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Climate of Minnesota

Part V. Precipitation Facts, Normals, and Extremes

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The thirsty earth soaks up the rain,
And drinks, and gapes for drink again;
The plants suck in the earth, and are
With constant drinking fresh and fair.
Anacreon, *Odes* No. 21. (Cowley, tr.)

Earlier publications in this series dealt with air and soil temperatures. This publication begins another climatic topic—water. Although the emphasis is upon precipitation falling within Minnesota, the types, sources, measurement, and process of precipitation are briefly described.

Earth, air, fire, and water were considered by the ancients as the essential constituents from which all life was derived. They were not far wrong. From the earth or soil come most of the elements necessary for plant and animal life. The air provides carbon dioxide which, together with water, forms the building blocks of plant materials. It also provides oxygen for animal life. And it serves as a vast reservoir of both water—in the form of vapor—and nitrogen. Fire or solar energy provides energy for the biochemical and physical processes occurring on earth including the evaporation of water from the earth's surface.

Finally, water, the universal solvent, is the largest single constituent of almost every living organism. The importance of natural precipitation cannot be overemphasized. For some time to come, we shall be limited to naturally occurring precipitation to satisfy our water requirements. Supplementary sources cannot fulfill our future or even some of our present needs.

By international agreement, for example, water cannot be removed from the Great Lakes drainage basin which includes a portion of northeastern Minnesota. In some cases, particularly in western Minnesota, water from other surface and underground sources is limited in both quantity and quality. Cloud seeding, popularly known as rainmaking, is not yet effective in regions of relatively level topography such as Minnesota.

Our water supply depends essentially upon the precipitation falling from the moist air masses that travel the long path from an oceanic source.

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The authors wish to acknowledge the valuable service rendered by the many volunteer cooperative weather observers who regularly record necessary measurements.

> *There is a sumptuous variety about the [Minnesota] weather that compels the stranger's admiration—and regret. The weather is always doing something there . . . In the spring I have counted one hundred and thirty-six different kinds of weather inside of twenty-four hours.*
>
> Mark Twain, *New England Weather*

Types of Precipitation

Although rain is the most common form of precipitation in Minnesota, it is not the only form. Moisture, whether liquid or frozen, reaches the earth's surface in a variety of ways. But precipitation is distinguished from other hydrometeors such as fog, dew, or frost because it must fall. And it is distinguished from clouds and virga because it must reach the ground (figure 1). The different types of precipitation, as defined by the American Meteorological Society (8)*, are:

Drizzle—liquid drops less than 0.5 millimeter (mm.) (about 0.02 inch) in diameter. An accumulation of precipitation at the rate of less than 0.04 inch per hour is ordinarily drizzle. Drizzle drops are so fine that they frequently seem to hang in the air without falling. Laymen often use the term "mist" to describe drizzle.

Rain—liquid drops equal to or exceeding 0.5 mm. in diameter. The word rainfall is sometimes used interchangeably with the preferred word precipitation. But precipitation refers to all water, regardless of form, that falls on the earth's surface.

Hail—frozen precipitation forming irregular lumps or balls of ice 5 mm. (0.2 inch) or more in diameter. Hail is always produced by convective clouds.

Ice Pellets—translucent or transparent ice which may be spherical, irregular, or even conical in shape. They are 5 mm. or less in diameter. Ice pellets are usually hard enough to bounce upon impact with a surface and make a sound. Basically the two types of pellets are:

1. **Sleet or Ice Grains**—ice which forms from either frozen raindrops or the refreezing of partly melted snowflakes. The grains generally are transparent and spherical.
2. **Small Hail**—generally snow pellets surrounded by a thin ice layer. The hail is usually translucent. The ice layer forms due to the freezing of waterdrops on the surface or the partial melting and refreezing of the pellet surface.

Snow Pellets—white, opaque, rounded ice particles that are about 2-5 mm. (0.07-0.2 inch) in diameter. The pellets, also known as soft hail, graupel, and tapioca snow, are formed from falling ice crystals to which supercooled water droplets adhered.

Ice Crystals—unbranched ice particles that fall slowly and sometimes appear to float in the air due to their small size. Clouds may or may not be present when they occur. These small crystals do not reduce visibility appreciably and are visible only in direct sunlight or in an artificial beam of light.

Snow—white or translucent ice crystals formed into a complex, branched, hexagonal shape. This form of precipitation usually occurs with below freezing temperatures; it is the solid equivalent of rain.

Snow Grains—very small, white, opaque particles of ice that are the solid equivalent of drizzle.

Dew—not a true form of precipitation. It is formed when atmospheric water vapor condenses upon a surface which has a temperature below the dew point of air.

Frost—the frozen equivalent of dew.

In this region, rain and snow are the most important precipitation types from the standpoint of both economics and quantity. The localized destruction or damage by hail occasionally causes it to be of economic importance also.

Figure 1. Precipitation that evaporates into the atmosphere before reaching the earth's surface is termed virga. This photo is of virga over a mountain meadow in Colorado. (Collection of the authors)

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* Numbers in parentheses refer to the literature citations on page 44.

Men judge by the complexion of the sky
The state and inclination of the day.
William Shakespeare, *King Richard II*

The Precipitation Process

Almost all precipitation results from the lifting and cooling of air. The type of air—its origin, temperature, and water content—and the method of lifting and cooling determine the amount and type of precipitation produced. Over Minnesota, precipitation generally results from one of two types of synoptic[1] conditions: (1) a mixing and convergence of air in frontal areas or (2) convective activity[2] within an unstable air mass due to strong surface heating by the sun.

In both cases, air near the earth's surface lifts, expands, and cools sufficiently so that both condensation[3] and precipitation occur. In the frontal precipitation situation, mechanical lifting of air is caused by a wedge of cold air forcing the warmer air aloft. In the air mass situation, heating decreases the air's density and causes the air to rise.

The first situation usually occurs when two air masses of different origin and properties meet. The interface or contact zone between the two air masses is termed a front. If the warmer air mass replaces the cooler one, the contact zone between the two air masses is termed a warm front (figure 2). When cooler air replaces warmer air, the boundary or contact zone is called a cold front. In both cases the warmer air, by virtue of its lower density, is forced up and over the colder and, therefore, heavier air. This lifting of the warm air generally causes moisture condensation and, therefore, clouds. Precipitation occurs in addition to condensation if certain other conditions are met.

The relationship between clouds and a frontal system is portrayed strikingly in figure 3. The top picture shows a series (mosaic) of TIROS weather satellite photos that cover a region from the mid-Pacific to the Great Lakes. This mosaic was corrected for distortion of the camera viewing angle. When a synoptic weather map was superimposed upon the corrected cloud mosaic, the composite shown in the lower picture resulted. In this figure, H = center of high pressure area, L = center of low pressure area, and Cu = cumulus cloud. The ratios, 8/10 for example, indicate the total cloud cover in 10ths. The numbers, 1032 for example, indicate the sea level atmospheric pressure in millibars.

In general, the cloud cover in figure 3 correlates well with the pressure system. The situation represents a classical model of a polar frontal system (7) with its series of cyclones. Areas to the east of the 984 millibar low and to the southeast of the 1004 millibar low have cloud cover in association with relatively mature wave cyclones. Dense overcast (10/10 cloud cover) marks the connecting and trailing fronts associated with them. In all these areas, precipitation is likely.

To the ground observer, the approach of the warm frontal system is often heralded by high cirrus clouds with hooks or strands (figure 4). Progressively invading the sky, these clouds generally become denser as a whole and indicate that the warm, moist air mass is beginning to override and replace the denser, colder air. If this situation is the beginning of classical frontal precipitation, the cirrus with strands will be replaced by a sheet of high and thin cirrostratus (figure 5). Because

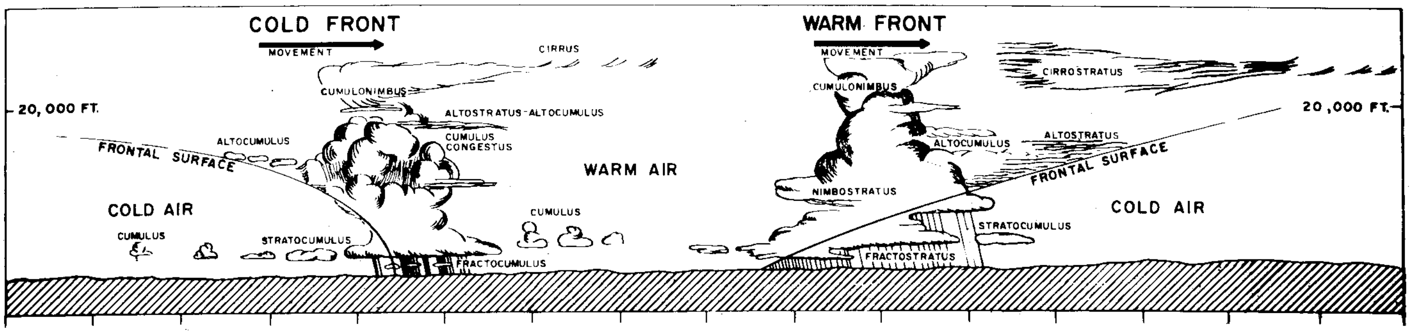

Figure 2. A cross section of a classical frontal system showing the types of clouds associated with it. The vertical, short tic marks at the bottom represent distances of about 100 miles. The vertical scale is greatly exaggerated.

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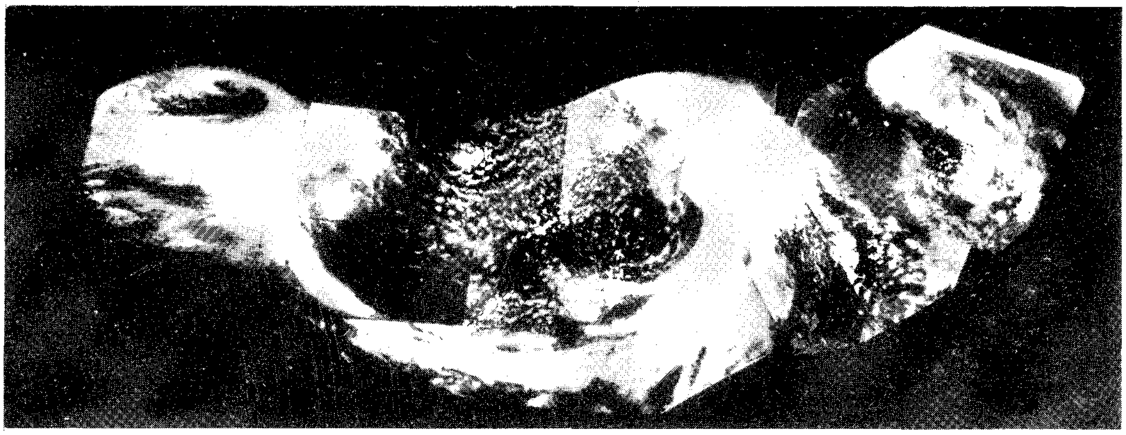
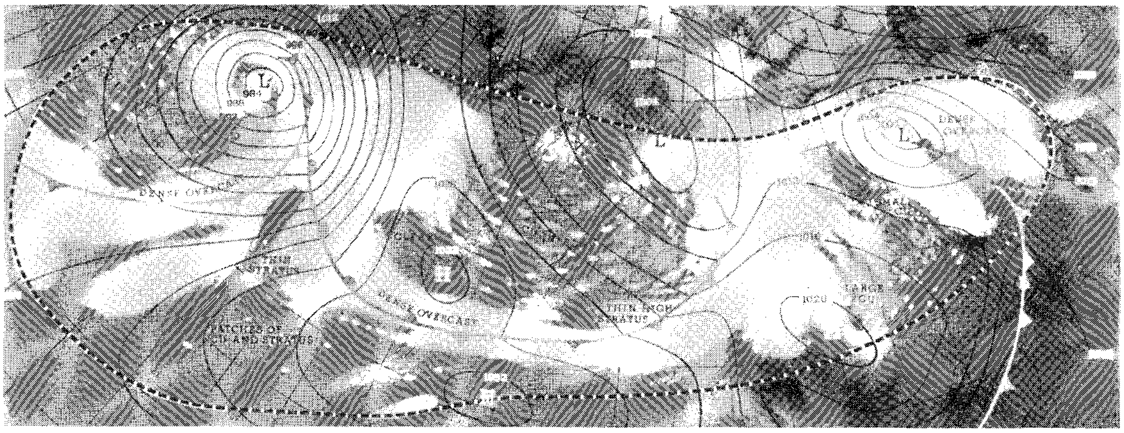
[1] Synoptic means a general view. In meteorology, it refers to the general meteorological situation at a particular moment in time.

[2] Convection refers to air movement due to temperature and, therefore, density differences. Convection in meteorology denotes vertical overturnings in unstable air masses (8).

[3] Condensation is merely an initial step leading to precipitation—a complicated and not entirely understood process. For rain, precipitation involves increasing growth of the waterdrop around a hygroscopic nucleus until the drop can no longer remain suspended but must precipitate from the atmosphere.

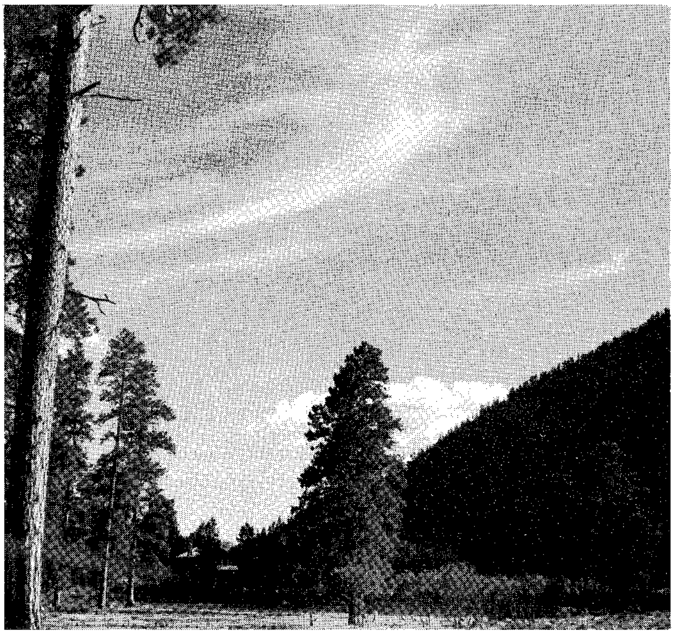


MOSAIC OF TIROS PHOTOGRAPHS



WEATHER MAP, MAY 20, 1960, WITH TIROS CLOUD DATA

Figure 3. A mosaic (top) of cloud photographs viewed by the weather satellite TIROS I. The photos were superimposed (bottom) on a weather analysis map of the North Pacific Ocean and North America. The west coast of North America is in the center and extends from the top to the bottom of the photo. (Courtesy of Environmental Science Services Administration)



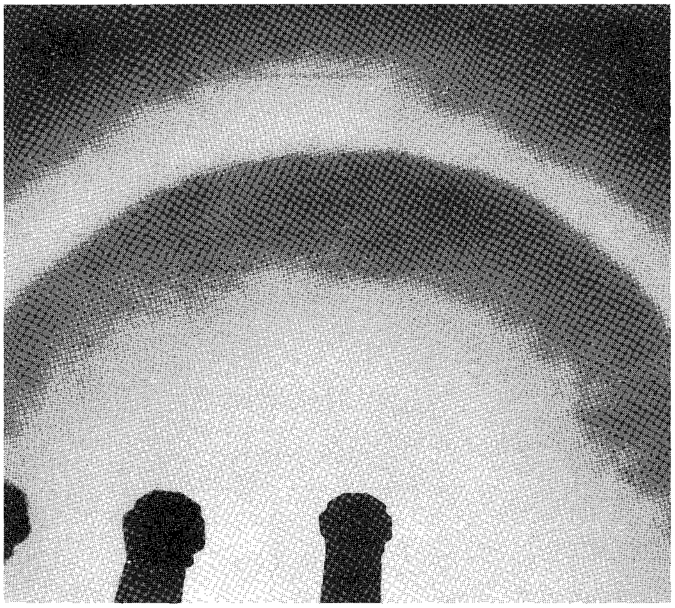


Figure 4 (top). An example of cirrus in the form of hooks and strands. Cumulus is also evident in the lower center. (Collection of the authors)

Figure 5 (bottom). A sheet of high thin cirrostratus. A halo surrounding the sun or moon often results from these ice crystal clouds. (Courtesy of Royal Meteorological Society, London)

Figure 6 (top). Altostratus with a "water" sun. Fragments of another deck of altostratus appear at a lower level. (Courtesy of Royal Meteorological Society, London)

Figure 7 (bottom). Nimbostratus increasing. Nimbostratus is gray colored and frequently dark. It is often rendered diffuse by more or less continuously falling precipitation of ordinary varieties but is not accompanied by lightning, thunder, or hail. (Collection of the authors)

cirrostratus are thin clouds, the sun or moon is visible. And since they are ice crystal rather than water vapor clouds, a visible halo may surround the sun or moon.

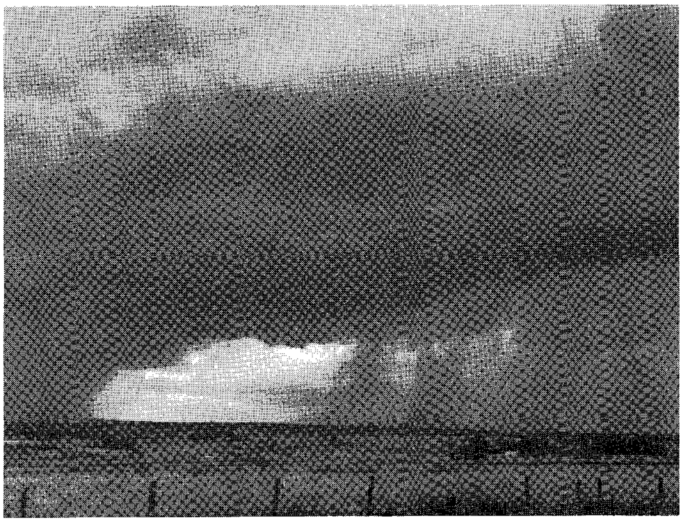
Next to appear is the middle cloud altostratus which is mainly semitransparent. As shown in figure 6, the sun or moon soon may be only weakly visible as if seen through ground glass. In turn, thick altostratus or nimbostratus occurs, the greater part of which is sufficiently dense to hide the sun or moon (figure 7). Light rain, drizzle, or snow often begins with the appearance of this cloud form. As the front nears, and if it is a fairly severe system, low clouds, usually stratus fractus or cumulus fractus of bad weather, move in below the altostratus and nimbostratus. Rain or snow increases in intensity. Fog may even form and the situation continues until the front passes.

Compared to the warm front, the typical cold front has a steeper slope and greater speed, thereby resulting in more rapid lifting (figure 2). So more intense precipitation of shorter duration is associated with the cold front, the leading edge of which is shown in figure 8. Its passage is not unlike the convective process described below.

The second synoptic situation leading to precipitation is convective activity. Due to strong solar heating, air near the ground becomes less dense than air above it. It becomes buoyant and begins to rise. The upward movement into regions of decreased pressure permits the rising air to expand. This expansion is accompanied by a fall in temperature. The cooling of the air causes the water vapor to condense and clouds to form. Because of the strong heating requirement, convective type precipitation takes place almost exclusively in the warm part of the year. The most intense precipitation and the most severe storms ordinarily occur due to a combination of both convective and frontal activities.

Although the convective precipitation process ordinarily occurs within the warm, moist air mass, it may happen at or near the cold front and, thus, be intensified. Cumulus clouds with little vertical development typically appear about midmorning (figure 9). By early afternoon, these fair weather cumuli show strong vertical development in the form of domes or towers (figure 10). As such, they are termed cumulus congestus. They may be accompanied by other cumulus clouds with their bases at about the same level.

By late afternoon the towering cumulus, aided by strong solar heating of the earth's surface, is above the freezing level and displays an upper section which is cirriform. This upper section frequently is in the form of an anvil. This final stage is the cumulonimbus or thunderhead that produces a heavy, showery type of precipitation (figure 11). Hail and even tornadoes may occur with the most intense thunderstorms. The tremendous convective activity in the cumulonimbus clouds produces the mamma (mammatus), the protuberances hanging on the underside of the cumulonimbus (figure 12).



