average Magnetic Field Greater than Given Value (Total number of classrooms: 268,300)

Field Source	>0.5 mG	>1 mG	>2 mG	>5 mG
Net Current	64,000	32,000	11,000	1,450

Distribution Line	11,700	3,550	1,300	0
Transmission Line	2,300	1,100	140	115
Electrical Panel	6,800	1,300	500	120
Office Equipment	5,500	2,600	100	0
Power Cable	1,950	720	410	8
Power Transformer	1,700	680	120	0
Current in Water Main	150	0	0	0
Fluorescent Lights	11,800	380	0	0
Air Conditioners	530	0	0	0

Table 4. Number of Classrooms in Which Different Sources Cause a Field Greater than Given Value in more than 5% of the Area (Total number of classrooms: 268,300)

Field Source	>1 mG	>2 mG	>5 mG	>10 mG
Net Current	61,000	34,000	7,800	2,200
Electrical Panel	13,800	6,400	2,150	490
Power Transformer	2,200	1,650	680	120
Office Equipment	6,000	3,200	490	100
Transmission Line	1,300	560	340	0
Distribution Line	6,100	1,700	270	0
Power Cable	1,700	620	8	0
Air Conditioners	2,200	810	0	0
Fluorescent Lights	11,500	700	0	0
Current in Water Main	0	0	0	0

The results of the electric field measurements performed outdoors, at 1 m above ground, are shown in Figure 7. Because of the large spread of values, the results are presented using a logarithmic scale of the field. In 50% of the schools the highest electric field is less than 7.5 V/m. In 5% of the schools the highest field exceeds 56 V/m. The largest measured value was 1,000 V/m. Fields in excess of 100 V/m were caused by transmission lines. Fields between 1.3 V/m up to 100 V/m were caused either by transmission or distribution lines.

Electric fields were measured also indoors, at the center of classrooms at 1 m above the floor. In 50% of the classrooms the electric field did not exceed 0.5 V/m. In 5% of the classrooms the field exceeded 4 V/m. The largest measured field was 15 V/m. All fields in excess of 2 V/m were caused by proximity to fluorescent lights. There was only one exception, in which a field of 3.5 V/m was measured and attributed to a transmission line near the classroom.

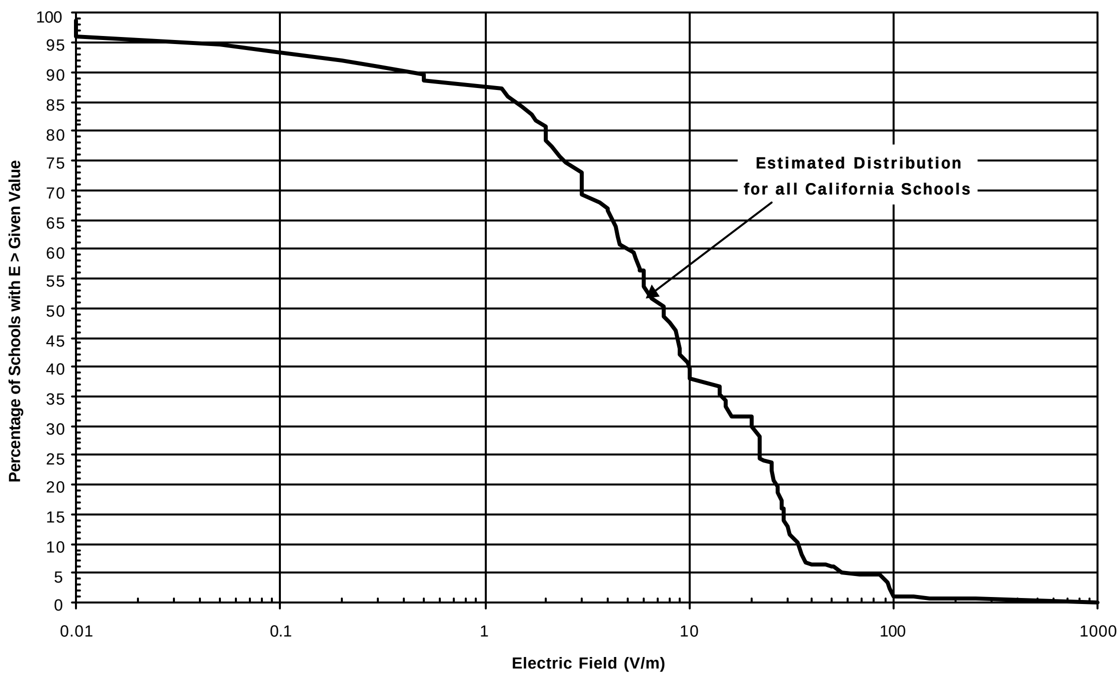

Figure 7. Highest Outdoor Electric Field Measured at 1 m Above Ground.

The DC magnetic field was measured in all the classrooms of the surveyed schools. The measurements were made in the center of the classroom at the height of 1 m above the floor. In addition, the geomagnetic field was measured outdoors at a location where the field was not perturbed by proximity to ferromagnetic objects. The field inside the classrooms was expressed as a fraction of the unperturbed geomagnetic field. This fraction indicates the degree of perturbation caused by the school building. The geomagnetic field was sometime decreased and sometime enhanced by the perturbation caused by the ferromagnetic components of the building structure. It was found that, in general, the field inside the classroom is slightly lower than the geomagnetic field. The median field reduction is 4.7%, indicating a shielding effect of the school building. The 95% range, however, goes from a field reduction of 11% to a field enhancement of 6%.

Cost of Field Reduction

A major product of this project is the “California School EMF Reduction Cost” computer program. Its purpose is to provide a tool for assessing the cost required for reducing magnetic field in California public schools from existing levels to lower levels and to assess the field reduction that can be achieved at a given cost.

