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STUDIES OF IMPACTS OF URBAN-RELATED WEATHER AND CLIMATE CHANGES AT CHICAGO AND ST. LOUIS

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INTRODUCTION

The general goal of this 2-year research project was to utilize existing data bases and results from St. Louis and Chicago to develop a more definitive understanding of urban inadvertent precipitation modification. A principal value of the project relates to the comparison of available extensive St. Louis results with the results developed at Chicago in this project, leading to the ultimate goal of being able to predict anomalies and their impacts elsewhere.

This third volume of a 3-volume series focuses on the impact-related research of this project. Studies of the impacts of precipitation anomalies in the St. Louis area have dimensionalized some of the effects of altered weather on agricultural production, water resources, societal behavior, and institutional responses (Changnon et al., 1977; Sherretz and Farhar, 1978).

One of the specific objectives of this 2-year project was to "perform economic studies of the impacts of the precipitation anomalies in the Chicago area; to collect further data on the impacts of urban-related pollutants on soils and crops (in the areas downwind of St. Louis and Chicago), and to collect data on public attitudes and institutional responses at Chicago, all in relation to the urban modified precipitation." A long-range goal of the Chicago and St. Louis impact results studies has been to compare results so as to test the transferability of the more extensive St. Louis focused impacts analysis to Chicago, and potentially to other urban locales. At the start of this project, all available evidence had suggested that the precipitation anomaly at Chicago was larger and likely more intense (greater percentage changes in rainfall) than that at St. Louis. Thus, comparison of all Chicago results obtained with those at St. Louis would serve as a good test of the transferability, or extrapolation, of the well-defined impacts at St. Louis to other cities, particularly those where weather anomalies could be defined, either on the basis of climatological data or with numerical models.

The proposed studies of the impact phase of the project were aimed at three objectives: 1) study of crop response functions to help ascertain economic effects; 2) field studies east of St. Louis and Chicago (NW Indiana) to investigate the effects of pollutants on crops and soils; and 3) a survey of public impacts and responses to altered precipitation in Chicago and northwestern Indiana.

As in most research, once these studies had begun, changes in the research plan evolved based on the availability of data and new opportunities that developed for the research staff. The general goal of testing and comparing the St. Louis and Chicago results was retained. However, the research followed certain general directions.

First, research relating to rain impacts on the agricultural sector was pursued. Professor Steven Sonka of the Agricultural Economics Department of the University of Illinois, with graduate research assistants, pursued a study of the potential effects on crop yields in northwestern Indiana. This economically-focused study was complemented by a study (by Stanley Changnon) dealing with the potential impacts of the crop-hail losses (due to added hail) and the ensuing impact on the insurance industry and farmers.

A second phase of the work addresses some of the many water resource impacts that could be potentially identified. In particular, the potential urban-related increase in storm rainfall events and amounts in the Chicago region was investigated for its affect on local flooding, particularly that involving the operation of the very complex urban water resources network in Chicago. This study, performed by Stanley A. Changnon, Jr., suggests changes in hydrologic design values that affect operation of the Chicago urban water resource system. One study relating to the possible effects of added rainfall on the streamflow of the Kankakee River basin is still in progress and is not included in the volume.

After extensive discussions with Purdue soil scientists, it was determined that available analyses of pollutants in soils in northwest Indiana were sufficient to dimensionalize the impacts in that area. A literature study, coupled with discussions with agronomists and plant physiologists, indicated that the rainborne pollutants in the Chicago and St. Louis area were likely having insignificant or non-measurable effects on the cash grain crops beyond 1 to 3 km of the industrial area. Thus, the research relating to pollutants effects on soils and crops focused on the soil quality issue and in the area downwind (east) of St. Louis. The research in this area was conducted by Donald F. Gatz, Janyce Bartlett, and John J. Hassett.

A fourth area of impact-related research has concerned the weather impacts on certain activities and institutions in the Chicago and La Porte areas. In the Chicago metropolitan and rural areas the answers to the question, "What happens when it rains in Chicago?" have been examined, particularly regarding rain and storm effects on transportation, communications, and power systems. Influences of altered summer precipitation on the city services of La Porte were studied. This research was pursued by Jan Bertness.

Basically, the impact related research performed in this project has been more extensive than originally planned. It was often the case of new and unexpected data or findings leading to redirected research with considerable staff dedication to the challenges involved.

The impact studies discussed herein help to dimensionalize further this general area of study which sorely needs more information (CEM, 1977). In certain instances, the impacts findings have also helped define both the reality and the areal and temporal extent of the anomalous precipitation. Thus, the impacts studies have been doubly valuable. In general, the comparison of findings of St. Louis and Chicago has shown similarity, indicating a reasonable transferability of impact findings to other cities.

The report is organized into chapters written by the various investigators. The figures and tables in each capter are numbered according to that chapter such that each stands alone. Each chapter has its own summary and conclusions, and thus, there is no general summary to this volume.

In general, it can be stated that urban-induced anomalous precipitation has sizeable and definable impacts on water resource and agricultural activities, as well as on transportation and energy usage and services.

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ECONOMIC IMPACTS OF THE LA PORTE WEATHER ANOMALY

Steven T. Sonka*

Introduction

This study has focused on a small area of northwestern Indiana where historical weather records have indicated an anomalous behavior in warm season precipitation since about 1940 (Changnon, 1968; Changnon and Huff, 1977). Generally, summer rain and hail in this very localized area centered around La Porte (where the weather records are collected) have been 30 to 40 percent higher than in surrounding areas. Although the dominant pattern has reflected these large increases, rainfall differences in any year or group of years in the 1940-1977 period have varied from indistinguishable to quite large amounts.

An important factor relative to assessing the importance of a purported alteration in a region's weather is the effect of that change on the economy of the region. However, quantitatively estimating that effect is a difficult task. Several factors contribute to this difficulty.

A major factor is the natural variability associated with weather events. These normal variations make it difficult to assess the physical extent of the anomaly. This variability also serves to disguise the effects of longer-run weather changes and the economic reactions of area residents to altered weather events.

A second factor which makes assessment of economic tasks difficult is that people may not realize that their weather has been altered. If the change in weather has occurred over a number of years, economic reactions may also be gradual and hard to discern.

This report is divided into two parts. Because agriculture is a weather sensitive activity, impacts of altered weather on this sector are often most easily discernible. The first segment of this report attempts to determine the impact of the local precipitation anomaly on crop production in the La Porte area. The second part is a description of the La Porte area and the potential for economic impacts from altered weather in several parts of the region's economy.

Effects on Crop Production

Crop production is a significant contributor to economic activity in La Porte County and throughout northwestern Indiana. Crop production is an especially attractive variable to consider in relation to a purported rainfall change because of the strong relationship between crop yields and summer rainfall (Huff and Changnon, 1972).

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Table 1: Average annual summer precipitation (June, July and August), 1907-76.

	Average annual rainfall (inches)		
Time period	La Porte	Valpariso	South Bend
1907-16	11.4	M[a/]	10.0
1917-26	9.2	9.8	8.5
1927-36	10.8	10.1	9.3
1937-46	15.8	12.0	11.0
1947-56	13.6	10.7	10.7
1957-66	14.4	11.8	11.0
1967-76	10.6	12.5	11.3

a/ M Indicates data not available

Source: National Climatic Center

Figure 1 and Table 1 display the pattern of summer rainfall which has prevailed in La Porte over the last seven decades. A striking feature of these data is the disparity in summer rainfall in the period 1937-1966 relative to rainfall in the 1907-1936 and 1967-1976 periods.

Changnon and Huff (1977) show that regional rainfall patterns indicate that the area of anomalous rainfall has shifted in the 1967-1976 period to be centered southwest of La Porte at Valparaiso. They also note the raingage at La Porte was moved to a seemingly poorer location in 1969.

Before considering the available crop yield data in this region, it is necessary to cite three potential drawbacks to the use of the data which is available. In this northwestern Indiana area, the only available crop yield data are those reported on a county basis (Indiana Crop and Livestock Reporting Service). Unfortunately local scale rainfall anomalies would not be expected to follow county boundaries. Therefore county-level data could mask or fail to reflect significant but local weather-caused yield variations.

A second drawback to the available yield data is that yield estimates are only available from 1929 to the present and then only for corn production.[1/] This means that only a few years of data exist prior to the start of the period of unusually heavy rainfall noted in Figure 1. The third drawback to the available county data is that they are also potentially subject to estimation error because they are sample data. It may be reasonable to assume, however, that any such error would be random and not bias the following regional comparisons.

The summer rainfall data of Figure 1 and Table 1 are for the station in La Porte and may not be a good estimate of the county average. Moreover, Lake and Porter counties lie between La Porte and Chicago. A natural question to consider would be if yield patterns were markedly different among these three Indiana counties (Lake, Porter and La Porte). Table 2 presents corn yield data for these three counties for the years 1929-1974.

In all three counties, corn yields have risen sharply throughout the five decades considered in Table 2. These yields largely reflect technological advances which would be expected to occur in a rather uniform manner in this small geographic area. The consistent pattern of yield increase shown in Table 2 indicates that pronounced summer rainfall differentials probably did not occur within this three county area. This conclusion is consistent with results shown elsewhere (Changnon et al., 1978) which indicate that urban-induced summer rainfall begins in the city and extends eastward. Therefore these three counties were considered as a group in this analysis.

1/ Data are also available for winter wheat production throughout this time period. However the effect of summer rainfall on wheat production is much less certain than for corn production. Whereas additional rainfall in early summer might increase wheat yields, rains later in the summer could interfere with harvest and decrease yields. Also winter wheat is a minor crop relative to corn in this area. Therefore wheat yield data were not to be utilized in this study.

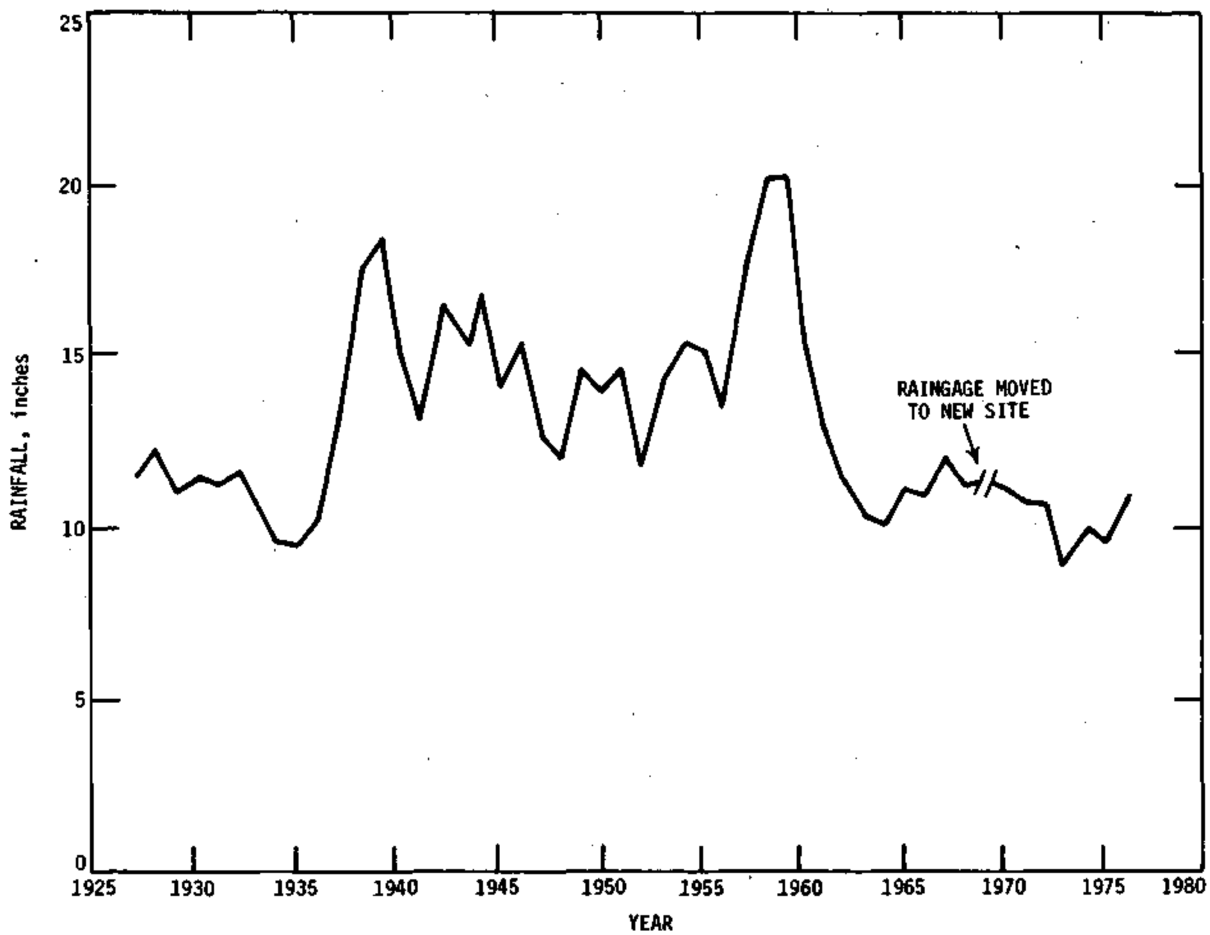

Figure 1. Three-year moving averages of summer (June, July, and August) rainfall at La Porte, 1927-1976.

Table 2: Corn yield data for Lake, La Porte and Porter counties, 1929-1974.

	Average Corn Yields (bu. per acre)		
Time period	Lake	La Porte	Porter
1929-1936	27	28	28
1937-1946	44	44	45
1947-1956	51	49	53
1957-1966	76	78	79
1967-1974	91	88	94

Source: Indiana Crop and Livestock Reporting Service.

Table 3: Ratio of corn yields for the control county and target county groupings, 1929-1974.

Time Period	Ratio of target county yields to control county yields (times 100)
1929-1933	104
1934-1938	94
1939-1943	105
1944-1948	97
1949-1953	104
1954-1958	105
1959-1963	98
1964-1968	96
1969-1974	93

Source: Indiana Crop and Livestock Reporting Service

The three counties just mentioned (Lake, La Porte, and Porter) are grouped with six other counties (Benton, Jasper, Newton, Pulaski, Starke and White) to form Indiana Crop Reporting District 1 (Indiana Crop Reporting Service). These nine counties were selected to form one statistical unit because of their similar soils, growing conditions and types of farming. Therefore it would seem reasonable to develop comparisons among counties within the crop reporting district. Newton, Jasper and Starke counties (hereafter referred to as the control counties) form the next tier of counties to the south and adjacent to Lake, La Porte and Porter counties (hereafter referred to as the target counties). Table 3 and Figure 2 presents yield comparisons between these two county groupings.

Prior to 1937, Figure 2 indicates corn yields oscillated, with control area values higher than target county yields in four years and lower in four years. But this pattern shifted markedly for the period 1937 to 1960. During that 24-year period, corn yields were higher in the target counties in 19 years. Although yields were consistently higher in the target group during this period, the increased yields were not of a major magnitude. For the period 1937-1960, yields in the target counties averaged three percent greater than in the control counties.

Following 1960, a second shift in yield advantage occurred between the two county groupings. For the 14 years following 1960, corn yields were lower in the target counties in 12 years. During this period, corn yields were almost five percent lower in the target counties than in the control counties.

An additional drawback to using county yield data is that such data reflect actual harvested yields. Other factors besides rainfall have impacts on yields, however. One of these is hail losses. But if hail occurrences are correlated with additional rainfall, then use of county yield data may understate yield effects due to additional rainfall. Data are presented in Table 4 which reflect relative hail intensity (as measured by the loss cost ratio) for the two county groups during the period 1948 through 1976.

For the period 1948 to 1956, hail losses were reported as identical in the two county groups. For the next 10 year period, however, hail losses were reported as sharply higher in the target counties. For the last period, 1967 through 1974, the relative positions of the two groupings shifted and hail losses were given as sharply lower in the target counties. These data also are somewhat consistent with the rainfall data given previously.

Description of the La Porte Area

The city of La Porte is located in La Porte County, Indiana. The county has a population of 105,900 (1974 est.) and covers 607 square miles (Indiana State Planning Services Agency, 1976). About 72 percent of its land is in agricultural use, 10 percent is urbanized, 7 percent is in forests, and 3 percent in small water areas. The western and eastern borders of the county are arbitrary north-south lines; the southern border is formed by the Kankakee River, a man-altered waterway draining much of the county, and the northern border is partly Lake Michigan and partly the state of Michigan. For the county as a whole, slightly over half the labor force (51.4 percent) is employed in the

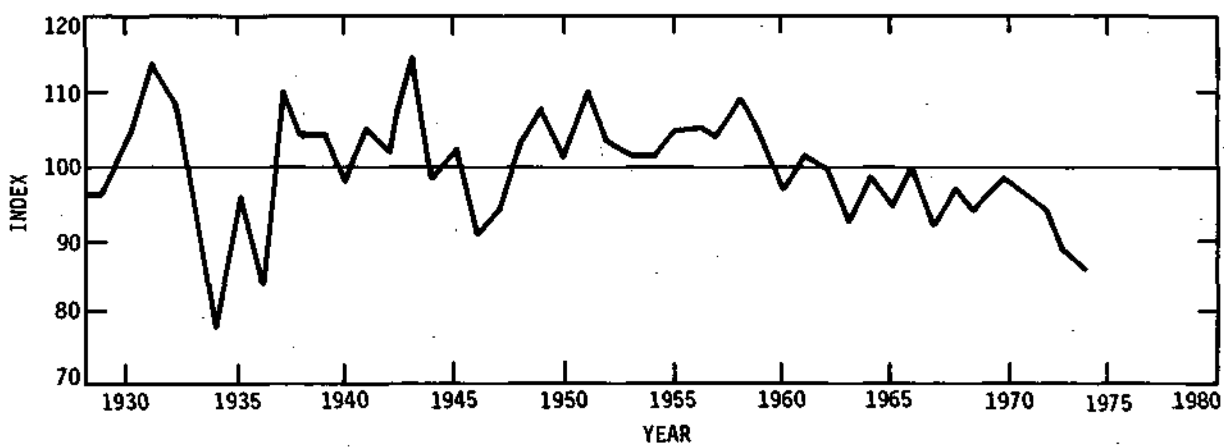

Figure 2. Index of target county average corn yields divided by control county average corn yields, 1929-1974.

Table 4: Hail loss-cost data for the control and target county groups; 1948-1976 a/

Time Period	Hail Loss Cost	
	Target Group	Control Group
1948-1956	$0.28	$0.28
1957-1966	0.42	0.24
1967-1974	0.24	0.44

a/ Data are not available prior to 1948.

Source: Crop Hail Insurance Actuarial Association manufacturing sector, 20 percent in trade, 13 percent in agriculture and related service areas, and between 2-5 percent each in construction, transportation, communications, public utilities, finance, and government (Indiana State Planning Services Agency, 1978).

Agriculture is a major factor in the county's economy, with a gross income in 1977 of about $50 million (Kalb, 1978). Production of corn and soybeans for cash disposal predominate with average acreages for La Porte County of 125,000 acres of corn, 55,000 acres of soybeans, and 20,000 acres of wheat. There are also about 90 dairy and 50 swine herds, and significant acreage is devoted to fruits and vegetables.

The city of La Porte, located in the north-central part of the county, covers 11 square miles and has a population of about 25,000 (Indiana State Planning Services Agency, 1976). La Porte is just south of the Valparaiso Moraine; the terrain along the moraine is hilly but in La Porte is fairly flat. With the exception of Michigan City, all the other towns in La porte County have populations under 4,000. Michigan City, situated on the lakeshore, 12 miles northwest of La Porte, has about 37,000 inhabitants.

About 64 percent of La Porte's workforce is employed by one of the nearly 50 manufacturing firms in the city, 7 percent by the local and county governments (La Porte is the county seat) and the remaining 29 percent in the other traditional service sectors. Because of the large number of manufacturing firms and lack of university-level educational facilities and research labs, employment opportunities are plentiful for skilled blue-collar or professional persons (Boucher, 1978).

In their spare time, La Porte residents have 5 glacier-formed lakes nearby, all of which are used for fishing, boating and swimming. The beaches of the Lake Michigan shoreline are also heavily used. Two small slopes serve the downhill skier and cross-country skiing is also popular.

Construction. La Porte, although a small community, does have the four major types of construction—residential, general building, highway, and heavy and specialized construction. Anomaly-caused increases in the number of days with light rain or snowfall does not always hinder outdoor construction activity; certain projects can continue sometimes virtually unaffected (Maunder et al., 1971; Russo et al., 1965). But the upgrading of a light snow or rainstorm to a moderate or heavy one would certainly cause the day's activities to be canceled, and a variety of extra costs to be incurred. For example, it will take longer for the ground to dry enough to support heavy machinery (as overhead costs continue to be incurred), and machinery left uncovered at the worksite will deteriorate more quickly and need to be replaced sooner. There will be fewer days in which work is possible, so that more time will be needed to complete each project. Although the extra costs to the construction industry because of the precipitation anomaly have not been measured precisely, they assuredly are substantial.

Manufacturing. A check with spokemen of the three largest manufacturing firms in La Porte (Crawford, 1978; Bourse, 1978; and Prickett, 1978) reveals that none can point to any increases (or decreases) in the cost of doing business solely due to the weather anomaly. None reported significant problems with lightning damage, weather-related employee tardiness, water damage to materials stored outdoors, or flooding of basements or other areas. In one case a roof collapse due to heavy snow was reported, but whether any of that snow was anomaly-caused has not been determined. Of course, these individuals (as well as the others cited here) may not be in a position to observe weather in other areas and therefore may not be aware that their area's rainfall or their business is affected by any anomaly.

All the firms reported costly disruptions during the severe winter snowstorms of 1977, but again it is unknown whether any of the snow was due to the anomaly, and if so, whether the economic affects would have been as bad even if that increment had not occurred. Although the above findings indicate that the anomaly does not result in cost increases which the spokesmen are aware of; the possibility that there are costs, of which they are unaware, should not be ruled out.

In general, the La Porte findings tend to support those of Bickert and Browne (1966), who studied a somewhat similar situation in Colorado and found that weather received little consideration in management decisions. However, Bickert and Browne were able to detect significant increases in direct and indirect costs due to weather.

Snow and Rain Accumulation and Removal. Although exact figures are unavailable, it is clear that to the extent that the anomaly upgrades light snowstorms to moderate ones or makes heavy ones heavier, snow removal, sand, and salt costs will rise. And since car owners will be more likely to use studded snowtires, damage to road surfaces will increase. Vehicle bodies will deteriorate faster because of more salt on the roads, although if the vehicles are not replaced sooner than otherwise, the economy won't be affected. Towing and service facilities will benefit from the anomaly, because of increased business during storms.

Flooding of low-lying areas, including viaducts and basements, would be expected to be more severe because of the anomaly. Whenever snow ro rain accumulation hinders travel, some travelers can be expected to halt their journeys and stay in motels and eat in restaurants till travel is easier, with predictable affects on that sector of the economy.

Traffic Accidents. Traffic accidents have been shown to increase in number (although not necessarily in severity) during rainy periods (Sherretz and Farhar, 1978). It is reasonable to expect that the same would be true in La Porte. However, no attempt has been made to determine which accidents in actuality were due to the anomaly, and what the economic impact was. Such a study would have to measure the amount of police time investigating the accidents, court costs, hospital bills, days lost from work, increased insurance premiums, car repair or replacement costs, and the expense to the city of repairing accident-damaged guardrails, signposts, utility posts, etc.

Lightning. The increased incidence of lightning, accompanying the additional summer thunderstorms, can be the cause of fires, power outages, and very rarely, lost human lives. It is not known whether lives actually have been lost due to anomaly-caused lightning, and how many fires have been caused.

Mr. Robert Dodge (1978), a spokesman of Northern Indiana Public Service Company power suppliers to the area, confirms that electric storms nearly always result in power outages. But the cost of repair in terms of time and manpower is relatively low.

Retail Trade. Retail sales of snowshovels and snow and rain protective gear would be expected to be higher because of the anomaly, since they would wear out faster due to increased use, assuming people are not content to use worn-out items. But whether sales of fine-weather sports equipment decrease or cold-weather sports equipment sales increase, depends on how people let the weather affect the timing and frequency of their activities. Do they cancel their activities when inclement weather occurs, or do they postpone them (Clawson, 1966)? This problem is further discussed in the next section.

Recreational Activity. The unresolved question of whether inclement weather causes people to postpone or to cancel their planned recreational events makes it very difficult to judge the economic effects of rain or such activities as swimming, boating or fishing. One fairly certain result of the anomaly, however, is that people will be forced to spend more time indoors either watching television, reading, playing games, or bowling, so that suppliers of these activities may benefit economically.

According to La Porte Water Department spokesmen, Mr. Marian Wojak (1978) and Mr. Phil Richey (1978), recreational activities on the five lakes have not been affected by the anomaly. There have not been any problems with water or pollutant levels being too high. The two area ski slopes may or may not have benefited from the increase in snow, because the La Porte area would have such a large amount even without the anomaly. So the ski areas might not have had a problem with insufficient snow, even without the anomaly.