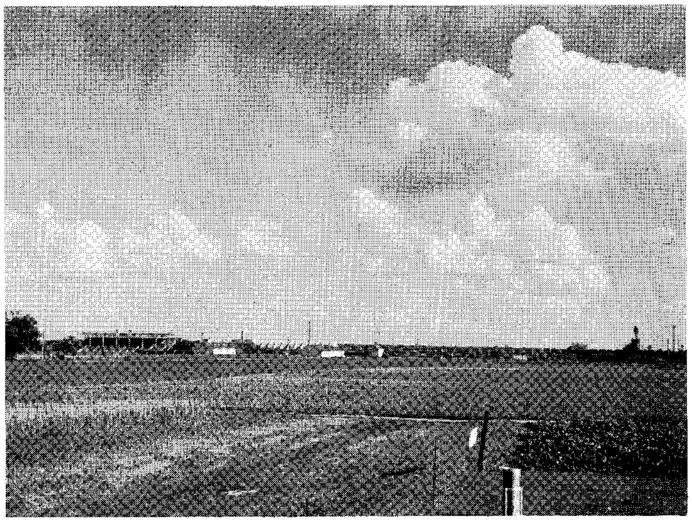


Figure 8 (left). The approach of a cold front. A heavy rain shower is seen at the far left in connection with a well developed thunderstorm cell. Lighter rain showers are falling, center and right, beneath a developing cumulonimbus cloud. (Collection of the authors)

Figure 9 (right). Cumulus with little vertical extent, sometimes called cumulus of fair weather. (Collection of the authors)

Figure 10. A towering cumulus cloud in the form of domes. It is accompanied by other cumulus at the same base level and dense cirrus at a much higher level. To its right, this same type of cloud is changing to the cumulonimbus (thunderhead) stage. (Collection of the authors)

Figure 11. A cumulonimbus with the typical anvil top. The upper portion is clearly fibrous (cirriform). Light precipitation or virga is beginning to fall from the lower right section of the cloud. (Collection of the authors)

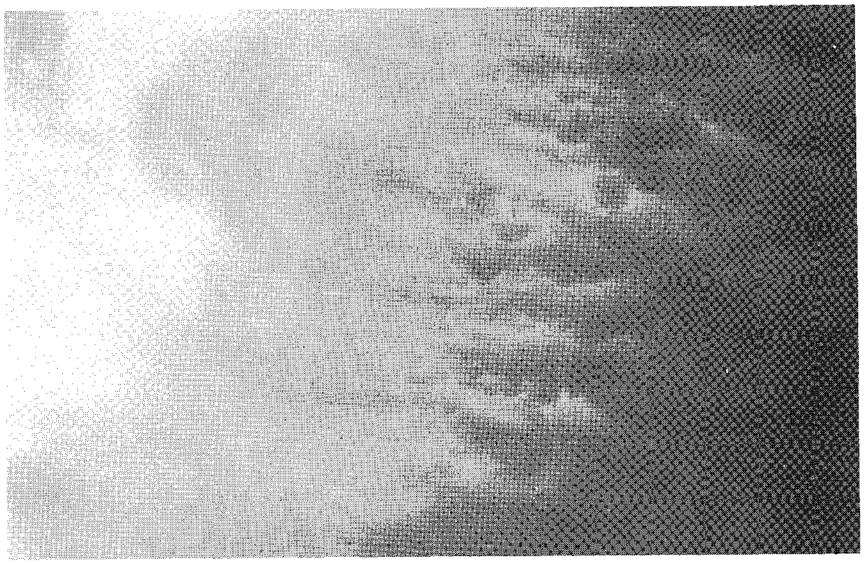


Figure 12. Cumulus mammatus at the base of the leading edge of a cumulonimbus. The photograph was taken with the camera directed overhead. (Collection of the authors)

The ceaseless rain is falling fast,
And yonder gilded vane,
Immovable for three days past,
Points to the misty main.
Henry Wadsworth Longfellow, *Travels by the Fireside*

Measurement of Precipitation

Precipitation measurements were made in India as early as the 4th century B.C.; the rain gage probably was used in Korea in the 15th century (12). The earliest continuous record in England commenced in 1727. The Charleston, S.C., station, the oldest in the United States, began its observations in 1738 but there are breaks in this record for the Revolutionary War and the War of 1812 (17).

Early in American history, the Surgeon General's Office of the U.S. Army became responsible for determining the climate of the then unknown interior of the continent. As a result, the earliest precipitation record in Minnesota was at Fort Snelling. It was begun in July 1836. As part of a similar assignment, the temperature record at Fort Snelling was begun even earlier, in October 1819. This fort is located at the confluence of the Mississippi and Minnesota Rivers near the present sites of St. Paul and Minneapolis.

Thanks to two men who continued the observations, Dr. C. L. Anderson in Minneapolis in 1856-58 and Rev. A. B. Patterson in St. Paul in 1859-70, there is no break in the record between the end of the Fort Snelling record (December 1855) and the start of the Signal Corps (later the Weather Bureau) record in January 1871 (10). Therefore, a continuous record is obtained by piecing together the several series of observations. However, the record is not ideal because it is not for a single site.

Today, Minnesota has 184 precipitation stations whose data are regularly processed and published (18). If these stations were equally distributed about the state, which they are not, there would be only one station for each 292,410 acres, certainly an inadequate distribution considering the variability of precipitation. A much more comprehensive and accurate picture of precipitation distribution would be possible with a denser measurement network than the present one.

For example, figures 13-15 show the precipitation catch on an annual, monthly, and daily basis centered around the Twin Cities metropolitan area in 1965. This area measures about 3,072,000 acres or 4,800 square miles. Such detailed analysis would have been impossible without the extremely high concentration of stations—a total of 28. This concentration is equivalent to one station per 109,700 acres or about 0.6 station per 100 square miles.

The distribution of Minnesota stations with 30-year normal records is even lower, only 64 such stations out of the 184 total. If perfectly distributed, there would be only one station per 840,700 acres. A comparison of the Minnesota distribution of total stations and 30-year normal record stations with other states and countries is shown in figure 16.

The rain gage most frequently used at these stations is a funnel-like receiver containing a cylindrical receptacle. The receiver is 8 inches in diameter; the receptacle in which water is stored is 2.53 inches in diameter. So the area of the receiver is 10 times greater than that of the receptacle (9). As a result of this 10-factor difference, 1 inch of rain falling into the receiver rises to a height of 10 inches in the receptacle. Since the depth of the water in the receptacle is what is measured, this "magnification" of depth permits measurements to the nearest 0.01 inch. Precipitation less than 0.005 inch is termed a trace.

The gage is modified in winter months to facilitate the entrance of snow into the receptacle. Two important snow measurements are made: snow depth and water content. The insulating value of snow is directly related to both depth and density. And water content is of consequence to the hydrologist; for example, he uses it when estimating the spring runoff.

As early as 1769 (12), it was determined that the catch in the gage was inversely proportional to height above ground. In reality, the height in itself is not important but rather the fact that wind speed normally increases with altitude. The wind moving across the mouth of the rain gage produces eddies around the orifice which decrease the catch. This effect is more serious with snow than rain.

Shielding devices are sometimes used to reduce wind speed across the top of the gage but they are not of great value. It is best to simply lower the mouth of the gage to about 12 inches above ground where wind speed is relatively low (12). Nevertheless, the gage should not be close to obstructions such as buildings or trees that cause turbulence in the immediate area. Turbulent winds can cause numerous undesirable situations. Large obstructions can also be responsible for an increased precipitation catch because they reduce wind speed in the gage area. The reduced wind speed decreases the wind's load carrying capacity. The accumulation of snow in drifts on the lee side of a windbreak is an example of this situation.

The weather observation is made only once each 24 hours at 174 of the 184 stations. Therefore, less than the actual precipitation usually is measured, partly because evaporation losses occur between the precipitation period and the observation time. Among others, Dale and

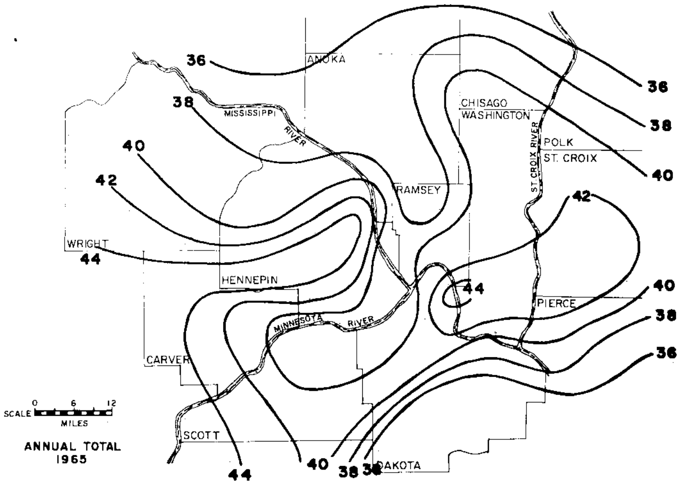


Figure 13. Annual precipitation in inches during 1965, metropolitan Minneapolis-St. Paul, using data from 28 precipitation reporting stations. The area showed a variation of 8 inches during that year, an 18-percent difference between extremes.

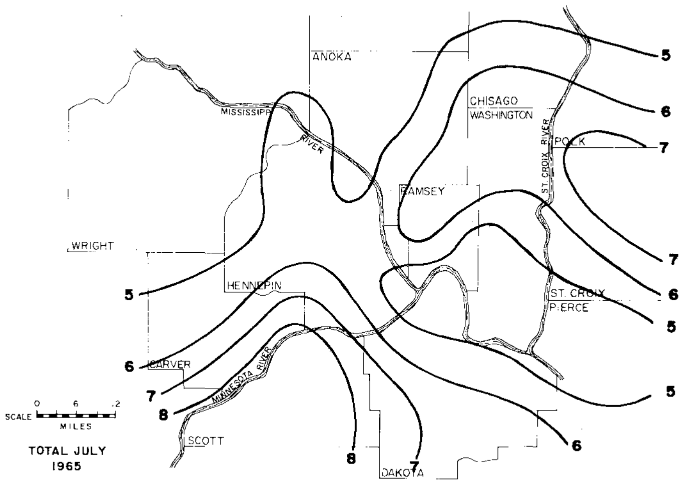


Figure 14. Monthly precipitation in inches during July 1965, metropolitan Minneapolis-St. Paul, using data from 28 precipitation reporting stations. The area showed a variation of 3 inches during that month, a 38-percent difference between extremes.

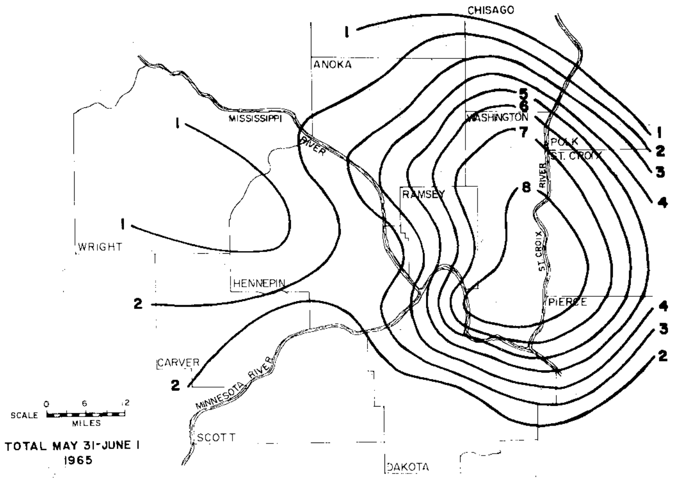


Figure 15. Precipitation in inches during a 48-hour period, May 31-June 1, 1965, metropolitan Minneapolis-St. Paul, using data from 28 precipitation reporting stations. The area showed a variation of 7 inches during these hours, an 87-percent difference between extremes.

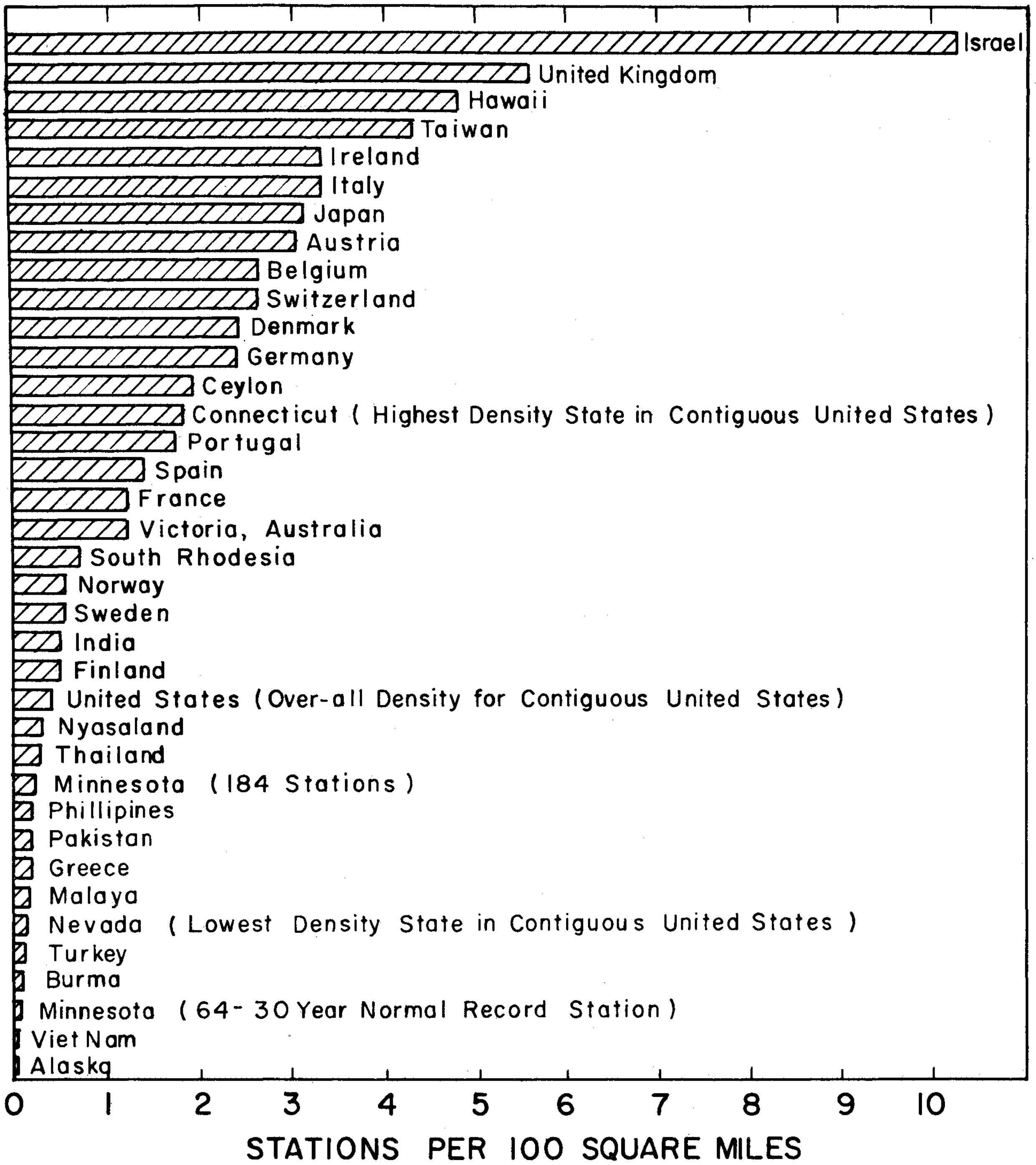


Figure 16. A comparison of the distribution of precipitation stations for various states and countries (17).

Shaw (4) suggested a procedure to correct this bias. A factor is applied which reduces the number of days on which precipitation less than a trace is recorded. In effect, the number of days with recorded precipitation greater than a trace is increased. Observations on days of light precipitation are most seriously affected by evaporation losses. This problem is less serious at the regular Weather Bureau and Federal Aviation Agency stations where observations are taken every 6 hours.

Recorded measurements also are often less than the actual precipitation amounts because of a combination of other causes: loss resulting from wind across the mouth of the gage, simple splash loss—particularly during an intense rain, and very light precipitation too small to measure adequately but probably a source of appreciable water in the aggregate.

It hain't no use to grumble and complain,
It's just as easy to rejoice;
When God sorts out the weather and sends rain,
Why rain's my choice.
James Whitcomb Riley, *Wet Weather Talk*

Sources of Precipitation

The water that makes up the cloud droplets comes from air moisture. But where does the moisture originate? Local contributions, such as evaporation from lakes and evapotranspiration from forests, once were thought to add enough water vapor to the atmosphere to be the sources of regional precipitation. Since forests normally are in areas of higher precipitation than other vegetation types, the question arises: Is the presence of the forest a result of the precipitation or is the higher precipitation a result of the forest? Similarly, is a desert due to a lack of vegetative cover which would contribute moisture to the atmosphere or does it exist because there is never enough moisture to support plant life?

These questions cannot be answered directly. It is impossible to compare by experiment two different natural conditions (forest versus prairie cover, for example) at the same time and the same place. Such questions must be answered by inference. In an excellent summary of relevant data on this question, Penman (11) concluded that "though vegetation may affect the disposal of precipitation, it cannot affect the amount of precipitation to be disposed." Arguments for Penman's conclusion are:

1. Air masses seldom stagnate over continental surfaces long enough to absorb the moisture necessary to reprecipitate the water previously evaporated.

2. The change in character from one vegetation zone to another (prairie to forest cover, for example) cannot induce the large-scale, vertical motion necessary for precipitation. Of course, the influence of topography is not included.

3. The occurrence of heavy precipitation over short periods does not leave the atmosphere appreciably drier than before. Therefore, the moisture for precipitation for a given local area must be drawn from an area many times greater than the one in question.

4. Except where water (precipitation) obviously is limited, the annual evaporation within the same climatic region is essentially independent of the vegetation and nearly constant across the region.

Sellers (13) presents interesting quantitative data relative to this subject. Ratios of the advected precipitation (moisture of a source external to the particular region) to the total precipitation that fell in 1949 in the United States and Canada combined amounted to 0.74, 0.60, 0.75, and 0.89 for spring, summer, fall, and winter, respectively. For the year as a whole, 73 percent of the precipitation was carried into the region from an external source. For the Mississippi River basin, it has been calculated that about 90 percent of the precipitation comes from an external source (1).

Atmospheric moisture mainly flows into the North American continent in two well defined water vapor streams: a strong southerly flow from the Gulf of Mexico and a comparatively diffuse westerly movement from the Pacific Ocean (2). Gulf moisture is the most important of the two in the midwest. The fact that air masses from the Pacific Ocean are relatively insignificant moisture sources in Minnesota is illustrated by the precipitation and vegetation patterns between Minnesota and the Rocky Mountains. Both indicate increasing aridity in the westward direction. Empirical studies (5) indicate that 90-95 percent of the precipitation at Columbia, Missouri, falls from air originating in the Gulf of Mexico.

Therefore, the primary cause of midwestern seasonal

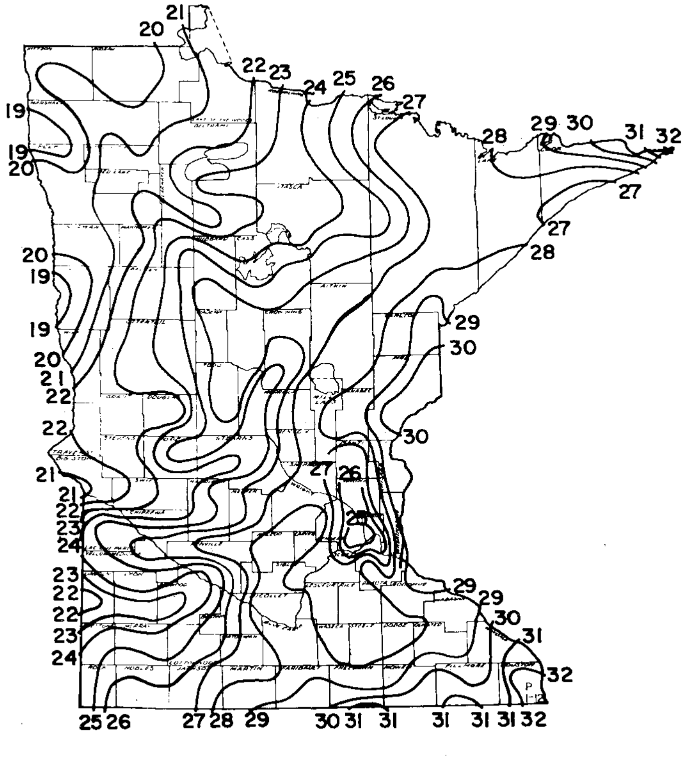


Figure 17. Annual normal precipitation in inches, Minnesota. In general, precipitation increases from the extreme northwest corner to the southeast with a secondary maximum in the northeast and a secondary minimum in the southwest.

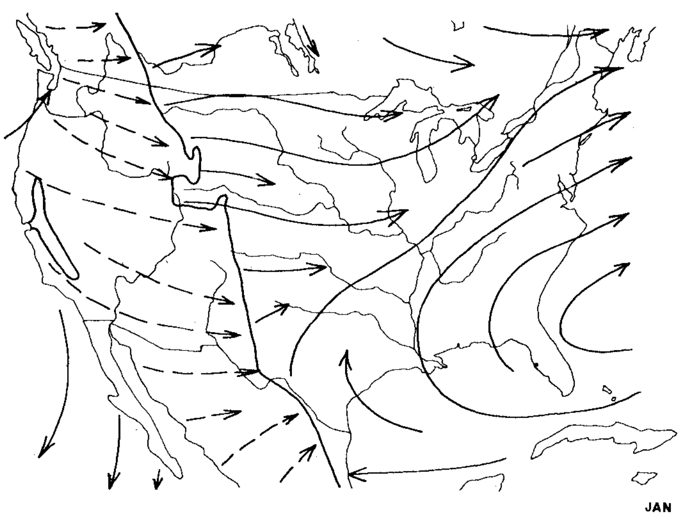


Figure 18. Resultant winds at 1,500 feet during January, United States. At this time, Minnesota is cut off from the Gulf of Mexico moisture supply (3).

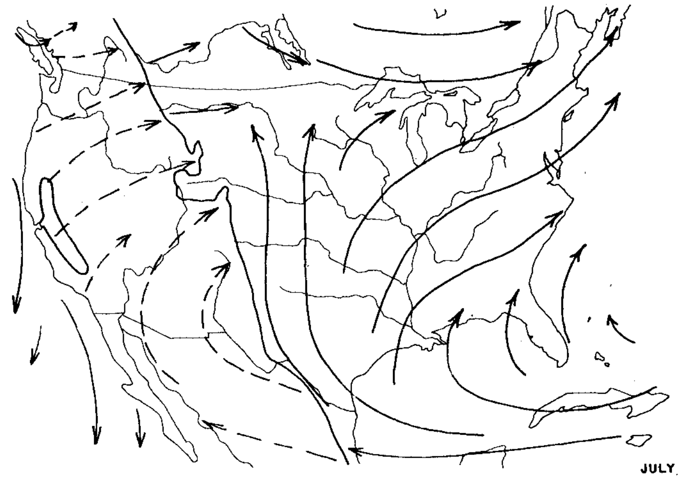


Figure 20. Resultant winds at 1,500 feet during July, United States. Winds from the Gulf of Mexico now dominate the eastern half of the country (3).

