A comparative study of eastern and western Iowa precipitation patterns

by

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INTRODUCTION AND LITERATURE REVIEW

To date there have been no major cloud-seeding experiments in the Midwest; however, the Illinois State Water Survey has recently been contemplating such a study for central Illinois (Dr. Stanley A. Changnon, Jr., Water Resources Building, 605 E. Springfield, Champaign, Illinois, personal communication, 1978). Because Illinois is in the Corn Belt, a major thrust of such research would be to better manage the supply of water available for crops. If crop yields could be thus increased in Illinois, the next step would be to apply the same technology to other areas in the Midwest.

Although most of the Midwestern states have a temperate continental climate (Trewartha, 1968), the region is not climatologically homogeneous. For instance, the position of the transition zone between that climatological region and the semiarid region to the west fluctuates from year to year. Because western Iowa is sometimes included in this transition zone, it would be incorrect to assume that the climatology of the entire state differs little from that of central Illinois. If one is interested in transferring cloud-seeding technology from central Illinois to western Iowa, it would seem logical to first assess differences in the precipitation patterns of the respective areas. Western Iowa data were compared with data from eastern Iowa, in place of those from central Illinois. This substitution was made primarily because the Iowa data were readily available. Although the Illinois data have been extensively analyzed by the Illinois State Water Survey, the exact details of their analyses were not given in their reports. The statistical procedures used in this study of eastern and western Iowa precipitation patterns are described in detail in the section on METHODS.

The purpose of this study was to compile and study the July-August storm climatologies of eastern and western Iowa to assess the feasibility of cloud seeding in Iowa and to determine the transferability of such technology within the Midwest. All results were based upon the assumption that seeding can only enhance the rainfall from naturally precipitating clouds. Neither suppression nor initiation of rainfall were considered.

An important difference between this study and those conducted in Illinois involved the density of the sampling networks. The Illinois studies relied upon data collected from networks in which the rain-gage density ranged from about 1 to 20 square miles per gage; however, the Iowa study relied upon data collected from the less dense network of climatological substations. Although the very dense networks will be vital in evaluating the effects of seeding experiments, such networks may not be always available when the technology is transferred to other areas within the Midwest. Researchers will have to rely instead upon the data acquired from the climatological substation network. Methods to compare the data from two of these sparse networks have been developed as a part of this study.

The Florida Area Cumulus Experiment (FACE) is one of the most recent cloud-seeding experiments. Woodley et al. (1977) state that "the best rough estimate of the magnitude of the mean seeding effect is ... 25 to 35 percent for total target rainfalls." Because this experiment was limited to maritime tropical air masses, the results may not be applicable to all Midwest storm types. During summer months, Iowa frequently receives warm moist air from the Gulf of Mexico, which leads to convective storms similar to those studied during FACE. Therefore, FACE results might be considered applicable to at least some Iowa summertime precipitation events. Iowa often experiences inadequate rainfall for corn and soybean crops during July and August; therefore, storm climatologies, including the occurrence of different storm types, have been compiled for these 2 months during the period extending from 1952 through 1976.

Using crop yield and climatological data for a 40-year period (1931-1970), a stress-index procedure, and the same constant-change rainfall modification levels as Huff and Changnon (1972), Shaw (1974) has computed the effects of rainfall changes in corn yields for each of Iowa's 9 crop-reporting districts. Shaw has found that if July and August precipitation were to be increased by 12% overall, then corn yields across the state could be increased by an average of 160 pounds per acre (about 3%). He cautions, however, that because the procedure presumes that yield decreases cannot occur with rainfall increases, yield changes may be overestimated. Using multiple regression equations, Shaw (1974) has shown that yields could be increased during wet months if precipitation were reduced.

Staff of the Illinois State Water Survey have worked extensively with precipitation climatologies of that state. Huff (1971) has addressed several aspects of the weather modification problem, including the potential for rainfall enhancement. Rainfall events were categorized by total or average depth, duration, season, synoptic type, and precipitation type (i.e., thunderstorms, rain showers, steady rain, snow). The seven synoptic classes included cold, warm, stationary, and occluded fronts, squall lines, air-mass instability, and the passage of low-pressure centers. Nomograms have been constructed to allow one to calculate the potential benefits of seeding under various hypotheses. When Huff (1971) assumed (1) that technology could achieve 20% enhancement of rainfall from all seeded storms, (2) that only those storms that would produce no more than 0.50 inch rain naturally would be seedable, and (3) that 80% of such storms would be seeded, he concluded that during an average dry year total May-September precipitation could be increased about 5%. Furthermore, the expected overall increase would be only 2-4% during a typical year if seeding was restricted to air-mass storms that would produce no more than 1.00 inch precipitation naturally. Huff (1971) concluded that if the agricultural and municipal water supplies of Illinois are to be increased, then large increases must be obtained from both frontal and nonfrontal storms and(or) from naturally non-precipitating clouds.

According to Huff and Semonin (1975), Illinois rainfall, both amount and frequency of occurrence, display a nocturnal maximum. The potential for enhancement would therefore be limited if seeding operations were restricted to daylight hours. Such a restriction could be imposed by the difficulty of spotting clouds from an airplane at night. The diurnal distribution of Iowa rainfall has been examined to determine how significantly the enhancement potential would be limited by this restriction.

If silver iodide (AgI) is the seeding agent, persistence could possibly compensate for part of that restriction by enhancing some of the nocturnal rains. Bottner et al. (1975) has found that an AgI-washout period of 2, 3, or even 12 hours may be insufficient to eliminate the possibilities of persistence. AgI persistence would provide a benefit to operational seeders but a detriment to researchers. Water supplies might be increased by the enhanced nocturnal rainfall, but during an experimental period, persistence could contaminate the control target, should the crossover experimental design be used. Schickedanz and Huff (1971) have recommended the crossover design for Illinois experiments because it "will provide verification of seeding effects on surface precipitation quicker than the other statistical designs discussed in [their] study." Control-target contamination could extend the length of time and thereby increase the expense of determining the significance of seeding effects.

DATA SOURCES

All of the data used in this study came from the U.S. Department of Commerce. Most of these data were available from local files; incomplete files were supplemented by those from the offices of Iowa's State Climatologist and the National Weather Service in Des Moines. Additional data were obtained from the National Climatic Center in Asheville, North Carolina.

Hourly rainfall amounts for all stations except Omaha, Nebraska were copied from Hourly Precipitation Data (U.S. Dept. of Commerce, 1952d-1976d). Data for that station were copied from Local Climatological Data (U.S. Dept. of Commerce, 1952e-1976e). Starting in the mid-1960's some of the Universal recording rain gages, which measure precipitation to the nearest 0.01 inch, were replaced by Fischer & Porter gages. These newer recording gages measure precipitation to the nearest 0.1 inch; thus, amounts less than 0.05 inch are recorded as 0.00.

After the rainfall data were separated into individual storms, Daily Series Synoptic Weather Maps (U.S. Dept. of Commerce, 1952a, 1954a-1956a), Daily Weather Map (U.S. Dept. of Commerce, 1957b-1967b), and Daily Weather Maps: Weekly Series (U.S. Dept. of Commerce, 1968c-1976c) were used to determine the synoptic classification of each storm. Because synoptic data for 1953 could not be located, that year's storms were excluded from the data analyses. Storms on July 6 and 7, 1976 were also excluded because that week's synoptic data were missing.

Information about the first-order weather stations at Dubuque and Omaha was obtained from _Station History_ (U.S. Dept. of Commerce, 1952g-1976g) for the respective stations. Similar data about all other stations were provided by _Report on Substation_ (U.S. Dept. of Commerce, 1952f-1976f).

STATION DESCRIPTIONS

Several factors were considered when selecting the climatological substations to be used in this study. Two networks were desired, comparable in size and with the same number of stations, which would represent the wetter and drier regions of the state. According to Shaw and Waite (1964), the east-central and southeastern parts of the state have the highest, and stations in the northwestern corner of the state have the lowest normal annual precipitation amounts (see Figure 1). Following a discussion with Mr. Homer Farmer (Room 10, Des Moines Municipal Airport, Des Moines, Iowa, personal communication, 1978), who supervises data collection from all the climatological substations in Iowa, a network of 6 stations in the eastern part of the state was selected. These stations are located in Cascade, Dubuque, Bellevue, Toronto, Central City, and Strawberry Point.

The 6 western stations were not so easily chosen. Although a network in northwestern Iowa was preferred, 6 adjacent stations that all had reliable, consistent records could not be found in that part of the state. The 6 stations at Soldier, Woodbine, Irwin, Shelby, Carson, and Omaha, Nebraska were finally selected to constitute the western region. The locations of the eastern and western stations are shown in Figures 2-4. A brief description of each station included in this study follows.

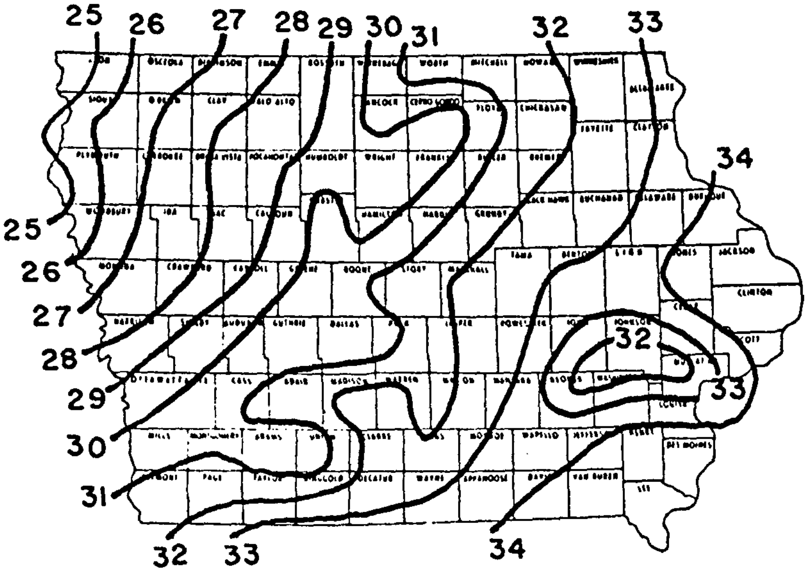


Figure 1. Iowa annual mean precipitation distribution (Shaw and Waite, 1964)

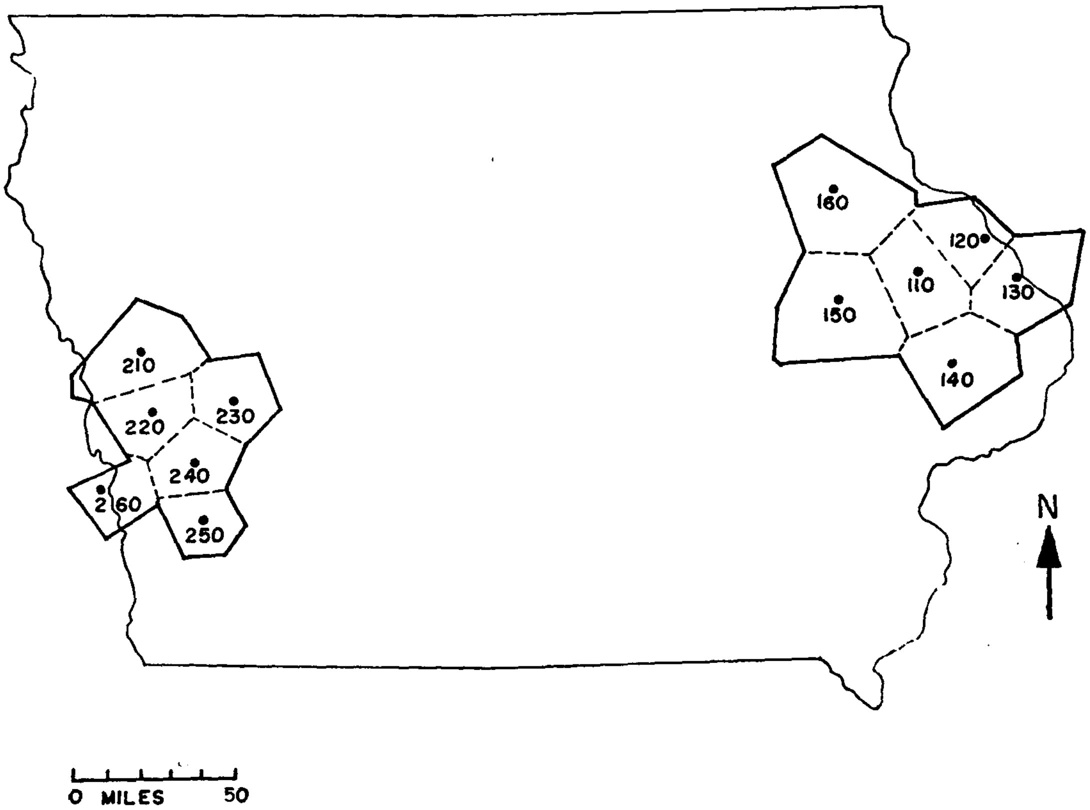


Figure 2. Station and network locations

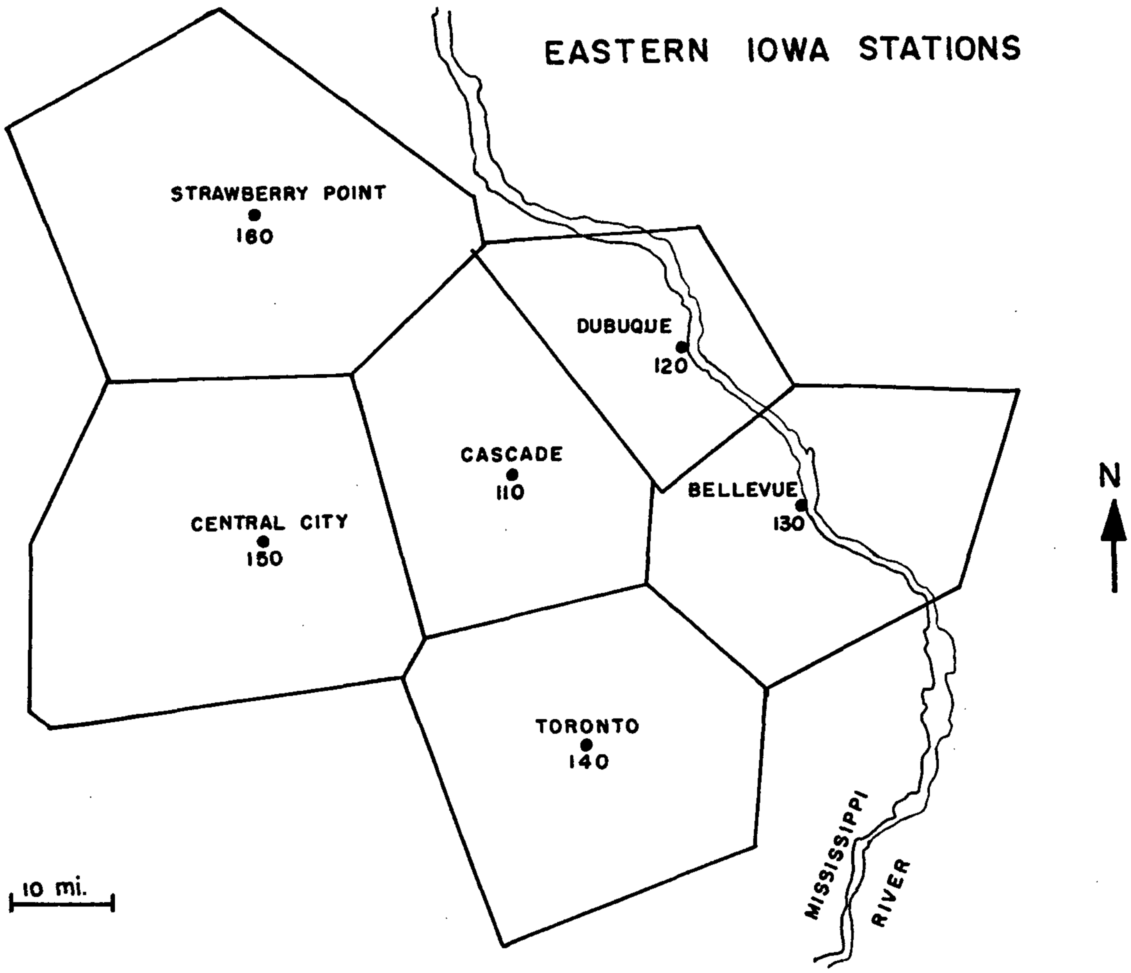


Figure 3. Map of eastern Iowa network

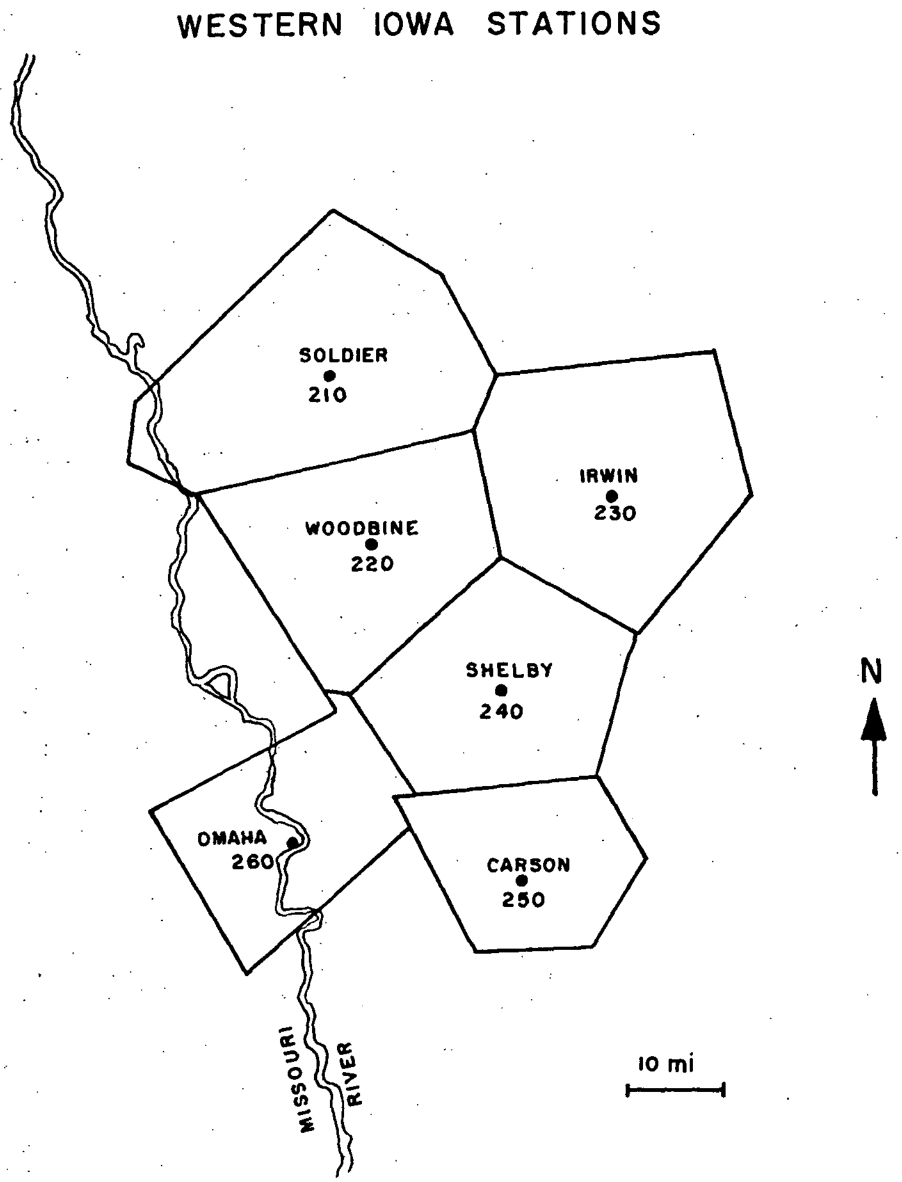


Figure 4. Map of western Iowa network

Cascade (Station 110)

Cascade is located in the southwestern part of Dubuque County, along the Maquoketa River. All data for the 25-year period were recorded by a single observer, and the rain gage was located at his home 0.2 mile southwest of the U.S. Post Office. Surrounding topography is described as gently rolling, sparsely wooded farmland.

The 9-inch unshielded Universal recording gage was located approximately 20 feet north of the observer's garage and about 35 feet southeast of his house. Large trees were located 30 feet to the north and 45 feet to the southwest of the gage. Another house and garage were located 50 feet to the northeast and 70 feet to the east, respectively (U.S. Dept. of Commerce, 1975e).

Dubuque (Station 120)

Dubuque is located at the eastern edge of Dubuque County, along the Mississippi River. After 1951 the gage was located at the Municipal Airport Administration Building, which is 6.8 miles south-southwest of the U.S. Post Office.