The anomaly can be expected to affect demand for fine-weather recreational activities in that demand is probably concentrated into shorter time periods. Thus, facilities will be more crowded and participants may enjoy the activity less.

Water Supply. Because La Porte receives all its water from deep wells, water department spokesmen feel that increased rain and snowfall would only be of minor benefit in increasing supplies. However, the demand for summer water may be reduced because of additional rainfall. There has been no problem with increased amounts of pollutants seeping down along with the increased water, as the earth cleanses the water as it seeps downwards.

Other. Various other effects have been ascribed to increased precipitation, some of which may apply to La Porte. Tobin (1976) reports that fewer crimes of violence occur under rainy conditions. Although he does not explain cause-and-effect, the statistical relationship alone is useful in determining economic impacts. Whatever the reason for the decline in violent crime, as long as it does not cause other types of crime to increase, significant alleviation of human suffering and expense and reduction of police costs would result.

Hoch (1976) has demonstrated that locales with 20 percent more rainfall (over a certain base) have, as compensation for the unfavorable climate and higher living expenses, average wage rates 1.8 percent higher than regions with less rainfall. It is questionable, however, whether this might be the case in La Porte. This northwestern area of Indiana is small enough so that workers probably wouldn't mind commuting to towns and cities with higher wage rates. Faced with a large supply of labor, employers in La Porte wouldn't have to pay higher wages to attract workers.

Summary

Additional rainfall in an agricultural region such as surrounds La Porte, Indiana, can have positive economic benefits. Crops such as corn and soybeans would be particular beneficiaries of augmented summer rainfall. But other economic activities may suffer losses from these summer weather events. Primary among these would be outdoor construction, recreation and even crops with competing weather needs.

Evaluation of historic data indicate that unusually heavy summer rainfall occurred in the La Porte area from the late 1930's to the mid-1960's. Corn yield data for Lake, La Porte and Porter counties, the three counties between the cities of Chicago and La Porte, exhibited similar patterns for the years 1929 to 1974. During the period of unusually heavy rainfall, yields in those three counties were consistently higher than the three control counties immediately to the south. However, these yield increases averaged only three percent annually.

Following 1960, however, corn yields in Lake, La Porte and Porter counties were lower than in the control counties in 12 to 14 years. These yield data correlate with the rainfall data. This correlation indicates that the rainfall measurements at La Porte seem to provide a reasonable description of local area rainfall patterns.

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IMPACTS OF URBAN-RELATED INCREASES IN HAIL LOSSES DOWNWIND OF CHICAGO

Stanley A. Changnon, Jr.

The precipitation anomaly far east (20 to 40 miles) of Chicago and centered at La Porte has great scientific interest and holds possible importance for local farmers and insurance groups. The historical weather records at La Porte showed sizeable increases, since the mid-1903's, in the amount of rain (in the warm season), the number of days with moderate to heavy rainfall, and the number of thunderstorm days (Changnon, 1968).

The extensive study in the 1968-1971 period of this localized precipitation anomaly led to the conclusion that the increases were likely related to inadvertent modification of the atmosphere including convective storms. The large Chicago-Gary urban area and related industrial complex located 25 to 30 miles upwind (west) of La Porte were seen as producing many atmospheric effects that could act to induce or enhance precipitation and, as a consequence, lead to increased thunderstorms. An increase in thunderstorms should also be accompanied by an increase in hail. Changnon's (1970) studies of La Porte hail days data indicated local increases beginning around 1950 and continuing up to 1968, the ending time of that earlier research.

This potential for an urban-related increase of hail loss was investigated in this impact-oriented study. This recent investigation, which was aided with nine years more data, 1969-1976, was aimed at investigating the local hail increase and, if present, its impacts.

The METROMEX investigations (Changnon, 1978) had shown an urban-induced doubling of hail events and hail intensities east of St. Louis. An increase in crop losses due to the added hail also was detected (Changnon et al., 1977). This goal of the Chicago study was tied to the general project goal of testing the transferability of the St Louis findings. Sonka's research, using decadal values of hail insurance loss 'figures in northwestern Indiana (reported in this report), showed a localized increase in hail loss in one part of northwestern Indiana during 1957-1966, but no increase in the 1947-1956 or 1967-1974 periods.

The number of hail days at La Porte in the 1951-1968 period was more than 200 percent greater than the average number at the surrounding stations (Changnon, 1970). This was considerably larger than the 31 percent increase shown for annual precipitation, 34 percent in rain days, and 38 percent in thunderstorms. This major increase in hail at La Porte began around 1950, several years after the rain increase began (late 1930's).

Hail changes due to cities have at least two aspects of potential importance for the hail insurance industry. One is that areas downwind of major cities may expect to experience more hail loss than other nearby rural area; and secondly, that the urban-induced hail changes may occur rapidly and be marked by sharp year-to-year fluctuations. Both factors also influence local farmers, both by increasing year-to-year fluctuations in income and by greater loss in yield and income.

Hail-Induced Losses to Crops

Figure 1 presents 5-year moving totals of crop-hail insurance loss costs (Loss ($)/Liability ($) x 100), as averaged for 3 counties in northwestern Indiana from 1947 to 1976. These 3 counties envelop La Porte and reflect the distant downwind area from the Chicago Metropolitan Area, as shown in the inset map on figure 1. The amount of liability did not change markedly in the area throughout the 1947-1976 period and could not affect the loss cost values. Only years with 3-county total liability of $100,000 or more used in this analysis, and these included all the years after 1946.

The 3-county mean loss costs for the 1947-1952 period were $0.07 per year on the average. The values ranged from a 1-year low of $0.03 to a high of $0.10. After 1952, a notable upward shift began. Values during the 1953-1968 period ranged from a low of $0.01 (in 1966) to a high of $1.93 (in 1965). The 16-year average loss cost was $0.27, the difference from the 1947-1952 value representing a 286 percent increase. These higher annual values, generally >$0.15 per year, led to noticeably higher 5-year totals, as shown in figure 1. The exceptionally high five values (1965-1969) are due to the single, very high loss value in 1965. After 1968, the 3-county mean loss costs became lower, ranging from 0 (in 1972 and 1973) to $0.32 in 1970. The average loss cost for 1969-1976 was $0.079, nearly equal to that of the 1947-1952 period. Hence, a 16-year period of anomalous, very high hail loss due to more storms and/or greater hail intensity, occurred in the La Porte area, then apparently disappeared during the 1969-1976 period. Since Chicago and its influences on the atmosphere did not disappear in 1969 (although the techniques of steel production in Gary had undergone a major shift in the late 1960's), the results suggest that either 1) the 16-year high loss was an unusual natural event and thus a sampling vagary, or 2) the urban influence on hail production in 1969-1976 was lessened in the La Porte area due to generally different weather conditions. This latter possibility is reinforced by the recent (after 1967) rain and crop yield data for the La Porte area which also suggest a disappearance of the urban influence on precipitation in the area. In fact, Changnon and Huff (1977) found that the warm season anomaly of high rainfall had shifted westward from the La Porte area in the 1964-1973 period. Although the evidence is not strong, it appears that an urban influence on thunderstorm and hailstorm activity leading to more crop loss does exist in the far downwind area, 15 to 40 miles east of Chicago at times. The increase in crop hail loss is quite sizeable, comparable to that at St. Louis, and exhibits considerable year-to-year variation. Such variations affect crop production, creating greater instability in yields and farm income. This also affects insurance companies, both in loss payments and uncertainity in payment planning and sales.

Reality of La Porte Anomaly

The question of the validity of the La Porte anomaly was investigated using the hail-day data from La Porte. Establishing its reality is an important phase of impact analysis because it impacts on local inhabitants and on the scientific community concerned about inadvertent climate modification. The major means of investigation was to compare the La Porte hail data with the hail insurance data for the counties in the immediate La Porte area. The annual loss cost data from La Porte and two other adjacent counties that could be

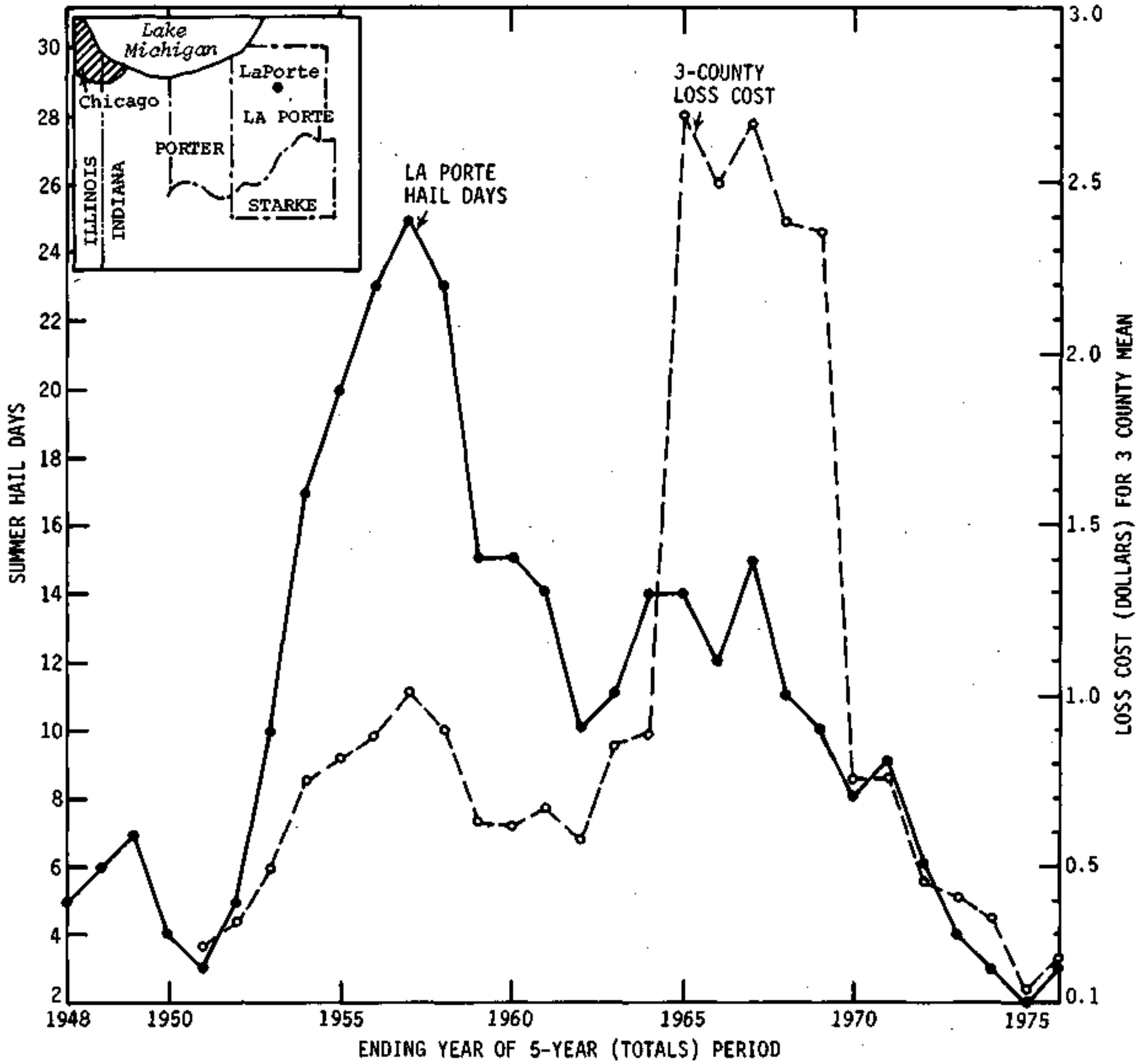

Figure 1. 5-year Moving Totals of Hail Days at LaPorte and of Crop-Hail Loss in the Area.

suspected of experiencing added hail were used to calculate regional annual mean loss costs for this comparison. Five-year moving totals of the 3-county average loss costs can be compared with the 5-year totals of La Porte hail days by examining figure 1. The La Porte hail day curve shows a reasonably good association, particularly in the trends, and considering it is a point record.

The La Porte summer (June-August) number of hail days during the 1943-1952 period ranged from 0 to 3 per year with a mean of 1 day per year. This low incidence changed abruptly in 1953. The 1953-1968 values ranged from 0 to 8 days per year with a summer mean of 3.3 hail days. The difference between the 1943-1952 mean and the 1953-1968 mean (2.3 days) represented a 230 percent increase over the 1943-1952 value. This is comparable to the 286 percent change in loss costs. As with loss costs, the hail day frequency then decreased greatly in the 1969-1976 period, averaging 1 hail day per summer.

It is interesting to note that Brennan and Smith (1978), in studying cyclone frequency in the Midwest during 1950-1974, found somewhat similar temporal distributions. The summer cyclone frequency increased in 1954, was highest (of the 25-year study period) in 1954-1966, then decreased rapidly, being quite low in the 1967-1974 period. This distribution is sufficiently similar to the La Porte area hail frequency and crop-hail loss to suggest that urban influences, if responsible for the downwind increases, were most effective in disturbed periods.

The good relationship of the La Porte hail days and local (3 county) loss cost values (based on insurance data) indicated in the temporal shifts (Fig. 1) is further supported in figure 2. Here, the 5-year totals are plotted and a good linear relationship appears, except for 5 values from the 1965-1969 period (see Fig. 1). These aberrations result from the exceptionally high loss cost in 1965 (which is reflected in five of the 5-year moving totals). The correlation coefficient of the logarithms of the 26 values is +0.71. The good similarity of the point hail days at La Porte, which were under question, and the insurance derived 3-county hail loss values indicates the La Porte hail days are likely realistic values. The results also suggest that the La Porte area anomaly in hail is an intermittent phenomena.

The average loss frequency (number of years with loss divided by the number of years with liability) of the three counties, as based on 44 years of data in each county (1933-1976), was 46 percent. That for the two counties east of La Porte and Starke Counties was only 30 percent. The differences indicate a greater frequency of hail losses in the area that apparently were related to urban-induced hail.

<u>Summary</u>

The incidence of hail in northwestern Indiana shows an unusually large frequency during the 1953-1968 period. This appears to be at least partially related to the inadvertent modification of convective storm activity by Chicago. The 16-year period of much higher hail incidence was sufficient to cause 286 percent higher hail losses and thus an impact on local farmers and crop-hail insurance interest. The La Porte hail day data had an anomalous behavior

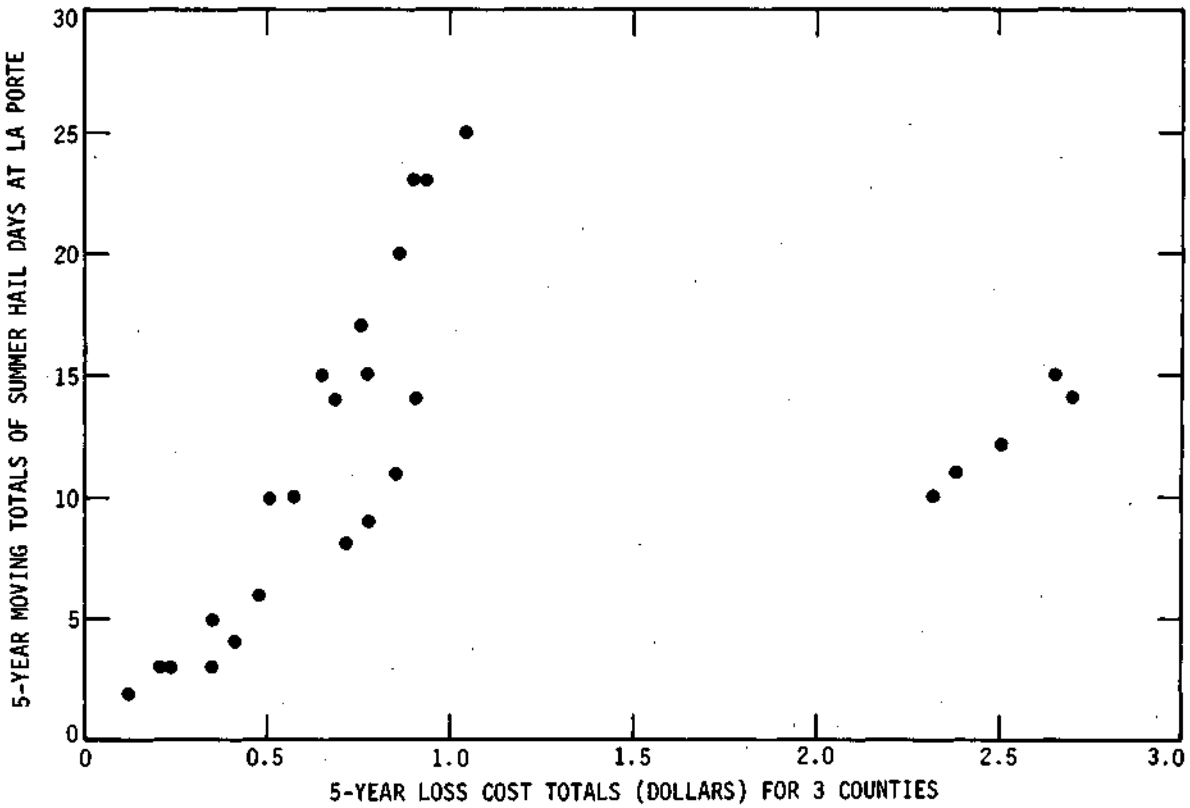

Figure 2. Relationship of 5-Year Moving Totals
of Loss Cost and Hail Days in LaPorte Area, 1947-1976.

comparable to that of an independent data source, the hail insurance losses. However, as at St. Louis, the increased crop-hail losses did not lead to local increase in insurance rates.

An important concept is suggested by the pulsations in the La Porte hail findings, as well as the region's crop-yield results during the 1930-1976 period. First, many of our studies reveal there are urban effects on the atmosphere, clouds, and rainfall directly over Chicago. Whether these extend or appear as far downwind as La Porte (30 to 40 miles away) in any year, or in runs of years, may well depend on larger scale general circulation factors. The temporal distribution of midwestern cyclones during 1950-1974 were similar to the temporal shifts in hail frequencies. A shift in such conditions might, for example, move the lake breeze front (and associated instability and moisture) such that storm intensification is aided over La Porte, as opposed to elsewhere. However, changes in cyclonic frequency could also lead to changes in the frequency of storm activity in the Chicago area, which could in turn, cause a downwind maximum of storminess to appear, or disappear. This possibility is made believable because the La Porte anomaly (particularly that in hail and heavy rains) was the result of local intensification of only a few storm events per year. Such time and space changes in urban storm anomalies produce greater than natural variability in damage conditions in local areas, resulting in increased variability in farm income.

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SUMMER FLOODING AT CHICAGO AND RELATIONSHIP TO URBAN-INCREASED HEAVY RAINFALL

Stanley A. Changnon, Jr.

Introduction

A major potential impact of urban-induced increases in rainfall is added flooding. Results for St. Louis indicated an increase in heavy rain rates and in the frequency of 1-inch or greater storm events (Changnon et al., 1977). These increases existed in the suburban and rural areas east of the city and were traced to added flooding, particularly in the suburbs.

A limited investigation of this possibility was performed in the Chicago area. A 3-step process was followed. First was the definition of local "flood events." Once this was done, the rainfall associated with these was identified. These values were compared with the findings on urban influences on rainfall.

Heavy Rains

Historical studies (Huff and Changnon, 1972) indicated urban-related increases in daily rain values in the range of 2 to 3 inches. The average increases inside Chicago for 1949-1968 was 33% (≥ 2 inches) and 14% (≥ 3 inches), and those in the La Porte area were 100% (≥ 2 inches) and 71% (≥ 3 inches). Dettwiller and Changnon (1976) showed how the warm season maximum daily rains at Chicago have trended upward by 18% over the past 100 years, going from a mean of 2.2 inches in 1871-1880, up to 2.6 inches per day by 1961-1970. Daily rains of 2 inches represent a 1.5-year recurrence interval, and 3 inches is a 4-year return value.

Research pursued as part of this project provided further indication of an increase in heavy rain events. The analysis of the storms during 1949-1974 that produced 1-inch or more in the Chicago area produced a mean storm pattern (for squall lines and cold fronts) that indicated 2.3 inches in the city and 1.5 inches or less in the surrounding rural areas. Hence, the "1-inch in the area" class of storms typically produced a 2-year or greater recurrence interval value inside Chicago. This also suggests a 50% increase in heavy urban rains.

Second, the distribution of the maximum rainfall centers with 1-inch or greater rainfalls in the CAP network in the summers of 1976-1977 was plotted. There were 46 such storms. The La Porte area had 270% more maximum events than control areas, and the city had 176% more, indicating much greater frequency of occurrences of 1-inch or more in these two areas. Finally, the analyses of the total rainfall yield by 1-inch network storms (1976-1978) indicated 19% more rain over the city than over the lake control area.

Thus, a variety of values exist than indicate 1) more point events of 1 to 3 inches (or more) in the city, with increases ranging from 14% (3 inches) to 176% (1 inch); and 2) more rainfall per heavy rain event, ranging from 19 to 50%, depending on what is measured.

Floods

One approach for defining urban floods is in relation to recorded problems in the storm runoff management system in Chicago. For example, the Chicago storm (and sewer) drainage is through the Illinois River system and not into Lake Michigan so as to maintain lake water quality. However, when the drainage system has not been lowered sufficiently to handle a heavy rain, the excess runoff has to be released into Lake Michigan. There were 21 such Chicago floods, or storm water resleases into the lake, in the 1947-1975 period as shown in Table 1. The urban rainfall associated with these 21 events produced averages of the storm area mean of 7.1 cm (2.8 inches) and point maximum of 10.16 cm (4.0 inches), with storm durations of 3 to 30 hours. Comparison of actual rain-duration values of Table 1 with storm frequency values shows that a flood defined by the Chicago principal drainage system is an event having point rainfall values with recurrence intervals at or in excess of once in 5 years. However, since the system integrates events over an area, the flood events occur nearly once a year on the average. It should be noted, however, that there were 19 other storm events in 1954-1975 period inside Chicago with 3 inches or more (about the flood-producing average of 2.8 inches in Table 1) when no reversals occurred. Thus, approximately half (21 of 40) of storm events produced these system reversals, or "floods."

Another informative definition of urban floods was derived by comparing all flood events in the Chicago Metropolitan area in May-August 1978, as reported by the local newspapers, with the intensity of rainfall measured in the Water Survey's dense network of recording raingages. The type of flooding for 19 events is shown in Table 2 along with the return frequency (years) of the short duration rainfall amounts, for both the flooded area and the peak single gage values. The ranges reveal a considerable difference in rain amounts producing an urban flood, as might be expected where extensive impervious surfaces and activities like traffic flow can produce newsworthy "flood problems." However, the floods related to relatively lighter rains (less than 1-year return intervals) were apparently minor and included flooded side streets, and golf courses. The more serious flooding of homes and major highways generally occurred with point frequencies of 5-year or greater frequency. The median values suggest "urban floods" defined in this manner occur when point rain values (for short durations) reach or exceed 4-year frequencies (3 cm or 1.2 inches for 30 minutes up to 6.35 cm or 2.5 inches for 6 hours).

Conclusion

Coupling of the rains associated with the flood event definitions and the urban-induced increases in rain events suggests the following conclusion. Minor and major flood events in Chicago are produced by rains having magnitudes equivalent to 1- to 5-year or greater recurrence intervals. Urban induced rainfall increases exist, producing anywhere from 14 to 176% more heavy rain events in the 1- to 4-year return intervals. Thus, it appears that flooding events in Chicago are anywhere from 10 to 100% more than expected due to urban influenc es on heavy rain conditions.

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Table 1. Rainfall Data for Drainage Reversals into Lake Michigan, 1947-1975 period.

		Rainfall			
		Storm			
Storm Dates	Duration (hrs)	Mean	Max.	Min.	Hourly Max. Rates
4/ 4- 5/47	18	4.68	4.90	4.46	M
4/19-20/47	15	1.88	2.00	1.76	M
6/ 1/47	8	1.85	2.09	1.62	M
3/19/48	6	2.31	2.50	2.11	M
5/ 6/48	10	1.13	1.15	1.12	M
5/10-11/48	17	1.68	1.73	1.63	M
4/18/75	15	2.76	3.83	1.91	1.08
3/24-25/54	15	2.81	4.86	1.82	1.69
10/9-10/54	27	5.99	7.58	5.10	1.70
7/12/57	12	5.88	7.67	4.03	2.50
9/12-13/61	12	2.24	2.63	1.37	1.08
9/13-14/61	9	2.86	3.66	2.40	0.95
9/25/61	15	1.82	2.19	1.18	0.48
8/ 2/62	8	2.65	3.77	1.02	1.50
12/24-25/65	30	2.52	3.42	2.06	0.25
5/11-12/66'	27	3.30	3.86	2.94	0.36
6/10/67	12	2.93	6.09	0.45	3.89
8/16/68	7	3.01	4.06	0.98	1.69
10/10-11/69	9	2.14	4.66	0.98	1.19
6/14/72	9	1.30	1.98	0.73	0.80
8/25/72	6	2.11	3.06	1.38	2.78
9/17/72	5	0.91	2.55	0.02	1.08
8/21/22/75	3	1.72	2.19	1.34	1.35
Mean	12.9	2.76	4.01	1.74	1.46

Table 2. Return Interval (Years) for Rainfall Values (30-minute to 6-hour Durations) in Chicago Area Locales with Reported Flooding During May-August 1978[1].