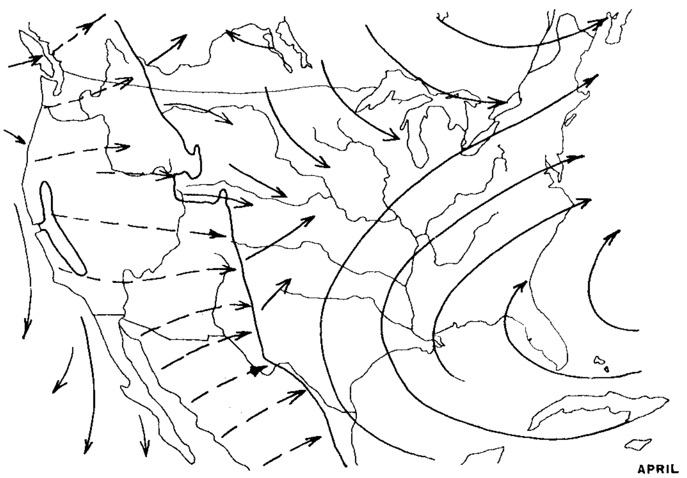


Figure 19. Resultant winds at 1,500 feet during April, United States. Moisture from the Gulf of Mexico is beginning to move into the upper midwest (3).

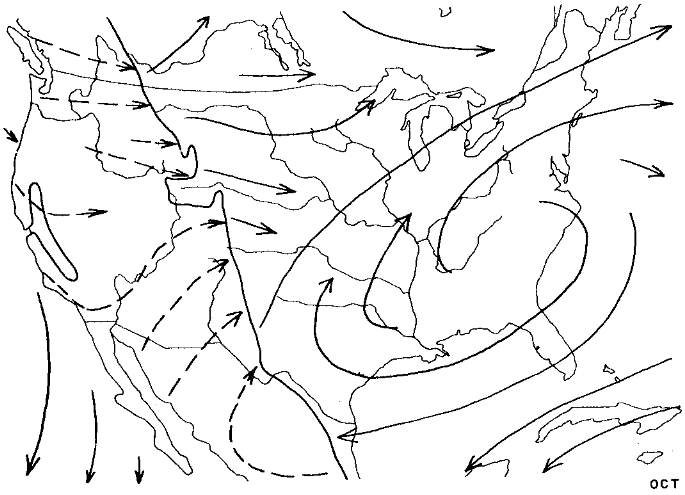


Figure 21. Resultant winds at 1,500 feet during October, United States. Anticyclonic winds centered over the southeastern United States now dominate most of the country from the Rockies eastward (3).

and yearly differences in precipitation appears to be due to significant geographic displacement of the high level wind system over the central United States. Although high level winds do not carry appreciable moisture, they direct movement of low level air masses.

The mean flow path carries water vapor from the Gulf straight northward, with the main axis along the Texas-Louisiana border. The major track then curves in an anticyclonic sense (to the right) and moves off the east coast over the central Atlantic seaboard. A station's position relative to this moist air current generally determines the amount of precipitation it receives. This factor is the major reason why Minnesota's annual precipitation varies from about 19 inches in the northwest to 32 inches in the southeast (figure 17). The southeastern counties are closer to and, therefore, more influenced by the moist, southerly air flow than are the northwestern counties.

The maximum mean intensity of moisture inflow is close to the land surface, normally at a height of about 2,500 feet m.s.l. (mean sea level). And the northward movement of water vapor decreases rapidly with increasing height. Thus, at 95° W at low latitudes along the axis of the water vapor stream, less than 25 percent of the inflow occurs above 10,000 feet m.s.l. Although this moist current is lifted while moving across the United States, the level of maximum intensity of the outflow remains below 5,000 feet m.s.l.

Seasonal changes in the general circulation system, as represented by the resultant winds at about 1,500 feet above the surface, explain several features of Minnesota's precipitation pattern. As shown in figure 18, Minnesota in January is strongly under the influence of west and northwest winds. Warm, humid winds off of the Gulf are restricted to the southeastern United States.

The Gulf winds just reach southeastern Minnesota in April (figure 19). States to the south and west of Minnesota, particularly the southern and southwestern Great Plains states, receive the major portion of their annual precipitation between April and July. Then the Gulf winds sweep far inland over the southern Great Plains before turning northeastward and the northern limit crosses the lower Great Lakes.

In July the winds are more southerly in the Mississippi valley which is fine for the midwest (figure 20). However, precipitation in the Great Plains is severely restricted because only a small portion of the Great Plains lies directly north of the Gulf.

Figure 21 illustrates that most of the eastern United States is effectively cut off from Gulf moisture by October. Under ideal conditions the lack of sufficient flow across the Gulf and the anticyclonic winds pictured produce the "Indian Summer" days of autumn.

Air masses carrying the moisture which eventually is released as precipitation in Minnesota travel some 1,200-1,500 miles. Because of this long northward trek, a minor change in the wind system can mean that Minnesota and areas farther west will have well above or below their normal precipitation. It is no wonder then that annual precipitation may vary appreciably from year to year.

The weather is beautiful; but as Noodle says (with his eyes beaming with delight), "We shall suffer for this, sir, by-and-by."
Sydney Smith, letter to Sir George Phillips

Precipitation Normals

For worldwide weather comparison, the World Meteorological Organization established a uniform method of determining normals. Normals are calculated in 30-year increments because short-term fluctuations in weather records generally smooth out in that time. The present 30-year normal period is 1931-60 and will remain so until the end of 1970. Normal data then will be determined over the 1941-70 period.

In this bulletin the word *normal* has a definite meaning; it refers to an arithmetic mean computed for the specific period 1931-60. A mean for any other period is termed an average. This method of data computation assures that relatively new weather stations are comparable with other stations. It also leads to a definition of normal precipitation as the average precipitation for an arbitrarily selected period of years. Long term records for many stations are available for other studies.

Figures 22-33 show the normal monthly precipitation patterns over Minnesota. With these smoothed maps the greatest and least precipitation areas as well as the month-to-month variability may be seen. Before examining these figures in detail, look at the sum total of the 12 months, the annual normal precipitation, for an idea of the overall distribution (figure 17).

The most striking feature of figure 17 is the pattern of increasing precipitation from Minnesota's extreme northwest corner to the extreme southeast. This spatial trend represents an annual precipitation range of 13 inches, from an average of 19 inches per year in the northwest to 32 inches in the southeast. A secondary maximum in the northeast is largely a result of lake effects. A secondary minimum in the southwest probably results from topographical features. Most other variations are not real but occur because a 30-year normal is not long enough to smooth out all short period oscillations.

It is fortunate from many standpoints that precipitation in Minnesota follows its month-to-month pattern. If the cycle suddenly developed a 6-month phase change, snow would bury the state in winter and only marginal moisture would occur during the growing season. As it is, only light precipitation falls in the winter season of December, January, and February with a fairly even month-to-month distribution pattern. Although totals increase from northwest to east and southeast, normal amounts are small when compared to other seasons of the year (figure 34).

Precipitation amounts increase steadily during the spring months of March, April, and May. A rough but recognizable design of increasing precipitation from northwest to southeast persists although strong maxima appear in central Minnesota in April and May. And, by May, the secondary maximum in the extreme northeast decreases. According to the spring 3-month composite (figure 35), the patterns remain the same as during the winter season even with the mentioned deviations.

The summer period of June, July, and August (figure 36) coincides with the major portion of the growing season and accounts for from 40 to 50 percent of the state's annual precipitation (excluding the extreme northeast) (figure 38). Although the northwest has the lowest annual total, a high percentage of its total precipitation fortunately occurs during this time. Continuing a reverse trend which began in May, the extreme northeast has by far the lowest percentage. The May-September total normal precipitation shown in figure 39 represents the growing season precipitation.

The individual months of June, July, and August show an interesting feature in the southwest. Through these 3 summer months (figures 27-29), precipitation amounts decrease; by August the region centered on Lyon County has the state's lowest amounts.

During the autumn season the patterns shift somewhat; precipitation increases from west to east. Totals are at a minimum along much of the western border with the smallest amounts in the lower northwestern counties (figure 37). Autumn totals are double these amounts in some eastern sectors. Precipitation totals for the 3 fall months are well under the summer normals and roughly an inch or more under spring totals. However, they are about double the winter season precipitation.

Figure 40 shows the normal monthly precipitation distribution for five Minnesota areas. Data were derived by taking precipitation amounts for each station within a particular section and then obtaining an average for that section. While June is easily the major precipitation month, August provides a secondary maximum in central and southern divisions. In the north, however, differences during June, July, and August are slight. In all divisions the normals indicate a rapid increase from a December-January-February low to a summer peak, then a rapid decrease until October, and a slower decrease in November. Annual totals vary from a low of 21.17 inches in the northwest to a high of 29.40 inches in the southeast.

Monthly and annual averages at the 64 stations having a continuous record during the normal period are listed in Appendix table 1.

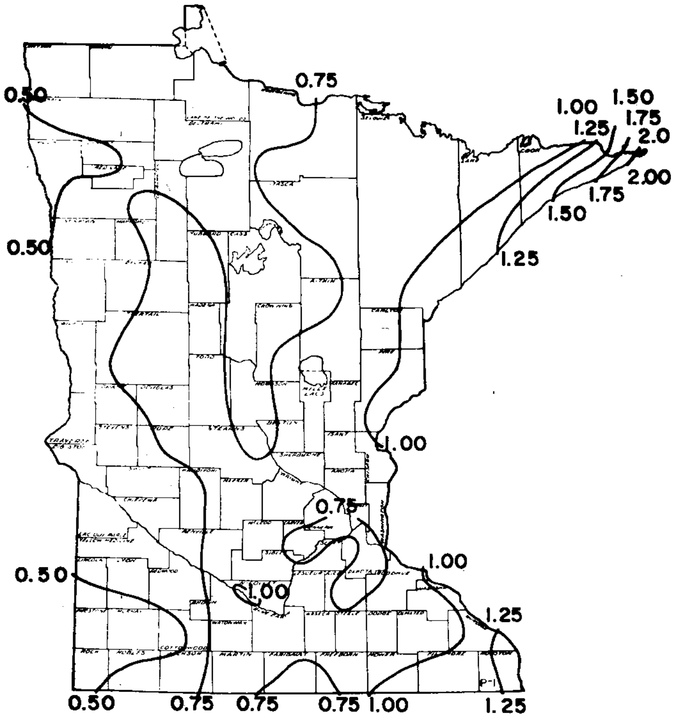


Figure 22. January normal precipitation in inches, Minnesota.

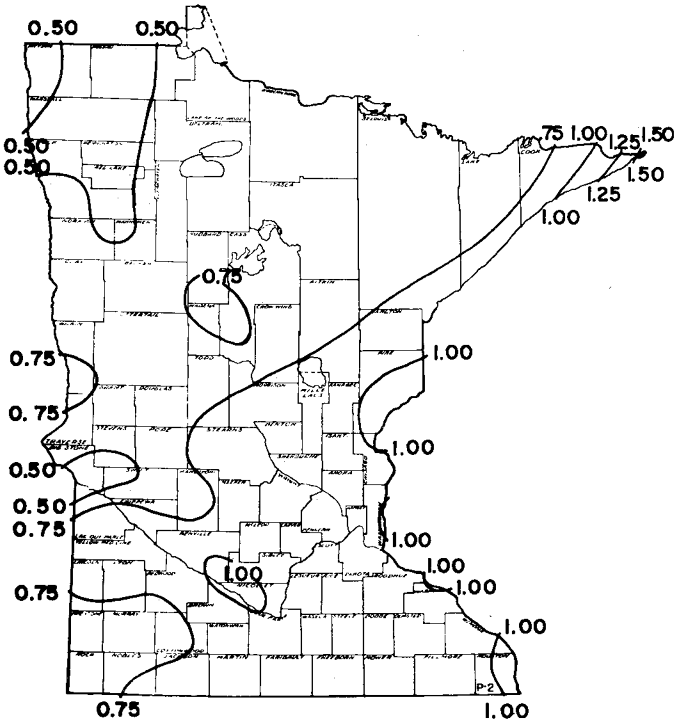


Figure 23. February normal precipitation in inches, Minnesota.

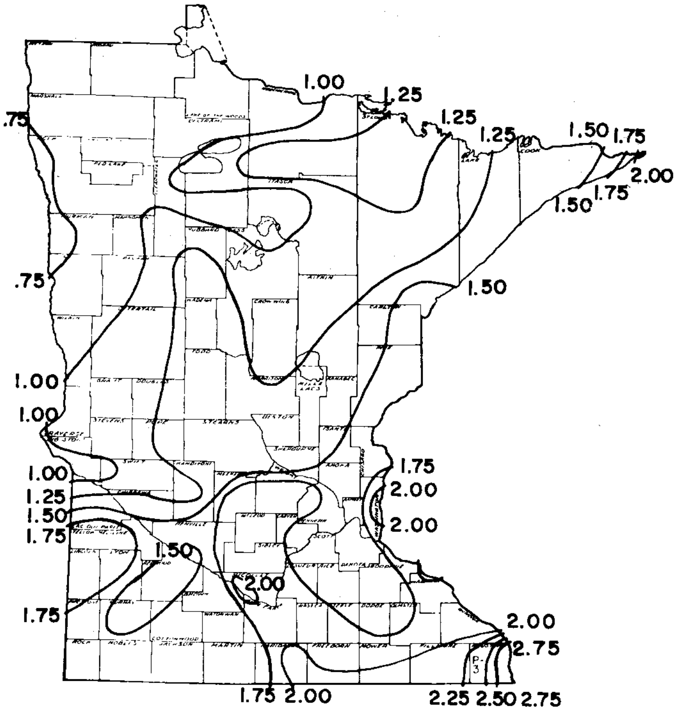


Figure 24. March normal precipitation in inches, Minnesota.

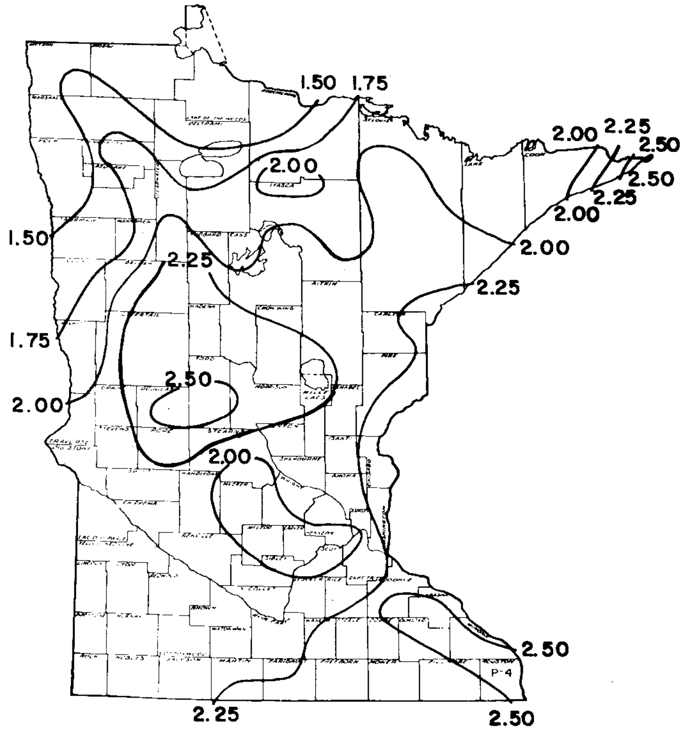


Figure 25. April normal precipitation in inches, Minnesota.

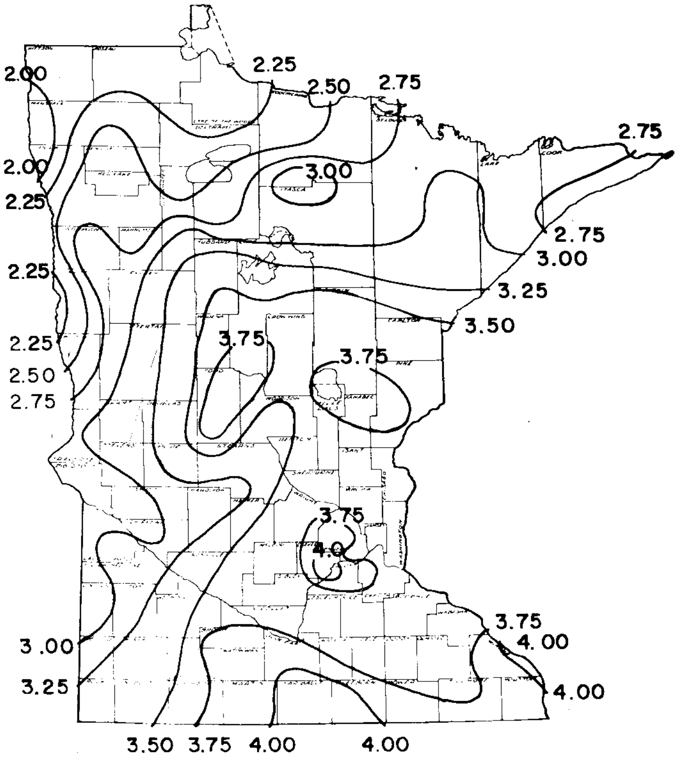


Figure 26. May normal precipitation in inches, Minnesota.

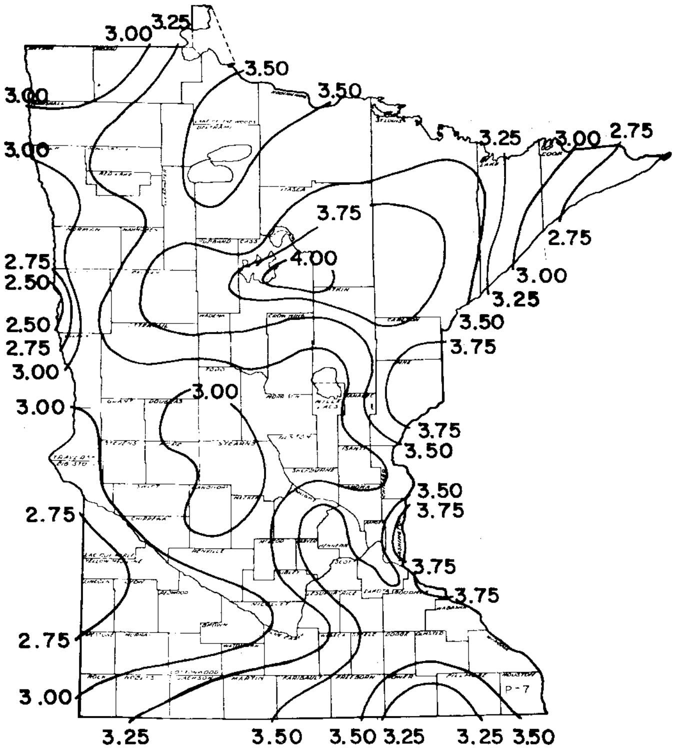


Figure 28. July normal precipitation in inches, Minnesota.

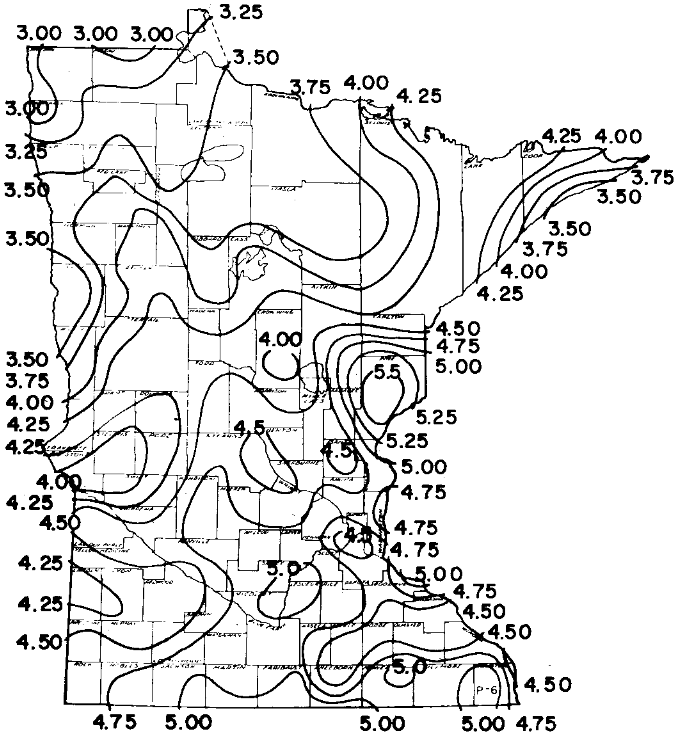


Figure 27. June normal precipitation in inches, Minnesota.

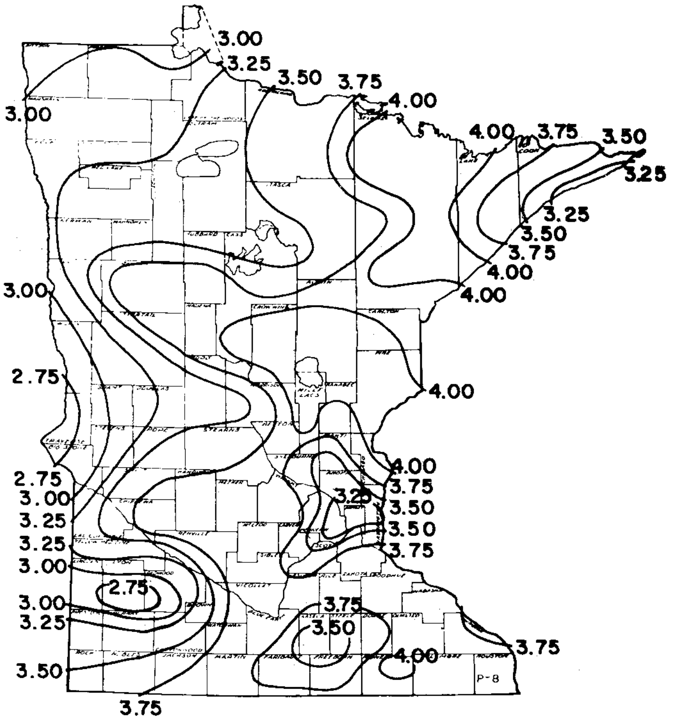


Figure 29. August normal precipitation in inches, Minnesota.