The Universal recording gage was supplemented by an 8-inch nonrecording gage. Although "traces" of rain were recorded at this station, as at all other first-order weather stations, those amounts were treated as 0.00 inch, to maintain consistency with the records from the other stations included in the study.

Bellevue (Station 130)

Bellevue is also located along the Mississippi River, in Jackson County. The substation was located 0.25 mile north-northeast of the U.S. Post Office, between the river locks, on a 30-foot wide retaining wall. The level flood plain of the Mississippi River gives way to partly wooded hills within about 1 mile of the river (U.S. Dept. of Commerce, 1952f-1976f).

Toronto (Station 140)

Prior to June 1962 the Toronto substation was located at and known as Wheatland. Wheatland is about 6 miles south-southeast of Toronto, which is on the Wapsipinicon River in western Clinton County. Although the 9-inch unshielded raingage was moved several times, the 4.5-mile relocation to Toronto was the most substantial move on record. In October 1975, however, the gage was replaced by a Fischer & Porter instrument.

For 5 years (1962-1967) the gage was 70 feet east of all buildings, and there were no obstructions to the northeast. Trees were at least 30 feet to the northwest, 40 feet to the south, and 65 feet to the southeast. In November 1967 the station was moved 200 feet north, to the new observer's home. Although this location was in town and only 100 feet south of the U.S. Post Office, the nearest building was 50 feet to the southwest (U.S. Dept. of Commerce, 1962f). A house was 60 feet to the west-northwest, and a large tree stood 90 feet to the north-northwest; the exposure was totally unobstructed to the east (U.S. Dept. of Commerce, 1967f). By 1976 the new gage had been moved to a location 0.2 mile east of the Post Office. The only obstructions were a house and garage, which were 35 feet north and 90 feet west, respectively, and 2 trees, which were 70 feet northwest and 50 feet southwest of the gage (U.S. Dept. of Commerce, 1975f).

Central City (Station 150)

Prior to December 1955 this station was located 10 miles south of Central City, and was known as Marion 4NE. The only subsequent relocation took place in October 1961, when the gage was moved 18 feet north. In October 1968 the 9-inch unshielded Universal recording rain gage was replaced by a Fischer & Porter recording gage.

Central City lies along the Wapsipinicon River, in northern Linn County, and the gage was 0.15 mile west of the river. A row of fruit trees stood about 40 feet to the south, and a small tree stood 25 feet to the north of the gage. The yard sloped down 30 feet north of the gage, and there was a steep bank 15 feet to the east. Although the station was located in town, there were no buildings within 100 feet of the equipment.

Strawberry Point (Station 160)

Strawberry Point is in southwestern Clayton County, and drainage is to the South Fork of the Maquoketa River. A single observer recorded all the data for the 25-year period, and the 9-inch recording gage was located at his residence in town.

The observer lived 0.3 mile south of the U.S. Post Office until October 1967, when he moved 0.2 mile north-northwest. At the first location buildings and trees were at least 50 feet away and were primarily east (southeast through northeast) of the gage. One more tree was about 100 feet northwest of the gage.

At the second location, the gage was 25 feet northeast of the city garage and 15 feet south of an alley. Large trees were located 90 feet south, 120 feet east, and 60 feet north of the gage.

Soldier (Station 210)

Soldier is in eastern Monona County, along the Soldier River. The climatological substation was located at the observer's home within the town and 0.2 mile west-northwest of the U.S. Post Office.

During the 25 years of the study the 12-inch unshielded Universal rain gage was about 30 feet from the nearest building and about 20 feet from the nearest tree. A house was 50 feet north, and garages were 30 feet west, 50 feet south, and 80 feet southwest of the gage. Very large trees were 40 feet northeast and at least 60 feet west and northwest of the gage, and smaller trees were 20 feet west and 50 feet north-northwest of the gage.

Woodbine (Station 220)

Woodbine is along the Boyer River, in Harrison County. The substation was relocated several times between 1952 and 1963, and in 1964 the 9-inch Universal recording rain gage was replaced by a Fischer & Porter gage.

Despite the numerous relocations, the substation was always within a 5-mile radius of Woodbine. The topography of the area is described as hilly, sparsely wooded farmland (U.S. Dept of Commerce, 1952f-1976f). In December 1963 the gage was moved to the new observer's home in town 0.4 mile north-northwest of the Post Office. The house was 80 feet and the garage was 30 feet west of the gage. Large trees were 40 feet north, 50 feet northeast, and 50 feet southwest of the gage.

Irwin (Station 230)

Irwin is in northern Shelby County, along the West Nishnabotna River. The 12-inch unshielded Universal rain gage was located in town 0.2 mile north-northeast of the U.S. Post Office. Although the gage was previously located in a few other positions, the moves were no greater than 300 feet, and the exposure remained essentially unchanged.

The observer's house was 60 feet northwest, and the garage was 30 feet west of the gage. Tall trees were at least 60 feet away to the northwest and southwest, but a row of tall bushes grew about 40 feet to the northwest. There were no obstructions to the east, where there was a large open field.

Shelby (Station 240)

Shelby is in the southwest corner of Shelby County. In past years the station was also known as Shelby 4SE and Shelby 3SE.

Before 1964 the gage was located on a farm 3.6 miles southeast of Shelby. A row of large trees was about 40 feet west of the gage, and one large tree was about 40 feet east of the gage. Buildings were about 80 feet to the northwest and northeast. After 1965 the 12-inch Universal recording gage was located in town. The nearest obstacle, a large tree, was 70 feet west of the gage. An open field lay 40 feet to the east.

Carson (Station 250)

Carson is on the West Nishnabotna River in south-central Pottawattamie County. The topography is described as "rolling, sparsely wooded farmland." (U.S. Dept. of Commerce, 1975f)

The 12-inch unshielded Universal rain gage was located in town at the observer's home 0.4 mile northeast of the U.S. Post Office. The house and garage were 30 feet south and 45 feet west of the gage, respectively. Large trees stood 35 feet to the northwest and 110 feet to the southeast, and a low, L-shaped hedge was 10 feet south and 75 feet east of the gage.

Omaha (Station 260)

Omaha is on the west bank of the Missouri River in Douglas County, Nebraska. The first-order weather station was located at Eppley Airfield (formerly, Omaha Municipal Airport), which lies between the river and Carter Lake.

In December 1953 the weighing rain gage was relocated from 130 feet north to 225 feet west-southwest of the U.S. Weather Bureau office. For 11 years (1961-1972) it was on the roof of the Administration Building, but in September 1972 the gage was moved back to the ground and 195 feet to the northwest. Two subsequent relocations consisted of moves of 0.25 mile to the south in January 1974 and 1.5 miles to the northwest in December 1974 (U.S. Dept. of Commerce, 1952g-1976g).

Summary

Although the eastern network was about 1.8 times the size of the western network, there were several similarities between the two. Each included one first-order weather station and at least two stations with very consistent records. Furthermore, Fisher & Porter gages, which record rainfall to the nearest 0.1 inch, were installed within both regions during the 1960's.

METHODS

Before storm climatologies could be compiled, it was necessary to compute hourly areal rainfall averages and to separate those data into individual storms. Flowcharts of the computer programs are included in APPENDIX A, and the storm data are presented in APPENDIX B.

Rain Periods

Each station's nonzero precipitation data were copied from Local Climatological Data (U.S. Dept. of Commerce, 1952e-1976e) or Hourly Precipitation Data (U.S. Dept. of Commerce, 1952d-1976d). If any station within the region reported at least 0.05 inch rain, the hour was classified as wet. Because some stations used the Fischer & Porter gage, which rounds data to the nearest 0.1 inch, this 0.05-inch cutoff was chosen to eliminate dependence of the classification on the type of gage used. This cutoff could add some error to the areal averages for light, regionwide rains; however, because such incidents occurred infrequently (once or twice per season), it was concluded that this additional error only minimally affected the overall storm data.

Data Voids

Because the records of several stations are incomplete, a listing of the data voids was compiled, and the method to be used to fill each void was determined. Three methods were considered for filling data voids: (1) a similar-storm method, (2) a substitution method, and (3) an averaging method. The similar-storm method described by Hashino (1973) would have been most accurate, but it is quite complicated. This method presumes that storms have already been delineated and classified according to synoptic type. These steps could not be completed without areal averages, but the voids would have to have been filled to compute areal averages. Hashino's method was rejected because of the excessive number of data manipulations it would have demanded.

The method that was selected to fill the voids is the substitution method described by Brooks and Carruthers (1953). This method presumes that, on the average, the ratio of rainfall amounts recorded at two stations remains constant. A constant, λ, is found for each pair of stations within a region by summing the rainfall for all n years that have complete records at both stations. If station A and B are compared,

$$\lambda = \frac{\Sigma a}{\Sigma b}$$

where a is the total rainfall at station A (record incomplete) and b is the total at station B. A so-called suitability term,

$$\frac{\sum_{i=1}^{n} (a_i - b_i)^2}{\sum_{i=1}^{n} (a_i - \bar{a})^2}$$

is computed for each pair of stations. If that suitability term is small enough, then, on the average, a = λb can be used to fill data voids for station A. Whenever possible ($\bar{\lambda}$ suitable), voids were filled by using the form: a = λb. When λ was not suitable, it was assumed that rainfall at the missing station was equal to the average over the remainder of the region (averaging method).

Areal Averages

According to Hjelmfelt and Cassidy (1975), areal averages of rainfall may be computed in any of three ways: (1) the simple average, (2) the Isohyetal Method, or (3) the Thiessen Polygon Method. The simple average is computed by summing the rainfall amounts at all 6 stations within the region, and dividing by 6. The simple average was rejected because it does not account for unequal spacing of gages.

Of the 3 methods, the Isohyetal Method gives the most accurate areal averages. Isopleths of precipitation amounts (isohyets) are drawn on a map of the region, and a weighted average is computed, using the relative areas included within the isohyets. This method was rejected because isopleths could not be confidently drawn for 6-station networks.

Furthermore, isohyets would have to have been constructed for every wet hour.

To use the Thiessen Polygon Method one first divides the region into polygons, the boundaries of which are determined by the positions of all stations in and around the region. Lines are drawn between adjacent stations, and the perpendicular bisectors are constructed. These bisectors serve as boundaries between polygons. After the percentage of the region's total area that is enclosed by each polygon (WT) is determined, a weighted average is computed. Technically, the polygons should be redrawn and the relative weights redetermined each time a rain gage is moved. The Thiessen Polygon Method was used to compute areal rainfall averages because it is more practical and more readily adaptable to computer methods than the Isohyet Method and, unlike the simple average, allows for a nonuniform grid. Figures 3 and 4 show the Theissen polygons, and Table 1 lists the areas and relative weights of each.

A planimeter was used to find the relative areas for each polygon, and these values (WT_i) were used to compute the areal averages for each region. An area meter, which was made available after the averages had been calculated, was used to check the relative weights. Although the more accurate measurements obtained with the area meter differ somewhat from those provided by the planimeter (see Table 1),

Table 1. Areas and relative weights of, and maximum error attributable to stations in eastern (Region 100) and western (Region 200) Iowa

	Area (mi²)		Relative Weight			
Station	Master	Alternate	Planimeter	Area Meter	Alternate	Maximum Error
110	746	833	.14	.14	.15	.071
120	482	478	.09	.09	.09	.000
130	776	776	.15	.15	.14	.071
140	930	924	.18	.18	.17	.059
150	1153	1141	.22	.22	.21	.048
160	1207	1299	.22	.23	.24	.091
	----	----	----	----	----	
Region 100	5294	5452	1.00	1.01	1.00	
210	645	662	.23	.22	.22	.045
220	478	521	.17	.17	.17	.000
230	578	558	.20	.20	.19	.059
240	457	535	.15	.16	.18	.200
250	322	305	.12	.11	.10	.200
260	390	419	.13	.14	.14	.071
	----	----	----	----	----	
Region 200	2870	3001	1.00	1.00	1.00	

none of the readings differ by more than 1% of the network's total area.

The area meter was also used to study adjustments that should have been made to the relative weights each time a station was relocated. From the _Report on Substation_ (U.S. Dept. of Commerce, 1952f-1976f) or _Station History_ (U.S. Dept. of Commerce, 1952g-1976g) for each station, it was learned that the true relative weights differed most greatly from the planimeter-derived values during 1963 (western Iowa) and before 1955 (eastern Iowa). New Theissen polygons were constructed for these station locations, and the areas and relative weights of these alternate ploygons listed in Table 1. Alternate relative weights differed from the weights actually used by no more than 0.02 for the eastern region and 0.03 for the western region. Table 1 also includes values of the greatest errors that can be attributed to inaccuracies in the planimeter-derived relative weights or to station relocations. Eastern Iowa areal averages include the maximum error on those occasions before 1955 when rainfall was measured only at Strawberry Point (Station 160). The errors are maximum for the western network during 1963 when rainfall was recorded only at Shelby (Station 240) or Carson (Station 250).

Storm Definitions

The areal averages served as the data base for the study of regional precipitation patterns. One of the first steps was to define a storm. Huff (1971) defined a storm as "a precipitation period separated from preceding and succeeding precipitation on the sampling area by six hours or more. This definition has been found most suitable for separating storms resulting from different synoptic causes on the sampling networks." (See also Schickedanz and Huff, 1971.) No quantitative basis has been given for the use of a 6-hour period as a delimiter of storms. Because of the lack of *a priori* knowledge of Iowa storm characteristics and because of possible differences between eastern and western Iowa, storm definitions were directly generated from the data. Sariahmed and Kisiel (1968) referred to such a period as τ_L, the time lag between storms, where τ_L has been chosen such that, on the average, the correlation between storms is not significant. This dependence can be judged by use of a rank correlation coefficient. Hashino (1973) found that his similar storm method for filling data voids was more accurate when he used the smallest time lag that was substantiated by his data. For example, if his data supported a τ_L as small as two hours, it was better to use a time lag of two, instead of six hours to delineate storms. Although Hashino's similar-storm method was not used, his study supports the decision to compute τ_L's for each Iowa region. The method used to compute τ_L was adapted from Grace and Eagleson (1966).

Serial correlation among the hourly rainfall averages (AVG) was tested by computing Spearman's rank correlation coefficients (Gibbons, 1976) for variates X and Y. The matched pairs, X and Y, were obtained by using $Y_i = X_{i+L}$, i = 1,2,..., (n-L), where X is the i-th nonzero hourly average precipitation in July or August, and L is the lag in hours. Because it is dependent upon X_i and the lag, Y_i can be zero or nonzero. This nonparametric statistic is a measure of the association between matched pairs of observations (the X's and Y's), and was chosen because it does not depend upon the underlying population distribution.

The null hypothesis states that X and Y are not associated, and is rejected if the rank correlation differs significantly from zero. If the hypothesis is rejected, dependence between X and Y is assumed.

The observations of each set are ranked according to their respective magnitudes, and are then replaced by the respective rankings. For instance, a set of 4 observations (0.5, 1.2, 0.9, 1.0) would be replaced by their rankings (1, 4, 2, 3). The rank correlation coefficient R is computed from the 2 sets of n rankings, U and V:

$$R = 1 - \frac{6 \sum_{i=1}^{n} D_i^2}{n(n^2 - 1)}$$

where $D_i = u_i - v_i$.

R can take on any value between -1 and +1; the sign indicates the nature of any correlation, and the absolute value indicates the magnitude. When R = -1, X and Y are in perfect disagreement; when R = +1, they are in perfect agreement; when R = 0, they are not associated.

This definition of R presumes that X and Y are continuous and that ties are nonexistent. If the proportion of ties is small, R is relatively unaffected. The rainfall data, however, displayed a high proportion of ties; hence, a form of R that corrects for ties was needed:

$$R = \frac{n(n^2 - 1) - 6 \sum_{i=1}^{n} D_i^2 - 6(u' + v')}{\sqrt{n(n^2 - 1) - 12u'}\ \sqrt{n(n^2 - 1) - 12v'}}$$

where $u' = \Sigma(u^3 - u)/12$ for u, the number of elements of X tied at a given rank, and

$v' = \Sigma(v^3 - v)/12$ for v, the number of elements of Y tied at a given rank.

Ties were assigned the average of the ranks that would have been assigned if no ties had occurred. Gibbons' (1976) corrected form of Spearman's rank correlation coefficient was rewritten:

$$r_s = \frac{n^3 - n - 6 \sum_{i=1}^{n} D_i^2 - 0.5(u' + v')}{\sqrt{n^3 - n - u'} \sqrt{n^3 - n - v'}}$$

where $u' = \Sigma(u^3 - u)$ and $v' = \Sigma(v^3 - v)$.

A 2-sided test was used, with $z = r_s \sqrt{n-1}$ for a sample size n greater than 20.

The null hypothesis of independence between X and Y was tested by computing r_s. The p-value was then obtained from the normal distribution. For a smaller sample size, p-values are given in Table I of Gibbons (1976). A correlation coefficient is significant if the p-value exceeds a predetermined level α.

To detect correlation for a given lag, and to disregard correlations arising from all other lags, "lag" different sequences were constructed. That is, to study a 2-hour lag, 2 sequences were constructed, one with i even, one with i odd; to study a 3-hour lag, 3 sequences were constructed, etc. The correlation coefficient was computed for each sequence, and the corresponding p-values were found. The smallest lag for which all sequences supported the null hypothesis of independence was selected as τ_L. The eastern region displayed a 6-hour time lag, at significance level 0.23. Western Iowa data, however, displayed a 4-hour lag at significance level 0.15.

Storm Types

The appropriate time lags were used to divide the rainfall data into separate storms, and each storm was classified according to the synoptic situation with which it was associated. Storms for which synoptic data were not available were excluded from the study. The 5 storm types include those associated with:

1. Cold fronts or squall lines
2. Air-mass convection
3. Low-pressure systems or positive vorticity advection (PVA)
4. Warm fronts
5. Stationary fronts.

The method used to classify the individual storms was somewhat subjective. Not only the surface station models for the area, but also, the regional precipitation patterns were studied to ascertain with which synoptic situation each storm had been associated. For instance, frontal storms usally produced a characteristic band of rainfall. Cold or warm fronts that moved very slowly across the state, and that were shown (on the synoptic maps) to advance and retreat slightly were considered to be stationary (type 5). Storms were classified as type 3 when (1) a low-pressure center, and(or) both the associated warm and cold fronts passed through the area during a single storm; (2) the area was included in the region of precipitation that frequently precedes the passage of a low-pressure system; (3) an upper-level trough passed through the area; or (4) a high-pressure center to the east of Iowa gave rise to a strong southerly flow. Huff (1971) apparently considered storms associated with this strong southerly flow to be air-mass storms. Included in the second category were only those storms for which no other apparent synoptic cause could be found. For each storm the type, depth, duration, region, year, beginning and ending hours and days, and the length of time (in both hours and days, rounded down) since the end of the previous storm were recorded.

RESULTS AND DISCUSSION

The storm data were analyzed to compare the July-August precipitation patterns of eastern and western Iowa and to assess the feasibility of cloud seeding in the state.

Rainfall Climatologies

Iowa annual precipitation averages range from less than 25 inches in the northwest corner of the state to more than 34 inches in the east, as is shown in Figure 1. Of this precipitation at least 60% (19-23 inches) is recorded during the 6 warmer months of the year, i.e., April-September. July and August rainfall averages amount to 6-8 inches, or about 25% of the annual precipitation (Shaw and Waite, 1964).

