Illinois State Water Survey Division

CLIMATE & METEOROLOGY SECTION

SWS Contract Report 449

AN EXAMINATION OF CHICAGO PRECIPITATION PATTERNS FOR WATER YEAR 1984

by

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Prepared for the
Illinois Department of Transportation
Division of Water Resources

Champaign, Illinois
July 1988

Illinois Department of Energy and Natural Resources

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INTRODUCTION

The volume of water diverted from Lake Michigan by Illinois is monitored to ensure that Illinois does not exceed its long-term allotment which has been reached by international agreement between the United states and Canada (Pavia, 1979). An important component of the accounting procedure is the accurate representation of the precipitation that falls over Chicago and Northeast Illinois during a water year. During the 1984 Water Year (October 1983 through September 1984) an unusual precipitation pattern was noted (Fig. 1). A general minimum of precipitation was found over northeast and southeast Chicago, and a general maximum was located west, north, and along a corridor from Midway east to Lake Michigan. The same type of pattern was also noted for the 1983 Water Year; it was evident in almost every month for those two Water Years. The pattern is quite different than the long-term patterns that had been previously noted for the Chicago area by Changnon (1961, 1968) and Huff and Changnon (1973). This led to a preliminary examination of the raingage data for the two Water Years which indicated that the precipitation at a number of sites appeared to be underestimated every month, and the precipitation at one site for one month appeared to be higher than it should be.

The object of this analysis was to determine if there had been a natural shift in the precipitation pattern over the Chicago area, or if the

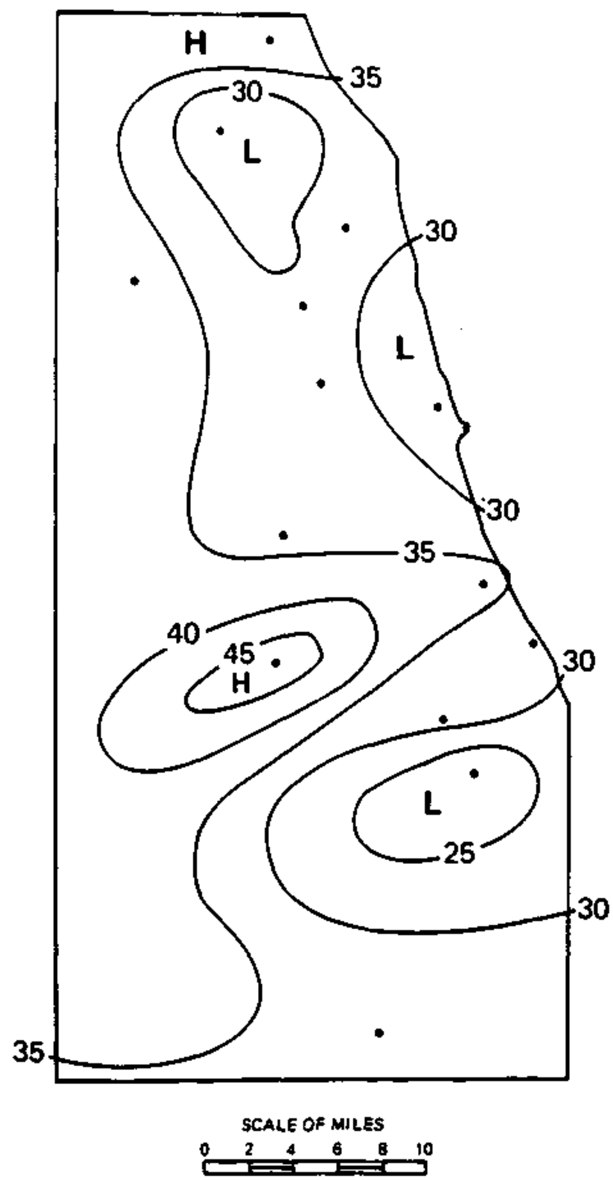

Figure 1. Water Year 1984 precipitation pattern in inches from original records (dots indicate raingages used in analysis)

different precipitation pattern in the 1983 and 1984 Water Years was due to inadequate measurements. If some of the measurements were not adequate, then a procedure to correct the precipitation amounts was needed. The study began with an inspection of 1) the raingages in the Chicago area routinely used for determining the precipitation for the analysis of the diversion of water from Lake Michigan into Illinois, and 2) other raingages maintained by the National Weather Service (NWS) which would be used to verify any potential shifts in the precipitation climatology of the Chicago area and Northeast Illinois. Beside the actual exposure of the raingages, this inspection included an appraisal of the observing procedures, and the quality control and reduction techniques applied to the data. Results from the inspection are presented. Secondly, an analysis of the long-term precipitation data for 6 counties in Northeast Illinois was made. Since there was no evidence of a long-term shift in the precipitation patterns in Northeast Illinois and substantial exposure and procedure problems were found, a procedure was developed to correct the precipitation amounts at those stations which were found to consistently underestimate the precipitation amounts. It was necessary to develop a procedure which would provide correction for individual storms, since part of the accounting process utilized in the evaluation of the diversion of waters from Lake Michigan requires storm precipitation amounts.

RAINGAGE INSPECTION

Douglas Jones and John Vogel inspected the various raingage sites maintained by the Metropolitan Sanitary District of Greater Chicago (MSD) and the City of Chicago, and utilized by the Illinois Department of Transportation

(IDOT) for the Lake Michigan Diversion Accounting Procedures (Fig. 2a). In addition, the location and relative exposure of the National Weather Service (NWS) raingages within the Metropolitan Chicago Area and surrounding counties (Fig. 2b) were assessed. The inspection was made from 17 to 19 September 1986.

In addition to the exposures of the raingages, the observing procedures, reduction techniques, and the quality control procedures of the three different groups operating raingages in the regions were examined. Table 1 lists the sites and raingage types that were visited during the inspection, an asterisk is used to delineate those 13 gages used in the accounting process for the diversion of Lake Michigan waters into Illinois. Tipping-bucket raingages were used by both the Metropolitan Sanitary District (MSD) and the City of Chicago. The NWS used a combination of the Standard 8-inch, the weighing bucket, and the Fischer-Porter raingages.

Table 1. Raingage Types, Locations, and Affiliation Inspected.

Standard 8-Inch	Tipping Bucket	Weighing Bucket	Fischer-Porter
Park Forest(N)*	Glenview(M)*	O'Hare Airport(N)*	Midway 3 SW(N)*
Aurora(N)	North Side(M)*	U of Chicago(N)*	
Barrington(N)	Mayfair(C)*		
Chicago Botanic Gardens(N)	Springfield(C)*		
	Sanitary Office(M)*		
Joliet Brandon Road Dam(N)	WSW Treatment(M)*		
	South Filter(C)*		
Wheaton(N)	Roseland(C)*		
	Calumet(M)*		

*Gages used for diversion accounting.
C = City of Chicago
M = Metropolitan Sanitary District
N = National Weather Service