Area Average[2]	Peak Gage Value[3]	Type of Flooding
2 years	3 years	Underpasses, side streets
1 year	2 years	Underpasses, side streets
1 year	3 years	Underpasses, side streets
2 years	5 years	Underpasses, side streets, basements
7 years	10 years	Interstate, highways
<1 year	1 year	Airport facilities
5 years	15 years	Highways, interstate
12 years	30 years	Highways, suburban roads
<1 year	<1 year	Express boulevard
3 years	10 years	Basements, suburban streets
4 years	10 years	Basements, suburban streets
<1 year	1 year	Major golf tournament
<1 year	<1 year	Side streets (auto accidents)
3 years	4 years	City streets, airport runways
10 years	25 years	Suburban streets, basements, businesses
3 years	5 years	Storm runoff released into Lake Michigan
2 years	4 years	Viaducts (one drowning)
1 year	2 years	City streets
<1 year	1 year	Side streets (accident)

Median = 2 years - - - 4 years

Range = <1 to 12 years - - - <1 to 30 years

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[1] Reports gleaned from all local newspapers

[2] Based on 4 raingages nearest to flooded areas (area of 93 km) for each duration

[3] Based on heaviest value at one of the 4 nearest raingages

Metal Pollutants in Agricultural Soils and the St. Louis Urban Rainfall Anomaly

Janyce Bartlett, Donald F. Gatz, and John J. Hassett

Introduction

A recently completed 5-yr investigation of urban effects on local weather (Changnon et al., 1977) has documented the existence of a city-produced rainfall anomaly at St. Louis. Project METROMEX (Metropolitan Meteorological Experiment) has shown (Huff, 1977) an area northeast of the city where total summer rainfall between 1971 and 1975 was 15-30% above the mean for the area. These results are shown in Figure 1.

One component of the METROMEX study measured the deposition of a number of common elements, both in rain and dry fallout, in the northeast quadrant of the study area (Gatz, 1974). Figure 2 shows the distribution of wet and dry deposition of Zn in two sampling networks. The lower rectangular network was operated between 1972 and 1974; the other network was used in 1975. The patterns show dry deposition maxima predominantly in urban areas, i.e., near sources, whereas the areas of maximum deposition in rain are displaced somewhat to the northeast in the direction of maximum urban rainfall anomaly.

These results suggested that the urban rainfall anomaly might be serving to increase metal concentrations in downwind agricultural soils. In sufficient concentrations, such metals could have possible harmful effects on crop production, or on animals that the consume the crops.

The goals of this work were:

1) to measure the concentrations of Zn, Cd, and Pb in soils northeast of St. Louis,

2) to evaluate the role of the urban rainfall anomaly in metal deposition in the area, and

3. to evaluate existing data on metal concentrations in northwestern Indiana soils for evidence of an increase in deposition caused by city-produced rainfall.

Experimental Methods

Fulfillment of these goals led to the sampling of soils. Figure 3 shows a map of the 21 sampling sites chosen. The sampled soils were all located within the precipitation chemistry networks. Lying along two NE-SW transects, the sites include both urban and rural locations-. The vertical

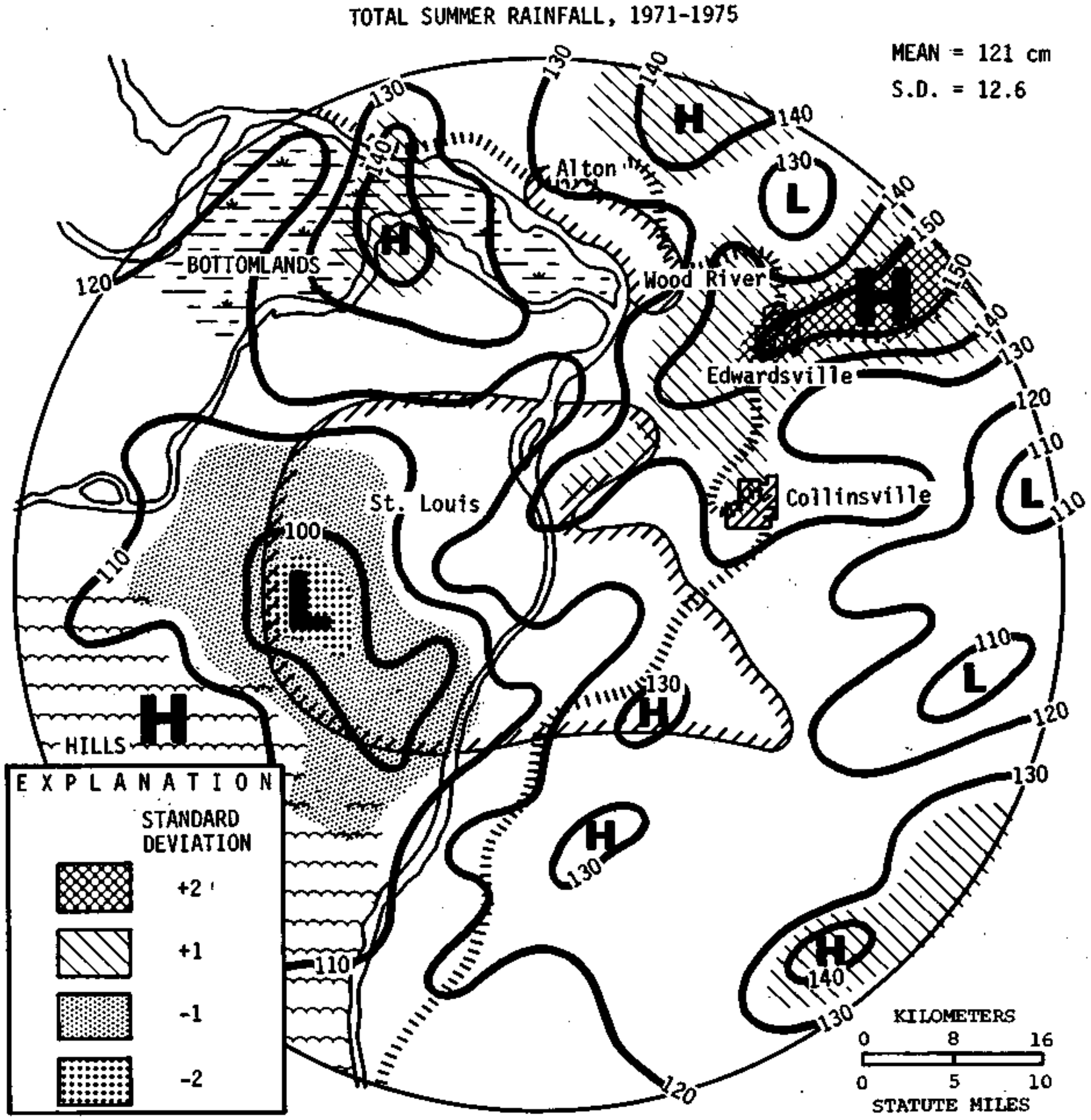

Figure 1. Distribution of total summer (June, July, and August) rainfall for the St. Louis area, 1971-1975. (From Huff, 1977).

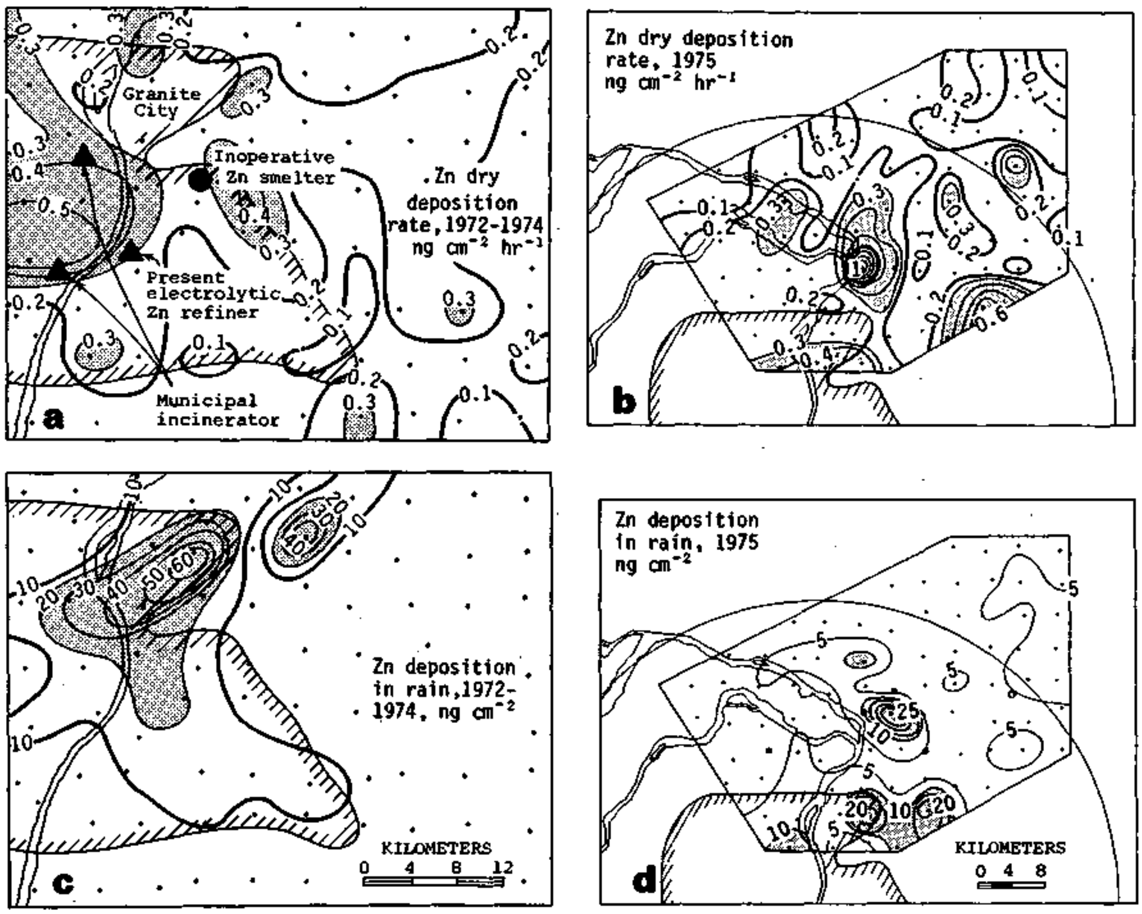

Figure 2. Measured atmospheric deposition of Zn near St. Louis. a) Median dry deposition rate from 21-1 day sampling periods, 1972-1974. b) Median dry deposition rate from 5-1 day sampling periods, 1975. c) Median deposition per rain event, for 26 rains, 1972-1974. d) Median deposition per rain event, for 5 rains, 1975. (From Gatz et a!., 1978).

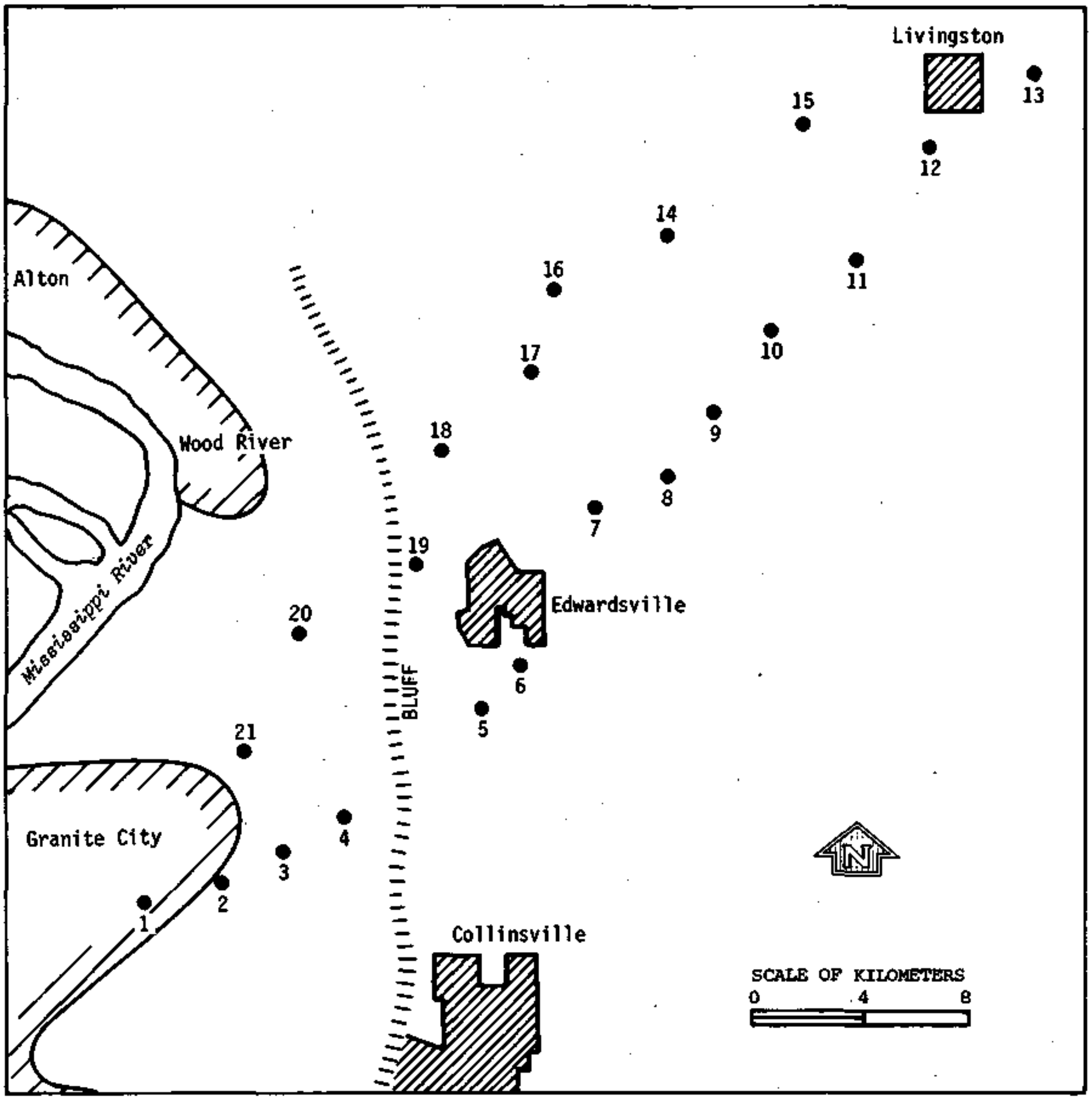

Figure 3. Map of soil sampling sites northeast of St. Louis.

dashed line indicates the bluff separating the Mississippi River bottomlands, containing alluvial soils, from uplands of loess soils. All the soil samples were obtained from agricultural fields.

The sampling procedure involved digging a hole 45 cm deep and removing three successive layers each 15 cm thick from an undisturbed wall of the hole, using a shovel. Each layer was placed separately in a plastic bucket, broken into small pieces, and transferred to a plastic bag. Each sample was approximately 1 kg dry weight. Sixty-three samples were collected from the 21 sites within a two day period during April, 1978, prior to spring field work.

Samples were air dried, ground to pass through a 2mm sieve, mixed and stored in plastic bags. After the drying procedure, four common physical or chemical parameters were measured: pH, texture, cation exchange capacity (CEC), and total organic carbon (TOC). The pH was measured using a standard meter as described by Banwart and Hassett (1976). Texture was determined by mechanical analysis, using the Bouyoucous hydrometer method (Banwart and Hassett, 1976). Analysis for CEC utilized the ammonium acetate procedure (Banwart and Hassett, 1976). TOC was determined with the Oceanography International Corporation TOC system by the ampule method. Duplicate analyses were performed for the CEC and TOC measurements. All procedures were tested for accuracy by an interlaboratory comparison of four soil samples with a soil laboratory in the Department of Agronomy, at the University of Illinois.

The samples were also analyzed for their zinc, cadmium, and lead content. A 5 g portion of each sample was ground using a mortar and pestle to a fine powder (200 mesh). Samples were oven dried for 24 hours at 105C. Duplicate 1.5 g (± 1 mg) samples were weighed and placed in teflon beakers. The metal ions were extracted in 20 ml of 4N HNO_3 solution for 4 hr at 80-90°C. The beakers were covered with watchglasses during digestion. Solutions were cooled, diluted to 25 ml, with 4N HNO_3 and filtered through 0.45 µm pore diameter Millipore filters to remove remaining insoluble matter. Concentrations of Zn and Pb were determined by flame atomic absorption spectrophotometry (AAS) and Cd by flameless AAS. Standards were adjusted to match the matrix of the samples.

In a preliminary analysis of four samples, the extraction procedure was tested for accuracy by comparison with a total dissolution procedure modified from that given by Peden (1976). The modification was to increase the acid volume by a factor of 10 in order to dissolve 1.5 g of soil. Results for duplicate Zn analyses are shown in Table 1.

In all cases except one the acid extraction procedure removed 90% or more of the total zinc. Furthermore, the precision of the acid procedure was better than the dissolution method based on the standard deviation of the duplicate samples. Comparison of samples 4-3 and 4-3A illustrates the reproducibility of different 5 gm portions for a given soil sample.

During the routine extractions of the remaining 59 samples, one of the four preliminary samples was extracted a second time with each group of samples, to test reproducibility. Comparative results for Zn are shown in Table 2. The error was determined by dividing the difference between

Table 1. Preliminary analyses: comparison of acid extraction and total dissolution procedures for measuring Zn content of soil.

	$4N\ HNO_3$		Total Dissolution		
Sample site-layer	Concentration, μg g-1	St. dev. μg g^{-1}	Concentration, μg g^{-1}	St. dev. μg g^{-1}	Percent extracted
4-3	62.0	2.8	79	33	78
4-3A	57.5	.7	60	12	95
18-1	49.0	1.4	41	0	120
14-2	38.0	1.4	34	1.4	112

respective mean values of duplicate analyses by the mean value for the preliminary extraction. The reproducibility within each experiment was very good, judging from the standard deviations of the duplicate samples. However, lower Zn concentration values were measured in all four routine extractions. The reason for this outcome is not clear, since the same procedures were used both times. A possible explanation is a lower hot plate temperature during the routine extractions, resulting from having 32 samples on the hot plate, as opposed to 8 in the preliminary test. The average error of 35%, though somewhat high, has no effect on distingushing the differences between samples found along the soil transects.

Results

A soil's ability to adsorb metals is generally dependent on four characteristics: pH, TOC, CEC and clay content. The distributions of these properties along our transects are presented in Figure 4. The two transects are represented on one linear scale. Distance is relative to site 1 in Granite City. There is great variability in the CEC, TOC, and clay contents of the bottomland soils but they fluctuate in a parallel fashion. This is characteristic of alluival flood plain soils (Brady 1974) in that alluvial deposits high in fine textured materials also tend to have higher organic matter contents and hence, higher CEC values. In contrast, somewhat smaller variations in these properties occurred in the upland soils due to the nature and origin of these loess soils. The range in pH values (4.93 to 7.66) for all the soils was characteristic of soils in humid regions. Texture of the soils ranged from clay loam to sandy loam with the majority of the soils being loams or silt loams.

The zinc, cadmium and lead concentrations found in the soils are shown in Figure 5. All three metal concentrations showed a decreasing trend from the urban to rural environment. Fifteen kilometers northeast of site 1 the concentrations reached a minimum and remained constant for the rest of the 45 km transect. The top layer (0-15 cm} had Zn, Cd, and Pb levels ranging from 20 to 250 ug g^{-1}, 0.06 to 2.37 ug g^{-1}, and 20 to 66 ug g^{-1}, respectively. The ratio of concentrations at site 1 (urban) to site 13 (most rural) was 7 for both Zn and Cd, but Pb had a ratio of only 3.

The second (15-30 cm) and third layers (30-45 cm) show a pattern similar to the first in concentration versus distance. Concentration also decreased with soil depth. The relative change with depth was greatest at the more urban sites closest to the urban area.

Importantly, comparison of Figures 4 and 5 reveals no apparent correlation between the soil properties and the metal content of the soils. No influence of the highly variable soil properties of the bottomlands is apparent in the smooth decrease in metal concentration with distance from the urban area. Comparison of near-urban sites 2 and 21 (Figures 4 and 5) illustrate this point. Although site 21 was more favorable for the adsorption and retention of metals because of its higher content of clay and organic carbon, and its high CEC, site 2 had the higher concentrations.

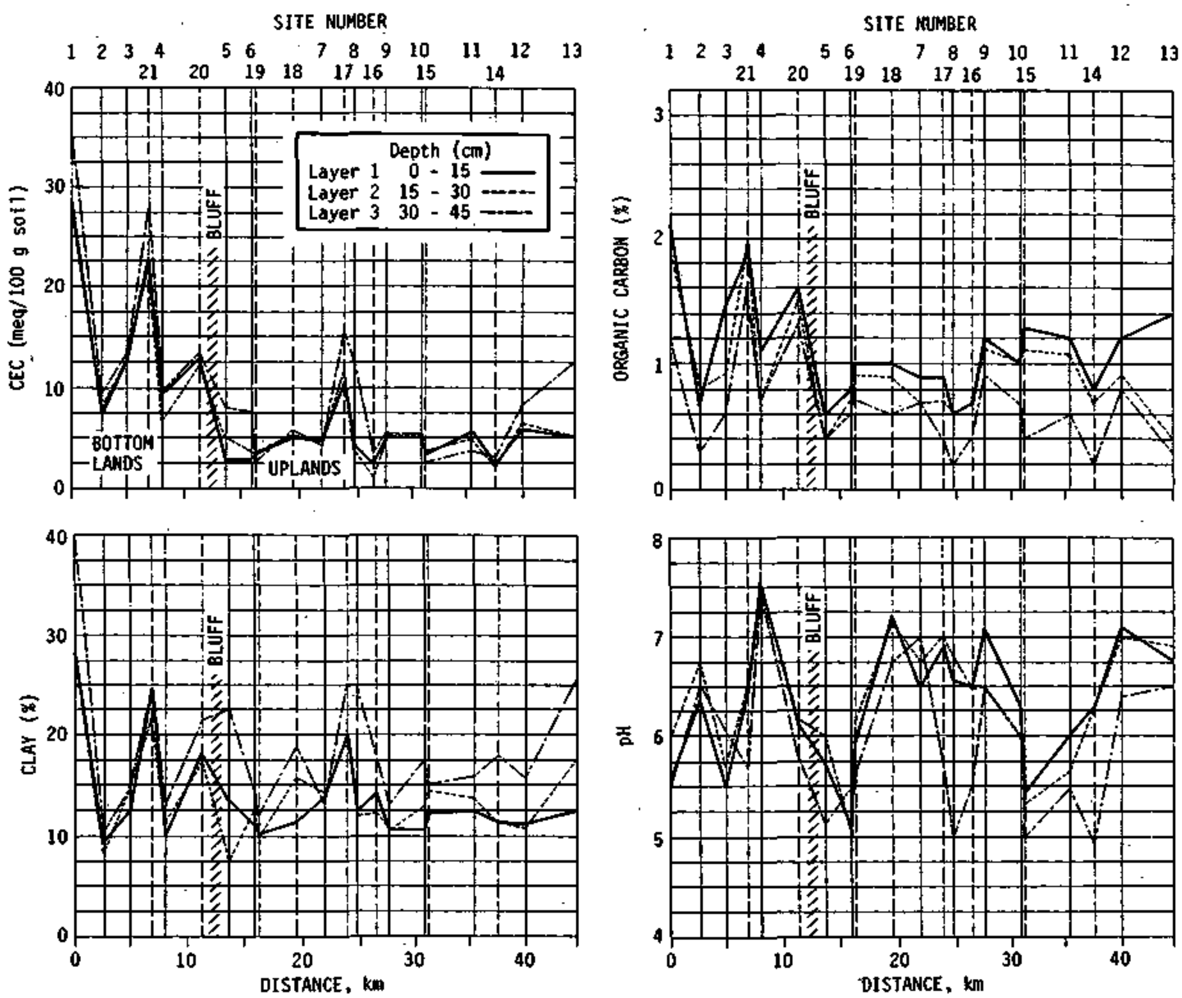

Figure 4. Variation of four common physical or chemical soil parameters with distance along sampling transects.

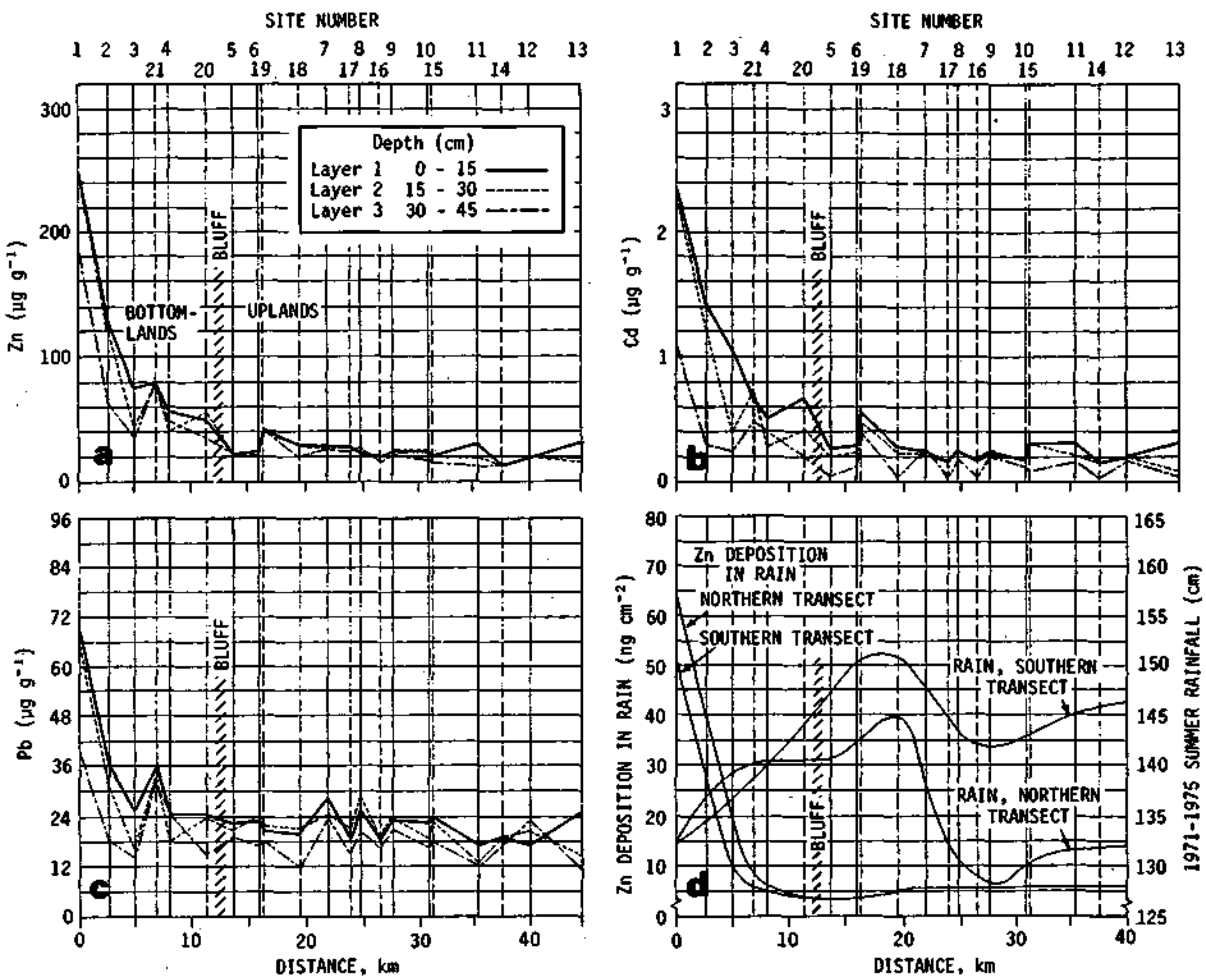

Figure 5. (a, b, c) Variation of metal concentrations in soil with distance along sampling transects. d) Variation of rainfall and Zn deposition in rainfall along sampling transects.

Table 2. Reproducibility of Extraction Procedure

Sample number	Preliminary extraction: Zn concentration, $\mu g\ g^{-1}$	Preliminary extraction: St. dev. $\mu g\ g^{-1}$	Routine extraction: Zn concentration, $\mu g\ g^{-1}$	Routine extraction: St. dev. $\mu g\ g^{-1}$	Percent error
4-3	62	2.8	47	2.1	24
4-3A	57	0.7	36	0.7	37
18-1	79	1.4	20	0.0	56
17-2	38	1.4	29	2.1	24
				Mean	35

Figure 5d shows the variation of the summer rainfall and Zn deposition data from Figures 1 and 2 along our transects. The Zn deposition fell sharply with distance from the urban area (sites 1-4) and became approximately constant with distance beyond site 5. Furthermore, both Zn deposition and Zn concentrations in soils were relatively constant northeast of site 5. The large summer rainfall peak at about sites 6, 7, 18, and 19 was not reflected in the metal concentration in the soil.

Background concentrations were determined using the values in the 30-45 cm layer at sites where the concentration was relatively constant which included sites 5 through 18 (see Fig. 5). The mean concentrations for Cd, Zn, and Pb in this layer and at these sites are given in Table 3.

These values are similar to others reported in the literature. Parker et al., (1978) found background levels in the 14-25 cm layer in dune soils at a rural site to be 10.3 µg g^{-1} for Zn, .1 ug g^{-1} for Cd, and 3.5 ug g^{-1} for Pb. The wetland soils from the same site produced concentrations of 19 ug g^{-1} for Zn, .5 ug g^{-1} for Cd, and 11 ug g^{-1} for Pb. In the work of Pietz et al., (1978) on agricultural soils in northwest Indiana, background levels were 38 ug g^{-1} for Zn, and .05 ug g^{-1} for Cd, at a depth of 45 cm.

Discussion

There are several processes, other than atmospheric deposition, that can contaminate soils with heavy metals. Runoff from nearby highways is a source of Zn, Cd, and Pb. Also farming activities such as application of sewage sludge and fertilizer could conceivably contribute significant quantities of these heavy metals. Due to the exploratory nature of this study (i.e. a limited number of soil samples and no quantitative data on specific sources) their possible contributions cannot be fully assessed.

Other studies have quantified roadway contributions (Lagerwerff and Specht, 1970; Peyton et al., 1976). Zn, Cd, and Pb levels in soils near the roadways sampled by Lagerwerff reached the background concentrations shown in Table 3 at a distance of 32 m from the highway. Peyton et al., found these metals approaching their background concentrations within 15 meters of a major highway. Our sampling sites were all at least 15 m away from any roadway. In most cases the nearest roads were secondary county roads.

A study on sewage sludge application (Kirkham, 1975) noted extreme elevation of these heavy metals over a period of 35 years. These concentrations were: Cd, 70.5 µg 9^{-1} Zn, 2065 ug g^{-1} and Pb, 1015 ug g^{-1} in the 0-30 cm layer. Comparison of these concentrations with those shown in Figure 5 suggests that if sewage sludge has been applied at any of the sites sampled, it must have been instituted within the last few years and only at the sites near the urban area. These facts, along with the smooth decrease of metal concentrations with distance suggest that the measured metal concentrations in soil depend primarily on proximity to the St. Louis urban-industrial area.

Table 3. Mean concentrations and standard deviations for the 30-40 cm layer at sites 5 through 18. These are considered background values for the sites sampled.

	Mean concentration, $\mu g\ g^{-1}$	Standard deviation, $\mu g\ g^{-1}$
Zn	20	7.0
Cd	0.10	0.06
Pb	17	4.0

Table 4. The metal content in excess of background of a 45-cm soil column having a cross-section of 1 cm2, at two locations.

	Mass, µg	
	Site 1	Sites 5-18
Zn	14,200	210
Cd	126	5.4
Pb	2,770	189

<u>A mass budget calculation</u>. A useful exercise in testing hypotheses regarding sources is to attempt a mass budget calculation. In this instance, we are interested in testing whether the measured metal content of the soil can be accounted for by atmospheric deposition, or whether other sources also contributed.

A mass budget generally requires measurements of the contents of, and transfer rates between, the various reservoirs in the system. Northeast of St. Louis, we had measurements of Zn, Cd, and Pb in the upper 45 cm of the soil, and measured or calculated atmospheric deposition rates. For simplication we assume there is no transport downward through the 45 cm level in the soil, knowing that any such transport would cause an underestimation of the total deposition of metals on the soil.

The exact time period of anthropogenic metal deposition is also unknown, so we took the approach of calculating the time required, assuming present atmospheric deposition rates, to accumulate the present soil burden in excess of background. If the calculated time period is a reasonable one for atmospheric deposition of anthropogenic pollutants, then ;that source can be assumed to dominate. If the calculated time is unreasonably long, then other sources must be important.

The metal content in excess of background, M_{45}, of a 45-cm soil column of 1 cm^2 cross-sectional area was calculated from the equation

$$M_{45} = \sum_{i=1}^{3} ((C_i - B_i) ALD)$$

where C_i is the metal concentration measured in layer i; B_i is the natural background content of layer i, assumed constant with depth and taken from Table 3, A is cross-sectional area, 1 cm^2; L is depth of each soil layer, 15 cm, and D is the bulk density of the soil, taken as 1.5 g cm^{-2}. Separate calculations were performed for site 1, where the largest metal concentrations in soil were found, and for sites 5 to 18, which were in the vicinity of the maximum urban rainfall anomaly. An average value was determined for sites 5 to 18. Results appear in Table 4. As one would expect from the metal concentration distributions shown in Figure 4, the non-background metal content of the soil at site 1, near Granite City, is much larger for all three metals than at sites 5-18, more distant from the urban area.

Evaluation of the contribution of atmospheric deposition to these soil concentrations requires estimates of deposition in precipitation (i.e., wet deposition), and materials deposited in dry form (dry deposition). These are considered next. Wet deposition of Zn in the area of the two transects was measured in project METROMEX during the summer of 1975. No nearby measurements of wet deposition were available for Cd and Pb, so they were estimated by an available calculation method, as was the deposition of all three metals.

Measured Zn deposition in rain at locations very near the soil sampling sites was extrapolated linearly to annual values, based on the amount of rain actually sampled and the mean annual rainfall. The results appear in Table 5,

Table 5. Annual Zn deposition in rainfall.

Site	Measured Zn deposition in rain, $\mu m\ cm^{-2}$			Rainfall corresponding to Zn deposition, mm	Mean annual rainfall (Changnon, 1969), mm	Total Zn deposition adjusted to annual rainfall, $\mu g\ cm^{-2}$
	Soluble	Insoluble	Total			
1[a]	1.71	0.92	2.63	330	838	6.68
5-18[b]	0.076	0.031	0.107	50.7	876	1.85

[a]Zn deposition and corresponding rainfall measured at METROMEX precipitation chemistry sampled (Gatz, 1974), 1.6 km north of site 1.

[b]Zn deposition and corresponding rainfall are mean values for 12 samples in the area of sites 5-18.

which shows that about 3.6 times more Zn (6.68 yg cm^{-2}) is deposited annually in rain near site 1 than in the area of sites 5-18 (1.85 yg cm^{-2}). These results are also given in Table 7, along with calculated total annual deposition values.

Calculations based on the scavenging ratio concept (Chamberlain, 1960) were used to estimated the deposition of Cd and Pb in precipitation. Wet deposition, D_w, on 1 cm^2 of the earth's surface is given by

$$D_w = kR$$

where k is the concentration of any element in precipitation, in yg cm^{-3}, and R is rainfall in cm, giving deposition in yg cm^{-2}. Use of the scavenging ratio allows an estimate of k, from

$$k = W \frac{\chi}{\rho}$$

where W is the scavenging ratio (dimensionless), p is the density of air, 1200 g nr^3, x is concentration in air near the ground in µg m^{-3}. A density of water equal to 1 g cm"^{3} was assumed.

Dry deposition of Zn, Cd, and Pb was calculated using the deposition velocity (Chamberlain, 1960). The annual dry deposition rate D_d (yg cm^{-2} yr^{-1}) is given by

$$D_d = \chi V_d K$$

where x is the concentration in air near the ground, in yg m^{-3} V_d is the deposition velocity, in cm sec-1, and K is a constant to convert to the proper units, given by

$$K = 10^{-6}\ m^3 cm^{-3} \cdot 3600\ sec\ hr^{-1} \cdot 8760\ hr\ yr^{-1} = 31.5$$

The values of parameters used in the calculation are shown in Table 6, and the results are given in Table 7. These results are of the same general magnitude as Zn, Cd, and Pb atmospheric deposition rates measured in northwestern Indiana (Peyton, et al., 1976; Parker et al., 1978). No estimates of Cd deposition at sites 5-18 were made, because atmospheric concentration data were not available.

The number of years required for the soil to accumulated the observed metal contents in excess of background by atmospheric deposition were calculated by dividing the soil contents (Table 4) by the annual atmospheric depositions (Table 7). Results in Table 8, show required time periods of 300 yr or more for the three metals at site 1, and 55 *yr* and 30 yr for Zn and Pb, respectively, at sites 5-18.

Table 6. Values of V_d, W, and x used in calculations of wet and dry depositions.

	V_d[a] cm sec^{-1}	W[a]	χ, $\mu g\ m^{-3}$ Site 1[b]	Sites 5-18[c]
Zn	0.62	---	0.113	0.104
Cd	0.45	125	0.018	-----
Pb	0.30	76	0.62	0.41

[a]Values taken from Gatz (1975).

[b]Zn and Pb concentrations are mean values from 23 filter samples collected near Granite City, IL, during summer, 1974, in Project METROMEX. The Cd concentration is the mean value for East St. Louis reported by U.S. EPA (1973) for 1968.

[c]Zn and Pb concentrations are mean values from 31 filter samples collected near Edwardsville, IL, during summer, 1975, in Project METROMEX.

Table 7. Atmospheric deposition for two locations near soil sampling sites.

	Annual deposition, µg cm^{-2} yr^{-1}					
	Site 1			Sites 5-18		
	Wet	Dry	Total	Wet	Dry	Total
Zn	6.7	2.2	8.9	1.8	2.0	3.8
Cd	0.16	0.26	0.42	---	---	---
Pb	3.3	5.5	8.8	2.3	3.9	6.2

The results for sites 5-18 are of approximately the proper magnitude (30-55 yr) for atmospheric deposition of industrial emissions to be a major source, especially in view of the fact that there is a natural mechanism, the growth and decay of plants, that can account for some of the observed enrichment of the surface layer (Swaine and Mitchell, 1960). Local sources of airborne metals have been operating for several decades. For example, an electrolytic Zn refiner in East St. Louis was built in 1929-1930, rebuilt and expanded in 1940, and expanded again slightly in the 1960's (McCown, 1979). Also a Zn smelter operated in Fairmont City, Illinois, until about 1960. These two sources would emit Cd as well as Zn, since the two elements occur together in Zn ores. Antiknock gasoline increased significantly as a source of Pb in the early 1940's and is for the major source of airborne Pb today (National Academy of Sciences, 1972).

The long accumulation times for site 1 in Table 8 show that atmospheric deposition, at present-day deposition rates, is insufficient to account for the accumulated metals. Parker, et al., (1978) obtained found similar long accumulation times for atmospheric deposition to a forested ecosystem in northwest Indiana. Their values were 1100 yr for Zn, 600 *yr* for Cd, and 200 yr for Pb.

The discrepancy at site 1 could be caused by any of the alternate sources of metals mentioned earlier, or some combinations of them. Another possibility is that atmospheric concentrations, and hence depositions, are currently much smaller than at some earlier time. Reductions in concentrations may have resulted from industrial emission controls installed recently, or by the closing of former sources. For example, the Zn smelter formerly located at Fairmont City, 8 km south of site 1 (See Figure 2a) is known to have been a prolific source (McCown, 1979). This is supported by some 1966 measurements of Zn in the local horseradish crop (Peck, 1976). Exceptionally high concentrations were measured near Fairmont City, and the local grower attributed this to an industry "belching yellow smoke." Such a source might be expected to cause deposition rates much higher than those occurring at the present time, and could account for at least a portion of the unknown source of all three metals at site 1.

Metals in northwest Indiana soils. The third objective of this work was to evaluate existing data on metal concentrations in northwestern Indiana soils for evidence of increased deposition caused by city-produced rainfall.

Zinc and cadmium accumulation in agricultural soil was investigated by Pietz et al., (1978) in northwestern Indiana. They sampled soils along two transects. One ran from northwest to southeast from Gary to Culver, Indiana. The other ran west to east from Calumet City, Illinois, to La Porte, Indiana. Results are shown in Figure 6. The northwest-southeast transect indicates decreasing metal concentrations from the urban to the rural environment. However, the curve is not as smooth as along the St. Louis transects and the maximum concentrations were not as large. In Indiana Zn varied from 16-126 $\mu g\ g^{-1}$ and Cd from 0.05 to 0.6 $\mu g\ g^{-1}$ in the surface layer; the comparable values near St. Louis were 15-253 $\mu g\ g^{-1}$ for Zn and 0.15-2.37 $\mu g\ g^{-1}$ for Cd. These differences could simply reflect the relative

Table 8. Years required to accumulate soil contents in excess of background by atmospheric deposition only.

	Time, yr	
	Site 1	Sites 5-18
Zn	1600	55
Cd	300	--
Pb	320	30

proximity of the sampling sites to sources, or they could also be influenced by differences in soils. The Indiana soil was mostly sandy in texture, ranging from sand to silt loam, while the soils sampled at St. Louis were predominantly loam or silt loam ranging from clay loam to sandy silt loam.

, The west-east transect showed a much different pattern (Figure 6), with both metals having large fluctuations in concentration from one end to the other. In particular, the samples from the La Porte area (see Figure 6) had high concentration of both Zn and Cd, relative to other samples on the same transect. Since La Porte has been noted for its rainfall anomaly (Changnon, 1968) the question arises as to whether the high metal levels there might be attributed to the rainfall anomaly. However, Pietz et al. (1978) attribute the large variations along the east-west transect to natural variations in background levels of different soil types. At La Porte, particularly, this view is supported by the high metal concentrations found at the 45 cm level (Figure 6). Indeed the 45 cm level concentrations of both Zn and Cd at the La Porte sampling site equal or exceed those in the plow layer. The interpretation of the ug g^{-1} high soil metal contents (80-120 for Zn and 0.31 for CD) at La Porte, is based, unfortunately, on samples from only one site in the area. This interpretation, however, appears to be consistent with the observations at St. Louis where 1) comparable concentrations were observed only within 20 km of sources, and 2) relatively low metal concentrations (about 20 ug g^{-1} for Zn and 0.2 ug g^{-1} for Cd) were found in areas where atmospheric deposition was a major source.

Another relevant issue is that of possible health effects from metal contamination of the food chain. Pietz et al., (1978) also examined metal concentrations in the leaves and grain of corn, finding that there were smaller concentrations in crops on the northwest-southeast transect than at their control site in Lafayette, Indiana. They concluded that because of the limited areas of metal-contaminated soil, and the relatively low concentrations, "... no human or animal health problems are expected from harvested crops or silage." This is supported by other studies which have indicated that most heavy metal absorption occurs in the roots, and very little progresses into the stem, leaves, and grain (Kirkham, 1975; Parker et al., 1978; John et al., 1972), even in soils treated by sewage sludge, and containing much greater metal concentrations.

Conclusions

Concentrations of Zn, Cd, and Pb were measured in soils collected along two transects running northeast from Granite City, Illinois. The highest concentrations observed were near Granite City, and coincided with the area of maximum Zn deposition in rain area found in the METROMEX study. Only slight increases over background were found for the same three metals in the soils in the region of maximum urban rainfall anomaly, near Edwardsville, Illinois. Calculations of the time period required for atmospheric deposition to account for metal concentrations in the soils shows that atmospheric deposition is a major source of the low metal concentrations in the area of the city-produced rainfall anomaly, but other sources must have contributed to the maximum values found near Granite City.

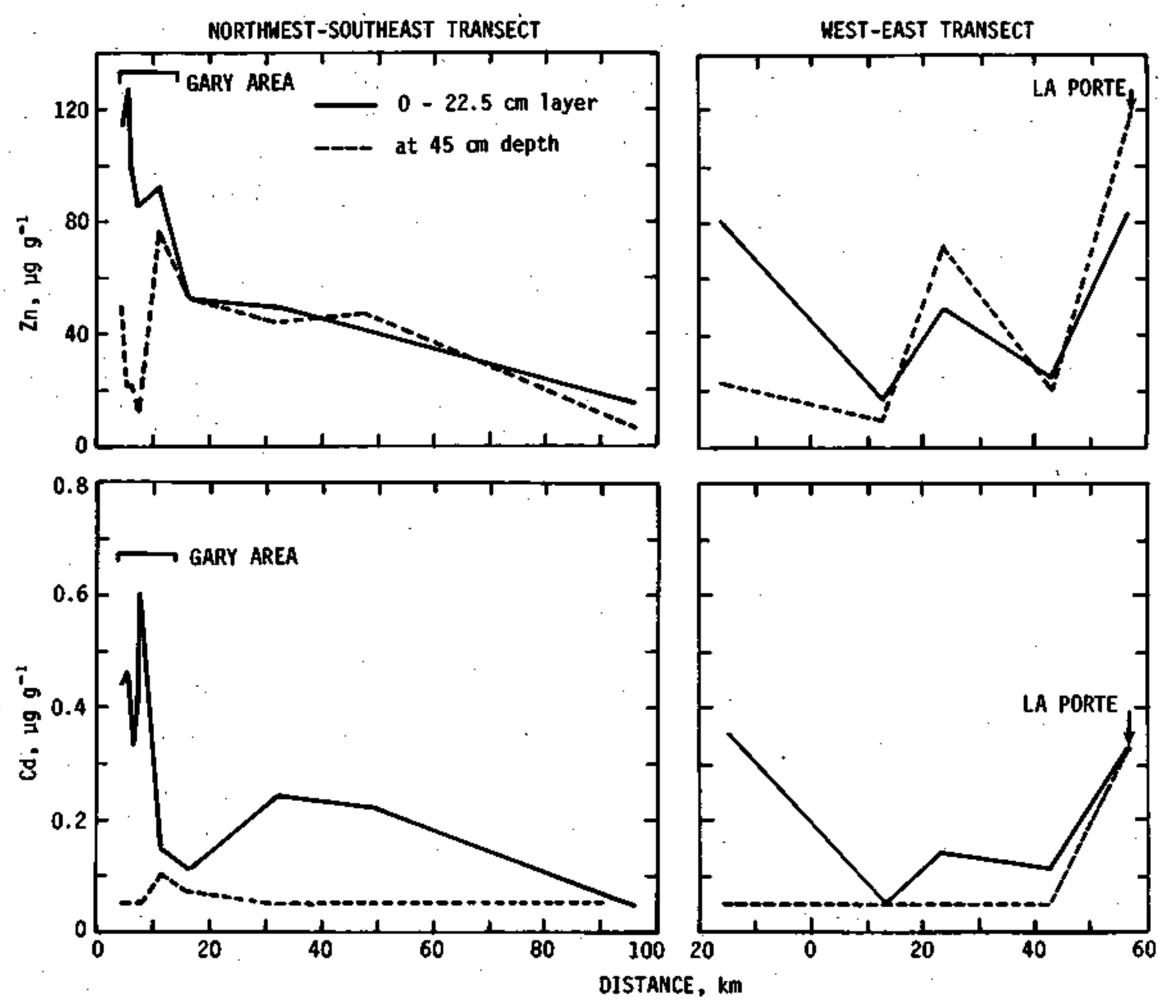

Figure 6. Variation of Zn and Cd in soils along two transects in north-western Indiana. (Data from Peitz et al., 1978).

Data available in the literature on soil concentrations of Zn and Cd in northwest Indiana lead to similar conclusions. The highest concentrations of metals in soils were found near urban area sources. High metal concentrations were also found in soils in the area of the La Porte rainfall anomaly. However, evidence available from one sampling site near La Porte, and extrapolation of the results from St. Louis suggests that these high concentrations were probably natural variations, and caused by city-produced rainfall. Additional evidence to confirm these present indications would be *very* desirable.

Observed concentrations of metals in soils affected by city-produced rainfall while influenced by man's activities, are well within the range of natural variations in soils, and appear to offer no threat to crop production or contamination of the food chain.

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SELECTED IMPACTS RELATED TO SUMMER PRECIPITATION CONDITIONS IN THE CHICAGO AREA

Jan Bertness

INTRODUCTION

Background

It has been recognized for many years that weather phenomena in cities differ somewhat from those of the surrounding countryside (Landsberg, 1956). Unfortunately there was relatively little systematic research in the United States on the inadvertent modification of weather by urban areas until the late 1960's. In 1968, however, Changnon demonstrated that the Chicago urban area received more precipitation, more thunderstorms and more hail days than did the surrounding regions and that the increases were greatest not in the city itself but in an area about 30 miles downwind, near the town of La Porte, Indiana (Changnon, 1968). The report generated a great deal of interest, partly because of the range of weather phenomena altered by the urban area, partly because of the magnitude of change in these phenomena (31% more precipitation, 38% more thunderstorms, 246% more hail days), and partly because of the discovery that alterations in atmospheric phenomena were not confined to the city of Chicago itself. In fact, people living some distance from the urban area and presumably not responsible for the altered weather, were the ones who had to accept the consequences—whether good or bad.

Studies of other cities supported the findings from La Porte and Chicago, finding that rainfall, heavy rainfall, thunderstorms, and hail were increased in, and especially downwind from, the cities (reported in Changnon, 1976). Finally, a major research study of inadvertent weather modification, the Metropolitan Meteorological Experiment (METROMEX), was designed and executed in the St. Louis area. The magnitude of the anomalous weather conditions in the St. Louis area are described elsewhere (Changnon et. al., 1977). It is sufficient to note that marked increases in rainfall, especially summer rainfall, in the number of heavy rainstorms, and in the frequency of thunderstorms and hail were again found to result from the presence of the city.

The consistency with which urban areas were found to have anomalous weather conditions and the magnitude of these anomalous conditions suggest that the modified weather is not only interesting meteorologically, but of great importance. In fact, it is reasonable to assume that the modified weather has marked impacts on the people, activities, institutions, and structures in an urban area. Based on this assumption, the present research project was planned to examine the range of impacts which the modified weather might have on human activities and to determine quantitatively the effect of the modified weather on a number of specific human activities in the Chicago area. However, as will be seen in the next section, this was not easily accomplished. It is *very* difficult to find adequate geographical control areas for some types of human activities. Similarly, changes over time in an activity may be a function of a host of variables integrated with modified weather. In addition, it usually is not possible to determine whether a particular rainstorm, hailstorm, etc., is a result of urban effects or would have occurred naturally. For these reasons, the determination of the effects of modified weather on a particualr social activity or condition becomes most difficult, particularly given the time and financial constraints of this project. Because of this, the goals of the project were restricted to the analyses of the relationships between particular types of weather (those types which are modified in an urban area, such as rain, thunderstorms, etc.) and various human activities, without any attempt to isolate the specific contribution of the modified component of the weather to the human activity. Ascertaining the impacts from modified weather usually involves one of two approaches. The first approach, the "target area vs. control area" approach results in statements about the human impacts of modified weather, but requires historical data and control areas. The second approach, the "matched-pair" approach, requires neither, but only allows statements to be made about the relationship between a type of weather and a human impact, without being able to isolate the modified component.

Available Methodologies

Currently there is relatively little literature on the social impacts of inadvertently modified weather or on appropriate methodologies for determining these impacts (*), although some of the difficulties involved in this type of study were outlined by the Weather Modification Advisory Board (1978) and Robinson (1977).

However, at least one research effort to determine a range of impacts resulting from modified weather has been completed. This study (Changnon, et. al., 1977) was part of the METROMEX project and examined the impact of the St. Louis weather anomalies on a number of activities and conditions in the area. Major emphaisis was placed on water resources and agriculture although a few impacts on business and industry, on plants and animals and soils, and on human health and activities were analyzed. A variety of methodologies were employed and were summarized by Changnon (1979). Of those methodologies which resulted in quantitative statements of the impacts of the modified weather on an activity, most were by calculations from historical values. In some cases the present magnitude of an activity or condition was compared to its magnitude at a time before the pronounced urban weather modification began. In other cases, impacts were calculated on a "target vs. control area" bases. Changnon (1979) illustrated this technique for the analysis of the effect of urban modified rainfall on crop yields.

While the use of historical records and/or control area data is probably the ideal way to determine the impact of modified weather on activites, it did not appear to be a practical approach for this study, which had limited time and resouces and which concentrated on transportation, utilities, and city

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*A systematic in-depth review of the literature was not possible in this study.

services, as will be outlined below. Frequently, historical records of these types of activities or even adequate historical records of weather conditions for very small areas (corresponding to a bus route, for instance) are nonexistent or extremely difficult to obtain. Or, if the records exist, changes in the human activity over time for a variety of reasons unrelated to the weather, may far overshadow the weather-induced changes. For instance, changes in traffic volume, driving speeds, types of automobiles, etc., over the past 30 to 40 years may well be more important in influencing accident rates than is the weather.

The identification of acceptable control areas would have been even more difficult. For instance, suppose the total number of automobile accidents occurring during a summer in a target area were known. It would be hazardous to compare this value to the number of accidents in a control area, since it would probably be impossible to find a control area that was comparable in traffic volume, type or condition of roads, percentage of drinking drivers, and a host of other known and unknown variables which might influence accident rates. Resulting differences in accident rates might reflect the anomalous weather conditions in the target area, but might be primarily a reflection of any of the other variables. To compare the changes in accident numbers over time between target and control areas would also be hazardous, since road conditions, etc., in the target area might have changed over time in a manner very different from the changes in the control area.

Fortunately, another technique is available which does not require long historical records or the existence of a separate control area. This approach, which was used by Sherretz and Farhar (1978) in a study of traffic accidents in the St. Louis area, makes use of matched pairs of days. On one of the matched days some weather phenomenon, such as rainfall, has occurred. On the other day of the pair no rainfall occurred. Human activities occurring on one of the days are then compared to the same activity on the other day. For instance, Sherretz and Farhar compared the mean number of traffic accidents occurring between 4:00 and 9:00 p.m. on summer days having rainfall between those hours with the mean number of traffic accidents between 4:00 and 9:00 p.m. on a set of matched days (each occurring exactly one week from one of the rain days and having no rainfall). The difference between the means was then compared using the t-test for matched pairs. (The technique is discussed in more detail below). This approach can be employed even when only a year or two of data are available and the study area can serve as its own control. Many variables having nothing to do with the weather are controlled rather effectively, whether or not their existence is known.

The major disadvantage to this methodology is immediately apparent. The results actually do not indicate the impact of modified weather (such as increased rainfall) on a human activity. Instead all that is learned is the relationship between a particular type of weather (whether natural or urban-induced) and the occurrence of some type of human event. The results, for instance, might indicate that rainfall causes traffic accidents to double, but do not indicate what percentage of total accidents are the result of modified conditions. In fact, the only thing that can be said about the role of the modified weather is that if weather type x leads to impact y then an increase in weather type x should lead to an increase in impact y.

A second disadvantage is that the methodology is not appropriate for some types of data. It obviously could not be used (at least not if it employed pairs of days) to study crop yields, which are a function of rainfall for the season as a whole. Similarly, many water supply problems, from flooding to drought, will reflect conditions over a period of time rather than being dependent on one day's weather. Fortunately, many of the activities for which the matched-pair approach is inappropriate (such as agriculture and water supplies) are those for which it is possible to use the target-control approach. Other disadvantages will be explained below, after a more detailed description of the methodology.

The methodology is not without its advantages, however. Besides having low data requirements (neither historical data nor a control area is needed), it is easy to use and is applicable to a wide variety of activities. More importantly, since it considers the relationship between a particular type of weather in general and a social impact, a variety of relevant studies are already available in the literature. The results from many of these studies are not in a form from which useful assumptions about the impact of modified weather on the activity can be made. However, there are certainly many studies which do contain appropriate types of information. These range from surveys of the impact of weather on a variety of human activities to technical reports which examine the relationship between a specific weather condition and a specific activity. Again a comprehensive literature review was not undertaken, but works by Maunder (1970), Changnon (et. al., 1977), the Weather Modification Advisory Board (1978), Sewell (1966), McQuigg (1975), the Special Study Team of the South Dakota State University Agricultural Experimental Station (1973), Ferrar (1976), Taylor (1972), and Taylor (1974) discuss dozens of these studies and provide useful bibliographies.

The results of this methodology can not address the specific impacts of modified weather, but do at least identify those activities which are probably affected by the modified weather and give some indication of the magnitude of impacts to be expected.

Purpose

Because the types of human impacts examined in this study did not easily lend themselves to the target-control area approach, the matched pair approach was used in most cases. This meant that the original goal of determining the impact of modified weather on human activities was not attainable. Instead the general effect of rainfall, heavy rainfall, etc., on human activities was determined.

The purpose of the project then became to identify the range of impacts that rainfall, and where possible those due to heavy rainfall and thunderstorms, has had on human activities in the Chicago area, and to examine quantitatively the impacts these weather phenomena have had on selected aspects of life. The ultimate goal was to answer such questions as "What happens on a rainy day in an urban area? Do car accidents increase? If so, by how much? Does ridership on the mass transit system increase or decrease, and by what percent? How much money does the transit system lose or gain? If a person plans to fly out of a major airport, what are his chances of a delayed flight compared to his chances on a non-rain day?" Also, where possible, the effects of rainfall or thunderstorms on a particular phenomenom (such as car accidents or electrical power interruptions) were compared for different parts of the urban area.

Study Area

The Chicago area, including parts of northern Indiana (downwind from Chicago) was selected for this study. The choice was based primarily on the availability of extensive rainfall data for the area for the past three years. A network of 320 recording raingages was in operation from the spring of 1976 until the fall of 1978 as part of the Chicago Hydrometeorological Area Project (CHAP) (Changnon and Huff, 1977).

Activities occurring in Cook County, Illinois (which contains the city of Chicago and many of its suburbs) and the northern parts of Lake, Porter and La Porte Counties in Indiana were studied. (The exact study area varied for different activities depending on the availability of data, but areas will be described in the appropriate sections below). Some of this area does not experience modified weather modification. However, since the purpose was to examine the effects of particular types of weather, with no effort being made to isolate the effects of modified weather, this did not matter. Also it seemed worthwhile to look at weather effects on all types of communities (from densely populated urban areas to suburban and rural areas). It is quite possible that the effects vary, which could be important when planning urban expansion into areas of modified weather.

The summers (June-August) of 1976, 1977, and 1978 were chosen for the analysis. Summer was chosen since it is the season of greatest urban precipitation modification. These particular summers were chosen to correspond to the extensive data available from CHAP.

SUMMER WEATHER IMPACTS ON HUMAN ACTIVITIES REPORTED IN NEWSPAPER ARTICLES

Even an exhaustive literature search would not provide a list of all impacts which summer weather might have on human activites in an urban area. Since no extensive literature search was possible in this study, a list of impacts was prepared from newspaper accounts of weather-related incidents in Chicago. Articles and pictures which reported these incidents were clipped from the Chicago Tribune, the Gary Post-Tribune, the Valparaiso Vidette-Messenger, and the La Porte Herald-Argus for the period May - August of 1978. These articles contained descriptions of impacts resulting from the types of weather associated with summer rains and storms (and which are subject to modification in an urban area), or from a conspicuous absence of summer rainstorms (such as a drought). The impacts were primarily a function of rain, heavy rain, or thunderstorms, but in some cases were a function of the winds, changes in temperature, or fog accompanying rain. Events which occurred outside of the Chicago - Northwest Indiana area were not listed.

The resulting articles were analyzed to prepare a list of the specific impacts which occurred in the Chicago area. Those impacts receiving the most newspaper coverage included severe car, boat, and plane accidents; delayed arrivals and departures at O'Hare Airport; interruptions in power supplies and telephone service; lightning - causes fires; flooded streets and viaducts; fallen tree limbs and power lines; flooded basements; and agricultural problems. Also, a large number of articles and pictures covered sports and recreational events which were delayed, postponed, cancelled, or made unpleasant by the weather, and some events which were made more pleasant by ideal weather conditions. Finally, there were many photographs of people enjoying, or not enjoying because of the weather their everyday activities. Table 1 gives a complete list of the impacts reported in the newspapers.

Even the complete list, of course, includes only a fraction of the total weather-induced impacts in the area, and a biased fraction at that. It contains only these impacts which are noticed by reporters and which the reporters perceive to be the most newsworthy or interesting to their readers. Many other impacts which are less noticeable or less interesting are not included even if important. For instance, car accidents increase greatly on rainy days, yet this normally was not mentioned in newspaper accounts. Only the severe accidents were reported.

Still, the list in Table 1 provides some indication of the range of impacts resulting from summer weather in the Chicago area. More important, it provides a very good indication of the types of impacts familiar to people in the area (either from observation or after reading their newspapers). The list also gives some indication of the human activities which may be particularly affected by modified summer weather.

Based primarily on this list a number of specific types of impacts were selected for extensive analysis. The results of the analyses are presented in the following section.

Table 1. Impacts of Summer Weather on Human Activities in the Chicago Area Reported by Newspapers (May-August 1978).

Transporation

Automobile traffic
- accidents
- highway closed due to heavy rain

Boating
- accidents
- rescue efforts delayed

Air traffic
- departure and arrival delays
- small plane crashes

Mass transit
- passenger delays due to damage to tracks or loss of power

Communications

Telephone
- service interrupted

Power

Electrical power
- power interrupted

City Services

Water supply
- water availability
- water consumption

Sewage treatment
- pollution (treatment facilities unable to handle increased discharges after heavy rains)

Fire protection
- lightning caused fires
- fires due to fallen electrical wires

Street maintenance
- flooding of streets and viaducts
- fallen trees, limbs, and power lines
- potholes

Sports and Recreation

- delayed, postponed, or cancelled events
- physical discomfort during sports or recreation (rain, cold, heat)
- decreased ability to pursue recreation (poor fishing, etc.)
- heightened enjoyment of sports or recreation due to particularly pleasant weather

Non-Recreational Activities (children walking to shcool, etc.) - mostly pictures

- heightened enjoyment of daily activities because of weather
- physical discomfort during daily activities

General Property Damage (other than that listed under city services)

- water damage to buildings and flooded basements
- other flooding
- wind damage to roofs, windows, and equipment
- falling and fallen trees, limbs, and power lines

Injuries, Illness, and Death

- drownings in flooded ditches, culverts, and sandpits
- lightning deaths and injuries
- injuries due to flying glass or falling structures
- sunburn
- increases in mosquito population
- changes in air pollution levels

Agriculture

- delayed planting
- changes in type of crop planted
- insufficient rain
- increased numbers of insect pests

Miscellaneous

- delays in construction
- interruptions in other work activities (such as cemetery maintenance
- losses in retail trade
- changes in commodity prices on the Chicago Board of trade
- changes in human behavior
- reports of tornado watches
- suggested precautions for floods and tornadoes

QUANTITATIVE ANALYSIS OF SELECTED IMPACTS IN THE CHICAGO METROPOLITAN AREA

Methodology

A number of impacts were selected for more detailed analysis from the preceding list and from other literature on weather impacts, especially Maunder (1970) and Changnon et al., (1977) These were impacts on transportation, communications, and power supply for the entire Chicago-Northwest Indiana area and on city services and recreation in the town of La Porte, Indiana. These impacts were selected for their importance in the daily functioning of the urban area. Impacts on other activities were not pursued due to the time limitations of the project. Selections and omissions were also governed in part by the availability of data and by the availablility of other studies (for example, impacts on agriculture are included elsewhere in this report). La Porte was chosen as the site for additional study because of its location in the area of maximum weather modification.

The complete list of activities and occurrences which were selected includes: automobile accidents, traffic volume, aircraft accidents, departure delays at O'Hare Airport, boating emergencies, ridership on mass transit systems, interruptions in telephone service, and interruptions in power supplies. For the town of La Porte, the investigation included an examination of weather impacts on the services provided by the Fire, Water, Sewage, and Parks and Recreation Departments, and by a municipal golf course.

The impact of rain (and where possible, heavy rain and thunderstorms) on these activities was determined in most cases using a methodology similar to that of Sherretz and Farhar (1978). Mean numbers of traffic accidents, delayed flights, or park users on rain days were compared with mean numbers of traffic accidents, delayed flights, or park users on non-rain days.

Most analyses employed the following procedure. First, a data set (such as records of ridership on the Chicago bus system) was acquired from the appropriate agency. If possible, records were obtained for June, July, and August (summer) of 1976, 1977, and 1978, but shorter records were also accepted. Next, the boundaries of the relevant geographical area (for instance, the city limits of Chicago) were delineated. Also, particular hours of observation were selected (for example, 4:00 - 9:00 p.m. for traffic accidents, 5:00 a.m. - 9:00 p.m. for mass transit riders). The selected hours depended on a number of factors which will be discussed later. After determining the location and time periods of interest, project rainfall records were searched to identify "rain days" and "non-rain days." The search employed computer printouts of rainfall totals during specific time periods over the CHAP network. For instance, it was possible to obtain a map giving the total rainfall, by station, between 4:00 and 9:00 p.m. in the Chicago-Northwest Indiana area for each day on which it rained between these hours.

Using the boudaries already defined, a rain-day (for most analyses) was defined as one on which at least 80% of the CHAP raingages within the area received at least .01 inch of rainfall during the selected hours. A non-rain day was defined as one on which no more than 20% of the raingages received .01 inch of rainfall or more (exceptions will be noted below).

A list was then prepared of all days meeting the "rain-day" criteria. Next, the day exactly one week later than each rain day was checked to see if it met the criteria for being a non-rain day. If it did, it was selected for the sample. If it did not (if more than 20% of the gages reported rain), or if it fell on the Fourth of July weekend or after the end of August, it was rejected. In this case, the day one week prior to the rain-day was examined. If it was acceptable (and had not been matched to any other rain-day) it was included in the sample. If neither of the potential "non-rain days" were acceptable, both they and the rain day were eliminated from the sample.

Using these lists, mean numbers of accidents, mean numbers of bus passengers, mean percentages of delayed flights, etc. were prepared for rain days and then for the matched non-rain days. The resulting means could then be compared to determine the relative impacts of the rain days on the phenomena being studied. (For example, traffic accidents doubled in some locations on raindays, bus ridership decreased by 3-4%, park usage decreased by almost 50%, etc.). For some of the analyses it was not possible and/or appropriate to use the methodology as outlined here and it was either modified or a different methodology substituted. The reasons for this and descriptions of the alternate procedures used will be described in the appropriate sections below.

Necessary Precautions for Interpretation of Results

The results obtained from this methodology and from the data collected must be regarded with some caution. First, the rain/non-rain day approach is meant only to indicate the types and degrees of impacts which may be expected to coincide with rain days. Causation is not necessarily implied. For instance, the tremendous increase in delayed departures from O'Hare on rain days is probably due more to poor visibility, turbulence, etc. than it is to rainfall itself. However, given the exploratory nature of this study, this approach is perhaps still reasonable, as long as the proper interpretation of results in used.

Another difficulty in this study, due more to available data than to the methodology, was the inability (in some cases) to match the time occurrence of a social phenomenon with rainfall records. In some cases (particularly mass transit), only daily records of events were available. This posed a problem since the rainfall frequently occurred during only a small portion of the day. There was no good solution to this problem so in some cases it was assumed that most passengers ride between 5:00 a.m. and 9:00 p.m., most golfers play between these hours, most boating accidents occur between 9:00 a.m and 9:00 p.m. etc. Then, the daily frequencies were compared to rainfall during these periods. This still posed a problem, since a number of distinctly different weather types could occur within these hours. The section on mass transit reveals some further attempts to overcome this problem, but in most cases the problem remained. This may mean that many of the results underestimate the impact of the rainfall. Again, the best remedy for this difficulty is a guarded acceptance of the results.

A related problem was the selection of time periods. Selections were based in part on information about rush hour times, in part on intuition, and in some cases, convenience. Given the limitations of the study and the large amounts of time required to select and analyze computer printouts for various time periods, it was necessary to standardize the analyses in some way. To do this, three time periods (5:00 a.m. - 9:00 a.m., 9:00 a.m. - 4:00 p.m., and 4:00 p.m. - 9:00 p.m.) were selected and printouts of all rainfall during these 3 periods were obtained. The 5:00 - 9:00 a. m. period was chosen for its correspondence to the morning rush hours, the 4:00 - 9:00 p.m. period was chosen to correspond to Sherretz and Farhar's study and to include the evening rush hour. The 9:00 a.m. - 4:00 p.m. period was selected as suitable for the study of mid-day activities (such as shopping) and to fill in between the other two periods. It was assumed for most analyses that activities between 9:00 p.m. and 5:00 a.m. could be ignored. (Exceptions will be noted below).

Another difficulty involved the availability and comparability of data. Often, an entire data set (June-August for all three summers) could not be obtained. Also, in one case, it was available by quarters (July, August, and September) rather than for the three summer months. The result is that the following analyses are based on varying periods of record, reducing their overall comparability. This is unfortunate, but in most cases probably a smaller source of error than the problems mentioned above.

Finally, because of relatively short records and selection criteria that eliminated most days from consideration, conclusions are sometimes based on very small samples.

Because of these limitations, the numbers and percentages in the following sections must be regarded as approximations at best, or perhaps only as an indication of impacts that deserve further study.

<u>Traffic Accidents</u>

Previous studies have indicated that rainfall, and particularly heavy rainfall, result in increased numbers of automobile accidents (Sherretz and Farhar, 1978; Codling, 1974), although the effect of rainfall on accident severity has not been well established. The present study examined the relationship between rainfall in the Chicago-Northwest Indiana area and the number and severity of accidents occurring there during June, July, and August of 1976, 1977, and 1978. Specifically, it compared numbers of automobile accidents occurring on summer "rain-days" to those occurring on summer "non-rain days" for 1) the city of Chicago, 2) each of the outlying townships in Cook County, and 3) the northern sections of Lake, Porter, and La Porte Counties in Indiana. Also, accident severity on rain and on non-rain days was compared for each of these divisions. Finally, the effects of heavy rainfall on accident numbers and on accident severity were examined for Cook County as a whole and for the entire sample area in northern Indiana.

<u>Accidents Numbers</u>. The number of accidents occurring on a rain day in the Chicago area was determined following the methodology outlined above. First, the area was divided into the regions (primarily townships) listed in Tables 2 and 3. Next, rain days and non-rain days were identified for each region. A

Table 2. Number of Accidents on Rain and Matched Non-Rain Days in Cook County, Illinois by Township.[1]

Township	Population per sq. mile	Mean Number of accidents on rain days	Mean Number of accidents on matched non-rain days	N (No. of Pairs)	Significance[3]	Ratio of Accident Numbers on rain days to accident numbers on non-rain days
Barrington	210	4.00	1.73	15	S	2.31
Berwyn, Oak Park, Cicero	12,644	12.50	4.92	12	S	2.54
Bloom	1,978	4.09	1.82	11		2.25
Bremen	2,531	5.90	3.00	10	S	1.97
Calumet	5,133	1.60	1.60	10		1.00
Chicago	15,051	43.00	17.12	8	S	2.51
Elk Grove	2,756	3.00	1.55	11	S	1.94
Evanston	10,641	4.94	1.75	16	S	2.82
Hanover	979	2.40	1.30	10		1.85
Lemont	404	1.12	0.00	8	S	----
Leyden	4,578	8.38	5.31	13		1.58
Lyons	2,795	7.17	3.67	12		1.95
Maine	5,434	9.75	4.31	16	S	2.26
New Trier	3,938	3.24	1.71	17	S	1.90
Niles	5,172	13.00	5.92	12	S	2.20
Northfield	1,951	5.40	2.07	15	S	2.61
Norwood Park	7,197	1.91	0.64	11		3.00

Table 2 continued

Township	Population per sq. mile	Mean Number of accidents on rain days	Mean Number of accidents on matched non-rain days	N (No. of Pairs)	Significance[3]	Ratio of Accident Numbers on rain days to accident numbers on non-rain days
Orland	402	1.22	1.00	9		1.22
Palatine	1,486	4.43	3.29	14		1.35
Palos	976	3.73	1.55	11	S	2.41
Proviso[2]	5,607	12.92	4.58	12	S	2.82
Rich	1,170	3.50	1.50	8		2.33
Schaumburg	1,625	4.67	2.58	12	S	1.81
Stickney	3,187	2.08	0.58	12	S	3.57
Thornton	3,997	16.83	6.00	6	S	2.81
Wheeling	3,248	7.75	4.83	12	S	1.60
Worth	4,795	10.00	5.67	12	S	1.76

(1) Only accidents occurring on the selected days in June, July, and August of 1976 & 1977 between 4:00 p.m. and 9:00 p.m. are included.

(2) Includes River Forest and Riverside townships.

(3) S indicates significance at .05 level using matched pair t-test.

rain day in the city of Chicago was defined as one on which at least 80% of the 25 CHAP raingages within the city limits received at least .01 inch of rain each between 4:00 p.m. and 9:00 p.m. A non-rain day was one on which 20% or fewer of the raingages within the city received rainfall of .01 inch or more during those hours. In the townships the raingages were frequently not well centered with respect to township areas, so raingages within 0.5 mile of the township boundaries were also included, again using the 80% and 20% criteria.

Because volume of traffic and numbers of accidents vary by day of the week (Sherretz and Farhar, 1978), and possibly by time of summer or even by year, the matched pair approach was used in selecting and analyzing the rain days and the non-rain days. When the lists of rain days and matching non-rain days had been prepared, the numbers of accidents occurring on each of the days between 4:00 and 9:00 p.m. were determined. Accident numbers were obtained for Cook County from the Illinois Department of Transportation for 1976 and 1977. Data for the Indiana townships were obtained from the Indiana State Police for 1977 and 1978. Both sets of data included the date, time, and location of each accident as well as the number of injuries. Using these data, the total number of accidents on all rain days for a township were counted and then divided by the number of rain days to determine the mean number of accidents per rain day for the township. Similarly, a mean number of accidents per non-rain day was computed. The significance of the difference between these means was then tested using the t-test for matched pairs. For example, during the summers of 1976 and 1977 there were 15 matched pairs of rain and non-rain days in Barrington township in Cook County.

The average number of accidents on the 15 rain days was 4.0. The average number on the 15 non-rain days was 1.73 and the difference was significant at the .05 level. Table 2 gives the mean numbers of accidents on rain and non-rain days for Chicago and for each township in Cook County, and Table 3 gives information for the townships in Northwestern Indiana. It is immediately evident that far more accidents occurred on rain than non-rain days, with township having up to 3.57 times as many accidents on rain as on non-rain days. While the number of pairs for some townships is rather small, and not all differences are significant, there is little doubt that a rainy day in the Chicago area has a major impact on the number of automobile accidents. Also, these results are similar in magnitude to those for St. Louis. Codling (1974), in his study of British accidents, using a rather different methodology, obtained results similar in direction, but of generally smaller magnitude.

The results are particularly disturbing when it is remembered that a "rain day" was a five-hour period during which rainfall may have occurred for only a small segment of time. The impact of the rain during those times when rain was actually falling or the roads were actually wet may be much higher than that obtained here.

Spatial Variations in the Effects of Rainfall on Accident Numbers. It is apparent from the ratios of rain day/non-rain day accident rates (Tables 2 and 3) that there are large variations among the townships. These are no doubt due in part to chance. Some of the townships had relatively few pairs of

Table 3. Numbers of Accidents on Rain and Matched Non-Rain Days in parts of Lake, Porter, and La Porte Counties, Indiana[1].

County-Township	Population per sq. mile	Mean Number of accidents on rain days	Mean Number of accidents on matched non-rain days	N (No. of Pairs)	Significance[4]	Ratio of Accident numbers on rain days to accident numbers on non-rain days
Lake-North	3,868	13.31	6.54	13	S	2.04
Lake-Calumet	3,477	10.54	6.38	13	S	1.65
Lake-Hobart	1,541	2.10	1.40	10		1.50
Porter[2]	335	1.60	.60	10	S	2.67
La Porte-Michigan	2,217	2.50	1.79	14		1.40
La Porte[3]	268	1.55	1.27	11		1.21

(1) Only accidents occurring on the selected days in June, July, and August of 1977 and 1978 between 4:00 p.m. and 9:00 p.m. are included.

(2) Includes Portage, Westchester, Pine, Liberty, and Jackson townships.

(3) Includes Cool Spring, New Durham, Springfield, Center, and Scipio townships

(4) S indicates significance at .05 level using matched pair t-test.

days, and some of the rural townships had few or no accidents on some of the selected days. At the very best, the ratios can be viewed only as approximations. But since this type of research may eventually provide information for metropolitan planning, it seemed worthwhile to make at least a brief examination of variations between townships.

It might be the case that the ratios do vary systematically with type of community (urban, suburban, rural), with road types, etc. Perhaps traffic volume, traffic speed, or some combination of these affects the impact of rainfall on accident numbers. The time limitations of this project prevented an analysis of accident rates by road type (although the information is available in the data from the Illinois Department of Transportation and from the Indiana State Police). Also, it was not possible to determine percentages of road types in each township or volume of traffic by township. However, population density could be computed (U.S. Bureau of the Census 1970, 1973a and 1973b) for each township and this was used as a crude indication of traffic volumes and types of road. It was assumed that townships with low population densities would have generally lower traffic volumes and generally higher percentages of high speed country driving. Townships with very high population densities probably have more traffic congestion, but perhaps a higher percentage of low speed, city type driving. Obviously, this is not a very accurate way of approaching the problem, but was perhaps a reasonable first approximation.

Figure 1 shows the spatial distribution of accident ratios for the city of Chicago and outlying townships of Cook County. It appears that there is some tendency for ratios to decrease with increasing distance from downtown Chicago and, presumably, with population density. The quartile (7) of townships with the highest population densities and the quartile (7) of townships with the lowest population densities have been shaded. Accident ratios for each of these groups were averaged (unweighted). The seven most density populated townships had an average ratio of 2.59, while six of the least populated townships had an average ratio of 1.91 (Lemont did not have enough accidents to compute a ratio). If it is assumed that areas with high population densities also have higher traffic volumes, more congestion, etc., this indicates that in areas of high traffic volumes, rainfall has a greater impact.

None of the townships or township groups in Indiana have population densities comparable to those of the most densely populated quartile of townships in Cook County, but three of the township groups have population densities comparable to those of the least densely populated quartile. Two of these townships have relatively low ratios as would be expected in low density areas. The third has a *very* high ratio, but this may be a function of the small total number of accidents. Although very inconclusive, the results seem to agree with those from Cook County.

Obviously much additional research would be needed to definitely establish this relationship. Some of the townships do not fit the pattern (Barrington, for instance), having high accident ratios and low population densities. This may be a reflection of the relatively small sample size, or result from changes in population densities since the 1970 Census. In some cases, it may be due to major traffic routes existing in low density townships. Finally, it

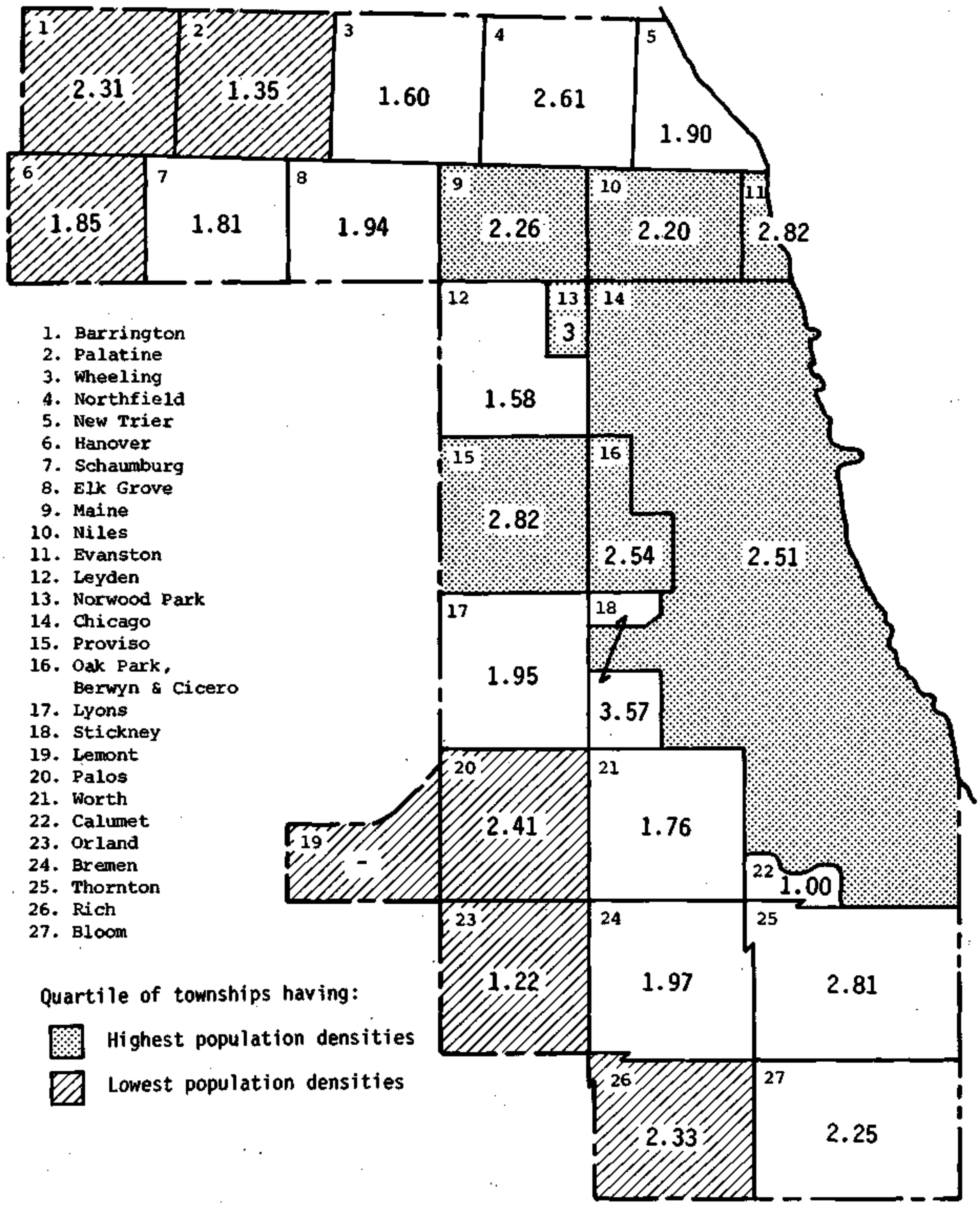

Figure 1. Ratios of mean number of accidents on rain days to mean number of accidents on non-rain days in Cook County townships (Township boundaries are approximate)

might mean that the assumed relationship between population density and traffic volume/congestion is invalid or that the hypothesized relationship between traffic volume and accident ratios is incorrect.

In spite of the uncertainties, the magnitude of the difference between the two sets of townships suggests that further study of the problem would be justified.

Accident Severity. Sherretz and Farhar examined the relationship between accident severity, defined as the number of injuries per accident, and rainfall conditions at St. Louis. They found no consistent relationship, with accident severity increasing on rain days in some St. Louis area towns and decreasing in others. This study has employed the same definition of accident severity and obtained the results shown in Tables 4 and 5. As in the St. Louis study, some areas show increases in accident severity on rain days and others show decreases. As in the case of accident numbers, these results may reflect chance. However, it is again hypothesized that the impact of rainfall on accident severity may be partly a function of traffic volume, type of road (low or high speed), etc. Because the data for this study are aggregated by township rather than by city or town relatively rural areas (presumably low volume, high speed) can be compared with predominantly urban areas. Again, in spite of its many limitations, population density has been used as an indicator of traffic volume and type.

Figure 2 displays the ratios of the number of injuries per rain day to the number of injuries per non-rain day for each township. The quartile of townships having the highest population densities have a mean severity ratio of 1.03, suggesting that rainfall has little impact on accident severity in the highly urbanized areas. The lowest quartile (excluding Lemont) has a mean ratio of 1.69. This means that there are, on the average, 70% more injuries per accident on rain days than on non-rain days in relatively rural areas. The results fron Indiana are less clear, but do not contradict the Cook County findings since the townships all have relatively high rain day/non-rain day severity ratios, as would be expected in areas of low and moderate population density. Importantly, the lowest ratios are in Calumet Township (city of Gary) and Michigan Township (Michigan City). (North Township is an exception to the trend with a relatively high population density and a high severity ratio).

While the conclusion that rainfall has varying effects on accident severity in different types of communities involves as many questionable assumptions and contradictions as conclusions with respect to accident numbers, it is reasonable to hypothesize that different parts of a metropolitan region may react very differently to increases in rainfall. Further study of this relationship would probably be useful.

Impact of Heavy Rainfall on Accident Numbers and Accident Severity. Urban areas not only increase the amount of rain which falls in and downwind (east) of them, but they also increase the amount of heavy rainfall. The impact of heavy rainfall on numbers of accidents and severity of accidents was therefore briefly examined.

Table 6 gives the average number of accidents per period for all townships in Cook County for periods having no rainfall, for periods having any amount

Table 4. Accident Severity on Rain and Non-Rain Days in Cook County, Illinois, by Township.[1]

Township	Number of injuries per accidents on rain days	N_1 Number of accidents on rain days	Number of injuries per accident on matched non-rain days	N_2 Number of accidents on non-rain days	Ratio of injuries per accident on rain days to injuries per accident on non-rain days
Barrington	.550	60	.346	26	1.59
Berwyn, Oak Park, Cicero	.473	150	.322	59	1.47
Bloom	.467	45	.700	20	.67
Bremen	.441	59	.467	30	.94
Calumet	.812	16	.562	16	1.44
Chicago	.378	344	.394	137	.96
Elk Grove	.485	33	.529	17	.92
Evanston	.342	79	.536	28	.64
Hanover	1.375	24	.538	13	2.56
Lemont	1.444	9	----	0	----
Leyden	.266	109	.348	69	.76
Lyons	.523	86	.432	44	1.21
Maine	.333	156	.290	69	1.15
New Trier	.255	55	.310	29	.82
Niles	.321	156	.296	71	1.08
Northfield	.444	81	.612	31	.72
Norwood Park	.476	21	.714	7	.67

Table 4 continued

Township	Number of injuries per accidents on rain days	Number of accidents on rain days	N_1 Number of injuries per accident on matched non-rain days	N_2 Number of accidents on non-rain days	Ratio of injuries per accident on rain days to injuries per accident on non-rain days
Orland	.727	11	.444	9	1.64
Palatine	.710	62	.283	46	2.51
Palos	.439	41	.353	17	1.24
Proviso(2)	.477	155	.382	55	1.25
Rich	.393	28	.667	12	.59
Schaumburg	.286	56	.677	31	.42
Stickney	.640	25	.143	7	4.48
Thornton	.564	101	.472	36	1.19
Wheeling	.376	93	.328	58	1.15
Worth	.308	120	.324	68	.95

(1) Only accidents occurring on the selected days in June, July, and August of 1976 and 1977 between 4:00 p.m. and 9:00 p.m. are included.

(2) Includes River Forest and Riverside townships.

Table 5. Accident Severity on Rain and Non-Rain Days in parts of Lake, Porter, and La Porte Counties, Indiana.[1]

County - Township	Number of injuries per accidents on rain days	Number of accidents on rain days	Number of injuries per accident on matched non-rain days	Number of accidents on non-rain days	Ratio of injuries per accident on rain days to injuries per accident on non-rain days
Lake-North	.382	173	.224	85	1.71
Lake-Calumet	.387	137	.301	83	1.29
Lake-Hobart	.524	21	.214	14	2.45
Porter[2]	.750	16	.500	6	1.50
La Porte-Michigan	.543	35	.400	25	1.36
La Porte[3]	.529	17	.357	14	1.48

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[1] Only accidents occurring on the selected days in June, July, and August of 1977 and 1978 between 4:00 p.m. and 9:00 p.m. are included.

[2] Includes Portage, Westchester, Pine, Liberty, and Jackson townships.

[3] Includes Cool Spring, New Durham, Springfield, Center, and Scipio townships.

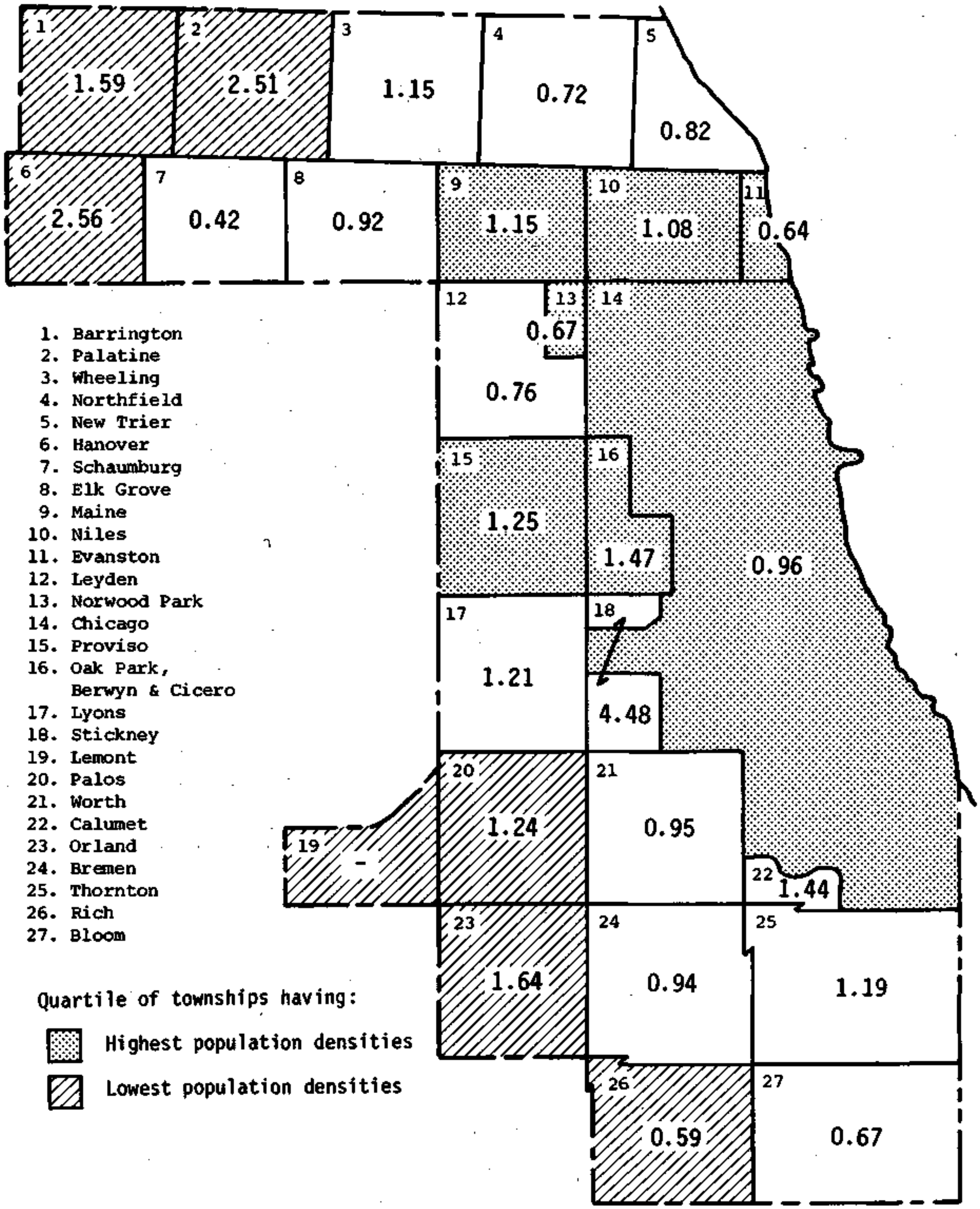

Figure 2. Ratios of injuries per accident on rain days to injuries per accident on non-rain days in Cook County townships (Township boundaries are approximate)

of rainfall, and for periods having the specific amounts: .01-.50 inch, .51-1.00 inches, 1.00-2.00 inches, and more than 2.00 inches. Accident numbers per period for all townships in the study area in Northern Indiana are also presented for the same rainfall conditions.

There is some tendency toward an increase in accident numbers with higher rainfall, but this conclusion is tenuous. The results are not consistent, and some results are based on only one time period. The results are not weighted by population of township (accident numbers per period on rain days in Chicago are summed with accident numbers from rather rural areas). Also, the periods are not independent (for instance, a rain period in Barrington Township might be on the same day as a rain period in Chicago with both being included in the study). In spite of this, the apparent tendency toward increasing traffic accidents with increasing rainfall may have some validity, since similar results were found for St. Louis.

The effect of rainfall amounts on accident severity was more easily examined, although the results were not conlusive. The total number of injuries in all Cook County townships occurring during periods of specific rainfall amounts were divided by the total number of accidents during those periods. Similar ratios were derived for Northern Indiana. The results are presented in Table 7. There is no discernable relationship between amount of rainfall and accident severity.

Summary. The results of the traffic accident analysis for Cook County and for Northern Indiana suggest strongly that rain days do result in greatly increased accident rates. The amount of increase varies with township and it appears that accident numbers are increased more by rainfall in densely populated urban areas than in more rural areas. Accident severity is sometimes increased and sometimes decreased by rainfall. Severity increases greatly on rain days in rural areas, but is approximately constant in dense, urban areas. The effects of heavy rainfall on accident numbers and severity were not clearly established. Heavier rainfall is probably accompanied by increased numbers of accidents, but amount of rainfall apparently has little influence on accident severity.

Traffic Volume

The impact of rain on traffic volume was not extensively pursued. The only data set obtained was from the Indiana Toll Road Commission. The impact of rainfall on Toll Road traffic volume may or may not be representative of its impact on other types of highways or roads in the metropolitan area.

The methodology for this analysis was generally similar to that used for the accident data. An important difference, however, was that no hourly traffic information was available. The available data were daily numbers of vehicles entering and leaving the Toll Road at each interchange. Three interchanges (Gary West, Gary East, and Burns Harbor) were chosen for study and the assumption was made that a large majority of the vehicles entered these points between 5:00 a.m. and 9:00 p.m. (a period for which rainfall data were available).

Table 6. Effect of Rainfall Amounts on Accident Numbers.

	Cook County, Illinois		Parts of Lake, Porter, and. La Porte Counties in Indiana[2]	
Rainfall amount (in inches)	Number of periods	Mean Number of accidents per period[1]	Number of periods	Mean Number of accidents per period[3]
0.0	315	3.20	71	3.20
Any amount over .01 inch	315	6.90	71	562
.01- .50	240	6.14	62	5.74
.51-1.00	51	9.88	7	4.29
1.01-2.00	16	7.69	1	10.00
≥ 2.01	8	9.12	1	3.00

(1) 4:00 p.m - 9:00 p.m. on selected days in June, July, and August of 1976 and 1977.

(2) See Table 3 for list of townships

(3) 4:00 p.m. - 9:00 p.m. on selected days in June, July, and August of 1977 and 1978.

Table 7. Effect of Rainfall Amount on Accident Severity.

	Rainfall amount (in inches)	Number of periods[1]	Number of accidents	Number of injuries	Number of Injuries per accident
Cook County	0.0	315	1007	398	.395
	Any amount over .01 inch	315	2173	935	.430
	.01- .50	240	1473	634	.430
	.51-1.00	51	504	207	.411
	1.01-2.00	16	123	60	.488
	≥ 2.01	8	73	34	.466
Lake, Porter, and La Porte Counties[2]	0.0	71	227	65	.286
	Any amount over .01 inch	71	399	170	.426
	.01- .50	62	356	153	.430
	.51-1.00	7	30	13	.433
	1.01-2.00	1	10	2	.200
	≥ 2.01	1	3	2	.667

(1) 4:00 p.m. - 9:00 p.m. on selected days in June, July, and August of 1976 and 1977 for Cook County, of 1977 and 1978 for Indiana Counties.

(2) See Table 3 for list of townships.

Rain and non-rain days for the sample were chosen using records for the summers of 1977 and 1978 from 11 raingages within 5 miles of the 3 interchanges. A rain day was defined as one on which at least 80% of the raingages reported rain during at least one period (5:00 - 9:00 a.m., 9:00 a.m. - 4:00 p.m., 4:00 - 9:00 p.m.) during the day. A non-rain day was one in which less than 20% of the raingages received rain in any one period. Also, non-rain days were included only if they matched (fell one week later or earlier than) one of the rain days. After selecting the rain and non-rain days, the total number of cars entering the 3 interchanges was computed for each day. Averages were then computed for matched weekday rain days and non-rain days, and for matched weekend rain days and non-rain days.

There were 22 pairs of weekday rain and non-rain days. The average number of entering vehicles on non-rain days was 21,180 and on rain days was 21,077 a decrease of only 0.5%. Eight weekend non-rain days averaged 19,445 entering vehicles and eight matched weekend rain days averaged 17,741, a decrease of 8.8%. (The impact of heavy rain on the Toll Road volume was not analyzed since there were an insufficient number of rain days for doing so). In both cases, the influence of the rain was probably underestimated since most rain days include many hours of non-rain traffic conditions. Also, the vehicles entering these 3 interchanges came from a variety of major highways as well as the local area, so that local rainfall may only be influencing the decisions of some of the drivers.

In spite of these limitations, results indicate that the impact of rainfall on weekday traffic volume (at least on the Indiana Toll Road) is only slightly affected by rainfall, but that weekend driving, which undoubtedly has a larger element of discretion, is significantly reduced. These conclusions are similar to Codling's (1974). He reported an average reduction in traffic volume on weekday rain days of just over 1% but found a decrease of 7.6% when it rained on Sundays in September in Great Britian.

Mass Transit

The Chicago Transit Authority serves almost 1 3/4 million passengers per day (including transfers), and various suburban bus and rain companies serve additional tens of thounsands. There are a number of possible impacts which summer rainfall might have on the use of these systems.

Use of mass transportation might be substituted for walking to nearby destinations, or for the use of a private car if parking problems are perceived. Rainfall might also result in the cancellation of shopping or other discretionary trips, or even of a trip to work. Other possibilities are that passengers would shift from one form of public transportation to another (such as from bus to subway), or that passengers would shift from public transportation to a private car or to a taxi. Actual ridership on any one rain day probably reflects decisions of each of these types and perhaps others.

The analysis was designed to provide an overall picture of differences in the ridership between rain and non-rain days, and to isolate the component factors as well as possible. The latter attempt was only moderately successful since most data sets provided daily rather than hourly data, and in no case was there any information available on the purpose of the trip. This analysis examined both bus and rail transportation.

Bus Ridership. Daily bus ridership figures were obtained for the summers of 1976, 1977, and 1978 from the Chicago Transit Authority (CTA, serving the actual city of Chicago), and the North Suburban Mass Transit District (NORTRAN, a public bus system serving north and northwest surburban communities). Data for 1977 and 1978 were obtained from the Gary Public Transportation Corporation.

Ridership on each of these systems was analyzed using the matched pairs approach. Unfortunately, the periods of analysis were not the same for each data set, being dependent on the availability of the data and various characteristics of it. June data were not used for the Chicago and NORTRAN analyses since an unknown number of school students ride the bus to school for part of that month. Since, for the Gary data, students could be identified and subtracted, and since only two years of data had been collected, June was included in the analysis. Finally, one NORTRAN route which was individually analyzed (route 209) did not exist until July 1977.

Rain and non-rain days were selected separately for each system using the 80% and 20% criteria for the raingages within the area served by the respective system. When individual bus routes were examined, raingages within two miles of the route were used. It was assumed that most ridership occurred between 5:00 a.m. and 9:00 p.m. Hence, only rainfall between these times was considered. Mean ridership (including transfers) on rain days and mean ridership on non-rain days were then computed and compared for each system.

Table 8 examines the impact of rainfall occurring between 5:00 a.m. and 9:00 p.m. on a weekday on ridership on the three bus systems. One must realize that the weather conditions during rainfall (such as dark skies, wind, etc.) in addition to the rain itself are integrated into the "rain day" influence being measured. Rainfall causes a small (3 to 5%) but unmistakable ridership decrease for each system.

These figures while perhaps of finanical interest to the transportation companies (an average loss of over $13,000 on a rain day for the CTA), reveal relatively little about the impacts of the rainfall on the travelers themselves. It is not evident whether the decrease in passengers is due to workers finding alternate means of transportation or even staying home, or whether the results are almost entirely due to decreases in the number of discretionary passengers. It was hoped that NORTRAN route 209 (which serves a large suburban shopping mall and should have a high proportion of shoppers) and route 211 (which operates only during rush hours and presumably primarily carries workers) would help resolve this question. Route 209 did show a greater decrease in passengers on rain days than route 211, but the amount of decrease was still not very large and was not statistically significant.

Table 9 represents a further attempt to isolate the impact of the rainfall on various types of passengers. It indicates that rainfall during the morning rush hour on the CTA decreased the daily number of passengers, but by only

Table 8. Impact of Rainfall on Weekday City Bus Ridership in the Chicago area - Rainfall occurring any time between 5:00 a.m. and 9:00 p.m.

Bus system or route	Mean Number of passengers on rain days	Mean Number of passengers on matched non-rain days	N Number of Pairs	Significance[1]	Percent loss of passengers on rain days
CTA[2]	1,525,490	1,576,555	18	S	3.2%
NORTRAN[3]	15,174	15,925	21	S	4.7%
Gary[4]	9,239	9,688	18	-	4.6%
NORTRAN Route 209 (Serving a major shopping mall)	483	514	16	-	6.0%
NORTRAN Route 211 (only running during rush hours)	216	224	12	-	3.6%

[1] S indicates significant at .05 level using matched pair t-test.

[2] Chicago Transit Authority records from selected days during July and August of 1976, 1977, and 1978.

[3] North Suburban Mass Transit District records from selected days during July and August of 1976, 1977, and 1978.

[4] Gary Public Transportation Corporation records from selected days during June, July, and August of 1977 and 1978.

Table 9. Impact of Rainfall at Selected Times on Weekday Bus Ridership in Chicago. (CTA records only).

Time of Rainfall	Mean Number of passengers on rain days	Mean Number of passengers on matched non-rain days	N Number of pairs	Percent loss of passengers on rain days
5:00 a.m. - 9:00 a.m. only	1,521,665	1,590,161	6	4.3%
9:00 a.m. - 4:00 p.m. (Two days had some morning rain also)	1,492,173	1,587,225	3	6.0%
4:00 p.m. - 9:00 p.m. only	1,529,680	1,558,734	4	1.9%

4.3%. Rain in the afternoon, presumably influencing larger numbers of discretionary passengers, has a somewhat greater effect -- a decrease of 6%. (The larger decrease may be partly due to the fact that two of the days in this sample also had morning rain). Rain only in the late afternoon and early evening has very little effect (1.9%). Perhaps passengers have already committed themselves to the day's activities and have little choice but to go home, regardless of rainfall. Of course, these figures must be viewed with extreme caution since they are based on so few pairs of days.

In summary, rainfall has a slight but noticeable effect on weekday bus travel. Rainfall at any time tended to decrease numbers of travelers. It seems, however, that its effect may be slightly larger for discretionary travelers than for those traveling to work, and that midday rains therefore have somewhat more effect on passenger numbers than do early morning or late afternoon rains.

It might be expected that weekend bus travel, presumably having a higher percentage of discretionary travelers, would be more affected by rainfall than is weekday travel. Table 10 shows mixed results. The city of Chicago seems to experience a larger decrease on rainy weekend days (5.2%) than it did on rainy weekdays (3.2%), although the small sample size again casts doubt on this conclusion. NORTRAN, however, experiences only a 3.8% decrease, even less than on weekdays. Gary actually had increased (5.2%) ridership on rainy weekend days. No explanation is available for this result unless it simply reflects chance and the small sample size.

Rapid Transit. Rapid Transit (subway and elevated trains) ridership figures were available from the CTA. These were analyzed in a manner identical to that for bus ridership and the results are summarized in Table 11. The effect of rain between 5:00 a.m. and 9:00 p.m. on a weekday resulted in a small, but significant, decrease in bus ridership (2.1%). It also resulted in a loss of revenue of $3600 per rain day. This decrease in ridership was somewhat smaller than the comparable decrease in bus passengers (3.2%). When rain occured during morning rush hours, the percentage decrease in rapid transit ridership was almost identical to that for bus ridership (4.4% vs. 4.3%).

Weekday afternoon rains seemed to have less influence on rail passengers than on bus passengers (2.4% vs. 6.0%). These results may be due entirely to the small number of pairs or they might reflect different types of ridership on the two systems. Rail ridership on days receiving rain during the evening rush hour actually increased very slightly, suggesting that rain may cause some bus passengers to switch to rapid transit. (An employee of the CTA suggested this phenomenon sometimes occurred on rainy days).

Finally, rain on a weekend day seems to cause a decrease in ridership, but of rather small magnitude.

In summary, rainfall generally decreased rapid transit ridership as it did bus ridership, but by even smaller percentages, an exception being evening rainfall, which apparently has little effect on rapid transit ridership.

Table 10. Impact of Rainfall on Weekend City Bus Ridership in the Chicago Area - Rainfall Occurring any Time Between 5:00 a.m. and 9:00 p.m.

Bus system	Mean Number of passengers on rain days	Mean Number of passengers on matched non-rain days	N Number of Passengers	Percent loss of passengers on rain days
CAT	788,487	831,486	6	5.2%
N0RTRAN	3,052	3,173	6	3.8%
Gary	3,401	3,224	7	5.2% increase

Table 11. Impact of Rainfall on Rapid Transit Ridership in Chicago.

Time	Mean Number of passengers on rain days	Mean Number on matched non-rain days	N Number of pairs	Percent loss of passengers on rain days
Weekdays - rain any time 5:00 a.m. - 9:00 p.m.	378,998	387,253[1]	18	2.1%
Weekdays - rain 5:00 a.m. - 9:00 a.m. only	374,890	392,261	6	4.4%
Weekdays - rain 9:00 a.m. - 4:00 p.m.	374,044	383,160	3	2.4%
Weekdays - rain 4:00 p.m. - 9:00 p.m. only	372,697	371,447	4	.3% increase
Weekends - rain any time 5:00 a.m. - 9:00 p.m.	151,491	156,411	6	3.1%

[1]The difference in means was significant at the .05 level.

Other Changes in Ridership Patterns. Two final possible rain effects with regard to mass transit ridership were examined. First, possible rainfall effects on proportions of transfer-to-originating passengers were examined. It might be expected that commuters would be more likely to take a bus, rather than walk to a commuter station during a rain. An examination of transfer passengers, as a percentage of total passengers, revealed that rain and non-rain days had essentially identical proportions of transfer passengers for both bus and rail. This was true for weekdays, weekdays with morning rain, weekdays with afternoon rain, weekdays with evening rain, and for weekends.

The other effect studied was whether passengers chose different methods of mass transportation on rain days, such as switching from bus to subway. Table 12 results demonstrate that rainfall had no noticeable effect on relative bus and rapid transit ridership.

The South Shore Line. Ridership records were also obtained for June, July, and August of 1978 for the South Shore Line railroad, a passenger rail line connecting communities along the south shore of Lake Michigan with Chicago. This commuter railroad provided a unique opportunity to examine the effect of rainfall on particular types of ridership, since passenger numbers were available by time of day.

The effect of rainfall on early morning commuting was determined by comparing numbers of passengers in the early morning (5:00 a.m. - 9:00 a.m.) for days on which it rained, and for days on which no rain fell within 5 miles of the South Shore track between Michigan City and a point just inside the city of Chicago. Table 13 reveals that rainfall had very little effect on the use of the railroad by early morning weekday commuters. There was an insufficient number of days with mid-day rain to examine their effects. In contrast, weekend use of the system shows a rather large decrease, although again the sample is too small to be meaningful.

Summary. Rainfall apparently decreases ridership slightly on mass transit, although who doesn't ride and why they do not ride is still unknown. There is some indication that those who ride on a discretionary basis, such as shoppers and weekend travelers, are more likely to stay home (or find alternate transportation) than are people commuting to work. The impact, at least on weekdays, seems to be somewhat higher for bus transportation than for rail transportation. This conclusion is not inconsistent with a study of mass transit in Massuchusetts (Joseph Napolitan Associates, Inc., 1964). In that study, 1 in 4 bus passengers stated that weather influenced their decision to take the bus, while only 1 in 10 rail passengers said it would influence them. (Further, a majority of the bus passengers said bad weather would decrease their chances of taking the bus, while a majority of the rail passengers said that it would decrease their chances of not taking the train).

While the percentage decreases in ridership tend to be small (usually less than 6%), they do have some economic impact for the transportation companies. A typical rainy weekday, for instance, costs the Chicago Transit Authority $13,193 in lost bus revenues, $3,619 in lost rail revenues, for a total of $16,812. (These are averages for the three summers and slightly underestimate costs at current fares). While these values are small compared to daily revenues (they represent a loss in income of about 3%), the total loss for the season from the area average of 40 rain days would equal the salaries of several employees.

Table 12. Impact of Rainfall on Choice of Public Transportation.

Time	Percent of Total Passengers[1] who rode the bus[2]: Rain Days	Matched non-rain days	No. of pairs of days
Weekdays - rain any time 5:00 a.m. - 9:00 p.m.	80.1%	80.3%	18
Weekdays - rain 5:00 a.m. - 9:00 a.m. only	80.2%	80.2%	6
Weekdays - rain 9:00 a.m. - 4:00 p.m.	80.0%	80.6%	3
Weekdays - rain 4:00 p.m. - 9:00 p.m. only	80.4%	80.8%	4
Weekends - rain any time 5:00 a. m. - 9:00 p.m.	83.9%	84.2%	6

(1) Total passengers includes originating and transfer bus passengers plus originating and transfer Rapid Transit passengers.

(2) Includes both originating and transfer bus passengers.

Table 13. Impact of Morning Rainfall on South Shore and South Bend Railroad Morning Ridership.

Time	Mean Number of passengers on rain days	Mean Number on matched non-rain days	N Number of pairs	Percent loss of passengers on rain days
Weekdays - rain 5:00 a.m. - 9:00 a.m.	1,989	2007	6	.9%
Weekends - rain 5:00 a.m. - 9:00 a.m.	**121**	**145**	**3**	**16.5%**

Boating Accidents

Records of calls for assistance on and near Southern Lake Michigan were provided for the summer of 1978 by the Coast Guard Stations at Michigan City, Indiana, and Calumet Harbor, Chicago. These records were used to determine the impact of the weather on boating emergencies in the Chicago-Northwest Indiana area.

Table 14 summarizes the relative importance of the weather in various types of emergencies handled by the Michigan City station between June and August. Calls for assistance which were false alarms, hoaxes, or involved drowning victims other than due to boating accidents, were eliminated, leaving 164 actual boating emergencies. These figures suggest that the role of the weather is rather limited in these emergencies. Weather is listed as a contributing cause in only about 16% of the cases. The only category in which weather is the major cause of accidents is capsizing (primarily of sailboats). However, some of the cases in which pilots were disoriented or their boats were taking on water occurred during fog and high winds, so the weather may be somewhat under-represented. Those emergencies which were attributed to the weather most often occurred in either fog or high winds. Rainfall itself was not listed as a factor, and in fact, only one of the emergencies occurred during rain.

Results from Calument Harbor were generally similar, although an even smaller percentage of emergencies were attributed to the weather. Those that were, again, occurred primarily during high winds or fog.

Undoubtedly a major reason for the relatively small impact of the weather on boating emergencies is that boaters, particularly recreational boaters, are most apt to be on the water on pleasant, non-stormy days. For instance, Boating Statistics 1977 (U.S. Coast Guard, 1978, concerned with recreational boating) reveals that the most common sea state during boating accidents is "calm", the most common wind condition is "light" and the most common visibility condition is "good." A check of three days which had unusually large numbers of emergencies in the Michigan City area revealed that all were warm, at least partly clear weekend days (although one had winds up to 20 knots and the other two had patches or periods of fog).

This leads to the interesting speculation that the types of weather produced by a city, particularly rainfall, might actually lead to reduced numbers of boating accidents (accompanied, of course, by reduced recreational opportunities). And, in fact, a check of mean numbers of accidents on rain days and on non-rain days at Michigan City revealed a slightly higher mean for the non-rain days. Similarly, non-rain days in the area served by the Calumet Harbor station (whose records indicated whether a boat was recreational or not) had more recreational vessel emergencies than did rain days.

While there exists a slight decrease in emergencies on rain days, it is reasonable to assume that the number of accidents per boater are probably much higher than on non-rain days. Unfortunately, no statistics on boating numbers in the study areas were available to determine this.

Table 14. Boating Emergencies Assisted by the Coast Guard Station, Michigan City(1).

Type of Emergency	Number of emergencies for which weather was not listed as a contributing cause	Number of emergencies for which weather was listed as a contributing cause
Engine failure or boat out of gas	100	0
Boat capsized (mainly sailboats)	8	22
Boat ran aground or on breakwall	5	2
Boat adrift (other than because of engine failure or lack of gas)	3	0
Boat taking on water	8	0
Boater disoriented (but boat not aground)	7	1
Boat overdue (other than because of engine failure or out of gas)	4	1
Miscellaneous	3	0
TOTAL	138 (84.1%)	26 (15.9%)

(1) False alarms, hoaxes, flares (if no problem was found) and drownings unrelated to boating were eliminated.

Statistics on non-recreational vessels (termed "Dry Cargo Freight" - barges), whose activities are not restricted to pleasant Sunday afternoons, were available from Calumet Harbor and suggest the potential impact of the weather. Of 15 emergencies which occurred between 9:00 a.m. and 9:00 p.m. (chosen to correspond to rainfall records) during the summer of 1978, 10 occurred during 25 rain days, and 5 occurred during the 67 non-rain days (.40 emergencies per rain day, .075 emergencies per non-rain day). The sample again is rather small, and in many cases the emegency consisted of barges breaking loose from mooring lines (sometimes with human help), but the implication is clear that rainfall and accompanying weather conditions have a significant impact on those vessels which must be exposed to it.

Summary. The expected effect of urban weather modification may be the reduction of recreation boating accidents, because the additional precipitation means additional periods unsuited to boating pleasure. However, to the extent that additional rainfall is accompanied by fog or high winds, there will perhaps be increased rates of accidents for those who by choice or necessity are still on the water. Another important impact, not pursued here, is that recreational opportunities are decreased.

Aircraft Accidents

During the summers of 1976, 1977, and 1978, 21 aircraft accidents occurred in Cook and DuPage Counties in Illinois, and Lake, Porter, and La Porte Counties in Indiana. These accidents (obtained from records of the FAA) were not analyzed using the rain vs. non-rain day technique, since the small number of accidents would make the results meaningless. Instead, the relative role of the weather in causing or contributing to these accidents was determined. Of the 21 accidents, 5 were, at least in part, the result of adverse weather conditions. Three of the accidents occurred in part because of adverse wind conditions, and two occurred in part because of low ceilings, fog and generally low visibility. There was no precipitation during any of the accidents. There were fatalities in two of these accidents (one fatality each). Only one of the 16 accidents which was not weather related included fatalities.

Given the small number of accidents, it would be unreasonable to speculate on the potential effect of inadvertent urban weather modification on future accidents. However, additional records were obtained from a publication by the National Transportation Safety Board (1978). These records list total numbers of general aviation (not air carriers) accidents in the U.S. during 1977 including the cause and number of fatalities. While long term averages of accident types in the Chicago area might vary in important ways from nationwide statistics for 1977, the national statistics are probably better than the small local sample. During 1977 there were 4245 general aviation accidents in the U.S. For 952 of these (22.4%), weather was a cause or contributing factor (about the same percent as in the small Chicago sample). The influence of the weather in causing severe accidents, however, is much more pronounced. While 16.0% of the 4245 accidents involved fatalities, 27.1% of those in which weather was a cause (or contributing factor) had fatalities compared to 12.8% of those for which weather was not a factor. (Even in the small Chicago sample, the fatality ratio was far higher for weather related accidents. This could be due to chance but the national statistics support it). Weather, then, is not only a major contributor to about one-fourth of the general aviation accidents, but is far over-represented as a cause of fatal accidents.

This still tells relatively little about the potential effect of rain or storm modification by urban areas on air accidents, without knowing what types of weather events are most likely to result in accidents. Table 15 is taken from the National Transportation Safety Board summary (p. xxxiv) and displays those types of weather which contributed to general aviation accidents in 1977. As in the Chicago accidents, unfavorable wind conditions, low ceilings, and fog lead the group. To the extent that urban areas modify these conditions, they may encourage greater number of accidents. The factors of most interest to this study, rain and thunderstorms, fall somewhat lower on the list with rainfall ranked number 5, (still a major contributor to accidents). Thunderstorm activity is only 8th in importance. This may in part be a function of pilots avoiding thunderstorms. Also, if figures for downdrafts, updrafts, squall lines, and sudden windshifts were added, thunderstorms would rank much higher. While rain and thunderstorms are not the most important weather causes of accidents, they are important. If combined with associated weather conditions, they are extremely important. Table 16 (causes of fatal accidents) further emphasizes their importance, with both rain and thunderstorms listed among the top 5 weather causes of fatal accidents.

Aircraft using an airport in an area of major urban weather anomaly (such as downwind from Chicago) would probably be subject to more risks than aircraft using an airport away from this area. Of course, flight regulations would usually mean the aircraft would be delayed rather than be subjected to the increased risks of adverse weather.

Air Traffic Delays

The accident figures presented in the preceding section would have been far higher if it were not for the efforts expended to avoid them. These efforts include delays, rerouting, and cancellations of flights in some instances. While these are necessary to prevent accidents, they do result in inconvenience and expense. This section of the report will look at some of the causes of flight departure delays and at the relative importance of the weather in causing these delays. Records of delayed departures from O'Hare Airport were made available by the Great Lakes Region Federal Aviation Administration. Those delays of greater than 30 minutes between the hours of 8 a.m. and 8 p.m. CDT during the summers of 1976, 1977, and 1978 were analyzed.

Before looking at the data for the present study, some data which the FAA had previously summarized should be considered. This summary showed that during 1975, weather was repsonsible for 85% of the delayed arrivals and departures at O'Hare. Thunderstorms accounted for about 26% of the total delays that year. Low ceilings and poor visibility accounted for another 25%. Wind accounted for 19% of the delays, snow and ice for 15%, and non-weather factors (runway repairs, etc.) about 15%.

Table 15. Types of Weather Which Caused or Contributed to General Aviation Accidents[1] in the United States during 1977(2).

		Number of Accidents Caused or Contributed to by weather type
1.	Unfavorable wind conditions	314
2.	Low ceiling	199
3.	Fog	163
4.	High density altitude	97
, 5.	Rain	93
6.	Downdrafts, updrafts	81
7.	Conditions conducive to carb/ induction system icing	60
8.	Thunderstorms activity	46
9.	Snow	37
10.	Sudden windshift	35
11.	Icing conditions - includes sleet, freezing rain, etc.	32
12.	Turbulence associated with clouds and/or thunderstorms	29
13.	High temperature	27
14.	Obstructions to vision	16
15.	Wind shear	12
16.	Local whirlwind	11
17.	Turbulence in flight, clear air	11
18.	Hail	3
19.	Adverse winds aloft	3
20.	Tornado	1
21.	Squall line	1
22.	Other	8
	TOTAL	1279[3]

[1] Information from the National Transportation Safety Board (1978), p. xxxiv

[2] The impacts of weather-altered airport facilities, such as wet or icy runways are not included in this table.

[3] Some accidents are attributed to more than one weather cause so the actual number of accidents due to the weather is less than this.

Table 16. Types of Weather Which Caused or Contributed to Fatal General Aviation Accidents[1] in the United States during 1977[2].

		Number of Accidents caused or contributed to by weather type
1.	Low ceiling	139
2.	Fog	99
3.	Rain	51
4.	Thunderstorm activity	24
5.	Snow	23
6.	High density altitude	20
7.	Icing conditions - includes sleet, freezing rain, etc.	16
8.	Downdrafts, updrafts	15
9.	Turbulence associated with clouds and/or thunderstorms	14
10.	Unfavorable wind conditions	12
11.	Obstructions to vision	11
12.	Conditions conducive to carb/ induction system icing	7
13.	Turbulence in flight, clear air	5
14.	High temperature	4
15.	Wind shear	3
16.	Hail	1
17.	Tornado	1
18.	Squall line	1
19.	Other	5
	TOTAL	451[3]

(1) Information from the National Transportation Safety Board (1978) p. xxxiv

(2) The impacts of weather-altered airport facilities, such as wet or icy runways are not included in this table.

(3) Some accidents are attributed to more than one weather cause so the actual number of fatal accidents due to weather is less than this.

The major causes of delays, not surprisingly, are *very* similar to those listed above as major causes of accidents. Thunderstorms seem to be relatively more important as a cause of delays than as a cause of accidents, but this may be precisely because extensive precautions are taken to avoid them (also, the air accident data is for general aviation, and O'Hare data for air carriers). Also, while rain is listed as a major cause of air accidents, it is not listed as a cause of delays (although accompanying thunderstorms, poor visibility, etc. are).

The role of rainfall in air delays and accidents poses a particular problem for this analysis, since it is difficult to separate the effects of rain from those of conditions accompanying rain (winds, poor visibility, thunderstorms at the airport, nearby thunderstorms blocking flight paths, etc). Since, however, hourly records of rainfall were available which were more accurate than those for other conditions, and since a major purpose of this study was to determine what social impacts occur during rainstorms in Chicago, flight delays were compared to rainfall.

First, days during the three sumners were divided into those which received a trace or less of rain (225 days) between 8:00 a.m. nd 8:00 p.m. and those which received at least .01 inch of rain during those hours (51 days). Also, 10 of the 51 rain days were identified as having more than 0.5 inch of rain. Comparison of these with FAA records of delayed departures revealed that less than 10% of the non-rain days had any delays, while more than 50% of the rain days had delays, and 90% of the 10 heavy rain days had delays. See the fourth column in Table 17.

These figures give little indication of the actual impact of rain days on passengers since they do not reveal the number of flights which were delayed. Using the FAA data, it was possible to compute the percentage of daily scheduled departures between 8:00 a.m. and 8:00 p.m. which were delayed. (There are usually between 700 ad 900 scheduled departures between these hours.) The percentages are probably somewhat low, since records are kept by air traffic controllers with a number of more vital tasks to perform. These percentages, ranging from 0 to 44.7%, were then averaged for the days in each rainfall category. Table 17 (last column) shows that an average of only 0.35% of the scheduled departures are delayed on non-rain days. This rises to 6.36% on rain days, and to 18.24% on heavy rain days. (The largest percentage (44.7%) of the scheduled flights were delayed on a day which received more than one inch of rain).

Obviously, a passenger's chance of having a departure delayed on a rainy day are many times greater than his chances on a non-rain day, although the actual cause of the delay might be winds, low visibility, local or nearby thunderstorms, or even non-weather factors which happened to occur on a rain day. Whatever the specific cause of the delays, there is no doubt that rain days in Chicago are accompanied by a large number of delayed flights at O'Hare. Increases in rainfall and especially in heavy rainfall could be expected to result in increased numbers of delays.

Table 17. Impact of Rainfall on 30-minute Departure Delays at O'Hare[1].

Amount of Rain (in inches)	Total Number of days	Number of Days having any 30-minute delays	Percent of days having delays	Mean Daily Percent of departures delayed for 30-minutes(2)
0.00	225	21	9.3%	0.35%
Any amount ≥ 0.01	51	29	56.9%	6.36%
≥ .50	10	9	90.0%	18.24%

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(1) Records cover 8:00 a.m. to 8:00 p.m. CDT during July, August, and September of 1976, 1977, and 1978.

(2) Means are based on all days having a specific rainfall amount. Zero's (for days with no delays) are included in the averages.

Power Interruptions

It would be desirable to determine the average number of customers (or of customer-minutes) who lose power during each thunderstorm in the Chicago area. This would be a useful statistic for estimating the impact of increases in thunderstorm frequency on power interruptions. Unfortunately, it is rather difficult to pinpoint thunderstorms in time or place from the records available.

Therefore, the analysis pursued had the more modest aims of 1) examining the relative effects of storms on power interruptions compared to other causes of interruptions (trucks hitting power poles, vandalism, bird's nests, planned interruptions, etc.), and 2) estimating the total magnitude and duration of the storm-caused interruptions.

Data were provided for the Chicago area by Commonwealth Edison Company and for Northwestern Indiana by the Indiana Public Service Commission (records for NIPSCO). The two sets covered different time periods and included rather different types of data, so were analyzed separately.

Power Interruptions in the Chicago Area. Power interruptions in the third quarters (July, August, September) of 1976, 1977, and 1978 were analyzed. Separate records were available for various divisions served by Commonwealth Edison in the Chicago area (see Fig. 3) so it is possible to see the effects of storms on a variety of urban and suburban areas. Table 18 shows the results of the analyses for each of these sections. The first column lists the average annual number of power interruptions due to storms (primarly thunderstorms) for the third quarter. If it is assumed that thunderstorm frequency in each of these divisions is equal (an only moderately inaccurate assumption, Huff and Changnon (1972), the impact of thunderstorms on power supply is markedly affected by characteristics of individual divisions. For instance, in Chicago Central (includes downtown Chicago) where most equipment is not exposed to the weather, the frequency of storm-related interruptions is far smaller than in suburban areas.

The second column gives some indication of the relative importance of weather as a cause of power interruptions. While weather is a major cause of interruptions in all divisions, only in the Harvey division it did account for more than half of the total number of interruptions. However, numbers of interruptions are less important to the functioning of a comnunity than are magnitude and duration. It is possible that storm related interruptions are different in magnitude and/or duration than other types of interruptions. This would mean that the inconveniences caused by storm-related power interrruptions relative to other types are not fairly represented by the figures in column 2.

Columns 3-5 provide a measure of the relative and absolute power disruptions caused by storms. During a 3-month period, storms would normally interrupt power in various parts of a power division for varying lengths of time. It is possible, however, to state the equivalent amount of time the entire division would have been without power, given the amounts of transformer capacity which were interrupted and the average duration of

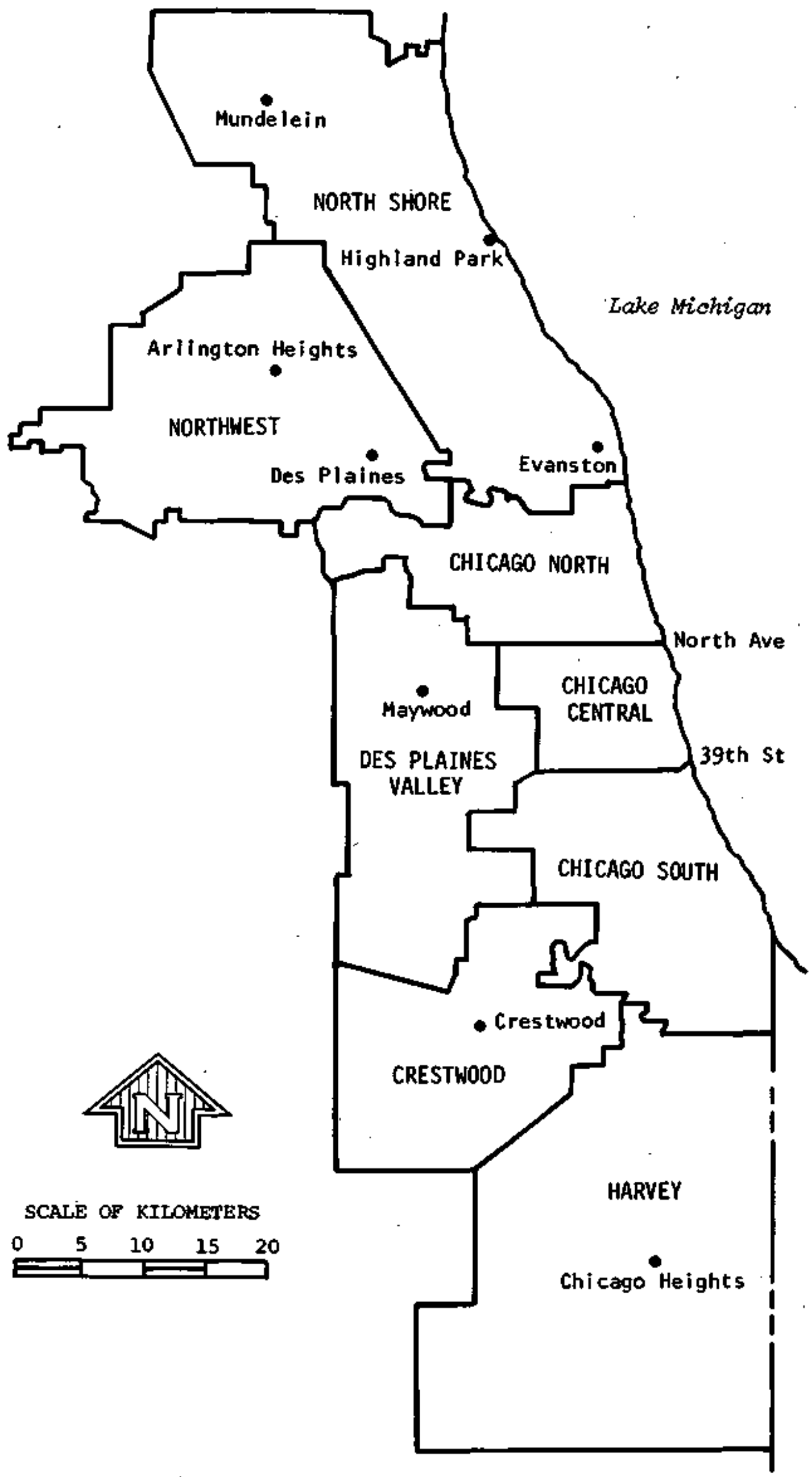

Figure 3. Commonwealth Edison Power Areas used in the study

Table 18. Power Interruptions in the Chicago Area .

Area	Average Yearly number of interruptions due to storms during third quarter	Percent of Total interruptions caused by storms	Mean Yearly equivalent time[3] of storm interruptions	Mean Yearly equivalent time of all interruptions	Percent of Total interrupted time due to storms
Chicago North	76.3	33.3%	3.12 min.	9.55 min.	32.7%
Chicago Central	66.0	38.1%	2.71	7.38	36.7%
Chicago South	142.7	40.7%	12.39	19.99	62.0%
Crestwood	201.3	44.4%	23.13	28.48	81.2%
Harvey	343.7	51.8%	20.46	29.22	70.0%
Des Plaines Valley	167.0	42.2%	13.39	29.95	44.7%
North Shore	158.0	36.9%	9.10	18.14	50.2%
Northwest	173.3	28.7%	15.45	40.13	38.5%

[1]Records cover July, August, and September of 1976, 1977, and 1978.

[2]See map (Fig. 3) for locations of power areas.

[3]See text for method of computation.

interruptions [1]. For instance, if power interruptions in the Chicago north division were equally divided among all customers, each customer would have averaged 3.1 minutes without power for the third quarter of each of the last 3 years.

The average number of minutes without power due to storms varies greatly between divisions. On the average, a customer in the Chicago Central region was without power only 2.7 minutes during July, August, and September due to storms, while a customer in the Crestwood area averaged over 23 minutes without power.

Column 4 gives the average time a customer is without power for any cause in each of the divisions, and column 5 shows the percentage of total time without power due to storms. Comparison of column 6 values with those in column 2 suggests that in all divisions, except Chicago North and Chicago Central,, power interruptions due to storms are more serious (affect more customers and/or last longer) than power interruptions due to other causes. For example, storms are responsible for 44.4% of the total number of interruptions in Crestwood, but are responsible for 81.2% of the total time customers are without power.

Unfortunately, analyses could not be made in the same detail for lightning. But since lightning was responsible for more than 90% of the storm interruptions in each division (winds were responsible for most of the rest), the above results may be considered to be primarily lightning-caused.

Northwestern Indiana. Information was available on major power interruptions in Lake and Porter Counties, and most of La Porte County during the summer of 1978. The data were in a rather different form than were the Chicago data, giving the number of customers and actual time without power for each interruption. From this data, it was possible to determine approximately the number of customer-minutes of power interruption (number of customers without power multiplied by duration of outage in minutes) due to storms and due to all causes. During the major interruptions reported, 86.4% of all customer-minutes without power were due to storms. While computed in somewhat different ways, this result can be compared with the percentages in column 5 of Table 18. The value for northwestern Indiana is somewhat higher than any for the Chicago area. This may in part be a function of method of computation, or it may reflect the limitation of the Indiana data to relatively large interruptions (normally 600 or more customers). It may also reflect the type of area being served, with rural areas being especially vulnerable to storm-produced power interruptions.

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[1] Calculated by equivalent time = $\frac{MVA_1 \times t}{MVA_2}$

where MVA_1 = Mega (million) volt amps of transformer capacity interrupted by storms

MVA_2 = Total transformer capacity of division in mega volt amps

t = the weighted average length of interruptions in minutes of the transformer capacity interrupted.

Summary. Weather, particularly those weather phenomena associated with thunderstorms, is a major cause of power interruptions. It is reasonable to expect that an urban-induced increase in thunderstorms would result in significantly larger numbers of power interruptions. The amount of this increase would depend very much on the characteristics of the power facilities being affected.

Interruptions in Telephone Service

Relatively little information was obtained on the impact of weather on telephone service. What is available (Illinois Bell Telephone Company) indicates that weather is a relatively minor problem in the Chicago area. Only 0.6% of all trouble reported during the second quarter of 1978 and only 1.7% of trouble reported during the third quarter was due to weather. The low figures are partly a function of the types of systems in the area with most equipment below ground. However, for Illinois as a whole, only 4.0% and 2.6 of trouble reported during the second and third quarters, respectively, was due to weather.

Perhaps a more important impact occurs during severe weather and disaster. At that time more calls are placed than the systems can handle and there are resulting delays in service.

CITY SERVICES IN La PORTE

It would have been impossible in this study to even sample effects of weather on city services throughout the Chicago-Northwest Indiana area. Instead, a case study approach was adopted and one city was chosen for a closer examination of the effects of weather on the use of city services. La Porte, Indiana, a city of over 20,000 population was chosen. It is located approximately 30 miles downwind from the Chicago-Gary industrial complex, in the area of maximum urban weather modification. It experiences approximately 17% more precipitation and 38% more thunderstorms because of the Chicago-Gary region (Changnon, 1976). It would not, of course, have been necessary to choose a city which experiences the anomaly, since events on rain and non-rain days are compared without attempting to sort out the influences of urban-induced precipitation. However, much meteorological information is available for La Porte and it seemed an appropriate city to examine.

Records and information were obtained and analyzed for the Fire, Water, Sewage, and Parks and Recreation Departments, and for a municipal golf course. No analyses were made for the Street Department since records were not kept of street maintenance resulting specifically from storm damage.

Fire Department

An examination of the records of the La Porte Fire Department for the summers of 1976, 1977, and 1978 revealed six general catagories of emergencies: fire on or inside buildings, outdoor trash, grass and brush fires, outdoor non-brush fires (tree limbs, overheated incinerator), automobile fires, non-fire emergencies (extricating accident victims, turning off leaking gas pipes, etc.) and false alarms. It was hypothesized 1) that thunderstorms might be responsible for a significant proportion of building fires and of outdoor non-brush fires and 2) that rainfall (or lack of rainfall) should have an effect on the number of outdoor grass and brush fires requiring the attention of the fire department. To check these hypotheses, only building fires and outdoor non-automobile fires were included in the analyses. If the records specifically stated that no fire had occurred (for instance, if lightning set off a fire alarm, but there was no fire and no damage), the emergency was eliminated from consideration. This left 148 emergencies, of which 85 were in or on buildings, 7 were outdoor fires involving tree limbs, incinerators, etc., and 56 were grass, rubbish, and brush fires.

Of the 85 building fires, seven (8%) were attributed to lightning and two others (involving electric wire) were probably a result of high winds during a storm. Nationally, about 1.3% of building fires were produced by lightning during 1974 (McKinnen, 1976). However, no conclusions can be drawn from the difference in percentage at La Porte. The La Porte sample size is small, the national figures are annual, and methods of deriving the national percentages probably differed greatly from those used here.

Of the 7 outdoor non-brush or grass fires, 4 were probably the result of weather, all four occurring on storm days. One was specifically attributed to lightning and the others involved tree limbs on electric wires, probably the result of wind or lightning.

Perhaps in some cases, brush and grass fires are begun by lightning. However, for this analysis, it was assumed that in most cases the fires were started in some other manner and that weather was primarily important in determining the ease with which the fire spread. As a crude approximation of moisture conditions, a list was made of all days during the three summers which followed at least four days of no rain. These dry days (43) were then compared with the dates of 56 grass and brush fires. Twenty-one of the fires occurred on the 43 days, for an average of .49 fires per "dry" day. The remaining 35 fires were spread among the 233 non-dry days for an average of .15 fires per day.

Frequent rainfall is obviously important in preventing the spread of grass and brush fires. If fireman in La Porte have to fight some additional building fires because of the many thunderstorms in the area, the high rainfall may spare them from fighting grass fires.

Water Department

There are a number of ways in which a town's water supply might be affected by rainfall. Prolonged periods of drought could result in insufficient water supplies, or too much rainfall could result in flooding and contamination of the water supplies. Also, it is possible that water use is in some way a function of weather conditions such as rainfall. La Porte, which relies on wells for its water, has had few problems with insufficient water supplies. An employee of the Water Department said that, at the worst, lawn watering may be restricted to even or odd days. The water works has had some problems with building flooding but this has not resulted in contamination of the water.

The other question, whether there was a relationship between rainfall and water usage was examined. Records were obtained of daily water usage for June, July, and August of 1976, 1977, and 1978. Using these records, average water usage on 71 days receiving at least .01 inch of rain was compared to average water usage on matched non-rain days. Water usage averaged 5,333,643 gallons per rain day compared to 5,572,845 gallons per non-rain day, a reduction of 4.3% (This might have been higher if no restrictions had been put on lawn-watering during dry spells). This result must be regarded with some suspicion since a number of industries in La Porte use large quantities of water and variations in their usage may overshadow the effects of lawn watering. If, however, the result is meaningful, perhaps increased rainfall downwind from cities not only makes additional water supplies available, but may also slightly decrease consumption. Some support for this conclusion comes from a study by Maunder and Westaway (1968, reported in Maunder, 1970, p. 137). Their study found that water usage in Victoria, British Columbia was only half as great on cloudy days with rain showers as on sunny rainless days, although they considered the decrease to be due more to cloudiness than rainfall.

Sewage Department

Rainfall has a very pronounced impact on the sewage system of La Porte. The city's sewer and storm sewer systems are combined and rainfall frequently results in by-passes of the sewage treatment plant. The combined discharge then flows into a lagoon and later a tributary of the Kankakee River. Sanitation problems have been analyzed using historical data (Changnon, et. al., 1977) for towns downwind of St. Louis, which have had considerable problems with by-passes and pollution. A historical study of the problem in La Porte was not possible at this time. However, records from the Sewage Department (June - August of 1977 and 1978) were compared to total daily rainfall records for the city of La Porte to determine the magnitude of rainfall necessary to cause a by-pass. Of 58 days receiving at least .01 inch of rainfall, 38 (65.5%) resulted in 2 or more hours of by-passing (although the volume of the by-pass was very small in many instances). A closer examination revealed that most rainfalls of less than .10 inch did not result in a by-pass, but that by-passes occurred on 34 of, 40 days (85%) receiving at least .10 inch. Heavy rain (≥ .50 inch) resulted in by-passes on 17 of 18 such days (94.4%). It is likely that the remaining day (which had over 2 inches of rain) also experienced a by-pass (but that there was an error in data collection).

Because of the inability of the system to handle even small rainfalls, additions of rain, and especially heavy rain, in the La Porte area have resulted in inadequate processing of some of the town's sewage.

Parks and Recreation Department

It might be expected that outdoor recreation would be particularly vulnerable to rainfall. Statistics on this are rather difficult to obtain, particularly on a daily basis. However, records of Saturday and Sunday municipal park parking permits were available for the summers of 1977 and 1978. They were of limited value since parking permits may be used all season and the number sold on any weekend is largely a function of time of summer (most are sold in late May, very few in August). To overcome this problem, numbers of parking receipts were compared between days one year apart (such as Sunday, June 5, 1977 and Sunday, June 4, 1978). Days were matched and used in the analysis only if one had at least .01 inch of rainfall between 5 a.m. and 9 p.m. and the other had none. (The total number of parking permits and the general distribution of sales throughout each summer were sufficiently similar to make this approach reasonable). Ten matched pairs were obtained, with an average number of 154.2 permits sold on non-rain days and an average of only 85.5 permits sold on rain days, a decrease of 44.6%. This figure is no doubt only approximate, but gives some indication of the types of decreases that may be expected in city park usage if the number of rainfall days increases. This decrease in park usage is probably of minor financial importance to the park district. Fees are not high and residents may simply postpone purchase of a season ticket, not give it up. The figure is much more important in its reduction of recreational opportunties for the potential park users. It is unfortunate that time and data availability did not allow more study of outdoor recreation since this may be one of the most important impacts of the urban weather anomaly. This is especially true for the Chicago area, since the part of Northwest Indiana experiencing the major impacts coincides very closely with a popular recreational area.

The impact of rainfall on golfing records for the sumners of 1976, 1977, and 1978 from a municipal golf course in La Porte was suprising. Presumably, golfing is a vuluntary activity ~ one that could easily be cancelled in inclement weather. Yet, analysis of 8 matched weekends (weekends one week apart on which one weekend received rain on at least one day between 5:00 a.m. and 9:00 p.m. and the other weekend received no rain during those hours), revealed only an 8.5% decrease in golfers. Heavy rains are somewhat more discouraging to golfers, resulting in a 16% decrease in numbers of golfers (based on only 4 matched pairs). These modest decreases are probably in large part a function of the method of analysis. Rainfall could have occurred during only an hour or two of one of the weekend days, with the remainder of the weekend ideal for the sport. Still, compared with the decrease in use of the park, the decrease in golfing seems somewhat small. It is probably safe to assume that, regardless of increases in rainfall, golfers will continue to play golf.

SUMMARY AND IMPLICATIONS

Summary

This study began by asking the question, "What happens when it rains in Chicago?" Perhaps it is most appropriate to summarize the study by answering this question, at least for a few specific activities. When it rains in the Chicago area, -

Automobile accidents approximately double. Accident rates particularly increase in areas of high traffic volume, such as inside the city of Chicago. Increases in areas of low population density are smaller, but the severity of those accidents increases by about 70%.

Traffic volume decreases. This decrease is very slight on weekdays, but weekends, with more discretionary driving, have a greater decrease.

City bus ridership decreases on three major transit systems by 3 to 5% on weekdays. The amount of decrease depends on the time of the rain, with midday rain causing especially large decreases and evening rain very small decreases. While decreases are small in percentage terms they do cost money. The CTA, loses about $13,000 for one rain day. CTA bus ridership experiences a larger relative decrease on weekends, probably because of a larger percentage of discretionary passengers. NORTRAN apparently loses fewer passengers on rainy weekends than on rainy weekdays, and the Gary system experiences an increase in passengers on rainy weekends. These mixed results, are hard to explain and may be a function of inadequate sample size. Ridership on Chicago's rapid transit system is decreased on rain days, but by smaller percentages than is bus ridership.

Recreational boating emergencies decrease slightly on rain days in the Chicago area, but there is a pronounced increase in non-recreational boating emergencies. Apparently, weather conditions accompanying rainstorms (especially high winds and fog) increase the likelihood of a boating emergency for those who are still on the water despite unpleasant conditions.

The likelihood of aircraft accidents is increased by rainstorms. This is especially true to the extent that the rainstorms include unfavorable winds, poor visibility, or lightning.

In most cases, flight regulations prevent rain-related aircraft accidents but rains result in major inconveniences for passengers. The chances of having a departing flight from 0'Hare delayed by at least 30 minutes average 0.3% on non-rain days; 6.4% on rain days, and 18.2% on days receiving at least 0.5 inch of rain.

Thunderstorms account for anywhere from 33 to over 80% of the total amount of time people in the Chicago area are without electrical power. The percentage varies greatly by power district, with downtown Chicago (most equipment is underground) having the least amount of time without power due to storms.

Telephone service is *very* little affected by rain in Chicago and the nearby suburbs. This is partly because most equipment is underground.

Information was not obtained on city services in the Chicago area in general, but to the extent that results from La Porte are typical, the following may be expected from added summer rain and storminess.

Thunderstorms increase the number of building and tree fires, but rainfall in general decreases the number of outdoor grass and brush fires.

Rain days not only help make water available for city water services but result in slightly decreased water consumption.

In cities (like La Porte) with combined storm drain and sewage systems, rainstorms result in more by-passing of the sewage treatment plant and pollution of nearby water bodies.

Park attendance, and many types of recreation, are particularly affected by rain days, with attendance decreasing drastically. Golf courses, however, seem to experience relatively small decreases in use compared to parks. The newspaper analyses and the quantitative analyses resulted in somewhat different pictures of the impacts of summer weather. The newspapers tended to emphasize the severe but unusual events (such as fatal car accidents) which occur during adverse weather conditions. The statistical analyses, while showing that weather often is responsible for very severe events, also show that weather is responsible for greatly increased frequencies of minor or moderately severe events. In fact, much inconvenience and expense is caused by the types of events which are not reported in newspapers. Also, newspaper reports generally did not consider such impacts as 3-5% decreases in mass transit ridership or increases in brush fires after short dry spells. These types of ommissions suggest that much of the impact of adverse weather may go unrecognized and that increased impacts due to modified weather may also be unnoticed.

Implications

While it was not the purpose of this study to determine the effects of modified weather on these activities, it is reasonable to speculate that increases in total summer rainfall, heavy rainfall, and thunderstorms will cause changes in the activities where impacts were found.

It would be hazardous at this time to speculate on the final quantitative impacts of modified weather. However, this may be possible for some impacts in future studies based on the matched-pair approach. For instance, suppose it were known that urban weather modification resulted in "x" additional rain days per summer and that each rain day cost the local transit system "y" dollars. Using these results it could be estimated that weather modification would cost the transit system $(x \cdot y)$ dollars for the summer. Most impacts could not be examined this simply, but the potential for quantitative estimates of effects does exist.

The results should be very useful to planners in urban areas and particularly to planners in areas downwind from cities where maximum weather modification may be expected.

Finally the same impacts studied at Chicago and at St. Louis (traffic accidents and lightning caused power outages) revealed similar results. In both locales more rain brought a statistically significant increase in vehicle accidents (but not in severity). Also, both locales had more power outages due to thunderstorm conditions.

RECOMMENDATIONS

A few specific recommendations should be made for anyone pursuing similar research and using the matched-pair approach.

First, a particular problem in this study was the generally small sample size. When using only 2-3 summers of data, there are a limited number of matched rain and non-rain days which can meet the selection criteria. This number is further reduced when only weekdays or weekend days are examined, or days with particular characteristics such as morning rain. If at all possible additional years of data should be obtained. However, this involves other problems, such as the availability of data on human activities, temporal changes in activities, or the availability of data on rainfall. Clearly, if comprehensive rainfall data are desired, such as that available from the' Chicago area raingage network, longer-term records do not exist. But such a network does not and has not existed for other cities (except St. Louis) and societal researchers would have to rely on the limited number of raingages already present in urban areas. When this is the case, several years of records should be used.

Another difficulty was the lack of hourly (or sometimes even daily) data on impacted activities. This meant that daily records of human activities had to be used to examine the impact of rainfall which fell only during a few minutes or hours during the day. The impact during the period when it actually rained was probably higher than it appeared to be in this study. To overcome this problem it may be necessary for researchers to collect hourly data themselves or to work with the relevant organization to collect it on a sample of days.

Further, interview techniques would be appropriate in some cases. For instance, the net statistics on decreases in mass transit ridership in this study probably mask a number of very different types of human decisions. The actual number of people who altered their travel patterns on rain days is probably higher than the statistics suggest and interviews would be effective in determining this.

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