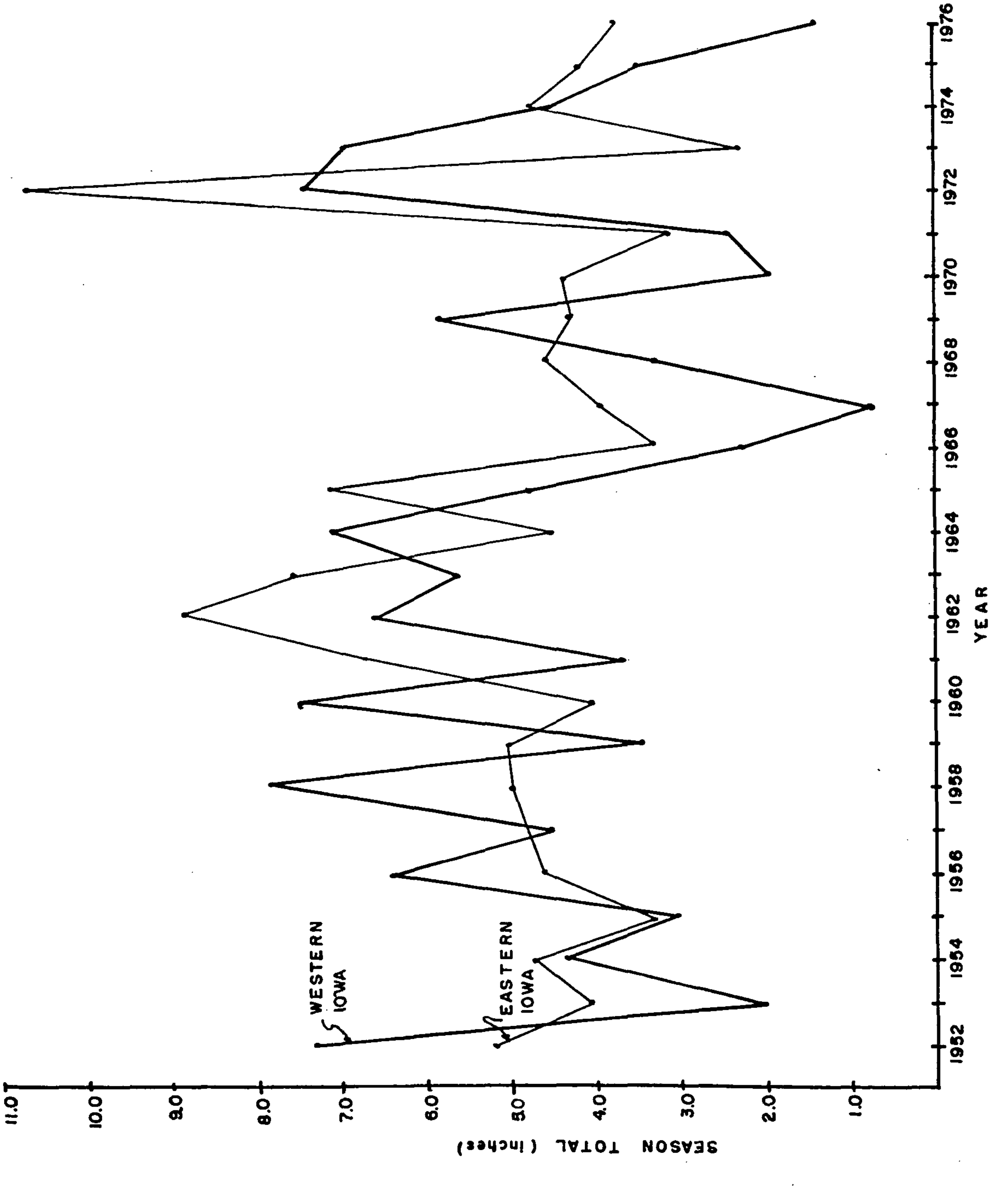
In this study the numbers, types, depths, and durations of "dry-", "normal-", and "wet-year" storms were examined. It should be noted that in this discussion the term "year" is used synonymously with "season" in reference to the period extending from July 1 through September 1. The method used to classify each season in terms of its wetness or dryness must be explained.

A "dry" year was one during which July and August rainfall data suggest that crop growth was impeded by insufficient water supplies. Two characteristics were used to distinguish such a year. The more obvious trait was below-average total rainfall; however, this factor alone was judged inadequate to distinguish a dry year. The season may have been dry except for a few heavy rains. In this case, to consider only total rainfall would have led to the erroneous conclusion that the year was not dry. The less obvious dry-year trait was, then, a small number of storms. A "dry" season was therefore defined as one during which either the total precipitation or the number of storms was at least 1 standard deviation below the computed mean. and a "wet" season was defined as one during which either the total precipitation or the number of storms was at least 1 standard deviation above the computed mean. A "normal" year was defined as one which could not be classified as "wet" or "dry", i.e., both the total precipitation and the number of storms was within 1 standard deviation of the computed mean. The number of storms and areal rainfall totals for each season are listed in Table 2. Graphs of the seasonal values are superimposed to facilitate the comparison between the 2 networks (see Figures 5 and 6). Data points for eastern Iowa are connected by thin lines and those for western Iowa, by heavy lines. In Figures 7 and 8 the numbers of storms and rainfall totals have been plotted against each other, and dashed lines drawn 1 standard deviation above and below each mean. Points lying within the center region represent normal years; points outside that region represent dry and wet years. There were no ambiguitites arising from this combined

Table 2. Numbers of storms and July-August rainfall totals for eastern and western Iowa

	Eastern Iowa		Western Iowa	
Year	No. Storms	Total Rainfall	No. Storms	Total Rainfall
1952	15	5.28	26	7.23
1953	-	3.97	-	2.04
1954	18	4.72	25	4.39
1955	13	3.26	12	2.97
1956	14	4.60	27	6.44
1957	18	4.83	19	4.51
1958	23	4.95	23	7.91
1959	22	4.99	14	3.52
1960	18	3.96	26	7.48
1961	25	6.79	15	3.66
1962	15	8.84	14	6.65
1963	18	7.53	17	5.56
1964	17	4.42	27	7.19
1965	21	7.14	20	4.71
1966	9	3.27	18	2.22
1967	17	3.96	10	0.69
1968	14	4.52	17	3.27
1969	16	4.21	15	5.83
1970	14	4.35	16	1.91
1971	17	2.97	15	2.43
1972	24	10.68	24	7.44
1973	18	2.26	22	6.90
1974	18	4.71	20	4.57
1975	21	4.15	17	3.45
1976	16	3.73	11	1.34

Figure 5. Seasonal precipitation totals for eastern and western Iowa


SEASON TOTAL (inches)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
YEAR
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
WESTERN IOWA
EASTERN IOWA

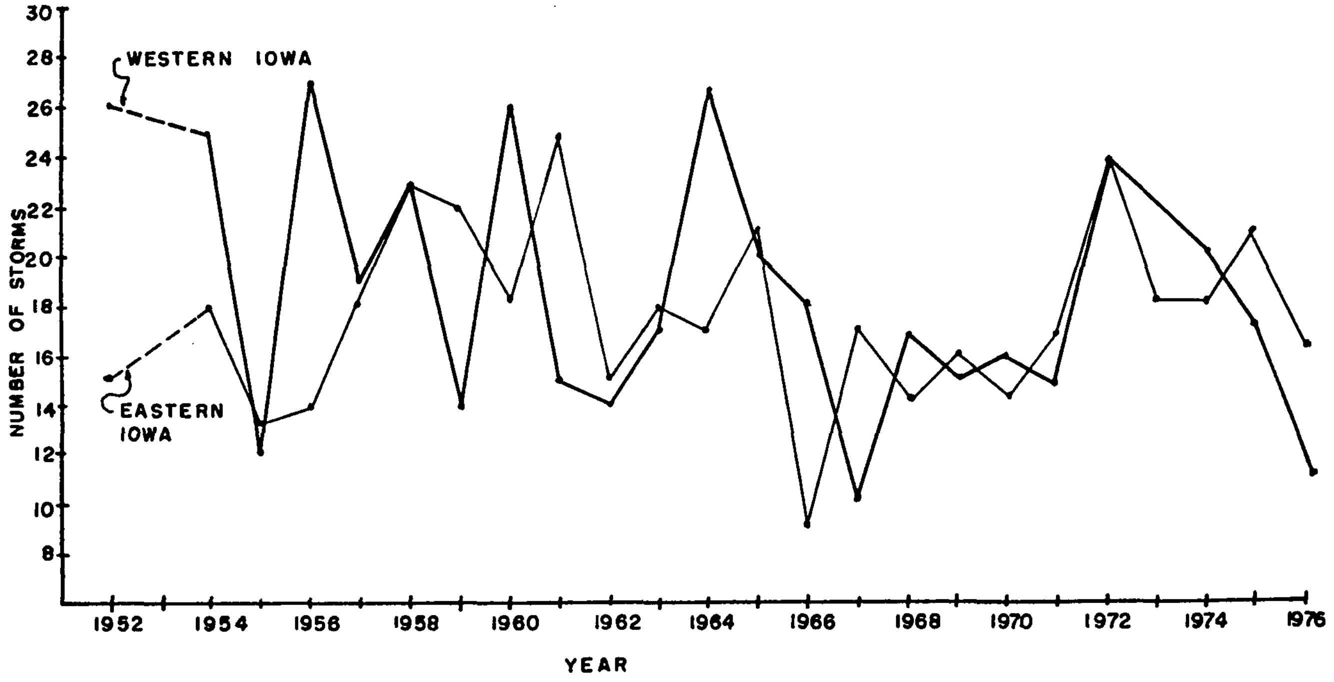


Figure 6. Numbers of storms for each season for eastern and western Iowa

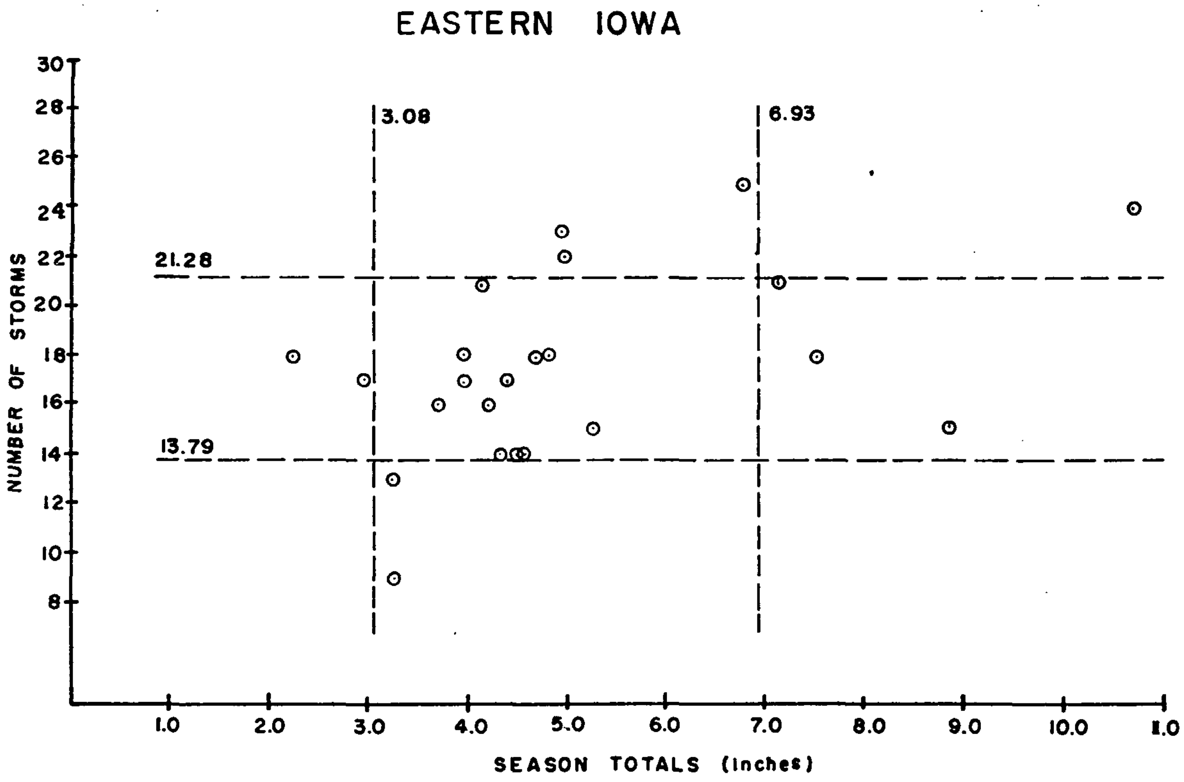


Figure 7. Graph of seasonal precipitation totals vs. numbers of storms for eastern Iowa

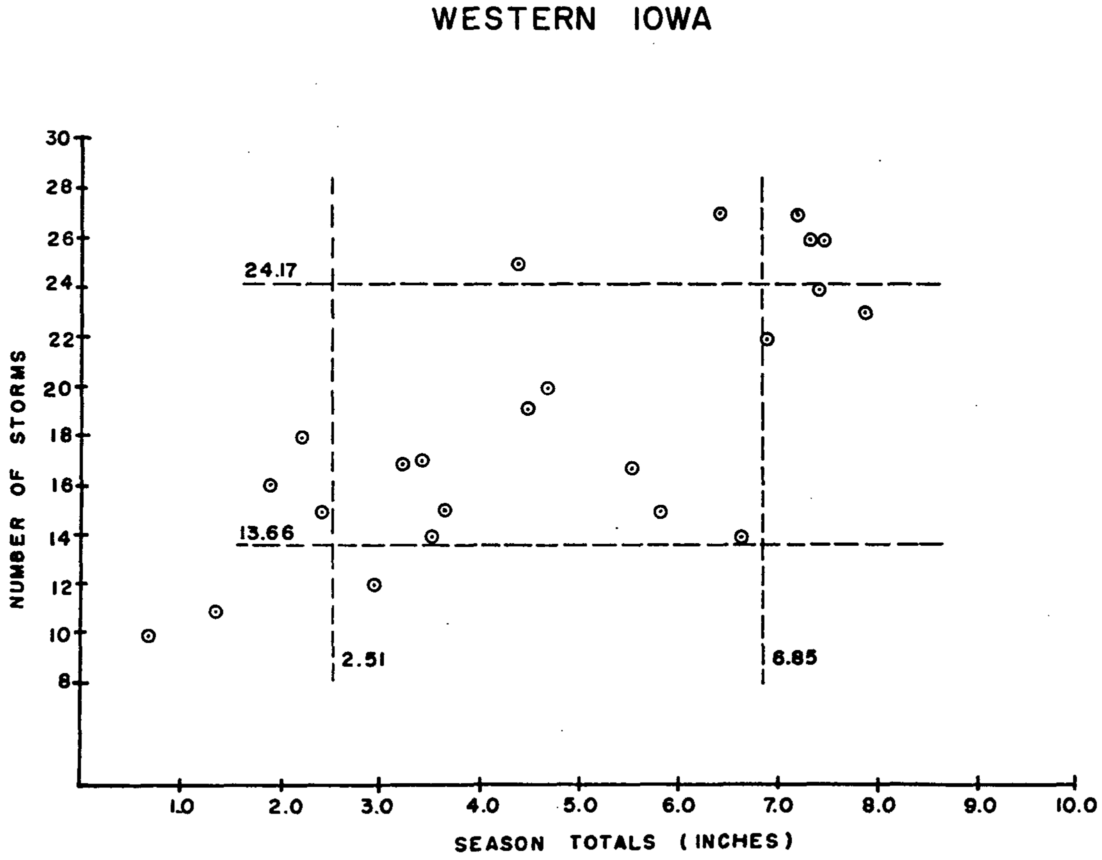


Figure 8. Graph of seasonal precipitation totals vs. numbers of storms for western Iowa

definition, as can be noted from the absense of points to the lower right and upper left of the "normal" region. A summary of the categorization is found in Table 3.

Storm depths and durations were analyzed according to storm type and seasonal wetness (dry, wet, or normal). Table 4 presents a summary of eastern Iowa's data for the entire 24-year period. Means and standard deviations have been calculated by year as well as by storm. For instance, consider type 1 storms. During the 24-year period 116 storms rained a total of 32.71 inches over 483 hours. This corresponds to an average of 4.83 storms, 1.36 inches, and 20.13 hours in one season, or 0.28 inch and 4.16 hours per storm. From the table it can be seen that nearly one-half the rainfall recorded during the 24 seasons was attributed to type 3 (PVA) storms. Tables 5 - 7 similarly summarize the data for the dry, normal, and wet years.

If one wishes to enhance rainfall to increase crop yields, it would be appropriate to study the distinguishing characteristics of dry years, in particular. That is, what makes a "dry" year dry? By definition, there are fewer storms and(or) less precipitation. Can these decreases be attributed to one or two types of storms, or to all storm types?

Looking at the distribution of storm types during each kind of year (Table 8), one sees that during all-except-dry

Table 3. Summary of dry-, normal-, and wet-year classifications

Year	Dry	Normal	Wet
1952		East	West
1953			
1954		East	West
1955	East, West		
1956		East	West
1957		East, West	
1958			East, West
1959		West	East
1960		East	West
1961		West	East
1962		West	East
1963		West	East
1964		East	West
1965		West	East
1966	East, West		
1967	West	East	
1968		East, West	
1969		East, West	
1970	West	East	
1971	East, West		
1972			East, West
1973	East		West
1974		East, West	
1975		East, West	
1976	West	East	
Totals			
East	4	13	7
West	6	10	8
	---	---	---
	10	23	15

Table 4. Summary of 24 years of eastern Iowa rainfall data

	Storm Types					
	1	2	3	4	5	total
<u>Totals</u>						
No. Storms	116	26	172	23	83	420
Depth (in)	32.71	1.05	59.05	3.27	23.81	119.89
Duration (hr)	483	48	912	72	383	1898
<u>Means/Year</u>						
No. Storms	4.83	1.08	7.17	0.96	3.46	17.50
Depth (in)	1.36	0.04	2.46	0.14	0.99	5.00
Duration (hr)	20.13	2.00	38.00	3.00	15.96	79.08
<u>SD/Year</u>						
No. Storms	2.44	0.97	3.09	1.00	1.89	-
Depth (in)	0.85	0.06	1.81	0.23	0.90	-
Duration (hr)	13.95	2.30	23.13	3.84	12.60	-
<u>Means/Storm</u>						
Depth (in)	0.28	0.04	0.34	0.14	0.29	0.29
Duration (hr)	4.16	1.85	5.30	3.13	4.61	4.51
<u>SD/Storm</u>						
Depth (in)	0.30	0.04	0.51	0.18	0.41	-
Duration (hr)	4.20	1.43	5.51	2.53	4.99	-

Table 5. Summary of rainfall data for eastern Iowa's 4 dry years

	Storm Types					
	1	2	3	4	5	total
<u>Totals</u>						
No. Storms	21	6	17	1	12	57
Depth (in)	4.71	0.12	3.22	0.03	3.58	11.66
Duration (hr)	74	10	89	1	43	217
<u>Means/Year</u>						
No. Storms	5.25	1.50	4.25	0.25	3.00	14.25
Depth (in)	1.18	0.03	0.81	0.01	0.90	2.92
Duration (hr)	18.50	2.50	22.25	0.25	10.75	54.25
<u>SD/Year</u>						
No. Storms	4.03	1.00	3.95	0.50	0.82	-
Depth (in)	0.72	0.02	0.53	0.02	0.64	-
Duration (hr)	12.34	2.08	21.00	0.50	6.80	-
<u>Means/Storm</u>						
Depth (in)	0.22	0.02	0.19	0.03	0.30	0.20
Duration (hr)	3.52	1.67	5.23	1.00	3.58	3.81
<u>SD/Storm</u>						
Depth (in)	0.23	0.01	0.26	-	0.34	-
Duration (hr)	2.79	1.21	4.98	-	3.63	-

Table 6. Summary of rainfall data for eastern Iowa's 13 normal years

	Storm Types					
	1	2	3	4	5	total
<u>Totals</u>						
No. Storms	57	11	91	16	40	212
Depth (in)	13.95	0.37	28.83	2.80	11.47	57.42
Duration (hr)	204	17	446	56	201	924
<u>Means/Year</u>						
No. Storms	4.38	0.85	7.00	1.23	3.08	16.30
Depth (in)	1.07	0.03	2.22	0.22	0.88	4.42
Duration (hr)	15.69	1.31	34.31	4.31	15.46	71.08
<u>SD/Year</u>						
No. Storms	1.68	0.80	2.52	1.09	2.25	-
Depth (in)	0.67	0.04	1.00	0.28	1.00	-
Duration (hr)	12.36	1.32	17.63	4.52	13.63	-
<u>Means/Storm</u>						
Depth (in)	0.24	0.03	0.32	0.18	0.29	0.27
Duration (hr)	3.58	1.55	4.90	3.50	5.03	4.36
<u>SD/Storm</u>						
Depth (in)	0.26	0.03	0.45	0.21	0.43	-
Duration (hr)	2.85	1.04	5.22	2.90	5.19	-

Table 7. Summary of rainfall data for eastern Iowa's 7 wet years

	Storm Types					
	1	2	3	4	5	total
Totals						
No. Storms	38	9	64	6	31	148
Depth (in)	14.05	0.56	27.00	0.44	8.76	50.81
Duration (hr)	205	21	377	15	139	757
Means/Year						
No. Storms	5.43	1.29	9.14	0.86	4.43	21.14
Depth (in)	2.01	0.08	3.86	0.06	1.25	7.26
Duration (hr)	29.29	3.00	53.86	2.14	19.86	108.14
SD/Year						
No. Storms	2.76	1.25	2.41	0.90	1.27	-
Depth (in)	0.95	0.09	2.50	0.08	0.87	-
Duration (hr)	14.92	3.51	26.85	2.48	13.33	-
Means/Storms						
Depth (in)	0.37	0.06	0.42	0.07	0.28	0.34
Duration (hr)	5.40	2.33	5.89	2.50	4.48	5.11
SD/Storm						
Depth (in)	0.38	0.05	0.63	0.04	0.43	-
Duration (hr)	6.00	1.94	6.05	1.05	5.25	-

Table 8. Percentages of eastern Iowa's rainfall contributed by each storm type

	Storm Type				
	1	2	3	4	5
Dry Years	40	1	28	0	31
Normal Years	24	1	50	5	20
Wet Years	28	1	53	1	17
All Years	27	1	49	3	20

years PVA (type 3) storms provided about one-half of all precipitation. Type 1 (cold-front and squall-line) and 5 (stationary-front) storms provided about one-fourth and one-fifth of the precipitation, respectively. The percentages were quite different during dry years. Type 3 storms appear to have provided less, and types 1 and 5, more of the rainfall. If one refers to Tables 5 - 7 to find the mean depths, however, one sees that the means for types 1 and 5 vary little among dry, normal, and wet years.

