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Health Effects of a Wastewater Treatment System

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HEALTH EFFECTS OF A WASTEWATER TREATMENT SYSTEM

by

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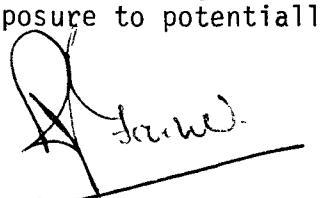
FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The primary mission of the Health Effects Research Laboratory in Cincinnati (HERL) is to provide a sound health effects data base in support of the regulatory activities of the EPA. To this end, HERL conducts a research program to identify, characterize, and quantitate harmful effects of pollutants that may result from exposure to chemical, physical, or biological agents found in the environment. In addition to the valuable health information generated by these activities, new research techniques and methods are being developed that contribute to a better understanding of human biochemical and physiological functions, and how these functions are altered by low-level insults.

This report provides an assessment and discussion of data obtained as part of a comprehensive health study in a community having an activated sludge wastewater treatment plant, to determine if the plant could be related to any illness in the community. With a better understanding of the health effects, measures can be developed to reduce exposure to potentially harmful materials.



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ABSTRACT

Data obtained as part of a comprehensive community health study conducted during 1965-1971 were utilized to examine the incidence of acute illness in a population surrounding an activated sludge wastewater treatment plant and a control location in Tecumseh, Michigan. Study participants were classified into concentric rings of approximately 600m each by dwelling unit distance from either site. School children were classified by school attended in a similar manner. The additive minimum discrimination information statistic was used to test for significant differences in the incidence of total, respiratory, and gastrointestinal illnesses among individuals dwelling within concentric rings. When specifying socioeconomic factors, education and income exerted an unequal influence on the significance of illness incidence variation and, in general, such variations between geographic locations were found to be greatest in groups having the lowest income and education.

Differences in illness incidence occurred during the May through October season at varying distances from the wastewater treatment plant, but persons within 600m appeared to have a greater than expected risk of respiratory and gastrointestinal illness. Persons dwelling within 600m of the plant had respiratory illnesses that exceeded those expected by 20% and 27%, and gastrointestinal illnesses that exceeded those expected by 78% and 50% when specified for income and education, respectively. The data suggest the higher illness rates are related to higher densities of lower socioeconomic families rather than the wastewater treatment plant.

The group within the 1800 to 2400m concentric rings from the wastewater treatment plant had a greater than expected incidence of respiratory illnesses during both warm and cold seasons. During the May-October season, income- and education-specific total illness as well as income-specific respiratory illness differences were found to be significant in the wastewater treatment plant-related groups. Significant differences were not found in the control location-related groups at this distance. However, the higher than expected illness cannot be related to the wastewater treatment plant itself.

Differences in total illness were observed in the school children with regard to distance of school attended from both the wastewater treatment plant and control location. The schools, however, were very unevenly distributed with reference to distance from these locations.

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ABBREVIATIONATIONS AND SYMBOLS

C -- concentric circles surrounding control location
χ^2 -- Chi-square
d.f. -- degrees of freedom
EPI -- exposure and potential for infection
GI -- gastrointestinal illness
i -- age interval (i = 1,2,...,18)
j -- distance interval from wastewater treatment plant or control location
k -- illness category (k = 1,2)
l -- income or education category (l = 1,2,3)
m -- meter
MGD -- million gallons per day
N -- number of individuals within a particular study population
O -- number of observations
Σ -- summation
2I -- minimum discrimination information statistic
W -- concentric circles surrounding wastewater treatment plant
WWTP -- wastewater treatment plant
X -- expected number of respondents

ACKNOWLEDGMENT

The cooperation of residents and officials of the City of Tecumseh is gratefully acknowledged. We are thankful to Daniel Myers, Water Quality Division, Michigan Department of Natural Resources for providing available sewage flow data. The statistical assistance provided by Donald E. Lamphiear is greatly appreciated. The contributions of Nelson Meade and discussions of James Koopman are gratefully acknowledged. This study is deeply indebted to the organizers and participants of the Tecumseh Community Health Study.

SECTION 1

INTRODUCTION

Centralized processes of wastewater treatment aid sanitation efforts in populated areas throughout the world. Most of these processes produce aerosols that can become windborne and be carried from the site of treatment. These aerosols can contain many of the chemical and biological substances found in wastewater. A literature review by Hickey and Reist (1975) showed that bacterial aerosols are emitted from these treatment processes and that they can be carried varying distances from the site of origin, depending upon environmental conditions. Although existing methodology is below the required sensitivity for the routine isolation of animal viruses from the airborne emissions of wastewater treatment facilities (Fannin *et al.*, 1977), enteroviruses have reportedly been recovered from aerosols emitted from wastewater spray irrigation processes (Johnson *et al.*, 1977; Teltsch and Katzenelson, 1978). The health significance of exposure to these emissions has not been adequately determined.

Some evidence regarding the health effects of exposure to wastewater is, however, available. Ledbetter *et al.* (1973) showed that wastewater treatment plant workers had a higher incidence of influenza than water treatment plant workers and Katzenelson *et al.* (1976), in a retrospective study, showed that persons living in agricultural communal settlements practicing wastewater spray irrigation had a higher incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis than those who lived in settlements that did not irrigate with wastewater.

Before undertaking extensive epidemiological studies regarding the health effects of wastewater treatment facilities, existing data were utilized for the evaluation of these effects. The city of Tecumseh, Michigan was selected as a study site because an intensive community health study was being conducted by The University of Michigan and it provided an opportunity to utilize uniquely comprehensive data on the epidemiological experience of an entire community.

The purpose of the study was: (1) to determine whether there are differences in general illness incidence, depending upon population dwelling distance from a wastewater treatment facility; (2) to determine the suitability of Tecumseh, Michigan as a site for a long-term prospective study regarding the influence of wastewater treatment upon the health of exposed populations.

SECTION 2

CONCLUSIONS

Income- and education-specific illness differences were most significant at differing study area locations among individuals dwelling within low income and education households. A consistently greater than expected number of illnesses were found in those persons residing within the 1800 to 2400m wastewater treatment plant concentric ring. The reasons for this higher illness incidence cannot be conclusively determined without further study.

Significant income- and education-specific illness differences occurred during the study period and during the colder months within concentric rings radiating from both the wastewater treatment plant and from a control location. Summed income- and education-specific total as well as income-specific respiratory illnesses were significantly different at varying distances from the wastewater treatment plant during May through October. No significant differences in the occurrence of these illnesses were, however, found during these months at varying distances from the control site. During the warmer seasons, summed respiratory illnesses within 600m of the wastewater treatment plant exceeded those expected by 20% and 27% and summed gastrointestinal illnesses exceeded those expected by 78% and 50% when specified for income and education, respectively. These are, however, suggestive and not necessarily significant differences.

Differences in illness incidence occurred from May through October at varying distances from the wastewater treatment plant and persons dwelling within 600m of this plant appeared to have a greater than expected risk of respiratory and gastrointestinal illness. The data do not, however, demonstrate a causal effect and factors other than the wastewater treatment plant, such as higher rates of illness transmission in areas of higher densities of lower socioeconomic families, could have contributed to these findings. Total illness differences, with respect to distance from both the wastewater treatment plant and control location, were observed in children by school attended, but these results are inconclusive since the schools were found to be very unevenly distributed with regard to distance from these locations. The available comprehensive data base, together with ongoing enteric disease investigations within the study area, make Tecumseh, Michigan a very suitable model for further evaluation of the influence of a wastewater treatment plant on community health.

SECTION 3

RECOMMENDATIONS

Further study should focus upon persons within lower socioeconomic groups throughout the study area and upon those dwelling within 600m of the wastewater treatment plant. Since this investigation did not demonstrate a causal effect, further retrospective study of available data should identify factors associated with apparent or suggested increased illness risks within the specified groups.

The dispersion of wastewater treatment plant aerosol emissions and the resultant probability of community exposure is influenced by local meteorological conditions. If dwelling unit locations of persons with higher illness risks were specified with respect to this exposure probability, an association between aerosol emission concentration and illness risk could be evaluated. Another approach would be to evaluate illness risk in terms of intrafamilial transmission rates. If, for example, an association were determined, the wastewater treatment plant may not be the major contributing factor to the higher than expected illness rates.

Further prospective study should determine probable exposure to wastewater treatment plant emissions while increasing tne surveillance of the population dwelling nearest the plant. A design permitting the estimation of community transmission parameters would enable separation of the influence of the wastewater treatment plant from other potential sources of transmission.

SECTION 4

EXPERIMENTAL PROCEDURES

RECRUITMENT AND SURVEILLANCE

Procedures for recruitment and surveillance have been previously described by Monto *et al.* (1971). The dwelling units of Tecumseh, Michigan were divided into 10 samples by stratified random sampling from each of five geographic strata described by Napier (1962)(Appendix). This sampling procedure resulted in 10 sets of households with characteristics exemplary of the entire community. Each of the households within the 10 samples was randomly ordered for visit by trained interviewers. For purposes of a study of acute respiratory infections, 18-24 families were introduced per sample, with exception of the first six months of the study when 48 families were recruited per sample. This family recruitment was interrupted during late 1966 upon completion of the tenth sample and then resumed in March, 1967. Until May, 1967 eligible study families contained parents under age 45 and least one child of school age or younger. After this date, as part of a chronic bronchitis study, families containing older adults were gradually added using the methods described. Data were obtained from the participating families regarding health history, socioeconomic factors, employment locations, and schools attended by all children. All data were punched onto computer cards and were later transferred to computer tape.

After recruitment, each family was contacted weekly by telephone or personal visit and a single respondent was questioned regarding the occurrence of short term illness within the family during the past week. When illness was reported, the details of the specific event were recorded using the questionnaire shown in figure 1.

The respondent was contacted during the weeks following the initial report and asked whether the illness persisted and to describe the symptoms. The date of illness termination, if any, was obtained and the respondent was questioned regarding other illness development within the family. An illness occurring at least two days after a termination date was regarded as a new event.

Report of Acute Illness, Tecumseh Community Health Study

A. Since last week has anyone in the family had a cold, a sore throat, or the flu or any other respiratory illness? N Y

B. Since last week has anyone in the family had an upset stomach or diarrhea? N Y

(If only Q.B, ask questions in boxes ☐ only.)

1. Would you tell me about _____'s illness, what was the trouble? _____

_____

☐2. When did this (cold, flu, upset stomach, etc.) first bother _____? Date _____

☐3. Was _____ seen by a doctor because of it?

☐ NO ☐ YES -- What did the doctor say about it; did he give it a medical name?

_____

4. Did _____ have any of the following symptoms?

☐a.	any fever? ..... _____° if known	N Y	j.	a cough?	N Y
☐b.	any chills?	N Y	k.	any phlegm from the chest?	N Y
☐c.	a headache?	N Y	l.	any wheezy breathing?	N Y
d.	an earache?	N Y	m.	pain or discomfort on breathing?	N Y
☐e.	any general aches or pains? .	N Y	☐n.	any nausea or an upset stomach?	N Y
f.	a stuffy or runny nose?	N Y	☐o.	any vomiting?	N Y
g.	a sore throat?	N Y	☐p.	any diarrhea?	N Y
h.	swollen or tender glands? ...	N Y	☐q.	burning, aching or redness of the eyes?	N Y
i.	any hoarseness?	N Y	☐r.	any stiffness of the neck?	N Y
			☐s.	any other symptoms? _____	

☐5. Was _____ in bed because of it? NO YES
In hospital
At home

Dates	# Days

☐6. Aside from days in bed (if any) was _____ away from work/school or restricted in _____ usual activities? NO YES

☐7. Does the _____ still bother _____? NO YES

IF NO, when did it last bother _____?

Specimens ☐ NO ☐ YES _____

Interviewer _____ Date _____

FIGURE 1. Questionnaire used in the investigation of acute infections in Tecumseh.