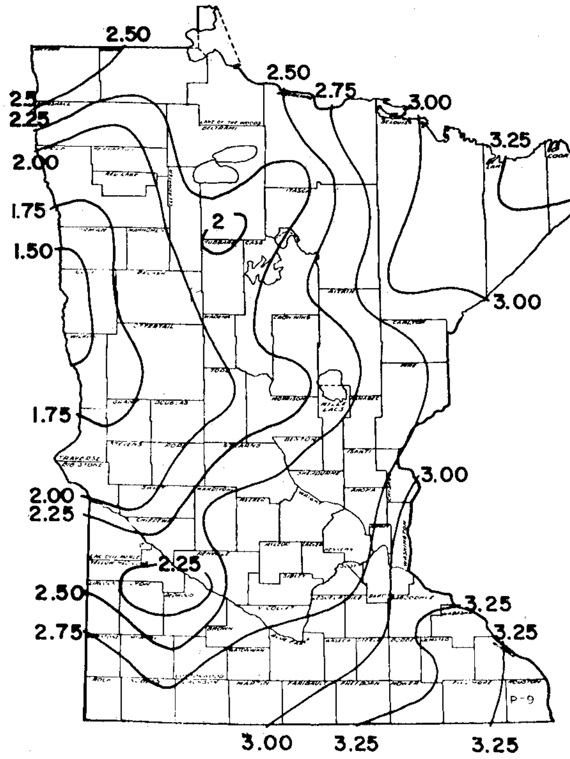


Figure 30. September normal precipitation in inches, Minnesota.

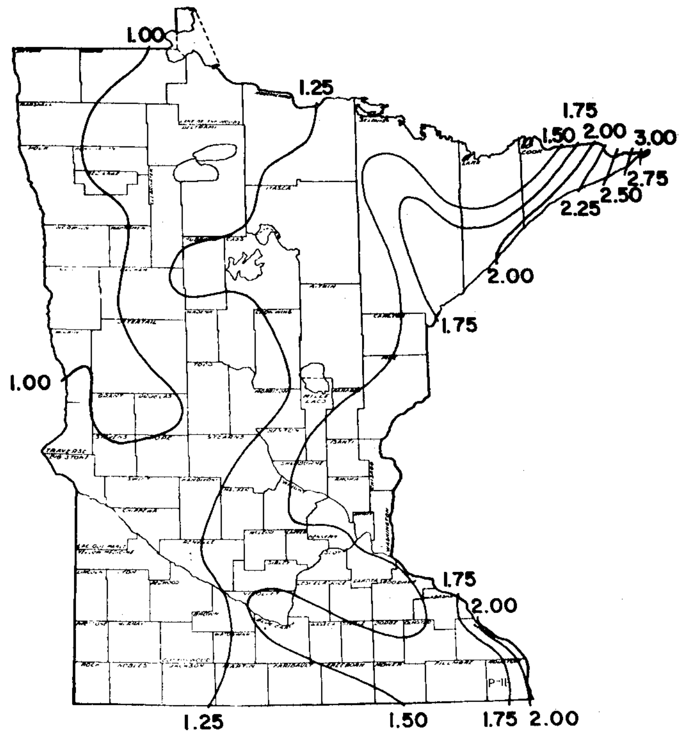


Figure 32. November normal precipitation in inches, Minnesota.

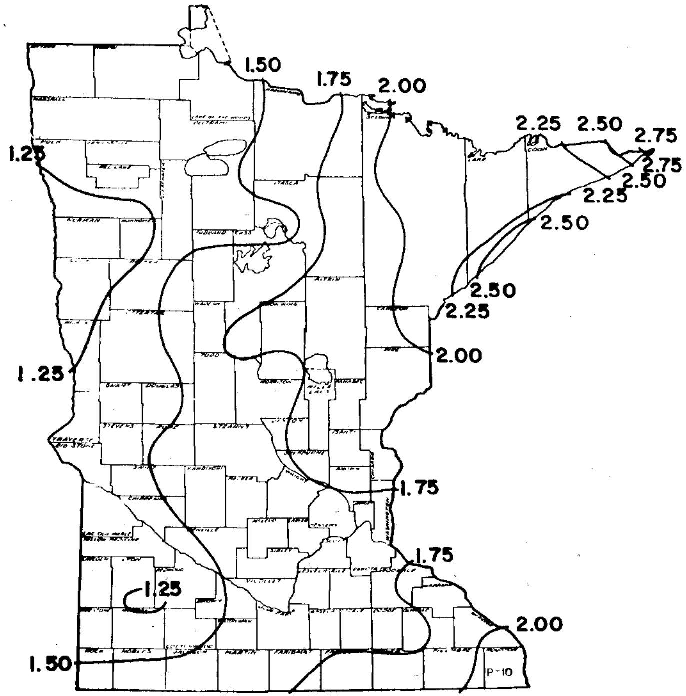


Figure 31. October normal precipitation in inches, Minnesota.

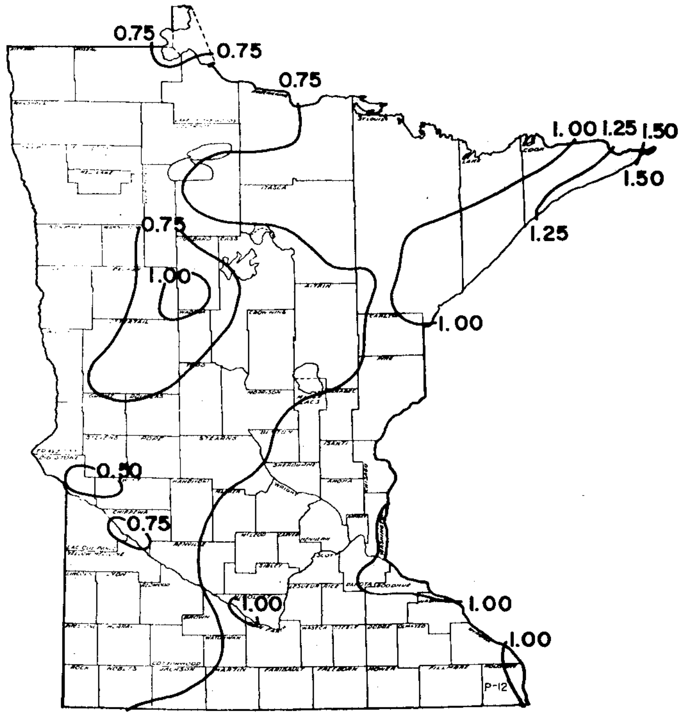


Figure 33. December normal precipitation in inches, Minnesota.

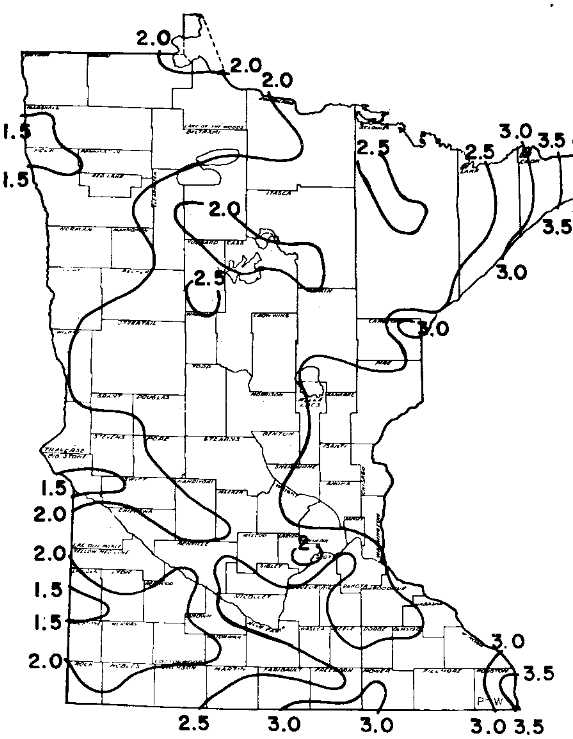


Figure 34. Winter (December, January, and February) normal precipitation in inches, Minnesota.

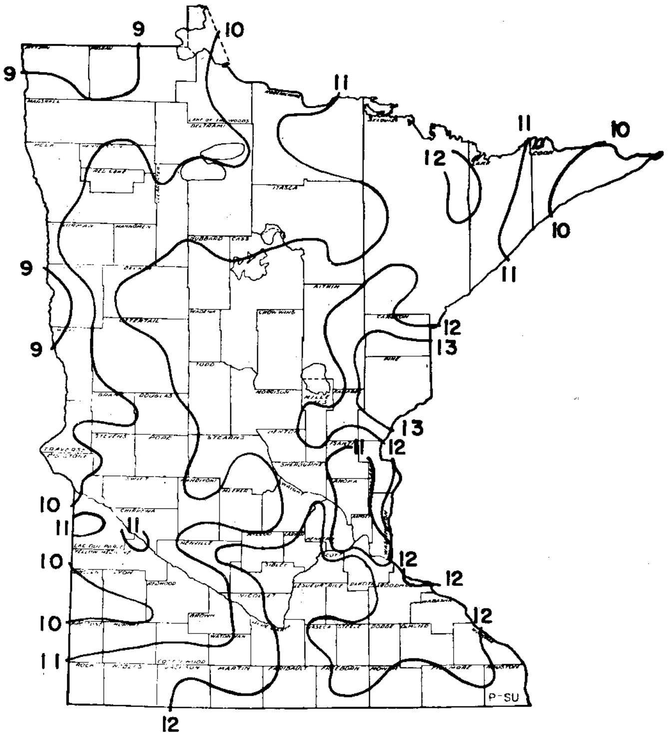


Figure 36. Summer (June, July, and August) normal precipitation in inches, Minnesota.

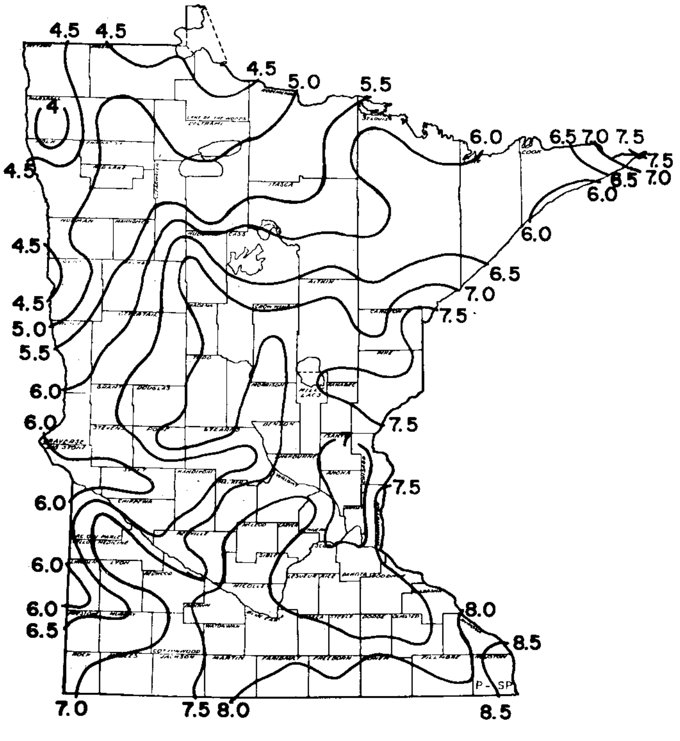


Figure 35. Spring (March, April, and May) normal precipitation in inches, Minnesota.

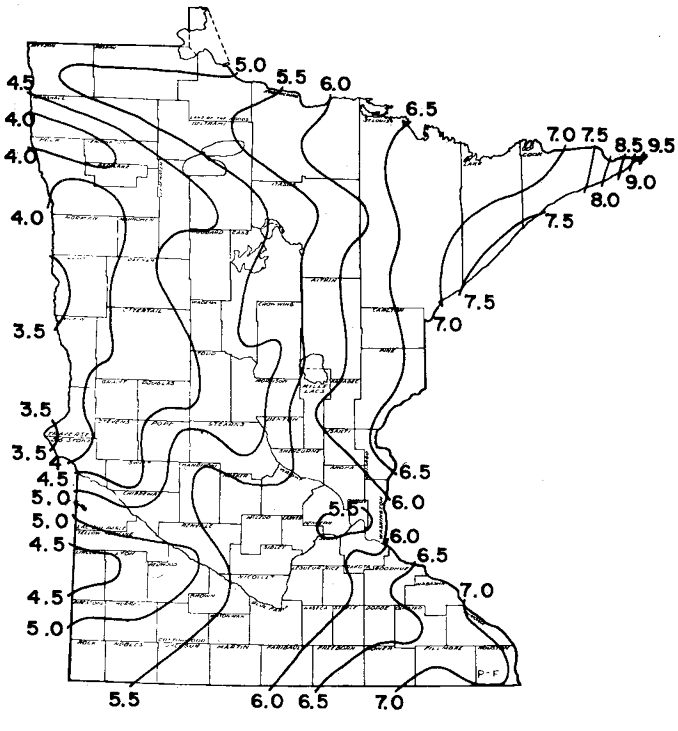


Figure 37. Fall (September, October, and November) normal precipitation in inches, Minnesota.

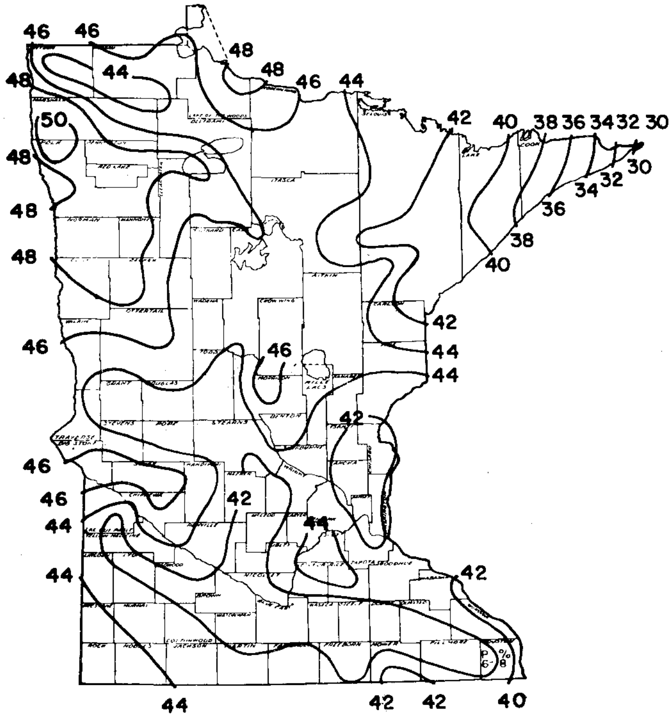


Figure 38. Percentage of Minnesota's annual normal precipitation occurring during the summer (June, July, and August).

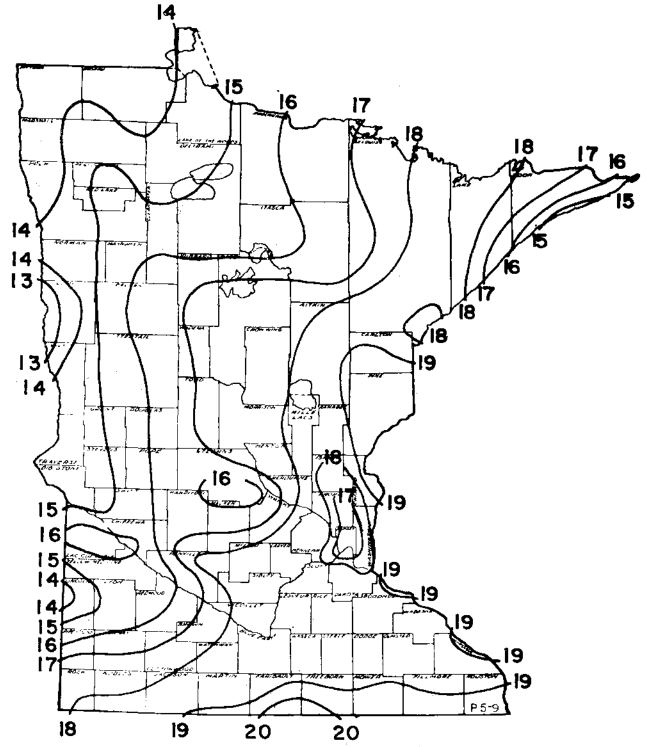


Figure 39. Normal precipitation during the May through September growing season in inches, Minnesota.

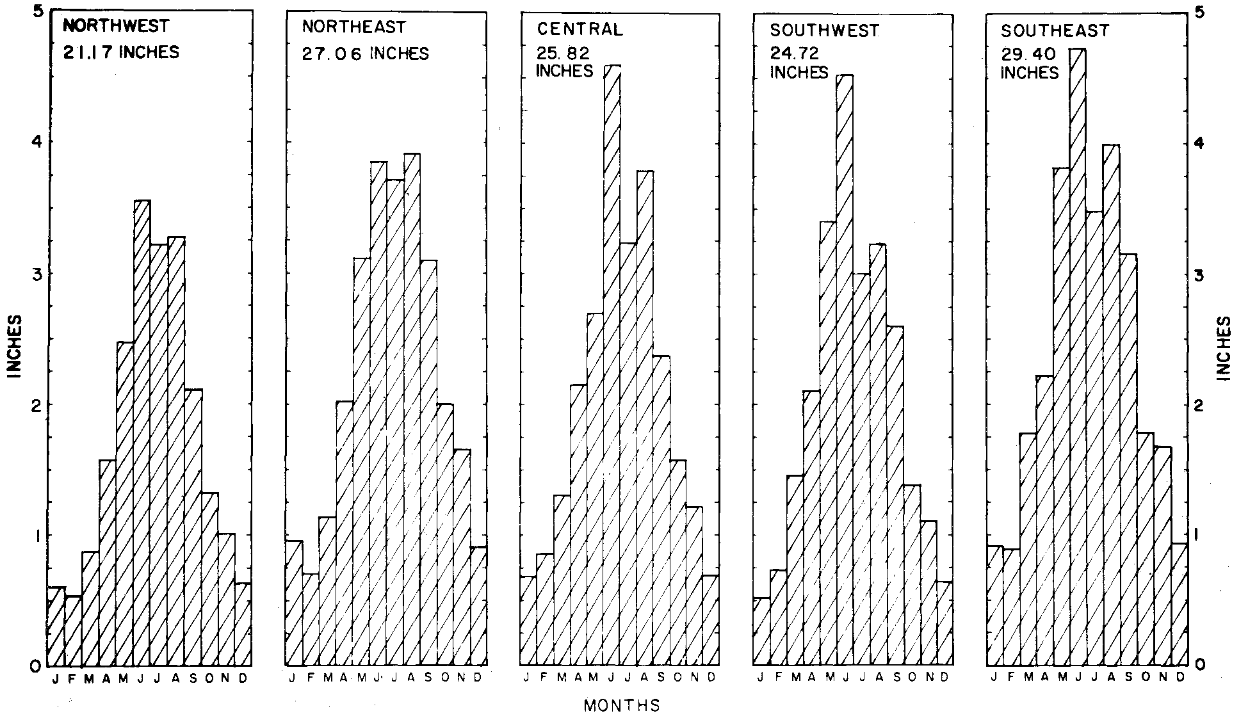


Figure 40. Normal monthly precipitation distribution in inches for five Minnesota sections. Total annual precipitation is indicated for each section.

God sendeth us down water from Heaven,
And causeth the earth to revive after it hath been dead.
The Koran, XVI, c. 625

Annual Precipitation Distribution

Distributions of annual precipitation at selected stations are shown in figures 41-50. Since annual totals are approximately normally distributed, the chances are about even of receiving an annual total either greater or less than the average value.

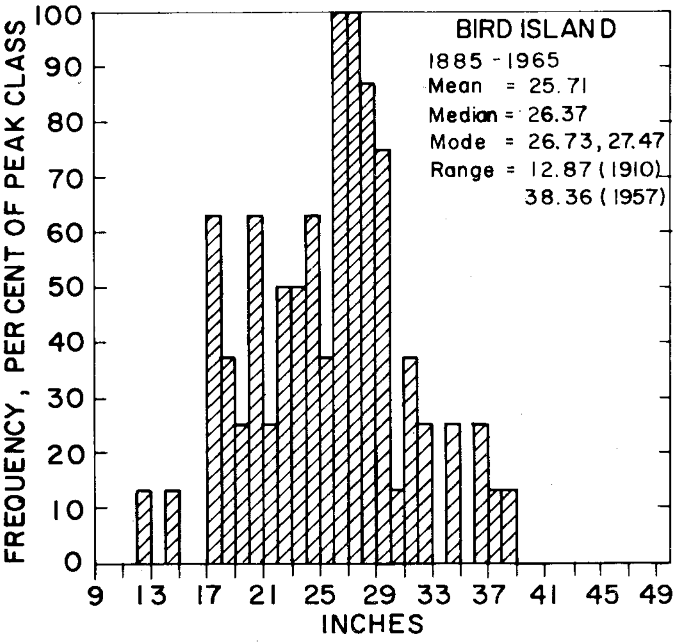
The range in annual total precipitation received at these stations is great, nearly equaling or even exceeding the average annual totals (table 1). For example, the combined 129-year record of Minneapolis and St. Paul has a range of 39.48 inches—a maximum of 49.69 inches in 1849 and a minimum of 10.21 inches in 1910 (figure 46). This large variation is substantiated by the much shorter Pine River Dam and Worthington records with ranges of 31.05 and 35.21 inches, respectively (table 1). This great variation between years in annual total precipitation is a feature typical of the midwestern climate. Nevertheless, in 50 percent of the years, total precipitation varied only about 3-4 inches above or below the annual average.

Because the total period of record at these 10 stations is considered in this section, data presented may differ appreciably from the normal period (1931-60) data.