Because the data were not normally distributed and because some of the classes had few elements, nonparametric tests were judged to be the most appropriate to use on the data. The Kruskal-Wallis test (Gibbons, 1976) was used to test for homogeneity among the various populations. Because type 2 and 4 storms provided such a small fraction of the rainfall, they were not included in the tests for homogeneity. The data were tested for significance (1) for all possible combinations within each region and (2) for all meaningful combinations between regions. Specifically, the following tests were made for comparisons within each region:

1a. Dry vs. normal for each storm type
1b. Dry vs. wet for each storm type
1c. Normal vs. wet for each storm type
1d. Type A vs. B ($A \neq B$) for dry years

1e. Type A vs. B (A ≠ B) for normal years

1f. Type A vs. B (A ≠ B) for wet years.

And the following comparisons were made between the regions:

2a. Dry vs. dry for each storm type

2b. Normal vs. normal for each storm type

2c. Wet vs. wet for each storm type

2d. Type A vs. A for dry years

2e. Type A vs. A for normal years

2f. Type A vs. A for wet years.

For the eastern Iowa data the only statistically significant (p-value less than or equal to 0.10) difference found among the depths and durations of the 3 types (1, 3, and 5) of storms was the duration of cold-front (type 1) storms. At the 0.080 significance level such storms were found to last longer during wet years than during normal years (test 1c). Yearly and storm means of both the depth and duration of PVA (type 3) storms appeared to differ greatly (see Tables 5-7) between dry and normal years, the difference being significant if the data were assumed to be normally distributed. The more appropriate Kruskal-Wallis test, however, did not substantiate a significant difference between the 2 populations.

The data for western Iowa have been summarized in Tables 9 - 12. As in eastern Iowa, nearly one-half the rainfall was provided by PVA (type 3) storms. The Kruskal-Wallis tests

Table 9. Summary of 24 years of western Iowa rainfall data

	Storm Types					
	1	2	3	4	5	total
Totals						
No. Storms	123	30	190	27	80	450
Depth (in)	27.10	3.52	47.80	5.43	28.42	112.27
Duration (hr)	374	52	626	88	331	1471
Means/Year						
No. Storms	5.13	1.25	7.92	1.13	3.33	18.75
Depth (in)	1.13	0.15	1.99	0.23	1.18	4.68
Duration (hr)	15.58	2.17	26.08	3.83	13.79	61.29
SD/Year						
No. Storms	2.44	1.03	3.84	1.51	1.95	-
Depth (in)	0.86	0.20	1.33	0.46	1.18	-
Duration (hr)	9.32	0.22	12.70	6.24	12.36	-
Means/Storm						
Depth (in)	0.22	0.12	0.25	0.20	0.36	0.25
Duration (hr)	3.04	1.73	3.29	3.26	4.14	3.27
SD/Storm						
Depth (in)	0.27	0.14	0.34	0.25	0.54	-
Duration (hr)	2.45	1.14	2.66	2.64	4.91	-

Table 10. Summary of rainfall data for western Iowa's 6 dry years

	Storm Types					
	1	2	3	4	5	total
<u>Totals</u>						
No. Storms	31	6	29	1	15	82
Depth (in)	5.74	0.54	3.21	0.31	1.76	11.56
Duration (hr)	82	10	67	4	35	198
<u>Means/Year</u>						
No. Storms	5.17	1.00	4.83	0.17	2.50	13.67
Depth (in)	0.96	0.09	0.54	0.05	0.29	1.93
Duration (hr)	13.67	1.67	11.17	0.67	5.83	33.00
<u>SD/Year</u>						
No. Storms	2.23	0.89	1.72	0.41	1.87	-
Depth (in)	0.83	0.11	0.31	0.13	0.34	-
Duration (hr)	7.81	1.86	5.56	1.63	5.12	-
<u>Means/Storm</u>						
Depth (in)	0.19	0.09	0.11	0.31	0.12	0.14
Duration (hr)	2.65	1.67	2.31	4.00	2.33	2.41
<u>SD/Storm</u>						
Depth (in)	0.20	0.10	0.11	-	0.17	-
Duration (hr)	1.82	1.21	1.49	-	1.54	-

Table 11. Summary of rainfall data for western Iowa's 10 normal years

	Storm Types					
	1	2	3	4	5	total
<u>Totals</u>						
No. Storms	48	13	64	8	35	168
Depth (in)	8.56	1.26	20.13	1.05	14.63	45.63
Duration (hr)	152	19	268	24	160	623
<u>Means/Year</u>						
No. Storms	4.80	1.30	6.40	0.80	3.50	16.80
Depth (in)	0.86	0.13	2.01	0.11	1.46	4.56
Duration (hr)	15.2	1.90	26.8	2.40	1.60	62.30
<u>SD/Year</u>						
No.-Storms	2.25	1.16	1.51	0.92	1.35	-
Depth (in)	0.47	0.12	0.89	0.24	1.03	-
Duration (hr)	5.96	1.85	10.02	4.60	11.33	-
<u>Means/Storm</u>						
Depth (in)	0.18	0.10	0.31	0.13	0.42	0.27
Duration (hr)	3.17	1.46	4.19	3.00	4.57	3.71
<u>SD/Storm</u>						
Depth (in)	0.18	0.09	0.32	0.12	0.57	-
Duration (hr)	2.11	0.97	3.14	2.00	5.47	-

Table 12. Summary of rainfall data for western Iowa's 8 wet years

	Storm Types					
	1	2	3	4	5	total
<u>Totals</u>						
No. Storms	44	11	97	18	30	200
Depth (in)	12.80	1.72	24.46	4.07	12.03	55.08
Duration (hr)	140	23	291	60	136	650
<u>Means/Year</u>						
No. Storms	5.50	1.38	12.13	2.25	3.75	25.00
Depth (in)	1.60	0.22	3.06	0.51	1.50	6.89
Duration (hr)	17.50	2.88	36.38	7.50	17.00	81.25
<u>SD/Year</u>						
No. Storms	3.02	1.06	3.44	1.98	2.60	-
Depth (in)	1.11	0.32	1.29	0.68	1.48	-
Duration (hr)	13.72	2.90	8.14	8.26	15.66	-
<u>Means/Storm</u>						
Depth (in)	0.29	0.16	0.25	0.23	0.40	0.28
Duration (hr)	3.18	2.09	3.00	3.33	4.53	3.25
<u>SD/Storm</u>						
Depth (in)	0.37	0.19	0.38	0.29	0.60	-
Duration (hr)	3.12	1.30	2.42	2.99	5.24	-

did detect several differences among the depths and durations of the various classes. Tests 1a - 1c showed that type 3 (PVA) storms lasted longest and provided the most precipitation during normal years, and that the depths of type 5 (stationary-front) storms were greater during normal and wet years than during dry years. Test 1e showed that depths and durations of PVA storms exceeded those of stationary-front storms during normal years. Although Table 13 shows that the percentage of rainfall attributed to type 1 storms was higher during dry years than during other years, the actual depths did not differ significantly. Another way of saying this is that cold-front (type 1) storms provide about the same amount of precipitation during dry, normal, and wet years. This result agrees with the conclusion of Huff (1979) that during dry years, cold-front/squall-line storms offer the greatest potential for increased precipitation by seeding.

When the data from the 2 regions were compared, the eastern region was found to have PVA (type 3) storms that lasted longer and stationary-front (type 5) storms that provided more precipitation than those in the western region during dry years (test 2a). During wet years, the eastern region experienced cold-front (type 1) and PVA (type 3) storms of greater duration than did similar storms in western Iowa (test 2c). The PVA (type 3) storms also provided more

Table 13. Percentages of western Iowa's rainfall contributed by each storm type

	Storm Type				
	1	2	3	4	5
Dry Years	50	5	28	3	15
Normal Years	19	3	44	2	32
Wet Years	23	3	44	7	22
All Years	24	3	43	5	25

rainfall to eastern Iowa during wet years (test 2f).

The fact that only a few differences were found to be statistically significant is, in part, a result of the definitions chosen for "wet", "normal", and "dry". The use of number of storms, as well as total seasonal precipitation, has created classes having large standard deviations (relative to the mean).

The question remains: what makes a season "dry"? On the basis of the Kruskal-Wallis tests it appears that, insofar as the eastern Iowa data are concerned, no single type of storm was responsible for the more-plentiful precipitation of a normal or wet year. The tests do indicate that in the western region, stationary-front (type 5) storms produced more rainfall during normal or wet years than they produced during dry years.

Cloud-Seeding Potential

To assess the feasibility of cloud seeding in Iowa one should ask four questions:

1. How much additional rainfall is needed?
2. Which storms can or should be seeded?
3. How much must the rainfall from these storms be enhanced to provide the additional rainfall needed?
4. Is the required technology available?

According to Shaw (1974), Iowa's crop yields would be increased during most years if July and August rainfall could be enhanced at least 12%. During wet years, however, rainfall enhancement could result in decreased yields. Therefore, the tables used in this study were based upon the 12% enhancement level. Table 14 lists the numbers of inches of additional rainfall that would have been required to supplement the seasonal totals by 12%. Over the 24-year period studied, 0.60 more inches of rain would have been needed per year in the eastern network and 0.56 inches in the western network. When wet years were excluded, 0.49 and 0.43 inches per year would have been needed.

The selection of storms to be seeded involves two different considerations: capability and advisability. Cloud-seeding capability is determined by technology. The FACE experiments provide data on the seedability of storms resembling types 2 (air-mass) and 3 (PVA) of this study. Therefore, these storms have been singled out for more detailed analysis. Technological changes may well affect both the types of storms that would be seeded and the level of enhancement that could be achieved.

The advisability of seeding is less clearcut. It is, perhaps, easier to discuss the times when it would be inadvisable to enhance rainfall. As was previosly mentioned, crop yields could be decreased if precipitation was augmented during wet years. Crops could also be damaged if heavy rains were increased. Other factors that would affect the decision

Table 14. Amounts of additional rainfall (inches) needed per year to increase totals by 12%

	Eastern Iowa	Western Iowa
Dry Years	0.35	0.23
Normal Years	0.53	0.55
Wet Years	0.87	0.83
	-----	-----
All Years	0.60	0.56
All Except Wet Years	0.49	0.43

to seed would include the potential for severe weather and the cost-benefit ratio.

Tables 15 and 16 list the rainfall totals for the 5 storm types for each network. Totals are given for storms of all depths and for storms of depth less than or equal to 1.00 and 0.50 inch. Because it has been hypothesized that type 2 and 3 storms are those for which FACE seeding results may be applicable, Tables 17 and 18, which list the totals for type 2 and 3 storms, have also been included. To determine the percentage increases needed from such storms, one merely divides the amounts listed in Table 14 by the respective amounts in Table 17 or 18. Results are listed in Tables 19 and 20. Percentage increases can similarly be calculated for other storm types. Alternatively, if a precipitation enhancement of, say, 1 inch is desired during dry years in the eastern (western) region, then a 34% (52%) increase in seasonal rainfall would be needed.

During normal years the rainfall from eastern Iowa's air-mass and PVA storms would have to have been increased by about one-fourth. If storms of depths greater than 0.50 inch were not considered for seeding, then rainfall would have to have been enhanced by about one-half in order to benefit crops. During dry years much higher levels of enhancement would have been needed. If a summer was dry enough, perhaps any enhancement would have helped to increase the crop yield.

Table 15. Eastern Iowa precipitation totals per year for storm depths and types

	Storm Type					
	1	2	3	4	5	Total
			All Storms			
Dry Years	1.18	0.03	0.81	0.01	0.90	2.92
Normal Years	1.07	0.03	2.22	0.22	0.88	4.42
Wet Years	2.01	0.08	3.86	0.06	1.25	7.26
All Years	1.36	0.04	2.46	0.14	0.99	5.00
			Storms ≤ 1.00 inch			
Dry Years	1.18	0.03	0.55	0.01	0.64	2.40
Normal Years	1.00	0.03	1.23	0.22	0.68	3.15
Wet Years	1.33	0.08	2.13	0.06	0.80	4.40
All Years	1.12	0.04	1.38	0.14	0.71	3.39
			Storms ≤ 0.50 inch			
Dry Years	0.57	0.03	0.55	0.01	0.41	1.56
Normal Years	0.60	0.03	1.08	0.12	0.53	2.36
Wet Years	0.55	0.08	0.93	0.06	0.43	2.06
All Years	0.58	0.04	0.95	0.09	0.48	2.14

Table 16. Western Iowa precipitation totals per year for storm depths and types

	Storm Type 1	2	3	4	5	Total
All Storms						
Dry Years	0.96	0.09	0.54	0.05	0.29	1.93
Normal Years	0.86	0.13	2.01	0.11	1.46	4.56
Wet Years	1.60	0.22	3.06	0.51	1.50	6.89
All Years	1.13	0.15	1.99	0.23	1.18	4.68
Storms ≤ 1.00 inch						
Dry Years	0.96	0.09	0.54	0.05	0.29	1.93
Normal Years	0.86	0.13	1.67	0.11	0.90	3.66
Wet Years	1.09	0.22	2.10	0.51	0.80	4.71
All Years	0.96	0.15	1.53	0.23	0.71	3.58
Storms ≤ 0.50 inch						
Dry Years	0.63	0.09	0.54	0.05	0.18	1.49
Normal Years	0.65	0.13	0.95	0.11	0.35	2.17
Wet Years	0.54	0.14	1.21	0.20	0.44	2.52
All Years	0.60	0.12	0.93	0.12	0.34	2.12

Table 17. Combined rainfall totals per year of type 2 (air-mass) and type 3 (PVA) storms

Eastern Iowa	All Storms	Storms ≤ 1.00 in	Storms ≤ 0.50 in
Dry Years	0.84	0.58	0.58
Normal Years	2.25	1.26	1.11
Wet Years	3.94	2.21	1.01
	-----	-----	-----
All Years	2.50	1.42	0.99
All Except Wet Years	1.91	1.10	0.98

Table 18. Combined rainfall totals per year of type 2 (air-mass) and type 3 (PVA) storms

	Western Iowa		
	All Storms	Storms ≤ 1.00 in	Storms ≤ 0.50 in
Dry Years	0.63	0.63	0.63
Normal Years	2.14	1.80	1.08
Wet Years	3.27	2.31	1.35
	-----	-----	-----
All Years	2.14	1.68	1.05
All Except Wet Years	1.57	1.36	0.91

Table 19. Percentage increases in type 2 and 3 rains needed to enhance total precipitation 12% in eastern Iowa

	All Storms	Storms ≤ 1.00 in	Storms ≤ 0.50 in
Dry Years	41.9	60.6	60.6
Normal Years	23.6	42.1	47.9
Wet Years	22.1	39.5	86.0
	-----	-----	-----
All Years	24.0	42.2	60.5
All Except Wet Years	25.5	44.4	49.7

Table 20. Percentage increases in type 2 and 3 rains needed to enhance total precipitation 12% in western Iowa

	All Storms	Storms ≤ 1.00 in	Storms ≤ 0.50 in
Dry Years	37.1	37.1	37.1
Normal Years	25.6	30.4	50.9
Wet Years	25.2	35.7	61.3
	-----	-----	-----
All Years	26.2	33.5	53.3
All Except Wet Years	27.3	31.5	47.3

In this case, the cost-benefit ratio could be a vital factor in the decision of whether to seed the clouds.

In western Iowa the dry-year needed-enhancement levels were only about one-third, even for storms of depths less than or equal to 0.50 inch. When all except wet years were combined, the required percentage increases were fairly similar for the two regions.

If one hypothesizes that the 25 - 35% mean seeding effect reported by Woodley et al. (1977) could be attained under somewhat-similar conditions in the Midwest, then it would appear that seeding would be feasible and of benefit to farmers within Iowa if all type 2 (air-mass) and 3 (PVA) storms were seeded during all except wet years. If seeding was limited to storms of depth no greater than 0.50 inch, however, it would not appear to be feasible.

Furthermore, if seeding was restricted to daylight hours, a high percentage of storms would not be seedable. The diurnal rainfall distribution was quite pronounced and quite similar for both regions. Figures 9 and 10 illustrate the similarity between the rainfall distributions of the two regions. In Figure 9 the relative frequencies of the precipitation events are plotted, and in Figure 10 the relative percentage of each hour's total rainfall. Because sunrise occurs between 5:30 and 6:30 a.m. and sunset occurs between 8:00 and 9:00 p.m. during July and August, the

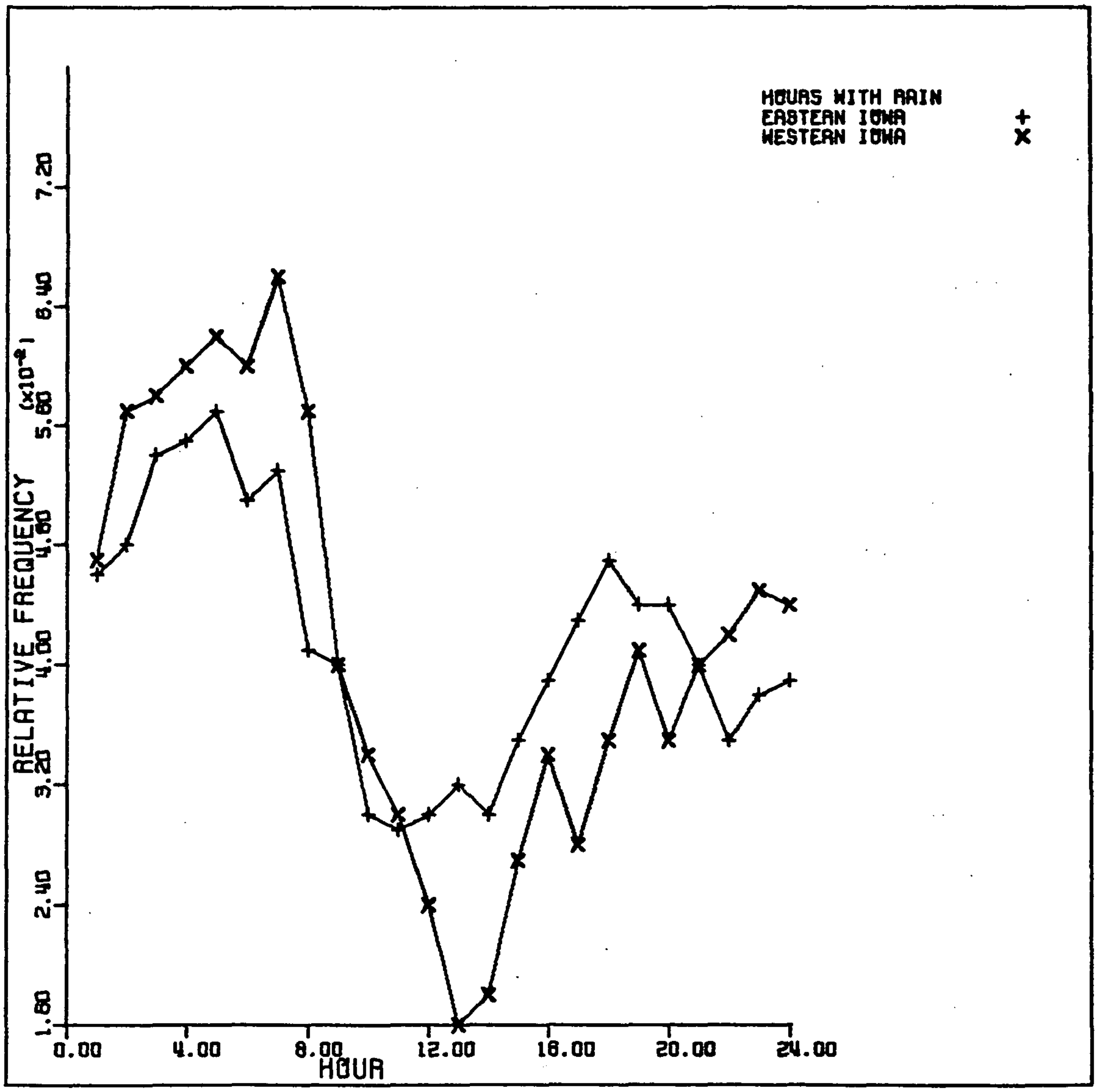


Figure 9. Diurnal frequency distributions of nonzero-precipitation hours for eastern and western Iowa