The program operates on an extensive database, consisting of:

(1) the California Public School EMF Survey Database,
(2) a list of magnetic field reduction techniques applicable to all the area sources and the field reduction calculation algorithms associated with each technique, and
(3) cost equations and cost coefficient tables applicable to each field reduction technique.

The output of the computer program includes:

- The cost estimate for reducing magnetic field below user specified target levels in all California public schools. The estimate is given as a statistical quantity, characterized by its median and by the lower and upper values of its 5% to 95% uncertainty range.
- The breakdown of the cost estimate by school. This is useful for the analysis of the association between cost and school characteristics.
- The breakdown of the cost estimates by magnetic field source type (transmission lines, distribution lines, power supply cables, net currents, electrical panels, fluorescent lights, power transformers, office equipment, air conditioners and heaters, and others), and, for each source type, by field reduction technique.
- The overall reduction in magnetic field exposure in California public schools that can be obtained by modification of a given source type at a given cost.

In order to calculate magnetic field reduction costs, the level below which the fields should be reduced must be established. This is accomplished, without making any decision on the merits of field reduction, by leaving the user of the cost program free to establish school area *target field* values. The output of the cost program consists of the cost of applying the field reduction techniques that achieve the target field values established by the user. The minimum field value that may be specified as a target is 0.5 mG, because field sources were not identified when magnetic fields were below 0.5 mG.

The process of calculating the cost of reaching a given field reduction target is outlined in Figure 8. The first step in the calculation process is to select a school from the California school EMF survey database. The database includes 89 schools. The field reduction cost is evaluated for each individual school. The next step is to analyze the field measured in each area of the selected school to ascertain whether or not it meets the specified magnetic field target. If the target value is exceeded in the school area being examined, the computer program interrogates the database to identify the sources that are causing the field in that school area and to determine the source characteristics.

In most school areas the field is caused by one source only. In some areas, however, two and, in some cases, three different area sources were identified. In these cases, the spatial distribution of the field that would have been caused by each source if it were acting alone is determined. The program considers all the sources of field in each area and all the possible field reduction techniques. For each field reduction technique, the field reduction factor is calculated, then the field reduction factor is applied to the spatial distribution of the field of that source, and a new spatial distribution is obtained for that source. For each combination of field reduction techniques, the field distributions of all the individual sources are combined, and the overall spatial field distribution in the area after field reduction is calculated. When different school areas have one or more common sources, they are analyzed as a group. All the combinations of field reduction techniques for the group are considered, the combinations that meet the target are determined, the total cost of each combination is obtained by adding the cost of the individual techniques, and finally, the combination that corresponds to the lowest total cost is selected.

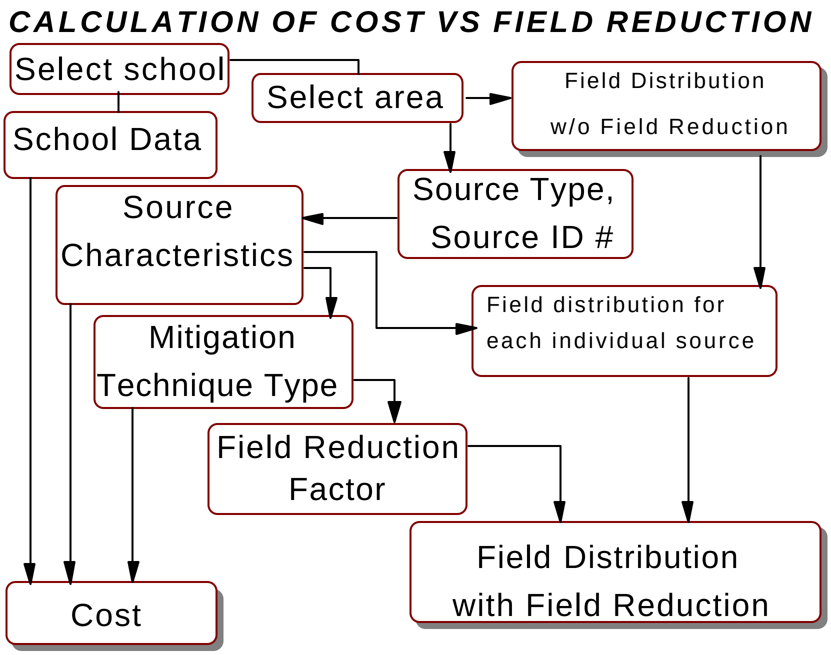

Figure 8. Calculation of Cost versus Field Reduction

The field reduction cost for a school is calculated by adding the field reduction costs for each area or group of areas. The cost for the entire school sample is obtained by adding the cost for each school. If the sample is used to estimate the cost of field reduction for all California public schools, each school must be appropriately weighted.

Each cost figure is expressed as a distribution of values. The results of the calculations are field reduction costs expressed as statistical quantities. Both median, 5%, and 95% values are calculated.

The cost of each field reduction technique is given in cost equations of the type: $C = f(k_1, k_2, k_{3,} ..., A, B, C, ...)$ where: k_1, k_2, and k_3 are cost coefficients considered as statistical quantities, whose median, 5%, and 95% values are given in the cost tables. The 5% to 95% range indicates the uncertainty with which the coefficient are estimated. A, B, and C are parameters that describe the source (e.g. the number of spans of a transmission line, the average span length, the location of the school, etc.).

The results of the calculations are presented in the form of spreadsheets, giving the breakdown of costs by school, by source type, and by field reduction option.

A significant component of this project was the assessment of all the possible techniques for reducing magnetic fields produced by the sources found in the schools. This assessment included the listing of the possible field reduction techniques for each source, the development of algorithms to calculate the effectiveness, and the estimation of the cost of each technique. For each source there may be more than one technique that can be used to reduce the field. Table 5 reports a list of the area sources identified during the magnetic field survey of the California public schools and of the techniques that were considered for reducing magnetic field exposure.