Table 1. Maximum, minimum, range of, and average annual precipitation at 10 selected stations

Station	Record	Maximum		Minimum		Range, inches	Average, inches
		Inches	Year	Inches	Year		
Bird Island	1885-1965	38.36	1957	12.87	1910	25.49	25.71
Cloquet	1912-1965	41.40	1953	19.60	1918	21.80	28.21
Crookston	1890-1965	32.87	1941	9.99	1936	22.88	20.78
Grand Rapids	1915-1965	36.21	1953	15.08	1929	21.13	24.82
Itasca	1912-1965	35.51	1949	13.93	1929	21.58	24.66
Minneapolis-St. Paul*	1837-1965	49.69	1849	10.21	1910	39.48	26.85
Morris	1886-1965	33.48	1965	15.31	1933	18.17	23.47
Pine River Dam	1887-1965	45.86	1902	14.81	1936	31.05	26.19
Waseca	1915-1965	41.58	1951	18.38	1958	23.20	28.38
Worthington	1894-1965	49.70	1903	14.49	1910	35.21	26.79

* St. Paul data 1837-1933 and Minneapolis data 1934-65.



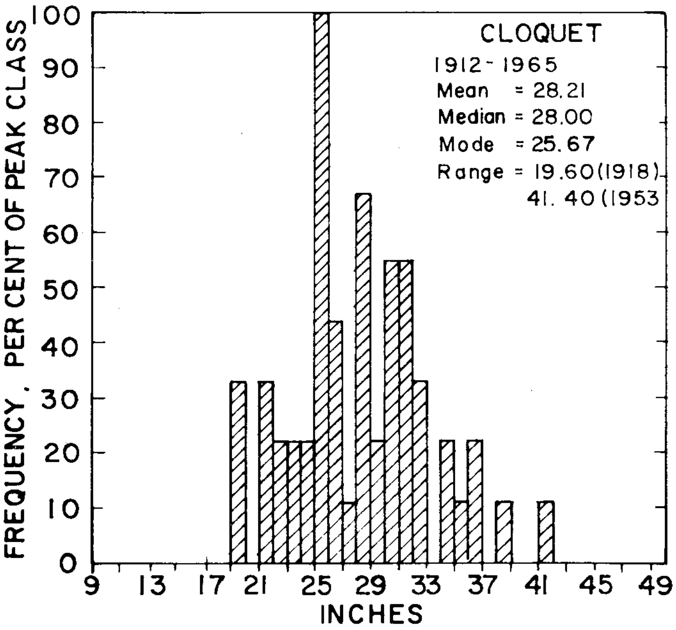


Figure 41 (left). Distribution of annual precipitation in inches in 1885-1965, Bird Island. The most frequently occurring class interval (precipitation amount) is assigned a value of 100 percent. All other precipitation intervals are expressed as a percent of the peak precipitation class.

Figure 42 (right). Distribution of annual precipitation in inches in 1912-65, Cloquet. Distribution is expressed as a percent of the peak precipitation class.

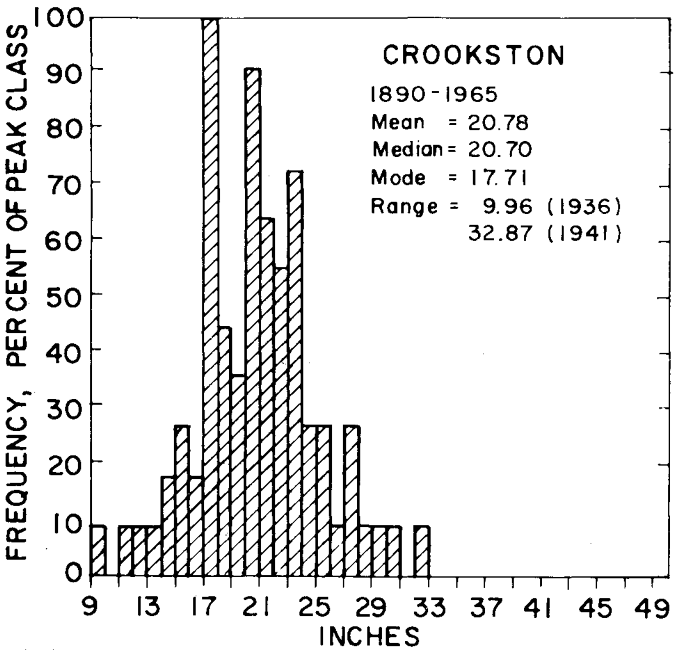


Figure 43. Distribution of annual precipitation in inches in 1890-1965, Crookston. Distribution is expressed as a percent of the peak precipitation class.

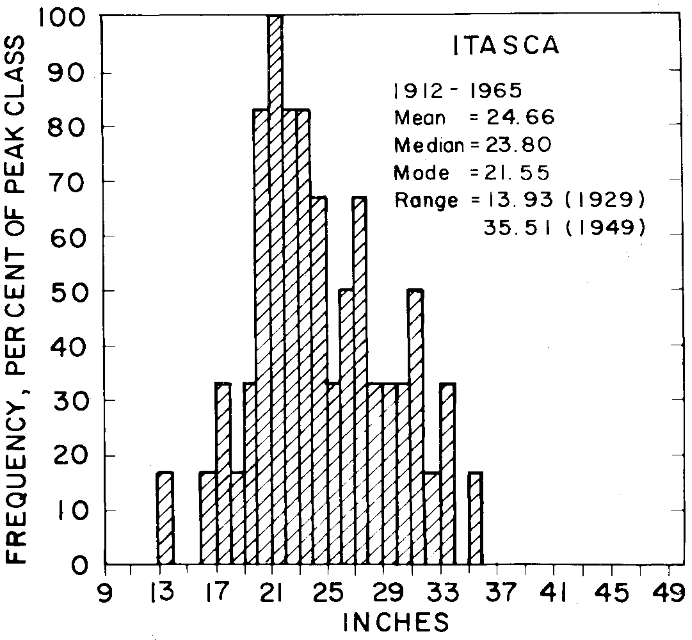


Figure 45. Distribution of annual precipitation in inches in 1912-65, Itasca. Distribution is expressed as a percent of the peak precipitation class.

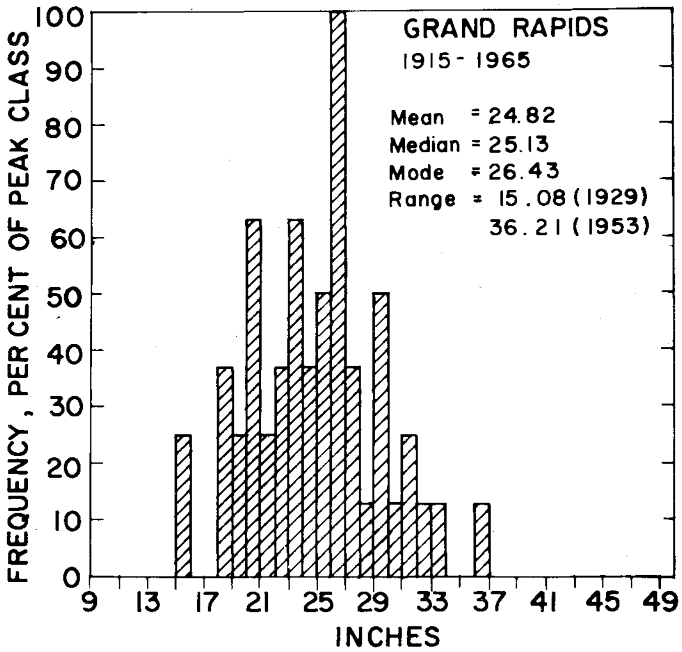


Figure 44. Distribution of annual precipitation in inches in 1915-65, Grand Rapids. Distribution is expressed as a percent of the peak precipitation class.

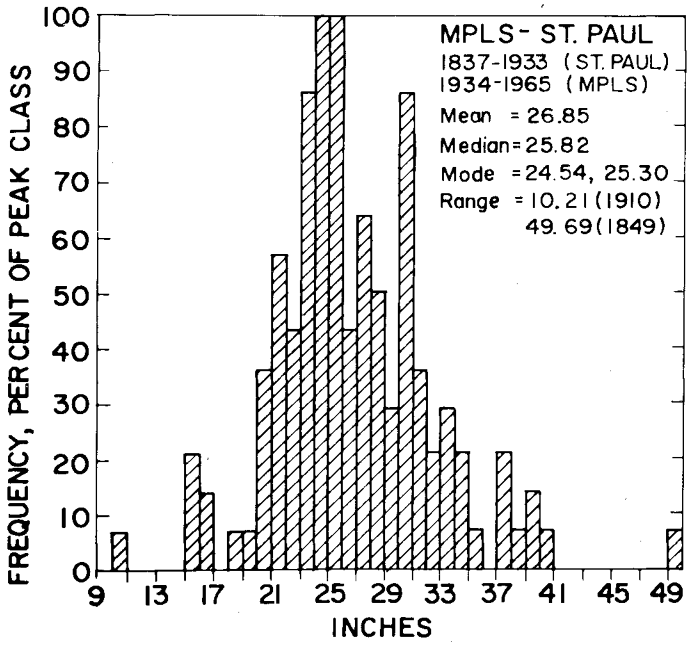


Figure 46. Distribution of annual precipitation in inches in 1837-1965, Minneapolis-St. Paul. Distribution is expressed as a percent of the peak precipitation class.

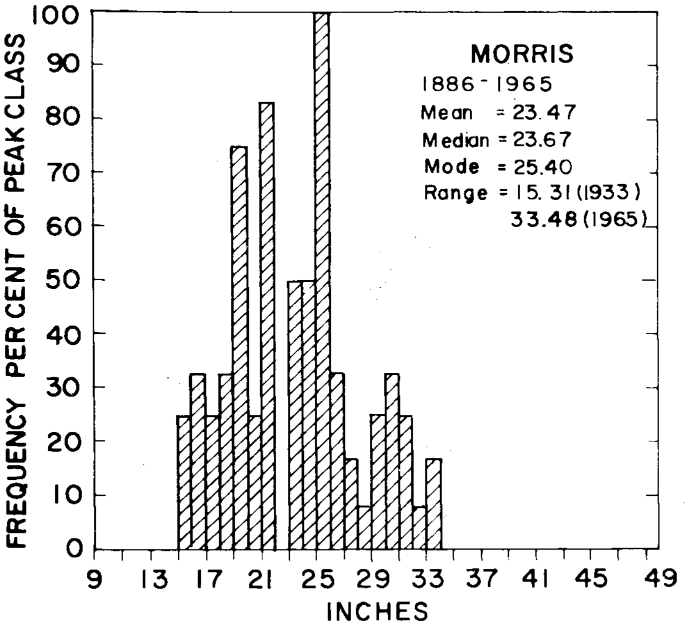


Figure 47. Distribution of annual precipitation in inches in 1886-1965, Morris. Distribution is expressed as a percent of the peak precipitation class.

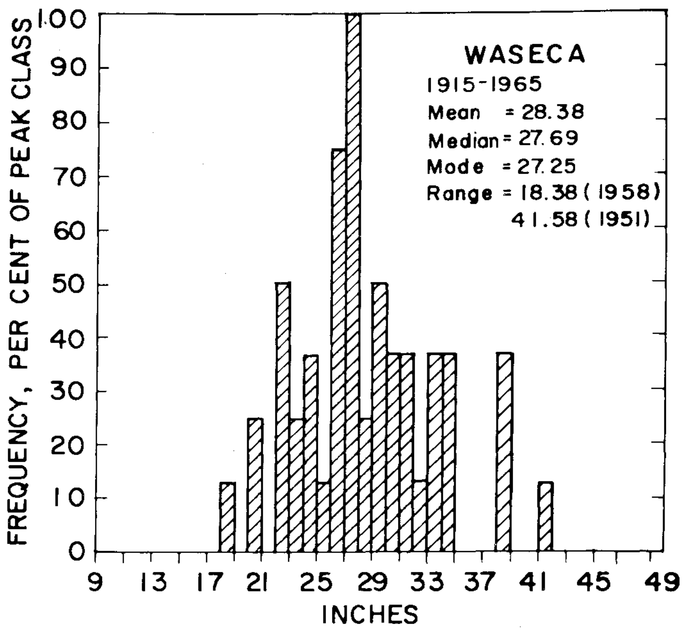


Figure 49. Distribution of annual precipitation in inches in 1915-65, Waseca. Distribution is expressed as a percent of the peak precipitation class.

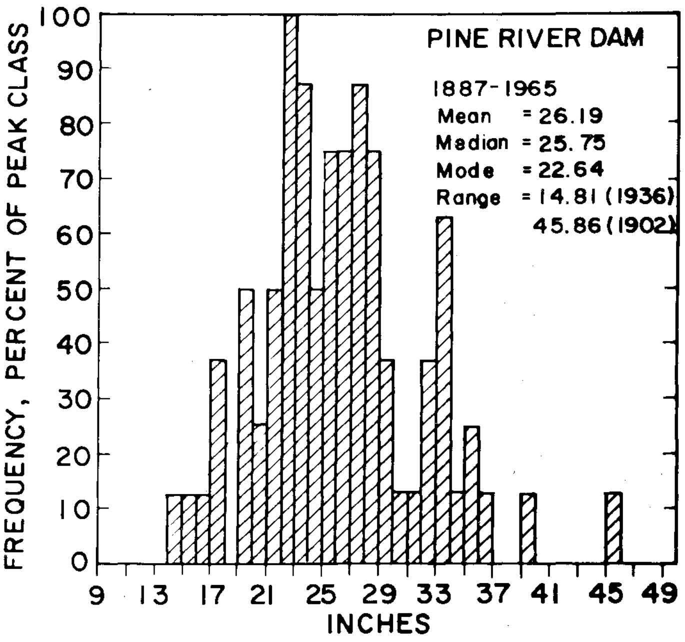


Figure 48. Distribution of annual precipitation in inches in 1887-1965, Pine River Dam. Distribution is expressed as a percent of the peak precipitation class.

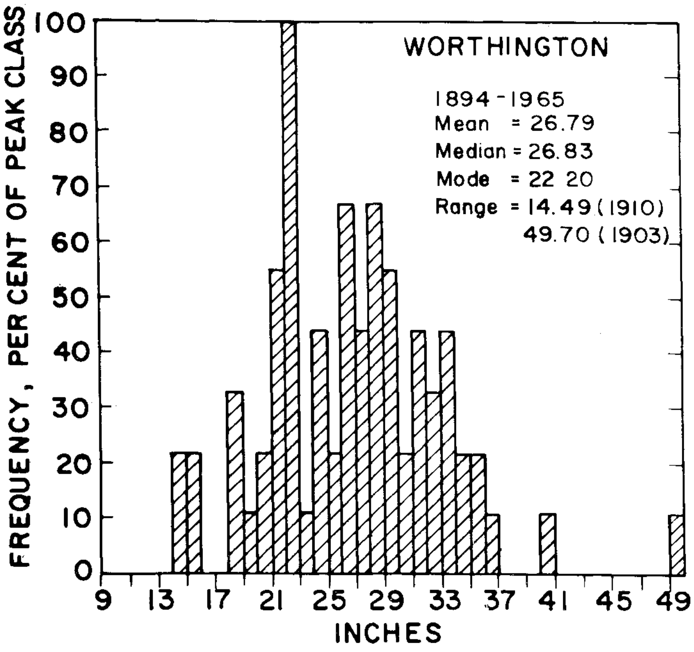


Figure 50. Distribution of annual precipitation in inches in 1894-1965, Worthington. Distribution is expressed as a percent of the peak precipitation class.

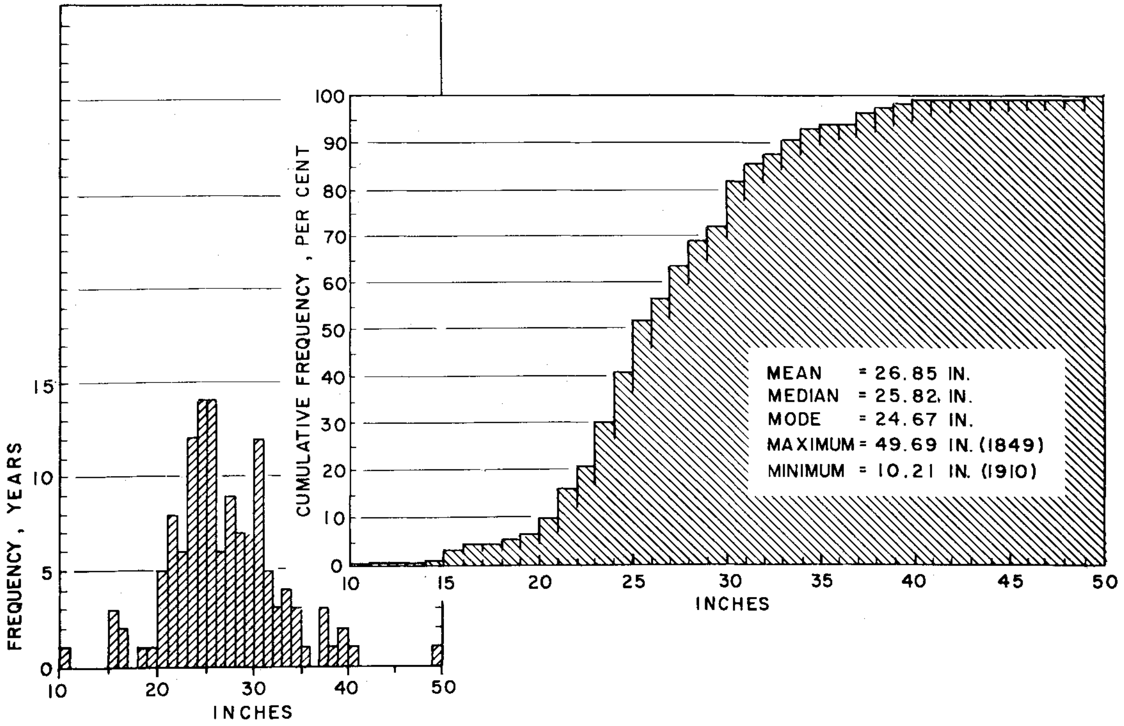


Figure 51. Frequency distribution and cumulative frequency distribution in inches of annual precipitation in 1837-1965, Minneapolis-St. Paul.

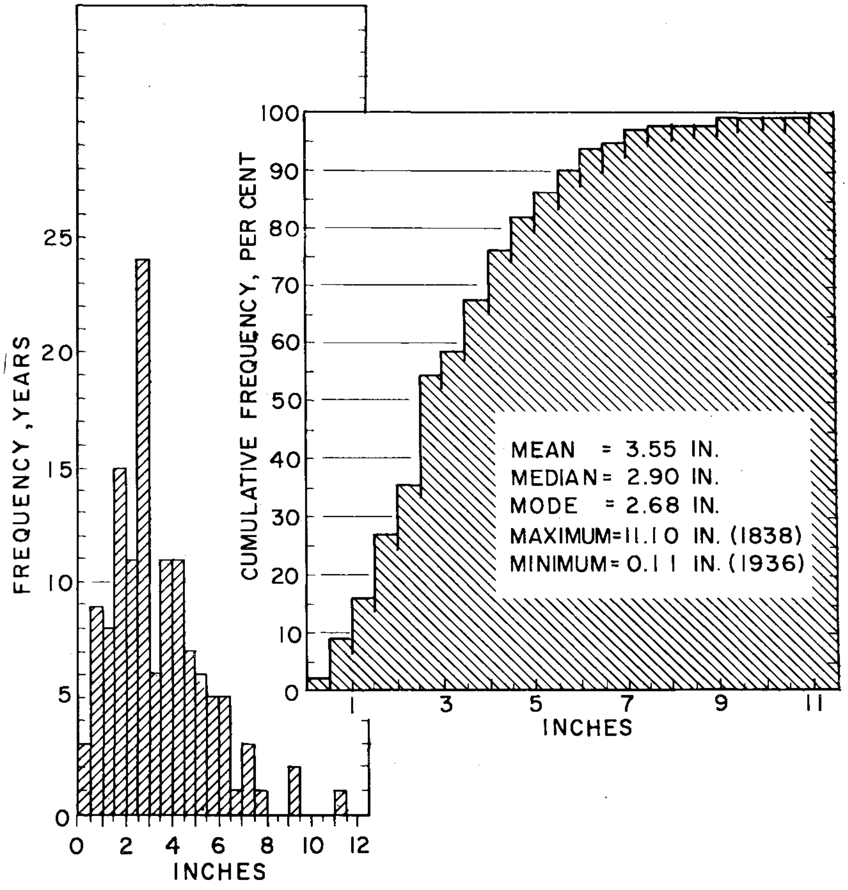


Figure 52. Frequency distribution and cumulative frequency distribution in inches of July precipitation in 1837-1965, Minneapolis-St. Paul.

March winds and April showers
Bring forth May flowers.
Unknown, *Old Nursery Rhymes*

Monthly Precipitation Distribution

The time period over which precipitation distribution is considered is extremely important. As the time period is decreased, the lack of normality of the distribution becomes increasingly evident. As shown for Minneapolis-St. Paul in figures 51 and 52, distribution of annual precipitation differs appreciably from monthly precipitation. Monthly distribution lacks normality, and there is a shift toward lower values in the most frequently occurring amounts. (The combined Minneapolis-St. Paul records, 1837-1965, were selected because they are longer than records of any station west of the Mississippi River.)

The cumulative frequency curves shown in figures 51 and 52 are sigmoid in shape (a drawnout "S" shape) in normal and near normal distributions. However, the "S" or sigmoid character of the cumulative frequency curve becomes increasingly distorted as the distribution becomes more and more skewed (figure 54).

This concentration of monthly precipitation totals toward low values is most evident in winter. Figure 53 shows the January and July distributions at Crookston (another station with a fairly lengthy record) as examples of the seasonal change. The spring and fall months have distributions that are expansions of the January distribution and contractions of the July distribution.

Winter precipitation totals are low and, consequently, the absolute variation cannot be great. Two reasons account for this situation. As discussed earlier, Minnesota is then essentially cut off from the Gulf of Mexico moisture source. In addition, with low air temperatures, the air cannot hold much moisture and, thus, can only precipitate small amounts.

The importance of these skewed distributions is that the average value is not centrally located; therefore, it is not the best measure of expected precipitation amounts. This fact is least serious in winter months due to the small range in values experienced. In any case, the average remains the most frequently used statistic due to its ease of calculation.

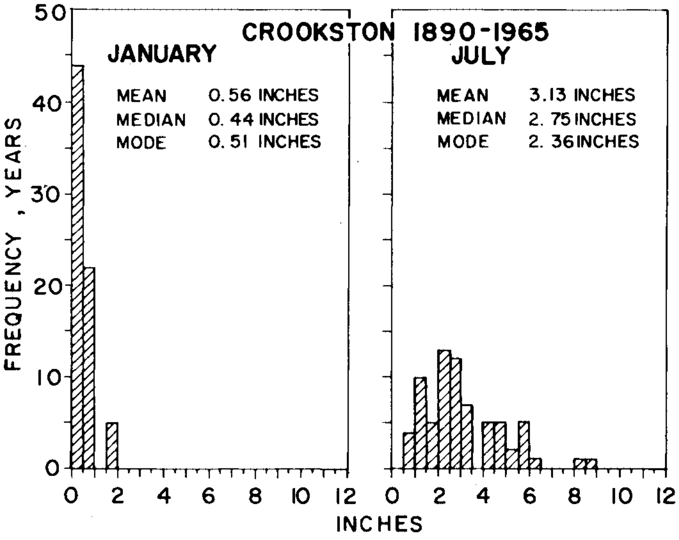


Figure 53. Frequency distributions in inches of January and July precipitation in 1890-1965, Crookston.

Here before the dying embers
I sit and weigh my last regrets;
When I'm right no one remembers;
When I'm wrong no one forgets.
A Weatherman's Lament

Daily Precipitation Distribution

As shorter and shorter time periods are considered, precipitation data show increasing skewness (table 2). For example, the event of greatest probability (0.52) on a July day in Minneapolis is no precipitation (figure 54), although the calculated mean is 0.12 inch. It is evident that the average daily precipitation amount is a misleading statistic.

The bulk of precipitation in Minnesota actually is received in a few days of high precipitation; many days have very low precipitation and an even greater number of days have no recorded precipitation.

Therefore, averages do not have their usual significance with these data; frequencies are better means of estimating expected precipitation. Frequencies and their translation into probabilities of expected precipitation amounts and times of occurrence will be discussed in a future *Climate of Minnesota* publication.

Table 2. Mean, median, and modal values of the annual total, monthly total, and daily total precipitation at Minneapolis-St. Paul*

Period	Mean	Median	Mode
		inches	
Annual total, 1837-1965	26.85	25.82	24.67
Monthly total (July), 1837-1965	3.55	2.90	2.68
Daily total (July), 1946-65	0.12	0.00	0.00

* The mean is the arithmetic average, the median is the middle value of all numbers arranged according to their magnitude, and the mode is the most frequently observed value. In a normal distribution the mean, median, and mode are equal.

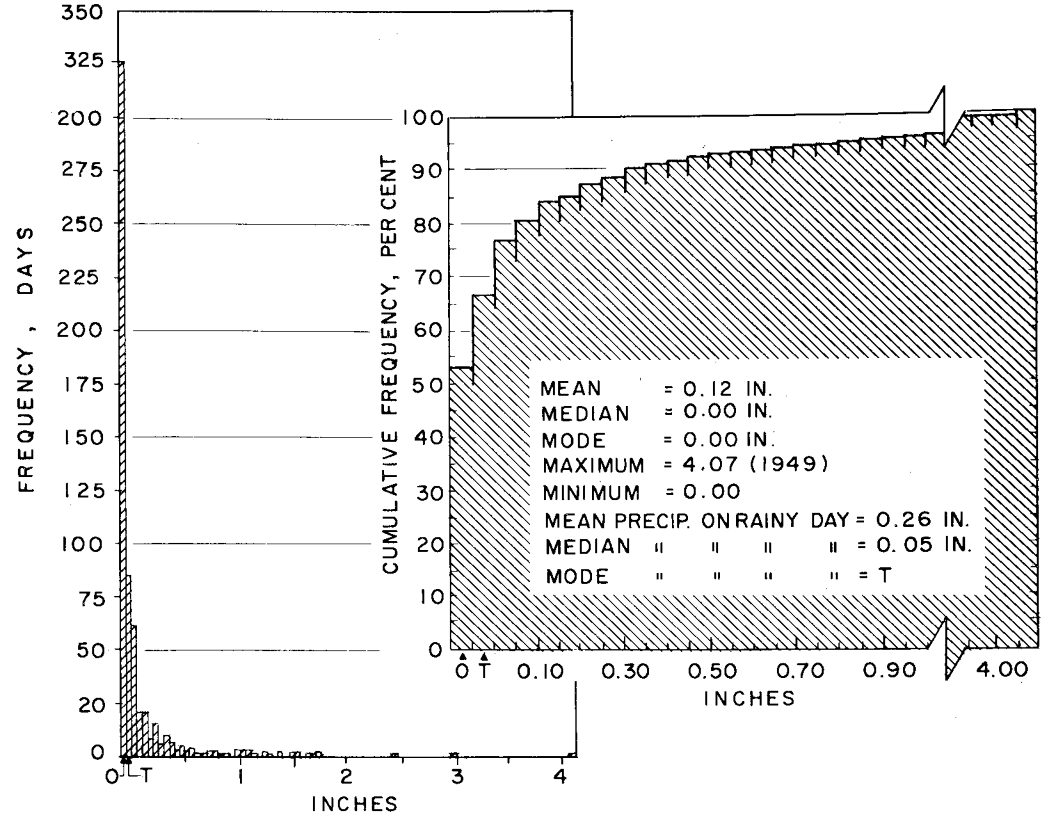


Figure 54. Frequency distribution and cumulative frequency distribution in inches of daily July precipitation in 1946-65, Minneapolis.

Our weather is never so safe that it destroys all initiative,
And never so bad that it destroys all hope.
L. P. Smith, *Farming Weather*

Long Term Precipitation Trends

Everyone is aware of the many short term fluctuations in precipitation that occur, for example, from week to week and year to year. But are these short term variations part of a broad general trend in the precipitation received?

The combined St. Paul-Minneapolis record of 1837-1965 (figure 55) is longer than any other record west of the Mississippi River and equal to records of all but a very few U.S. stations. However, complete confidence cannot be placed in this record because the stations were moved from time to time within the metropolitan area and, just as important, the record may have been influenced by urban growth and industrialization.

To verify as much of this record as possible, data from five rural northern stations are considered with these Twin Cities data. These five stations are Leech Lake Dam, Pine River Dam, Pokegama Dam, Sandy Lake Dam, and Winnibigoshish Dam. All apparently satisfy the climatological "benchmark" ideal (14); that is, the stations are rural in character and the environment changed little if any during the period of record.

Precipitation data shown in figure 56 are smoothed by a normal curve smoothing function of length $2\sigma = 9$ years (6) to eliminate the influence of year-to-year variation which might be compared to "noise" or "static." Therefore, any major trends are more apparent (compare figure 55 with figure 56). Values are plotted at the midpoint of the smoothing interval. Each season is considered as a 3-month period; the 1st month of spring, summer, fall, and winter is March, June, September, and December, respectively.

Figure 56 shows the seasonal and annual trends of precipitation at Minneapolis-St. Paul and the combined records of the five northern stations. Since records of Minneapolis-St. Paul and the northern stations are similar, the Twin Cities record apparently has not been unduly influenced by its ever changing environment. Statistical analysis of both records shows that there has been no definable long term trend in precipitation (table 3). However, the fall and winter precipitation totals show a slight but nonsignificant decreasing trend. The greatest decrease in precipitation at Minneapolis-St. Paul has occurred in fall.

Of course, there have been short continuous periods of both high and low precipitation—the drought of the 1930's is a bitter and still remembered example. This phenomenon is particularly evident in summer and annual precipitation. As shown in figure 56, this drought was not restricted to just the 1930's. From a peak reached in the early 1900's, precipitation progressively decreased almost without a break until about 1934. This fact, although not generally recognized, partly explains why the drought was so severe. If low precipitation during just 1 year created a drought, then a year such as 1910, when Minneapolis and St. Paul received only 11.59 and 10.21 inches, respectively, should have resulted in the most severe drought.

Table 3. Seasonal and annual precipitation changes over the indicated periods in inches*

Station	Period	Spring	Summer	Fall	Winter	Annual
St. Paul	1837-1965	0.57	−0.19	−1.09	−0.09	−0.86
St. Paul	1887-1965	0.17	0.07	−1.47	−0.35	−1.83
Five northern stations	1887-1965	0.72	−0.08	−0.10	−0.30	0.23

* Changes noted are based upon the best-fit linear trend line. None of the linear trend slopes is significantly greater than zero at the 5-percent level. Due to rounding errors and because the winter period used ended in February 1966, sums of seasonal changes do not exactly equal the annual change.

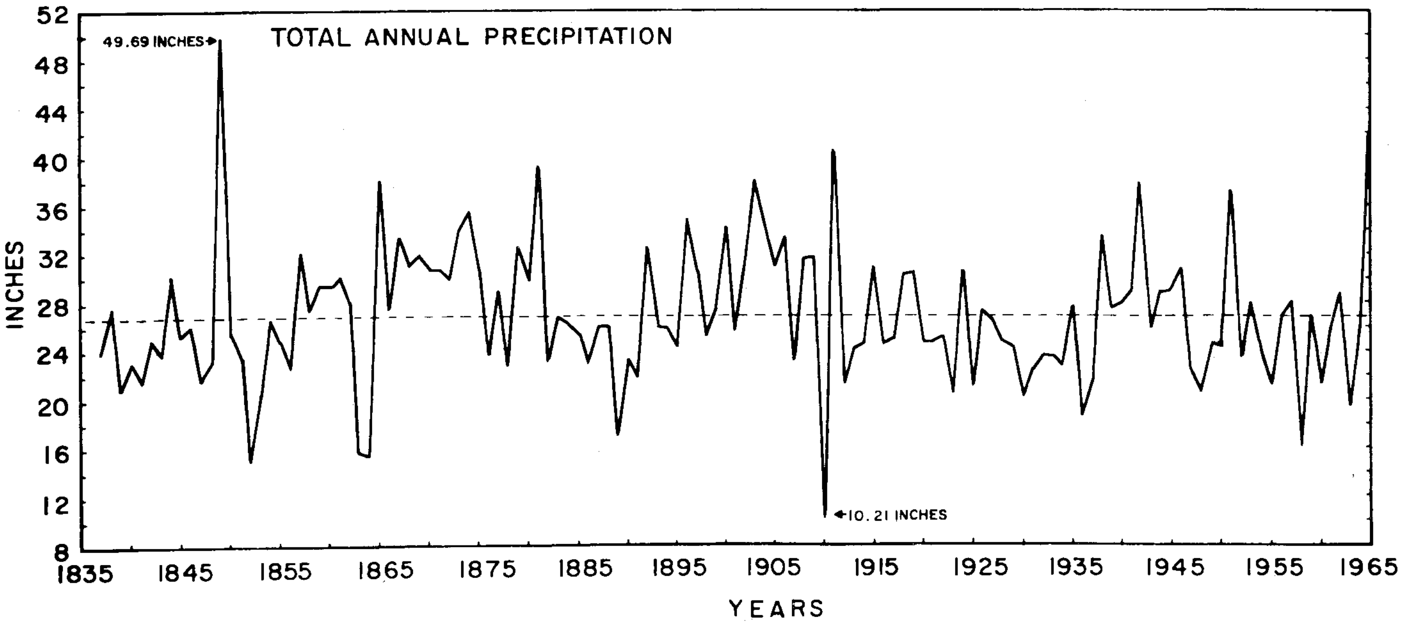


Figure 55. Annual precipitation in inches in 1837-1965, Minneapolis-St. Paul. The average annual precipitation, 26.85 inches, for this period is indicated by the dashed line.

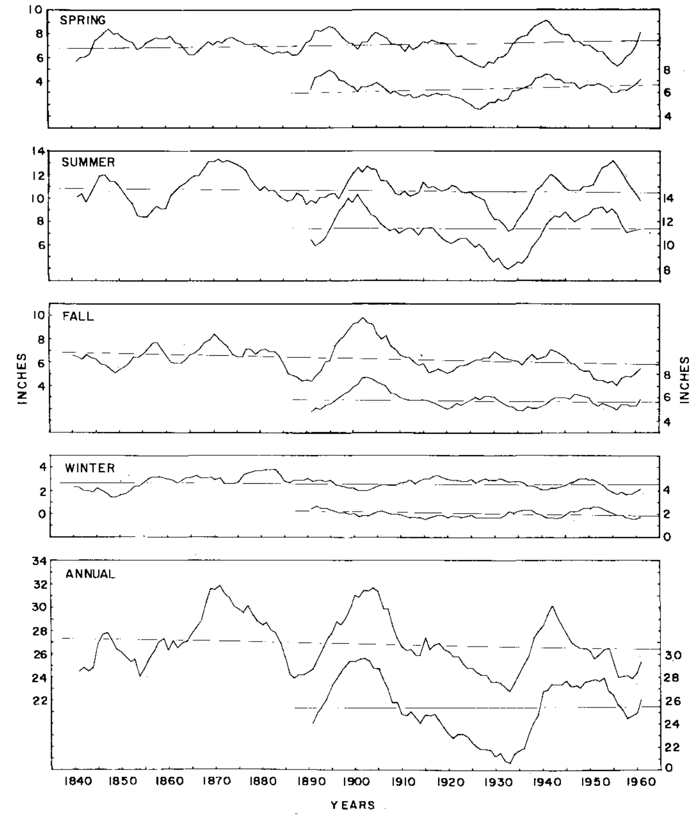


Figure 56. Time series of average seasonal and average annual precipitation for St. Paul-Minneapolis (longer record, scale at left) and the mean of five northern stations (shorter record, scale at right). Data are smoothed by a normal curve smoothing function of length $2\sigma = 9$ years. Values are plotted at the mid-point of the smoothing interval.

Good King Wenceslas look'd out,
On the Feast of Stephen;
When the snow lay round about,
Deep and crisp and even.
John Mason Neales, *Good King Wenceslas*

Snow

Snow amount, depth, and cover duration are important factors of the Minnesota climate. Snow can be a curse or blessing. The resort owner's livelihood depends upon sufficient winter snow to maintain ski trails. But heavy, frequent snow is the undoing of the motorist, cattleman, and wildlife.

The density of fresh snow largely depends upon the temperature of the air in which it forms and through which it falls. Thus, the densest snow occurs when the temperature is near 32° F. For this reason and because warm air can hold larger amounts of water than can cool air, Minnesota's heaviest snowfalls often occur in March rather than in the heart of winter.

New fallen snow may contain as much as 90 percent air or as little as 30 percent. In Minnesota the ratio of new snow to water equivalent is usually between 7 and 15 to 1; that is, it has a specific gravity of 0.07 to 0.15 (8). In other words, a fall of 7 to 15 inches of new snow equals about 1 inch of rain. However, other ratios are certainly not unusual. Determining the correct ratio is important for such things as flood forecasting or estimating snow weight on roofs. A 20-inch snow depth with a water equivalent of 2 inches represents 225 tons of water over an acre of land. The man shoveling snow from his sidewalk after a heavy, wet fall might have to lift 2 tons.

One study (16) contains national maps showing snow loads that may be expected once in 50 years. Such data are of special concern to structural engineers. Values are based on the water equivalence of snow accumulation on the ground for general elevations. Of course, unusual conditions such as drifting would alter the data. The maps were prepared from probability distributions of extreme annual water equivalents, using values from Weather Bureau first-order stations. Figure 57 shows the 50-year mean recurrence interval for Minnesota. This interval is most commonly used for building designs.

An idea of maximum accumulated depth of snow for state locations may be obtained by examining figure 58. The figure is based upon data from 45 stations reporting during 1949-65. Although the map does not necessarily give the maximum depths ever reported, it includes the

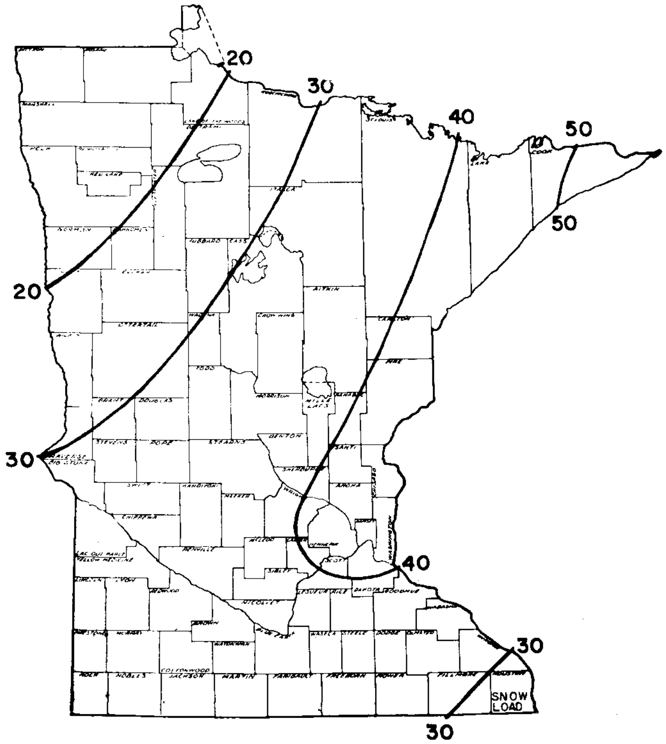


Figure 57. The 50-year mean recurrence interval of snow load, pounds per square foot, Minnesota (16).

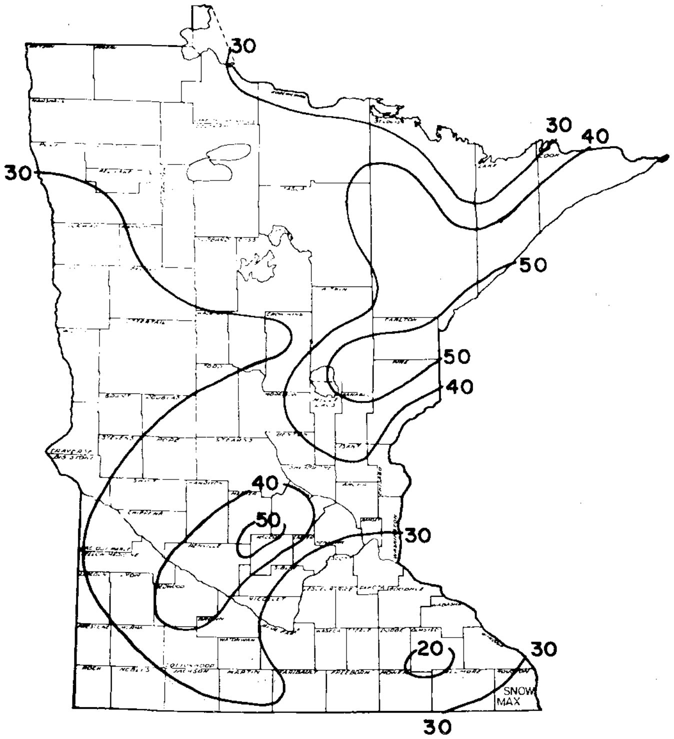


Figure 58. Maximum accumulated depth of snow on the ground in inches during 1949-65, Minnesota.

extremely heavy snow periods of 1950-51 and March 1965. Consequently, it gives the alltime maxima in some sectors, especially in the central and east central parts of the state. In Minnesota, 3- to 4-foot depths occur upon occasion. And when this happens, a modest home of 900 square feet may support a snow load of 10-20 tons.

During an average winter, extreme northern Minnesota can expect the first snowfall of 1 inch or more on or before November 10 (15). The southern area normally does not have snow of at least 1 inch until after November 20. Areas between these two sectors usually have their first snowfall sometime between these two dates.

The amount of snow to be expected during a normal (1931-60) winter season varies considerably across the state (figure 59). While the lowest annual snowfall amounts (under 40 inches per year) are found along the western border, a small section of northeastern Minnesota has almost double this amount (over 70 inches). The extreme eastern tip of this latter section averages over 100 inches a year.

Two of Minnesota's alltime snowfall extremes were set in the 1930's in eastern Cook County at Pigeon River. On April 4 and 5, 1933, the station recorded 28 inches of snow in a 24-hour period. During the 1936-37 season, the Pigeon River site received 147.5 inches of snow. These amounts are both state records. This station is in one of the few state locations subject to continuous climatic modification by Lake Superior. These high snowfalls undoubtedly were influenced by the moisture-laden winds from the lake.

The greatest recorded snowfall during a single storm, occurring at Duluth during December 5-8, 1950, was 35.2 inches. The record snowfall during a calendar month, 66.4 inches, occurred at St. Johns, Collegeville, Stearns County, during March 1965.

Because snowfall varies so much from the normals, extremes are important both temporally and spatially.

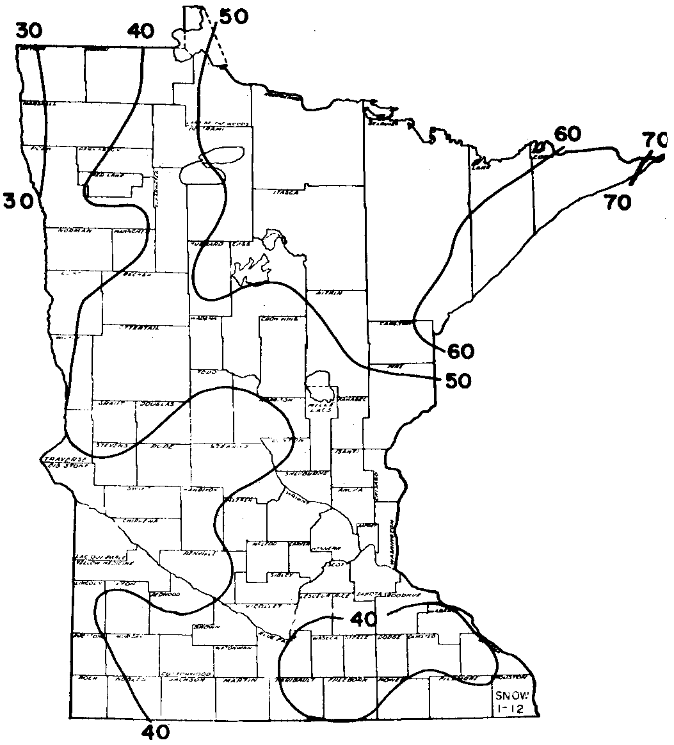


Figure 59. Normal (1931-60) annual snowfall in inches, Minnesota.

Table 4 shows monthly snowfall extremes recorded during the normal period (1931-60) by geographic division. The data were prepared by computing the total snowfall for all stations within each division each month and then obtaining an average of all stations for that division. The greatest and least figures obtained were tabulated for each month.

While March yields the highest figures in all but one of the nine sectors of the state, the other months do not

Table 4. Monthly snowfall extremes in inches for the normal period (1931-60) by region, Minnesota

Division		January	February	March	April	May	June	July	August	September	October	November	December
		inches											
Northwest	High	17.6	16.6	18.4	17.1	3.4	0	0	0	1.3	4.1	16.8	18.3
	Low	1.2	0.6	1.3	0	0	0	0	0	0	0	0.2	0.9
North Central	High	25.1	23.1	28.0	27.0	9.6	0.1	0	0	0.8	5.6	19.2	19.7
	Low	2.1	0.8	2.3	0	0	0	0	0	0	0	0.5	2.0
Northeast	High	32.4	19.6	25.1	10.3	1.8	0	0	0	1.9	8.6	21.9	22.0
	Low	2.4	2.4	0.1	0	0	0	0	0	0	0	0.7	1.1
West Central	High	23.0	18.3	36.0	11.7	4.3	0	0	0	2.6	7.1	20.4	14.3
	Low	0.3	0.3	1.5	0	0	0	0	0	0	0	0	0.2
Central	High	19.3	18.5	37.0	14.2	1.8	0	0	0	4.6	4.5	24.6	22.7
	Low	0.2	0.5	1.1	0	0	0	0	0	0	0	0.2	0.2
East Central	High	22.2	22.8	32.6	18.6	3.7	0.1	0	0	0.9	3.6	21.1	23.2
	Low	1.5	0.5	2.0	0	0	0	0	0	0	0	0.1	0.3
Southwest	High	18.8	26.0	30.9	8.2	3.4	0	0	0	1.1	1.6	19.3	17.5
	Low	0.2	0.7	1.7	0	0	0	0	0	0	0	0.1	0.1
South Central	High	22.9	27.9	33.9	8.8	1.6	0	0	0	2.6	1.9	17.3	23.0
	Low	1.4	0.3	2.4	0	0	0	0	0	0	0	0	0.3
Southeast	High	28.0	27.4	37.9	12.2	1.1	0	0	0	2.5	1.8	16.1	21.0
	Low	1.3	0.2	1.7	0	0	0	0	0	0	0	0	0

Table 5. Average annual number of 1-inch or more snowfalls and the percent chance that a snowstorm will produce snowfalls of given amounts at nine selected stations (data based upon normal period 1931-60)

Division	Station	Average annual number of snowfalls of 1 inch or more	Percent of the snowfalls resulting in totals of: 1-4 inches	4-8 inches	8-12 inches	12 inches or more
Northwest	Crookston	11.0	81	15	3	<1
North Central	Grand Rapids	15.6	75	20	4	<1
Northeast	Babbitt	18.8	83	13	4	<1
West Central	Fergus Falls	10.6	75	20	4	<1
Central	Wadena	11.4	73	22	4	<1
East Central	Minneapolis	10.6	76	17	6	1
Southwest	Worthington	9.7	74	20	5	<1
South Central	North Mankato	11.4	72	19	7	2
Southeast	Winona	9.8	69	19	8	4
Average		12.1	75.3	18.3	5.0	1.4

fall into as neat a pattern. December, January, and February have relatively high snow totals depending upon the division. In the central sector, November's average is second only to March. In the northwest and north central areas, the April high almost equals that of March. At the opposite extreme, very low snow averages can occur in any division over all months. The safest statement to be made concerning these data is that is impossible to fit the information into a simple state pattern.

The number of snowstorms to be expected each year and the amount of snowfall produced in each are as important as the annual averages and extremes. The average number of snowfalls of 1 inch or more was compiled for one station in each region with a category of depth of fall expressed as a percentage of the total number of falls (table 5). The northeast division, represented by Babbitt, has the greatest number of snowstorms per year, 18.8, but one of the lowest number of snowfalls of 12 or more inches, less than 1 percent. On the other hand, the southeast division, represented by Winona, has the second lowest number of snowstorms per year, 9.8, but the greatest percentage of falls of 12 or more inches, 4 percent.

The computed state averages probably are very close to the actual because the variance of the figures in any column is not great. In the 1-4 inch snowfall category, the range is only 14 percent (69 to 83 percent); in the 4-8 inch category, the range is just 9 percent (13 to 22 percent). In the 8-12 inch category, the range is 5 percent (3 to 8 percent); in the 12-inch or more column, the figures range from less than 1 to 4 percent. Therefore, a fair degree of confidence may be placed in the following probabilities:

- At a given Minnesota location, a snowstorm will produce less than 4 inches of new snow 75 percent of the time.

- Less than one storm in five will drop from 4 to 8 inches of snow in the area of its passage.

- Only 1 storm in 20 will produce from 8 to 12 inches of new snow.

- Only 1 or 2 storms in every 100 will yield 12 inches or more of snow at a given point.

This type of information is presented in a slightly different way in figure 60. Snowstorm data for Minneapolis were tabulated by total inches of fall per storm. Results are presented as percentage of occurrence for depths of 1 inch or more, 2 inches or more, and up to 16 inches or more. A plot of these data shows a surprisingly smooth approximation of an exponential curve. Examination shows that snowfalls of 3 inches or more account for less than 40 percent of the total and that the Twin Cities area averages about one storm a year with a 7-inch or greater fall.

The duration of snow cover after a storm depends upon several factors such as surface snow color and sunshine amount. (The reflectivity of newer snow is much

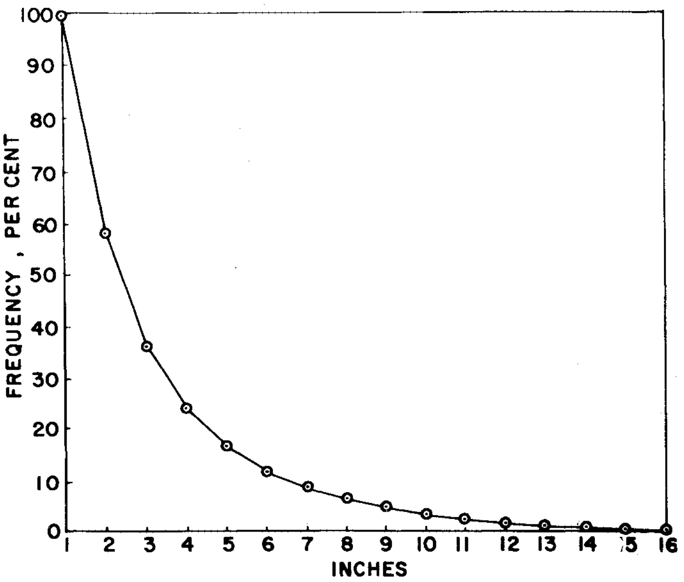


Figure 60. Snowstorm data presented as the frequency of occurrence of total inches of fall per storm in 1931-60, Minneapolis. As an example, a snowstorm will produce a snowfall of 4 inches or more 24 percent of the time.

higher than that of older, dirtier snow.) However, it primarily depends upon air temperature and snow depth. Figure 61 gives the average number of days each winter season that a snow cover of 1 inch or more on the ground may be expected. The data, based upon 34 stations, indicate a rather uniform pattern of increasing snow cover days from the south to the northeast. While extreme southern Minnesota experiences less than 90 days a season with snow cover, the northeast and much of the north-central area can expect at least an inch of snow cover for over 140 days each year.

The maximum and normal monthly snowfall totals for the 1931-60 period are listed in Appendix table 2.

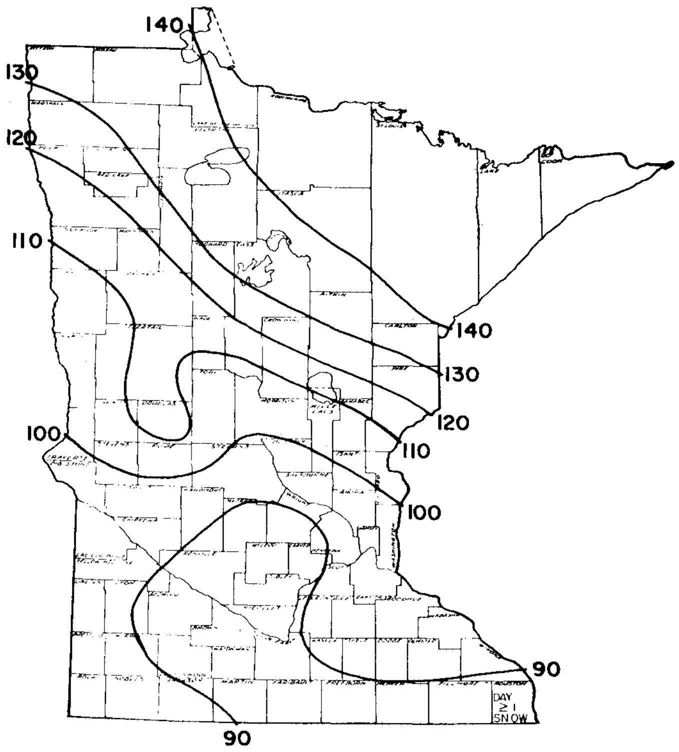


Figure 61. The average number of days per year with a snow cover of 1 inch or more on the ground in 1949-65, Minnesota.

Appendix Tables (20, 21)

Appendix Table 1. Monthly Maximum, Normal, and Minimum Total Precipitation in Inches, 1931-60.*

	J	F	M	A	M	J	J	A	S	O	N	D	Total
ADA													
Maximum	1.60	1.56	2.00	4.52	7.40	7.81	8.14	10.72	4.71	3.28	3.12	1.60	
Normal	0.51	0.55	0.74	1.64	2.81	3.80	3.16	3.35	1.67	1.11	0.98	0.56	20.88
Minimum	0.11	0.00	T	0.19	0.46	1.05	0.72	0.23	0.34	0.08	T	0.03	
ALBERT LEA													
Maximum	2.89	3.30	4.59	4.68	9.19	8.26	13.52	6.60	8.96	7.42	4.61	1.68	
Normal	0.77	0.81	1.70	2.21	4.09	4.39	3.80	3.56	3.05	1.90	1.49	0.91	28.68
Minimum	0.06	0.01	0.21	0.45	0.90	0.23	0.30	0.46	0.51	0.00	0.07	T	
ARTICHOKE LAKE													
Maximum	1.66	1.38	2.81	4.39	9.31	8.96	7.59	8.22	5.52	5.32	2.42	1.66	
Normal	0.40	0.44	0.94	1.93	2.84	3.72	3.23	3.27	1.85	1.42	0.92	0.49	21.45
Minimum	0.02	0.01	0.11	0.22	0.66	0.99	0.29	0.78	0.66	T	T	0.02	
BAUDETTE													
Maximum	1.62	1.30	1.59	5.04	4.08	7.12	12.50	7.26	6.82	3.52	3.15	1.68	
Normal	0.61	0.59	0.75	1.35	2.08	3.56	3.51	3.32	2.39	1.45	1.17	0.63	21.41
Minimum	0.13	0.09	0.07	0.18	0.35	1.08	1.40	0.83	0.11	0.33	0.11	0.05	
BEARDSLEY													
Maximum	1.72	2.10	3.23	6.06	6.86	7.45	7.55	6.47	3.93	3.60	2.23	1.80	
Normal	0.58	0.69	1.08	2.17	2.82	4.13	2.79	2.80	1.69	1.26	0.87	0.57	21.45
Minimum	T	0.05	0.12	0.32	0.89	1.16	0.18	0.72	0.23	T	0.05	T	
BEMIDJI													
Maximum	2.03	1.68	2.14	4.38	6.43	5.94	13.44	9.49	4.46	3.46	2.55	3.16	
Normal	0.65	0.51	0.94	1.80	2.59	3.72	3.10	3.34	1.97	1.32	1.05	0.67	21.66
Minimum	0.09	0.03	0.13	0.25	0.88	1.02	0.48	0.65	0.35	0.16	0.09	0.14	
BIRD ISLAND													
Maximum	1.81	2.54	4.86	4.93	8.73	12.88	12.12	7.78	8.01	4.69	3.81	2.21	
Normal	0.75	0.92	1.59	2.18	3.66	4.75	3.35	3.85	2.58	1.56	1.38	0.76	27.33
Minimum	T	T	0.29	0.36	0.80	1.30	0.52	0.65	0.33	0.03	0.23	0.13	
BRAINERD													
Maximum	2.85	1.80	3.17	5.34	9.40	8.13	9.92	7.78	4.72	5.37	2.90	1.85	
Normal	0.76	0.67	1.02	1.99	3.41	4.01	3.20	4.24	2.04	1.67	1.17	0.64	24.82
Minimum	0.04	T	0.14	0.51	0.37	1.18	0.38	0.63	0.17	0.05	0.05	0.11	

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*T signifies a "trace" of precipitation, i.e., less than 0.005 inches.

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
CASS LAKE													
Maximum	2.28	1.49	2.34	4.24	7.35	8.76	11.20	11.48	5.57	4.13	3.39	2.56	
Normal	0.71	0.55	1.01	1.93	3.21	3.92	3.40	3.45	2.21	1.47	1.26	0.70	23.82
Minimum	0.08	0.04	0.14	0.24	0.75	1.45	0.40	1.09	0.34	0.30	0.12	0.08	
CHASKA													
Maximum	1.95	1.69	3.17	4.11	8.55	9.00	8.06	7.94	8.66	4.93	3.32	1.98	
Normal	0.54	0.69	1.40	1.90	4.04	4.88	3.87	3.59	2.60	1.59	1.31	0.71	27.12
Minimum	0.02	0.05	0.23	0.29	0.45	0.95	0.58	0.79	0.37	T	0.25	T	
CLOQUET													
Maximum	2.54	2.60	3.31	4.80	7.77	9.73	8.60	7.22	6.33	5.70	3.47	2.36	
Normal	1.13	0.89	1.60	2.29	3.72	4.32	3.64	3.90	2.83	2.13	1.69	0.98	29.12
Minimum	0.15	0.11	0.15	0.41	0.65	0.84	0.54	0.76	0.43	0.32	0.18	T	
CROOKSTON													
Maximum	1.96	1.76	2.29	4.26	5.48	7.44	5.91	8.24	4.72	2.75	2.55	1.64	
Normal	0.57	0.55	0.89	1.36	2.50	3.59	2.95	3.24	1.86	1.31	0.94	0.58	20.34
Minimum	0.06	0.02	0.14	0.05	0.36	1.02	0.52	0.91	0.25	0.16	0.14	0.07	
DETROIT LAKES													
Maximum	2.25	2.32	3.07	5.00	6.64	10.33	12.15	10.66	4.21	3.72	2.30	1.92	
Normal	0.68	0.65	0.91	2.09	2.93	3.95	3.47	3.95	1.92	1.30	1.02	0.70	23.57
Minimum	0.08	T	T	0.31	0.73	0.67	0.40	0.63	0.52	0.22	0.14	0.06	
DULUTH													
Maximum	2.61	3.20	3.84	5.84	6.45	7.51	8.48	6.64	6.28	7.53	3.89	3.69	
Normal	0.15	0.96	1.62	2.36	3.29	4.27	3.54	3.81	2.86	2.17	1.78	1.16	28.97
Minimum	0.14	0.25	0.22	0.59	0.86	0.93	0.63	0.29	0.19	0.13	0.16	0.16	
FAIRMONT													
Maximum	2.20	2.75	5.75	4.84	10.41	10.14	7.15	8.80	9.62	6.27	3.21	2.48	
Normal	0.83	0.91	1.72	2.40	3.86	4.64	3.38	3.97	2.88	1.58	1.41	0.91	28.49
Minimum	0.05	0.09	0.36	0.71	0.34	1.02	0.19	0.84	0.62	T	0.02	0.07	
FARIBAULT													
Maximum	2.26	2.16	3.89	4.33	7.89	12.02	8.46	8.26	6.77	4.00	4.21	2.05	
Normal	0.72	0.74	1.52	2.09	3.56	4.91	3.52	3.99	2.78	1.56	1.26	0.92	27.57
Minimum	T	0.09	0.37	0.42	0.18	1.25	0.18	0.82	0.26	T	0.00	T	
FARMINGTON													
Maximum	2.65	2.24	4.83	3.99	9.28	9.10	8.37	11.76	12.68	5.36	5.17	3.18	
Normal	0.85	0.92	1.64	2.02	3.76	4.60	3.55	3.98	2.93	1.70	1.54	0.97	28.46
Minimum	T	0.07	0.41	0.62	0.22	0.64	0.35	1.14	0.10	T	T	0.00	

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
FERGUS FALLS													
Maximum	2.11	1.88	3.12	4.91	6.95	9.38	9.42	5.61	4.82	4.50	2.13	1.80	
Normal	0.77	0.68	1.21	2.24	3.04	4.39	3.09	3.11	1.73	1.33	0.99	0.81	23.39
Minimum	0.02	T	0.11	0.23	0.74	1.24	0.05	1.31	0.18	0.17	0.05	0.10	
FOSSTON													
Maximum	2.10	2.99	2.38	4.63	5.84	10.67	6.79	11.41	6.60	3.56	2.81	1.74	
Normal	0.77	0.59	0.99	1.81	2.64	4.17	3.22	3.40	1.95	1.26	1.08	0.67	22.55
Minimum	0.09	T	0.08	0.12	0.63	1.14	1.22	0.75	0.20	T	0.07	0.05	
GRAND MEADOW													
Maximum	2.63	2.75	4.89	5.21	6.78	9.14	9.71	8.82	7.57	3.90	5.80	2.19	
Normal	0.99	0.90	1.99	2.39	3.75	5.07	3.24	4.04	3.25	1.75	1.69	0.95	30.01
Minimum	0.06	T	0.45	0.55	0.91	0.62	0.73	0.37	0.44	0.05	0.02	0.01	
GRAND RAPIDS													
Maximum	2.13	1.76	2.30	4.06	6.76	7.69	9.04	7.60	6.50	4.97	5.38	2.59	
Normal	0.82	0.70	1.13	1.97	3.26	3.56	3.82	3.44	2.72	1.87	1.57	0.82	25.68
Minimum	0.19	0.05	0.15	0.15	0.39	0.60	0.75	0.85	0.66	0.15	0.07	0.16	
GULL LAKE DAM													
Maximum	2.12	2.21	2.73	6.25	7.31	10.55	9.13	8.26	5.94	5.54	2.75	1.79	
Normal	0.73	0.74	1.25	2.34	3.81	4.37	3.32	4.19	2.31	1.78	1.24	0.70	26.78
Minimum	T	T	0.18	0.29	0.48	1.20	0.24	1.02	0.32	0.05	0.02	0.01	
HALLOCK													
Maximum	1.57	1.45	3.51	5.63	5.12	6.20	7.23	8.26	11.91	4.76	3.95	1.45	
Normal	0.65	0.56	0.89	1.48	2.12	3.04	2.88	3.02	2.73	1.36	0.92	0.55	20.20
Minimum	0.09	T	T	0.10	0.28	0.91	0.28	0.35	0.03	0.07	0.01	0.02	
INTERNATIONAL FALLS													
Maximum	1.70	1.81	2.07	2.78	5.83	8.19	8.08	11.26	6.79	4.66	2.89	1.67	
Normal	0.84	0.71	1.03	1.56	2.61	3.87	3.49	3.64	2.90	1.74	1.46	0.84	24.69
Minimum	0.17	0.27	0.29	0.33	0.48	0.70	1.00	1.09	0.28	0.22	0.34	0.16	
ITASCA													
Maximum	1.93	1.85	2.95	4.06	7.32	10.80	13.15	7.92	5.92	4.24	2.61	3.68	
Normal	0.75	0.62	1.23	2.31	3.36	4.18	3.58	3.50	2.08	1.51	1.30	0.83	25.25
Minimum	T	T	0.23	0.16	1.09	1.28	0.99	0.91	0.35	0.14	0.09	0.14	
LEECH LAKE DAM													
Maximum	1.49	1.41	2.44	4.63	6.30	8.33	12.27	8.64	5.34	3.85	3.40	2.00	
Normal	0.69	0.55	0.97	2.12	3.16	3.95	4.08	3.32	2.34	1.57	1.23	0.73	24.71
Minimum	0.15	0.01	0.09	0.51	0.59	0.85	0.25	0.77	0.38	0.12	0.13	0.09	

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
MAHNOMEN													
Maximum	1.28	1.38	1.92	3.90	9.10	6.97	8.84	8.13	5.62	3.09	3.32	1.91	
Normal	0.52	0.47	0.77	1.72	2.64	3.83	3.25	3.44	1.88	1.18	0.97	0.57	21.24
Minimum	0.02	T	0.05	0.01	0.28	1.26	1.02	0.94	0.23	0.04	0.05	T	
MAHONING MINE													
Maximum	1.83	1.68	1.91	4.12	6.20	7.62	7.44	7.32	8.67	4.83	2.80	2.08	
Normal	0.73	0.59	1.05	1.88	2.83	3.57	3.80	3.32	2.93	1.71	1.29	0.76	24.46
Minimum	0.14	0.03	0.19	0.54	0.29	0.65	0.95	1.20	0.50	0.15	0.13	0.09	
MANKATO													
Maximum	2.50	2.04	4.98	4.49	7.09	9.74	5.80	10.33	9.98	4.91	3.95	2.04	
Normal	0.79	0.92	1.88	2.23	3.77	4.89	3.20	3.97	2.66	1.51	1.53	0.90	28.25
Minimum	0.03	0.02	0.52	0.49	0.17	0.93	0.21	0.82	0.36	0.00	0.00	T	
MAPLE PLAIN													
Maximum	2.10	2.33	3.44	5.86	9.91	10.72	12.12	7.04	7.26	4.24	4.78	2.30	
Normal	0.93	0.99	1.97	2.25	3.77	4.77	3.70	3.79	2.57	1.59	1.70	0.98	28.83
Minimum	0.04	0.07	0.26	0.39	0.13	1.40	0.30	0.23	0.36	0.02	T	T	
MEADOWLANDS													
Maximum	1.88	2.35	2.04	6.00	6.45	10.92	11.25	10.32	6.91	5.84	2.76	2.29	
Normal	0.81	0.63	1.05	2.15	3.20	3.96	4.13	4.12	3.16	1.93	1.36	0.71	27.21
Minimum	0.04	0.00	0.12	0.45	0.63	0.68	0.86	1.07	0.63	0.17	0.01	0.11	
MILACA													
Maximum	1.71	2.25	3.07	7.26	7.86	15.00	7.05	8.79	5.61	4.33	3.70	2.18	
Normal	0.82	0.84	1.32	2.22	3.68	4.70	3.52	4.12	2.59	1.94	1.48	0.84	28.07
Minimum	0.02	0.02	0.21	0.61	0.48	0.29	0.05	0.21	0.37	T	T	0.00	
MILAN													
Maximum	1.85	2.70	3.22	5.31	10.67	11.46	6.16	11.15	5.39	5.79	2.96	2.40	
Normal	0.68	0.81	1.32	2.18	2.84	4.12	2.79	3.63	1.98	1.42	1.10	0.76	23.63
Minimum	T	T	0.25	0.25	0.36	1.10	0.08	0.50	0.22	0.05	0.03	T	
MINNEAPOLIS													
Maximum	1.65	2.66	3.37	3.53	7.87	7.80	7.10	6.60	7.53	5.64	5.15	1.99	
Normal	0.70	0.78	1.53	1.85	3.19	4.00	3.27	3.18	2.43	1.59	1.40	0.86	24.78
Minimum	0.11	0.14	0.48	0.62	0.74	1.26	0.11	0.43	0.41	0.26	0.27	0.06	
MONTEVIDEO													
Maximum	1.86	2.34	4.33	5.57	7.66	11.01	6.96	9.21	8.94	3.61	3.84	2.37	
Normal	0.65	0.78	1.47	2.03	3.07	4.74	3.02	3.90	2.51	1.47	1.23	0.77	25.64
Minimum	0.03	0.01	0.24	0.31	0.46	0.34	0.12	0.59	0.38	0.04	0.01	0.00	

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
MORA													
Maximum	2.15	2.12	2.66	5.86	8.42	12.96	8.28	6.50	5.89	5.12	4.16	1.91	
Normal	0.88	0.85	1.35	2.22	3.71	4.90	3.29	3.92	2.59	1.94	1.66	0.87	28.16
Minimum	0.12	0.04	0.22	0.49	0.73	0.80	0.22	0.34	0.27	0.09	0.01	T	
MORRIS													
Maximum	2.55	1.82	3.82	8.54	8.89	6.93	9.77	6.58	5.94	4.12	2.50	1.90	
Normal	0.57	0.66	1.14	2.41	2.96	3.94	3.18	3.03	1.89	1.45	1.01	0.61	22.58
Minimum	0.01	0.01	0.12	0.29	0.98	1.08	0.34	0.14	0.43	0.01	0.07	0.00	
NEW LONDON													
Maximum	2.88	2.06	2.82	4.55	8.33	13.73	6.37	9.03	7.77	4.53	3.88	2.06	
Normal	0.69	0.70	1.25	2.03	3.18	4.74	3.02	3.83	2.70	1.63	1.23	0.69	25.69
Minimum	T	0.02	0.04	0.18	0.15	1.56	0.38	0.27	0.56	T	T	T	
NEW ULM													
Maximum	2.53	3.20	5.24	5.31	8.66	9.69	7.27	10.07	6.69	5.90	4.08	3.46	
Normal	1.00	1.07	2.05	2.31	3.71	4.91	2.96	4.04	2.77	1.84	1.52	1.17	29.35
Minimum	0.03	0.18	0.28	0.41	0.57	1.26	0.50	0.37	0.31	T	T	0.15	
PARK RAPIDS													
Maximum	2.90	2.04	3.60	5.58	7.51	9.26	11.60	11.79	4.74	4.25	3.24	3.16	
Normal	0.97	0.78	1.40	2.31	3.55	3.95	3.50	4.03	2.04	1.52	1.32	1.02	26.39
Minimum	0.12	0.01	0.19	0.37	0.67	0.97	0.20	0.89	0.20	0.22	0.19	0.21	
PINE RIVER DAM													
Maximum	1.86	2.25	2.34	4.81	8.59	8.73	7.66	7.55	6.92	5.65	3.09	1.62	
Normal	0.73	0.65	1.20	2.20	3.68	4.30	3.30	4.01	2.36	1.80	1.30	0.69	26.22
Minimum	0.04	T	0.21	0.31	0.45	1.41	0.24	0.45	0.49	0.12	0.05	0.02	
PIPESTONE													
Maximum	1.26	1.95	3.58	4.76	10.85	9.02	6.62	7.31	6.21	4.68	2.88	1.99	
Normal	0.49	0.69	1.30	2.10	3.23	4.66	2.87	3.29	2.85	1.40	0.91	0.58	24.47
Minimum	0.02	0.02	0.12	0.45	0.55	1.29	0.18	0.35	T	T	T	0.03	
POKEGAMA DAM													
Maximum	1.67	1.85	2.34	4.44	5.75	6.96	9.08	8.74	6.58	4.35	4.42	2.32	
Normal	0.68	0.59	1.04	2.09	3.12	3.54	3.97	3.59	2.71	1.76	1.37	0.70	25.16
Minimum	0.13	0.03	0.11	0.42	0.39	0.73	0.56	1.22	0.49	0.08	0.03	0.14	
RED WING													
Maximum	2.50	2.62	3.92	4.67	8.27	10.02	8.07	8.29	7.73	5.44	4.15	2.50	
Normal	0.92	0.88	1.77	2.28	3.54	5.01	3.86	3.60	3.05	1.72	1.64	1.07	29.34
Minimum	0.05	0.06	0.28	0.72	0.34	1.20	0.52	1.01	0.40	T	0.53	T	

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
REDWOOD FALLS													
Maximum	1.47	2.52	3.15	4.37	7.93	11.59	7.54	7.28	6.47	3.62	5.18	2.11	
Normal	0.54	0.77	1.38	1.97	3.27	4.28	2.84	3.21	2.15	1.36	1.18	0.64	23.59
Minimum	T	T	0.13	0.31	0.73	1.39	0.71	0.40	0.35	T	T	T	
ROCHESTER													
Maximum	2.19	2.03	4.01	5.34	7.28	7.41	8.14	6.51	7.95	3.17	4.50	2.18	
Normal	0.91	0.80	1.64	2.19	3.65	4.46	3.68	3.79	3.10	1.70	1.57	0.97	28.93
Minimum	0.13	0.18	0.59	0.46	0.40	1.67	0.41	0.31	1.03	0.01	0.09	0.01	
ROSEAU													
Maximum	1.33	1.35	2.47	4.27	4.37	5.93	6.45	5.96	8.31	3.62	2.16	1.39	
Normal	0.55	0.46	0.92	1.34	2.15	3.01	2.98	3.13	2.40	1.39	0.85	0.54	19.72
Minimum	0.11	0.05	T	0.09	0.40	1.25	0.51	0.84	0.40	0.07	0.12	0.19	
ST. CLOUD													
Maximum	2.12	2.76	2.61	3.62	6.80	9.34	8.00	7.55	6.12	4.24	4.02	1.80	
Normal	0.72	0.80	1.28	2.02	3.51	4.49	3.26	3.73	2.41	1.64	1.33	0.73	25.92
Minimum	0.02	0.09	0.27	0.25	0.88	0.80	0.94	0.42	0.07	0.07	0.01	0.07	
ST. PETER													
Maximum	2.82	1.97	3.34	5.08	8.84	11.46	9.52	7.58	8.41	5.63	3.86	2.21	
Normal	0.85	0.88	1.62	2.16	3.63	5.28	3.19	3.78	2.75	1.55	1.54	0.93	28.16
Minimum	0.03	0.09	0.29	0.55	0.16	1.22	0.50	1.04	0.51	T	T	T	
SANDY LAKE DAM LIBBY													
Maximum	2.01	1.67	2.43	4.50	6.91	12.42	11.12	12.96	6.83	5.80	3.03	1.78	
Normal	0.72	0.64	1.15	2.18	3.69	4.23	3.88	3.92	2.52	1.83	1.31	0.68	26.75
Minimum	0.16	0.01	0.13	0.40	0.77	1.44	0.41	0.61	0.44	0.20	0.05	0.06	
TOWER													
Maximum	1.85	1.91	2.52	4.16	7.65	8.71	7.05	8.18	8.59	5.53	3.96	2.47	
Normal	0.87	0.69	1.20	2.12	3.16	3.98	3.55	4.20	3.08	2.05	1.75	0.88	27.53
Minimum	0.20	0.03	0.19	0.53	0.73	0.68	1.27	1.15	0.56	0.42	0.19	0.20	
TRACY													
Maximum	1.19	1.49	3.06	5.15	6.46	7.80	7.48	6.04	7.66	3.49	3.94	2.51	
Normal	0.47	0.64	1.28	1.99	3.31	4.15	2.86	2.72	2.48	1.22	1.11	0.56	22.79
Minimum	0.01	0.00	0.15	0.28	0.83	1.28	0.51	0.33	0.44	0.00	T	T	
VIRGINIA													
Maximum	2.21	1.79	2.72	4.98	4.84	9.31	9.24	7.24	9.41	5.37	3.08	2.61	
Normal	0.95	0.69	1.26	2.11	2.90	3.76	3.76	3.78	3.04	1.98	1.76	0.92	26.91
Minimum	0.26	0.14	0.20	0.49	0.63	1.17	0.65	1.34	0.29	0.31	0.12	0.13	

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
WADENA													
Maximum	2.09	1.54	2.91	4.94	6.87	10.44	9.26	8.40	5.21	5.00	3.02	2.72	
Normal	0.73	0.72	1.26	2.36	3.09	4.21	3.38	4.14	2.00	1.63	1.25	0.72	25.49
Minimum	0.03	0.02	0.10	0.44	0.37	1.36	0.53	0.81	0.30	0.10	0.02	0.07	
WALKER AH GWAH CHING													
Maximum	1.82	1.69	2.60	4.09	7.36	7.65	13.51	9.23	5.77	4.57	3.03	2.31	
Normal	0.70	0.62	1.06	1.99	3.44	3.96	3.81	3.69	2.27	1.51	1.17	0.76	24.98
Minimum	0.08	T	0.22	0.02	0.20	0.96	0.27	1.08	0.18	0.08	0.05	T	
WARROAD													
Maximum	1.73	1.79	2.89	4.13	4.65	8.55	8.33	5.14	9.88	5.01	2.79	1.96	
Normal	0.74	0.61	0.97	1.40	2.10	3.25	3.36	2.92	2.30	1.42	1.16	0.76	20.99
Minimum	0.18	0.06	0.25	0.10	0.27	1.03	0.67	1.29	0.29	0.20	0.18	0.21	
WASECA													
Maximum	2.54	2.41	4.85	5.49	7.78	8.79	8.55	10.11	6.19	4.22	4.39	2.64	
Normal	0.86	0.96	1.76	2.33	3.68	4.58	3.26	3.47	2.92	1.54	1.56	0.93	27.85
Minimum	0.12	T	0.32	0.38	0.14	1.01	0.42	0.41	0.46	T	0.00	0.04	
WHEATON													
Maximum	2.71	2.05	3.08	6.33	7.41	10.20	6.94	7.15	5.25	4.37	2.56	1.60	
Normal	0.62	0.70	1.14	2.25	3.01	4.48	2.85	2.73	1.75	1.30	1.08	0.57	22.48
Minimum	T	T	0.11	0.37	0.78	1.03	0.69	0.34	0.51	T	T	T	
WILLMAR													
Maximum	1.87	1.81	3.84	4.86	7.10	12.94	8.12	8.10	11.13	4.23	3.28	1.73	
Normal	0.58	0.66	1.16	2.04	3.22	4.48	2.81	3.60	2.67	1.73	1.65	0.57	24.47
Minimum	T	T	0.14	0.27	0.29	1.25	0.59	0.31	0.81	0.02	0.03	0.00	
WINNEBAGO													
Maximum	2.06	2.21	4.33	4.49	8.73	10.71	7.79	10.18	8.48	4.31	3.67	1.88	
Normal	0.78	0.80	1.55	2.09	4.11	4.87	3.47	3.69	2.92	1.43	1.44	0.93	28.08
Minimum	0.06	T	0.34	0.57	0.41	1.50	0.58	0.98	0.60	0.00	0.02	0.03	
WINNIBIGOSHISH DAM													
Maximum	1.84	1.83	2.16	5.16	5.69	8.03	10.70	7.86	4.79	3.40	2.73	2.12	
Normal	0.75	0.62	0.98	2.06	2.83	3.66	3.75	3.22	2.38	1.47	1.24	0.71	23.67
Minimum	0.08	0.05	0.09	0.49	0.49	0.94	0.59	0.55	0.24	0.12	0.06	0.04	
WINONA													
Maximum	2.93	2.52	5.30	4.51	8.73	7.52	7.77	5.97	8.38	5.68	5.52	1.97	
Normal	1.05	0.93	1.85	2.35	4.17	4.68	3.68	3.81	3.20	1.85	2.23	0.94	30.74
Minimum	0.15	0.04	0.22	0.61	0.84	0.29	0.13	1.80	0.41	0.15	0.11	T	

Appendix Table 1. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
WORTHINGTON													
Maximum	1.89	1.74	4.55	4.80	8.82	9.19	7.10	6.90	11.16	3.65	3.54	1.86	
Normal	0.59	0.75	1.63	2.09	3.46	3.82	3.24	3.70	2.77	1.54	1.14	0.74	26.47
Minimum	T	0.03	0.37	0.53	0.20	2.04	0.30	0.61	0.44	0.00	0.03	0.02	
ZUMBROTA													
Maximum	2.34	2.37	3.57	4.67	8.07	7.56	9.94	9.76	9.05	5.22	5.07	1.57	
Normal	0.79	0.71	1.51	2.23	3.49	4.44	3.67	3.81	3.38	1.75	1.42	0.82	28.02
Minimum	0.10	T	0.30	0.50	0.18	1.90	0.74	0.88	0.35	0.00	0.03	T	

Appendix Table 2. Maximum and Normal Snowfall for the Period 1931-60 except as noted.*

	J	F	M	A	M	J	J	A	S	O	N	D	Total
ALBERT LEA													
Maximum	28.0	32.5	31.0	16.0	0.5	0.0	0.0	0.0	2.0	4.0	19.4	22.0	
Normal	7.6	8.0	11.1	2.3	T	0.0	0.0	0.0	T	0.3	4.8	7.4	41.5
BRAINERD													
Maximum	38.2	27.0	39.5	22.5	5.0	0.0	0.0	0.0	2.0	7.0	24.0	21.0	
Normal	11.6	10.5	10.3	3.6	0.5	0.0	0.0	0.0	0.1	0.9	7.5	8.7	53.7
CANBY													
Maximum	14.0	22.9	36.0	12.0	1.5	0.0	0.0	0.0	1.0	5.0	25.0	15.0	
Normal	5.8	7.9	9.5	2.9	0.2	0.0	0.0	0.0	0.0	0.6	6.3	5.7	38.9
CROOKSTON													
Maximum	21.5	16.5	21.3	17.9	4.0	0.0	0.0	0.0	0.6	5.1	32.5	17.4	
Normal	8.4	6.8	8.1	3.2	0.3	0.0	0.0	0.0	T	0.6	7.5	7.2	42.1
DULUTH													
Maximum	39.3	31.5	45.5	31.5	8.1	0.2	0.0	T	T	14.0	28.9	44.3	
Normal	13.1	12.1	14.5	6.8	0.9	T	0.0	0.0	T	1.4	8.2	12.4	69.4
FAIRMONT													
Maximum	27.5	23.2	29.4	9.0	0.5	0.0	0.0	0.0	2.0	2.8	16.0	15.1	
Normal	8.1	8.2	10.9	1.8	T	0.0	0.0	0.0	0.1	0.3	5.0	8.0	42.4
FARMINGTON (1929-58)													
Maximum	26.5	22.5	43.0	10.2	3.0	0.0	0.0	0.0	1.5	2.0	25.0	20.0	
Average	8.2	8.2	9.9	2.2	0.1	0.0	0.0	0.0	0.1	0.1	6.2	8.3	43.3
FERGUS FALLS (1928-57)													
Maximum	20.8	24.1	28.6	14.3	7.9	0.0	0.0	0.0	2.6	4.0	22.0	15.5	
Average	8.8	8.5	8.6	3.4	0.4	0.0	0.0	0.0	0.1	0.8	6.1	7.6	43.9
GRAND RAPIDS (1928-57)													
Maximum	25.0	26.0	31.5	29.5	9.0	T	0.0	0.0	0.8	13.0	23.8	26.5	
Average	10.9	8.8	9.1	3.9	0.9	T	0.0	0.0	T	1.7	7.6	10.1	53.0
HALLOCK (1928-57)													
Maximum	25.5	19.5	22.0	8.0	2.0	0.0	0.0	0.0	1.5	5.5	31.0	18.5	
Average	8.1	6.1	6.6	1.7	0.2	0.0	0.0	0.0	0.1	1.0	5.6	6.3	35.7
INTERNATIONAL FALLS													
Maximum	23.1	25.8	31.5	23.0	13.4	0.0	0.0	0.0	1.9	5.4	29.7	22.6	
Normal	9.5	8.7	9.6	6.2	1.0	0.0	0.0	0.0	0.2	1.2	11.3	10.1	57.8

* T signifies a "trace" of snow, i.e., an amount too small to measure.

Appendix Table 2. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
JORDAN (1949-63)													
Maximum	12.0	34.0	45.9	11.2	T	0.0	0.0	0.0	0.0	8.5	8.0	22.3	
Average	5.4	7.4	12.3	2.1	0.0	0.0	0.0	0.0	0.0	0.6	3.0	5.3	36.1
MARSHALL (1936-63)													
Maximum	14.2	32.3	35.0	12.5	2.5	0.0	0.0	0.0	1.1	3.0	24.0	17.4	
Average	6.1	9.8	10.8	3.2	0.1	0.0	0.0	0.0	T	0.3	6.2	6.8	43.3
MINNEAPOLIS													
Maximum	17.0	26.5	40.0	9.6	3.0	0.0	0.0	0.0	1.7	3.7	26.3	25.0	
Normal	6.3	8.0	11.5	2.7	0.2	0.0	0.0	0.0	0.1	0.3	6.1	7.0	42.2
MONTEVIDEO													
Maximum	18.0	22.2	44.0	10.0	2.0	0.0	0.0	0.0	1.0	5.0	17.6	17.0	
Normal	5.7	6.4	8.4	2.5	0.1	0.0	0.0	0.0	T	0.4	4.7	5.6	33.8
MORRIS (1930-59)													
Maximum	22.5	17.0	46.5	12.5	4.0	0.0	0.0	0.0	5.5	9.5	23.3	18.0	
Average	6.7	7.5	8.1	2.9	0.3	0.0	0.0	0.0	0.2	0.7	5.3	5.9	37.6
PIPESTONE													
Maximum	13.2	24.4	26.7	7.0	1.5	0.0	0.0	0.0	T	6.0	17.2	15.9	
Normal	5.0	6.7	9.9	2.4	0.1	0.0	0.0	0.0	T	0.4	4.0	5.5	34.0
ROCHESTER													
Maximum	11.8	19.1	18.9	12.9	T	0.0	0.0	0.0	0.8	0.2	4.8	18.3	
Normal	6.6	8.4	14.6	5.2	T	0.0	0.0	0.0	0.2	0.1	2.2	7.7	45.0
ST. CLOUD													
Maximum	18.2	20.0	51.7	11.1	3.3	0.0	0.0	0.0	1.8	4.1	26.9	21.8	
Normal	6.5	7.7	11.5	2.8	1.0	0.0	0.0	0.0	1.0	0.4	6.3	7.0	42.4
VIRGINIA													
Maximum	30.4	26.2	26.6	31.8	17.8	5.0	0.0	0.0	4.1	18.9	29.2	28.4	
Normal	12.8	9.9	12.0	7.3	2.1	T	0.0	0.0	0.1	2.6	11.4	11.4	69.5
WADENA (1928-58)													
Maximum	30.8	21.0	30.7	24.0	5.7	T	0.0	0.0	4.6	11.9	22.6	18.5	
Average	8.4	8.0	8.9	4.5	0.6	T	0.0	0.0	0.2	1.2	6.2	7.4	45.2
WASECA													
Maximum	24.1	24.6	41.0	12.0	2.0	0.0	0.0	0.0	4.0	1.5	17.3	23.1	
Normal	7.0	7.4	10.3	1.9	0.2	0.0	0.0	0.0	0.2	0.1	4.7	7.7	39.5

Appendix Table 2. (continued)

	J	F	M	A	M	J	J	A	S	O	N	D	Total
WINONA													
Maximum	33.2	36.0	36.5	10.4	T	0.0	0.0	0.0	0.0	2.5	15.8	26.6	
Normal	10.0	8.3	10.1	1.6	T	0.0	0.0	0.0	0.0	0.1	4.0	7.8	41.9
WORTHINGTON (1928-57)													
Maximum	28.3	22.5	29.2	7.5	6.0	0.0	0.0	0.0	1.5	6.5	16.5	16.1	
Average	6.8	10.4	11.1	2.2	0.4	0.0	0.0	0.0	0.1	0.3	5.6	6.5	43.4

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