STUDY POPULATION SELECTION

The study population was defined as those participants in The University of Michigan Tecumseh Community Health Study from 1965 to 1971 who resided in dwelling units at specific distance ranges from the Tecumseh wastewater treatment plant, located in the southeast quadrant of the city (figure 2). Dwelling units located within each of five concentric rings and beyond, radiating from the plant in approximate multiples of 600m, were identified. Dwelling units were likewise identified with a second set of concentric rings constructed around a nonemitting location. This site was located in the northwest quadrant of the city in an undeveloped area approximately 180m west of Seminole and 275m south of Brown Roads. This control location was selected because it is upwind from the wastewater treatment plant and had a surrounding population density comparable to that of the study groups. The dwelling units within the study area were primarily single family houses, although multiple family units occurred at various locations within the area. Confirmation of dwelling unit locations near concentric ring boundaries was made by site visitation. All dwelling units studied were assigned to concentric rings surrounding both the wastewater treatment plant and control location. Data with reference to each index point were analyzed separately.

The population used in nonseasonal-related analyses included those individuals who were contacted at least 50 weeks in a row with no absences during four or more weeks. The illnesses included are those whose onset occurred within this 50-week period. The entire population on report from 1965 to 1971 was used for determination of true illness incidence rates.

As used in this study, colder months included November through April whereas warmer months included May through October. In each case, the study population was defined as those persons on report for the entire 26 week period, with no long periods (two weeks or more) off report. The illnesses included are those whose onset occurred during the 26-week period.

ILLNESS CLASSIFICATION

Acute illnesses were grouped into three general categories: total, respiratory, and gastrointestinal. Data are reported as incidence rates and as individual illness rates. Age-sex-distance-specific true incidence rates were determined by dividing the number of each kind of illness by the number of person-years observed within each group. Age-sex-distance-specific individual illness rates were calculated by number of illnesses during report period/number of weeks on report.

STATISTICAL ANALYSES

The objective of the statistical analyses was to determine whether the incidence of illness varied with distance of the dwelling unit from the wastewater treatment plant, and, in children, also whether incidence depended upon distance of the school attended from the wastewater treatment plant. Dwelling units and schools were also classified with respect to distance from a control

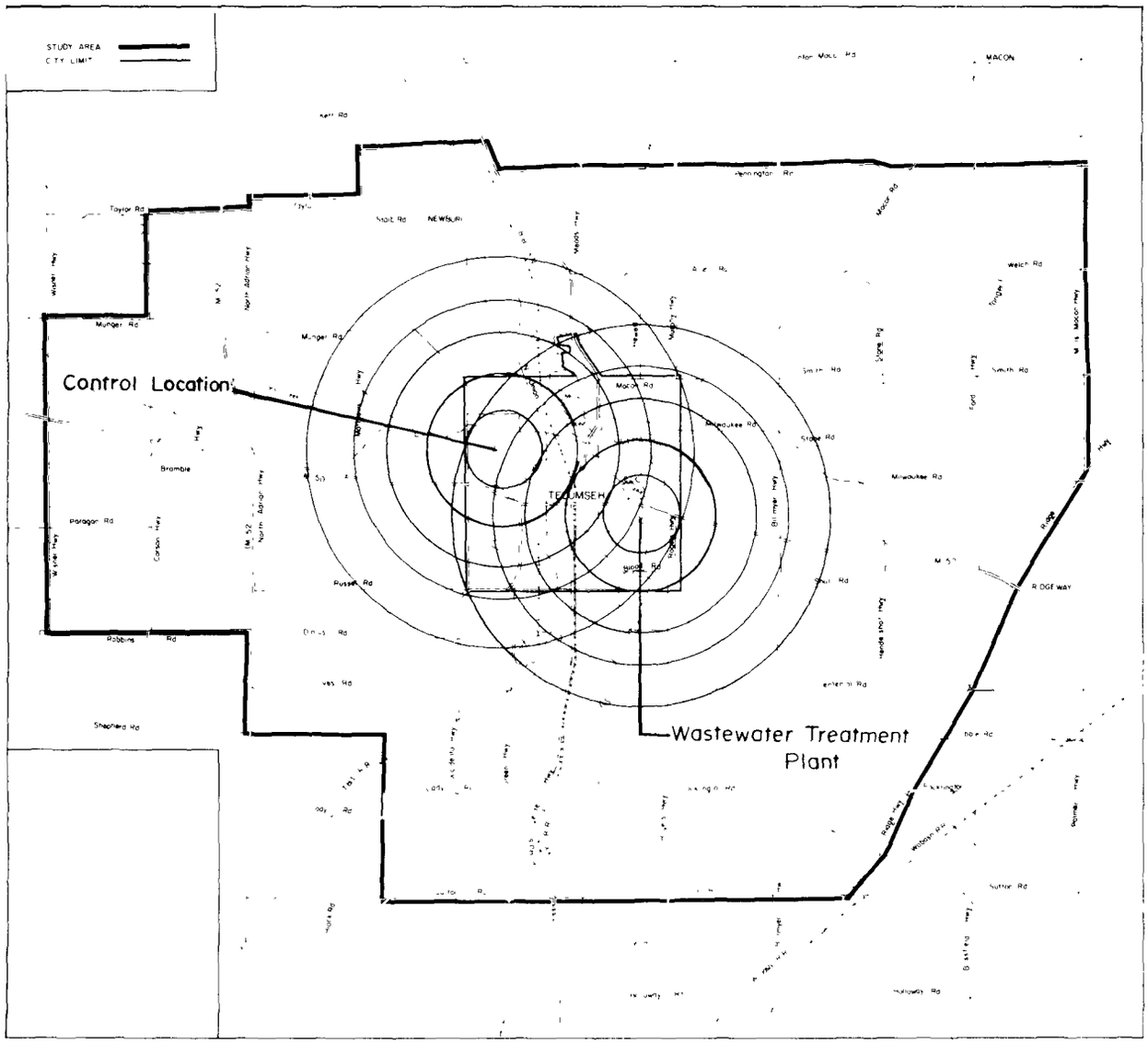

FIGURE 2. Wastewater treatment plant and control location concentric circles within Tecumseh study area.

point. Ancillary information for each respondent included, age, sex, education of the head of the household, and family income.

The null hypothesis, tested separately for the wastewater treatment plant and the control point, was that the proportion of persons in the high incidence category was the same in the subsets defined by distance from the index point. The distribution of respondents by age and sex varied from one distance category to another, and also depended on which of the index points was being considered. The test statistic for the null hypothesis was a chi-square goodness of fit test in which the expected frequencies were determined by a model which incorporated differences in age and sex distributions of illness rates in the distance categories.

We let O_{ijk} be the observed number of individuals in the i^{th} age-sex group in the j^{th} distance interval from the index point, in illness category k where

i = 1,2,...,18, where the nine age intervals are those indicated in table 1

j = 1,2,...,6: the six distance intervals determined by the five concentric rings about the index point

k = 1,2: the illness categories
1: n or fewer illnesses in the interval
2: n+1 or more illnesses in the interval
where n was selected for each analysis according to type of illness and duration of the interval.

Then, summing, the following counts were obtained:

$O_{\cdot jk} = \Sigma O_{ijk}$: the number of individuals in the j^{th} distance category and k^{th} illness category

$O_{i..} = \Sigma\Sigma_{jk} O_{ijk}$: the number of individuals in the sample in the i^{th} age-sex group

$O_{i.k} = \Sigma_{j} O_{ijk}$: the number of individuals in the i^{th} age-sex group who are in illness category k

Assuming, as specified by the null hypothesis, that illness category was independent of distance from the index point, the expected number of individuals in the i^{th} age-sex group was

$$X_{ijk} = \frac{O_{i.k}}{O_{i..}} O_{\cdot jk}$$

Thus, within the i^{th} age-sex group, the expected number of individuals in the jk^{th} cross-classification was proportional to the marginal totals. The expected number of persons at distance j in illness category k was

$$X_{jk} = \Sigma_{i} X_{ijk}$$

The test statistic was the minimum discrimination information statistic, described by Kullback (1959) and Kullback *et al.* (1962),

$$2I = 2\Sigma O_{jk} \ln \frac{O_{jk}}{X_{jk}}$$

The information statistic is distributed as chi-square with (k-1)(j-1) degrees of freedom[1]. Significant departures of the observed from the expected frequencies, as indicated by the test statistic, led to rejection of the null hypothesis against the alternative of an association between high illness rates and distance from the index point.

Besides the differences in age and sex among the distance categories, the socioeconomic status of respondents varied geographically, and differences in proportions of respondents at different levels of illness might have accounted for associations of illness rate and distance from the index point. The observed number of respondents in illness category k, in distance category j, and at level l was O_{jkl}, where l was the family income or education level, depending on the analysis, and was defined as follows:

Family Income[2]

1: less than $7000
2: $7000-9999
3: $10000 or more

Education of head of household

1: less than high school diploma
2: high school degree
3: some college or college degree

Within age-sex categories, the observed number was O_{ijkl} and the expected number was X_{ijkl}, calculated from the marginal frequencies as before. Summing over the 18 age-sex categories

$$X_{jkl} = \sum_i X_{ijkl}$$

---

[1]Degrees of freedom was verified as follows: Within the age-sex group, (1) expected frequencies in the cells of the cross-classification table were proportional to the marginal totals of the table, and (2) the sum of the expected values for the table was equal to the sum of the observed values. Degrees of freedom for the age-sex-specific table was (j-1)(k-1). The table obtained by summing over the 18 age-sex groups had marginal totals which were sums of the margins; hence was subject to the same linear restrictions, and therefore had the same number (j-1)(k-1) degrees of freedom.

[2]Specific income amounts reflect levels relative to the study period.

The test of significance was a conditional test for a fixed value of l. Among persons at socioeconomic level l, the proportion in the high incidence category was the same in all subsets as defined by distance from the index point. The test statistic was

$$2I_l = 2\Sigma O_{jkl} \ln \frac{O_{jkl}}{\chi_{jkl}}$$

with (j-1)(k-1) degrees of freedom.

The hypothesis of equality of illness rates in the distance categories for a given socioeconomic level was the conditional hypothesis for fixed, but not specified, socioeconomic levels. The test was a joint test on the three levels simultaneously. The test statistic was the sum of the information statistics for the three individual tests

$$2I = \sum_l 2I_l$$

with degrees of freedom l(j-1)(k-1), the sum of the degrees of freedom for the individual tests.

WASTEWATER TREATMENT PLANT

The Tecumseh wastewater treatment plant (WWTP) is located in the southeast quadrant of the city (Figure 2). The plant is at a lower elevation than most of the populated study area and is surrounded by deciduous trees on the east, west, and south. This plant processes approximately 1 million gallons of wastewater per day (MGD) by activated sludge secondary treatment. Activated sludge has been in use since 1965, when the plant was redesigned from a trickling filtration facility. Data that might be used to estimate the fecal contribution to the wastewater, such as total or fecal coliform concentrations, are not available for the study period. Wastewater flow rates for the study period were not available from the Tecumseh WWTP, but available data were obtained from the Michigan Department of Natural Resources.

METEOROLOGY

The dispersion of airborne contaminants from wastewater treatment plants is strongly influenced by wind direction and velocity. Local data on these parameters are not available from the immediate Tecumseh vicinity. A STAR program printout consisting of windspeed averages from 16 compass points for six stability classes based on data collected at the Detroit Metropolitan Airport was obtained from the National Climatic Center, Asheville, N.C. The data are for the years 1969 through 1973, however, and are not strictly inclusive of the study period.

SECTION 5

RESULTS

SEWAGE FLOW

Average monthly sewage flow rates at the Tecumseh wastewater treatment plant ranged between 0.64 and 1.18 MGD from 1965 to 1971. Data, however, were not available for 1966 and some data for 1965, 1968, and 1969 are missing. As shown in figure 3, the lowest sewage flow rates were observed during 1965 and the highest monthly average was seen in 1968. Although flow rate fluctuations are observed, no consistent flow pattern is evident among the study years.