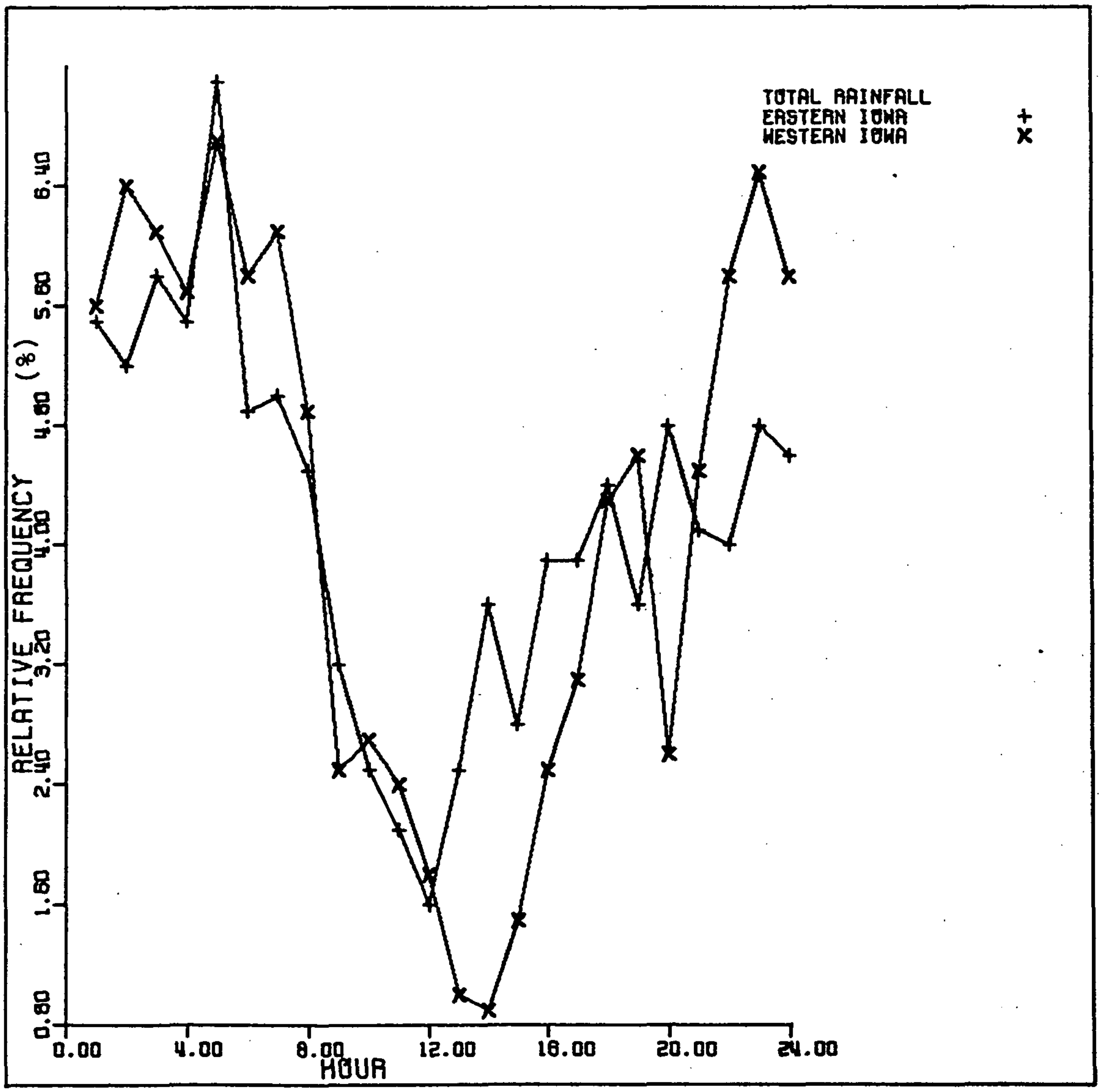


Figure 10. Diurnal percentages of total rainfall for eastern and western Iowa

restriction of operations to daylight hours would reduce the number of storms available for seeding by one-half.

One must be careful when thus assessing the feasibility of seeding. Although the tables presented in this section are based upon a clearly stated set of hypotheses, similar tables, based upon different assumptions, could easily be derived in the same manner. The storm data for each region have been listed in APPENDIX B in order to facilitate such work.

CONCLUSIONS

The July - August storm climatologies of eastern and western Iowa rain-gage networks have been compiled and studied to assess the feasibility of cloud seeding in Iowa. Analyses of data from the 24-year period have shown that cold-front, PVA, and stationary-front storms provided most of the state's summertime precipitation.

Each year was classified as "dry", "normal", or "wet", based upon the numbers of storms and(or) total seasonal precipitation, and the data were analyzed to determine whether the rainfall attributed to a particular storm type might have been associated with below-average seasonal rainfall. No such relationships could be established for the eastern Iowa data. In western Iowa, however, the relationship between stationary-front storm depths and average or above-average seasonal rainfall was significant at the 0.020 level.

In order to assess the feasibility of cloud seeding, a few assumptions were made. It was hypothesized that:

1. Seeding would only enhance the rainfall from naturally precipitating clouds
2. Type 2 (air-mass) and 3 (PVA) storms would be likely candidates for seeding

3. At least 12% overall enhancement of rainfall would be needed during dry and normal years in order to increase Iowa crop yields.

It was found that if only type 2 (air-mass) and 3 (PVA) storms of depth no more than 0.50 inch were seeded during all-except-wet years, then enhancement levels near 50% would be needed to increase crop yields. Tables (14-16) have been provided to facilitate similar calculations for different assumptions.

The results of this study agree with those of Huff (1979) for Illinois, which stress the need to seed type 1 (cold-front/squall-line) storms if substantial precipitation increases are to be expected during dry years. For instance, if even a 15% increase could be achieved for type 1 storms, in addition to a 20% increase for type 3 (PVA) storms, then by using the results of Table 8 (Table 13), one sees that the net annual dry-year increase would be 11.6% (13.1%) for eastern (western) Iowa. Furthermore, if type 5 (stationary-front) storms were also shown to be seedable, average precipitation increases in excess of 12% may well be feasibile.

Although Iowa is not climatologically homogeneous, significant differences between the 2 regions, which could hinder attempts to transfer cloud-seeding technology within the state, were not detected. Despite some apparent differences between the 2 regions among the percentage increases in type 2 and 3 rains needed to enhance total precipitation 12% in dry years (Tables 19 and 20), the percentages for all-except-wet years were quite similar. Furthermore, Tables 8 and 13 show that the rainfall distributions among storm types were quite similar. It must therefore be concluded that when the technology to enhance rainfall in eastern Iowa has been developed, the same methods should be successful in western Iowa. Because eastern Iowa's rainfall climatology does not differ greatly from that of central Illinois, cloud-seeding technology developed in Illinois could most likely be effective in Iowa.

BIBLIOGRAPHY

Brooks, C. E. P., and N. Carruthers. 1953. Handbook of statistical methods in meteorology. Her Majesty's Stationery Office, London.

Changnon, S. A., Jr. 1973. Precipitation enhancement program for Illinois. J. Irrig. and Drain. Div., Proc. ASCE, 99(IR3):215-226.

Gibbons, J. D. 1976. Nonparametric methods for quantitative analysis. Holt, Rinehart, and Winston, New York.

Grace, R. A., and P. S. Eagleson. 1966. The synthesis of short-time-increment rainfall sequences. MIT Dept. CE Hydrodynamics Lab Report No. 91.

Hashino, M. 1973. A similar storm method on filling data voids. Pages 161-173 in D. A. Woolhiser, ed. Decisions with inadequate hydrologic Data: Proc. 2nd Intl. Hydrol. Symp., Sept. 1972, Fort Collins, Colorado, U.S.A. Water Resources Publications, Fort Collins, Colorado.

Hjelmfelt, A. T., Jr., and J. J. Cassidy. 1975. Hydrology for engineers and planners. The Iowa State University Press, Ames, Iowa.

Huff, F. A. 1971. Evaluation of precipitation records in weather modification experiments. Pages 59-134 in H. E. Landsberg and J. Van Mieghem, eds. Advances in geophysics. Vol. 15. Academic Press, New York.

Huff, F. A. 1979. Assessment of weather modification potential for alleviating agriculatural droughts in the Midwest. J. Weath. Modification 11:28-49.

Huff, F. A., and S. A. Changnon, Jr. 1972. Evaluation of potential effects of weather and modification on agriculture in Illinois. J. Appl. Meteorol. 11:376-384.

Huff, F. A., and S. A. Changnon, Jr. 1973. Precipitation modification by major urban areas. Bull. Amer. Meteorol. Soc. 54:1220-1232.

Huff, F. A., and R. G. Semonin. 1975. Potential of precipitation modification in moderate to severe droughts. J. Appl. Meteorol. 14:974-979.

International Mathematical and Statistical Libraries, Inc. 1977. The IMSL Library. 6th ed. Author, Houston, Texas. 2 vols.

Rottner, D., S. R. Brown, and O. H. Foehner. 1975. The effect of persistence of AgI on randomized weather modification experiments. J. Appl. Meteorol. 14:939-945.

Sariahmed, A., and C. C. Kisiel. 1968. Synthesis of sequences of summer thunderstorms volumes for the atterbury watershed in the Tucson area. Pages 439-447 in Proc. of the IASH Symp. on the use of analog & digital computers in hydrol. Vol. 2. Publication No. 81 AISH.

Schickedanz, P. T., and F. A. Huff. 1971. The design and evaluation of rainfall modification experiments. J. Appl. Meteorol. 10:502-514.

Shaw, R. H. 1974. Evaluation of effects of weather modification on Iowa corn yields. Iowa State J. Res. 48(3):209-218.

Shaw, R. H., and P. J. Waite. 1964. The climate of Iowa. Part III: Monthly, crop season and annual temperature and precipitation normals for Iowa. Iowa Agric. and Home Economics Experiment Station Spec. Report No. 38.

Trewartha, G. T. 1968. An introduction to climate. 4th ed. McGraw-Hill Book Company, New York.

U.S. Dept. of Commerce. 1952a, 1954a through 1956a. Daily series synoptic weather maps. Part I: Northern hemisphere sea level and 500 millibar charts. Govt. Printing Office, Washington, D.C.

U.S. Dept. of Commerce. 1957b through 1967b. Daily weather map. National Climatic Center, Asheville, North Carolina.

U.S. Dept. of Commerce. 1968c through 1976c. Daily weather maps: Weekly series. National Climatic Center, Asheville, North Carolina.

U.S. Dept. of Commerce. 1952d through 1976d Hourly precipitation data. National Climatic Center, Asheville, North Carolina.

U.S. Dept. of Commerce. 1952e through 1976e. Local Climatological Data. National Climatic Center, Asheville, North Carolina.

U.S. Dept. of Commerce. 1952f through 1976f. Report on Substation. National Climatic Center, Asheville, North Carolina.

U.S. Dept. of Commerce. 1952g through 1976g. Station history. National Climatic Center, Asheville, North Carolina.

Woodley, W. L., J. Simpson, R. Biondini, and J. Berkeley. 1977. Rainfall results, 1970-1975: Florida area cumulus experiment. Science 195:735-742.

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APPENDIX A : COMPUTER PROGRAM LOGIC

An important part of this study involved the handling of vast amounts of data. Flowcharts outlining the major programs and subroutines are therefore included (see Figures 11 - 18).

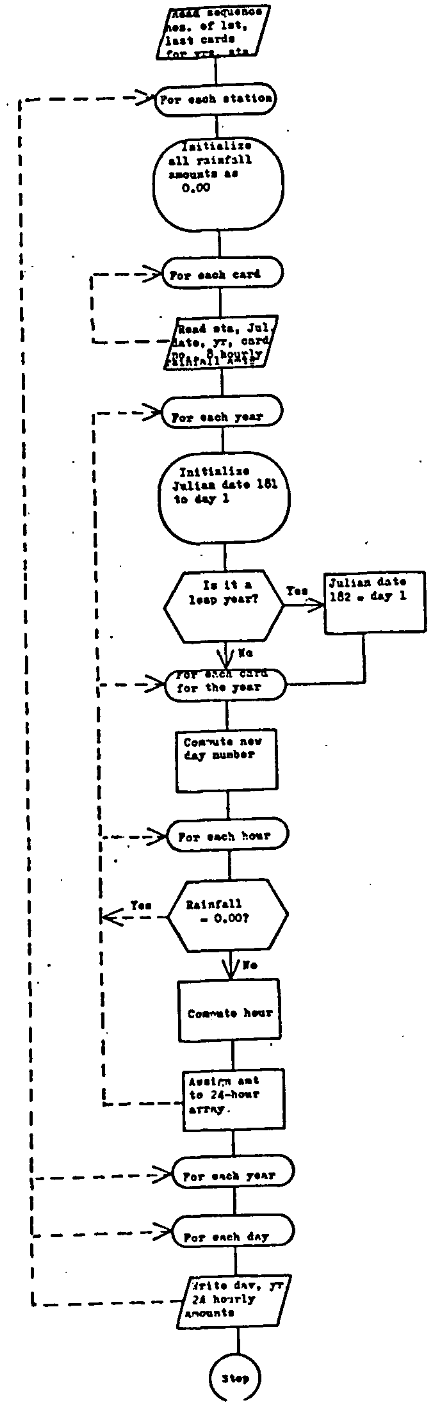
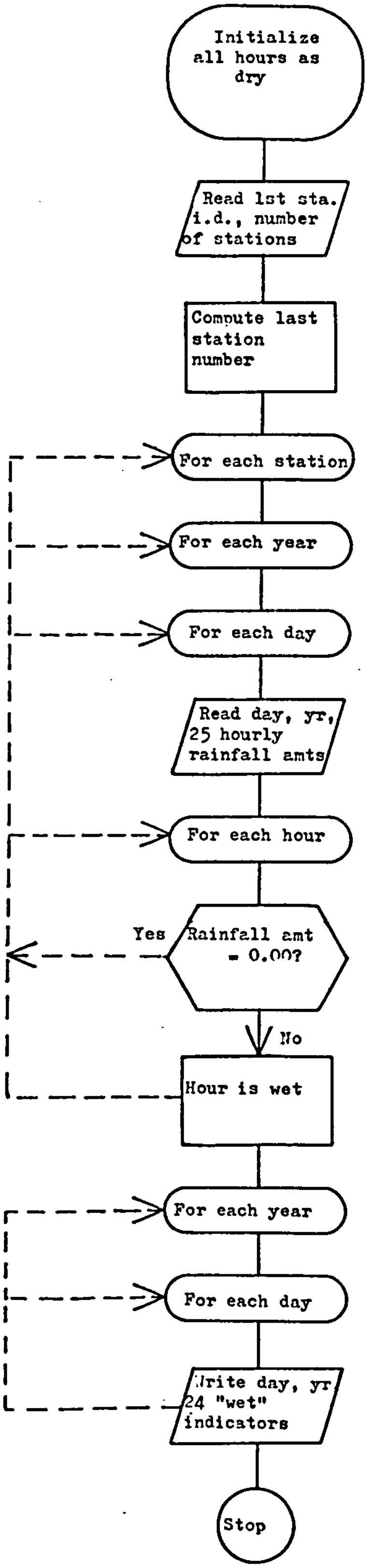


Figure 11. Flowchart of logic for computer program used to change data to include all (zero and nonzero) precipitation amounts

Figure 12. Flowchart of logic for computer program used to indicate for each hour whether rainfall was recorded at any station witihin a region


Initialize all hours as dry
Read 1st sta. i.d., number of stations
Compute last station number
For each station
For each year
For each day
Read day, yr, 25 hourly rainfall amts
For each hour
Yes
Rainfall amt = 0.00?
No
Hour is wet
For each year
For each day
Write day, yr, 24 "wet" indicators
Stop

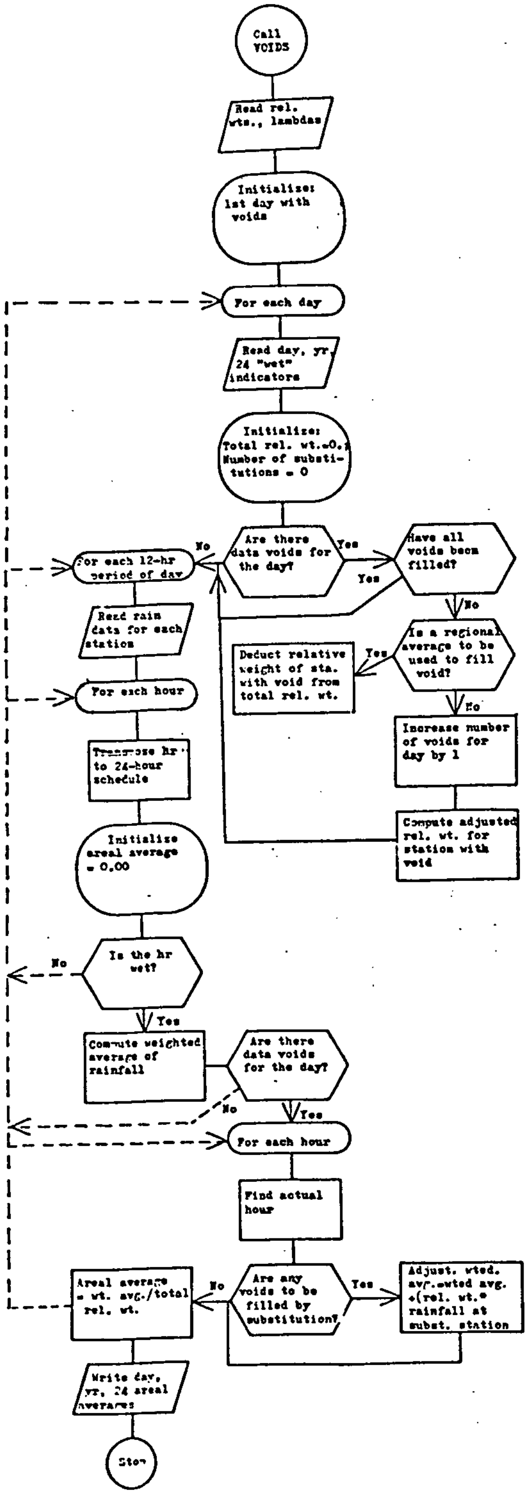
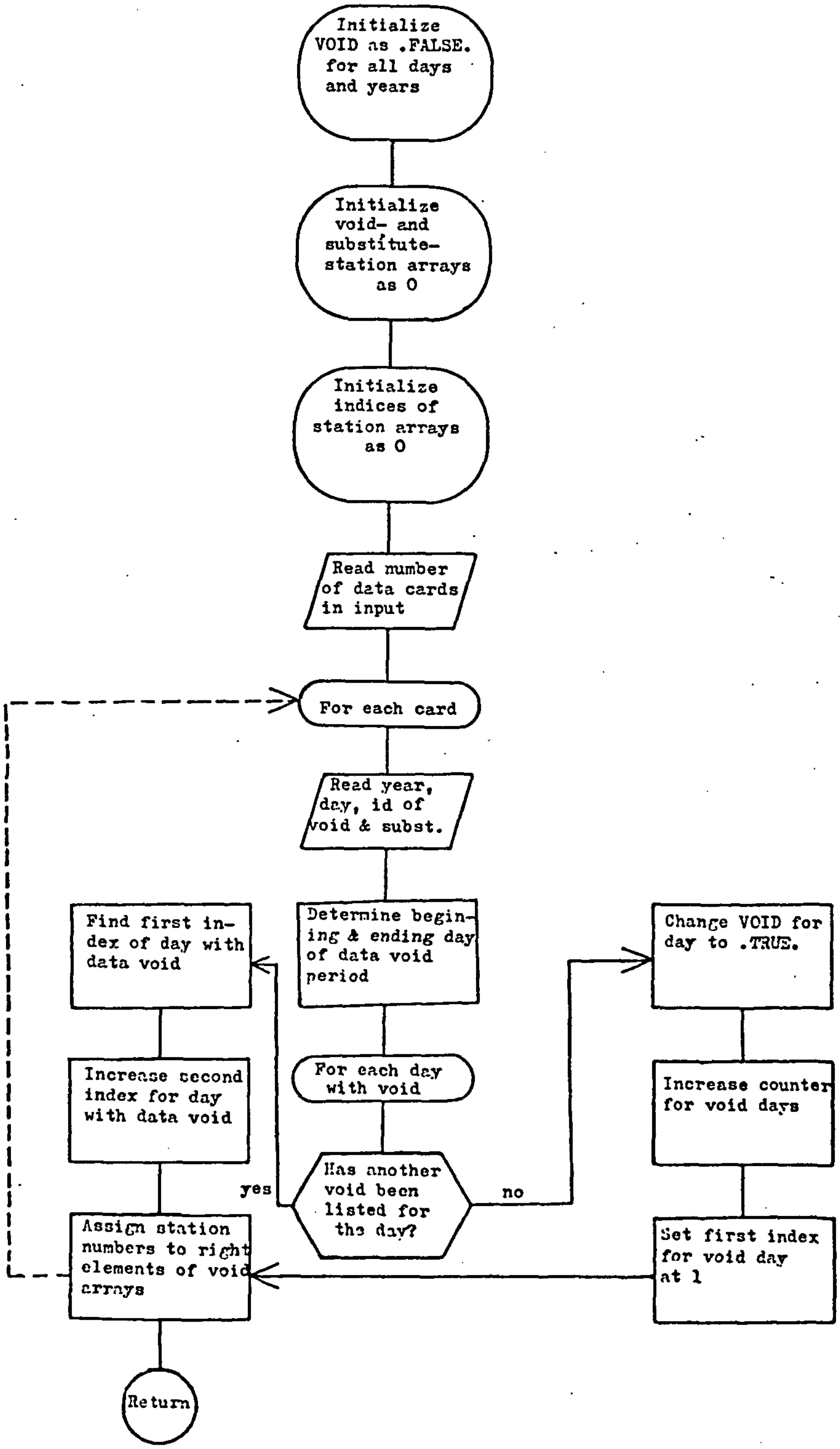


Figure 13. Flowchart of logic for computer program used to compute hourly areal averages for a region

Figure 14. Flowchart of logic for Subroutine VOIDS, which was used to organize data-void information for the program used to compute areal averages


Initialize VOID as .FALSE. for all days and years
Initialize void- and substitute-station arrays as 0
Initialize indices of station arrays as 0
Read number of data cards in input
For each card
Read year, day, id of void & subst.
Determine begining & ending day of data void period
For each day with void
Has another void been listed for the day?
yes
no
Find first index of day with data void
Increase second index for day with data void
Assign station numbers to right elements of void arrays
Change VOID for day to .TRUE.
Increase counter for void days
Set first index for void day at 1
Return

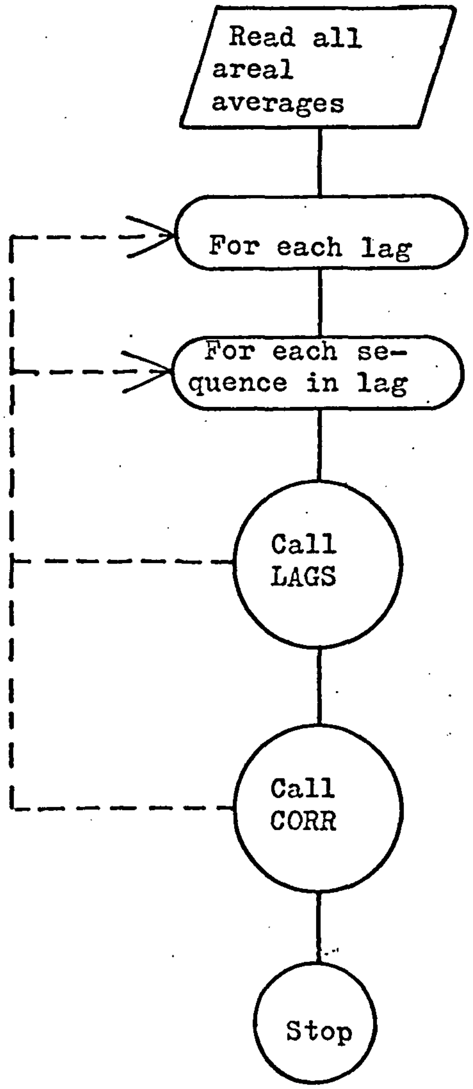


Figure 15. Flowchart of logic for main computer program used to compute Spearman's rank correlation coefficient for each possible sequence of each time lag considered

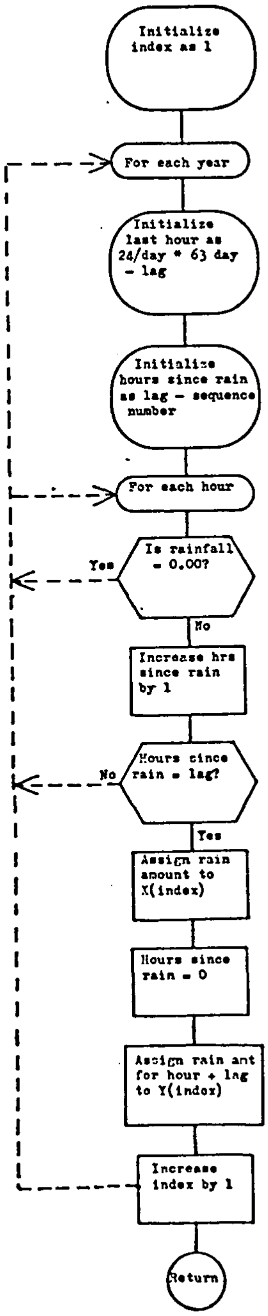
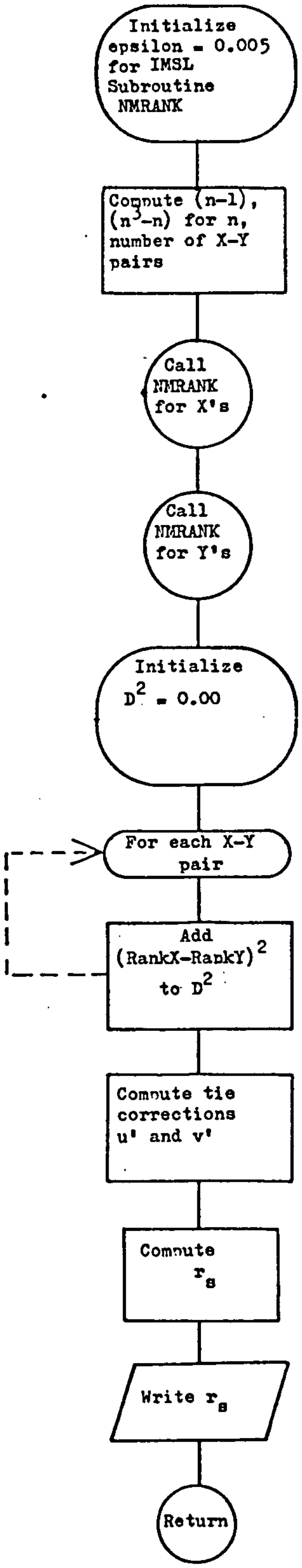


Figure 16. Flowchart of logic for Subroutine LAGS, which was used to obtain all X-Y pairs used to compute Spearman's rank correlation coefficient

Figure 17. Flowchart of logic for Subroutine CORR, which was used to compute Spearman's rank correlation coefficient for X-Y pairs


Initialize epsilon = 0.005 for IMSL Subroutine NMRANK
Compute (n-1), (n^3-n) for n, number of X-Y pairs
Call NMRANK for X's
Call NMRANK for Y's
Initialize D^2 = 0.00
For each X-Y pair
Add (RankX-RankY)^2 to D^2
Compute tie corrections u' and v'
Compute r_s
Write r_s
Return

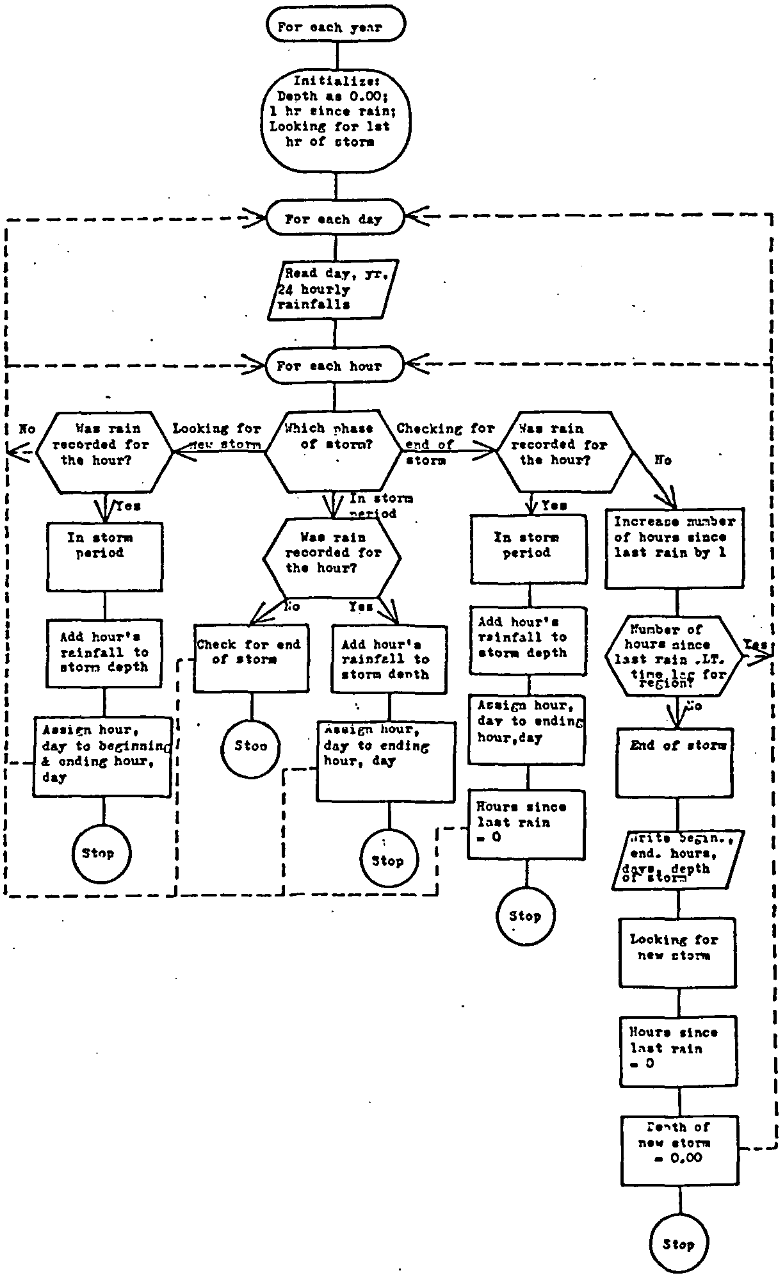


Figure 18. Flowchart of logic for computer program used to separate rainfall data into storms

APPENDIX B: STORM DATA

Listings of the storm data for the eastern and western Iowa networks have been included . The headings are as follows:

Type -- Storm type (1-5,6=type unknown)

Depth -- Storm depth (inches)

Dur -- Storm duration (hours)

Reg -- Region (1=east,2=west)

TB -- Beginning time (CST) of storm (1-24)

DB -- Beginning day of storm (1-63)

TE -- Ending time (CST) of storm (1-24)

DE -- Ending day of storm (1-63)

Hrs -- Hours since last storm ended (99=first day of season)

Days -- Days since last storm ended (99=first day of season).

Table 21. Eastern and western Iowa storm data

Eastern Region											Western Region										
Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days	Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
1	0.18	3	1	1	19	2	21	2	99	99	4	0.02	1	2	1	8	1	8	1	99	99
1	0.04	3	1	1	8	13	10	13	250	10	4	0.02	1	2	1	19	1	19	1	10	0
3	0.61	5	1	1	14	14	18	14	27	1	5	0.05	1	2	1	9	2	9	2	13	0
5	0.28	25	1	1	12	17	12	18	65	2	1	0.08	1	2	1	19	2	19	2	9	0
2	0.01	1	1	1	4	19	4	19	15	0	1	1.57	16	2	1	21	6	12	7	97	4
2	0.11	1	1	1	3	23	3	23	94	3	1	0.12	2	2	1	24	12	1	13	131	5
2	0.01	1	1	1	18	28	18	28	134	5	3	0.81	7	2	1	2	14	8	14	24	1
1	0.05	1	1	1	3	30	3	30	32	1	2	0.02	1	2	1	8	19	8	19	119	4
1	0.99	7	1	1	13	34	19	34	105	4	4	0.19	2	2	1	24	19	1	20	15	0
1	0.36	9	1	1	13	39	21	39	113	4	5	0.07	7	2	1	9	31	15	31	271	11
1	0.02	1	1	1	8	46	8	46	154	6	3	0.05	2	2	1	6	32	7	32	14	0
3	0.64	3	1	1	19	46	21	46	10	0	1	0.52	7	2	1	7	34	13	34	47	1
3	1.94	5	1	1	5	51	9	51	103	4	3	0.08	4	2	1	11	36	14	36	45	1
1	0.01	1	1	1	17	51	17	51	7	0	5	0.08	3	2	1	14	38	16	38	47	1
5	0.03	1	1	1	5	60	5	60	203	8	1	0.69	5	2	1	3	39	7	39	10	0
1	0.17	3	1	3	4	3	6	3	99	99	1	0.04	1	2	1	17	39	17	39	9	0
3	0.27	4	1	3	21	6	24	6	86	3	4	0.07	2	2	1	2	45	3	45	128	5
1	0.68	6	1	3	23	20	4	21	334	13	3	0.13	7	2	1	10	45	16	45	6	0
1	0.04	3	1	3	12	23	14	23	55	2	3	0.25	5	2	1	1	46	5	46	8	0
3	0.05	2	1	3	8	28	9	28	113	4	3	0.08	1	2	1	17	46	17	46	11	0
5	0.32	6	1	3	19	30	24	30	57	2	2	0.34	2	2	1	5	50	6	50	83	3
3	0.24	11	1	3	13	35	23	35	108	4	3	0.11	3	2	1	4	51	6	51	21	0
3	0.10	5	1	3	1	39	5	39	73	3	1	0.20	6	2	1	13	51	18	51	6	0
1	0.10	2	1	3	17	40	18	40	35	1	3	0.10	2	2	1	8	56	9	56	109	4
4	0.27	3	1	3	2	45	4	45	103	4	5	1.62	25	2	1	5	59	5	60	67	2
1	0.34	3	1	3	4	47	6	47	47	1	3	0.02	1	2	1	6	61	6	61	24	1
3	0.03	6	1	3	8	48	13	48	25	1	5	0.13	1	2	3	21	1	21	1	99	99
3	1.22	6	1	3	1	49	6	49	11	0	3	0.04	4	2	3	3	17	6	17	365	15
3	0.05	1	1	3	18	49	18	49	11	0	5	0.31	6	2	3	14	30	19	30	319	13
3	0.05	2	1	3	7	53	8	53	84	3	3	0.03	1	2	3	6	35	6	35	106	4
5	0.11	2	1	3	4	55	5	55	43	1	3	0.15	7	2	3	5	38	11	38	70	2
3	0.07	5	1	3	8	56	12	56	26	1	3	0.04	2	2	3	16	38	17	38	4	0
4	0.61	6	1	3	2	57	7	57	13	0	3	0.05	2	2	3	22	38	23	38	4	0
3	0.02	1	1	4	7	2	7	2	99	99	3	0.08	1	2	3	8	39	8	39	8	0
5	0.38	1	1	4	17	4	17	4	57	2	3	0.07	2	2	3	1	42	2	42	64	2
5	0.20	7	1	4	19	5	1	6	25	1	3	0.12	3	2	3	10	42	12	42	7	0
1	0.65	4	1	4	4	9	7	9	74	3	3	0.15	6	2	3	19	42	24	42	6	0
3	0.11	2	1	4	8	10	9	10	24	1	5	0.06	1	2	3	6	45	6	45	53	2
2	0.04	2	1	4	20	14	21	14	106	4	3	0.85	4	2	3	5	48	8	48	70	2
2	0.01	1	1	4	14	15	14	15	16	0	3	0.09	1	2	3	22	48	22	48	13	0
1	0.01	1	1	4	21	22	21	22	174	7	1	0.10	2	2	3	5	49	6	49	6	0
1	0.12	2	1	4	13	23	14	23	15	0	3	0.08	2	2	3	9	52	10	52	74	3
1	0.54	3	1	4	21	31	23	31	198	8	3	0.21	1	2	3	15	52	15	52	4	0
5	0.93	12	1	4	2	36	13	36	98	4	4	0.03	2	2	3	21	52	22	52	5	0
3	0.09	2	1	4	5	37	6	37	15	0	3	0.46	1	2	3	7	53	7	53	8	0
1	0.16	3	1	4	13	60	15	60	558	23	5	0.03	1	2	3	16	53	16	53	8	0
3	0.05	2	1	5	15	6	16	6	99	99	4	0.83	8	2	3	21	53	4	54	4	0
3	0.46	12	1	5	15	7	2	8	22	0	4	0.02	1	2	3	9	54	9	54	4	0
3	0.34	3	1	5	17	17	19	17	230	9	5	0.09	1	2	3	22	54	22	54	12	0
3	0.03	1	1	5	17	18	17	18	21	0	5	0.05	2	2	3	24	57	1	58	73	3
3	0.14	2	1	5	18	19	19	19	24	1	5	0.32	1	2	3	12	58	12	58	10	0
4	0.19	2	1	5	1	28	2	28	197	8	5	0.02	1	2	4	18	4	18	4	99	99
3	0.74	5	1	5	3	31	7	31	72	3	1	0.61	4	2	4	7	8	10	8	84	3
3	0.05	1	1	5	4	32	4	32	20	0	1	0.08	2	2	4	24	8	1	9	13	0
3	0.03	1	1	5	7	39	7	39	170	7	3	0.10	1	2	4	9	10	9	10	31	1
3	0.24	4	1	5	17	43	20	43	105	4	1	0.09	3	2	4	19	13	21	13	81	3
1	0.23	3	1	5	8	49	10	49	131	5	2	0.28	2	2	4	15	19	16	19	137	5
3	0.02	2	1	5	11	57	12	57	192	8	3	0.14	2	2	4	5	20	6	20	12	0
1	0.10	2	1	5	3	60	4	60	62	2	1	0.13	1	2	4	18	22	18	22	59	2
3	1.98	20	1	5	5	61	24	61	24	1	1	0.42	2	2	4	7	32	8	32	228	9
5	0.30	3	1	6	9	3	11	3	99	99	1	0.70	5	2	4	21	40	1	41	204	8
1	0.04	1	1	6	7	4	7	4	19	0	1	0.15	3	2	4	17	52	19	52	279	11
1	0.25	1	1	6	5	8	5	8	93	3	1	0.25	4	2	4	4	60	7	60	176	7
3	0.33	3	1	6	10	12	12	12	100	4	1	0.09	1	2	5	6	1	6	1	99	99
5	0.05	5	1	6	3	13	7	13	14	0	3	0.08	2	2	5	15	3	16	3	56	2
5	0.15	1	1	6	9	16	9	16	73	3	4	0.87	5	2	5	2	7	6	7	81	3
1	0.33	8	1	6	15	21	22	21	125	5	3	0.48	2	2	5	18	7	19	7	11	0
1	0.04	1	1	6	14	22	14	22	15	0	3	0.80	4	2	5	16	11	19	11	92	3
4	0.07	3	1	6	13	28	15	28	142	5	1	0.03	1	2	5	2	13	2	13	30	1
5	0.56	2	1	6	18	31	19	31	74	3	4	0.26	3	2	5	24	14	2	15	45	1
1	0.46	3	1	6	9	34	11	34	61	2	3	0.17	2	2	5	17	15	18	15	14	0
3	0.48	4	1	6	23	44	2	45	251	10	3	0.05	1	2	5	23	17	23	17	52	2
3	0.15	3	1	6	4	49	6	49	97	4	3	0.03	1	2	5	20	18	20	18	20	0
3	0.13	3	1	6	15	49	17	49	8	0	4	0.78	13	2	5	21	27	9	28	216	9

Table 21. (Continued)

Eastern Region											Western Region										
Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days	Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.16	6	1	6	13	54	18	54	115	4	5	0.11	3	2	5	21	28	23	28	11	0
3	0.40	15	1	6	4	58	18	58	81	3	5	0.19	2	2	5	21	30	22	30	45	1
5	0.48	4	1	6	6	59	9	59	11	0	3	0.31	2	2	5	21	31	22	31	22	0
5	0.45	6	1	6	23	60	4	61	37	1	4	0.03	2	2	5	4	33	5	33	29	1
1	0.27	12	1	7	5	2	16	2	99	99	3	0.02	1	2	5	21	35	21	35	63	2
3	0.41	7	1	7	23	3	5	4	30	1	3	0.03	1	2	5	11	37	11	37	37	1
3	0.01	1	1	7	15	4	15	4	9	0	4	0.08	2	2	5	7	38	8	38	19	0
3	0.19	4	1	7	12	11	15	11	164	6	3	0.42	4	2	5	23	38	2	39	14	0
3	0.83	6	1	7	24	13	5	14	56	2	3	0.18	6	2	5	8	39	13	39	5	0
1	0.14	5	1	7	13	14	17	14	7	0	3	0.06	1	2	5	20	39	20	39	6	0
2	0.01	1	1	7	19	17	19	17	73	3	3	0.03	1	2	5	18	43	18	43	93	3
3	0.09	2	1	7	11	19	12	19	39	1	1	0.65	5	2	5	24	46	4	47	77	3
1	0.11	3	1	7	20	24	22	24	127	5	3	0.16	2	2	5	5	48	6	48	24	1
1	0.27	2	1	7	8	27	9	27	57	2	1	0.48	7	2	5	2	49	8	49	19	0
2	0.10	2	1	7	5	29	6	29	43	1	1	0.03	1	2	5	22	59	22	59	253	10
4	0.03	2	1	7	9	35	10	35	146	6	3	0.02	1	2	5	12	61	12	61	37	1
1	0.27	3	1	7	3	36	5	36	16	0	1	0.09	2	2	6	9	1	10	1	99	99
5	0.05	1	1	7	16	37	16	37	34	1	3	0.03	1	2	6	7	3	7	3	44	1
5	0.08	1	1	7	8	38	8	38	15	0	1	0.17	1	2	6	4	8	4	8	116	4
1	0.03	7	1	7	4	42	10	42	91	3	5	0.02	1	2	6	7	13	7	13	122	5
1	0.19	3	1	7	14	43	16	43	27	1	5	0.16	1	2	6	3	14	3	14	19	0
1	0.54	4	1	7	1	46	4	46	56	2	5	0.01	1	2	6	7	15	7	15	27	1
2	0.09	3	1	7	3	48	5	48	46	1	1	0.19	2	2	6	8	20	9	20	120	5
1	1.11	11	1	7	8	51	18	51	74	3	1	0.12	5	2	6	15	21	19	21	29	1
3	0.03	2	1	7	12	54	13	54	65	2	1	0.09	5	2	6	4	22	8	22	8	0
3	0.07	2	1	7	24	54	1	55	10	0	4	0.09	1	2	6	6	27	6	27	117	4
1	0.03	1	1	7	20	61	20	61	162	6	1	0.01	1	2	6	8	44	8	44	409	17
1	0.44	7	1	8	10	4	16	4	99	99	3	0.33	2	2	6	18	44	19	44	9	0
1	0.58	3	1	8	17	8	19	8	96	4	3	0.32	4	2	6	1	49	4	49	101	4
3	0.11	1	1	8	19	10	19	10	47	1	3	0.08	2	2	6	5	51	6	51	48	2
3	0.02	1	1	8	12	17	12	17	160	6	3	0.37	7	2	6	13	51	19	51	6	0
1	0.53	7	1	8	23	17	5	18	10	0	3	0.06	3	2	6	1	54	3	54	53	2
3	0.05	1	1	8	17	22	17	22	107	4	3	0.98	10	2	6	22	57	7	58	90	3
1	0.02	1	1	8	13	23	13	23	19	0	1	0.77	5	2	6	3	59	7	59	19	0
3	0.13	4	1	8	3	29	6	29	133	5	5	0.62	4	2	6	5	60	8	60	21	0
1	0.09	7	1	8	22	29	4	30	15	0	1	0.04	7	2	7	5	1	11	1	99	99
5	1.04	8	1	8	1	34	8	34	92	3	5	2.89	13	2	7	20	1	8	2	8	0
3	0.35	4	1	8	6	37	9	37	69	2	1	0.01	1	2	7	13	2	13	2	4	0
3	0.03	2	1	8	18	37	19	37	8	0	5	0.26	10	2	7	11	3	20	3	21	0
3	0.02	1	1	8	15	42	15	42	115	4	3	0.06	2	2	7	22	8	23	8	121	5
5	0.67	11	1	8	20	45	6	46	76	3	1	0.03	2	2	7	20	9	21	9	20	0
5	0.04	2	1	8	16	46	17	46	9	0	3	0.04	2	2	7	1	11	2	11	27	1
5	0.07	1	1	8	9	47	9	47	15	0	1	0.10	1	2	7	4	14	4	14	73	3
3	0.37	4	1	8	23	52	2	53	133	5	2	0.13	2	2	7	8	17	9	17	75	3
3	0.01	1	1	8	7	54	7	54	28	1	3	1.75	12	2	7	2	19	13	19	40	1
5	0.02	1	1	8	13	57	13	57	77	3	1	0.19	3	2	7	6	24	8	24	112	4
3	0.12	2	1	8	12	58	13	58	22	0	1	0.32	2	2	7	2	27	3	27	65	2
3	0.02	1	1	8	2	60	2	60	36	1	2	0.02	2	2	7	10	29	11	29	54	2
1	0.15	3	1	8	12	61	14	61	33	1	5	0.72	14	2	7	22	29	11	30	10	0
3	0.04	1	1	9	21	2	21	2	99	99	1	0.08	1	2	7	18	36	18	36	150	6
3	0.06	1	1	9	19	5	19	5	69	2	1	0.14	1	2	7	24	36	24	36	5	0
3	1.36	18	1	9	9	9	2	10	85	3	1	0.07	2	2	7	16	43	17	43	159	6
1	0.14	4	1	9	15	12	18	12	60	2	5	0.37	4	2	7	8	44	11	44	14	0
2	0.01	1	1	9	18	18	18	18	143	5	2	0.11	1	2	7	12	51	12	51	168	7
5	0.05	2	1	9	21	22	22	22	98	4	3	0.33	6	2	7	3	54	8	54	62	2
1	0.12	4	1	9	17	25	20	25	66	2	3	0.17	4	2	7	18	54	21	54	9	0
1	0.06	2	1	9	19	26	20	26	22	0	3	0.05	4	2	7	7	56	10	56	33	1
5	0.01	1	1	9	15	33	15	33	162	6	5	0.03	1	2	7	3	60	3	60	88	3
3	0.10	1	1	9	21	34	21	34	29	1	1	0.04	1	2	8	2	4	2	4	99	99
3	0.01	1	1	9	2	37	2	37	52	2	1	0.02	1	2	8	2	8	2	8	95	3
3	0.44	2	1	9	2	38	3	38	23	0	3	0.08	1	2	8	20	12	20	12	113	4
3	0.36	3	1	9	3	40	5	40	47	1	5	0.12	2	2	8	12	31	13	31	447	18
1	0.07	1	1	9	1	45	1	45	115	4	5	1.32	7	2	8	3	33	9	33	37	1
3	0.26	4	1	9	3	50	6	50	121	5	3	0.06	2	2	8	9	36	10	36	71	2
3	0.04	2	1	9	17	50	18	50	10	0	1	0.01	1	2	8	22	40	22	40	107	4
3	0.09	5	1	9	7	51	11	51	12	0	1	0.09	5	2	8	18	44	22	44	91	3
1	0.74	8	1	9	20	59	3	60	200	8	1	0.42	6	2	8	3	45	8	45	4	0
1	0.59	5	1	10	5	1	9	1	99	99	5	0.09	1	2	8	23	45	23	45	14	0
1	1.03	5	1	10	20	1	24	1	10	0	3	0.01	1	2	8	5	50	5	50	101	4
5	0.30	10	1	10	24	3	9	4	47	1	2	0.35	3	2	8	18	53	20	53	84	3
5	0.39	5	1	10	20	4	24	4	10	0	3	0.33	4	2	8	18	59	21	59	141	5
5	0.01	1	1	10	9	5	9	5	8	0	3	0.58	3	2	8	10	62	12	62	60	2
3	0.15	14	1	10	17	12	6	13	175	7	3	0.04	2	2	9	15	5	16	5	99	99
3	0.05	1	1	10	13	13	13	13	6	0	3	0.11	6	2	9	3	9	8	9	82	3

Table 21. (Continued)

Eastern Region											Western Region										
Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days	Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.33	7	1	10	1	15	7	15	35	1	3	0.28	2	2	9	22	11	23	11	61	2
3	0.09	1	1	10	16	15	16	15	8	0	3	0.42	5	2	9	4	12	8	12	4	0
3	0.14	2	1	10	2	19	3	19	81	3	1	0.03	2	2	9	19	12	20	12	10	0
3	0.30	9	1	10	1	21	9	21	45	1	2	0.63	4	2	9	20	17	23	17	119	4
3	0.12	6	1	10	17	21	22	21	7	0	1	0.01	1	2	9	2	26	2	26	194	8
3	0.26	4	1	10	22	22	1	23	23	0	1	0.10	1	2	9	24	29	24	29	93	3
3	0.20	2	1	10	22	23	23	23	20	0	3	0.05	1	2	9	4	36	4	36	147	6
3	0.28	6	1	10	2	27	7	27	74	3	3	0.02	1	2	9	12	36	12	36	7	0
5	0.07	3	1	10	4	28	6	28	20	0	3	1.31	3	2	9	18	36	20	36	5	0
5	0.11	2	1	10	4	30	5	30	45	1	3	0.05	1	2	9	5	37	5	37	8	0
5	0.13	3	1	10	5	31	7	31	23	0	3	0.79	7	2	9	21	37	3	38	15	0
3	0.70	11	1	10	17	31	3	32	9	0	1	0.01	1	2	9	18	44	18	44	158	6
3	0.19	18	1	10	18	33	11	34	38	1	4	0.08	3	2	9	15	47	17	47	68	2
1	0.09	2	1	10	23	34	24	34	11	0	1	0.86	8	2	9	8	48	15	48	14	0
3	0.25	3	1	10	21	35	23	35	20	0	1	0.23	4	2	9	20	48	23	48	4	0
2	0.11	3	1	10	14	36	16	36	14	0	3	0.01	1	2	9	17	49	17	49	17	0
1	0.89	6	1	10	2	41	7	41	105	4	3	0.03	1	2	9	22	49	22	49	4	0
2	0.01	1	1	10	14	59	14	59	438	18	3	0.03	1	2	9	19	50	19	50	20	0
5	2.10	26	1	11	16	1	17	2	99	99	1	0.59	9	2	9	20	54	4	55	96	4
5	0.02	2	1	11	18	11	19	11	216	9	2	0.30	4	2	9	14	55	17	55	9	0
5	0.48	5	1	11	2	12	6	12	6	0	3	0.01	1	2	9	5	56	5	56	11	0
3	1.67	25	1	11	12	13	12	14	29	1	1	0.24	2	2	9	10	56	11	56	4	0
3	0.04	1	1	11	19	14	19	14	6	0	1	0.01	1	2	9	9	59	9	59	69	2
3	0.22	4	1	11	12	19	15	19	112	4	1	1.24	9	2	9	15	59	23	59	5	0
1	0.71	7	1	11	24	19	6	20	8	0	3	0.10	7	2	10	1	11	7	11	99	99
3	0.04	1	1	11	1	22	1	22	42	1	1	0.06	1	2	10	19	11	19	11	11	0
3	0.62	9	1	11	13	22	21	22	11	0	1	0.04	1	2	10	11	12	11	12	15	0
1	0.11	3	1	11	18	24	20	24	44	1	1	0.03	1	2	10	12	13	12	13	24	1
3	1.40	9	1	11	2	28	10	28	77	3	3	0.02	1	2	10	19	14	19	14	30	1
1	0.01	1	1	11	18	39	18	39	271	11	5	0.24	4	2	10	4	18	7	18	80	3
5	0.01	1	1	11	19	50	19	50	264	11	3	0.09	5	2	10	10	23	14	23	122	5
5	0.10	9	1	11	2	51	10	51	6	0	3	0.01	1	2	10	11	26	11	26	68	2
1	1.31	23	1	11	20	54	18	55	81	3	5	0.75	4	2	10	23	27	2	28	35	1
2	0.03	1	1	12	10	3	10	3	99	99	3	1.06	6	2	10	18	31	23	31	87	3
5	0.01	1	1	12	7	4	7	4	20	0	3	0.20	2	2	10	21	40	22	40	213	8
5	0.32	13	1	12	11	5	23	5	27	1	1	0.51	6	2	10	16	49	21	49	209	8
3	0.88	18	1	12	19	12	12	13	163	6	3	0.35	6	2	10	8	52	13	52	58	2
4	0.10	3	1	12	7	16	9	16	66	2	3	0.19	5	2	10	19	52	23	52	5	0
3	0.14	3	1	12	3	17	5	17	17	0	3	0.01	1	2	10	12	58	12	58	132	5
3	3.20	17	1	12	15	18	7	19	33	1	1	0.43	4	2	11	22	7	1	8	99	99
3	0.43	5	1	12	16	19	20	19	8	0	2	0.02	1	2	11	7	10	7	10	53	2
1	0.12	5	1	12	20	27	24	27	191	7	2	0.04	1	2	11	1	13	1	13	65	2
2	0.01	1	1	12	22	28	22	28	21	0	3	0.87	6	2	11	7	13	12	13	5	0
5	0.52	3	1	12	24	33	2	34	121	5	3	0.16	9	2	11	23	13	7	14	10	0
3	0.05	1	1	12	3	37	3	37	72	3	1	0.83	5	2	11	21	19	1	20	133	5
1	0.22	2	1	12	7	40	8	40	75	3	3	0.62	3	2	11	20	21	22	21	42	1
3	0.03	1	1	12	15	47	15	47	174	7	3	0.19	5	2	11	19	27	23	27	140	5
5	0.82	8	1	12	23	54	6	55	175	7	4	0.05	2	2	11	7	34	8	34	151	6
4	0.04	3	1	12	13	55	15	55	6	0	5	0.07	2	2	11	7	37	8	37	70	2
3	0.02	1	1	12	20	58	20	58	76	3	5	0.10	1	2	11	8	40	8	40	71	2
3	0.59	3	1	12	3	59	5	59	6	0	2	0.17	4	2	11	4	45	7	45	115	4
5	0.48	3	1	13	6	3	8	3	99	99	1	0.30	8	2	11	21	54	4	55	229	9
3	0.21	3	1	13	10	7	12	7	97	4	5	2.80	29	2	11	1	61	5	62	140	5
3	0.21	4	1	13	20	8	23	8	31	1	5	0.38	5	2	12	12	5	16	5	99	99
3	0.03	1	1	13	15	11	15	11	63	2	5	0.01	1	2	12	14	8	14	8	69	2
3	0.09	2	1	13	19	13	20	13	51	2	3	0.08	2	2	12	14	12	15	12	95	3
1	0.02	2	1	13	12	20	13	20	159	6	3	0.15	2	2	12	15	16	16	16	95	3
3	0.12	2	1	13	23	24	24	24	105	4	3	0.34	3	2	12	1	17	3	17	8	0
2	0.05	2	1	13	19	27	20	27	66	2	1	0.17	4	2	12	14	27	17	27	250	10
1	0.18	3	1	13	20	28	22	28	23	0	5	0.31	5	2	12	22	30	2	31	76	3
4	0.16	9	1	13	3	31	11	31	52	2	2	0.15	1	2	12	5	32	5	32	26	1
4	0.03	2	1	13	20	40	21	40	224	9	1	0.04	2	2	12	20	33	21	33	38	1
1	0.32	2	1	13	1	42	2	42	27	1	3	0.37	6	2	12	2	36	7	36	52	2
5	0.02	2	1	13	11	49	12	49	176	7	3	0.85	5	2	12	22	36	2	37	14	0
3	1.53	14	1	13	12	51	1	52	47	1	1	0.22	4	2	12	5	40	8	40	74	3
1	0.10	3	1	13	18	55	20	55	88	3	2	0.05	1	2	12	12	41	12	41	27	1
4	0.01	1	1	13	21	58	21	58	72	3	4	0.01	1	2	12	24	46	24	46	131	5
1	0.86	4	1	13	22	60	1	61	48	2	3	0.64	4	2	12	4	58	7	58	267	11
3	0.07	7	1	14	23	1	5	2	99	99	3	1.05	5	2	12	23	58	3	59	15	0
3	0.34	4	1	14	17	6	20	6	107	4	5	0.74	9	2	12	2	62	10	62	70	2
1	1.30	6	1	14	22	8	3	9	49	2	5	0.08	2	2	13	10	1	11	1	99	99
3	0.06	2	1	14	2	16	3	16	166	6	5	1.15	4	2	13	23	2	2	3	35	1
3	0.01	1	1	14	23	16	23	16	19	0	5	0.37	3	2	13	2	5	4	5	47	1
3	0.82	12	1	14	16	30	3	31	328	13	3	0.23	3	2	13	6	7	8	7	49	2

Table 21. (Continued)

Eastern Region

Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
2	0.16	7	1	14	11	31	17	31	7	0
5	0.02	1	1	14	17	32	17	32	23	0
3	0.01	1	1	14	18	36	18	36	96	4
1	0.92	32	1	14	19	38	2	40	48	2
5	0.09	5	1	14	23	46	3	47	164	6
5	0.58	4	1	14	22	47	1	48	18	0
1	0.69	4	1	14	5	49	8	49	27	1
2	0.04	2	1	14	18	49	19	49	9	0
3	0.08	5	1	14	21	52	1	53	73	3
1	0.01	1	1	14	21	55	21	55	67	2
4	0.06	2	1	14	6	56	7	56	8	0
5	0.10	2	1	14	18	56	19	56	10	0
3	0.46	2	1	14	20	57	21	57	24	1
3	1.21	19	1	14	13	60	7	61	63	2
3	0.11	4	1	14	17	61	20	61	9	0
5	0.37	4	1	15	4	4	7	4	99	99
1	0.03	7	1	15	21	5	3	6	37	1
4	0.03	1	1	15	11	8	11	8	55	2
1	0.51	2	1	15	13	9	14	9	25	1
5	1.02	4	1	15	1	14	4	14	106	4
3	0.10	5	1	15	24	22	4	23	211	8
3	0.16	3	1	15	14	32	16	32	225	9
1	0.02	3	1	15	8	38	10	38	135	5
3	1.03	19	1	15	21	51	15	52	322	13
5	0.20	6	1	16	7	1	12	1	99	99
3	0.01	1	1	16	7	2	7	2	18	0
3	0.01	1	1	16	14	2	14	2	6	0
2	0.03	1	1	16	21	3	21	3	30	1
3	0.03	1	1	16	14	20	14	20	400	16
1	0.33	3	1	16	17	26	19	26	146	6
5	0.05	2	1	16	15	27	16	27	19	0
1	0.01	1	1	16	17	29	17	29	48	2
3	0.03	1	1	16	9	30	9	30	15	0
1	0.45	3	1	16	1	33	3	33	63	2
5	0.18	4	1	16	4	34	7	34	24	1
3	1.07	14	1	16	7	37	20	37	71	2
4	0.60	9	1	16	8	39	16	39	35	1
3	0.31	11	1	16	4	48	14	48	203	8
5	0.15	13	1	16	5	49	17	49	14	0
3	0.03	3	1	16	8	50	10	50	14	0
5	0.37	5	1	16	6	53	10	53	67	2
2	0.01	1	1	17	15	4	15	4	99	99
3	0.07	3	1	17	4	7	6	7	60	2
3	0.42	14	1	17	5	17	18	17	238	9
5	0.05	2	1	17	21	21	22	21	98	4
5	0.46	14	1	17	5	23	18	23	30	1
1	0.22	2	1	17	1	31	2	31	174	7
5	2.61	15	1	17	17	35	7	36	110	4
3	0.01	1	1	17	5	38	5	38	45	1
3	0.07	1	1	17	9	39	9	39	27	1
5	0.03	1	1	17	8	46	8	46	166	6
3	0.09	2	1	17	5	47	6	47	20	0
1	0.09	3	1	17	16	47	18	47	9	0
5	0.05	2	1	17	20	60	21	60	313	13
3	0.34	21	1	17	24	61	20	62	26	1
4	0.15	2	1	18	17	2	18	2	99	99
3	0.01	1	1	18	4	4	4	4	33	1
5	0.23	7	1	18	11	6	17	6	54	2
5	0.05	4	1	18	1	7	4	7	7	0
5	0.49	5	1	18	14	7	18	7	9	0
3	1.39	8	1	18	6	8	13	8	11	0
3	0.47	4	1	18	3	17	6	17	205	8
5	0.71	5	1	18	6	18	10	18	23	0
5	0.16	3	1	18	19	18	21	18	8	0
1	0.05	1	1	18	8	23	8	23	106	4
4	0.01	1	1	18	3	26	3	26	66	2
1	0.27	5	1	18	16	26	20	26	12	0
2	0.04	1	1	18	19	27	19	27	22	0
1	0.13	1	1	18	7	38	7	38	251	10
3	0.02	1	1	18	24	39	24	39	40	1
5	0.03	1	1	18	3	51	3	51	266	11
1	0.01	1	1	19	1	3	1	3	99	99
3	0.22	9	1	19	23	13	7	14	261	10
1	0.01	1	1	19	21	14	21	14	13	0