Table 5. Field Reduction Techniques for Area Sources

Area Source		Field Reduction Technique	
Type	**Description**	**Type**	**Description**
1	Transmission Line	1.1	Re-phasing of double circuit lines
		1.2	Change flat line configuration into compact delta
		1.3	Increase structure height
		1.4	Application of a two-wire cancellation loop on existing structures
		1.5	Application of a two-wire cancellation loop on separate structures
		1.6a	Application of a three-wire cancellation loop on the existing structures of single circuit lines
		1.6b	Application of a three-wire cancellation loop on the existing structures of double circuit lines
		1.7	Application of a 3-wire cancellation loop on separate structures
		1.8a	Conversion to optimum split-phase arrangement with change in supporting structures
		1.8b	Conversion to optimum split-phase arrangement without change in supporting structures
		1.9	Conversion to 5-wire split phase vertical
		1.10	Conversion to hexagonal split-phase arrangement
		1.11	Conversion to split-phase double-circuit vertical arrangement
		1.12a	Undergrounding using solid dielectric cables
		1.12b	Undergrounding using solid dielectric cables and placing steel plates on top and sides of the cable encasing
		1.12c	Undergrounding using high pressure oil filled (HPOF) cables
		1.13	Limitation of access to affected areas
		1.14a	Combination of techniques: re-phasing and increasing the height of double circuit lines
		1.14b	Combination of techniques: change to compact delta and increase the height of the structures
		1.14c	Combination of techniques: re-phasing and three-wire cancellation loop on existing structures of double circuit lines
		1.14d	Combination of technique 1.13 with any of the other techniques or combination of techniques.
		1.15a	Special technique for a specific application (69-115 kV transmission line with "triangle top" configuration and underbuilt distribution lines): conversion to hexagonal split-phase and insertion of net current control transformers in the primaries of the distribution lines.

Area Source		**Field Reduction Technique**	
Type	**Description**	**Type**	**Description**
		1.15b	Special technique for a specific application (transmission line with underbuilt distribution lines): no modification of the transmission line and insertion of net current control transformers in the primaries of the distribution lines.
		1.15c	Special technique for a specific application (transmission line with underbuilt distribution lines): undergrounding of the transmission line (using solid dielectric cables) and insertion of net current control transformers in the primaries of the distribution lines.
2	Distribution Line	2.1	Re-phasing of double circuit lines
		2.2	Change flat line configuration into compact delta
		2.3	Use spacer cable
		2.4a	Increase pole height
		2.4b	Combination of technique 2.1 (change flat into compact delta) and technique 2.4a (increase pole height)
		2.7	Conversion to split-phase arrangement
		2.8	Undergrounding
		2.9	Limitation of access to affected areas
		2.10	Increase size of neutral wire
		2.11	Insert net current control transformer in the primary
		2.12	Insert dielectric unions in water main and water lines
		2.13a	Combination of technique 2.11 (net current control transformer) with technique 2.12 (dielectric unions)
		2.13b	Combination of any of technique 2.1 to 2.8 with any of technique 2.10 to 2.13a
		2.13c	Combination of technique 2.9 (limitation of access to affected areas) with any other technique or combination of techniques
3 and 12	Power Supply Cable	3.1	Install steel plates above the cables
	(3: to main panel)	3.2	Reroute the cable
	(12: between panels)	3.3	Net Current Control Transformer
		3.4	Dielectric Insert in water pipe entrance to school building
		3.5	Place cables in welded steel pipes
		3.6	Limitation of access to affected areas
4	Main Distribution Panel	4.1	Place shielding plates on walls (or floor) of adjacent rooms
		4.2	Limitation of access to affected areas
5	Net Current in Electrical Conduits	5.1	Locate and fix the wiring errors: inspect and measure currents at panels, identify circuits with net current, estimate type of wiring errors, locate and repair wiring errors, recheck field.
		5.2	Limitation of access to affected areas
6	Electrical Panel	6.1	Place a shielding plate on the wall in the back of the panel
		6.2	Shield the front of the panel
		6.3	Limitation of access to affected areas
7	Heater / Air Conditioner	7.1	Replace device with another with low EMF
	/ Air Filter Fan	7.2	Limit access to affected areas
8	Fluorescent Lights	8.1	Increase height of light above the floor (if affected area is in the same room)

Area Source		Field Reduction Technique	
Type	**Description**	**Type**	**Description**
		8.2	Lower height of light above the floor (if affected area is on the floor above)
		8.3	Replace with lights with electronic ballast
		8.4	Move kindergarten rooms to rooms that do not have fluorescent lights on the ceiling of floor below
10	Power Transformer	10.1	Move transformer to another location
		10.2	Place steel plates on walls of adjacent rooms
		10.3	Limit access to affected areas
11	Office Equipment / Computer lab equipment / Appliances / Copy room equipment / Shop equipment	11.1	Change equipment layout
		11.2	Replace high field equipment (certain typewriters and monitors that have high fields)
		11.3	Rearrangement of appliances
		11.4	Reduce field exposure in copy room
		11.5	Reduce field from appliances in kitchen
13	Water Main	13.1	Insert dielectric union in water main and water lines
		13.2	Limitation of access to affected areas
14	Service Drop	14.1	Install Net Current Control Transformer
		14.2	Limitation of access to affected areas
15	Unknown	15.1	Engineering work to identify source. Assuming that the source is a net current, locate and fix wiring errors
		15.2	Limitation of access to affected areas
16	Field is low. No source identified.	16.1	No field reduction technique is applied
17	Other Source	17.1	Technique and related cost vary from source to source.
		17.2	Limitation of access to affected areas

The field reduction efficiency of a technique was expressed by the field reduction factor, which is the ratio between the field caused by a source before and after the application of that technique. The field reduction factor is a function of the characteristics of the source, of the type of technique, and of the location of the area in relation to the source. The field reduction factor was given for all the combinations of source and field reduction options.

