THE CLIMATE OF THE COPPER-NICKEL STUDY REGION of NORTHEASTERN MINNESOTA

Part "A"

The Long-term Climatological Record

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in cooperation with the Regional Copper-Nickel Study
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TABLE OF CONTENTS

LIST OF FIGURES

FIGURES CONT.

LIST OF TABLES

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

CHAPTER 1
INTRODUCTION

This report describes the general climate of the "Copper-Nickel Study Region" of Minnesota as based on data gathered from stations in existence prior to the Copper-Nickel Study. By definition, this Region (all figures and tables are contained in the back of this report) has the boundaries depicted on the map (figure 1.1). In essence it is the "heartland" of the northeastern Minnesota "Arrowhead" region. The "Arrowhead" is that portion of Minnesota that has a western boundary roughly determined by drawing a line from the general vicinity of International Falls to Duluth. The Region narrows eastward where Lake Superior approaches the Ontario border, with a sharp tip at Pigeon Point in Lake Superior just east of Grand Portage. The Copper-Nickel Study Region is the "heartland" of this area in that it borders neither on the Ontario line nor on Lake Superior. In this report we sometimes quote data along the Lake or along the border, but only to form a frame of reference. Most surely, the climate along Lake Superior deserves a study of its own, being highly unique in the world because of the steady year-round temperature of that great, freshwater inland sea.

The climate of the Copper-Nickel Study Region, hereafter referred to as the Region, is principally a reflection of its mid-continental location, characterized by cold winters and warm summers. However, as the forest vegetation reflects, it is just far enough to the east of the continent center to avoid being a prairie, due to atmospheric circulation patterns which bring generous amounts of warm-season rains. This, coupled with low summertime evaporation caused by the absence of hot southwesterly wind penetrating the Region, results in an environment favorable for the climax vegetation to be forest rather than prairie grasses or even savanna. Thus, the Region is solidly forest, even though it is at the extreme western edge of the eastern forest area of North America.

Lake Superior has a weak influence on the climate of the Region. Although the elevation of the Region, about 600 meters (which is higher than most surrounding territory), plays a role in modifying the weather, the Lake chills the Region a bit extra when an easterly wind prevails, and precipitation and cloudiness are a bit greater than they would otherwise be without the presence of the Lake. Elevation works in the direction of cooling temperatures and increasing precipation and cloudiness, and the effect is of about the same magnitude as the Lake effect.

The elevation variation of the Region, between 400 meters on the west to over 600 meters on the east, has an effect on temperatures in various ways. Because air cools 1°C every 100 meters during times of dry adiabatic lapse rate, the higher elevations tend to be a bit cooler during adiabatic conditions.

Radiation and air drainage at night cause temperatures on locally high ground to run much warmer than over low ground when the air is still or nearly still, especially when skies are clear, partly cloudy or of just thin, high cloudiness. Atmospheric water vapor content responds to the temperature drop in the radiation-air drainage situation by decreasing via condensation in the cooler areas and by fog formation at vertical and horizontal cold air-warm air boundaries.

All-in-all, the Region is not so large that there is a significant latitudinal temperature variation. The elevation variation and Lake effect, although not large, eclipse the latitudinal variation.

CHAPTER 2
PRESSURE AND WIND

INTRODUCTION

The distribution of air over different parts of the globe varies and is never the same from one hour to the next. Under the influence of gravity, air moves from regions of high pressure to regions of low pressure much like a ball under the influence of gravity rolls down the slope of a roulette wheel. Unlike the roulette wheel situation, however, the end to atmospheric motion is never reached as new regions of low pressure are born—a parcel of air spiraling toward one low pressure region begins spiraling toward another region as soon as the first-mentioned low pressure region becomes filled.

Many high and low pressure systems migrate around the globe, while others are permanent features of some regions. Certain other areas, such as the lee of the Rocky Mountains, are regions where storms form for dynamic reasons.

These pressure systems shape the weather and climate of all places on earth by moving various air masses, and variations in their distribution are responsible for "unusual" weather such as drought, hot spells, dry spells, and cold spells. Any average weather regime, and any unusual weather regime, can be explained by pressure system distribution. It is the pressure systems which forge the winds that blow around the world and in the Copper-Nickel Study Region—the winds are responses to pressure system distribution.

Charts of average pressure distributions may be drawn. Such maps reflect the positions of the permanent and semipermanent pressure systems and the paths of migrating pressure systems. Charts are most meaningful at the latitudes of the Copper-Nickel Study Region if drawn dividing the year into at least the warn season and the cold season. In the cold season air tends to pile up over the continents; in the warm season it piles up over the oceans. At the peak of the cold season in January, high pressure systems stretching from the Yukon to Georgia dominate North America, and the ridge to the west of the Copper-Nickel Study Region accounts for the prevailing northwesterlies at that time of the year. In the warm season, low pressure systems centered over the western portion of North America dominate and account for the abundance of southerlies in the Copper-Nickel Study Region at that time.

Discussion of pressure and wind in this section is based on 24-hour data taken by the U.S. Federal Aviation Agency at the Hibbing weather station. Hibbing is located 50 kilometers to the west of the Study Region.

PRESSURES AND WINDS ALOFT

The Study Region is in the tropospheric stream of westerly winds which girdles the entire globe at this latitude. At altitudes from 2 to 8 kilometers, westerly winds prevail aloft. The strongest winds are found in the cold season, and the weakest winds are found in the warm season. At three kilometers, the upper level tropospheric winds through the winter and spring months are from slightly to the north of west as a high pressure ridge exists over western North America, while a trough lies to the east of the continent. Around June 1, winds aloft are from the south of west as a trough displaces the ridge in the west of the continent.

In early July, the west wind circulation breaks down over most of the United States as the Bermuda high forces its way westward. The return of the western trough comes around August 20 and lasts until late September. The western ridge re-establishes itself by the end of October, the month of transition from the warm season to the cold season.

Figures 2.1 to 2.12 present maps of average pressure distributions over North America, prepared from publications of the U.S. National Weather Service (1), Environment Canada (2), pressure data tabulated by the U.S. Navy (3), and by the National Weather Service (4), (5). Values are in millibars--10 millibars equal 1 kilopascal. In drawing the charts, discrepancies noted between Canadian and American data were eliminated.

Table 2.1 gives the average height of various pressure levels* over International Falls. Table 2.2 gives extremes of height and standard deviation of height (at each level). The influence of the Bermuda High in July and August is apparent, as is the influence of the polar low in the winter.

ANNUAL WIND PATTERNS

The annual distribution of wind speeds and directions at Hibbing is remarkably similar to that of Minneapolis-St. Paul and quite dissimilar to that of Duluth (influenced by Lake Superior) and International Falls (influenced somewhat by the prairie wind regime). Both Hibbing and the Twin Cities

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*To make upper level weather charts, instead of determining barometric pressure at given altitudes, weather services determine the altitude of given pressure values. If the pressure is high, the altitude of a pressure surface is high; if the pressure is low, the altitude of a pressure surface is low.

have most (about 75 percent) of their winds from directions between 300^{o} and 360^{o} and from 120^{o} and 190^{o}. Northeasterlies and southwesterlies are infrequent at Hibbing--even less frequent than in the Twin Cities.

Figure 2.13 give the percent of time the winds blow from various octants (compass points divided into eight sections) at Hibbing. Again, note that the majority of the winds blow either from the northwest or from the southeast, and that a good portion of the time the winds are calm (14.7%).

Figures 2.14 to 2.62 are annual, monthly, and 10-day interval wind roses from Hibbing, based on tabulations made by the author of the original data. Wind roses are graphical representations that show the frequency of the direction from which winds blow. On the monthly and annual wind roses, envelopes are drawn (lines) for 1½ meter per second wind speed intervals; while on the 10-day wind roses, only the total frequency of occurrence envelope is drawn. Appendix II gives a detailed explanation of wind roses. The average wind speed at Hibbing is 3.95 meters per second.

January and February at Hibbing mark the strong domain of northerly winds, while June through August are slightly favored by southerlies. This distribution favors accentuation of the contrast between the cold season and the warm season, for northerlies bring in cold air from Canada while southerlies bring warm air from the southern United States. If the prevailing wind regimes were reversed, the climate of northeastern Minnesota would be much less extreme.

Throughout January and February, the northwest wind prevails at Hibbing, with no marked changes between 10-day interval wind roses. The Hibbing wind roses are remarkably stable in this regard as compared to International

Falls and the Twin Cities. The prevailing direction is primarily influenced by the high pressure ridge from the Yukon to Georgia and the low pressure over the northeast of the North American continent. The constancy of the northwesterly direction at Hibbing as compared to points south and west may well be due to the influence of Lake Superior, which has the effect of lowering barometric pressure. The enhanced low pressure over the Lake tends to reinforce, or "lock-in," the winds blowing from the northwest towards the Lake.

In January and February, northwesterlies are vigorous (over 4.5 meters per second half of the time), while the infrequent southerlies and southeasterlies tend to be weak (less than 4.5 meters per second) most of the time. As mentioned earlier, southwesterlies and northeasterlies are especially infrequent during these two colder months.

The arrival of March signals a change in the wind. The high pressure ridge over the North American continent weakens considerably, decreasing the contrast between it and the Lake Superior low. The "locking-in" effect of the Lake loosens its hold, and the isobars become oriented northeast-southwest over the area. Winds blow more from the north-northwest rather than due northwest, and southeasterlies increase in frequency. Daily weather maps at this time show low pressure systems passing closer to the Region. Consequently, fewer strong highs are sliding from the Yukon to the southeastern United States.

About April 8, a strong break in the wind pattern takes place. At this time, the mean isobars become oriented east-west along the Canadian border, largely reflecting the passage of storms in a west-to-east direction and to the south of the region. The period from April 8 to May 31 marks the reign of the east wind. Even northeasterlies are abundant at this time of the year. Speeds from all directions are vigorous--this is the windy time of the year.

The regime changes suddenly with the arrival of June. A strong, persistent trough forms from the Yukon through Manitoba and the Dakotas to western Kansas and into New Mexico. Southeasterly winds prevail, generally emerging in abundant rainfall from the Gulf of Mexico. Southwest winds peak in frequency during the last part of June. These winds are generally weaker than in the previous weeks.

Air pressure increases in July over the general region from 30^{0} north latitude to 50^{0} north latitude as the high pressure belt ringing the hemisphere makes its seasonal movement northward. This high pressure dominates the region from July through most of October and marks the fine-weather time of the year. Precipitation of short duration is abundant at this time due to convective showers. In contrast with areas just to the west, the Region does not "dry out" in July, August, and September--rainfall is about the same for all three months.

Southwesterlies make their debut about mid-July and are abundant to around August 20. Although they never are the prevailing direction, they blow around one-third of the time during this period. They often blow with appreciable velocities (5 to 10 meters per second), and bring sunny, hot, dry weather. Excess southwesterly winds in some years is associated with low rainfall and high evaporation. These winds bring the scene of white-capped waves on deep-blue lakes surrounded by deep-green evergreens murmuring as the air moves through their needles. Warm air, fed by the heat of the bright sun, envelopes the earth and small, white cumulus clouds dot the afternoon milky-blue sky. When the southwesterly winds overstay their desired time, the result is dusty air in mining areas and low water levels to the thousands of lakes in the Region.

Southeasterlies and northwesterlies alternately blow in the summer when the southwesterlies are not active. As southeasterlies give way to northwesterlies during cold front passages, scattered thunderstorms are a common part of the scene. Southeasterlies bring the warm, muggy nights of summer, while the northwesterlies bring brilliant sunshine and cool nights and pleasant days. As the northwesterlies die with the arrival of a high pressure center, temperatures after dark fall to freezing in low-lying areas, even in July.

The summer wind regime begins to yield to the cold season wind regime about September 20, when northwesterlies increase in frequency with the first sharp cold air outbreaks from northwestern Canada. To very near October 25, northwesterlies and southeasterlies alternate, but on that date, the high pressure system over the Great Basin of the western United States begins to form simultaneously with the Great Lakes' low pressure system, bringing prevailing northwesterlies for the rest of the year.

Figure 2.63 gives the seasonal vertical wind profile over International Falls at various barometric pressure levels. The stratospheric winds in the summer are easterly and are due to heating of the ozone layer associated with the perpetual sunlight of the polar summer. The strength of the tropospheric westerly wind year-round is evident.

CHAPTER 3
SUNSHINE AND CLOUDINESS

The sky over the Region displays a great variety of clouds dependent upon time of day and season. Because of the Region's mid-continental location, cloud types vary from the low, grey stratus (reminiscent of the arctic winter) to the enormous, ice cream-castle cumulus and thunderclouds of summer.

In January, February, and March the sky conditions go through a typical sequence lasting about three days as winter storms pass in succession over the region. As an example, a cold high pressure ridge envelops the area after a storm passage; the sky is brilliant blue by day and deep black at night with thousands of stars visible. As the leading edge of the next storm appears in the west, cirriform (clouds made of ice particles) clouds move in from the southwest. The sun (or moon) grows dimmer as clouds and moisture begin to arrive at successively lower and lower levels. Only the faint outline of the sun or moon remains after a few hours as ice crystals falling from clouds between 10,000 and 20,000 feet fill the sky. Typically, a few hours later the sun or moon is obscured totally when clouds become so low that precipitating ice particles reach the ground as tiny snowflakes.

Several hours later the low level wind shifts to southeasterly and transports warm moist air under the colder southwesterly flow aloft. The process produces an unstable atmosphere and results in strong overturning of the air, vigorous clouds, and heavy snow. Several bands of overturning air may pass over the region as the storm moves eastward. The climax to the storm comes as cold air sweeps in from the northwest along a broad front. A good portion of the time, especially when Pacific air follows a front, skies will clear almost immediately. At other times, especially when polar air follows the storm front, stratocumulus clouds (grey "blobs" of cloud) located between about 1 to 2 kilometers above the ground, cover the sky for a day or more. This sequence brings some light snow showers ("flurries") lasting generally from 12 to 48 hours. The snow showers generally bring less than an inch of snow and seldom bring more than two inches. A few bands of stratocumulus often pass over after the main part of a storm passes on. These bands often appear in association with short-lived (6 to 18 hours) convergent zones formed by successive impulses of cold air behind the storm. The effects of these zones are stronger by day and weaker by night; hence, skies are clearer at night than by day when such a regime is present. They will be interspersed with areas of clear sky. Frequently, the first clear sky will be seen with the passage of the front of cold air, behind which there is strong downward movement of air. This zone is called a groove by satellite meteorologists. The leading edge of the first stratocumulus band can often be seen coming from the west while the clouds of the main storm system are still visible in the east.

A cold front forming the leading boundary of Pacific air will typically be followed by mild weather, whereas a polar air mass will be followed by cold weather. In either case, small, short-lived cumulus clouds may form briefly in the afternoon following frontal passage.

A day or so after the front is well to the east some patchy cirrus or altocumulus clouds may pass over as moist pockets in weak convergent areas aloft drift over the region.

The sequence to the pattern follows as the leading edge of the next storm system is seen in the west. Once or twice a winter the sequence may take place in less than a day. At other times, especially during the last two weeks of February, a week or more may elapse between storms.

In April and May storm centers track over or near the region. When storm centers pass just to the south of the Region the sky becomes overcast with thick clouds delivering heavy snows and/or rains borne on northeast winds. In such a case, Lake Superior moisture gives an extra "kick" to precipitation in the Region. If the storm center passes to the north the sky may be filled with moderate-sized cumulus, which are harbingers of spring.

At this time frontal passages and prefrontal cloud bands are often marked by thunderstorms. The nature of the weather to the rear of the storms is also different from winter. Instead of just stratocumulus bands, large cumulus and small cumulonimbus form to bring passing showers. These showers are composed of snow early in the spring and rain later in the spring. The storm patterns can be frequent and brief as the heavy showers are usually interlaced with periods, on the order of a half-hour, of bright, warm sunshine.

During June, July, August, and early September storm centers track most often far to the north. These summer storms also have weaker winds. The diurnal variation shapes the sky much more strongly than in the winter. Here, a typical day has fair skies in the morning, escept in a few areas where fracto-stratus from a "lifted fog" may dot the sky. Around the ninth hour of the day the first small cumulus forms at a height of perhaps 400 meters. Vertical mixing then increases to greater heights as air becomes heated by the warming ground, and the cloud bases increase their height to around one kilometer or more by midday.

If the air aloft is relatively dry, mixing may proceed to the height at which so much dry air is brought into the mixture that all the clouds die out. If the air aloft has a stable layer around two kilometers or so the clouds' tops will spread out below it bringing them longevity and permitting a few light showers to form.

However, if the air has appreciable moisture content and there are no strong stable layers in the first several kilometers, thunderclouds may form, bringing generous rains to the Region (sometimes very scattered rain). These storms generally do not form until late in the day or early evening.

Nighttime brings generally clearing skies. After days without much cloud development the air sinks in connection with density contraction near the surface as the result of diurnal cooling. If thunderstorms rage into the night the sky may be cloudy the next morning with perhaps a few raindrops, in cases where the storms have not had a chance to die out completely. Probably most morning cloudiness in the region is due to left-over thunderstorm parts. However, by noon these remnants usually dissipate.

Occasionally, during the summer, a general storm may pass over the Region bringing an all-day or two-day rain. This is unusual, however, at least during July and August. In such a case, the cloud sequence is similar to that of the winter storm.

In the course of a summer, many varieties of thunderstorm clouds are seen. This variety is created because a thunderstorm causes the generation of various parcels of air differing in temperature and moisture content and these parcels are subjected to three-dimensional movement at various stages of their life.

September and October bring a gradual phasing out of summertime convective cloudiness and a phasing in of winter-type storm cloud sequences. Most striking perhaps are the weaker cumulus cloud types by day and the appearance of more vigorous stratocumulus bands following cold front passages. Late September and perhaps the first two-thirds of October, however, have the highest incidence of perfectly clear skies. For this period is the end of the summertime cumulus season and the precursor to the general winter storm season. Also, morning fog is especially common in the vicinity of low-lying areas and over lakes at this time. This is due to the mild mixing of air of different temperatures and water vapor contents. The differences of air temperature and humidity are fashioned by long, still, clear nights. When the micro-air masses come into contact, warmer air containing more moisture is chilled by mixing with cooler air which has lost moisture through dew or frost deposit. The result is a super-saturated mixture, and, therefore, fog.

In late October and early November the winter storm season begins. The air is still moist in the upper layers due to water vapor that has been pumped aloft during the warm season. Storm centers track near the Region at this time, causing lots of snow and the well-known gales of Lake Superior.

However, when storms are not present the sky is usually cloudy with dull, low, grey stratus clouds. From late October through early December there usually is a shallow (around ½ kilometer) inversion persistent over the Region. The stratus may be present under the inversion for days in a row; at other times, they may break up a bit in the afternoon. Snow in the form of single ice crystals may fall from these clouds for several days, continuously, and yet not add up to a measurable amount of precipitation. By mid-December these clouds are no longer part of the winter scene except as an occasional happenstance.

When storms pass through in the late fall, the cloud sequence is much the same as in January, February, and March. The sequence, then, repeats each following year until, of course, a major climatic change disrupts the atmospheric pressure systems as we now know them.

It perhaps seems cruel to reduce sunshine and clouds to mere statistics, for numbers cannot quantify the beauty of the northern skies nor the cheer which the sun produces on a fine summer day or a cold, snow-engulfed winter morning.

Nevertheless, Table 3.1 presents data on the percent of possible sunshine over the general Region, as well as average percentages of time of clearness, and conversely the percentages of cloudiness. The charts were compiled from National Weather Service data from surrounding stations using the author's climatological model of Minnesota, 1973(8). Percent of possible sunshine is not directly related to percent of clearness (or cloudiness) of the sky, since clearness (or cloudiness) is based on the perspective of the observer and the sun to "see each other" at angles in the sky ranging variously from 0^{o} to 75^{o} (at the region). Further, percent of possible sunshine includes views through thin clouds, while even thin clouds are considered, in the statistics, to constitute "cloudiness." Greatest sunshine occurs in July when the sun is high in the sky, and the least occurs in stratus-engulfed November when the sun is low in the sky.

Looking at percent of clearness of the sky, it is seen that the greatest clearness occurs around midnight in the summer (Table 3.1). Although the values may be somewhat enhanced by the difficulty of observers in seeing thin clouds on moonless nights, this time is undoubtedly the clearest, because daytime convective clouds have usually dissipated by midnight and morning fogs have had little opportunity to form.

Cloudiness is maximum in November in the early afternoon, due mostly to the autumnal stratus. When the stratus are not present the sky is generally plagued at this time either by diurnal stratocumulus or by a November storm. The beauty of the November northland can be appreciated by only those who admire the unusual, peaceful aspect presented by brown vegetation protruding through shallow snow under uniformly leaden skies.

The greater clearness of the February sky is brought by the fine weather occurring during the last two weeks of the month, a statistic correlated with the lack of snowfall at that time. (Note: February is fairer than June.) All-in-all, the statistics reflect the ever-changing cloud regimes over the year.

Near low-lying areas, cloudiness will run higher due to higher incidences of fog.

In conclusion, it is worth noting that there is a definite time cycle to summer cloudiness. Historical data from this part of the country show that summers in cycles of 40 years alternate between cloudy and sunny. This is related to the 40-year summer rainfall cycle. In the 1890s, 1930s, and 1970s summer skies were especially fair, while in the 19-teens and 1950s summers were cloudy. The cloudform corresponding especially to cloudy summers appears to be stratocumulus and altocumulus formed by the spreading out of cumulus types.

CHAPTER 4
TEMPERATURE

INTRODUCTION

Perhaps the most distinctive feature of the northeastern Minnesota climate is the extreme temperature range. Because the Region is located near the center of the continent, there is a minimum of temperature influence by the oceans. The appendix to this report gives many temperature statistics for Babbitt, Minnesota, which the reader should examine.

Extreme winter-to-summer temperatures in the Region do not vary as much as in the prairies of western Minnesota, however. Rather, the significant variation in temperature as compared to the rest of Minnesota is between night and day. Nowhere in the state do temperatures fluctuate as greatly from morning to afternoon as in the flat "meadowlands" areas and in the scattered, isolated depressions of the Region. Topographic braking of the nighttime wind and decoupling of the low-level air from air aloft by radiational cooling form cold air pockets and bring occasional freezing temperatures even during the short nights of June and July. Conventional agriculture is largely precluded because of the occasional occurrences of summer frost, and gardens are possible only where the gardeners can cover their plants on cold summer nights.

Although temperatures in the -40s C (degrees Celsius, as all temperatures herein) are commonplace on the long winter nights, southwesterly winds bringing dry air from the Great Plains can raise summer temperatures as high as 40C on rare occasions. Summer temperatures as high as 39C and 40C have been recorded at Babbitt and Virginia, respectively.

YEARLY TEMPERATURE CYCLES

At Babbitt the date of the warmest mean temperature is July 26 (as it is nearly everywhere else in Minnesota) with an average temperature of 19.1^{O}C. The average high on this date is 25.1^{O}C; the average low is 14.2^{O}C. The coldest date average is January 26, at -16.3^{O}C, and with an average high of -11.8^{O}C and an average low of -20.9^{O}C. The hottest day of record was July 11, 1936, at 39^{O}C; the coldest was -41^{O}C on January 23, 1935 and again on January 15, 1972.

Since the Babbitt weather station is located high on the hills of the Embarrass Range in the vicinity of the former location of the city, the lowest temperatures of record are higher than those found at stations on lower ground.

A sharp rise in the mean temperature curve analyzed from published chronological data (7) (see Appendix III) begins to take place around February 21, with a leveling off around April 28 when warmer weather generally becomes established. The mean temperature on April 28 is 6.9^{O}C. An initial peak in the curve occurs on July 13 with a cooler period between that date and the second, stronger peak on July 26. This twin-peak is characteristic of the mean temperature curve throughout Minnesota.

There is very little dropping in the daily mean temperature throughout August; a sharper drop begins setting in around September 4 as the longer nights over the continent begin to have a chilling effect on the air.

Typically for Minnesota, there is an autumnal warming peak on October 2, followed by little change in the mean temperature until October 16, when a very sharp drop commences. The strong drop ceases around November 28 when the winter cold regime becomes well established. The decline in mean temperature is then slow to the January 26 minimum with very little change between November 28 and December 23. The difference in the mean temperatures between the two dates is only 2.6 degrees. However, a cold minimum between these dates bottoming out on December 20 occurs in the Region as elsewhere in Minnesota.

DISTRIBUTION OF MONTHLY MEAN TEMPERATURES

Averages of monthly mean temperatures and the mean maximum and mean minimum at various places in northeastern Minnesota provide a convenient way to examine areal variations. Table 4.1 gives values for 17 sites in the northeast, identified with the respective elevations as shown in Figure 1.1.

The values are derived from National Weather Service observations, except for Brimson and Whiteface where they are derived by an interpolation which considers topographical influence. However, the observations were processed through a model developed by Watson (1973). The model adjusts the data to long-term (on the order of 150 years) means. This is done by comparing the maximum temperature data observed over a 15-year period at each station with observations over the same period made at Farmington, Minnesota;

in turn, the Farmington data were adjusted to be consistent with that station's long-term (years between 1885-1973) means and values from Fort Snelling (1819-1858, 1886-1892) as adjusted to Farmington using concurrent Farmington-Fort Snelling comparisons from 1880 to 1892. The 1858-1866 gap was filled in by using data from elsewhere in the Twin Cities, making comparisons of those observations with Fort Snelling. All data were corrected for differences caused by variations in observation time by a curve derived from observations over 10 years (1964-1973) at Minneapolis-St. Paul International Airport. The Isabella data were for a slightly shorter time period since observations were not available for the full time period.

Diurnal temperature range data for places over 20 kilometers from Lake Superior are based on adjusted-for-observation-time data at Farmington, which is considered to be a "perfect" observation site (For reasons too complex to be discussed here, it is true that Farmington values reflect very well the diurnal temperature range to be expected over northeastern Minnesota away from Lake Superior, which are not significantly affected by cold air drainage). Diurnal temperature ranges along the shore were derived from studies using Duluth Harbor and Grand Marais data, again making appropriate corrections.

Some of the shortcomings of the information include: 1) each station has a different diurnal temperature curve due to the local environment (forest, open plain, "heat island" locality, etc.); 2) length of day varies slightly over the area; and 3) all observers are not equally competent. Nevertheless, the area of the northeastern Minnesota region depicted is large enough that the errors are about an order of magnitude less than the real variations.

Armed with these caveats, it is observable that temperature stations along Lake Superior are warmer in the winter and cooler in the summer as compared to inland stations. It is also apparent that Isabella and Babbitt show generally cooler yearly temperatures than stations to the west. Elevation is a major cause of this coolness. However, the coolness of these stations is much enhanced in the warm season, especially at Isabella, because of Lake Superior. When easterly winds blow, lake air invades Isabella (and the eastern end of the Copper-Nickel Study Region) and, to some extent, Babbitt and Brimson. In winter some slight warming of the Region takes place. Sufficient data are not available for Gunflint Lake to be included in this Study, but long-term observation for that area show a general coolness.

TEMPERATURES ALOFT

Table 4.2 gives International Falls' mean monthly temperatures versus various pressure levels (measured to a height of 6250 meters - slightly over 20,000 feet). The values are based on monthly averages of observations made at 6 AM and 6 PM Central Standard Time, taken over the 10-year period, 1946 to 1955.

The data show the presence of a year-round inversion except in November. The inversion is even present in June, despite short nights and the fact that June observations are made about two hours after sunrise and two hours before sunset (These data differ from radiosonde data from St. Cloud where there is no mean inversion between May and September). The reason for the inversion's presence is that at the time of the 6 AM observation, solar heating has not been strong enough during the first two hours after sunrise to overcome the inversion that forms at nighttime.

From December through February, the inversion is about one kilometer deep. The data suggest that the inversion is often present throughout the winter day, at least aloft, because the short day and the low-angled sun cannot break up such a deep layer, except when a low pressure system is near the station.

November is a stormy time, and the lack of the inversion suggests that the air is usually moving and the temperatures aloft are usually colder than the surface (bare or snow-covered) temperature, resulting in a prevailing condition of local instability.

Table 4.3 lists separately the monthly extreme temperatures and the standard deviation of temperatures versus various pressure levels above International Falls for the same period of record as Table 4.2. Figure 4.1 graphically shows the mean monthly temperature versus various pressure levels above International Falls.

CHAPTER 5

HUMIDITY

Humidity expresses the water vapor content of air. There are a number of expressions for humidity because there are a variety of ways in which water vapor content can be viewed and measured. Relative humidity expresses the ratio of the amount of water vapor in the air to the amount of water the air could hold at the ambient temperature of the air.

Humidity is high at sunrise in July and August because of radiational cooling under the frequently fair nighttime skies combined with high amounts of water vapor in the air. Values are low in mid-May, and especially so in the afternoon, because ot the downward deep mixing of dry air aloft.

Table 5.1 gives monthly mean values of relative humidity for the general Copper-Nickel area, derived from climatological studies by the author (8) using Babbitt temperatures and water vapor data from suffounding stations. The table also gives mean values of dew point and vapor pressure, to slide rule accuracy. Dew point is the temperature at which water vapor would begin to condense out (in the form of dew, frost, or fog) from air of a given moisture content. Dew point is highest in July and lowest in January, following the trend of the mean temperature curve quite closely. