Environmental Health Perspectives
Vol. 75, pp. 173-195, 1987

Upper Ottawa Street Landfill Site Health Study

by Clyde Hertzman,* Mike Hayes,† Joel Singer,‡ and Joseph Highland§

This report describes the design and conduct of two sequential historical prospective morbidity surveys of workers and residents from the Upper Ottawa Street Landfill Site in Hamilton, Ontario. The workers study was carried out first and was a hypothesis-generating study. Workers and controls were administered a health questionnaire, which was followed by an assessment of recall bias through medical chart abstraction. Multiple criteria were used to identify health problems associated with landfill site exposure. Those problems with highest credibility included clusters of respiratory, skin, narcotic, and mood disorders. These formed the hypothesis base in the subsequent health study of residents living adjacent to the landfill site. In that study, the association between mood, narcotic, skin, and respiratory conditions with landfill site exposure was confirmed using the following criteria: strength of association; consistency with the workers study; risk gradient by duration of residence and proximity to the landfill; absence of evidence that less healthy people moved to the area; specificity; and the absence of recall bias. The validity of these associations were reduced by three principal problems: the high refusal rate among the control population; socioeconomic status differences between the study groups; and the fact that the conditions found in excess were imprecisely defined and potentially interchangeable with other conditions. Offsetting these problems were the multiple criteria used to assess each hypothesis, which were applied according to present rules. Evidence is presented that supports the hypothesis that vapors, fumes, or particulate matter emanating from the landfill site, as well as direct skin exposure, may have lead to the health problems found in excess. Evidence is also presented supporting the hypothesis that perception of exposure and, therefore, of risk, may explain the results of the study. However, based on the analyses performed, it is the conclusion of the authors that the adverse effects seen were more likely the result of chemical exposure than of perception of risk.

Introduction

From the early 1950s until it was closed in 1980, the Upper Ottawa Street Landfill Site in Hamilton, Ontario, received a large variety of domestic and commercial waste, as well as solid and liquid industrial wastes (*1*). By the mid-1960s, as much as five truck loads a day of industrial waste were being received by the landfill. However, the annual tonnage increased markedly during the 1970s. Available records suggest that at least 25,000 gallons of liquid wastes were disposed of in the site in 1970. Larger volumes of liquid waste began entering the landfill in 1976 with the opening of a solidification operation. The largest volumes of liquid wastes appear to have been disposed of during 1978: approximately 8 to 12 million gallons (*2*). The site was closed to landfilling in 1980. Between November 1980 and June 1981, it was covered by a layer of steel industry wastes, and sealed with a thin clay cap.

Throughout the 1950s and 1960s, a small collection of houses was found within 750 meters of the south dumpface. By the late 1970s, these had been largely removed, to make way for light industrial development. Development of large residential areas to the west, north, and northeast of the site began in the early 1970s and continued into the early 1980s. These consisted of single detached dwellings and townhouses, which were built as close as 250 meters from the dumpface.

While the site was active, there were four sources of potential human exposure to landfill site emissions. Airborne exposure to vapors, fumes, dusts, and ash may have resulted from on-site burning and from open air release of volatile substances and solid industrial residues at the landfill. For those working at the site, direct skin contact could have occurred. Airborne deposition of landfill site emissions on residential properties left open the possibility of contact through soil, indoor dust, window cleaning, and other domestic activities. Use of parkland areas adjacent to the site left open the potential for recreational contact.

*Department of Health Care and Epidemiology, University of British Columbia, Mather Building, 5804 Fairview Crescent, Vancouver, BC, Canada, V6T 1W5.
†Geography Department, McMaster University, Hamilton, Ontario, Canada.
‡Department of Family Practice, McMaster University, Hamilton, Ontario, Canada.
§Environ Corporation, Princeton, NJ 08540.

In response to public concern (*3,4*), a Study Committee was established by the Ontario Ministry of Health in 1980 which attempted to determine from records what was buried in the landfill itself; examine the environment around the landfill for chemicals; and examine the health of workers and residents to determine what ill health effects, if any, might be attributable to exposure to landfill chemicals.

The complex toxicology of the landfill and the subjectiveness of the residents' perceived complaints made it difficult to identify a short list of health problems of particular interest. The nature and potential intensity of chemical exposures could not be reliably reconstructed through a multidisciplinary evaluation including botanic, hydrogeological, geophysical, engineering, and chemical toxicologic studies. However, a variety of compounds were ultimately indentified in the landfill that were known respiratory irritants, neurotoxins, and skin irritants or sensitizers in the industrial context. Identification and follow-up of the residential population was expected to be complicated by a high rate of migration to and from the housing developments adjacent to the landfill site. Some of the health problems of concern, in particular those related to birth defects, were expected to be too uncommon for adequate study power to be achieved among a population living sufficiently close to the landfill site to be deemed exposed.

It was decided that a morbidity survey of landfill workers would precede a study of the residents. The workers represented a potentially high dose exposure subgroup, and might have been particularly vulnerable to any potential health impact associated with exposure to the landfill. Apparent increases in specific morbidity found in a workers' study could receive special attention in the residents' study, thereby mitigating the multiple comparisons problem inherent in the analysis of a general morbidity survey. If consistent results were found on two separate health surveys with different designs, the surveys might be more credible than one study that combined workers and residents in one protocol.

Those health problems found in excess among the workers were rated as high, moderate, or low credibility depending upon whether the association between landfill exposure and the health problem met certain criteria (specified in Table 9). Those associations with high and moderate credibility formed the main hypotheses that were tested in the residents' health survey.

Morbidity surveys are commonly conducted in situations similar to this (*5*). Such surveys have raised concerns within the scientific community regarding the interpretation of both positive and negative findings (*6–8*). Some investigators have argued that they cannot help define etiologic associations in relation to liquid waste disposal unless certain preconditions are met. These have been summarized separately by Landrigan (*6*), Heath (*7*), and Anderson (*8*) and are paraphrased as follows: the nature and quantities of the major environmental emissions from the site should be known; the probable routes of human exposure (transcutaneous, inhalation, or ingestion) should be defined; individual exposure estimates should be definable or biologic assessments of absorption conducted; and high risk subpopulations should be defined prior to study.

These expectations create a dilemma, since each depends upon the existence of prospectively collected, high quality exposure information that is never available. Instead, analysis of landfill contents, hydrogeological surveys, or scrutiny of the waste production records of companies using the landfill may be attempted to help reconstruct exposures. Where sites were owned or operated for the use of specific companies or industries, this process might succeed in identifying specific substances with known toxicities, from which target health problems could be identified (9). However, when a site was used for multisource dumping, indeterminate quantitites of large numbers of chemicals will likely be identified. Thus, specific causative hypotheses may be harder to generate (*10*), and the specified conditions for epidemiologic study may not be met.

Failure to meet these conditions does not reduce public concern regarding possible health effects, and the potential is great for a conflict between public perceptions and scientific needs (*11*). A pragmatic approach needs to be taken that provides the best documentation of health status possible under the constraints imposed by the situation.

In the absence of high quality exposure information, investigators have used duration of residence and proximity to exposure source in place of individual estimates of chemical-specific exposure, and have used nonspecific health indicators as outcome variables (*9,10,12,13*). Careful selection of such indicators and adoption of strategies to avoid subject recall biases will help overcome validity problems.

Suggestions for appropriate nonspecific indicators include both clinical and pathologic outcomes. Among the clinical outcomes, reproductive and developmental effects (*10,12*), cancer (*12*), respiratory and skin problems (*9,12,13*), irritant symptoms (*9,12,13*), and neuropsychological deficits (*12,14*) have received the most attention. Those health problems that are long-term, most serious, or potentially most clinically distinct may be too rare to achieve acceptable study power, since populations exposed to landfills, unlike occupational cohorts, often include few long-term or high-dose individuals (*6*). Studies that confine themselves to such outcomes will therefore be uninterpretable if they give negative results. Studies confined to common respiratory, irritant, dermal, or neuropsychological problems will tend to lack credibility if they are positive, since recall biases, the health effects of lifestyles and occupation, and problems with the reliability and biologic relevance of symptom histories will threaten their overall validity.

Surveying markers of environmental pathology has been raised as a theoretical solution to the difficulties posed by clinical markers. Markers may be grouped by pathologic process and organ-system (*10,14,15*) or by exposure (*16,17*). If markers of exposure-specific, chronic disease were able to identify a larger at-risk

subpopulation than would be possible using the disease itself, the problem of low study power would be mitigated. With respect to symptom histories, sensitive markers might be able to distinguish self-reports attributable to the exposures of interest from those related to other factors.

Pathological markers were not available to the Upper Ottawa Street Landfill Site Study because the hypotheses were not related to knowledge of specific exposures. An effort was made to validate the results of the health questionnaire survey by strategies, which are detailed in the "Materials and Methods" section of this report. This approach corresponds to the strategy recommended by an Executive Scientific Panel convened by the Universities Associated for Research and Education in Pathology in their report *Health Aspects of the Disposal of Waste Chemicals* (*18*).

Workers Study

This chapter describes the design and conduct of a historical prospective morbidity survey of a cohort of workers from the landfill site. The study compared the self-reported health histories of those working at or near the site since 1965 with a sample of city and municipal workers working at other outdoor occupations during the same time period. In addition, the mortality experience of the exposed cohort was compared with that of all Ontario males using standardized mortality (SMR) analysis. The year 1965 was taken as the starting date because there was a consensus among long-term workers that industrial waste disposal had begun by that date.

Materials and Methods

Study Subjects. On-site employees included scalemen, security guards, heavy machinery operators, waste testers, liquid waste solidification plant attendants, and supervisors, whose jobs ended with the closing of the site in 1980. Sewer and water works personnel had on-site storage facilities at the landfill which continued to be used after the site was closed. Altogether, there were 66 regional employees in these nine categories. City employees (102 in all) worked at a works yard adjacent to the landfill including garbage men who unloaded at the landfill several times a day. Twenty-two salvage pickers were licensed to follow garbage trucks onto the landfill and recover paper, metal and wood directly from the dumpface. Seven firefighter instructors worked seasonally at a firefighter training center which was also adjacent to the landfill. In general, on-site employees and salvage pickers were potentially exposed through inhalation and direct contact while city employees and firefighters were potentially exposed through inhalation only. A cohort of 176 live and 21 deceased workers was identified who worked at any time between 1965 and the site's closure in 1980.

Controls. The City of Hamilton and four other municipalities within the Region of Hamilton Wentworth provided names of streets and sanitation workers with no known landfill site exposure or regular exposure to herbicides and pesticides, and with names of retired outdoor workers. In all, 235 useable names were supplied of those ever working between 1965 and 1980.

Employer assignment of workers to landfill or non-landfill work generally occurred after hiring and suitability for outdoor work was determined. Therefore, the control groups likely shared with the exposed workers any health-related selection factors that lead to outdoor work. Moreover, the wage scales of the two groups were similar because of the overlap between collective bargaining units. Because of the heterogeneous nature of the exposed group, and a lack of age information from available records, one-to-one matching was not feasible. Post-hoc matching was not considered because of the loss of power expected from a large number of unmatchable respondents. As well, information regarding start dates and specific job details was lacking for both exposed workers and many controls, so self-reported work histories were used throughout the study.

Questionnaire Design and Administration. Items on the questionnaire covered concerns raised from three sources: the health problems found in excess on an informal survey done by residents; a summary of the inherent toxic properties of more than 100 substances tentatively identified in the air, water, and soil at the landfill (*19*); and certain groups of conditions commonly associated with exposure to toxic industrial substances, such as respiratory and skin conditions, irritant symptoms, and narcotic and anesthetic effects. Items not thought to be related to environmental exposures were included to distract respondents from items of particular relevance, and to find out whether potential differences in health status were confined to environmentally related health problems. No information was collected on the use of prescription or illicit drugs. Respondents were asked to give the year in which each health problem began, and whether or not it had persisted until the time of interview.

An interviewer-administered format was selected instead of a telephone interview because of the length and complexity of the questionnaire. Pre-tests were completed on 13 workers from two other landfill sites in southern Ontario.

Interviews were conducted in respondents' homes during the spring of 1983 by professional interviewers experienced in dealing with sensitive issues. Because of the publicity surrounding the landfill site, the interviewers could not be kept blind to the respondents' exposure status. Instead, interviewer bias was minimized by not informing the interviewers of the difference between target and distractor items on the questionnaire.

Medical Chart Abstraction. Subjects' family physician records were searched to confirm self-reported health problems in order to measure the potential reporting bias from the exposed workers. The possibility of such bias might have been increased by the subjective nature of many of the health problems and by the long recall period.

Four nurses conducted a pilot study of medical abstraction on 18 respondent medical charts. This exercise demonstrated that family physician records were sufficiently comprehensive for the abstraction study, but that it was not feasible to abstract each respondent's medical chart for all 120 health problems on the questionnaire in a fashion that would preserve abstractor blindness. Two feasible approaches were identified. In the first, abstraction would be confined to those health problems reported by a respondent. Abstractors would be unblinded to the health reports of respondents, but would be able to use all their medical knowledge in evaluating the relationship between the physician records and the individual self-reports. In the second, abstraction would be confined to a randomly selected list of health problems. In this case, the abstractors could be blinded to the respondents' self-reports but many health problems would be left unabstracted. The former approach was used in this study. Abstractor bias was reduced by blinding the nurse abstractors to the exposure status of the study subjects. In the residents study the latter approach was used.

Nurse abstractors were required to determine whether each health condition could be confirmed, possibly confirmed, or not confirmed in the physician's chart and to provide evidence for their decision. They were given nine descriptions of the possible relationship between the information in the medical chart and the self-reported complaint. Two of the descriptions represented confirmation, four represented possible confirmation, and three represented nonconfirmation. The abstractor was required to report each condition by the most appropriate of the nine categories. This approach to chart abstraction allowed us to calculate the proportion of confirmed, possibly confirmed, and nonconfirmed among reported conditions and thus, to compare overreporting between the exposed workers and controls in a search for recall bias. The approach to medical chart abstraction on the residents' study allowed estimation of both over- and underreporting biases.

Nonconfirmation of a condition does not necessarily mean respondent overreporting. Inadequate physician record-keeping or poor communication between specialists and family physicians could have resulted in apparent overreporting. It has been assumed that the quality of record-keeping was equal among the physicians of each group, so that there would not be a bias imposed by apparent overreporting. If correct, then an analysis of the relative proportions of nonconfirmed events would be a valid method to assess recall bias.

Main Analysis. Analysis was confined to individual health conditions and organ-system groupings where there was a 50% or greater difference in the crude incidence between exposed workers and controls, and at least 15 events in total. All biologically plausible confounders were then included in Cox proportional hazards models (*20*) of each of these health conditions.

Risk time began with the year of first exposure at the landfill for all exposed workers. For those who worked there before 1965, 1965 was taken as the first year at risk. Controls' risk time began with the first year of the job that qualified them for the control group, or 1965, if they began work before that year. Follow-up continued until the year of interview (1983), regardless of whether or not the individual had left the job. Only first incident events occurring after first exposure to the landfill site or the analogous municipal/city job in the control group were included in the analysis. All events prior to 1965 were excluded. When organ system groups of health conditions were analyzed, only the first eligible incident event within the group was counted. Those reporting first events prior to exposure did not contribute risk time to the analysis. Exposures to chemicals and other toxic agents throughout the respondents' working lives were included as potential confounders in appropriate analyses. Each condition was analyzed using three inclusion criteria.

ANALYSIS 1. All self-reported events were included except those where the individual had reported seeing a physician and no evidence of the condition could be found on the physician chart. In such cases, person-years were contributed up to, but not beyond, the date of self-reported illness. Events reported by those refusing chart abstraction were also included.

ANALYSIS 2. All events which were not confirmed or possibly confirmed on medical chart abstraction were excluded. This meant that information from those refusing chart abstraction, those who did not see a physician, or who saw a physician uncontacted by us, was excluded.

ANALYSIS 3. Only those events which were confirmed on medical chart abstraction were included.

This approach allowed data relating to recall bias to be incorporated into the analysis. Analysis 1 was most statistically powerful, but most subject to bias. Analysis 3 was least statistically powerful, but least subject to bias. The relative risk for each analysis was derived from the exponent of the hazard function in the Cox model.

Subanalyses. Subanalyses evaluated temporal relationships between symptom onset and workplace exposure patterns, as well as dose-response gradient by those working directly on-site, adjacent to the site, and controls.

Analysis by time period addressed the question: did the onset of conditions in the main analysis tend to occur during the time period when it was thought that the largest volumes of waste were being disposed of at the landfill? If the conditions of interest were related to short-term exposures and did not involve a long follow-up period before onset of symptoms, intensity of exposure should have corresponded with concurrent risk.

A descriptive analysis was conducted to identify the conditions whose maximum risk of first onset was during either 1970–75 (the period of rapidly increasing volume of disposal) or 1976–80 (the period of maximum disposal). These were the periods of greatest potential environmental exposure, while 1965–69 (a period of presumed low volume disposal) and 1981–83 (the period after the site was closed) were periods of lower potential

exposure. Cumulative incidence rates for each condition were calculated for each time period, including in the denominator the person-years of exposure within the time period of interest and excluding the person-years of exposure of those who had reported onset of symptoms in a previous time period.

Results

Response Rates. Of exposed workers, 84.5% and 71.9% of the controls completed an interview. Twenty-five percent of controls and 14% of exposed workers refused for nonhealth reasons, while 3.1% and 1.7% refused for health reasons, respectively. The consent rates for medical chart abstraction were excellent, with 86.3% of eligible exposed workers and 83.8% of controls consenting. At least one usable chart was abstracted for 92.5% of consenting exposed workers and 91.5% of controls.

Comparability of Groups. SELECTED POPULATION VARIABLES. The mean age of the exposed workers was 49.0 years and of the controls was 47.4 years. There were no appreciable between-group differences in national or language background or home ownership. A greater proportion of controls were single, separated, or divorced (24.4%) than exposed workers (10.9%), while a greater proportion of controls got their drinking water from wells (19.5%) than the exposed workers (6.1%). This reflected the fact that some controls were sampled from mixed urban-rural municipalities outside the City of Hamilton.

INCOME AND EDUCATION. A trend toward higher income among the exposed workers reflected the inclusion of some employees who had been promoted to professional jobs and of the presence of firefighter senior officers in this group (10.9% of exposed workers' families had incomes of $40,000 or more, but only 4.9% of families of control workers). The modal income range was the same ($20,000–$29,999) for both groups. Studies relating income to health status in Canada have shown differences in health status between the highest and lowest quintile groups, with decreasing income correlating with decreased health status (*21*). The income differences seen between our study groups do not put them in different income quintiles and gave us little cause for concern. There were some differences in educational attainment as well. Grade 8 was not completed by 18.4% of exposed workers and 23.2% of controls.

CIGARETTES AND ALCOHOL. Table 1 shows a trend toward increased smoking activity and younger age of onset of smoking among exposed workers. Appropriate statistical adjustments were made in the analysis of respiratory conditions because of this trend. No between-group differences were noted in alcohol consumption. Daily alcohol consumption was reported by 30.6% of exposed workers and 30.5% of controls. Total abstention was reported by 14.3% and 15.2%, respectively.

EXPOSURE TO TOXIC SUBSTANCES. The respondents were asked to report exposures to toxic substances in jobs other than those at the landfill site since the beginning of their working lives. This meant that the controls were able to report a complete list of exposures, while the exposed workers could only report exposures before (or after) landfill site employment. Accordingly, large differences were seen in reported exposure to petroleum products (42.9% of exposed workers, 57.3% of controls), solvents (25.9% of exposed, 51.2% of controls), fertilizers and pesticides (21.8% of exposed, 48.8% of controls), and paints and plastics (32.0% of exposed, 51.8% of controls).

Table 1. Experience of cigarette smoking.

Question	% Responding "yes"	
	Exposed (*n*)	Controls (*n*)
History of smoking		
Ever smoked cigarettes daily	76.9 (113)	70.7 (116)
Never smoked	17.0 (25)	21.3 (35)
Used to smoke occasionally	5.4 (8)	7.3 (12)
Now smoke occasionally	0.7 (1)	0.6 (1)
Currently smoke cigarettes daily	44.2 (65)	40.9 (67)
Number of cigarettes now smoked		
0	55.8 (82)	59.1 (97)
Less than 10	3.4 (5)	4.9 (8)
10–19	6.8 (10)	6.7 (11)
20–25	26.5 (39)	22.7 (37)
More than 25	7.5 (11)	6.1 (10)
Age started smoking daily[a]		
10 or younger	8.7 (10)	6.6 (8)
11–15	35.7 (40)	24.0 (28)
16–20	44.3 (50)	57.0 (66)
Older than 20	11.3 (13)	12.4 (14)

[a] Proportion of those who ever smoked daily.

Main Analysis. Table 2 gives results for 13 individual health conditions and groups of related complaints from the main list of 120 complaints in the questionnaire. Together, the items in Table 2 include all individual health conditions or biologically related clusters of conditions where there was a 50% or greater difference in the incidence (not adjusted for age or follow-up time) between exposed workers and controls and at least 15 eligible events in total. In all cases, the cumulative incidence among the exposed workers was greater than the controls.

Analyses 1, 2, and 3 were conducted using the rules described previously. The following relationships were observed:

There was a consistent association between reports of chronic bronchitis, daily cough, and combined respiratory complaints with landfill site exposure, irrespective of the exclusion of unconfirmed self-reports. Preliminary analysis indicated that exposed-control differences existed both for smokers and nonsmokers. No between-group differences were noted for other respiratory problems such as asthma or pneumonia.

There was an association between the combined skin variable and landfill site exposure, irrespective of the exclusion of unconfirmed self-reports. This association was weaker than that with the respiratory group.

Strong and consistent associations were found be-

Table 2. Risk of adverse health outcomes associated with landfill site exposure.

Health condition (confounding variables included in the model)[a]	Analysis 1				Analysis 2				Analysis 3			
	Relative risk	p[b]	No. of events		Relative risk	p[b]	No. of events		Relative risk	p[b]	No. of events	
			Cases	Controls			Cases	Controls			Cases	Controls
Chronic bronchitis (*a,b,c,d*)	3.52	0.015	12 (135)[c]	4 (149)	4.18	0.015	10	3	6.49	0.008	10	2
Difficulty breathing (*a,b,c,d*)	1.45	0.143	19 (142)	15 (160)	2.12	0.038	16	9	1.58	0.167	11	8
Daily cough (*a,b,c,d*)	2.38	0.006	22 (135)	14 (155)	3.29	0.005	16	7	2.83	0.030	10	5
Combined bronchitis, emphysema, difficulty breathing, daily cough (*a,b,c,d*)	1.81	0.008	40 (147)	30 (164)	2.57	0.0009	32	17	2.31	0.006	25	15
Skin rash (*d,e,g,h*)	1.40	0.204	14 (143)	12 (187)	1.73	0.125	12	8	1.60	0.166	11	8
Combined skin rash, unusual acne, discolored patches on skin (*d,e,g,h*)	1.83	0.024	27 (147)	21 (164)	1.83	0.057	17	13	1.83	0.057	17	13
Cardiac: angina, heart attack (*a,b*)	2.19	0.016	20 (146)	12 (162)	1.76	0.077	15	10	1.70	0.115	12	9
Arthritis/rheumatism (*a,b,c*)	1.59	0.043	32 (137)	26 (153)	1.93	0.019	25	17	1.83	0.057	22	16
Red, itchy eyes (*d,e,g*)	1.63	0.130	13 (142)	10 (160)	4.14	0.021	8	3	N/A[d]			
Mood symptoms: anxiety depression insomnia irritability restlessness (*a,e,f,g,i*)	4.70	< 0.0001	29 (147)	11 (164)	3.58	0.003	17	8	4.72	0.0001	15	6
Narcotic symptoms: headaches, dizziness, lethargy, balance problems (*a,e,f,g,i*)	2.45	0.005	25 (147)	14 (164)	2.49	0.014	19	10	4.72	0.005	17	5
Tremors, cramps, spasms (*a,e,f,g,i*)	2.23	0.078	13 (144)	6 (161)	N/A[d]				N/A[d]			
Muscle weakness (arms and legs) (*a,e,f,g,i*)	2.58	0.015	16 (146)	9 (163)	2.89	0.022	11	6	1.64	0.240	5	4

[a] Confounding variables are: *a*, age (stratified by age at onset of entry into study group: 0–29, 30–49, 50+); *b*, smoking status: *c*, nonlandfill site exposure to dusts; *d*, nonlandfill site exposure to fumes and gases; *e*, nonlandfill site exposure to solvents; *f*, nonlandfill site exposure to pesticides; *g*, nonlandfill site exposure to plastics; *h*, nonlandfill site exposure to petroleum products; and *i*, nonlandfill site exposure to alcohol intake.

[b] Values of p are based on Z distribution, one-tailed.

[c] Numbers in parentheses are total subjects available for analysis in analysis 1.

[d] Too few events were seen by a physician to warrant further analysis.

tween mood symptoms (anxiety, depression, insomnia, irritability, and restlessness) and narcotic symptoms (headaches, dizziness, lethargy, balance problems) with landfill site exposure, irrespective of medical chart abstraction status.

The analysis of the association between irritant symptoms and neuromuscular symptoms with landfill site exposure was limited as a result of the relatively small proportion of these symptoms reported to a physician or confirmed by medical chart abstraction.

A consistent, though biologically unexplained, association between arthritis and landfill site exposure was identified, irrespective of medical chart abstraction status. It should be noted that the relative risk did not exceed 2.00.

An association of angina and heart attack with landfill

site exposure was seen in analysis 1, but the association lost its statistical significance when only medical chart-confirmed events were considered in analysis 3.

No association was found between landfill site exposure and several major chronic health problems not thought to be related to toxic chemicals. These included high blood pressure (crude incidence in exposed workers equalled 20.7%, in controls, 15.3%), stroke (1.4%, 1.8%), diabetes (2.7%, 2.4%), gall bladder disease (2.1%, 1.8%), and stomach ulcer (6.8%, 6.3%). No associations were seen between landfill site exposure and any gastrointestinal, hematologic, or genitourinary conditions.

Time Patterns. Table 3 shows the conditions by period of maximum relative risk and the magnitude of the relative risk using all eligible events from analysis 1. The conditions tended to cluster in the 1970–75 and 1976–80 periods, with the 1970–75 period predominant. Two conditions were clustered in the 1981–83 period: red, itchy eyes and tremors, cramps, and spasms. Concurrent exposure would likely be required if landfill exposure were to have led to red, itchy eyes, so the credibility of this association is reduced. A possible latent effect of landfill exposure on the development of tremors cannot be excluded. The combined respiratory and combined skin groups clustered in the 1965–69 period, despite the fact that the principal contributing conditions to both groups clustered in the 1970–75 period. This is a statistical artifact based on counting the first event within each group and does not reduce the credibility of these associations.

Risk Gradient with Duration of Exposure and Time Since First Exposure. Table 4 identifies maximum relative risks by time period since first exposure using analysis 1 methods of counting events. Three time periods were used: 0 to 5 years, 6 to 10 years, and 11 to 18 years since first exposure. The onset of most conditions tended to cluster in the first 5 years since exposure. The four conditions whose period of maximum relative risk occurred 6 to 10 years after first exposure included two (tremors, cramps, spasms; and red, itchy eyes) that also clustered in the 1981–83 period, and one (combined cardiac) that is highly age dependent.

Table 3. Period of highest relative risk by events/1000 man-years in exposed versus controls.

Condition	Period	Relative risk[a]
Combined respiratory	1965–69	3.65
Combined skin	1965–69	5.05
Chronic bronchitis	1970–75	Inf
Difficulty breathing	1970–75	3.32
Daily cough	1970–75	3.30
Combined cardiac	1970–75	2.54
Skin rash	1970–75	Inf
Arthritis/rheumatism	1970–75	2.28
Mood symptoms	1976–80	9.41
Narcotic symptoms	1976–80	8.53
Muscle weakness (arms and legs)	1976–80	2.99
Red, itchy eyes	1981–83	2.27
Tremors, cramps, spasms	1981–83	9.19

[a] A relative risk of inf (infinity) indicates a situation in which there were some events in the exposed group but none in the controls. Before we would accept this as indicating the period of highest relative risk, it had to meet the criterion of at least five events in the exposed group. If there were fewer than five events, the period was not considered, and instead the period of highest relative risk in which there were at least some events in both groups is indicated in the table.

Table 4. Period of highest relative risk (exposed versus controls) in terms of years since first exposure.

Condition	Years since first exposure	Relative risk
Chronic bronchitis	0–5	3.42
Difficulty breathing	0–5	3.85
Combined respiratory	0–5	2.03
Skin rash	0–5	1.92
Combined skin	0–5	4.85
Arthritis/rheumatism	0–5	2.06
Narcotic symptoms	0–5	3.59
Mood symptoms	0–5	5.11
Muscle weakness (arms and legs)	0–5	6.61
Daily cough	6–10	3.31
Combined cardiac	6–10	3.89
Red, itchy eyes	6–10	6.73
Tremors, cramps, spasms	6–10	6.69

Risk Associated with On-Site Exposure Versus Exposure Adjacent to the Landfill. The exposed workers were divided between those who worked directly on the landfill site and those who worked at the city works yard or firefighter training station adjacent to the site. In the absence of valid individual exposure data, this distinction represented the best available index of intensity of exposure and was not confounded by differing age distributions. Table 5 shows the gradient of risk associated with on-site exposure, exposure adjacent to the landfill, and nonexposure. Linear trends were demonstrated for chronic bronchitis, daily cough, mood and narcotic symptoms, as well as for muscle weakness in arms and legs, and the combined respiratory variable. Evidence of a monotonic increase in the incidence rate of the combined skin variable was also evident, but did not achieve conventional levels of statistical significance.

Reproductive Health. Ten percent of exposed husbands and 6.7% of controls reported being unable to initiate a pregnancy after one year of attempting to conceive ($p=0.33$). Eighteen spontaneous abortions (19.1%) were reported by exposed workers and eight (10.5%) among unexposed ($p=0.12$). Problems with spouse recall, identification of spontaneous abortions, and denial of infertility make interpretation of these nonstatistically significant trends difficult. No stillbirths occurred among the pregnancies beginning after first exposure at the landfill. Three birth defects were reported among 94 offspring of exposed workers who were born after the workers' first exposure (i.e., one hearing problem, one kidney/bladder problem, and one large birth mark). Four birth defects were reported among 76 offspring of controls born after first exposure to the job that qualified them for the study (i.e., one muscular dystrophy, one hemangioma, one hip displacement, and one toe deformity).

Table 5. Risk associated with gradient of exposure.

Condition	Exposure group	Incidence, % (*n*)	χ^2 lin	$p(\chi^2)$
Chronic bronchitis	On-site	13.3 (8)	8.44	< 0.0001
	Adjacent	5.3 (4)		
	Controls	2.7 (4)		
Difficulty breathing	On-site	17.5 (11)	2.50	0.114
	Adjacent	10.1 (8)		
	Controls	9.3 (15)		
Daily cough	On-site	23.0 (14)	6.75	0.009
	Adjacent	10.8 (8)		
	Controls	9.0 (14)		
Combined respiratory	On-site	34.3 (23)	6.28	0.012
	Adjacent	21.3 (17)		
	Controls	18.3 (30)		
Cardiac	On-site	11.9 (8)	1.85	0.173
	Adjacent	15.2 (12)		
	Controls	7.4 (12)		
Skin rash	On-site	12.1 (8)	0.98	0.323
	Adjacent	7.8 (6)		
	Controls	7.6 (12)		
Combined skin rash, unusual acne, discolored patches on skin	On-site	22.4 (15)	3.07	0.080
	Adjacent	15.0 (12)		
	Controls	12.8 (21)		
Red, itchy eyes	On-site	12.5 (8)	2.07	0.150
	Adjacent	6.4 (5)		
	Controls	6.3 (10)		
Arthritis/ rheumatism	On-site	15.9 (10)	0.13	0.715
	Adjacent	29.7 (22)		
	Controls	17.0 (26)		

Table 6. Standardized mortality ratios among exposed workers.

Cause of death	Expected[a]	Observed	SMR	CI95[b]
All cancer (including leukemia)	5.31	6	113	41–247
Respiratory cancer	1.83	3	164	33–481
Cardiovascular	11.72	9	77	34–146
Respiratory system (excluding cancer)	1.47	2	136	14–146
Other causes	4.30	3	70	14–205
Totals	22.80	20	88	

[a] Expected cause of death based on age-specific, cause-specific mortality rates for all Ontario males by 5-year intervals, 1965 to the present. From International Classification of Disease (*26*).
[b] 95% Confidence intervals around SMR estimates.

Mortality. Twenty-one exposed workers died between 1965 and 1983, of whom 20 were found in the Ontario Death Registry. Their identities were verified by occupation and address at death and analyzed using the standardized mortality ratio (SMR) approach (Table 6). The expected deaths are derived from the cause-, age-, sex-, and year-specific death rates among all Ontario males. We assumed that all deceased workers began work before 1965, and therefore contributed maximum person-years at risk before death. A healthy worker effect is reflected in the all causes SMR of 88, based on reduction of cardiovascular and other causes of mortality. A nonstatistically significant trend to increased respiratory mortality from cancer and noncancer causes is noted. Because of the low power of this analysis, it could not be concluded that landfill site exposure had not conferred a mortality risk on those exposed. However, no statistically detectable risk was evident by 1983.

Quality of Self-Reported Health Histories. Table 7 shows the rate of confirmation for the time periods before (up to 1977) and after (1978–83) the beginning of intense public concern about the landfill. Between-group differences in the distribution of confirmed, possibly confirmed, and not confirmed events were not evident in either time period. However, the proportion of not confirmed events rose 9.9% in the exposed group and 4.8% in the controls after the onset of publicity.

Table 8 examines the conditions in the main analysis where a physician visit was reported. This table includes events that occurred both before and after first work at the landfill site, while analysis 1 in Table 2 includes events that were not subject to medical chart abstraction. Therefore, the numbers in Table 8 are not quite the same as those in Table 2. None of the conditions of interest showed trends to overreporting among the exposed workers, but narcotic symptoms were relatively overreported among the controls. If the exposed workers were more concerned than controls about their health as a result of landfill site exposures, it would be anticipated that they would see physicians for their health problems more readily than controls. There was no evidence of an increased rate of self-reported physician attendance for the exposed workers compared to the unexposed when conditions were analyzed by organ system. In general, the trend was toward increased physician attendance among the unexposed. Only one nurse abstractor noted a case where a physician reported that a workers' visit was due to concern about landfill site exposure.

Overall, the data suggest that overreporting rates were unbiased between groups, and that knowledge of landfill site exposure did not increase physician utilization. Underreporting could not be assessed from these data. However, confirmation from medical charts was

Table 7. Confirmation of illness by period before and after publicity about the landfill site began (in those who reported seeing a doctor).

Group	Confirmed	Possibly confirmed	Not confirmed	Total
Prepublicity period (before 1965–1977)				
Exposed	214 (73.3%)	55 (18.8%)	23 (7.9%)	292
Controls	179 (73.7%)	47 (19.4%)	17 (7.0%)	243
Totals	393	102	40	535
$\chi^2 = 0.158$, $p = 0.924$				
Postpublicity period (1978–1983)				
Exposed	175 (67.8%)	37 (14.4%)	46 (17.8%)	258
Controls	167 (72.9%)	35 (15.3%)	27 (11.8%)	229
Totals	342	72	73	487
$\chi^2_2 = 3.47$, $p = 0.176$				

Table 8. Association between landfill site exposure and status after medical chart abstraction for selected health conditions.

Condition	Confirmed	Possibly confirmed	Not confirmed	χ^2	p
Chronic bronchitis					
Exposed	16	1	—		0.348[a]
Controls	10	2	—		
Difficulty breathing					
Exposed	12	4	—		0.768[a]
Controls	8	2	—		
Daily cough					
Exposed	13	3	—		0.593[a]
Controls	7	1	—		
Combined respiratory					
Exposed	45	8	—		0.659
Controls	26	6	—	0.194	
Skin rash					
Exposed	10	1	2		0.282[a]
Controls	7	0	0		
Combined skin rash, unusual acne, discolored patches on skin					
Exposed	17	3	6		0.158[a]
Controls	14	0	2		
Angina/heart attack					
Exposed	17	4	—		0.847
Controls	15	3	—	0.037	
Arthritis/rheumatism					
Exposed	17	4	2		0.215[a]
Controls	18	1	0		
Red, itchy eyes					
Exposed	3	3	3		0.315[a]
Controls	4	1	1		
Mood symptoms					
Exposed	15	3	1		0.633[a]
Controls	5	1	2		
Narcotic symptoms					
Exposed	26	2	3		0.036[a]
Controls	8	6	1		
Tremors, cramps, spasms					
Exposed	3	2	2		0.545[a]
Controls	3	0	1		
Muscle weakness (arms and legs)					
Exposed	4	8	—		0.456
Controls	4	4	—	0.556	

[a] Exact probability by Fisher's exact test, for 2 × 2 table of "confirmed" versus "other."

made for 36.5% of self-reports when a physician visit was not reported. This suggests either that underreporting might have been a significant problem or that our possibly confirmed categories were too all-inclusive.

Discussion

Table 9 summarizes the credibility of each association between landfill site exposure and the health conditions, according to criteria which could be met by the available data. The associations with the highest overall credibility include chronic bronchitis, daily cough, combined respiratory problems, narcotic symptoms, and mood disorders. An intermediate level of credibility was evident with difficulty breathing, skin rash, combined skin problems, and muscle weakness. Associations with cardiac disorders; arthritis; red, itchy eyes; and tremors, cramps, and spasms were of low credibility.

Would a control group from another landfill site have been more appropriate than a group of nonlandfill outdoor workers? It is possible that the selection factors that determined landfill site employment might not have been found among other outdoor workers. If these factors were health-related, then important confounders were missed in this study. Such a possibility cannot be discounted. However, obtaining landfill controls from other sites would have introduced new problems. There is no way to guarantee that industrial waste would not have been disposed of in other landfill sites, leaving open the possibility of comparing exposed workers with ex-

Table 9. Summary of criteria for evaluating the association of specific health problems and landfill site exposure.

Condition	Biologic plausibility	Strength of association: RR > 2.0 for analysis 3[a]	Strength of association: $p < 0.05$ for analysis 3	No evidence of nonconservative recall bias	Time cluster (1970–75) or (1970–80)	Risk gradient by intensity of exposure[b]	Overall credibility of the association
Chronic bronchitis	+	+	+	+	+	+ +	High
Difficulty breathing	+	−	−	+	+	+	Moderate
Daily cough	+	+	+	+	+	+ +	High
Combined respiratory	+	+	+	+	N/A	+ +	High
Combined cardiac	+	−	−	+	+	−	Low
Skin rash	+	−	−	+	N/A	+	Moderate
Combined skin	+	−	−	+	N/A	+	Moderate
Red, itchy eyes	+	?[c]	?	+	−	+	Low
Arthritis	−	−	−	+	+	−	Low
Narcotic symptoms	+	+	+	+	+	+ +	High
Mood disorders	+	+	+	+	+	+ +	High
Tremors, cramps, spasms	+	?	?	+	−	−	Low
Muscle weakness	+	−	−	+	+	+ +	Moderate

[a] See text for description of analysis 3.
[b] In the risk gradient column only, + means the presence of a monotonic trend, while + + indicates that the p-value associated with linear trend was < 0.05.
[c] ? = Insufficient data for analysis 3.

posed workers. Landfill workers from sites outside the area would not experience the same ambient air pollution at work as the exposed workers. This is important in the Hamilton Wentworth area, where air pollution has been a public health concern. Also, the feasibility of blinding medical chart abstractors to the exposure status of out-of-town study subjects would have been drastically reduced.

The problem of the 13% difference in response rate between exposed workers and controls leaves open the possibility that some or all of the results may have been explained by volunteer bias alone. However, interview refusals by both exposed and control subjects were primarily for non-health related reasons. In order to explain away the relative risks of 2.0 or greater found among the high credibility associations, the incidence of the complaints of interest among the refusing controls would have had to have been much greater than among the refusing exposed workers.

Finally, alcohol intake and smoking patterns were similar between groups. Differences between controls and exposed workers were most marked for exposures to industrial toxins. In general, adjustment for these exposures did not change the magnitude of the relative risk. In the case of skin disorders, adjustment for exposure to fumes and gases did slightly increase the relative risk.

Residents Study

The high and moderate credibility conditions from the workers study are presented in Table 10. Beside them are the corresponding items from the residents study questionnaire which served as the primary hypotheses for this latter study. Secondary hypotheses included other items that might have been expected to be related to landfill site exposure on the basis of biologic plausibility, but did not emerge from the workers study.

This report is confined to adults, that is, those over age 16 at the time of first residence at the landfill or the control community.

Materials and Methods

Landfill Area Residents. Available records suggested that 1976–80 was the period of highest volume disposal of industrial waste at the landfill and so was selected as the exposure window. During 1980, the site was closed to disposal, and was capped late in the year. Residence time prior to 1976 was counted as exposed time for those who moved into the area before then, but those who lived in the area and moved out before 1976 were excluded from the study.

Six groups of landfill area households were selected for health survey interviews, based on tax assessment records. They were: (a) those living 250 to 500 meters from the edge of the dumpface at the time of interview who had been resident there for 3 or more years between 1976 and 1980 (1000 series) (Table 11); (b) those living 250 to 500 meters from the edge of the dumpface at the time of interview, who had been resident there for less than 3 years between 1976 and 1980 (2000 series); (c) those living 500 to 750 meters from the edge of the dumpface at the time of interview who had been resident there for 3 or more years between 1976 and 1980 (3000 series); (d) those living 500 to 750 meters from the edge of the dumpface at the time of interview who had been resident there for less than 3 years between 1976 and 1980 (4000 series); (e) those living 250 to 750 meters from the edge of the dumpface at the time of interview but who had not been resident there between 1976 and 1980 (7000 series); (f) those who lived 250 to 750 meters from the edge of the dumpface sometime between 1976 and 1980 but who subsequently moved out of the area (8000 series).

There were no data available documenting commu-

Table 10. Correspondence between workers study conditions and residents study hypotheses.

Conditions found in excess among exposed workers	Health problems eligible for hypothesis-testing in residents study
Chronic bronchitis	Attacks of bronchitis Chronic bronchitis
Difficulty breathing	Shortness of breath
Daily cough	Cough and phlegm
Combined bronchitis, emphysema, difficulty breathing, daily cough	All symptoms listed above
Skin rash	Recurrent or severe problems with skin rashes or hives
Combined skin rash, unusual acne	Recurrent or severe problems with: Scaly, dry, or itchy skin Unusual acne Boils, warts, cysts White or dark patches on the skin All skin problems listed above
Combined headaches, dizziness, lethargy, balance problems (narcotic symptoms)	Frequent or severe headaches Frequent dizziness or blurred vision Constant fatique, lethargy, drowsiness Problems with balance, coordination, reaction time, clumsiness All narcotic symptoms listed above
Combined anxiety, depression, insomnia, irritability, restlessness	Insomnia Frequent feelings of anxiety or depression Frequent feelings of irritability Frequent feelings of hyperactivity, restlessness Learning or memory disorders All mood symptoms listed above
Muscle weakness (arms and legs)	Muscle weakness (arms, legs, hands, feet)

nity exposure patterns during the period of peak disposal activity, so there was no scientific basis for establishing a cutoff distance beyond which no exposure to landfill emissions had occurred. Bisection of the 250 to 750 meter zone into two bands made it possible to plan three-point analyses by proximity to the site: those 250 to 500 meters from the dumpface, those 500 to 750 meters from the dumpface, and controls.

Tax assessment roles revealed that virtually none of the eligible households had been established near the landfill before 1972. Therefore, 1972 was defined as the year of first exposure for the purposes of questionnaire design and control selection. Sample size considerations were dominated by detecting the rarest important outcome: a risk of birth defects, if one existed. Calculations showed that achieving 90% power to detect a two- to threefold increase in a conditions with a 1% prevalence in controls (i.e., all clinically significant birth defects) would require 950 to 3000 childbirths among both exposed and controls groups. A household interview sample large enough to guarantee this many childbirths could not be found adjacent to the landfill. Ultimately, a sample of 614 houses were identified in the 1000 to 4000 series (Table 11). Assuming an 80% response rate and 1.3 childbirths per household following first residence at the landfill, this sample size would have allowed 80% power to detect a relative risk of 3.0 for all birth defects.

Controls. Control selection was designed to achieve comparability in family size, age distribution, and socioeconomic status, since these factors would likely correlate closely with occupational and personal health risk factors that could confound the outcome of the study. Identification of an acceptable control community was hampered by several factors. Since the Upper Ottawa Street Landfill Site area was developed during the mid-1970s, it was necessary to restrict the search for controls to other newly developed communities. In addition, the Landfill Site community was spread out over four census tracts and eight Hamilton Planning Department neighborhoods. However, only 20 to 75% of each census tract and 0.5 to 34.0% of each planning neighborhood fell within the study area. Thus, data routinely collected by tract and neighborhood on family size, occupation, and income were unhelpful in identifying a control community.

As an alternative, information on house size, type, building dates, and resale value provided by the planning department and real estate board were used as surrogates for family size, age, and socioeconomic status. Thus a control community was identified in the same air pollution region as the landfill site. Resale values of houses within the two areas for August, 1983, were available. Thirty-three houses in the landfill area had sold for an average of $75,840 (range $54,500–$99,900). In the control community, 18 houses sold for an average of $74,570 (range $48,500–$104,900).

Table 11 shows control households from tax assessment rolls divided into two subgroups: the 5000 series and the 6000 series. The 5000 series is composed of those who lived in the control area for less than 3 years during 1976 to 1980. Their duration of residence is comparable to landfill residents in the 2000 and 4000 series. The 6000 series is composed of those who lived in the control area for 3 or more years between 1976 and 1980. Subjects in the 5000 and 6000 series were current residents at the time of interview. Migrators (analogous to the 8000 series) were not sampled from the control community because the assessment rolls revealed a very low rate of emigration. Similarly, too few control area residents moved in after 1980 to form a group comparable to the 700 series.

The ratio of 5000 to 6000 series households (1:2.7) was lower than the ratio for 2000 plus 4000 series to 1000 plus 3000 series households (1:1.1). Therefore, it was clear from the outset that the control community had a higher proportion of long-term residents and was less migratory than the landfill site community.

Table 11. Evolution of eligible households for study.

Sampling group		Households available for assignment	Households lost during interviewer contact		Households eligible after interviewer contact
Series	Short titles used in tables		Ineligible	Moved	
Landfill residents					
1000	Long-term[a]	152	0	22	130
2000	Short-term[a]	117	6	21	90
3000	Long-term[a]	256	3	35	218
4000	Short-term[a]	248	11	61	176
7000	Recent residents	219	8	49	162
8000	Movers	435[b]	39	48	348
Controls					
5000		195	1	24	170
6000		526	4	56	466

[a] Also exposed or nonmovers.
[b] Includes 32 households originally assigned as 1000 through 4000 series who were found at a new address outside the landfill area.

Questionnaire Design and Administration. The questionnaire was designed for administration to the female head of household who would report on behalf of each family member. The workers study questionnaire served as the starting point for the residents questionnaire. Feedback from the interviewers was available to help revise it as appropriate. Preliminary results of the workers study suggested that specific respiratory, dermal, and neurological conditions might ultimately emerge as main hypotheses from the workers study. The corresponding sections in the residents questionnaire were strengthened. Questions were borrowed from the Respiratory Standardization Questionnaire to supplement the existing respiratory questions; items regarding body distribution and qualifying phrases regarding frequency and severity of symptoms were added to the dermal section. Qualifying phrases were similarly added to the neurological sections. Sections on pregnancy history, maternal risk factors, and outcome were developed *de novo* for the residents study. A list of congenital anomalies was adapted from that used by Frank and Corey (*22*).

The questionnaire was pretested on the households of 33 former residents who had lived between 500 and 750 meters from the landfill for less than 3 years from 1976 to 1980. These individuals were excluded from the tabulation of 8000 series residents found in Table 11. Feedback demonstrated that questions from the Respiratory Standardization Questionnaire were found lengthy, annoying, and redundant, and so many were deleted.

Interviews were conducted in-home because of the need for access to the female head of household (who was frequently a homemaker) for an hour or more. When the female head was unavailable, the interviewer called upon alternate individuals according to a preset hierarchy given to them by the study team. Publicity surrounding the landfill site and the study precluded the possibility of blinding exposed respondents to the purpose of the interview. However, an attempt was made to conceal the principal objectives of the study from the controls. The letter of introduction said the purpose of the interview was "to study the health of persons who live at various distances from the Upper Ottawa Street Landfill Site." Because the control community was less than 5 miles from the landfill, we thought it possible that controls might not identify themselves as unexposed. If this were so, recall biases might be reduced, while at the same time, response rates might be enhanced.

Interviewers were blind to the hypotheses being tested and were unaware of which questionnaire items were distractors. Interviewers were each assigned a mixture of households from different subgroups. An informal survey of interviewers after the field work was completed revealed that no distinct impressions or theories of cause and effect had emerged among them.

Multiple call-backs were used in all situations where initial interview contact met with refusal or no answer. All initial refusals, multiple delays, or failures to keep an interview appointment were logged by the interviewers and screened for reassignment and recontact. Thirty-six percent of the refusers recontacted as a result of the screen agreed to be interviewed.

When households were not found at the assigned address, an attempt was made to find the family through drivers license records, local contacts, and leads picked up by the interviewers. Usually this resulted in a household in the 1000 to 4000 series being reassigned to the 8000 series.

Data Analysis. The overall analytic strategy was to assess the strength of association, consistency with the workers study, and gradient of response by duration of exposure through comparisons between current landfill residents who were present between 1976 and 1980, and controls. Analyses involving the other subgroups (7000 and 8000 series) were designed to indirectly assess biases in the main analysis which might have resulted from the high emigration rate from the landfill area and from the possibility that the health of those choosing to live adjacent to a waste disposal facility might differ systematically from other people of similar socioeconomic status not living in the area. Other analyses were confined to the main study groups. These included hypothesis-generating analyses; analyses checking the specificity of associations between landfill exposure and

the main health problems (through analyzing conditions not expected to be related to exposure); and medical chart abstraction for recall bias. In all, five criteria for causation (strength of association, gradient, temporality, specificity, and consistency) and three sources of bias (recall, migrator, and risk-taker bias) could be addressed through this analytic strategy.

Cox proportional hazards models (*20*) were employed in the main analyses. All biologically plausible confounders were entered stepwise, with a p to enter of 0.10 and a p to remove of 0.15. Important factors (such as smoking in respiratory disease) were forced into the model regardless of their statistical impact. Follow-up began with the year of first residence at the landfill site or control community. Only current residents of the landfill (1000 to 4000 series) or controls (5000 and 6000 series) were included. For those who lived in either community before 1971, 1972 was taken as the first year at risk. Follow-up went until the year of interview (1984). Only first incident events occurring after first residence at the landfill site or control community were included in the analysis. When biologically related groups of health conditions were analyzed, only the first eligible incident event during the follow-up period was counted. Those reporting first events prior to exposure did not contribute risk time to the analysis. Smoking history, work history, and other risk factors with a cumulative impact were considered for inclusion even if they occurred before first residence in the community of interest.

The relative risk was derived from the exponent of the hazard function in the Cox model. P-values were based on the Z score from the ratio of the partial coefficient for exposure group, given the confounders, to the standard error of the coefficient.

An alpha level of 0.01 was adopted to simultaneously account for multiple testing of five organ-system groups and for four to five conditions within each organ-system group among the main hypotheses. The secondary hypotheses were declared positive if $p < 0.05/n$ where n was the number of secondary hypotheses. This approach was appropriate for multiple testing by organ system. However, it is conservative within an organ system, since the assumption of independence of symptoms is likely to be violated.

Subanalyses were conducted only on organ-system groups, using Cox proportional hazards models with the same confounding variables as in the respective main analyses. Specific approaches are described in the results section.

Reproductive Problems. A reproductive mini-questionnaire was included to screen for evidence of adverse outcomes associated with residence adjacent to the landfill site. The pregnancy experience of all females in the study households was solicited from 1968 to the date of interview. Those preganancies occurring after first residence in the qualifying household were included in the analysis. The main study groups (1000 to 4000 series and 5000 to 6000 series) were compared by risk factors using simple univariate techniques. Negative pregnancy outcomes considered in the analysis included low birth weight, stillbirth/spontaneous abortion, and the presence of any major or minor birth defects. These too were compared using simple univariate techniques as an initial screen. Multivariate analyses and clinical follow-up were to have been contemplated if any positive results emerged from univariate analyses.

Medical Chart Abstraction. The approach taken to medical chart abstraction in the workers study had two basic flaws: abstractors were unblinded to respondent self-reports, and underreporting of health problems could not be reliably assessed. The approach taken in the residents study overcame these problems. The twin objectives of blinding abstractors to study subjects' reported complaints and of obtaining parallel data on respondent under- and overreporting were achieved by abstracting a limited number of health conditions.

All conditions on the questionnaire were grouped by organ system or biologically related cluster, and two groups that were thought to be least relevant among a young population were excluded: cardiac and arthritic complaints. The rest of the conditions were divided into nine groups: respiratory, hematologic, renal, digestive, skin, head and neck, central nervous system, peripheral nervous system, and psychological. Two conditions were randomly sampled from each of these nine groups. The first condition was designated for abstraction, while the second was kept as an alternate. The alternate condition substituted for the designated condition if the number of abstractable events for the designated condition was less than 30 or more than 100, or if it was found to be a subsidiary symptom to a variety of conditions not being abstracted (and was thus unabstractable).

The final list of abstracted conditions included: pneumonia, including bronchopneumonia; nosebleed (not from injury); needing to get up more than once at night to urinate; loss of weight; recurrent or severe problems with unusual acne; prolonged, irritated sore throat; ringing in the ears or tinnitus; constant fatigue, lethargy, or drowsiness; and numbness, fatigue, tingling, prickling or loss of sensation on arms or hands.

The study investigators developed new guidelines for confirmation, possible confirmation, and nonconfirmation for each of the conditions. Ten nurse abstractors pretested the instruments on a total of 21 family physician charts not included in the main abstraction study. Before beginning the study, a reliability workshop was held in which each abstractor reviewed six charts from the main study sample. No discussion was allowed between abstractors. A second reliability workshop was conducted 6 weeks later at the end of the abstraction study, using the same format and the same six charts as previously. The time and mass of work (34 abstractions each) in the intervening 6 weeks made abstractor recall unlikely. The data from the workshops was used to calculate pretest and post-test reliability of the tools for abstraction, and also to estimate intra-abstractor reliability.

Results

Descriptive Statistics. RESPONSE RATE. The response rate for the exposed households was 82.2%, while 75.3% of mover households, 80.3% of recent resident households, and 67.8% of controls responded. The differences in response rate are readily explicable by the degree of self-interest each group of households had in the results. Unfortunately, the control group's response rate leaves open the possibility of a volunteer/nonrespondent bias affecting the study results. The reasons most often given for refusal were "too busy" or "not interested." This was true for all groups. Refusals for reasons of ill-health were rare, accounting for about 3% overall. Nonetheless, it is possible that other refusals were related to health status in an unstated way.

SOCIODEMOGRAPHIC CHARACTERISTICS. The modal income for exposed, control, and mover households was $30,000–39,999 in 1983, and for recent resident households was $20,000–29,999. Controls had a higher overall income distribution. Only 6.7% of control households had incomes of less than $20,000, while 35.2% were $40,000 or more. Among exposed households, 12.8% had incomes of less than $20,000, while 21.2% were $40,000 or more. These differences do not suggest that the main study groups fall into separate income quintiles within the Canadian range.

The modal education level for each group was completion of grade 11 to 13. Among controls, 19% had completed grade 10 or less, while 31.6% had completed college or other postsecondary education. Among exposed households, 29.1% had completed grade 10 or less, while 21.7% had completed college or other postsecondary education. The exposed group had a higher proportion of blue collar (39.9%) than white collar workers (31.3%), while the control group had the reverse: 28.4% blue collar and 46.3% white collar. Fortunately, these differences were not reflected in the experience of jobs with dust exposure or work with industrial chemicals. Among exposed individuals, 29.8% reported work on jobs with dust exposure compared to 25.8% in the controls. Chemical fume and gas exposure was reported by 24.6% of exposed individuals and 21.4% of controls.

No differences were seen in the proportion of subjects born outside of Canada. Small differences were found in the proportion of individuals whose first language was English (77.9% of exposed, 80.8% of controls). The most common second language of both communities was Italian.

The modal age at first residence was 26 to 30 for all groups. The controls were slightly older than the exposed groups; 11.1% of controls and 9.7% of exposed were over 45, while 29.1% of exposed and 20.5% of controls were under 25 at the time of first residence. Gender balance was similar: 47.7% of exposed adults and 49% of controls were male.

HEALTH HABITS. No differences in drinking habits were found. Among the exposed, 13.5% were daily drinkers and 19.4% were abstainers. Among controls, 13.1% drank daily and 16.8% abstained. Forty percent of exposed adults, but only 26.8% of controls, were current daily smokers. The difference in proportions who had ever been daily smokers was more similar: 56.9% of exposed and 47.3% of controls. The age of first smoking was similar for current smokers in both study groups, the modal age range being 16 to 20 years.

Main Analysis. Table 12 shows the analysis of the conditions which form the main hypotheses, as well as red, itchy eyes. This latter was included because it was the only secondary hypothesis that achieved an adequate level of statistical significance to warrant further analysis. Conditions are divided into six organ-system groups. Four of the six include more than one condition. The combined organ-system variables counted the first event among the contributing conditions that occurred after first residence in the qualifying household. Only the exposed group (1000 to 4000 series) and controls (5000 to 6000 series) were included. Analysis of conditions within the organ-system groups were used to identify those that contributed most to the exposed-control differences. This purpose was largely descriptive, but an alpha level of 0.01 was applied to identify which conditions could be thought to be independent contributors.

Table 12 shows positive associations between residence adjacent to the landfill and five of six organ-system groups: respiratory, skin, narcotic symptoms, mood symptoms, and red, itchy eyes. Each association was strongly positive, with relative risk greater than 1.50 and $p < 0.001$. Between-group differences in respiratory health were not found among smokers and nonsmokers when compared separately. In fact, smoking status had to be forced into the model for biologic credibility, since no smoking effect was detected at all. This is likely due to the young age of the respondents. In general, crude relative risks approximated those derived from the Cox model analyses. All crude relative risks were within ± 0.3 of the adjusted value.

The principal contributing conditions within the respiratory group were attacks of bronchitis, shortness of breath, and periods or episodes of cough and phlegm lasting for 3 weeks or more. Recurrent or severe problems with scaly, dry, or itchy skin was the principal contributor to the skin group. Frequent or severe headaches, frequent dizziness or blurred vision, and constant fatigue, lethargy, drowsiness were the principal contributors to the narcotic group. Frequent feeling of anxiety or depression and frequent feelings of irritability were the principal contributors to the mood group.

Subanalyses were carried out on the combined respiratory, skin, narcotic, and mood groups as well as red, itchy eyes, but not on the individual conditions within those groups. Muscle weakness was excluded from further analysis.

Gradient Analyses. Tables 13 and 14 relate to risk by proximity of residence to the landfill and duration of residence adjacent to the site. Table 13 gives three-point analyses by those living within 500 meters of the landfill (1000 and 2000 series), 500 to 750 meters from the landfill (3000 and 4000 series), and controls. Statistical meth-

Table 12. Risk of adverse health outcomes associated with landfill site exposure: main hypotheses.

Condition	Confounding variables in model[a]	No. of events		Relative risk	p[b]
		Exposed	Controls		
Combined respiratory	All	149	91	1.56	< 0.001
Attacks of bronchitis	All	44	21	2.07	0.004
Chronic bronchitis	All	8	7	1.04	0.47
Shortness of breath	All	48	21	2.00	0.005
Cough and phlegm	All	88	53	1.55	0.007
Combined skin	All	130	68	1.76	< 0.001
Recurrent or severe problems with scaly, dry, or itchy skin	*b*	59	23	2.32	< 0.001
Recurrent or severe problems with skin rashes or hives	*b*	31	15	1.93	0.05
Recurrent or severe problems with unusual acne	*b,e,f*	8	5	1.92	0.13
Recurrent or severe problems with boils, warts, cysts	*b*	36	23	1.53	0.06
White or dark patches on the skin	*b*	18	10	1.66	0.09
Combined narcotic symptoms	All	170	67	2.29	< 0.001
Frequent or severe headaches	*a,b,e,f*	106	41	2.21	< 0.001
Frequent dizziness or blurred vision	*b,f*	38	13	2.65	0.01
Constant fatigue, lethargy, drowsiness	*b,e*	63	22	2.54	< 0.001
Problems with balance, coordination, reaction time, clumsiness	*b*	13	8	1.54	0.17
Combined mood	All	129	66	1.70	< 0.001
Insomnia	*b,c,f*	63	41	1.30	0.10
Frequent feelings of anxiety or depression	*a,b*	62	23	2.50	< 0.001
Frequent feelings of irritability	*b,c,e*	48	20	2.22	0.01
Frequent feelings of hyperactivity, restlessness	*b,c,e*	17	8	1.96	0.08
Learning or memory disorders	—	4	1	—	0.12
Muscle weakness (arms, legs, hands or feet)	—	15	8	1.36	0.09
Red, itchy, watery, sore, all dry, or inflamed eyes	All	76	42	1.87	< 0.001

[a] Confounding variables: *a*, age; *b*, sex; *c*, ever smoked daily; *d*, ever worked in job with dust exposure; *e*, ever worked with fumes or gases, *f*, highest level of schooling.
[b] p - Based on Z-distribution, one-tailed.

Table 13. Risk gradient by proximity of residence to landfill site: short- and long-term residents.

Condition	Proximity of residence to landfill, meters	No. of events	Crude incidence, per 1000 person-years	Z(linear trend)	p
Combined respiratory	Within 500	61	25.6	4.01	< 0.001
	500–750	88	19.2		
	Controls	91	13.5		
Combined skin	Within 500	44	18.1	3.16	< 0.001
	500–750	86	18.9		
	Controls	68	10.1		
Combined narcotic	Within 500	67	28.9	5.89	< 0.001
	500–750	103	23.0		
	Controls	67	9.9		
Combined mood	Within 500	58	24.1	4.49	< 0.001
	500–750	71	15.7		
	Controls	66	9.8		
Red, itchy eyes	Within 500	28	11.4	2.69	0.004
	500–750	48	10.4		
	Controls	42	6.3		

Table 14. Risk gradient by proximity of residence to landfill site: long-term residents only.

Condition	Proximity of residence to landfill, meters	No. of events	Crude incidence, per 1000 person-years	Z(linear trend)	p
Combined respiratory	Within 500	44	26.1	3.73	< 0.001
	500–750	45	14.5		
	Controls	69	12.4		
Combined skin	Within 500	34	19.8	3.04	< 0.001
	500–750	52	17.0		
	Controls	56	10.1		
Combined narcotic	Within 500	52	32.3	5.44	< 0.001
	500–750	58	19.2		
	Controls	57	10.3		
Combined mood	Within 500	42	24.7	3.27	< 0.001
	500–750	35	11.2		
	Controls	57	10.3		
Red, itchy eyes	Within 500	22	12.6	2.68	0.004
	500–750	28	9.0		
	Controls	35	6.4		

ods, inclusion of events, and confounding variables were similar to the main analyses, except that the outomce variable was the linear trend of incidence rate by proximity to the landfill. All five groups of conditions show statistically significant linear trends. A monotonic trend in crude incidence rates is evident for respiratory, narcotic, and mood systems, as well as red, itchy eyes. The crude incidence rates of skin symptoms do not show a monotonic trend. The observed statistical trend is based on differences between the exposed group as a whole and controls. This observation led us to consider whether or not skin symptoms might be more closely related to direct skin contact through recreational activities in and around the landfill area. An analysis of exposed residents showed that 28.6% of those reporting such recreational activities also reported one or more skin symptom, while 11.9% of those not reporting these activities reported skin symptoms. ($\chi^2 = 16.02$, $p = 0.00006$).

Table 14 repeats the analyses in Table 13, but is confined to the long-term exposure subgroups (1000, 3000, and 6000 series). Highly statistically significant, monotonic linear trends are evident in all analyses. When those who spent less than 3 years in their qualifying community during the peak period of dumping were considered, no linear monotonic trends were found. These data support a duration of residence gradient for the main health conditions of interest. Analyses comparing long-term directly with short-term residents were avoided because they involved nonconcurrent comparisons. It was not thought safe to assume that the level and type of exposure to landfill emissions was constant at all times. Thus, short-term exposure may have been confounded by higher (or lower) average emissions.

The gradient by proximity to landfill is also addressed in Table 15. In this analysis, the designation of household by subgroup was replaced by the distance of each individual home from the closest edge of the landfill. This allowed calculation of a monotonic trend within the exposed group, free of confounding due to differences with the controls. The analysis suffers from the weakness that the sample of landfill area residents was not identified at the outset of the study to meet criteria for it. In particular, we did not extend sampling beyond 750 meters and into areas we thought were unexposed. Also, we had not assumed that meteorologic patterns in the area would distribute airborne pollutants in a monotonic decline, meter-to-meter from the landfill. Nonetheless, Table 15 shows a montonic trend in risk reduction by distance from the landfill for respiratory, narcotic, and mood symptoms among long-term residents. The trend of skin symptoms was much weaker, as expected from previous analyses. The trends among short-term residents were weak, and were not in the direction of risk reduction by distance from the site. These results suggest a gradient of effect by proximity to the landfill site for the long-term residents.

Table 15. Risk gradient by proximity of residence to landfill site: Exposed group only by individual household distance from site.

Condition	χ^2(trend)	p	Risk reduction per 100 meters from landfill,[a] %
Long-term residents			
Combined respiratory	4.74	0.015	−17
Combined skin	0.79	0.186	−8
Combined narcotic	6.66	0.005	−18
Combined mood	4.94	0.013	−18
Red, itchy eyes	2.36	0.062	−16
Short-term residents			
Combined respiratory	0.14	0.65	+4
Combined skin	0.74	0.80	+11
Combined narcotic	1.61	0.90	+12
Combined mood	0.27	0.70	+5
Red, itchy eyes	0.46	0.83	+7

[a] Based on the slope of the exponential coefficient for distance from landfill, given confounding variables, in the proportional hazards model. This should be interpreted as "for each 100 meters from the landfill, the risk decreased X% from the level 100 meters closer."

Analysis of Events Occurring Before 1981. Table

16 repeats the main analyses including only health events occurring before 1981. Thus, the analyses are confined to the time when the landfill site was open to waste disposal. Since most of the conditions contributing to the organ-system groups (and red, itchy eyes) were acute, it could be expected that any differences seen in incidence rates should have emerged before the site closed (and presumably, exposure declined). Comparing Table 16 with Table 12, the relative risks for respiratory, skin, and narcotic conditions increased when only events occurring before 1981 were considered. The relative risks for mood conditions and red, itchy eyes were slightly lower, but not enough to require an alternative explanation.

Migratory Effects. Table 17 compares the movers (8000 series) to the exposed group (or nonmovers) and Table 18 compares the movers to the controls. The expectation was that the movers would have similar health status to the exposed group. Table 17 shows that this was true for skin, narcotic, and mood conditions and for red, itchy eyes. Respiratory conditions differed in that there was a trend to a lower incidence rate among movers. These observations were mirrored in Table 17 where large differences in incidence rates were found between movers and controls for skin, narcotic, and mood, but not for respiratory conditions. These data suggest that migrators were more like exposed residents than controls in health status.

Table 19 divides the follow-up period at the end of 1980 so that temporal changes in risk can be compared between migrators and nonmigrators. The period before 1980 represents both the time when the landfill site was open and the time when (virtually) all the migrators were still resident near the landfill. The period after 1980 (1981–84) represents the time after the site was closed and after the migrators had left the area. The table shows that, in all cases, the relative risk (nonmigrators/migrators) increases between the two periods. For all except red, itchy eyes, the relative risk before the end of 1980 is less than 1.00. This means that the migrators were more frequently complaining of the target health problems than the nonmigrators before they left the area, but less often thereafter. The former observation may be interpreted as a conservative migrator bias (supports positive results in the main analyses). This is because were the migrators to be included with the other exposed groups (nonmigrators) in a comparison with controls, the estimated relative risks would have been increased.

Health Status Differences—Controls versus Recent Residents. Table 20 compares controls with those who moved into the landfill area after the site was closed. All health problems reported from 1972 to the time of interview were included, regardless of whether or not they were reported before the household had moved to the qualifying location. This approach allowed for a concurrent analysis, based on the premise that the health of the two groups ought to be similar unless the landfill site area attracted residents who were less healthy than other members of the community. Table 20 shows no statistically significant difference in incidence rates of the main groups of conditions. Moreover, the relative risks are all close to 1.0. The landfill site area does not appear to attract people who are less healthy.

Conditions Not Thought to be Related to Landfill Site Exposure. Twenty-five conditions met the criteria described in the Methods section as "not being related to landfill site exposure" and were analyzed to answer the question, "Are differences found between the exposed and control groups in the main analyses merely a reflection of global increases in health problem reports, or are they specific to the hypothesized conditions?" Ten of these conditions were subjective in nature, and 15 were disease labels. To answer the question, the data were interpreted as a whole, rather than condition-by-condition. Ten risk ratios were below 1.0 and 15 were above 1.0, suggesting no overall trend among these conditions. However, risk ratios greater than 4.0 are found for three conditions: loss of appetite, loss of weight, and burns requiring admission to hospital. These conditions were missed in the hypothesis-generating exercise because they did not seem to have biological credibility as outcomes of airborne or recreational exposure to an uncharacterized mixture of volatile organics, dust, and fumes.

Pregnancy. Tables 21 through 23 outline the pregnancy experience of all women in the study. Pregnancies were included if they terminated on or after the year

Table 16. Events occurring before 1981.

Condition	Groups	No. of events	Incidence, per 1000 person-years	Relative risk	p
Combined respiratory	Exposed	72	20.8	2.12	< 0.001
	Controls	36	9.9		
Combined skin	Exposed	68	20.1	2.26	< 0.001
	Controls	30	8.3		
Combined narcotic	Exposed	98	29.4	2.91	< 0.001
	Controls	36	10.0		
Combined mood	Exposed	56	16.5	1.51	0.027
	Controls	38	10.6		
Red, itchy eyes	Exposed	33	9.8	1.60	0.045
	Controls	22	6.2		

Table 17. Migrator status and risk of adverse health outcomes. I: Landfill residents who moved versus landfill residents who did not move, 1976–1980.

Condition	Comparison groups	No. of events	Incidence, per 1000 person-years	Relative risk	p[a]
Combined respiratory	Movers	49	15.5	0.72	0.046
	Nonmovers	149	21.3		
Combined skin	Movers	55	17.4	0.92	0.60
	Nonmovers	130	18.6		
Combined narcotic	Movers	81	26.8	1.04	0.79
	Nonmovers	170	25.0		
Combined mood	Movers	63	20.1	1.08	0.62
	Nonmovers	129	18.3		
Red, itchy eyes	Movers	29	9.0	0.82	0.19
	Nonmovers	76	10.8		

[a] Two-tailed.

Table 18. Migrator status and risk of adverse health outcomes. II: Landfill residents who moved versus controls, 1976–1980.

Condition	Comparison groups	No. of events	Incidence, per 1000 person-years	Relative risk	p[a]
Combined respiratory	Movers	49	15.5	1.15	0.23
	Controls	91	13.5		
Combined skin	Movers	55	17.4	1.67	0.0026
	Controls	68	10.1		
Combined narcotic	Movers	81	26.8	2.33	< 0.001
	Controls	67	9.9		
Combined mood	Movers	63	20.1	1.90	< 0.001
	Controls	67	9.8		
Red, itchy eyes	Movers	29	9.0	1.38	0.09
	Controls	42	6.3		

Table 19. Migratory effects: relative risks before and after 1981, nonmovers versus movers.

Condition	Time	Relative risk: nonmovers/ movers	p[a]	95% confidence interval
Combined respiratory	To 1980	0.83	0.400	0.55–1.28
	1981–84	2.60	0.0003	1.45–4.65
Combined skin	To 1980	0.98	0.912	0.63–1.52
	1981–84	1.28	0.296	0.79–2.08
Combined narcotic	To 1980	0.89	0.201	0.56–1.13
	1981–84	1.28	0.267	0.81–2.02
Combined mood	To 1980	0.62	0.033	0.40–0.96
	1981–84	1.23	0.365	0.77–1.93
Red, itchy eyes	To 1980	1.02	0.96	0.52–1.98
	1981–84	1.37	0.21	0.75–2.51

[a] Two-tailed.

of first residence in the house that qualified a woman for study. For exposed, control, and migrator pregnancies, 1976–80 was the most prevalent period of termination, followed by 1981–84. The modal age of exposed and control mothers at onset of pregnancy was 25–29, followed by 30–34 and 20–24. A higher proportion of control women than exposed were 35 or over (10.4% and 4.4%, respectively).

No differences were seen between exposed and control women in their experience with seven medications, five diseases, and 14 chemical exposures of particular interest in reproductive outcome (Table 21). There were no differences in smoking and alcohol experience during pregnancy.

Table 22 shows that the distribution of live births, stillbirths, miscarriages, and abortions did not differ between groups. The trend was toward higher overall rates of adverse pregnancy outcome in the controls. In addition, there was no trend toward lower birthweight among the exposed mothers. Most of the low birthweight babies in both exposed and control groups were also preterm. Table 23 shows the site of each reported birth defect and the number of pregnancies resulting in birth defects. No unique or unusual pattern of birth defects was noted, and no increase in total birth defects was seen. Once again, the trend was toward an increased adverse pregnancy outcome in the controls. In summary, there was no evidence of a relationship between residence adjacent to the landfill site and adverse pregnancy experience.

Medical Chart Abstraction Study. The medical rec-

Table 20. Comparison of those who moved to the landfill site after the site as closed with controls.

Condition	Comparison groups	No. of events	Incidence, per 1000 person-years	Relative risk	p[a]
Combined respiratory	Recent residents	35	10.7	0.97	0.90
	Controls	105	11.9		
Combined skin	Recent residents	37	11.4	1.22	0.32
	Controls	91	9.5		
Combined narcotic	Recent residents	36	10.9	1.11	0.60
	Controls	96	10.1		
Combined mood	Recent residents	29	8.7	1.04	0.86
	Controls	77	8.0		
Red, itchy eyes	Recent residents	20	6.1	1.16	0.14
	Controls	52	5.4		

[a] Two-tailed.

Table 21. Summary of pregnancy risk factors and health habits.

Risk factor	Response	Exposed	Controls	χ^2	p
Any medications/procedures[a] during pregnancy	Yes	66	60	0.008	0.93
	No	320	286		
Any diseases[a] during pregnancy	Yes	59	62	0.918	0.34
	No	327	284		
Chemical exposures[a] at work during pregnancy	Yes	21	19	0.001	0.98
	No	365	327		
During this pregnancy, how often did you drink alcoholic beverages?	Daily	2	3	0.002[b]	0.97
	A few times a week	8	9		
	A few times a month	9	8		
	Occasionally	169	148		
	Never	197	175		
On the average, how many cigarettes did you smoke each day when the pregnancy started?	None	295	272	0.629[c]	0.43
	1–10	28	27		
	11–20	36	29		
	20	26	16		
On the average, how many cigarettes were you smoking each day when the pregnancy ended?	None	299	280	1.55[c]	0.21
	1–10	28	23		
	11–20	35	26		
	20	23	15		

[a] Medications/procedures: dilantin, X-rays, hormones, bendectine/other nausea drugs, coumadin, tetracycline, thyroid medication. Diseases: diabetes, vaginal/pelvic infections, operation requiring anesthetic, rubella, other serious infection or illness. Chemical exposures: benzene, chloroprene, formaldehyde, mercury, PCB, styrene, toluene, anesthetic gases, arsenic, ethylene oxide, lead fumes, carbon monoxide, vinyl chloride, beryllium.
[b] χ^2 Based on "never" versus all others (exposed and controls).
[c] χ^2 Based on "none" versus all others (exposed and controls).

Table 22. Outcome of pregnancy.

Group	Outcomes: Live birth	Twins, one stillborn	Miscarriage/ spontaneous abortion	Intentional abortion	Stillborn	χ^2	p
Exposed	330	0	43	8	5	2.86[a]	0.091
Controls	278	2	55	5	4		
Movers	175	0	25	7	0		
Recent	31	0	9	2	0		

[a] χ^2 = Live births versus the rest for exposed and controls.

Table 23. Birth defects.

A. Specific birth defects by group[a]

Group	Neural tube	Limbs	Face	Genitalia	Cardiac	Chromosomal	Eyes	GI abdominal	Respiratory	Skin	Miscellaneous
Exposed	3	10	2	1	4	2	0	5	1	0	21
Controls	2	7	1	0	6	2	2	4	1	0	17
Movers	0	2	0	0	6	0	2	0	2	1	9
Recent	0	0	1	0	0	0	0	0	0	0	2

[a] Multiple birth defects counted separately.

B. Summary table[a]

Group	⩾ 1 birth defect	No birth defects	Totals
Exposed	37	349	386
Controls	40	306	346
Movers	19	188	207
Recent	6	36	42

$\chi^2 = 0.756$ (based on exposed versus controls)
$p = 0.38$

[a] Multiple birth defects counted together.

ords of 340 respondents (219 exposed, 131 controls) were reviewed for a total of 3060 individual decision regarding over- or underreporting (340 × 9 conditions). The completion rate was 98%. A total of 2804 decisions about adults were analyzed (302 related to overreporting, 2502 related to underreporting), instead of 3060. This exclusion of 8.4% of decisions was based on an editing step which intervened between data collection and analysis. The written description of information found on each chart was reviewed, and where the confirmation categories and methods artificially created over- or underreporting errors, the decision was excluded. For example, many underreports of red, itchy, watery, sore, dry or inflamed eyes resulted from individuals reporting hayfever on the questionnaire instead. When selected for medical chart abstraction, red, itchy eyes would be confirmed, based on the descriptions of symptoms found by the abstractor. When this confirmation was merged with questionnaire data, no self-report of red, itchy eyes would be found, and the events would appear to be underreported. Therefore, such events were excluded from the analysis of medical chart abstraction data.

Table 24 gives separate summary tables for over- and underreporting. No evidence of bias was seen in over- or underreporting among adults. 37.5% of reported conditions were overreported among the exposed group, while 39.3% were overreported among the controls. The rate of underreporting was 10.9% for the exposed and 11.3% for the controls.

Table 24. Medical chart abstraction study.

Group	Confirmed/ possibly confirmed	Not confirmed	Total
Overreporting			
Exposed	133	80	213
Controls	54	35	89
Total	187	115	302
$\chi^2 = 0.083$, $p = 0.772$			
Underreporting			
Exposed	172	1404	1576
Controls	105	821	926
Total	227	2225	2502
$\chi^2 = 0.107$, $p = 0.757$			

Reliability workshops were held before fieldwork began and after it was completed in order to assess inter- and intra-abstractor reliability. A total of 46 individual decisions were made by each abstractor on 6 selected medical charts. The same charts were used for both workshops. Confirmations were scored as "1"; possible confirmations as "2"; and nonconfirmations as "3." Intraclass correlation coefficients were calculated according to the method of Winer (*23*) to assess interabstractor reliability. The intraclass correlation coefficient between decisions was 0.73 in the first workshop and 0.65 in the second, indicating a moderately high level of reliability. Intra-abstractor reliability was assessed using the agreement between specific decisions made in each workshop. Overall, agreement occurred in 87% of pairs of decisions, and the unweighted kappa (*24*) was 0.76 (95% confidence limits, 0.70–0.82). Moreover, there was no bias in the disagreements between the first and second workshop. Individual observer reliability ranged from acceptable (kappa = 0.52) to excellent (kappa = 0.96).

Discussion

Table 25 summarizes the results of hypothesis testing. Nine criteria are identified for assessing the validity of the association between landfill site exposure and the conditions of interest, based on the following concepts: strength of association, consistency with the workers study, gradient of exposure, lack of migrator bias, risk occurring first when site was open, no evidence that less healthy people moved to the landfill area, specificity, and absence of recall bias. These latter two criteria apply generally to all conditions rather than to each condition individually. Specificity was assessed by look-

Table 25. Summary of hypothesis testing.

Criteria for assessing the association	Condition				
	Respiratory	Skin	Mood	Narcotic	Red, itchy eyes
Was the relative risk on the main analysis greater than 1.5?	Yes	Yes	Yes	Yes	Yes
Was it greater than 2.0?	No	No	No	Yes	No
Was the probability value for the relative risk in the main analysis less than 0.01?	Yes	Yes	Yes	Yes	Yes
Was it less than 0.001?	Yes	Yes	Yes	Yes	No
Were these results consistent with the workers study?	Yes	Yes	Yes	Yes	No
Was there a monotonic gradient of risk comparing residents within 500 meters of the site, those further away, and controls?	Yes	Yes	Yes	Yes	Yes
Was the gradient found primarily among long-term residents?	Yes	Yes	Yes	Yes	Yes
Was there a gradient within the exposed group only, among long-term residents?	Yes	No	Yes	Yes	Yes
Was there evidence that migrant bias might explain the differences between exposed and controls on the main analyses?	No	No	No	No	No
Did the landfill site attract people who were less healthy than controls with respect to this condition?	No	No	No	No	No
Had the risk developed before the landfill site was closed?	Yes	Yes	Yes	Yes	Yes
Were increased risks among exposed residents confined to the conditions hypothesized?	No general trend to increased risks among nonhypothesized conditions, but there were a few associations.				
Was there any evidence of overreporting or underreporting recall bias on medical chart abstraction?	There was no evidence of over- or underreporting recall bias.				

ing for associations between landfill exposure and conditions not believed to be related to an environmental exposure. The investigation of recall bias was based on comparisons of questionnaire responses with medical records, according to defined categories of confirmation and nonconfirmation. Strength of association was determined by the magnitude of relative risk and the level of statistical significance of the findings. Migrator bias was assessed by comparing health events among movers versus nonmovers separately for those events occurring before the landfill site closed and then after it closed. Table 25 shows that all criteria were fulfilled by the combined narcotic group of conditions. Red, itchy eyes fulfilled the fewest criteria, while the respiratory, skin, and mood conditions fulfilled most criteria. These results imply that the association between landfill site exposure and the narcotic conditions is most valid, followed by respiratory, skin, and mood conditions. Evidence of a valid association is weakest for red, itchy eyes.

The strength of the evidence for valid associations between residence adjacent to the landfill site and conditions identified in Table 25 is reduced by three principal problems: the high refusal rate among the control population; socioeconomic status differences between the study groups; and the fact that the conditions found in excess are imprecisely defined and potentially interchangeable with other conditions. Offsetting these problems are the multiple criteria used to assess the hypotheses, which were identified and evaluated according to preset rules. The principal problem, however, is found in trying to relate valid associations to causation. Two competing causes may be proposed: airborne contact with an unknown combination of vapors, fumes, and particulate matter emanating from the landfill site, and direct skin exposure from recreational activities in and around the landfill; or the perception of exposure and, therefore, of risk, may have led to an increased tendency on the part of exposed residents to notice new health problems, become concerned about them, and subsequently report them in a health survey.

This study permits an indirect assessment of the evidence for each potentially causal mechanism. There are five lines of reasoning that suggest a chemical mechanism:

The gradient of risk by proximity to the landfill site would be difficult to explain on the basis of perception of risk alone. While perception of risk may be directly related to proximity to the landfill, it is difficult to believe that the relationship could be precise enough to explain the gradient by house distance from the landfill and the fact that the gradient effect involved only long-term residents.

Biologic plausibility is difficult to evaluate when the exposures relate to more than 100 substances and the adverse effects are common and nonspecific. However,

it is difficult to explain how a perceptual mechanism could have selected for those conditions which could also be related to environmental exposure without including more of the other conditions on the questionnaire that could not be plausibly related to environment exposure.

The consistency of symptoms between workers and residents was remarkable, considering the lack of social contact between them and the differing attitudes to the potential for risk expressed by members of the two groups. Despite the fact that a previous health survey of a minority of residents was conducted by the residents themselves, and the results published, the conditions found in excess in our study did not confirm their results. Had our study confirmed the previous study's results, the most likely explanation would have been that the residents had learned the symptoms through publicity. Rather, the conditions found in excess in our study were largely unrelated to those found in excess on the residents' original survey.

Were there to have been a significant perceptual component to the associations found in our study, this ought to have been reflected in evidence of recall bias on medical chart abstraction. This was not the case.

In contrast, there are four lines of reasoning which can be offered to support the case for a perceptual mechanism:

There has never been any evidence presented to show that residents or workers were exposed to airborne concentrations of any substances in sufficient concentration to cause the health problems found in excess in this study.

The health problems found in excess in this study can all be well explained by behavioral mechanisms. None uniquely requires chemical exposure and none is based on evidence of human tissue damage.

The same objections which were raised regarding the validity of the association between landfill site exposure and the health problems of interest can also be raised as issues in causation. In particular, the socioeconomic status differences between groups and the unblinded study design may influence perceptual and behavioral factors that affect one's experience and recall of symptoms. Review of medical records would not necessarily be able to detect such an effect, assuming that individuals did in fact seek medical assistance for their identified health problems.

The analyses relating to migrator bias did demonstrate that nonmigrator tended to have higher rates of first onset of health problems than migrators, after the landfill had been closed. Three hypotheses were advanced to explain this observation. One of the hypotheses suggested that location of residence (and thus, perception of exposure) is the crucial determining factor.

While some of the lines of reasoning presented in favor of each causal mechanism are speculative, those in support of a chemical mechanism are based on the fulfillment of preset analytic criteria for the study, which could easily have gone unmet. However, examples exist where residents exposed to environmental chemical contamination reported excess symptoms in a way that would have appeared to point to the contamination as a cause; only to find that the original evidence of environmental contamination was incorrect, and had not occurred (*18*). On the other hand, the first and second arguments for a perceptual mechanism are based on inherent limitations of the study which could not have been overcome by any changes in study design. The fourth argument for a perceptual mechanism is based on the last 4 years of a survival analysis, excluding the first 9 years. The simplest explanation for the results so obtained would be a survival effect, and not a phenomenon regarding perception of exposure. In the end, the strongest argument for a perceptual mechanism is the familiar evidence that psychological distress is an important correlate of perceived health status (*25*). The authors of this report believe that the lines of reasoning supporting chemical causation are stronger than those that support a perceptual mechanism. It is recognized that both mechanisms could variously contribute to each group of reported symptoms to a different degree, but the nature of such relationships is presently a matter of speculation.

This study did not produce any evidence of adverse reproductive outcomes related to exposure to the landfill site. This was a very significant negative finding. There was no evidence of increases in major chronic diseases among exposed residents. The question of increased cancer risks cannot be addressed by this study because a sufficient follow-up period has not occurred between the time of first residence (1972) and the study date (1984). Answering this question would require following-up the cohort of exposed residents over the next 10 to 20 years to assess their cancer experience, and will be hampered by small numbers identifying excesses in rare cancers.

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