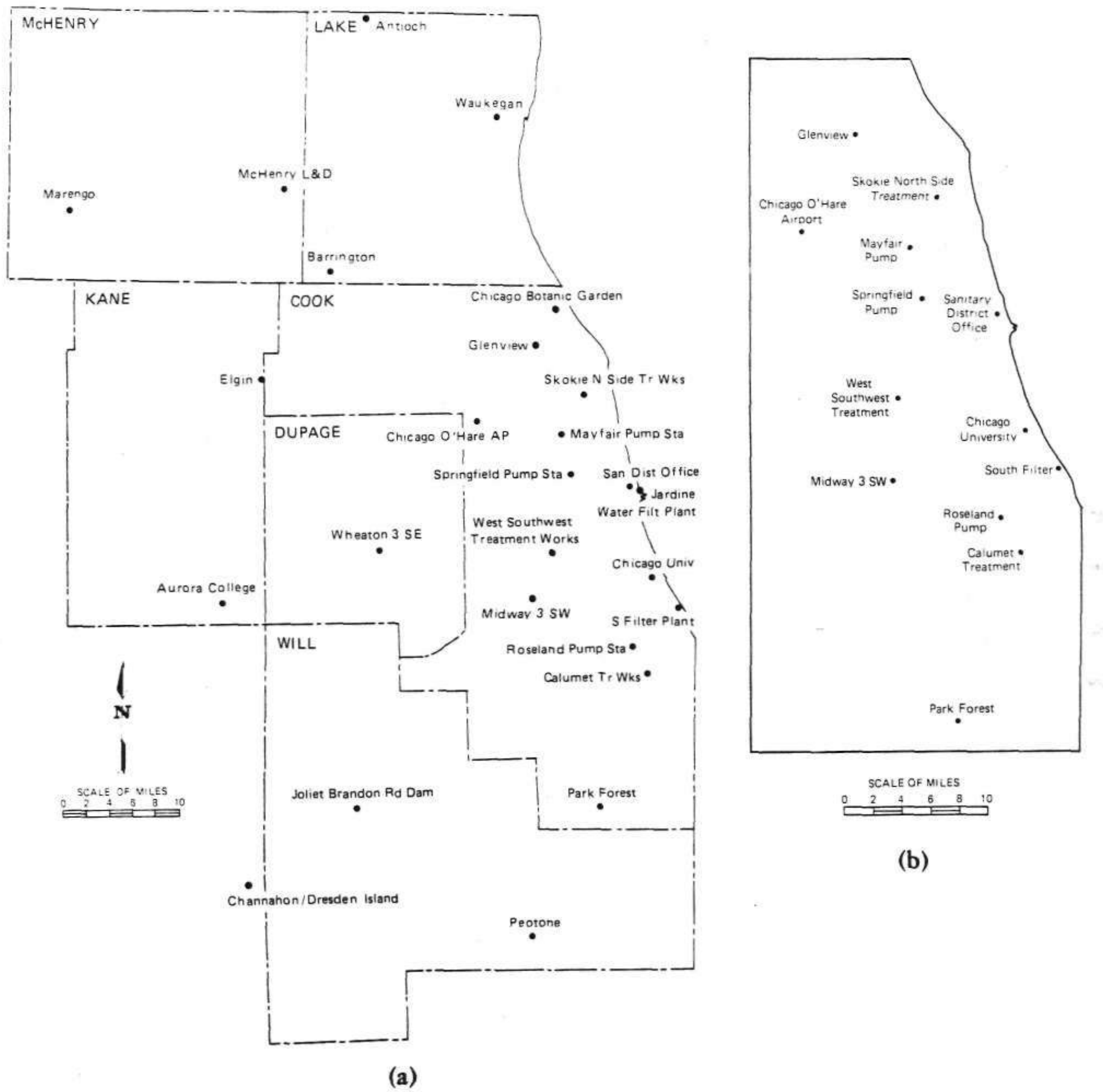

Figure 2. Raingage locations a) in Northeast Illinois and b) in Chicago Area

Raingages

The MSD uses tipping-bucket raingages recommended, and also used as backup gages by the NWS. These gages have a heater element built into the gage, so that the funnel is heated to allow snow and freezing precipitation to be recorded. The City of Chicago's tipping-bucket raingages are older, and when acquired, heaters were not available. To compensate for this, these gages have a trapozoid-like shelter surrounding each gage. Each shelter was locally built and no two are exactly the same. Within the shelter, the City of Chicago has installed a heater which heats the whole enclosure whenever the temperature inside the shelter is at or below freezing. The local flow patterns around the City of Chicago gages are all a little different. The shelters around the City of Chicago raingages alter the flow pattern around the raingages compared to the MSD raingages. The NWS maintains weighing-bucket raingages at Chicago O'Hare Airport and at the University of Chicago, while at Midway 3 Southwest the official hourly instrument is a Fischer-Porter raingage. All of these raingages have different flow patterns around them which can result in altered rainfall amounts (Jones, 1969).

Tipping-bucket raingages also have the problem that during intense rains the number of recorded tips is less than the total amount of rain that falls within the raingage, since the rain is falling faster than the raingage can record. This is a function of the intensity of the rain rather than the amount (Middleton and Spilhaus, 1953).

The Fischer-Porter raingage records only to the nearest tenth of an inch, so that in some instances it can underestimate and at other times it can overestimate the amount of rain that falls during a storm. It will tend to underestimate the actual amount of rain captured compared to the standard 8-inch raingage because of evaporation between storms. The Fischer-Porter raingage has a much taller and much bigger housing and this will affect the amount of precipitation captured (Jones, 1969).

The MSD and the City of Chicago gages are heated during winter which induces convective currents over the top of the gage, decreasing the catch. In addition, the heat causes evaporation and further reduces the catch during winter (World Meteorological Organization, 1971). The method used by the two groups to heat the raingages is also different.

Exposure

The exposures of the various raingages were examined from 17 to 19 September 1986. This inspection indicated that there are problems with many of the existing raingage exposures. An urban area represents a difficult region in which to properly expose a raingage. Typically, the area is covered by houses, trees, buildings, and major structures. Such conditions make it difficult to properly expose a raingage, and often roof tops are the only exposure available. A roof-top exposure must be established very carefully to insure that the raingage is not unduly affected by eddies or by general flow patterns which would alter the precipitation catch. Ideally, raingages on top of roofs should be near the center of the roof, and should not be affected by any major obstructions nearby. The raingage at any site should be located well away from any vertical structures to reduce eddies and to reduce the effect of the wind flowing over the top of the raingage.

Different Reduction Procedures

There are three different agencies in Chicago recording hourly and daily rainfall amounts. The procedures that are used to che?? the measurements and the final quality control are considerably different for all three.

The City of Chicago makes a stick measurement at noon at all of their raingages. At that point they compare the total amount of rain that was captured in a calibrated tube and compare this to the number of times that the bucket tipped. This provides an estimate, especially for intense rainfalls, of any under recording of the total amount of rainfall when compared to the number of tips recorded on the strip chart of the tipping bucket raingage. This means that the raingage is inspected on a daily basis and a comparison of the 24-hour rainfall indicated by the number of tips and the amount of rain that is measured is made. The City of Chicago also maintains a separate snow gage near all of their tipping-bucket raingages. During the winter when snow falls, the water equivalent of the snow caught in this gage is compared to the number of times the raingage tips. This provides a comparison of the amount of precipitation caught on any day. Such a procedure is especially important during the winter to compensate for precipitation that might not be recorded because of evaporation or because of a loss of snow due to convective currents caused by the heated enclosure. This provides quality control on a daily basis. Data are then reduced by the City of Chicago using the paper tape records to obtain hourly amounts.

The Metropolitan Sanitary District does not compare the number of tips with the actual amount of rain that fell into the tipping bucket raingage. Maintenance on the MSD raingages is performed once every 6 months, or when necessary. Each tip is telemetered to the MSD central office, and daily or storm amounts are recorded. For some of the gages the data are recorded on recording charts, which were reduced by the Northeast Illinois Planning Commission to obtain hourly amounts.

The NWS calibrates their weighing bucket raingages and the Fischer-Porter raingages at least once a year, and until 1985 tried to reach each raingage at least twice a year for calibration and maintenance. At each maintenance visit, the raingages are cleaned and calibrated. The observers, who maintain the records for the weighing-bucket raingages, are able to compare the rainfall totals captured in the weighing-bucket raingages to a standard 8-inch raingage. This provides a check on the reliability of the gage every time it rains. The weighing-bucket raingage charts are removed by the observer and forwarded to the National Climatic Data Center (NCDC) in Asheville, NC, for digitizing into hourly amounts. However, the NCDC does not compare daily amounts from the 8-inch raingage to the accumulated hourly amounts as part of their quality-control procedures.

The Fischer-Porter raingages, which are maintained by the NWS, record precipitation amounts on paper tape, and these tapes are forwarded to the NCDC for processing and reduction to hourly precipitation amounts. There is no way for the observer to determine if the Fischer-Porter raingage is functioning correctly.

A description of each raingage will be made. Only the raingages in Table 1 were inspected. The location of these and other raingages maintained by the NWS in Northeast Illinois are shown in Fig. 2.

Metropolitan Sanitary District Raingages

Calumet——The Calumet raingage is located on the southwest corner of a flat-roofed building about 15 feet above ground level, and extends 3 feet above the building. This raingage was moved to its present location in the late 1970's, response to an extensive building program at the Calumet Treatment Plant. The raingage was originally situated in a parking lot, west of the building upon which the raingage now resides.

The gage is situated only 2 feet north and east of the edge of the building. The area to the south of the gage is clear except for three locust trees to the southeast. About 60 feet east and northeast the building is 18 feet taller. Similarly, about 90 feet north the building is 12 feet taller. Another building approximately the same height is situated 65 feet west, with obstructions to the wind atop this building.

A considerable portion of the precipitation associated with strong winds coming from the southeast through northwest will be blown over the top of the gage, and will greatly diminish the precipitation catch in the gage. Precipitation associated with strong winds from the east will decrease the precipitation catch somewhat, while precipitation associated with winds from the north should be affected minimally. However, much of the precipitation in the Chicago region is associated with winds from the south through northwest, and this raingage should underestimate the amount of precipitation.

Since the expansion at Calumet around the area of the raingage has stabilized, it is recommended that this raingage be moved to a ground location in an open area. This would greatly improve the catch of this gage.

Glenview——The Glenview tipping-bucket raingage is situated on the top of a garage for the Glenview Public Works on Depot Street. The building is oriented east-west and the top of the domed roof is about 30 ft high. There are two tipping bucket gages on top of this roof; one is thermally insulated (MSD), and the other is uninsulated (Village of Glenview).

Such a roof location means that precipitation associated with all strong winds, except those directly from the east or the west, will be lifted over the top of the gages. This will result in a considerable underestimation of the actual precipitation. It would not be possible to relocate this gage at this Glenview Public Works location because of the small amount of ground space available and the large amount of traffic in the yard. One possibility would be to move it north to a newer garage maintained by the Village of Glenview, but the best option would be to obtain permission to locate the raingage at a ground location on the Glenview Naval Air Station.

Northside Treatment Plant——For the 1984 and 1985 water years, and up to August 1986, the tipping bucket raingage was located in an open field west of the gage's present location. The gage, at the location in this field, had little or no obstructions according to personnel at the Northside Treatment Plant. However, no evaluation of this prior location could be made because of construction changes. If there were no obstructions, the raingage should have been primarily affected only in those storms characterized by high intensity rains, or during the winter when the gage was heated. The raingage was moved because of an extensive building program presently underway at the Northside Treatment Plant.

The tipping bucket raingage at the Northside Treatment Plant is presently located in the northwest corner on top of a 4-story building south of the aeration pond. This gage was placed there in August 1986. Facades are situated 13 to 15 feet west and north of the gage. Immediately east is relatively clear, but there are facades northeast and a 1-story extension from the roof about 10 feet southeast. About 15 feet south is the extension of the staircase to the roof (approximately 1 story high). This raingage is subject to wind eddies from almost all directions, which should reduce the amount of precipitation associated with strong winds from any direction.

It is recommended that the raingage be relocated to a site less susceptible to eddies. Several possibilities exist. If at all possible relocation to a ground location is preferred. However, it is possible that the building roofs north of the aeration pond might be a feasible location. There are other possible locations at the surface within the plant area which could be investigated by the personnel at the Northside Treatment Plant.

Sanitary District Office——The Sanitary District Office tipping-bucket gage is situated on top of the 6-story building at 100 East Erie. About 25 feet west and 35 feet east of the gage are 1-story walls which block winds from the west and east. Precipitation occurring with strong winds from these directions would tend to be blown over the top of the gage. The biggest obstruction is a new building built by MSD across the street south of the 100 East Erie location. This building subtends an angle of about 45°) with the gage, and blocks precipitation when winds are from the south through southwest. Another building is located southeast and subtends about a 25° angle with the gage. The only direction which is relatively clear is from the north.

A second tipping-bucket gage is situated just east of the gage that is telemetered to the Central Dispatching Office at the Sanitary District Office. This gage has a wind shield around it, and was to be part of a comparison by MSD to determine whether or not it is reasonable to place wind shields around their gages. No comparison has been made to date.

Stickney West-Southwest Treatment Plant——The tipping-bucket raingage at the West-Southwest Treatment plant is located on the roof of a 4-story building. The raingage is in a relatively open area; but skylights and vents about 3 feet above the roof are situated about 15 feet south and about 10 feet west. In addition, facades, about 1-story high, are located about 25 feet north and about 30 feet east. The precipitation catch associated with strong winds from most directions would be influenced by the many obstacles. The precipitation catch from this gage would be better if it were located at a ground location.

City of Chicago Raingages

Mayfair——The Mayfair tipping-bucket raingage is located on top of a 2-story building about 7 feet from the west roof edge, and sits about 3 feet above the roof edge. There are no vents or other obstacles nearby. To the north and northeast, there is a 1 1/2 story wall, which is at least 30 feet from the gage. There is a large smokestack northeast of the gage, but the stack is far enough away that it would not present any obstructions to the precipitation catch. It is anticipated that precipitation associated with winds from the south and west would affect the catch of this raingage.

Roseland——The tipping-bucket raingage at Roseland Pump Station is located 5-stories high on top of a portion of the roof which is about 20 feet square. The raingage is about 8 feet from the east edge of the roof, and is centered from the south and north roof edges. Major obstacles are a raised roof (about 4 feet) to the west, and an old smokestack on the northeast corner of this portion of the roof. The precipitation catch associated with winds from the northeast will be underestimated. Precipitation associated with winds from other direction will tend to be lifted over the top of the roof. If possible, this gage should be relocated to a ground location. The gage is high in the air, and is affected by the stronger winds at that elevation.

South Filter Plant——The South Filter tipping-bucket gage is situated atop a 2-story building near Lake Michigan. The portion of the roof on which the raingage is located is about 100 feet wide and 240 feet long. A facade that is 10 to 12 feet high encloses the roof area in all directions, but to the west. The west part of the building is about 28 feet higher than the raingage, and the northwest part of the main building rises about 50 feet above the location of the raingage. The roof is relatively clear of all obstacles. The raingage, which is centered near the middle of this area, is sheltered from most winds, and is similar to a raingage exposed in a small forest clearing. Except for high-intensity rains, this raingage has good exposure and should provide good measurements through August 1986.

Springfield——The Metropolitan Sanitary District and the City of Chicago maintain tipping-bucket raingages at the Springfield Pump Station. Both raingages are located on top of a 2-story building, and are situated within 20 feet of each other. The City of Chicago gage is about 6 feet from the south edge of the roof, and the MSD gage is about 20 feet north of the City of Chicago raingage. Both gages are situated about 15 feet from the east and west edges of the building. There are a few air vents on top of the building, but all of these are below the height of the raingage, and are not close to the raingages. Overall, for a roof top, the exposure is fair.

National Weather Service Raingages

Chicago O'Hare WSO——The weighing-bucket raingage for Chicago O'Hare Airport is now situated near the Hardstand Building. This raingage location was moved from the top of the Old International Terminal in 1985. No evaluation of the previous location was possible because of remodeling. The weighing-bucket raingage, a standard 8-inch raingage, and a Cotton Region Shelter (to record temperature and humidity) are all presently located about 2.5 feet above the roadway. Obstructions at this site are the Hardstand Building about 60 feet north of the gage and two trees about 30 feet east of the weighing-bucket raingage. These are the only obstacles which would influence the precipitation catch. Precipitation catch for this raingage should be good.

Midway 3 Southwest——The Midway Airport site was moved in 1980 to a private residence 3 miles southwest of the airport. This site has three raingages: 1) a standard 8-inch, 2) a weighing-bucket, and 3) a Fischer-Porter raingage. The official hourly recording raingage is the Fischer-Porter raingage unless it malfunctions, then the weighing-bucket raingage is used. The raingages are located between two 1-story houses to the north and south. The house to the north is about 25 feet from the gages, and the house to the south is about 28 feet away. No other major obstructions were noted, except for a tree about 45 feet southeast. For an urban site, this raingage is quite well located, and the observer has been collecting climatic data since 1946.

Park Forest——The Park Forest raingage is a standard 8-inch instrument which is free from obstructions in all directions except for three trees to the northeast through southeast. The closest tree is about 35 feet due east, and the angle subtended between the raingage and the trees varies from about 30° to the northeast and southeast to about 45° to the east. A cotton region shelter to measure temperature and humidity is located 15 to 20 feet east, and the branches from one tree are beginning to extend over the shelter. The trees would block some precipitation associated with strong winds from the east. For an urban location it is a fair site.

University of Chicago——A weighing-bucket raingage and a standard 8-inch raingage are used to measure precipitation at the University of Chicago site. Hourly rainfall data are recorded by the weighing-bucket raingage. The gages are located between a 4-story house 30 feet to the west, and 1 1/2-story garage 20 feet to the east. The angle subtended relative to the raingage, by the house is about 45°, and the angle subtended by the garage is between 15 and 20°. An Alter wind shield surrounds the weighing-bucket raingage to cut down the turbulence around the gage. There are no obstructions north or south. The precipitation catch would be affected with strong winds from the east or west. However, it would be hard to find a better location in this urban area.

Aurora——The Aurora raingage is a standard 8-inch daily raingage, and is located in an open area at the Aurora Water Plant. The closest obstructions are a row of trees about 75 feet to the west. A small tree has been planted about 30 feet west of the gage, but at this time it poses no problem. However, as the tree matures it could shelter the precipitation catch.

Barrlngton——A standard 8-inch raingage is located at the Barrington Water Filtration Plant. The gage is located between a settling basin to the west which is elevated about 4 feet and a rise in the ground to the east crowned by bushes and small trees. These two features are separated by about 25 feet. To the north and the south there are no obstructions. However, the precipitation catch in the raingage would be affected with strong wind from any direction except from due north or south.

Chicago Botanic Gardens——The Chicago Botanic Gardens has a 8-inch daily raingage, and is an excellent site. The site is open with the nearest obstruction being some trees about 40 feet south. Generally, the site resembles a forest clearing.

Jollet Brandon Road Dam——The standard 8-inch daily raingage was moved to its present location in spring 1986. This site is blocked from the west through north by storage buildings, trees, and the Gatekeepers 2-story house. The site was moved because of construction activity. Previously, the gage was in an open area about 150 to 200 feet south of the present location. The raingage site prior to the spring of 1986 was open and would have suffered little or no blockage. The present location is suspect.

Wheaton——The standard 8-inch daily raingage located at the Morton Arboretum is in a small area surrounded by trees and bushes. To the west the bushes are only 15 feet away; and to northeast the branches from a tree, which subtends an angle of approximately 70° with the raingage, are within 15 feet of the raingage. The precipitation catch at this gage can be expected to be affected by strong winds from the west and northeast.

CHICAGO AREA PRECIPITATION CLIMATOLOGY

The long-term precipitation climatology for the Chicago urban area was examined to determine if there was a change in the precipitation catch at some of the stations and to establish if changes in precipitation pattern for the Chicago area had occurred. Emphasis was placed on determining if there was a secular change in the precipitation patterns due to a change in raingage exposure or reduction techniques.

Most of the precipitation data used for this analysis were published since 1952 in the Illinois Climatological Data produced by the National Climatic Data Center. Prior to this time the precipitation data from the City of Chicago and the MSD raingages were not readily available. Again, after about 1977 the precipitation data from the City of Chicago and MSD raingages were not published in a routine manner by the National Climatic Data Center. However, precipitation data were obtained from MSD for their raingages through 1984.

Comparison between raingages was made by double-mass curves for the entire period and by comparing nearby raingages from a dense raingage network maintained by the Illinois State Water Survey between 1977 and 1979.

Double Mass Curve Comparison

Double mass curves compare the cumulative annual precipitation over time of one raingage to the average cumulative annual precipitation from two or more independent raingages (Linsley et al., 1958; Kohler, 1949). This technique has been found useful in determining whether or not a move of a raingage from one location to another has substantially affected the precipitation climatology. It has also been used to determine if the exposure of one raingage when compared to other raingages has changed with time; i.e., have trees or buildings over time affected the catch efficiency of a raingage.

The most complete NWS raingages in the Chicago urban area from 1952 through 1984 were the combination of 1) the University of Chicago and 2) Midway Airport (maintained by the NWS as a first-order station through 1980) and Midway 3 SW (a cooperative station since 1980). The cumulative annual precipitation totals from the raingages at these locations were compared for 1952 through 1984 using a least squares fit. The records from these raingages, when compared to each other, were found to have a slope of nearly 1.0 (0.999) and a correlation coefficient of 0.999. Midway Airport until 1980 was the official Chicago raingage. 0'Hare International Airport has been the official station since 1980. However, this site did not have a raingage prior to 1959, and it was not chosen for this comparison because of the record did not encompass the period from 1952 through 1984.

The annual precipitation from the University of Chicago and Midway were averaged and accumulated. The annual precipitation for the other raingage stations used in the Lake Michigan division assessment, and raingage stations in the surrounding countries (Table 1) was also accumulated. These data were plotted on the y-axis against the cumulative average total of Midway and the University of Chicago on the x-axis (see Fig. 3 for three representative examples). The diagrams were then examined to determine if there were any major deviations in the slope of the cumulative totals over the years using a least squares fit.

A double-mass curve between the raingage at Joliet Brandon and the average annual totals of the University of Chicago and Midway is shown in

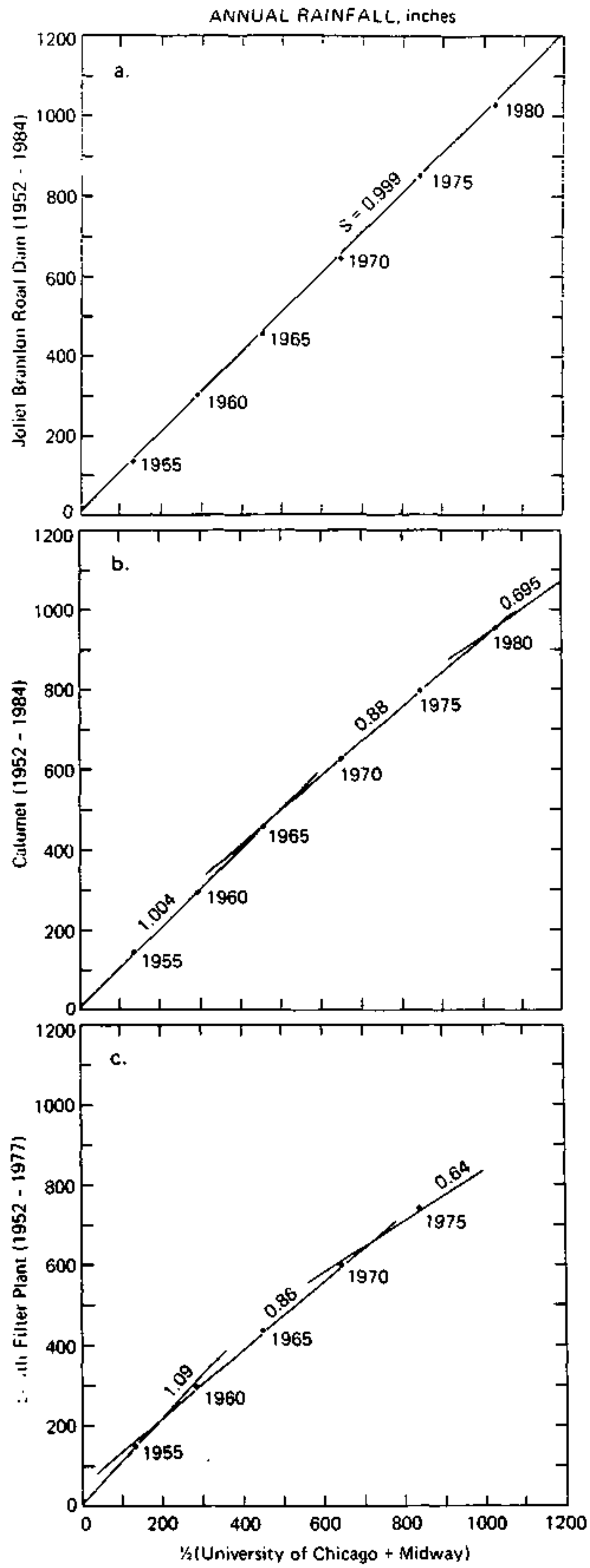

Figure 3. Double-mass curves comparing average rainfall from the University of Chicago and Midway to a) Joliet Brandon Road Dam, b) Calumet, and c) South Filter Plant

Fig. 3a. From 1952 through 1984 the slope of this curve is 0.999, and no consistent slope changes were observed. On the average, since the slope is a little less than 1.0, the annual precipitation at Joliet Brandon Road Dam is just slightly less than what was observed, on the average, at the University of Chicago and Midway.

In contrast the double mass curves for the Calumet Sewage Treatment Plant and the South Filter Plant (Fig. 3b and c) exhibit significant changes in slope. At Calumet the annual precipitation from 1952 through 1966 had a slope of 1.04 compared to the average annual precipitation at the University of Chicago and Midway. After 1966 the annual precipitation at Calumet, relative to the average annual precipitation at the University of Chicago and Midway, averaged 12% less, and the slope of the curve became 0.88. About 1979 the slope changed to 0.70, and the annual precipitation at Calumet dropped to about 70% of the average annual precipitation caught at the University of Chicago and Midway. Similar mass curves were obtained for the remaining MSD raingages except for the slope change at Calumet in 1979 (Table 2). Between 1965 and 1967 all of the MSD gages showed a change in slope from near 1.0, compared to the average annual precipitation at the University of Chicago and Midway, to a slope between 0.82 and 0.89. Calumet was the only MSD raingage to show a drop in the slope to 0.7 in 1979. This latter change can be attributed to a location change from a ground-based exposure to an inadequate roof-top exposure. No ready explanation can be given for the consistent change in slope that occurred in the period from 1965 to 1967 at all of the MSD raingages. However since the slope at all of the MSD raingages changed about the same time; it would appear that there was some shift in observing procedures or quality control. Conversations with MSD

Table 2. Double-Mass Curve Slopes Compared to Average Annual Precipitation at the University of Chicago and Midway.

Station	Years	Slope	Years	Slope	Years	Slope
Calumet (M)	1952-1966	1.00+	1967-1978	0.88	1979-1984	0.70
Mayfair (C)	1952-1958	1.13	1959-1979	0.90		
Roseland (C)	1952-1956	1.06	1957-1977	0.91		
Sanitary District Office (M)	1952-1964	1.05	1965-1984	0.87		
Skokie Northside Treatment Works (M)	1952-1964	0.99	1965-1984	0.82		
South Filter Plant (C)	1952-1956	1.09	1957-1970	0.86	1971-1977	0.64
Springfield Pump (C)	1952-1984	0.96				
Stickney West Southwest Treatment Plant (M)	1952-1966	1.05	1967-1984	0.89		
Arlington Heights/ O'Hare (N)	1952-1984	0.96				
Aurora (N)	1952-1984	1.01				
Joliet Brandon Road Dam (N)	1952-1984	0.99				
Park Forest (N)	1952-1958	1.08	1959-1976	1.01	1977-1984	0.93
Peotone (N)	1952-1984	1.03				
Waukegan (N)	1952-1984	0.96				
Wheaton (N)	1952-1974	1.03	1975-1983	0.96		

C = City of Chicago
M = Metropolitan Sanitary District
N = National Weather Service

personnel do not point toward exposure changes in this period. Long-term data for Glenview were not available, and no double-mass analysis was performed for this station.

The mass comparison curve at the South Filter Plant shows that about 9% more precipitation fell through 1956 than at the University of Chicago and Midway. From 1957 to 1970 the slope fell to 0.86, and from 1971 to 1977 the slope dropped to 0.64. Measurements from the South Filter Plant were not readily available after 1977. The same was true for Mayfair and Roseland. However, these three raingages all showed a slope change from between 1.06 and 1.13 prior to 1957 through 1959 to between 0.86 and 0.90 after 1959 (Table 2). The additional slope change to 0.64 at the South Filter Plant beginning in 1971 was caused by an extension of the roof of the trapezoid shelter above the lip of the raingage. This has been subsequently corrected. The 1957-1959 slope changes again would seem to point toward some change in procedure or quality control, or might point toward the addition of the trapezoid shelters. The only City of Chicago station that did not exhibit such a change was at the Springfield Pumping Station. The slope at Springfield from 1952 through 1984 was 0.96. The only aberration noted at Springfield was an unusually low annual precipitation total in 1966.

The NWS stations which showed changed slopes were Park Forest and Wheaton (Table 2). Park Forest showed two changes, the first in 1959 and again in 1977. Both of these represent decreases of annual precipitation compared to the University of Chicago and Midway. Wheaton had a slope of 1.03 from 1952 through 1974, and since 1975 has been only 0.96. Interestingly, no slope change occurred with the move in 1966. The slope change since 1975 probably indicates the period when the trees and other bushes, which presently surround the raingage at Wheaton, matured enough to affect the precipitation catch. Similar occurrences might have occurred at Park Forest or some of these slope changes may be due to minor moves of the Park Forest station.

Aurora was moved from Aurora College to its present location in 1976, and the raingage at Arlington Heights was shifted to O'Hare Airport in 1959. None of the site movements at these stations provided any slope changes. Peotone and Waukegan maintained the same slope throughout the period from 1952 to 1984.

The double-mass curve analysis points toward some type of changes in procedure, exposure, quality control or personnel changes at the MSD after 1966 and at the City of Chicago from 1957 to 1959. The shift in slope toward lower precipitation values at those stations operated by MSD and the City of Chicago relative to other raingages in the area would have the effect of creating relative minimums in the spatial distribution of precipitation. Several of the NWS raingages also indicate some shift in slope; and in several instances these shifts seem to be related to exposure. The changes occurred either at the site or by moving the station.

Dense Raingage Network Comparison

According to the double-mass curve analysis, the precipitation measured by the City of Chicago and MSD raingages was generally lower than expected when compared to the University of Chicago and Midway raingages. During the period from 1977 through 1979 the Illinois State Water Survey operated a dense raingage network (Huff and Changnon, 1977; Huff et al., 1981) in and around the Chicago urban area. Weighing-bucket raingages were used, which are the same raingages used by the NWS as the official raingage at first-order stations. The availability of data from that dense network within the same region afforded an opportunity to compare the MSD and City of Chicago raingages with raingages which had good exposures and were consistently reduced and quality controlled. A comparison was therefore made of the annual and monthly precipitation totals of the City of Chicago and MSD raingages and the nearest raingage within the dense network operated by the Illinois State Water Survey from 1977 through 1979.

The Water Survey gages, as much as possible, were located with only minor obstructions which would restrict flow around the gage within the urban area. Generally, most of the raingages were located on the ground, rather than on roof tops. In addition, the weighing bucket raingages used by the Water Survey are not subject to loss of precipitation due to extreme rain storms which most often occur in the Chicago area from June through August (Huff and Vogel, 1976).

Table 3 compares the annual precipitation at some Chicago urban stations with the closest Water Survey gage for the years 1977-1979. The annual precipitation totals for this period, their average, and the difference between averages for the Chicago urban gage and the Water Survey gage are given. The Water Survey gages were placed on a 3-mile grid across the region, so generally the closest raingage to the Chicago urban area gage was used for comparison. However, the Sanitary District Office and the Springfield Pump raingages were approximately half way between Water Survey gages, so the closest two gages were used for comparison.

The annual precipitation at the Springfield Pump gage was higher than both Water Survey gages in 1977; and the annual precipitation at the Sanitary

Table 3. Comparison of Annual Precipitation Amounts (Inches) Between Chicago Urban Raingages (CUR) and Nearby Water Survey (WS) Raingages (Inches).

	1977	1978	1979	Average	Difference (WS-CUR)
Calumet	33.40	28.34	30.84	30.86	
ISWS	35.59	33.84	38.01	35.82	+4.96
Glenview	26.88	36.76	27.96	30.56	
ISWS	36.90	38.58	34.77	36.78	+6.22
Sanitary D. O.	33.19	34.70	33.34	33.74	
ISWS #1	39.73	38.82	37.44	38.66	+4.92
ISWS #2	38.40	32.61	40.36	37.12	+3.38
Skokie	29.30	33.88	28.20	30.46	
ISWS	36.46	39.98	32.96	36.47	+6.01
Springfield	41.21	34.73	36.56	37.50	
ISWS #1	38.54	38.99	40.43	39.32	+1.82
ISWS #2	40.21	40.00	40.05	40.08	+2.58
Stickney	34.07	30.27	33.92	32.75	
ISWS	37.65	33.84	37.33	36.27	+3.52

District Office gage was greater than one of the two nearby Water Survey gages in 1978. Otherwise, the Water Survey gages all had greater annual precipitation amounts than nearby Chicago urban area gages. On the average for the 3-year comparison, the Water Survey gages received 1.82 to 6.22 inches more precipitation than did the Chicago urban gages.

A frequency count of the number of months that a MSD or City of Chicago raingage had the greatest precipitation total was made (Table 4). For example, in 1977 there were four months during which the Calumet raingage had a greater precipitation total than the nearby ISWS raingage. Over the 3-year period there were only 5 months in which the Calumet raingage had a greater monthly total than the ISWS, and during one month there was a tie. In 1977 and 1978 the Sanitary District Office raingage had monthly precipitation totals which were equal to or greater than one of the nearby Water Survey gage; and, the raingages at the Springfield Pump Station had monthly precipitation totals which were greater than or equal to the two Water Survey gages in 1977. Otherwise, the monthly precipitation totals at the Water Survey raingages were greater than the corresponding Chicago urban raingages 7 to 11 times each year. On the average, the monthly precipitation total at each of the Water Survey gages was greater than the nearby Chicago urban raingage 8 times a year. One would expect over a 3-year period that the frequency of monthly precipitation totals would be about equal to each other if there was no bias in precipitation catch.

The Chicago urban area raingages underestimated the monthly precipitation totals least often during the summer, but even then the total monthly precipitation at Chicago urban area raingages was generally less the monthly precipitation totals at nearby Water Survey raingages.

Table 4. Frequency Count of Greatest Monthly Precipitation. Between Chicago Urban Raingages (CUR) and Water Survey (WS) Raingages.

Raingages	1977	1978	1979	Total
	CUR/WS	CUR/WS/TIE	CUR/WS/TIE	CUR/WS/TIE
Calumet/WS	4/8	0/11/1	1/10/1	5/29/2
Glenview/WS	0/12	5/7	0/12	5/31
Sanitary District Office/WS #1	3/9	3/9	2/10	8/28
Sanitary District Office/WS #2	6/6	7/5	3/9	16/20
Skokie NSTW/WS	1/11	1/11	1/11	3/33
Springfield/WS #1	7/5	4/8	2/9/1	13/22/1
Springfield/WS #2	6/6	3/9	3/7/2	12/22/2
Stickney WSWTW/WS	4/8	4/8	3/8/1	11/24/1

Example

The comparison between the Chicago Urban raingages maintained by the MSD and the City of Chicago and the dense network maintained by the Water Survey indicates that 1) the annual precipitation amount at the Chicago Urban raingages was generally lower than at the comparable Water Survey raingage, and ?.) the precipitation catch of the Chicago Urban gages underestimated the monthly precipitation amounts consistently during the 3-year comparison period.

Spatial Analysis of Long-Term Data

Long-term precipitation data were examined to check for spatial consistency in the region and to determine if the long-term spatial analysis showed the same unusual cellular structure in the Chicago area found in the 1983 and 1984 Water Years (e.g., Fig. 1). Four different periods were chosen for this analysis. They are: 1) 1952-1966; 2) 1952-1970; 3) 1971-1980; and 4) 1951-1980 (Fig. 4). It was anticipated that these periods would highlight any changes in the precipitation pattern over Chicago and Northeast Illinois, and would allow a comparison with the long-term 1951-1980 normals published by the National Climatic Center (1981). The 1952-1970 pattern was chosen to demonstrate how just a few years with altered precipitation data can change the spatial pattern even for a period as long as 19 years. In addition, it was expected that the 1971-1980 period would exhibit much the same pattern in the Chicago area that was experienced in 1984 (Fig. 1), and would confirm that these unusual patterns due to data problems had been occurring for some time.

Average annual precipitation amounts for the four different time periods are shown in Fig. 4. The first period (Fig. 4a), 1952 through 1966, is the

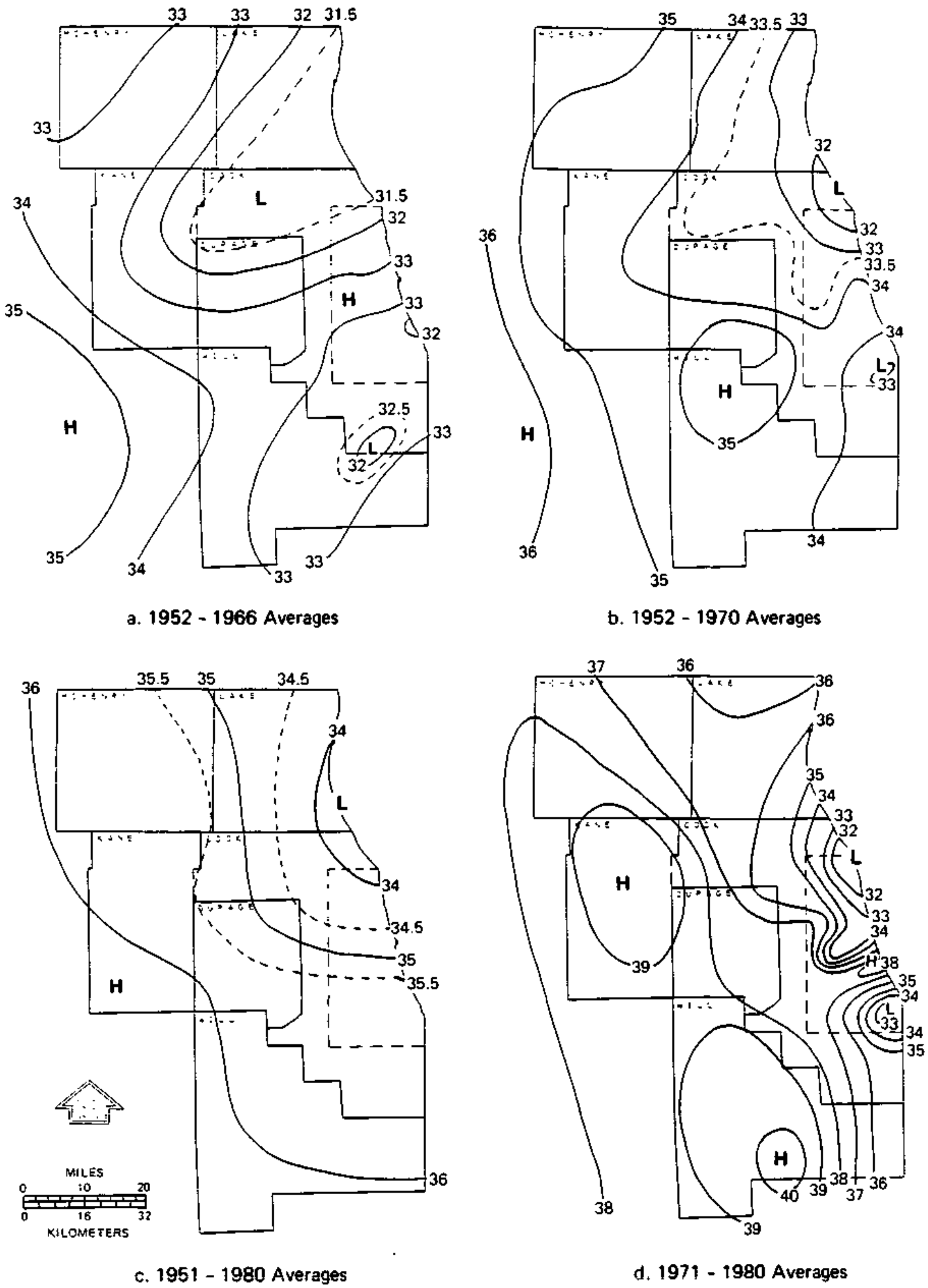

Figure 4. Average annual precipitation (inches) for Northeast Illinois: a) 1952-1966, b) 1952-1970, c) 1951-1980, and d) 1971-1980

period during which there was no change in the slope at the MSD gages. Precipitation data from NWS and MSD gages, which were available during this period, were used for this analysis. No City of Chicago data, except Springfield Pumping Station, were used since the slope at these gages changed as early as 1957. Generally, there was a minimum over Lake and northern Cook counties; a minor maximum in the vicinity of the Loop; and a minimum around Park Forest. This pattern agrees well with that found by Changnon (1961) for 1945 through 1956, and is considerably different than the pattern along Lake Michigan found in Fig. 1 .

Between 1966 and 1970, the annual precipitation was generally much above normal at most NWS stations, but the measured rainfall at MSD and City of Chicago raingages did not rise in the same manner. Figure 4b shows the average annual pattern for 1952 through 1970. A comparison between Figs. 4a and b shows that the annual precipitation rose by 1 to 2 inches at most NWS stations, but at the MSD gages the average annual precipitation changed little. As a result, the gradient in the northern and southern parts of Chicago have begun to tighten. The precipitation high, previously noted over the Loop area, slipped south toward the University of Chicago and Midway Airport. Even though only 4 years of data were added, a noticeable change in the spatial pattern over the Chicago area is thus noted. This shows how only a few years of altered data can begin to change the overall pattern.

The 1951 through 1980 annual average precipitation from NWS stations is shown in Fig. 4c. The average annual amount rose during this period compared to the 1941-1970 normals. One factor causing this rise was that during this 30-year period there were no major drought episodes in northern Illinois. As a result, the normals for the 30-year period 1951-1980 in Northeast Illinois are as high as they have ever been for any 30-year period since 1930 (National Climatic Center, 1981). As in the previous maps, there is a precipitation minimum in Lake and northern Cook counties with the average annual precipitation amounts increasing toward the west and the south. However, no precipitation minimum was noted with the 30-year normals near Park Forest in southern Cook county or Crete in northern Will county.

The 10-year average annual precipitation for 1971 through 1980 (Fig. 4d), using all available NWS, MSD, and City of Chicago raingages, provide a much different pattern than any of the other average annual patterns in Fig. 4. The precipitation gradient along the shore of Lake Michigan is very tight, and there is a difference between the southern parts of Chicago and the University of Chicago of about 6 inches, compared to a difference of about 0.5 inch during 1952 through 1966. Similarly, the difference between the southern Chicago area and northern Cook county from 1971 through 1980 is about 5 inches, whereas this difference was only about 1.5-2.0 inches for 1952-1966 and 1951-1980. The 1971-1980 pattern that is seen along Lake Michigan is similar to the pattern found in more recent observations (Fig. 1). It would appear that the precipitation catch from the City of Chicago and MSD raingages after 1970, when compared to NWS raingages, is considerably less than the catch prior to 1966. The only exception is the raingage at the Springfield Pump Station. This gage has maintained a relation to NWS gages in 1971-1980 similar to the relation it had for 1952-1966.

The pattern over northeast Illinois for the 1951-1980 period compares well with the general pattern determined by Changnon (1968) using data for 1931-1952 for cooperative stations and 1921-1950 for first-order stations. The major difference is that on the average the pattern shown in Fig. 4c for northeast Illinois is about 2 inches greater than the pattern found by Changnon. This agrees with the general difference found for the Northeast Crop Reporting District by National Climatic Center (1981). It is recommended that the pattern from 1951-1980 depicted in Fig. 4c be used as the best available climatic pattern.

EVALUATION OF PRECIPITATION FOR WATER YEAR 1984

The raingage inspection and the long-term analysis of precipitation data in the Chicago area indicated that some of the raingages used for guidance in the accounting of water diverted from Lake Michigan into Illinois consistently underestimated the monthly and annual precipitation totals during the 1983 and 1984 water years. As a result, a procedure to correct the precipitation totals was found to be needed and was accordingly devised-. A major requirement of any procedure that was developed was to make corrections on an individual storms basis. This was necessary because part of the accounting procedure involves using storm and hourly precipitation amounts in a continuous hydrologic model.

The data used in the original analysis for the 1984 Water Year (Fig. 1) was obtained from the Northeast Illinois Planning Commission (NIPC) . For the 13 sites used in the accounting procedure this included hourly precipitation amounts from the MSD, the City of Chicago, and NWS raingages and daily data for Park Forest. In addition to the data supplied by NIPC, precipitation data from raingage sites at the Chicago Botanic Gardens, Barrington, Aurora, Wheaton, and Joliet Brandon Road Dam were used to supplement the spatial distribution of the storm data, and to aid in preparing isohyetal patterns of individual storms.

Hourly precipitation amounts for each of the recording raingages used in the accounting procedure were printed chronologically in columns by hour and day, providing a matrix of all hourly precipitation data with all stations printed side by side. This matrix was used to check the data for possible time inconsistencies, and to divide the precipitation data into storms. For the purposes of this work, a storm was defined as a rain period separated from preceding and succeeding precipitation by 6 hours or more. This definition has been used successfully by Huff (1967) for a similar sized area in Central Illinois, and by Vogel (1986) in the Chicago area.

Overall, 113 individual storms were defined and plotted using the hourly precipitation data from raingages in Chicago and Northeast Illinois, and daily precipitation amounts from other NWS raingages. The isohyetal pattern for each storm was determined by using all available precipitation data in Chicago area and the surrounding counties. The NWS gages were given more weight in defining the isohyetal pattern because of exposure problem of many of the raingages from the MSD and the City of Chicago, previously discussed. After a generalized precipitation pattern was analyzed for each storm, a corrected storm precipitation total was determined for those raingages used in the accounting procedure which were believed to be in error. This corrected total was estimated directly from the storm isohyetal pattern using linear interpolation.

The accumulated storm correction for the 1984 Water Year was largest at Calumet (Figure 5). There was a deficit of 13.36 inches of precipitation at this station. The second highest deficit was Glenview in the northern part of the network. Interestingly enough, the precipitation at Midway was reduced by 1.69 inches. Most of this reduction was due to a "rainstorm" that

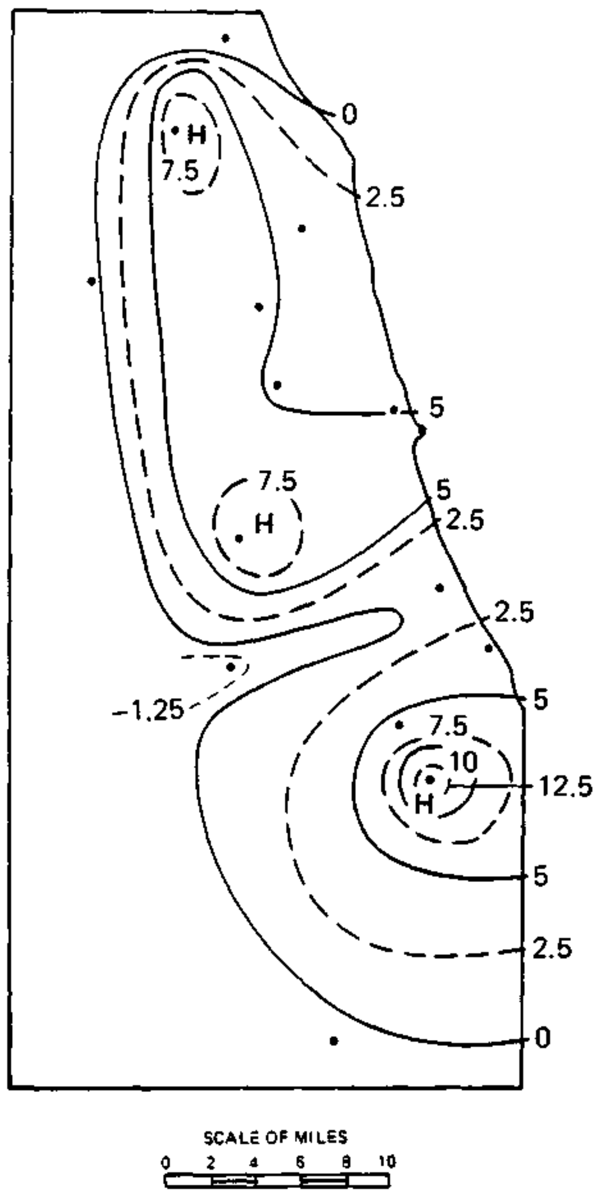

Figure 5. Accumulated storm corrections (inches) for 1984 Water Year

allegedly occurred on 1 April 1984 at Midway 3 Southwest. The records suggest that this "storm" was a very intense 1-hour storm, and was only observed at Midway 3 Southwest. A check of the 3-inch and weighing-bucket raingage measurements at that station for 1 April indicated that no rain fell in either of these gages. No rain was recorded in any part of northeast Illinois on that particular day. Apparently, the raingage was being inspected on that particular day, and no remarks were made on the paper tape that a test was conducted on this Fischer-Porter raingage. This reveals a weakness in the NCDC quality control procedures.

Total corrected precipitation amounts for the 1984 Water Year ranged from 3 to about 7.5 inches at either the City of Chicago or MSD raingages. The measurements at the University of Chicago raingage were increased by 0.5 inch. As at Midway, this correction was made by comparing a concurrent measurement at the 8-inch raingage standing within 6 feet of the weighing-bucket raingage. The University of Chicago weighing-bucket raingage on that particular day appeared to be an underestimation, and this was confirmed when a comparison was made with the 8-inch raingage.

This indicates that even though the precipitation data from the NWS generally have better exposure and better quality control, there are no comparisons made by the NCDC to determine whether or not the hourly rainfall amounts agree with other measurements at the site. The NCDC accepts the data from each gage. They do not compare measurements to other gages at the site; nor do they compare for spatial continuity in the region.

Figure 6 gives the percent change from the original 1984 water year estimates. Generally the changes range from -4% to 1%, for three NWS gages;

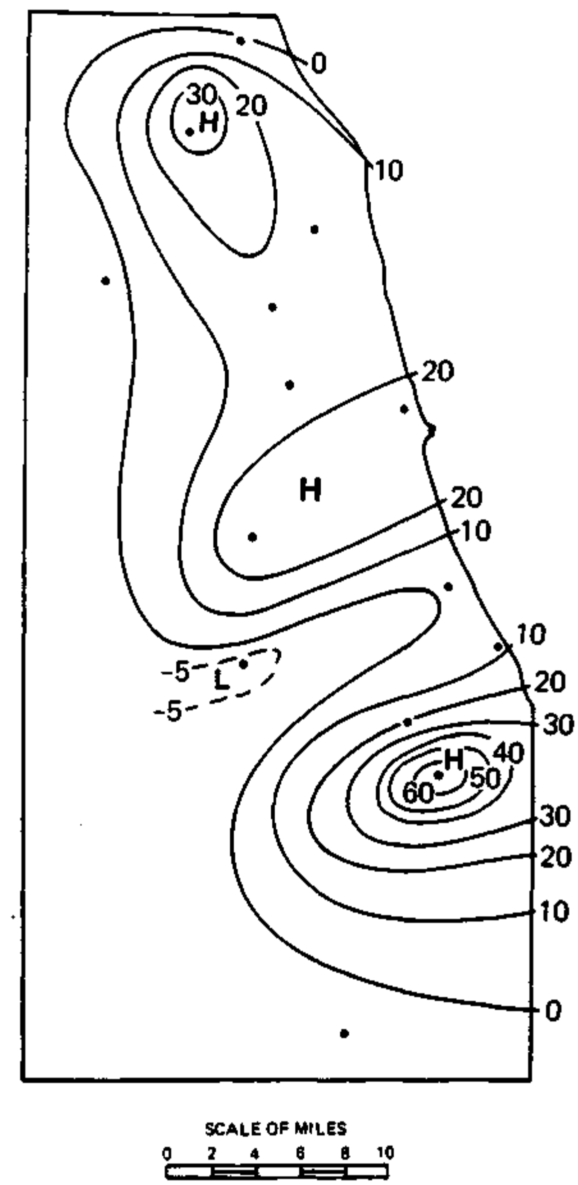

Figure 6. Percent change of precipitation from original 1984 Water Year

12 to 62? for the Metropolitan Sanitary District; and 8 to 18? for the City of Chicago.

The final 1984 Water Year revised precipitation is shown in Figure 7. A maximum was observed near the West-Southwest Treatment Plant and Midway with a general maximum from Glenview to Park Forest. Lesser precipitation amounts were found along Lake Michigan and to the west. The precipitation amounts at the Sanitary District Office and the South Filter Plant were difficult to estimate because of a lack of gages to the east for comparison. For several storms even though the individual storm amounts appeared low, they were accepted as reported. Therefore, it is possible that the revised estimates for these locations are slight underestimates of the precipitation captured in this region.

Table 5 gives the number of storms and the percent number of storms by gage for which precipitation amounts were changed during the 1984 Water Year. The station with the highest number of corrections was Calumet with 48% of all storms being revised. Glenview was second with 43% of all storms being changed. The Northside Treatment Plant had 26? of all the storms changed, but this represented only a 12? change in the total amount of precipitation. Until August 1986 this particular gage was situated in a relatively open region with only minor obstructions. The 12% increase represents the inability of the tipping-bucket raingage to measure intense rainfall rates accurately and the problems encountered measuring snowfall during winter with a heated raingage.

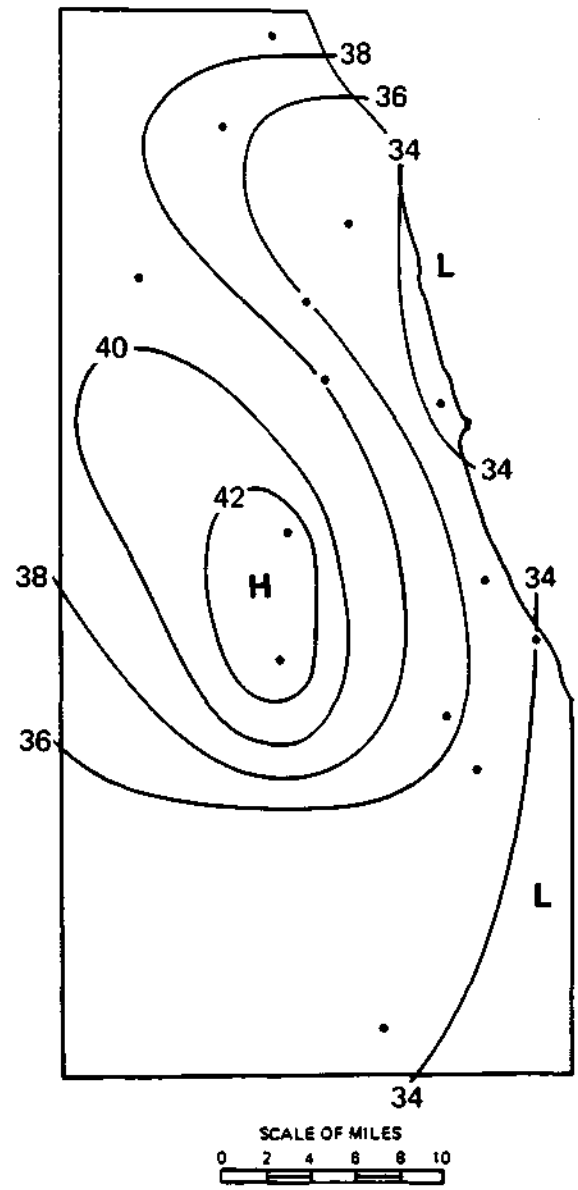

Figure 7. Revised 1984 Water Year precipitation (inches)

Table 5. Number, Percent of Storms Corrected, and Percent Change of Precipitation by Station during Water Year 1984.

	Number of Storms	Percent of Storms	Percent Change of Precipitation
Park Forest (N)	0	0	0
O'Hare Airport (N)	0	0	0
Midway 3 SW (N)	13	12	-4
WSW Treatment Plant (M)	38	34	22
Mayfair Pump Station (C)	35	31	18
Springfield Pump Station (C)	26	23	13
Roseland Pump Station (C)	31	27	17
Calumet Treatment Plant (M)	54	48	61
University of Chicago (N)	9	8	1
South Filter Plant (C)	20	18	8
Northside Treatment Plant (M)	30	27	12
Glenview (M)	49	43	34
Metropolitan Sanitary Office (M)	41	36	25
Chicago Botanic Gardens (N)	0	0	0

C = City of Chicago
M = Metropolitan Sanitary District
N = National Weather Service

CONCLUSIONS AND RECOMMENDATIONS

The 1984 Water Year illustrates the problems that can be encountered when precipitation observations from several networks operated by different organizations are merged and treated as one data set. The exposures of the different raingages were not comparable, and, in some instances, not adequate. Changes in personnel with time and/or changes in the original exposure provide additional problems. The data reduction procedures from the three different organizations result in a non-uniform set of quality-control standards. Also during the inspection, it was noted that the enthusiasm of the observers within the different groups varied greatly. Some observers looked upon it as a job which had to be done by the low man on the totem pole, while others took great pride in maintaining a high quality set of observations.

With these types of differences it will always be hard to maintain a consistent set of high-quality precipitation observations for the Chicago urban area. A precipitation network which must produce a set of high-quality observations should have a consistent set of gages; should be managed by one group with fixed quality control procedures, exposure criteria, and a set operating procedure. Management by one group would allow for consistent 1) observations, 2) quality control, and 3) spatial and temporal precipitation patterns.

To achieve this, it is recommended that a raingage network be established to monitor the precipitation over northeast Illinois relevant to the diversion of Lake Michigan waters. This network should consist of 10 to 15 weighing-bucket recording raingages. The raingages should be reasonably spaced across the affected area. The network should be managed by one group to ensure that the best possible exposures are obtained initially, and that these exposures are inspected at least annually. The data from such a network should all be quality-controlled in a consistent manner. Weighing-bucket raingages with daily charts would be capable of obtaining hourly or smaller time increments if daily charts are used. To reduce costs and to increase security, it is further recommended that these raingages be located on private property, and that the observers be given a modest annual stipend. The charts from the observers should be mailed to a central location for data processing, quality control, and extraction of hourly precipitation totals. Raingages should be evenly spaced, as much as possible, and sites would be found after consulting with the agencies involved.

ACKNOWLEDGEMENTS

This work was supported by a contract from the Illinois Department of Transportation (STILTRWRCMOBRAQSY110). Dan Injerd, the contract monitor has supplied many helpful suggestions, and assisted in obtaining data for sources in Chicago. Jim Angel performed the computer work, and guided the general reduction of data for the analysis of the hourly precipitation data. Doug Jones assisted in the assessment of the raingage exposures in the Chicago region. Rebecca Runge has patiently typed this report. John Brother and Linda Riggin prepared the figures.

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