The work of developing cost data for transmission and distribution line modifications was performed by Enertech Consultants and Power Engineers of Hailey, Idaho, an engineering firm specialized in the design of power lines. The Enertech research team identified a number of power line situations near schools for which cost data were desirable and provided specific scenarios to use for the cost estimates. Power Engineers provided cost estimates for various methods to reduce magnetic fields around schools in California. A large number of field reduction options was considered.

Cost formulas were developed for global, statewide applications. The methodology used to generate statewide estimates could be misleading if applied to a specific school.

Cost estimates are intrinsically subjective and dependent on the approach and experience of the estimators. The cost program uses the cost data provided in this report as default values, and gives the user of the program the ability to modify the cost coefficients and increase or decrease the cost of each different field reduction option.

The cost estimates are expressed in 1997 dollars. When the field reduction option included a significant modification (increase or decrease) of losses and maintenance requirements, the present worth of the cost of losses and maintenance was included in the estimate. Maintenance costs were not added when it was assumed that the modified line would have the same reliability and maintainability as the original line. The costs are all the direct and indirect costs of the contractor. Utility costs may be accounted for by a general multiplier (for instance 1.1) applied to all cost equations for transmission lines.

Some of the proposed field reduction options may not be conforming to utility practices, or may be too experimental to be widely accepted, or may not be allowable under CPUC rules. The computer program allows the user to include all possible options or to disallow the use of specific options.

The most common sources of magnetic field in the schools were net currents in electrical conduits. Therefore particular attention was given to the cost of reducing the magnetic field caused by wiring internal to the schools. A pilot program involving six schools was performed to identify the tasks that are necessary for locating and eliminating the wiring problems that cause magnetic fields. The magnetic field survey in these schools was performed with the same protocol used in all the schools to be surveyed. The identification of net currents that are a significant source of magnetic field and the tracing of the paths of these net currents was a part of the protocol. The survey identified 42 net current paths in 5 of the six schools used for this pilot program. In one school no significant net current was detected. The five schools in which net current paths were identified were revisited to find the causes of the net currents and to determine the remedial actions necessary to eliminate the net currents. The remedial actions were discussed to the degree needed for an electrical contractor to estimate the cost of these actions, as it would be done for a quotation for work to be executed. Cost equations were developed to calculate the cost of net current problem diagnostics and the cost of remedial actions necessary to eliminate the net currents. It was noted that the cost of net current reduction has a large uncertainty caused by the variety of wiring problems that may be encountered and by the varied proficiencies of electricians, accentuated by the fact that they are not accustomed to deal with magnetic fields and net currents.

The “California School EMF Reduction Cost Program” was exercised to obtain the answers to several questions. The target levels used to obtain the results presented here do not imply any recommendation about desirable field levels. Also, there is a concern that the results presented here may be used without adequate appreciation of the subjective nature of cost estimates. Enertech and its sub-contractors applied their best efforts to provide reasonable cost estimates and avoid bias. However, it is likely that different organizations would arrive at different cost estimates. Efforts were made to provide cost ranges that account for cost variability. The program allows the user the flexibility to change target levels, allowable field reduction techniques, and cost data. The number of parameters that can be varied and that can influence field reduction costs is staggering. This report presents the most significant results.

The estimated cost of reducing the average magnetic field in all areas of all the California schools below a specified target is shown in Figure 9. For instance, the figure shows that the cost of reducing the average field below the 2 mG level in all school areas is $79.2 million, (C.I. 63.0 - 95.0), i.e. an average of $ 10,100 per school.

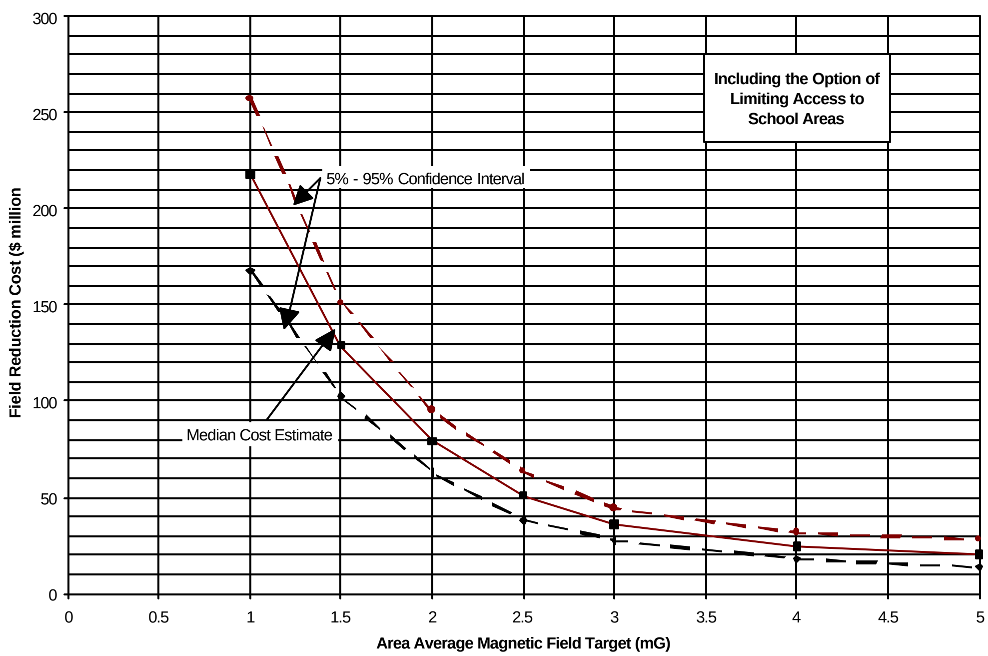

Figure 9. Cost of Reducing the Average Field in All School Areas below a Specified Target

Figure 10 shows the breakdown of costs among: survey cost, cost of modifying power lines, and cost of modifying internal sources. The cost of EMF surveys is practically independent of the target level and it is, on average, about $1,200 per school. The cost of modification of internal sources is much greater than the cost of modification of power lines. With a 2 mG average field as a target, the cost of modification of power lines is $ 14.8 million (average of $1,900 per school) and the cost of modifying the internal sources is $ 53.6 million ($6,800 per school).

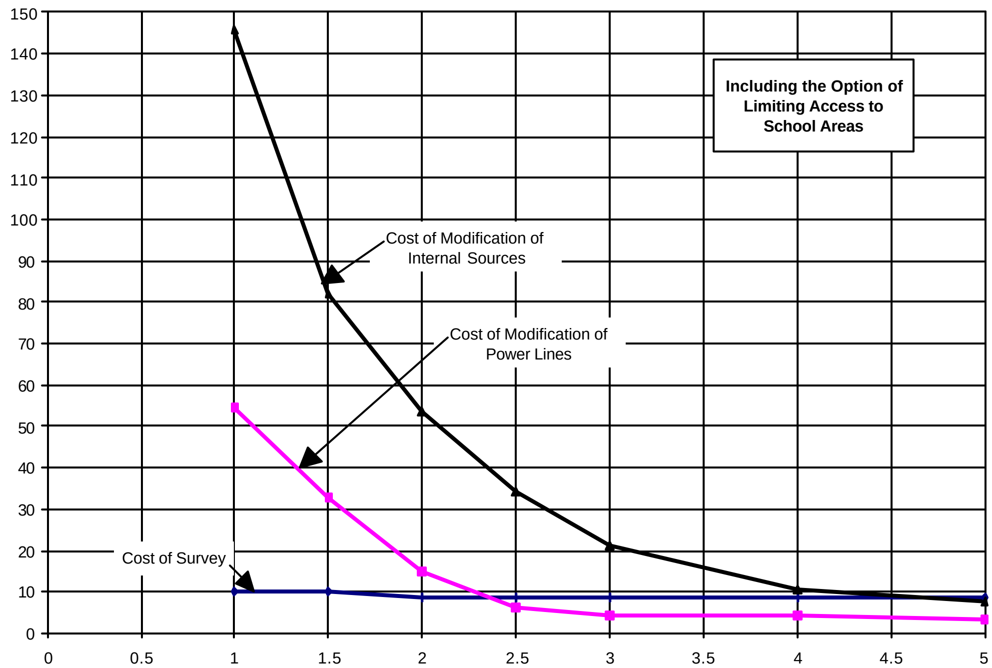

Figure 10. Breakdown of Cost of Reducing the Average Field in All School Areas: Cost of Survey, of Modification of Power Lines, and of Modification of Internal Sources

The results presented in Figures 9 and 10 were obtained including the option of limiting access to school areas rather than modifying field sources. The cost of limiting access to school area was included whenever it was less than the cost of source modification. With this approach, many of the expensive source modifications (for instance, placing a transmission line underground) do not need to be implemented. Cost calculations were repeated by excluding the option of limiting access to affected areas. In this way the computer program was forced to consider all the other source modification options. It was still possible to meet the target in all areas in all the schools, when the target was 2 mG or greater. However the costs are higher than if the option of limiting access to school areas is included. For a target of 2 mG, for instance, the cost goes from \$ 79.2 million to \$ 94.2 million. The increase is caused by the greatest cost of modifying power lines.

Figure 11 provides the breakdown of the cost of power line modification between transmission and distribution lines. For targets below 2.5 mG the cost of modifying distribution lines is of the same order as that of modifying transmission lines. For targets of 2.5 mG or greater, the cost of modifying distribution lines is much smaller than that for transmission lines.

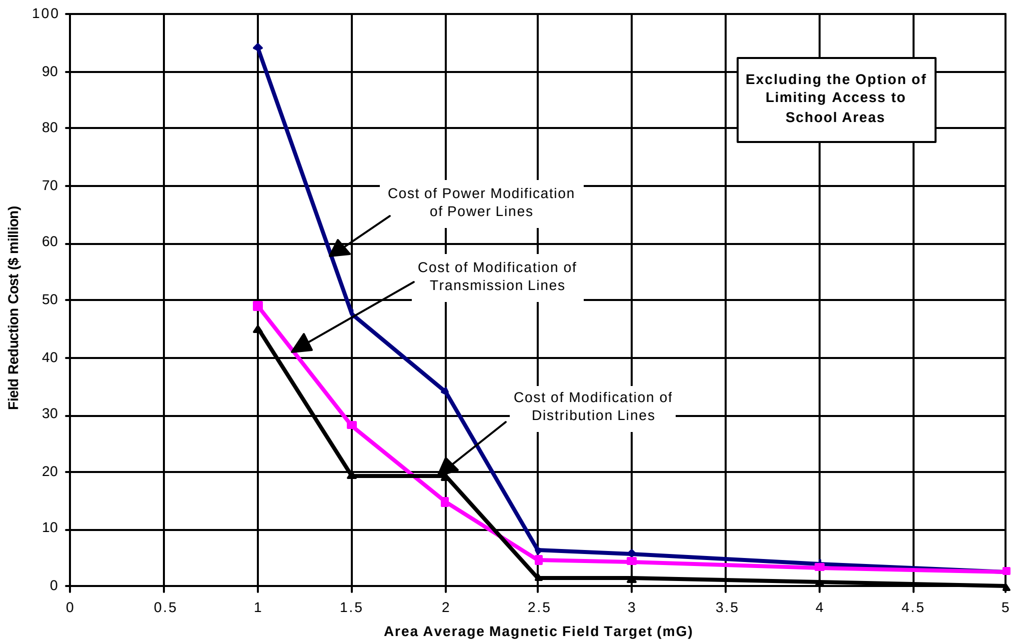

Figure 11. Breakdown of Cost of Modification of Power Lines to Reduce the Average Field in All School: Cost for Transmission and for Distribution Lines

The breakdown of the cost of modifying internal sources is shown in Figure 12. The largest costs are for reducing the net currents, followed by the cost to reduce the field from electrical panels.

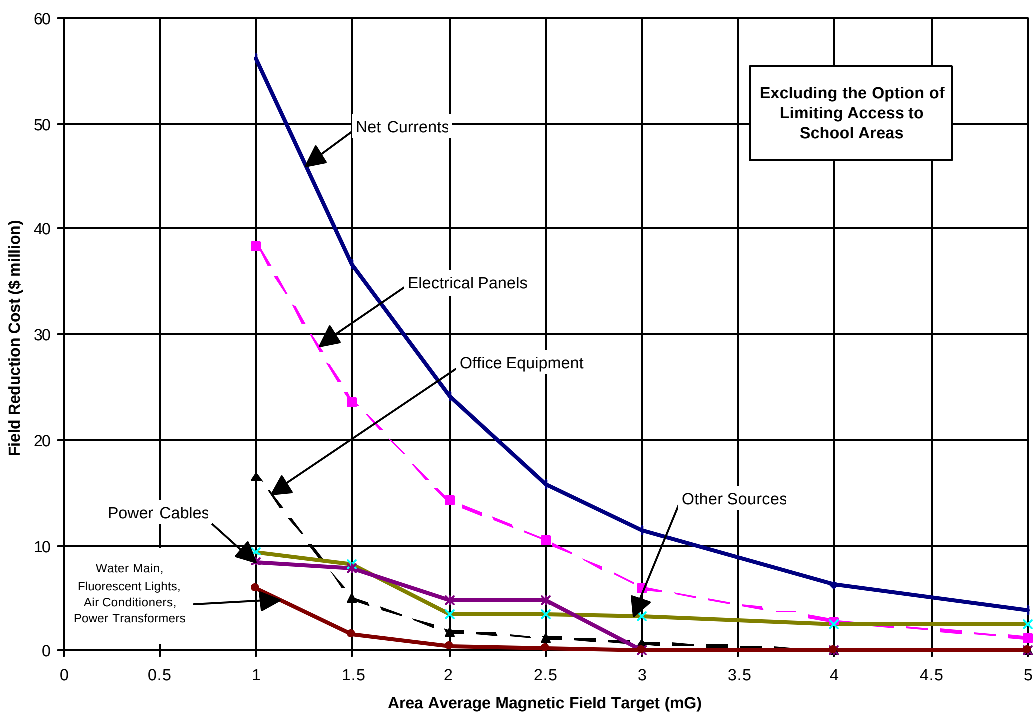

Figure 12. Breakdown of Cost of Modifying Internal School Sources to Reduce the Average Field in All School Areas.

The previous results were obtained using the average field in each area as the target. It may be desirable, however, to set two separate targets in each area, one about the average field and the other about the largest field that could be encountered. It was not possible to set up the survey to provide reliable assessment of the maximum field, which is too much dependent on the proximity to walls and equipment. The 95th percentile value (value not exceeded in 95% of the area) is a reasonable measure of the region of highest field in an area. Calculations were performed by specifying for each area that the average field be lower than a given target, X, ($B_{ave} < X$) and that the 95th percentile field be lower than a value 2.5 times greater than the target for the average field ($B_{95} < 2.5\,X$). For instance, if a target average field of 2 mG is used, a target 95th percentile value of 5 mG is also set. The results are shown in Figure 13. The addition of a 95th percentile field target, increases the cost of field reduction considerably, for instance, from $ 79million to $ 106 million for an average field target of 2 mG. Practically all of the increase is caused by internal sources.

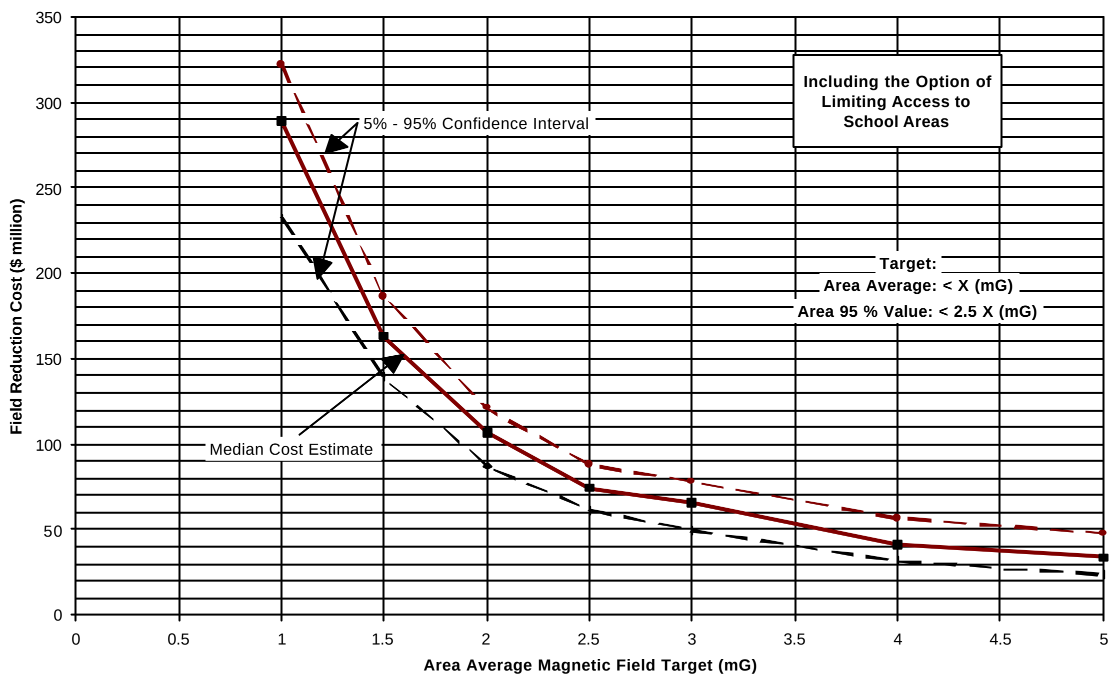

Figure 13. Cost of Reducing the Magnetic Field in All School Areas Below a Specified Average Field, (X), and a Specified 95th Percentile Field (2.5 X).

The previous results were obtained considering all the areas of all the California schools. If the field reduction objectives were restricted to classrooms, the cost would be significantly less, as shown in Figure 14. The breakdown of cost of classroom field reduction between internal and external sources is shown in Figure 15.

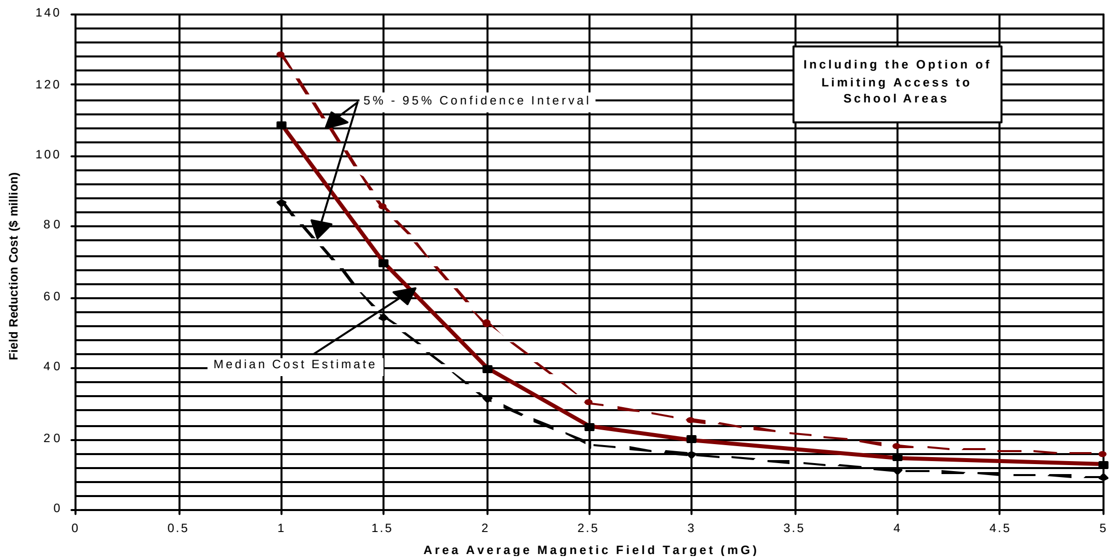

Figure 14. Cost of Reducing the Average Field in All Classrooms

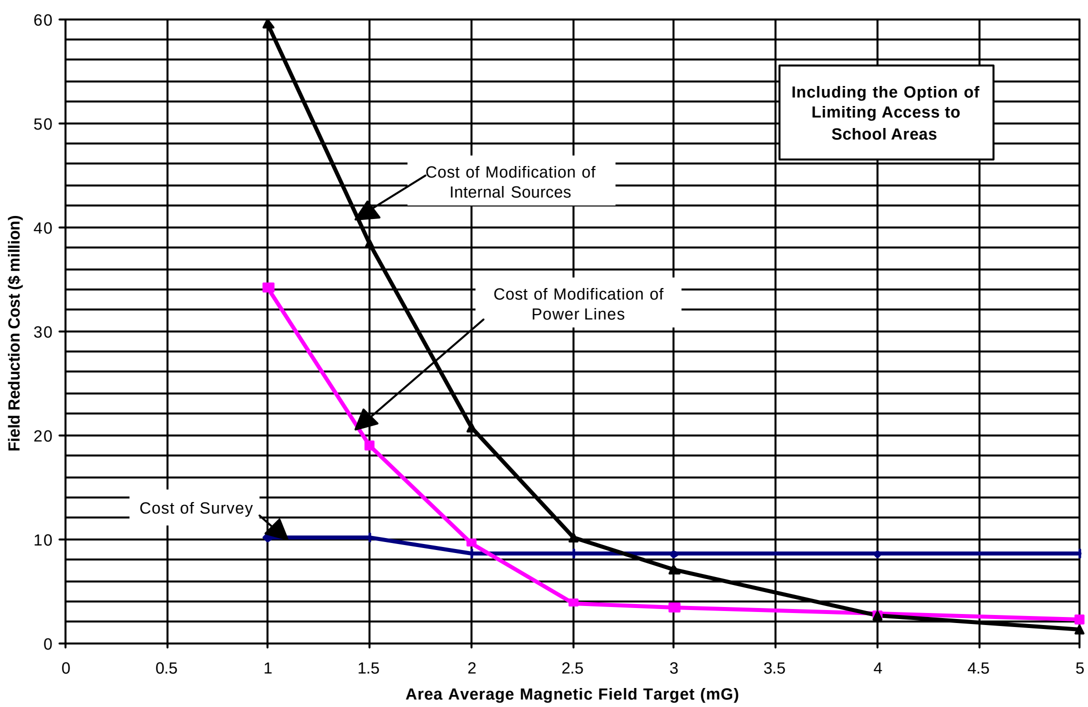

Figure 15. Breakdown of Cost of Reducing the Average Field in All Classrooms Below a Specified Average Field: Cost of Survey, Cost of Modification of Power Lines, and Cost of Modification of Internal Sources.

The computer program was set up to answer also another type of question: how much field reduction can be achieved for a given cost? This information may be of interest when the available resources are limited. Calculations of this type were performed separately for each source type. All the possible source modification options for all the schools and all the areas were considered and appropriately listed to calculate magnetic field exposure reduction versus the cumulative cost of the options. The results for all school areas are shown in Figure 16. Exposure was defined as the sum (for all school areas) of the excess of the average magnetic field above 0.5 mG. The reduction in exposure is expressed as a percent of the total exposure before reduction.

The total estimated exposure before reduction is 172,000 mG·area in 458,000 school areas. Figure 16 indicates that it costs about $ 1.6 million for each percentage of magnetic field exposure reduction in California classrooms if the work consists in fixing the wiring responsible for net currents. By eliminating net currents, 70% of the exposure can be eliminated. In contrast, it would cost $ 48.4 million to modify transmission lines and obtain a 2.2% reduction in exposure ($ 22 million / %). Modification of distribution lines is the second most efficient work for reducing magnetic field exposure in classrooms. A total exposure reduction of about 6.8% can be achieved at a cost of $ 102.4 million ($ 14.6 million / %). It is interesting to note, however, that the first $ 4 million may bring a reduction of about 3.2% ($ 1.25 million / %), while it takes an additional $ 20 million to obtain an additional 2.0% ($ 9.9 million / %), and it takes an additional $ 58.1 million for the final 1.2% exposure reduction ($ 67 million / %). Work on office equipment ($ 6.3 million / %) and fluorescent lights ($ 7.9 million / %) is significantly more efficient than work on transmission lines, but also in these cases, the maximum exposure reduction achievable in classrooms is small (2.5 to 3%). Work on shielding electrical panels is not very efficient in reducing the average magnetic field exposure ($ 19 million / % and only a maximum exposure reduction of 1%).

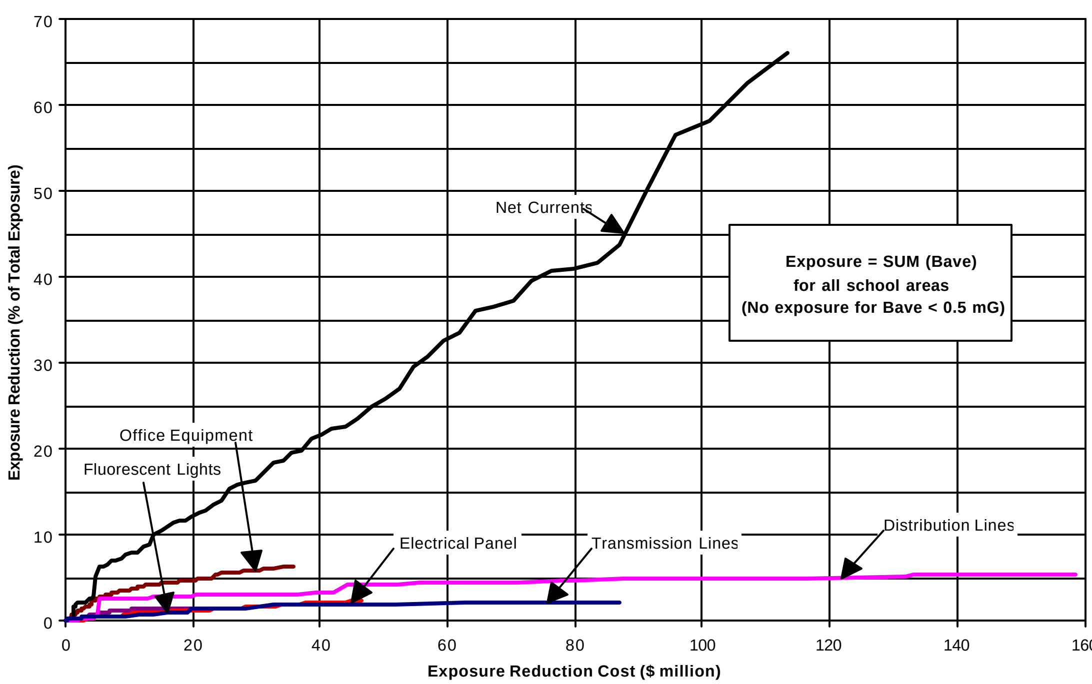

Figure 16. Magnetic Field Exposure Reduction in All California School Areas Vs Cost for Different Field Sources

Modification of sources internal to schools requires a much greater cost than modification of power lines. For instance, reaching a target of less than 1.5 mG average field in all California classrooms requires an estimated $ 38.3 million for internal sources and an estimated $ 18.9 million for power lines. The cost of reducing the field caused by net currents represents the largest share of the cost of reducing the field of internal sources. In fact, fixing the wiring responsible for net currents requires an estimated $21.8 million.

The estimate of the total field reduction cost is most sensitive, among all the parameters affecting cost, to the cost coefficients used for the calculation of cost to eliminate net currents. In particular, the proficiency of the electricians that determine the causes of each net current found in a school and fix the wiring responsible for net currents has a great impact on cost. The cost of eliminating net currents, in fact, is mostly for electrician time, because the cost of required materials is negligible in comparison. Cost estimates were generated assuming a wide dispersion in electrician's proficiency and assuming an average proficiency much worse (half) than that of well trained electricians. Large increases in the average proficiency of electricians may be possible through training. Therefore, training and licensing electricians for the job of eliminating net currents in schools appears to be very cost effective.