Western Region

Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.23	2	2	13	8	10	9	10	71	2
3	0.66	7	2	13	4	11	10	11	18	0
3	0.02	1	2	13	16	11	16	11	5	0
3	0.04	1	2	13	8	16	8	16	111	4
3	0.11	4	2	13	22	19	1	20	85	3
3	0.37	6	2	13	5	30	10	30	243	10
4	0.03	1	2	13	5	31	5	31	18	0
5	0.87	8	2	13	23	34	6	35	89	3
2	0.05	4	2	13	10	36	13	36	27	1
3	0.14	6	2	13	6	37	11	37	16	0
4	0.11	4	2	13	7	40	10	40	67	2
4	0.11	2	2	13	21	40	22	40	10	0
1	0.27	1	2	13	21	41	21	41	22	0
2	0.02	1	2	13	17	43	17	43	43	1
3	0.08	2	2	13	16	44	17	44	22	0
3	0.03	1	2	13	17	50	17	50	143	5
3	0.01	1	2	13	5	51	5	51	11	0
3	0.59	2	2	13	16	51	17	51	10	0
3	0.02	2	2	13	24	52	1	53	30	1
3	0.01	1	2	13	24	53	24	53	22	0
4	0.30	4	2	13	19	57	22	57	90	3
1	1.24	5	2	13	16	58	20	58	17	0
1	0.05	1	2	13	16	60	16	60	43	1
4	0.07	1	2	14	13	1	13	1	99	99
3	0.12	4	2	14	2	2	5	2	12	0
1	0.42	3	2	14	2	6	4	6	92	3
1	0.17	1	2	14	22	8	22	8	65	2
1	0.01	1	2	14	7	13	7	13	104	4
3	0.10	1	2	14	22	16	22	16	86	3
3	0.28	5	2	14	3	18	7	18	28	1
3	1.28	18	2	14	22	18	15	19	14	0
1	0.24	3	2	14	19	30	21	30	267	11
5	0.02	1	2	14	14	33	14	33	64	2
1	0.14	5	2	14	23	36	3	37	80	3
1	0.10	3	2	14	19	37	21	37	15	0
1	0.01	1	2	14	3	38	3	38	5	0
1	0.14	2	2	14	16	38	17	38	12	0
5	0.03	1	2	14	17	47	17	47	215	8
1	0.06	3	2	14	24	48	2	49	30	1
3	0.34	4	2	14	6	52	9	52	75	3
3	0.13	2	2	14	10	55	11	55	72	3
3	0.06	4	2	14	8	60	11	60	116	4
3	0.99	7	2	14	23	60	5	61	11	0
2	0.02	1	2	15	7	5	7	5	99	99
4	0.31	4	2	15	5	8	8	8	69	2
5	0.03	1	2	15	10	13	10	13	121	5
3	0.07	1	2	15	11	14	11	14	24	1
1	0.02	1	2	15	9	22	9	22	189	7
1	0.02	1	2	15	15	22	15	22	5	0
3	0.48	5	2	15	10	26	14	26	90	3
1	0.03	1	2	15	2	28	2	28	35	1
5	0.05	2	2	15	9	29	10	29	30	1
1	0.10	1	2	15	7	32	7	32	68	2
3	0.09	1	2	15	21	35	21	35	85	3
5	0.26	5	2	15	19	37	23	37	45	1
1	0.04	4	2	15	18	38	21	38	18	0
3	0.13	5	2	15	23	43	3	44	121	5
1	0.30	6	2	15	18	48	23	48	110	4
3	0.06	1	2	15	12	51	12	51	60	2
3	0.07	2	2	15	17	51	18	51	4	0
3	0.14	1	2	15	24	51	24	51	5	0
1	0.12	1	2	16	10	8	10	8	99	99
3	0.18	4	2	16	20	9	23	9	33	1
3	0.02	1	2	16	13	21	13	21	277	11
2	0.03	1	2	16	20	35	20	35	342	14
2	0.06	1	2	16	2	36	2	36	5	0
3	0.05	2	2	16	2	37	3	37	23	0
3	0.06	4	2	16	2	39	5	39	46	1
3	0.01	1	2	16	4	48	4	48	214	8
1	0.14	5	2	16	3	57	7	57	214	8
1	0.02	1	2	16	8	60	8	60	72	3
3	0.11	5	2	17	2	16	6	16	99	99
3	0.85	4	2	17	23	16	2	17	16	0
2	0.04	1	2	17	10	20	10	20	79	3

Table 21. (Continued)

Eastern Region											Western Region										
Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days	Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.03	1	1	19	6	17	6	17	56	2	3	0.14	6	2	17	24	28	5	29	205	8
3	0.28	5	1	19	6	18	10	18	23	0	4	0.29	6	2	17	18	29	23	29	12	0
3	0.05	4	1	19	1	19	4	19	14	0	1	0.03	1	2	17	19	30	19	30	19	0
3	0.20	3	1	19	20	27	22	27	207	8	5	0.13	1	2	17	7	35	7	35	107	4
3	1.29	27	1	19	2	29	4	30	27	1	3	0.06	2	2	17	8	38	9	38	72	3
1	0.69	3	1	19	16	31	18	31	35	1	3	0.32	9	2	17	1	39	9	39	15	0
2	0.02	1	1	19	7	34	7	34	60	2	1	0.04	2	2	17	19	40	20	40	33	1
3	0.05	2	1	19	6	35	7	35	22	0	5	0.02	1	2	17	7	46	7	46	130	5
3	0.01	1	1	19	11	37	11	37	51	2	4	0.30	5	2	17	6	49	10	49	70	2
3	0.01	1	1	19	8	38	8	38	20	0	4	0.20	4	2	17	18	49	21	49	7	0
3	1.48	20	1	19	20	38	15	39	11	0	1	0.10	4	2	17	16	54	19	54	114	4
1	0.06	1	1	20	10	4	10	4	99	99	5	0.44	11	2	17	12	57	22	57	64	2
1	0.12	1	1	20	3	8	3	8	88	3	5	0.17	7	2	17	22	60	4	61	71	2
3	0.50	7	1	20	14	10	20	10	58	2	3	0.03	2	2	17	17	61	18	61	12	0
5	0.02	1	1	20	11	12	11	12	38	1	5	0.15	4	2	18	6	6	9	6	99	99
1	0.75	3	1	20	21	12	23	12	9	0	5	0.45	4	2	18	8	7	11	7	22	0
1	0.30	4	1	20	17	18	20	18	137	5	3	0.04	1	2	18	4	8	4	8	16	0
2	0.01	1	1	20	16	20	16	20	43	1	3	0.86	9	2	18	22	8	6	9	17	0
1	0.01	1	1	20	7	22	7	22	38	1	3	0.14	2	2	18	1	16	2	16	162	6
5	0.06	8	1	20	24	22	7	23	16	0	3	0.61	8	2	18	4	17	11	17	25	1
1	0.12	4	1	20	17	25	20	25	57	2	2	0.14	2	2	18	7	25	8	25	187	7
1	0.03	5	1	20	1	32	5	32	148	6	1	0.13	4	2	18	15	26	18	26	30	1
1	0.16	11	1	20	23	32	9	33	17	0	3	0.06	2	2	18	15	30	16	30	92	3
2	0.01	1	1	20	2	41	2	41	184	7	3	0.09	2	2	18	10	35	11	35	113	4
1	0.12	2	1	20	13	41	14	41	10	0	1	0.32	9	2	18	20	37	4	38	56	2
1	0.37	4	1	20	2	45	5	45	83	3	5	0.36	4	2	18	21	39	24	39	40	1
1	0.01	1	1	20	8	50	8	50	122	5	5	0.94	7	2	18	4	51	10	51	267	11
5	0.22	2	1	20	6	54	7	54	93	3	5	1.52	16	2	18	18	61	9	62	247	10
3	0.02	1	1	21	19	6	19	6	99	99	5	0.02	2	2	18	14	62	15	62	4	0
3	0.92	6	1	21	21	8	2	9	49	2	3	0.02	1	2	19	5	1	5	1	99	99
4	0.12	1	1	21	16	10	16	10	37	1	1	0.01	1	2	19	2	2	2	2	20	0
1	0.34	6	1	21	4	12	9	12	35	1	1	0.04	1	2	19	3	3	3	3	24	1
1	0.16	2	1	21	17	12	18	12	7	0	2	0.01	1	2	19	15	13	15	13	251	10
1	0.13	4	1	21	4	13	7	13	9	0	1	0.30	2	2	19	18	14	19	14	26	1
1	0.02	1	1	21	10	14	10	14	26	1	3	0.15	4	2	19	4	18	7	18	80	3
1	0.48	5	1	21	19	14	23	14	8	0	1	0.05	5	2	19	20	18	24	18	12	0
3	1.70	11	1	21	7	17	17	17	55	2	2	0.14	4	2	19	23	25	2	26	166	6
4	0.09	4	1	21	12	19	15	19	42	1	1	0.01	1	2	19	7	27	7	27	28	1
1	0.11	4	1	21	6	23	9	23	86	3	3	0.04	1	2	19	8	29	8	29	48	2
5	0.36	5	1	21	4	24	8	24	18	0	5	0.01	1	2	19	3	33	3	33	90	3
3	0.88	9	1	21	4	26	12	26	43	1	1	0.65	4	2	19	20	33	23	33	16	0
3	2.93	23	1	21	3	32	1	33	134	5	3	0.05	4	2	19	2	35	5	35	26	1
5	0.02	1	1	21	13	34	13	34	35	1	5	0.10	4	2	19	4	48	7	48	310	12
3	0.91	10	1	21	16	36	1	37	50	2	3	0.10	2	2	19	16	48	17	48	8	0
1	0.02	1	1	21	1	39	1	39	47	1	3	0.23	5	2	19	17	52	21	52	95	3
3	0.52	11	1	21	2	42	12	42	72	3	3	0.21	2	2	20	12	3	13	3	99	99
5	0.06	1	1	21	1	43	1	43	12	0	1	0.10	1	2	20	3	5	3	5	37	1
5	0.02	1	1	21	13	43	13	43	11	0	1	0.49	7	2	20	20	7	2	8	64	2
5	0.15	2	1	21	15	50	16	50	169	7	1	0.19	2	2	20	6	9	7	9	27	1
3	0.69	20	1	21	1	56	20	56	128	5	5	0.66	3	2	20	4	10	6	10	20	0
3	0.01	1	1	21	4	57	4	57	7	0	1	0.02	1	2	20	23	17	23	17	184	7
1	0.02	1	1	21	22	62	22	62	137	5	3	0.01	1	2	20	8	22	8	22	104	4
3	0.02	1	1	22	13	1	13	1	99	99	5	0.13	5	2	20	21	22	1	23	12	0
5	0.14	1	1	22	7	3	7	3	41	1	1	0.09	4	2	20	15	27	18	27	109	4
1	0.48	10	1	22	20	3	5	4	12	0	5	0.09	4	2	20	7	34	10	34	156	6
5	0.02	1	1	22	9	9	9	9	123	5	3	0.05	2	2	20	5	35	6	35	18	0
5	0.03	1	1	22	21	9	21	9	11	0	3	0.02	1	2	20	9	43	9	43	194	8
5	0.19	1	1	22	18	19	18	19	236	9	1	0.35	5	2	20	1	50	5	50	159	6
3	0.10	11	1	22	6	20	16	20	11	0	5	0.01	1	2	20	4	62	4	62	286	11
3	0.04	3	1	22	3	21	5	21	10	0	5	0.01	1	2	20	12	62	12	62	7	0
3	0.02	1	1	22	21	21	21	21	15	0	3	0.12	3	2	21	18	1	20	1	99	99
2	0.03	4	1	22	12	26	15	26	110	4	3	0.58	6	2	21	6	6	11	6	105	4
3	0.07	2	1	22	17	29	18	29	73	3	3	0.26	3	2	21	18	6	20	6	6	0
2	0.02	1	1	22	7	30	7	30	12	0	4	0.24	4	2	21	16	10	19	10	91	3
3	0.15	4	1	22	7	35	10	35	119	4	3	0.68	5	2	21	11	11	15	11	15	0
1	0.14	2	1	22	3	40	4	40	112	4	1	0.07	2	2	21	7	12	8	12	15	0
3	0.37	7	1	22	14	44	20	44	105	4	1	0.40	2	2	21	5	14	6	14	44	1
3	0.03	1	1	22	14	52	14	52	185	7	1	0.02	1	2	21	17	14	17	14	10	0
3	0.38	12	1	22	24	53	11	54	33	1	3	0.42	11	2	21	3	17	13	17	57	2
3	0.03	8	1	22	9	62	16	62	189	7	5	0.03	1	2	21	1	24	1	24	155	6
4	0.01	1	1	23	1	2	1	2	99	99	3	2.20	6	2	21	23	25	4	26	45	1
1	0.09	5	1	23	16	3	20	3	38	1	3	0.09	2	2	21	2	32	3	32	141	5
1	1.01	6	1	23	15	10	20	10	162	6	3	0.11	2	2	21	8	32	9	32	4	0
1	0.09	2	1	23	4	11	5	11	7	0	3	0.23	3	2	21	18	32	20	32	8	0

Table 21. (Continued)

Eastern Region

Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.32	7	1	23	1	19	7	19	187	7
3	0.46	3	1	23	21	21	23	21	61	2
3	0.33	6	1	23	2	32	7	32	242	10
3	0.06	4	1	23	14	32	17	32	6	0
3	0.06	4	1	23	15	33	18	33	21	0
3	0.03	7	1	23	11	34	17	34	16	0
3	0.45	12	1	23	1	41	12	41	151	6
1	0.10	1	1	23	23	41	23	41	10	0
1	0.64	14	1	23	6	43	19	43	30	1
3	0.25	2	1	23	11	47	12	47	87	3
2	0.03	4	1	23	3	51	6	51	86	3
1	0.55	9	1	23	18	52	2	53	35	1
1	0.30	6	1	23	22	57	3	58	115	4
5	0.03	1	1	23	21	61	21	61	89	3
5	0.03	2	1	24	21	3	22	3	99	99
5	0.79	8	1	24	3	5	10	5	28	1
3	0.04	4	1	24	2	6	5	6	15	0
3	0.04	1	1	24	20	9	20	9	86	3
3	0.41	3	1	24	6	23	8	23	321	13
1	0.06	3	1	24	17	23	19	23	8	0
1	0.27	10	1	24	3	40	12	40	391	16
1	0.02	1	1	24	3	41	3	41	14	0
5	0.21	3	1	24	11	42	13	42	31	1
5	0.01	1	1	24	24	42	24	42	10	0
1	0.13	9	1	24	20	43	4	44	19	0
2	0.05	3	1	24	14	47	16	47	81	3
5	0.23	4	1	24	8	50	11	50	63	2
1	0.15	5	1	24	5	53	9	53	65	2
4	0.50	4	1	24	17	53	20	53	7	0
4	0.01	1	1	24	8	54	8	54	11	0
1	0.02	1	1	24	12	55	12	55	27	1
1	0.49	7	1	24	23	55	5	56	10	0
4	0.03	1	1	24	4	59	4	59	70	2
5	0.60	18	1	24	18	59	11	60	13	0
3	0.06	2	1	24	19	60	20	60	7	0
6	0.02	6	1	25	2	7	7	7	99	99
3	0.22	4	1	25	8	15	11	15	192	8
3	0.04	5	1	25	7	19	11	19	91	3
3	0.01	1	1	25	9	20	9	20	21	0
1	0.43	3	1	25	20	20	22	20	10	0
5	0.02	1	1	25	18	26	18	26	139	5
3	1.55	6	1	25	3	28	8	28	32	1
3	0.08	3	1	25	1	36	3	36	184	7
5	0.16	5	1	25	18	42	22	42	158	6
5	0.28	6	1	25	19	44	24	44	44	1
4	0.13	8	1	25	1	48	8	48	72	3
4	0.02	3	1	25	7	49	9	49	22	0
3	0.16	2	1	25	14	56	15	56	172	7
3	0.31	3	1	25	16	57	18	57	24	1
1	0.27	3	1	25	23	58	1	59	28	1
1	0.03	1	1	25	22	59	22	59	20	0

Western Region

Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.10	1	2	21	5	37	5	37	104	4
1	0.56	2	2	21	22	38	23	38	40	1
2	0.02	1	2	21	7	39	7	39	7	0
3	0.05	1	2	21	1	42	1	42	65	2
1	0.18	2	2	21	24	51	1	52	238	9
3	0.01	1	2	21	17	53	17	53	39	1
3	0.08	2	2	21	8	54	9	54	14	0
3	0.79	6	2	21	1	56	6	56	39	1
3	0.09	2	2	21	16	61	17	61	129	5
3	0.11	1	2	21	22	61	22	61	4	0
3	1.17	2	2	22	23	1	24	1	99	99
5	0.54	2	2	22	3	3	4	3	26	1
1	0.36	1	2	22	23	3	23	3	18	0
5	0.20	4	2	22	6	9	9	9	126	5
5	0.47	4	2	22	17	9	20	9	7	0
3	0.04	2	2	22	2	18	3	18	197	8
1	0.12	3	2	22	24	18	2	19	20	0
3	0.55	9	2	22	3	20	11	20	24	1
3	0.01	1	2	22	16	20	16	20	4	0
3	0.42	7	2	22	2	21	8	21	9	0
1	0.60	5	2	22	4	24	8	24	67	2
5	0.13	2	2	22	24	28	1	29	111	4
3	1.24	8	2	22	12	29	19	29	10	0
5	0.05	1	2	22	4	39	4	39	224	9
5	0.73	7	2	22	15	39	21	39	10	0
3	0.03	1	2	22	10	42	10	42	60	2
5	0.03	2	2	22	8	44	9	44	45	1
2	0.08	1	2	22	19	47	19	47	81	3
3	0.03	1	2	22	22	53	22	53	146	6
1	0.03	2	2	22	6	61	7	61	175	7
3	0.02	1	2	22	4	62	4	62	20	0
3	0.05	3	2	22	14	62	16	62	9	0
1	0.14	4	2	23	3	3	6	3	99	99
2	0.02	1	2	23	1	10	1	10	162	6
2	0.04	1	2	23	12	10	12	10	10	0
1	0.19	6	2	23	20	10	1	11	7	0
1	0.06	2	2	23	5	25	6	25	339	14
3	0.02	1	2	23	16	27	16	27	57	2
4	0.04	4	2	23	7	31	10	31	86	3
3	0.27	12	2	23	21	31	8	32	10	0
3	0.42	3	2	23	17	39	19	39	176	7
3	0.50	9	2	23	6	40	14	40	10	0
3	0.34	3	2	23	19	40	21	40	4	0
1	0.11	3	2	23	3	41	5	41	5	0
5	0.93	8	2	23	9	44	16	44	75	3
5	0.03	1	2	23	16	45	16	45	23	0
1	0.34	3	2	23	8	46	10	46	15	0
3	0.36	2	2	23	6	47	7	47	19	0
3	0.38	4	2	23	10	48	13	48	26	1
1	0.04	1	2	23	7	52	7	52	89	3
2	0.13	1	2	23	12	54	12	54	52	2
1	0.21	6	2	23	23	57	4	58	82	3
3	0.02	1	2	24	18	5	18	5	99	99
3	0.10	3	2	24	2	19	4	19	319	13
3	0.47	4	2	24	24	22	3	23	91	3
1	0.01	1	2	24	21	23	21	23	17	0
1	0.36	3	2	24	17	32	19	32	211	8
1	0.19	2	2	24	2	41	3	41	198	8
5	0.03	1	2	24	8	42	8	42	28	1
1	0.23	7	2	24	19	43	1	44	34	1
3	0.02	1	2	24	5	46	5	46	51	2
2	0.07	1	2	24	4	47	4	47	22	0
5	0.93	7	2	24	1	49	7	49	44	1
2	0.04	1	2	24	3	55	3	55	139	5
1	0.12	1	2	24	20	55	20	55	16	0
5	0.02	1	2	24	2	58	2	58	53	2
5	0.10	2	2	24	8	58	9	58	5	0
3	0.04	4	2	24	9	59	12	59	23	0
5	0.60	4	2	24	24	59	3	60	11	0
1	0.04	1	2	25	14	14	14	14	99	99
1	0.18	2	2	25	15	20	16	20	144	6
3	0.28	3	2	25	4	26	6	26	131	5
5	0.02	1	2	25	7	27	7	27	24	1
3	0.02	2	2	25	14	27	15	27	6	0

Table 21. (Continued)

Western Region

Type	Depth	Dur	Reg	Yr	TB	DB	TE	DE	Hrs	Days
3	0.32	5	2	25	24	27	4	28	8	0
3	0.07	2	2	25	23	29	24	29	42	1
5	0.11	2	2	25	5	30	6	30	4	0
5	0.25	3	2	25	3	45	5	45	356	14
5	0.01	1	2	25	15	45	15	45	9	0