INDIVIDUAL ILLNESS INCIDENCE

Age-sex-location-specific individual illness incidence rates per person-year for the Tecumseh study population during 1965 to 1971 are presented in tables 1-6. The data are grouped for each sex into nine age intervals at six distances from both reference points. The concentric ring boundaries are those for a specific ring and are not cumulative. For example, the 1200m boundary is from 600m to 1200m and not 0m to 1200m In general, illness incidence rates were higher in females than in males and varied inversely with age in both sexes. Lower incidence rates were observed for gastrointestinal illnesses than for the other illness classifications. Although illness incidence variations were observed among individuals dwelling within WWTP or control location concentric rings, statistical analyses of these data, in the form presented, are not appropriate.

EVALUATION OF ILLNESS INCIDENCE BY DISTANCE FROM WASTEWATER TREATMENT PLANT

The illness experience of individuals on report for 50 or more weeks during 1965-1971 according to distance of their dwelling units from the wastewater treatment plant or control location is presented in table 7. The number of persons reported in the total illness category is not necessarily the sum of those in respiratory and gastrointestinal illness classifications since the criteria for inclusion within a specific group are based upon different numbers of illness occurrences. For analyses, the number of persons having four or more total, three or more respiratory, or one or more gastrointestinal illnesses during the report period was determined. Total and respiratory illnesses were shown to be significantly different

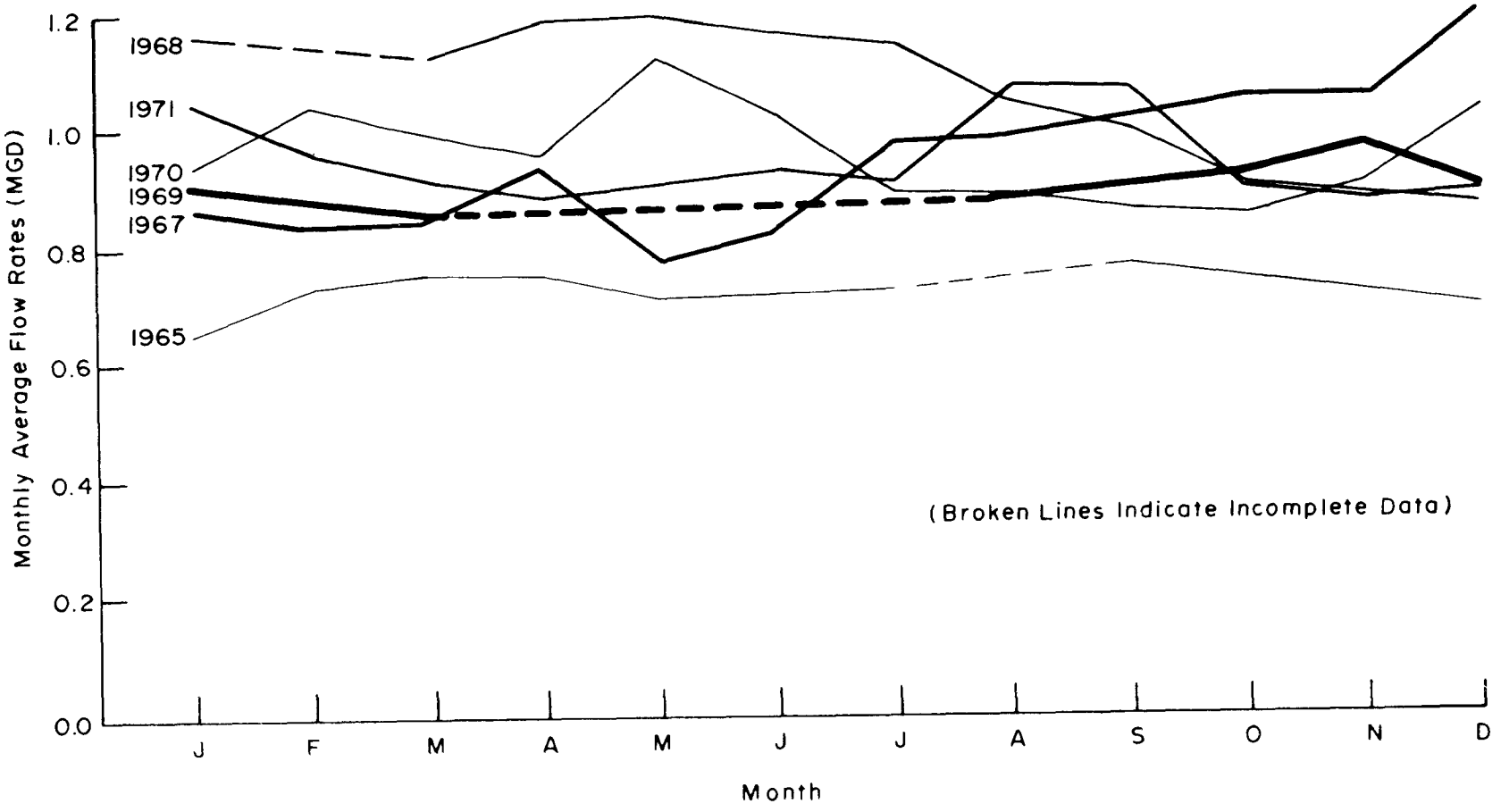

FIGURE 3. Monthly average sewage flow rates for the Tecumseh, Michigan wastewater treatment plant from 1965 to 1971. (Source: Michigan Department of Natural Resources).

TABLE 1. TOTAL ILLNESS INCIDENCE IN MALES BY APPROXIMATE DWELLING DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965 TO 1971

Age (yr)	Concentric Circle Boundary (m x 100) 6		12		18		24		30		>30	
	W[a]	C	W	C	W	C	W	C	W	C	W	C
<1	8.2[b]	4.6	5.8	6.9	6.3	6.4	7.8	7.3	6.5	0	7.1	7.0
1 - 4	6.1	7.2	5.6	7.3	6.4	6.2	7.6	7.2	6.4	7.2	6.6	7.2
5 - 9	4.1	5.6	3.6	4.8	4.6	4.3	4.6	4.4	4.5	4.0	4.8	4.6
10 - 14	3.3	3.8	3.2	3.1	3.1	2.9	3.4	3.3	3.0	3.7	3.5	3.8
15 - 19	3.7	2.4	2.6	2.8	2.9	3.1	3.1	2.7	2.4	2.9	2.7	2.8
20 - 29	2.9	2.2	2.7	3.0	3.1	3.1	3.2	3.4	3.1	2.7	3.1	2.9
30 - 39	2.9	2.5	2.4	3.0	3.1	2.6	2.7	2.4	2.5	3.6	2.8	2.8
40 - 49	1.9	1.8	2.0	2.0	2.1	2.1	2.2	2.3	2.0	1.7	2.0	2.0
>50	0.3	0.9	1.5	1.4	1.5	1.5	1.2	1.2	1.6	1.8	1.7	1.7
Total	3.4	3.3	3.1	3.7	3.6	3.3	3.7	3.7	3.5	3.7	3.8	3.7

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

[b] Incidence per person-year.

TABLE 2. TOTAL ILLNESS INCIDENCE IN FEMALES BY APPROXIMATE DWELLING DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965 TO 1971

Age (yr)	Concentric Circle Boundary (m x 100) 6		12		18		24		30		>30	
	W[a]	C	W	C	W	C	W	C	W	C	W	C
<1	7.5[b]	8.6	5.4	7.5	6.5	6.2	7.3	5.9	6.9	5.4	6.2	6.3
1 - 4	5.9	8.9	6.2	6.2	6.3	6.7	7.4	6.2	5.9	5.4	6.2	5.4
5 - 9	5.8	5.3	3.9	5.0	5.3	4.9	5.8	4.7	3.9	4.2	5.2	5.5
10 - 14	2.5	3.5	3.8	4.2	4.4	3.8	4.2	3.8	3.2	4.4	3.7	3.8
15 - 19	2.2	4.4	3.5	3.6	3.8	3.3	3.9	4.1	2.9	2.1	3.3	3.1
20 - 29	3.1	3.7	3.9	4.5	4.0	4.3	4.6	3.8	4.0	3.2	4.4	4.4
30 - 39	3.0	4.4	3.4	3.7	4.3	3.7	4.0	4.0	3.1	3.0	3.6	3.6
40 - 49	2.3	2.7	2.6	2.7	3.1	2.6	2.8	2.8	2.9	1.8	2.2	2.6
>50	2.3	2.0	1.7	2.1	2.3	2.0	1.8	1.9	2.0	2.2	2.5	2.7
Total	3.5	4.4	3.7	4.4	4.4	4.2	4.7	4.1	3.8	3.8	4.3	4.4

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

[b] Incidence per person-year.

TABLE 3. RESPIRATORY ILLNESS INCIDENCE IN MALES BY APPROXIMATE DWELLING DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965 TO 1971

Age (yr)	Concentric Circle Boundary (m x 100) 6		12		18		24		30		>30	
	W[a]	C	W	C	W	C	W	C	W	C	W	C
<1	5.9[b]	2.5	5.4	5.7	4.8	5.4	6.3	5.8	5.2	0	6.2	6.0
1 - 4	4.9	5.7	4.3	5.6	4.7	4.6	6.0	5.4	5.0	6.4	5.1	6.4
5 - 9	3.4	4.2	2.5	3.4	3.3	3.2	3.4	3.1	3.2	3.5	3.5	3.3
10 - 14	2.0	2.7	2.4	2.3	2.3	2.0	2.3	2.2	2.1	2.8	2.5	2.6
15 - 19	2.8	1.9	2.3	2.1	2.0	2.2	2.2	2.2	1.7	2.9	2.1	2.0
20 - 29	2.1	1.4	1.8	2.2	2.1	2.2	2.3	4.5	2.3	1.9	2.3	2.2
30 - 39	2.4	1.8	1.7	2.0	2.1	1.8	1.8	1.6	1.8	2.4	1.9	2.0
40 - 49	0.9	1.6	1.6	1.3	1.4	1.5	1.6	1.6	1.5	1.3	1.3	1.3
>50	0.3	0.5	1.2	1.2	1.3	1.3	0.9	1.0	1.4	1.5	1.2	1.2
Total	2.4	2.5	2.3	2.7	2.6	2.5	2.7	2.7	2.6	2.9	2.8	2.7

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

[b] Incidence per person-year.

TABLE 4. RESPIRATORY ILLNESS INCIDENCE IN FEMALES BY APPROXIMATE DWELLING DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965 TO 1971

Age (yr)	Concentric Circle Boundary (m x 100) 6		12		18		24		30		>30	
	W[a]	C	W	C	W	C	W	C	W	C	W	C
<1	5.5[b]	6.8	4.3	6.2	5.7	5.2	5.8	4.7	5.9	4.1	5.0	5.1
1 - 4	4.6	5.9	5.0	4.9	4.9	5.3	5.5	4.7	4.7	4.3	5.0	4.3
5 - 9	2.9	4.1	2.7	3.7	3.8	3.4	4.4	3.4	2.7	3.0	3.8	4.1
10 - 14	1.7	3.0	3.0	3.3	3.5	3.0	3.3	2.9	2.3	3.0	2.8	2.9
15 - 19	1.4	4.2	2.8	2.8	2.9	2.5	3.0	2.7	2.4	1.8	2.3	2.3
20 - 29	2.4	2.4	3.0	3.4	3.0	3.1	3.3	2.8	2.9	2.7	3.2	3.2
30 - 39	2.4	3.4	2.4	2.5	3.1	2.7	2.7	2.7	2.3	2.2	2.5	2.5
40 - 49	2.0	1.8	2.0	1.8	2.2	2.0	1.9	2.1	2.0	1.4	1.7	1.8
>50	1.8	1.3	1.3	1.5	1.8	1.5	1.0	1.4	1.6	1.9	1.8	1.9
Total	2.5	3.4	2.8	3.3	3.3	3.1	3.5	3.0	2.8	3.2	3.2	3.3

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

[b] Incidence per person-year.

TABLE 5. GASTROINTESTINAL ILLNESS INCIDENCE IN MALES BY APPROXIMATE DWELLING DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965 TO 1971

Age (yr)	Concentric Circle Boundary (m x 100) 6		12		18		24		30		>30	
	W[a]	C	W	C	W	C	W	C	W	C	W	C
<1	2.3[b]	2.5	1.1	2.1	2.0	1.9	2.8	1.9	1.7	0	1.6	1.6
1 - 4	1.7	1.4	1.6	2.3	2.1	1.8	2.2	2.2	1.9	1.0	1.9	1.0
5 - 9	0.7	1.7	1.2	1.6	1.5	1.2	1.4	1.5	1.4	1.0	1.5	1.4
10 - 14	1.3	1.0	0.9	0.8	1.0	1.0	1.0	1.0	0.9	1.1	0.9	1.0
15 - 19	1.3	0.4	0.5	0.8	0.9	1.0	0.9	0.6	0.7	0	0.6	0.8
20 - 29	1.5	1.0	0.9	0.9	1.2	1.0	1.0	1.1	0.9	0.7	1.1	1.1
30 - 39	1.0	0.7	0.9	1.0	1.1	0.8	1.0	1.0	0.7	1.3	0.9	0.8
40 - 49	0.9	0.3	0.6	0.7	0.6	0.7	0.8	0.7	0.6	0.6	0.6	0.6
>50	0.0	0.2	0.2	0.3	0.2	0.3	0.2	0.1	0.3	0.9	0.5	0.4
Total	1.1	0.9	0.9	1.2	1.1	1.0	1.2	1.2	1.0	1.0	1.1	1.1

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

[b] Incidence per person-year.

TABLE 6. GASTROINTESTINAL ILLNESS INCIDENCE IN FEMALES BY APPROXIMATE DWELLING DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965 TO 1971

Age (yr)	Concentric Circle Boundary (m x 100)											
	6		12		18		24		30		>30	
	W[a]	C	W	C	W	C	W	C	W	C	W	C
<1	2.7[b]	3.0	1.8	2.0	1.4	2.1	2.4	1.7	1.6	1.7	1.8	1.7
1 - 4	1.8	2.5	1.6	1.7	1.7	1.8	2.3	1.8	1.6	1.2	1.6	1.2
5 - 9	3.1	1.4	1.2	1.5	1.8	1.5	1.5	1.4	1.2	1.4	1.6	1.7
10 - 14	0.2	0.7	1.0	1.2	1.2	1.0	1.0	0.8	0.9	1.5	1.0	1.0
15 - 19	0.8	0.2	0.8	1.0	1.0	0.9	1.1	1.6	0.6	0.2	1.2	0.9
20 - 29	1.1	1.5	1.2	1.4	1.4	1.5	1.6	1.3	1.3	1.0	1.4	1.4
30 - 39	0.8	1.1	1.3	1.5	1.6	1.3	1.5	1.5	0.9	1.0	1.1	1.1
40 - 49	0.1	1.0	0.5	1.0	0.9	0.7	1.0	0.7	0.9	0.5	0.7	1.0
>50	0.5	0.7	0.4	0.6	0.7	0.6	0.8	0.6	0.5	0.3	0.9	0.9
Total	1.1	1.2	1.1	1.3	1.4	1.3	1.5	1.3	1.1	1.2	1.3	1.3

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

[b] Incidence per person-year.

Table 7. ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION FOR POPULATION ON REPORT FOR 50 OR MORE WEEKS DURING 1965-1971 (N=4889)

	Concentric Circle Boundary (m x 100)						
	6	12	18	24	30	>30	Information Statistic
Total Illness(≥4)							
WWTP	33 (38)[a]	234 (257)	442 (430)	617 (569)	314 (342)	660 (665)	17.86**
Control Loc.	89 (83)	541 (525)	550 (553)	433 (450)	72 (75)	615 (614)	3.14
Resp. Illness(≥3)							
WWTP	40 (39)	253 (267)	447 (446)	626 (591)	319 (354)	700 (688)	13.02*
Control Loc.	98 (87)	548 (545)	568 (574)	448 (467)	78 (77)	645 (635)	4.60
G.I. Illness(≥1)							
WWTP	49 (48)	308 (321)	560 (535)	733 (705)	394 (418)	794 (811)	11.02
Control Loc.	108 (106)	657 (646)	703 (688)	546 (558)	86 (91)	738 (748)	2.90

[a] Number of individuals observed with number expected presented in parentheses.

* Significant at the 95% confidence level.

** Significant at the 99% confidence level.

between populations dwelling within the concentric rings located at varying distances from the wastewater treatment plant. These observations were significant at the 99% confidence level for total illnesses and at the 95% confidence level for respiratory illnesses. No significant differences in illness were observed in similar analyses for the population radiating from the control location. Observed illnesses were consistently greater than expected illnesses in the concentric rings having outer boundaries of 1800m and 2400m from the wastewater treatment plant, with greater differences observed in the latter ring.

INDIVIDUAL ILLNESS INCIDENCE BY LOCATION AND SEASON

Illness differences according to distance from the wastewater treatment plant were examined on a seasonal basis during 1966-71. As shown in table 8, significant variation in persons having two or more total and one or more gastrointestinal illnesses between concentric ring dwelling units radiating from the wastewater treatment plant was observed during the warmer months. Differences with respect to total and gastrointestinal illness were found significant at the 95% and 99% level of confidence, respectively. No significant differences in illness experience were observed in the individuals living within concentric rings radiating from the control location. Although the number of individuals observed in the concentric ring within 600m of the wastewater treatment plant is low, relative to the other rings, the number of persons observed with two or more total and respiratory or one or more gastrointestinal illnesses exceeded the number expected by 20%, 27% and 50%, respectively, during the warmer months. The number of individuals within the 2400m concentric ring with observed illnesses exceeding those expected by 10%, 11% and 10% for total, respiratory, and gastrointestinal illnesses, respectively.

No significant differences were found, however, in the colder months during 1966-1971 between the number of observed and expected individuals having one or more illnesses, dwelling within concentric rings radiating from either the wastewater treatment plant or control location. As shown in table 9, the number observed in these months did not exceed those expected for any illness category within the 600m wastewater treatment plant concentric ring. The number observed was, however, higher than the number expected in the concentric ring having a 2400m boundary.

The number of persons experiencing acute illness who were on report for 50 or more weeks during 1965-1971, differed significantly among the concentric rings in which they dwelled. The number of persons experiencing four or more total, three or more respiratory, or one or more gastrointestinal illnesses exceeded those expected in concentric rings with 1800 and 2400m boundaries but not in the 600m circle (see table 7). That is, during the entire study period, persons living closest to the wastewater treatment plant did not experience more illness than expected for that population.

TABLE 8. ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION IN MAY-OCTOBER DURING 1966 THROUGH 1971 (N=3031)

	Concentric Circle Boundary (m x 100)						
	6	12	18	24	30	>30	Information Statistic
Total Illness (≥2)							
WWTP	24(20)	120(135)	216(224)	368(333)	184(198)	378(379)	12.82*
Control Loc.	74(79)	392(400)	435(445)	363(343)	43(43)	434(432)	4.43
Resp. Illness (≥2)							
WWTP	19(15)	99(102)	166(170)	279(252)	135(151)	281(290)	8.74
Control Loc.	39(36)	240(232)	236(236)	190(193)	32(29)	242(254)	2.31
G.I. Illness (≥1)							
WWTP	21(14)	83(95)	170(158)	258(234)	118(140)	258(267)	17.38**
Control Loc.	34(34)	235(213)	203(220)	184(178)	20(27)	232(236)	8.35

[a] Number of individuals observed with number expected presented in parentheses.

* Significant at the 95% confidence level.

** Significant at the 99% confidence level.

TABLE 9. ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION IN NOVEMBER-APRIL DURING 1966 THROUGH 1971 (N=2843)

	Concentric Circle Boundary (m x 100)						
	6	12	18	24	30	>30	Information Statistic
Total Illness (≥2)							
WWTP	29(32)	200(216)	351(336)	390(371)	242(256)	479(480)	9.34
Control Loc.	78(69)	378(367)	395(402)	313(330)	62(63)	465(460)	6.09
Resp. Illness (≥2)							
WWTP	21(26)	155(169)	265(265)	313(294)	206(204)	378(381)	6.06
Control Loc.	63(54)	302(290)	304(317)	246(262)	48(50)	375(365)	6.89
G.I. Illness(≥1)							
WWTP	22(26)	165(176)	288(273)	322(302)	189(208)	388(390)	10.17
Control Loc.	55(56)	318(298)	333(327)	254(269)	48(51)	366(373)	5.01

[a] Number of individuals observed with number expected presented in parentheses.

ILLNESS INCIDENCE SPECIFYING SOCIOECONOMIC FACTORS

The distribution of the study population by education of household head is shown in figure 4. Data are available on 4877 of the 4889 study participants. A similar distribution for family income is illustrated in figure 5. There were fewer cooperative individuals for income disclosure, with data available on 3627 of the study participants. In general, persons living in wastewater treatment plant 600m boundary concentric circle had less education and lower incomes than in either the comparable control group or other wastewater treatment plant rings.

The education-and income-specific acute illness incidence in persons dwelling at varying distances from the wastewater treatment plant and control location was examined. The numbers of individuals experiencing four or more total, three or more respiratory,and one or more gastro-intestinal illnesses within education-specific groups residing in WWTP concentric rings are presented in table 10. Occurrence of all three illness classifications was significantly different between these circles at the 99% level of confidence among families in the least educated group. No differences, however, were found among intermediate and higher educated families for any illness classification. As shown in table 11, no significant education-specific illness differences were observed between individuals dwelling at specified distances from the control location. Significant illness differences were, however, seen in both the WWTP and control location concentric rings when income was specified. The most significant differences were seen at the lowest income level in the WWTP population for total and respiratory illnesses (table 12) and in the control group for all three illnesses in this low income group (table 13). In addition, differences in income-specific total illness incidence were seen in the WWTP population with intermediate income.

Education-specific illnesses during the warmer months showed significant differences among the WWTP populations for total and gastrointestinal illnesses in the lowest educated group but no significant differences were detectable at other education levels (table 14) nor at any level in the control population (table 15). As seen in table 16, significant differences in income-specific illnesses were only observed in the WWTP study population for total illnesses at the intermediate income level. Conversely, income-specific respiratory and gastrointestinal illnesses were seen in the lowest income group in the control population (table 17) but not in other groups.

As indicated in table 18, during November through April, significant differences were seen within the lowest educational group for total and gastrointestinal illness classifications. During this same period, significant education-specific illness differences, relative to dwelling unit distance from the control location, were only seen for gastrointestinal illness, and then only in the most educated group (table 19). Income-specific illnesses during the colder months showed significant differences between WWTP groups only at the low income level for respiratory illnesses

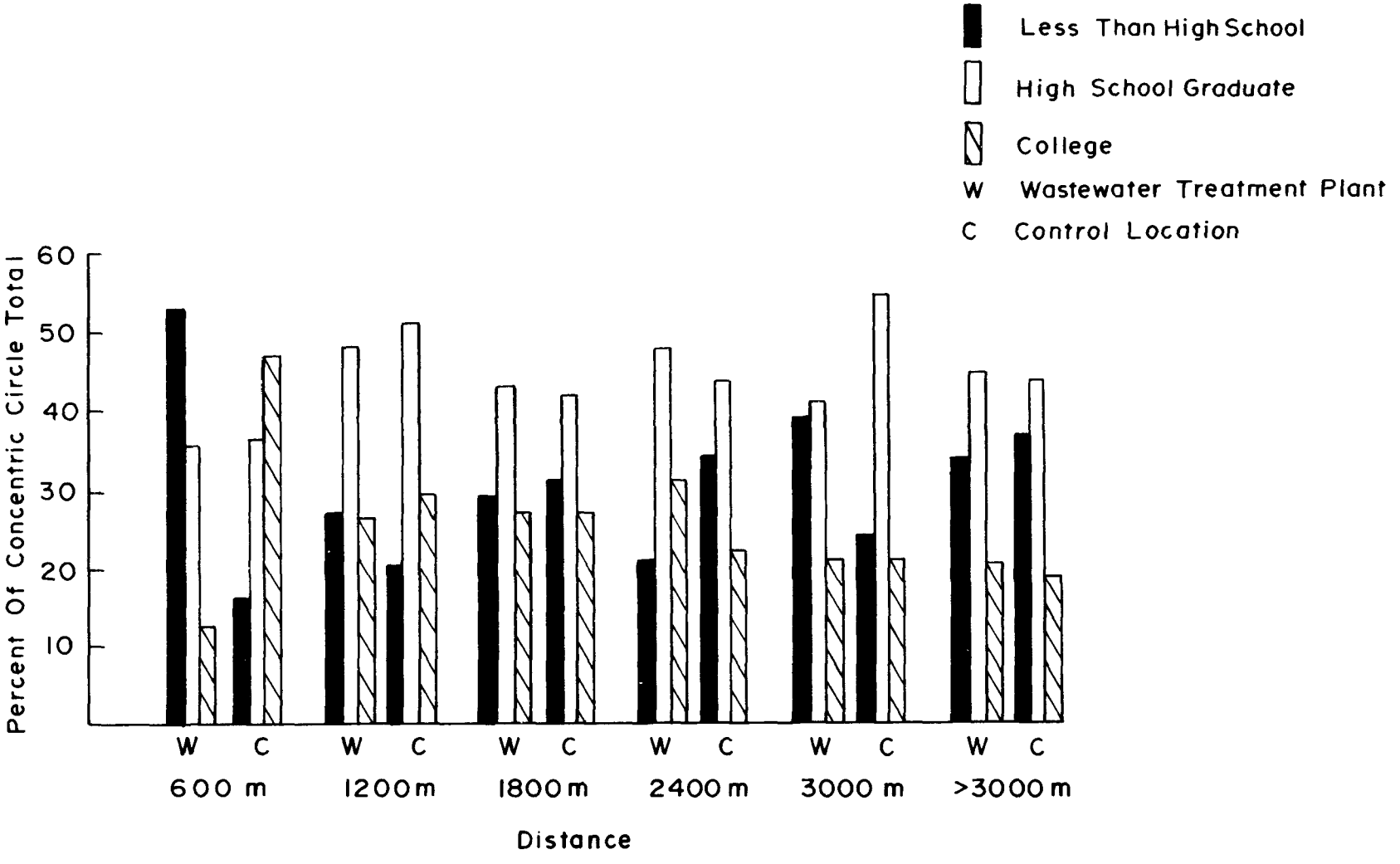

FIGURE 4. Education of household head by distance from wastewater treatment plant and control location.

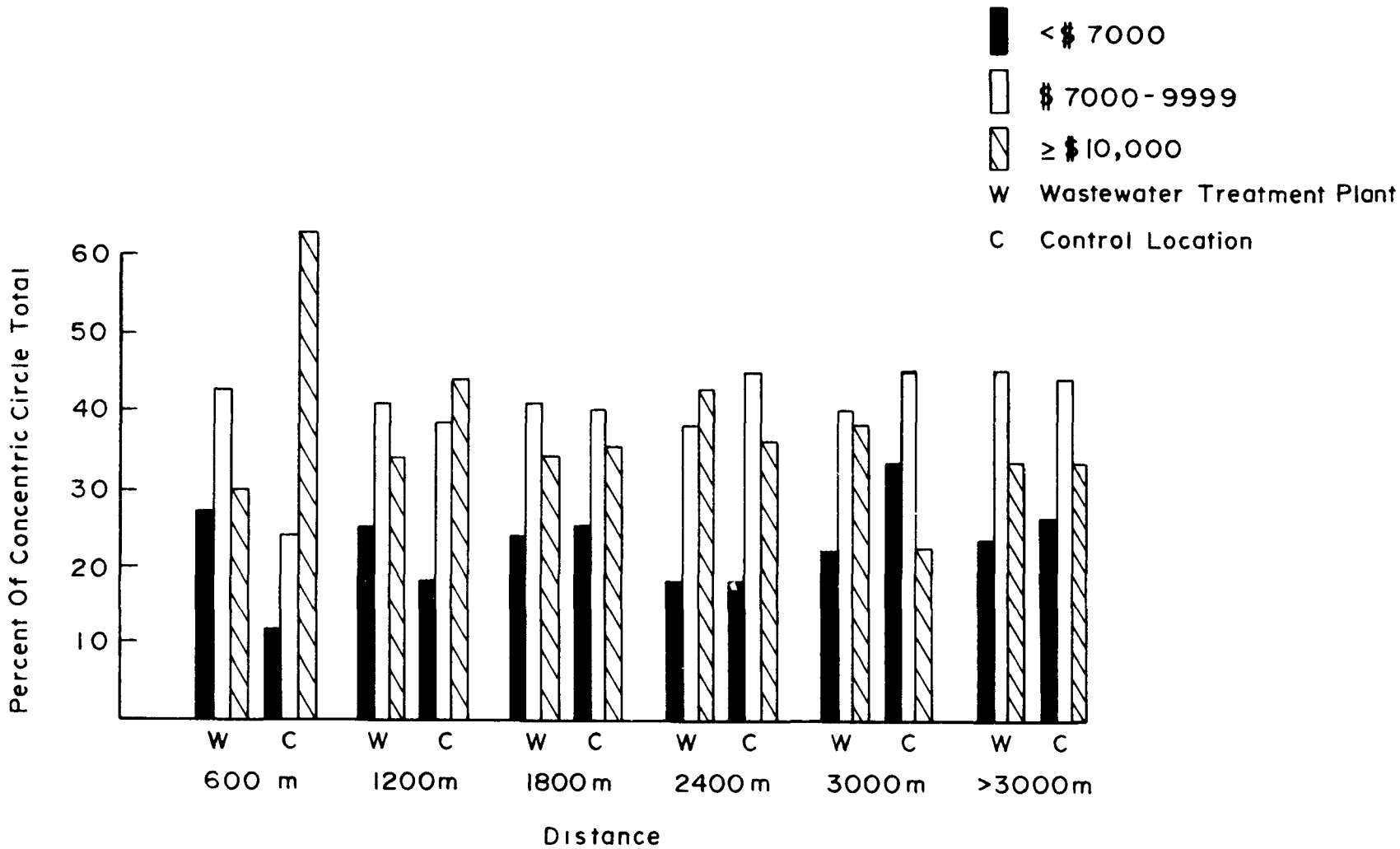

FIGURE 5. Annual family income by distance from wastewater treatment plant and control location.

TABLE 10. EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT FOR POPULATION ON REPORT 50 OR MORE WEEKS DURING 1965-1971 (N=4877)

Education of Household Head	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Less than High School Diploma	Total (≥4)	20 (18)[a]	45 (50)	97 (100)	123 (88)	65 (99)	183 (177)	41.59**
	Respiratory (≥3)	24 (20)	49 (55)	106 (109)	125 (98)	69 (110)	212 (193)	44.50**
	G.I. (≥1)	23 (24)	67 (72)	154 (140)	147 (129)	118 (141)	239 (242)	17.11**
High School Diploma	Total (≥4)	9 (12)	120 (128)	202 (196)	291 (287)	157 (150)	306 (312)	3.33
	Respiratory (≥3)	12 (13)	130 (132)	206 (202)	292 (296)	160 (155)	319 (321)	0.73
	G.I. (≥1)	19 (16)	155 (157)	244 (240)	352 (348)	175 (180)	373 (377)	2.43
Some College or College Degree	Total (≥4)	4 (5)	69 (82)	143 (137)	199 (204)	92 (81)	170 (168)	9.77
	Respiratory (≥3)	4 (5)	74 (82)	135 (137)	205 (203)	90 (81)	167 (166)	4.76
	G.I. (≥1)	7 (6)	85 (92)	161 (156)	230 (232)	101 (91)	179 (185)	5.52

[a] Number of individuals observed with number expected in parentheses.

** Significant at the 99% confidence level.

TABLE 11. EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION FOR POPULATION ON REPORT 50 OR MORE WEEKS DURING 1965-1971 (N=4877)

Education of Household Head	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Less than High School Diploma	Total (≥4)	14(12)[a]	81(80)	140(135)	112(118)	8(12)	178(175)	3.83
	Respriatory(≥3)	15(13)	85(87)	152(148)	113(131)	10(14)	210(192)	9.26
	G.I. (≥1)	17(17)	116(112)	193(190)	171(169)	17(18)	234(242)	1.08
High School Diploma	Total (≥4)	35(31)	277(280)	237(242)	198(206)	45(43)	293(283)	2.85
	Respiratory(≥3)	38(32)	281(290)	251(250)	211(213)	42(43)	296(291)	2.66
	G.I. (≥1)	41(39)	328(340)	313(296)	234(250)	52(51)	350(341)	7.07
Some College or College Degree	Total (≥4)	40(44)	179(174)	173(176)	123(119)	18(19)	144(145)	1.74
	Respiratory(≥3)	45(45)	178(174)	165(176)	124(119)	24(19)	139(143)	6.31
	G.I. (≥1)	50(53)	209(197)	196(199)	140(135)	14(21)	154(158)	9.64

[a] Number of individuals observed with number expected in parentheses.

TABLE 12. INCOME-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT FOR POPULATION ON REPORT 50 OR MORE WEEKS DURING 1965-1971 (N=3627)

Family Income	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
<$7000	Total (≥4)	9 (9)[a]	47 (56)	100 (94)	111 (95)	53 (63)	114 (117)	13.60*
	Respiratory (≥3)	10 (9)	51 (57)	94 (95)	116 (97)	57 (64)	113 (120)	13.92*
	G.I. (≥1)	12 (10)	62 (69)	115 (114)	126 (117)	74 (76)	144 (146)	5.87
$7000 $9999	Total (≥4)	13 (13)	72 (81)	140 (145)	207 (188)	96 (111)	239 (230)	11.28*
	Respiratory (≥3)	12 (13)	86 (84)	140 (149)	204 (193)	97 (114)	251 (236)	10.52
	G.I. (≥1)	17 (15)	93 (99)	166 (172)	237 (222)	123 (127)	266 (266)	4.91
≥$10,000	Total (≥4)	3 (5)	67 (63)	106 (104)	183 (185)	77 (83)	145 (141)	3.43
	Respiratory (≥3)	6 (6)	67 (66)	108 (109)	193 (195)	78 (88)	160 (148)	3.79
	G.I. (≥1)	8 (8)	80 (79)	145 (133)	236 (238)	92 (109)	186 (179)	8.64

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

TABLE 13. INCOME-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION FOR POPULATION ON REPORT 50 OR MORE WEEKS DURING 1965-1971 (N=3627)

Family Income	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
<$7000	Total (≥4)	8(10)[a]	109(84)	107(127)	74(74)	19(16)	117(123)	29.26**
	Respiratory (≥3)	10(11)	104(84)	113(130)	76(74)	20(17)	118(125)	19.35**
	G.I. (≥1)	7(12)	113(99)	146(157)	93(91)	19(20)	155(154)	15.56**
$7000 - $9999	Total (≥4)	13(15)	160(160)	195(190)	160(171)	22(24)	217(207)	3.74
	Respiratory(≥3)	15(16)	158(164)	207(196)	157(176)	27(25)	226(213)	8.55
	G.I. (≥1)	19(20)	187(189)	236(224)	198(201)	21(27)	241(241)	5.44
≥$10,000	Total (≥4)	42(38)	148(153)	149(140)	118(115)	5(9)	119(126)	6.19
	Respiratory(≥3)	45(41)	158(162)	150(147)	122(121)	4(9)	133(131)	7.17
	G.I. (≥1)	55(51)	190(197)	188(180)	145(149)	17(11)	152(159)	10.64

[a] Number of individuals observed with number expected in parentheses.

** Significant at the 95% confidence level.

TABLE 14. EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT DURING MAY-OCTOBER, 1966-1971 (N=3023)

Education of Household Head	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Less than High School Diploma	Total (≥2)	12 (7)[a]	22 (21)	41 (48)	51 (41)	51 (62)	107 (105)	14.31*
	Respiratory (≥2)	8 (5)	18 (15)	29 (36)	37 (29)	36 (44)	78 (77)	9.48
	G.I. (≥1)	9 (5)	17 (16)	40 (38)	35 (31)	31 (46)	84 (81)	11.53*
High School Diploma	Total (≥2)	6 (8)	57 (69)	111 (111)	185 (171)	86 (88)	174 (171)	7.03
	Respiratory (≥2)	5 (8)	46 (52)	87 (84)	142 (130)	64 (67)	124 (130)	3.81
	G.I. (≥1)	8 (6)	40 (50)	83 (80)	135 (121)	58 (63)	118 (122)	7.66
Some College or College Degree	Total (≥2)	6 (5)	41 (48)	64 (66)	128 (125)	47 (42)	96 (97)	3.82
	Respiratory (≥2)	6 (4)	35 (37)	50 (52)	96 (97)	35 (33)	78 (77)	2.40
	G.I. (≥1)	4 (3)	26 (31)	47 (42)	85 (80)	29 (27)	55 (64)	5.18

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

TABLE 15. EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION DURING MAY-OCTOBER, 1966-1971 (N=3023)

Education of Household Head	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Less than High School Diploma	Total (≥2)	7(5)[a]	40(39)	75(75)	52(59)	3(3)	107(102)	2.89
	Respiratory(≥2)	6(3)	32(29)	50(54)	36(43)	3(2)	79(75)	5.30
	G.I. (≥1)	5(3)	35(30)	51(57)	46(45)	1(3)	78(78)	4.20
High School Diploma	Total (≥2)	15(15)	173(170)	146(141)	104(121)	21(22)	160(149)	6.13
	Respiratory(≥2)	12(11)	127(129)	113(106)	87(92)	17(17)	112(113)	1.20
	G.I. (≥1)	13(10)	126(121)	91(100)	89(86)	12(16)	111(107)	4.52
Some College or College Degree	Total (≥2)	31(32)	94(95)	102(97)	78(72)	13(12)	64(75)	5.04
	Respiratory(≥2)	21(24)	77(74)	73(76)	67(57)	11(10)	51(59)	6.16
	G.I. (≥1)	16(20)	71(61)	61(62)	49(47)	6(8)	43(49)	5.70

[a] Number of individuals observed with number expected in parentheses.

TABLE 16. INCOME-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT DURING MAY-OCTOBER, 1966-1971 (N=2285)

Family Income	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
<$7000	Total (≥2)	8 (6)[a]	20 (23)	53 (57)	55 (52)	34 (34)	75 (72)	3.26
	Respiratory (≥2)	7 (5)	17 (18)	41 (44)	47 (39)	26 (26)	49 (56)	6.28
	G.I. (≥1)	8 (4)	15 (17)	41 (43)	36 (38)	22 (24)	56 (52)	5.55
$7000 - $9999	Total (≥2)	3 (5)	53 (57)	66 (63)	139 (123)	52 (67)	145 (143)	13.74*
	Respiratory (≥2)	2 (4)	45 (44)	51 (49)	104 (96)	38 (52)	117 (112)	10.27
	G.I. (≥1)	6 (4)	34 (40)	53 (44)	95 (85)	39 (46)	92 (99)	9.95
≥$10,000	Total (≥2)	3 (2)	24 (32)	52 (55)	123 (109)	46 (52)	82 (80)	8.31
	Respiratory (≥2)	3 (1)	17 (23)	37 (40)	92 (80)	30 (37)	61 (58)	9.84
	G.I. (≥1)	2 (1)	18 (22)	43 (38)	84 (77)	33 (36)	53 (58)	4.71

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

TABLE 17. INCOME-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION DURING MAY-OCTOBER, 1966-1971 (N=2285)

Family Income	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
<$7000	Total (≥2)	4(5)[a]	60(49)	59(69)	44(42)	5(6)	73(74)	8.55
	Respiratory(≥2)	4(3)	54(39)	43(52)	31(32)	5(5)	50(56)	14.42*
	G.I. (≥1)	2(3)	41(37)	41(49)	40(31)	1(4)	53(53)	11.94*
$7000 - $9999	Total (≥2)	13(10)	101(99)	122(118)	88(102)	13(13)	121(118)	5.91
	Respiratory(≥2)	10(7)	78(77)	89(91)	74(80)	12(10)	94(91)	2.90
	G.I. (≥1)	4(7)	79(68)	74(82)	71(70)	7(9)	84(82)	6.60
≥$10,000	Total (≥2)	23(24)	92(90)	92(80)	55(66)	1(3)	67(67)	8.71
	Respiratory(≥2)	16(17)	65(65)	65(58)	46(48)	0(2)	48(49)	7.16
	G.I. (≥1)	17(16)	68(63)	61(56)	43(46)	1(2)	43(48)	4.16

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

TABLE 18. EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT DURING NOVEMBER-APRIL, 1966-1971 (N=2831)

Education of Household Head	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Less than High School Diploma	Total (≥2)	17 (18)[a]	54 (58)	95 (92)	86 (74)	55 (73)	143 (136)	14.72*
	Respiratory (≥2)	13 (14)	35 (42)	67 (70)	66 (56)	45 (55)	116 (104)	10.79
	G.I. (≥1)	10 (14)	42 (47)	81 (75)	76 (60)	41 (60)	116 (110)	22.49**
High School Diploma	Total (≥2)	12 (13)	96 (95)	136 (129)	171 (173)	109 (110)	223 (228)	1.45
	Respiratory (≥2)	8 (10)	76 (75)	107 (103)	138 (137)	91 (88)	173 (180)	1.60
	G.I. (≥1)	12 (10)	83 (78)	111 (105)	134 (142)	86 (91)	187 (186)	3.25
Some College or College Degree	Total (≥2)	0 (0)	50 (60)	118 (114)	129 (128)	78 (70)	113 (116)	8.44
	Respiratory (≥2)	0 (0)	44 (49)	89 (92)	105 (102)	70 (59)	89 (95)	7.41
	G.I. (≥1)	0 (0)	40 (48)	95 (90)	108 (103)	62 (56)	85 (93)	6.74

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

** Significant at the 99% confidence level.

TABLE 19. EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION DURING NOVEMBER-APRIL, 1966-1971 (N=2831)

Education of Household Head	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Less than High School Diploma	Total (≥2)	10(9)	64(74)	113(107)	108(111)	13(13)	142(135)	4.66
	Respiratory(≥2)	7(7)	51(56)	82(80)	79(85)	6(10)	117(103)	6.77
	G.I. (≥1)	10(7)	57(61)	91(87)	90(90)	13(11)	105(110)	3.77
High School Diploma	Total (≥2)	32(29)	167(163)	170(168)	114(126)	38(39)	226(222)	4.26
	Respiratory(≥2)	26(23)	135(130)	127(134)	91(99)	32(31)	182(176)	3.72
	G.I. (≥1)	23(24)	133(134)	152(137)	88(105)	31(32)	186(182)	9.02
Some College or College Degree	Total (≥2)	36(34)	141(129)	112(126)	91(88)	11(11)	97(100)	8.75
	Respiratory((≥2)	30(27)	110(104)	95(102)	76(73)	10(10)	76(82)	3.88
	G.I. (≥1)	22(27)	123(103)	90(101)	76(70)	4(9)	75(80)	20.42**

[a] Number of individuals observed with number expected in parentheses.

** Significant at the 99% condidence level.

(table 20). In the population radiating from the control location, income-specific illness differences during this colder period were seen only for gastrointestinal illnesses in the low and high income groups (table 21).

Because of the additive characteristic of the information statistic, summation of education-and income-specific illnesses by distance from the wastewater treatment plant and control location was performed. Summations over the entire study period are presented in tables 22 and 23 for individuals dwelling within WWTP and control location concentric rings. Significant differences in the population surrounding the WWTP were seen for all illness categories except income-specific gastrointestinal illnesses. On the other hand, income-specific but not education-specific illness differences were seen in the population surrounding the control site.

The summation of income-and education-specific illnesses during the warmer months for both study groups is presented in table 24 and 25. Income and education-specific differences in total illnesses were seen in individuals residing in rings radiating from the WWTP but not in those studied with respect to the control site. Income-specific respiratory illness occurrences were found to be significantly different only in the WWTP study group.

Tables 26 and 27 show the summation of income-and education-specific illnesses during the colder months in both study groups. Education-specific differences in gastrointestinal illnesses were seen in both the WWTP and control location groups. Income-specific differences in respiratory illness occurrences were only seen in the WWTP group whereas income-specific gastrointestinal illness occurrence differences were seen only in the control site group.

For illustrative purposes, the percent differences of the summed income-and education-specific illnesses observed over the number expected by distance from the wastewater treatment plant and control location are presented in tables 28 and 29. For both income-and education-specific illnesses, the number observed in the WWTP study population exceeded those expected by the greatest amount in the 600m concentric circle during the warmer months for respiratory and gastrointestinal illnesses. Respiratory illnesses exceeded those expected by 20% and 27% whereas gastrointestinal illnesses exceeded those expected by 78% and 50% when specified for income and education, respectively. Differences of this magnitude were not observed during the colder months nor during the entire study period.

Greater than the expected number of illnesses were consistently observed within the 2400m WWTP concentric ring for all income-and education-specific illnesses during the warmer and colder months as well as during the entire study period. Within the control location concentric rings, greater than expected illness occurrences were most consistently observed at the 1200m distance. During both the warmer and colder months, the expected number of income and education specific illnesses was exceeded in all categories. It is noteworthy that, in many cases, the dwelling units included in the WWTP 2400m concentric ring were identical to those in the 1200m control ring.

TABLE 20. INCOME-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT DURING NOVEMBER-APRIL, 1966-1971 (N=2086)

Family Income	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
<$7000	Total (≥2)	4 (3)[a]	43 (49)	71 (69)	64 (58)	35 (33)	53 (59)	8.81
	Respiratory (≥2)	4 (2)	29 (38)	56 (56)	51 (47)	34 (26)	41 (46)	15.32**
	G.I. (≥1)	2 (2)	35 (39)	56 (57)	56 (48)	27 (27)	46 (48)	3.91
$7000 - $9999	Total (≥2)	14 (13)	40 (47)	104 (109)	117 (106)	72 (75)	167 (165)	6.80
	Respiratory (≥2)	9 (10)	35 (37)	75 (87)	94 (84)	58 (61)	142 (134)	7.35
	G.I. (≥1)	9 (10)	35 (40)	90 (89)	101 (88)	55 (62)	134 (136)	6.58
≥$10,000	Total (≥2)	4 (5)	69 (63)	86 (82)	137 (139)	60 (69)	124 (122)	5.58
	Respiratory (≥2)	3 (4)	55 (48)	64 (62)	107 (107)	48 (53)	91 (94)	2.91
	G.I. (≥1)	4 (4)	54 (52)	70 (66)	109 (113)	43 (56)	109 (99)	9.17

[a] Number of individuals observed with number expected in parentheses.

** Significant at the 99% confidence level.

TABLE 21. INCOME-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION DURING NOVEMBER-APRIL, 1966-1971 (N=2086)

Family Income	Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
								Control
<$7000	Total (≥2)	5(6)[a]	62(51)	87(89)	44(47)	12(14)	60(64)	8.53
	Respiratory(≥2)	5(5)	53(42)	59(70)	38(37)	12(11)	48(50)	10.48
	G.I. (≥1)	4(5)	56(43)	79(73)	27(38)	8(12)	48(51)	20.00**
$7000 - $9999	Total (≥2)	9(9)	97(94)	135(129)	101(108)	12(12)	160(162)	2.38
	Respiratory(≥2)	5(7)	73(74)	109(104)	80(87)	11(10)	135(131)	2.73
	G.I. (≥1)	7(8)	88(77)	116(107)	86(90)	7(10)	120(132)	9.00
≥$10,000	Total (≥2)	52(45)	106(107)	93(102)	104(106)	13(10)	112(110)	7.16
	Respiratory(≥2)	43(35)	81(82)	72(78)	81(81)	5(8)	86(84)	6.81
	G.I. (≥1)	36(37)	78(86)	78(83)	90(86)	16(8)	91(89)	23.59**

[a] Number of individuals observed with number expected in parentheses.

**Significant at the 99% confidence level.

TABLE 22. SUMMATION OF INCOME-AND EDUCATION-SPECIFIC ILLNESS DURING STUDY PERIOD BY DISTANCE FROM WASTEWATER TREATMENT PLANT

Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Income							
Total (≥4)	25 (27)[a]	186 (199)	346 (342)	501 (469)	226 (258)	498 (487)	28.31*
Respiratory (≥3)	28 (28)	204 (206)	342 (354)	513 (487)	232 (266)	524 (502)	28.22*
G.I. (≥1)	37 (33)	235 (247)	426 (420)	599 (579)	289 (313)	596 (590)	19.42
Education							
Total (≥4)	33 (38)	234 (255)	442 (430)	613 (566)	314 (342)	659 (664)	54.69**
Respiratory (≥3)	40 (39)	253 (265)	447 (446)	622 (588)	319 (354)	698 (686)	49.98**
G.I. (≥1)	49 (48)	307 (319)	559 (534)	729 (702)	394 (418)	791 (808)	25.06*

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

** Significant at the 99% confidence level.

TABLE 23. SUMMATION OF INCOME-AND EDUCATION-SPECIFIC ILLNESS DURING STUDY PERIOD BY DISTANCE FROM CONTROL LOCATION

Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Income							
Total (≥4)	63(65)[a]	417(399)	451(456)	352(360)	46(48)	453(454)	39.19**
Respiratory (≥3)	70(69)	420(413)	470(472)	355(373)	51(50)	477(467)	35.07**
G.I.(≥1)	81(84)	490(488)	570(559)	436(443)	57(58)	548(550)	31.64**
Education							
Total (≥4)	89(83)	537(523)	550(551)	433(450)	71(73)	615(614)	8.43
Respiratory (≥3)	98(87)	544(542)	568(572)	448(467)	76(75)	645(635)	18.23
G.I. (≥1)	108(106)	653(643)	702(686)	545(558)	83(89)	738(748)	17.78

[a] Number of individuals observed with number expected in parentheses.

**Significant at the 99% confidence level.

TABLE 24. SUMMATION OF INCOME-AND EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT DURING MAY-OCTOBER

Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Income							
Total (≥2)	14 (14)[a]	97 (112)	171 (177)	317 (285)	132 (152)	302 (293)	25.32*
Respiratory (≥2)	12 (10)	79 (84)	129 (134)	243 (216)	94 (116)	227 (223)	26.38*
G.I. (≥1)	16 (9)	67 (79)	137 (125)	215 (200)	94 (108)	201 (208)	20.21
Education							
Total (≥2)	24 (20)	120 (135)	216 (224)	364 (331)	184 (198)	377 (377)	25.16*
Respiratory (≥2)	19 (15)	99 (102)	166 (170)	275 (250)	135 (150)	280 (288)	15.69
G.I. (≥1)	21 (14)	83 (95)	170 (158)	255 (232)	118 (139)	257 (266)	24.37

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

TABLE 25. SUMMATION OF INCOME-AND EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION DURING MAY-OCTOBER

Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Income							
Total (≥2)	40(39)[a]	253(241)	273(265)	187(210)	19(21)	261(257)	23.16
Respiratory (≥2)	30(29)	197(184)	197(201)	151(159)	17(16)	192(196)	24.48
G.I. (≥1)	23(28)	188(170)	176(187)	154(148)	9(15)	180(183)	22.70
Education							
Total (≥2)	53(48)	307(301)	323(313)	234(254)	37(36)	331(333)	14.06
Respiratory (≥2)	39(36)	236(230)	236(236)	190(192)	31(27)	242(253)	12.66
G.I. (≥1)	34(34)	232(211)	203(220)	184(178)	19(26)	232(235)	14.41

[a] Number of individuals observed with number expected in parentheses.

TABLE 26. SUMMATION OF INCOME-AND EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM WASTEWATER TREATMENT PLANT DURING NOVEMBER-APRIL

Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Income							
Total (≥2)	22 (20)[a]	152 (159)	261 (261)	318 (305)	167 (176)	344 (343)	21.20
Respiratory (≥2)	16 (16)	119 (124)	195 (206)	253 (238)	140 (141)	274 (270)	25.59*
G.I. (≥1)	15 (16)	124 (130)	216 (214)	266 (250)	125 (145)	289 (281)	19.65
Education							
Total (≥2)	29 (32)	200 (214)	349 (333)	386 (369)	242 (256)	479 (481)	24.60
Respiratory (≥2)	21 (26)	155 (167)	263 (263)	309 (291)	206 (204)	378 (381)	19.80
G.I. (≥1)	22 (26)	165 (174)	287 (271)	318 (300)	189 (208)	388 (390)	32.48**

[a] Number of individuals observed with number expected in parentheses.

* Significant at the 95% confidence level.

** Significant at the 99% confidence level.

TABLE 27. SUMMATION OF INCOME-AND EDUCATION-SPECIFIC ILLNESS BY DISTANCE FROM CONTROL LOCATION DURING NOVEMBER-APRIL

Illness	Concentric Circle Boundary (m x 100) 6	12	18	24	30	>30	Information Statistic
Income							
Total (≥2)	66(59)[a]	265(253)	315(322)	246(260)	37(37)	332(333)	18.07
Respiratory (≥2)	53(46)	207(199)	240(254)	199(205)	28(29)	269(262)	20.02
G.I. (≥1)	47(49)	222(208)	273(263)	203(213)	31(29)	259(273)	52.59**
Education							
Total (≥2)	78(69)	372(361)	395(400)	313(330)	62(63)	465(461)	17.67
Respiratory (≥2)	63(54)	296(285)	304(315)	246(262)	48(50)	375(366)	14.36
G.I. (≥1)	55(56)	313(294)	333(325)	254(269)	48(51)	366(374)	33.21**

[a] Number of individuals observed with number expected in parentheses.

** Significant at the 99% confidence level.

TABLE 28. PERCENT DIFFERENCE OF SUMMED INCOME-SPECIFIC ILLNESSES OBSERVED OVER NUMBER EXPECTED BY DISTANCE FROM WASTEWATER TREATMENT PLANT AND CONTROL LOCATION

Illness	Concentric Circle Boundary (m x 100) 6 W[a]	6 C	12 W	12 C	18 W	18 C	24 W	24 C	30 W	30 C	>30 W	>30 C
Study Period												
Total (≥4)	-7	-3	-7	5	1	-1	7	-2	-12	-4	2	0
Respiratory (≥3)	0	1	-1	2	-3	0	5	-5	-13	2	4	2
G.I. (≥1)	12	4	-5	0	1	2	3	-2	- 8	-2	1	0
May-October												
Total (≥2)	0	3	-13	5	-3	3	11	-11	-13	-10	3	2
Respiratory (≥2)	20	3	- 6	7	-4	-2	13	- 5	-19	6	2	-2
G.I. (≥1)	78	-18	-15	11	10	-6	8	4	-13	-40	-3	-2
November-April												
Total (≥2)	10	12	- 4	5	0	-2	4	- 5	- 5	0	0	0
Respiratory (≥2)	0	15	- 4	4	-5	-6	6	- 3	- 1	- 3	1	3
G.I. (≥1)	-6	-4	- 5	7	1	4	6	- 5	-14	7	3	-5

[a] Concentric circles radiating from WWTP expressed by W and those indicating from control location expressed by C.

TABLE 29. PERCENT DIFFERENCE OF SUMMED EDUCATION-SPECIFIC ILLNESSES OBSERVED OVER NUMBER EXPECTED BY DISTANCE FROM WASTEWATER TREATMENT PLANT AND CONTROL LOCATION

	Concentric Circle Boundary (m x 100)											
	6		12		18		24		30		>30	
Illness	W[a]	C	W	C	W	C	W	C	W	C	W	C
Study Period												
Total (≥4)	-13	7	-8	3	3	0	8	-4	- 8	-3	-1	0
Respiratory (≥3)	3	13	-5	0	0	-1	6	-4	-10	1	2	2
G.I. (≥1)	2	2	-4	2	5	2	4	-2	- 6	-7	-2	-1
May-October												
Total (≥2)	20	10	-11	2	-4	3	10	-8	-7	3	0	-1
Respiratory (≥2)	27	8	- 3	3	-2	0	10	-1	-10	15	-3	-4
G.I. (≥1)	50	0	-13	10	8	-8	10	3	-15	-27	-3	-1
November-April												
Total (≥2)	- 9	13	- 7	3	5	-1	5	-5	- 5	-2	0	1
Respiratory (≥2)	-19	17	- 7	4	0	-3	6	-6	1	-4	-1	2
G.I. (≥1)	-15	- 2	- 5	6	6	2	6	-6	- 9	-6	-1	-2

[a] Concentric circles radiating from WWTP expressed by W and those radiating from control location expressed by C.

ILLNESS INCIDENCE IN SCHOOL CHILDREN

The illness experience of school children who were on report for 50 or more weeks during 1965-1971 was examined with respect to school location relative to the wastewater treatment plant or control location. The schools were not evenly distributed throughout the study area. As shown in table 30, most of the schools were contained in the 1800m or >3000m concentric circle boundaries, with one school located within 1200m of the wastewater treatment plant. Eight of the eleven schools examined shared the same WWTP and control location concentric ring. The experience of children having five or more total illnesses, four or more respiratory illnesses, or two or more gastrointestinal illnesses is shown in table 31. Significant differences in total illness experience were observed in the school children with regard to school attended relative to both the wastewater treatment plant and control location. Since schools are not in session during the summer months, no seasonal analyses were performed.

METEOROLOGY

The wind direction, velocity, and atmospheric stability greatly influence the dispersion of wastewater treatment plant airborne emissions (Kenline, 1968). Local data on these parameters were not available from the Tecumseh area for the study years. Wind velocity and direction frequency distribution summaries were, however, obtained for the Detroit Metropolitan Airport, located approximately 60 miles east of Tecumseh for the years 1969-1973. Although these data are not inclusive of the study dates, they do indicate wind trends in the area over a four year period. Figure 6 is a wind rose presentation of these data. Prevailing winds of the highest velocity are from the west, but there is substantial fluctuation in both direction and velocity. Depending upon the atmospheric stability, wastewater treatment emissions could be dispersed in any direction. Meteorological data by individual study period seasons or years were not obtainable for this study.

TABLE 30. STUDY AREA SCHOOLS AND LOCATION RELATIVE TO WASTEWATER TREATMENT PLANT AND CONTROL LOCATION

School	Concentric Circle Boundary (m) WWTP	Control Location
Herrick Park	1200	2400
Patterson	1800	1200
St. Elizabeth	1800	1200
Tecumseh Acres	1800	1800
Tecumseh Nursery	1800	1800
West Branch	1800	1800
Macon	>3000	>3000
Ridgeway	>3000	>3000
Sutton	>3000	>3000
Tipton	>3000	>3000
Stevens Lutheran	>3000	>3000

Table 31. ILLNESS IN CHILDREN ON REPORT 50 OR MORE WEEKS BY DISTANCE OF SCHOOL ATTENDED FROM WASTEWATER TREATMENT PLANT OR CONTROL LOCATION DURING 1965-1971 (N=1077)

	Concentric Circle Boundary (m x 100)[a]					
	12	18	24	>30	Information Statistic	d.f.
Total Illness (≥5)						
WWTP	57 (72)[b]	338 (334)	[c]	112 (102)	8.15*	2
Control Loc.	208 (195)	130 (139)	57 (72)	112 (101)	10.69*	3
Resp. Illness (≥4)						
WWTP	54 (66)	302 (299)	[c]	99 (91)	5.23	2
Control Loc.	177 (175)	125 (124)	54 (66)	99 (91)	5.24	3
G.I. Illness (≥2)						
WWTP	47 (58)	289 (279)	[c]	86 (85)	4.41	2
Control Loc.	181 (163)	108 (116)	47 (58)	86 (85)	7.74	3

[a] No schools located in concentric circles with 600 and 3000m boundaries.

[b] Number of individuals observed with number expected presented in parentheses.

[c] No school located in this category.

* Significant at the 95% confidence level.

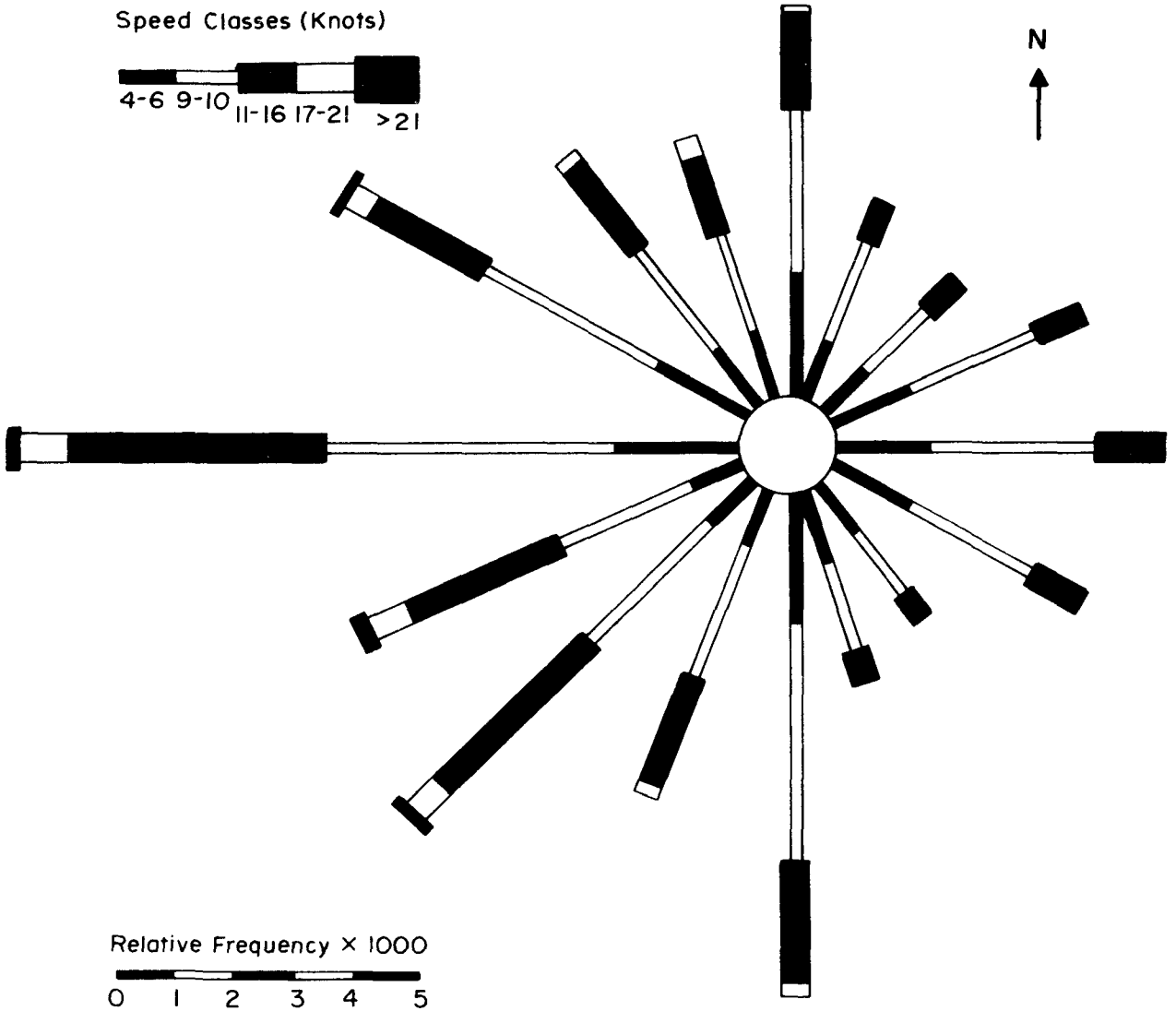

FIGURE 6. Wind rose for Detroit Metropolitan Airport, 1969-1973.

SECTION 6

DISCUSSION

The Tecumseh, Michigan wastewater treatment plant is small relative to those which serve larger metropolitan areas. This plant was selected for use in this investigation because of its location within a comprehensive community health study area and because it was not considered to be uniquely different from activated sludge plants serving comparably sized communities. Consequently, the observations made in this study should not be considered unique to Tecumseh but to represent those made with the participation of a highly cooperative community.

Attribution of acute illness occurrence within a population to a single source, such as wastewater treatment plant aerosol emissions, is a difficult problem compounded by many factors. The exposure and potential for infection (EPI) probability of a population to the airborne emissions of a wastewater treatment plant is dependent upon the concentration, survival, and dispersion of aerosolized infectious organisms. The concentrations of potentially infectious organisms in the Tecumseh sewage during the study period are not available. Domestic sewage should, however, be assumed to contain any material excreted by the contributing community which survives transport to the wastewater treatment facility. Potentially pathogenic bacteria and viruses are among the organisms known to occur in domestic wastewater (Kabler, 1959; Grabow, 1968). Studies on the airborne emissions of bacteria from wastewater treatment plants have been reviewed by Hickey and Reist (1975), but conclusive studies concerning viral emissions from these plants have, however, been hampered by limitations in methodology, although enteric viruses have reportedly been recovered from wastewater spray irrigation aerosols (Johnson *et al.* 1977; Teltsch and Katzenelson, 1978). While the aerosols from the Tecumseh plant were not characterized as part of this study, it is reasonable to assume that this plant does emit aerosols containing potentially infectious organisms, as has been observed with the other activated sludge plants studied.

The significance of exposure to infectious aerosols is related to the susceptibility, size, and density of the population. All persons exposed will not develop infection and many infected individuals will not develop disease. With the enteroviruses, for example, the ratio of infection to clinical illness is very high. Such considerations make it difficult to determine sources of infection and resulting illnesses when they occur. Such determinations require examination of a sufficiently

large population with subgroups sharing similar exposure probabilities. In this study, acute illness occurrences in 4889 people, living at six different general locations from a wastewater treatment plant and control location were observed over a seven year period.

More than the expected number of persons living closest to the wastewater treatment plant (within 600m) appeared to experience income-and education-specific respiratory and gastrointestinal illnesses during May through October. This experience was not found in the control groups nor in those persons observed in WWTP concentric rings during the entire study period or from November through April. As seen in figures 4 and 5, persons dwelling within 600m of the wastewater treatment plant had both less education and lower incomes than those dwelling in either the concentric rings at greater distances from the plant or in those rings radiating from the control location. The larger than expected number of persons developing illnesses nearest the wastewater treatment plant during the summer may be attributable to reduced levels of sanitation within a lower socioeconomic group during a period of higher enterovirus infection incidence. Melnick *et al.* (1954) demonstrated the seasonal distribution of enteroviruses while Monto and Cavallaro (1971) confirmed a higher late summer incidence of enteroviral infection in the Tecumseh study population.

Higher than expected illness occurrences were made during both seasons and the entire study period in the least educated and lowest income population dwelling within the wastewater treatment plant concentric ring with 2400m boundary. Since both income and education were specified in this study, these observations cannot be explained on the basis of socioeconomic factors.

The WWTP population dwelling within the 2400m concentric ring was found to have a consistently greater than expected incidence of all education-and income-specific illnesses during the entire study period as well as during the colder and warmer seasons. Furthermore, the control concentric ring showing the most consistent greater than expected illness incidence is at the 1200m distance that partly overlaps the 2400m WWTP ring. The reasons for the greater illness incidence within this group are not readily explainable with available evidence. As shown in figures 4 and 5, persons dwelling within the 2400m concentric ring had both a slightly higher education and income than did comparison control populations. There are no known sources of exposure in these areas which would increase the likelihood of increased acute illness.

The dispersion of biological emissions from activated sludge treatment plants has been estimated by various investigators (Kenline, 1968; Buchan, 1972; and Lighthart and Frisch, 1973). The models used for predicting downwind concentrations of these emissions were based upon Pasquill's model as described by Turner (1967). The Tecumseh wastewater treatment plant aerosol emissions may, however, behave differently than might be predicted with previously employed models based upon the

theoretical diffusion equations. The plant is located at a lower elevation than the portions of the study area containing most of the population and is surrounded on the east, south, and west by deciduous trees. Although the activated sludge units were treated as zero height emission sources in predictive models, local airflow disturbances as might occur in the immediate vicinity of trees or other obstacles were not considered. Pasquill (1962) indicated that present methods of estimating diffusion are based upon idealized airflow conditions and that these methods cannot be expected to give reliable information when there are local disturbances of this airflow.

While the four year wind direction and velocity averages from the Detroit Metropolitan Airport illustrated in figure 6 indicate general area trends, the dispersion of emissions from the Tecumseh wastewater treatment plant is probably more affected by local conditions. Depending upon wind direction, velocity, and atmospheric stability, surrounding trees may act as a partial barrier for persons dwelling nearest the plant while lofting the airflow, resulting in further downwind dispersion.

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APPENDIX

GEOGRAPHICAL STRATA
(As described by Napier (1962)[a])

Stratum	
1	Area immediately surrounding Tecumseh city - mixed farm and non-farm.
2	Area outside stratum 1, but in the Tecumseh study area - mostly farm.
3	Northeast third of city - nice homes area (i.e. more expensive houses)
4	Southeast third of city - business district; older homes
5	Western third of city - newer homes; middle class

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[a] A sixth stratum was described by Napier to include scattered new construction found during 1959-1960 study.

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16. ABSTRACT

Data obtained as part of a comprehensive community health study conducted during 1965-1971 were utilized to examine the incidence of acute illness in a population surrounding an activated sludge wastewater treatment plant and a control location in Tecumseh, Michigan. Study participants were classified into concentric circles of approximately 600m each by dwelling unit distance from either site. School children were classified by school attended in a similar manner. The additive minimum discrimination information statistic was used to test for significant differences in the incidence of total, respiratory, and gastrointestinal illnesses among individuals dwelling within concentric circles.

Differences in illness incidence occurred from May through October at varying distances from the wastewater treatment plant and persons dwelling within 600m of this plant appeared to have a greater than expected risk of respiratory and gastrointestinal illness. The data do not, however, demonstrate a causal effect and factors other than the wastewater treatment plant, such as higher rates of illness transmission in areas of higher densities of lower socioeconomic families, could have contributed to these findings.

17. KEY WORDS AND DOCUMENT ANALYSIS		
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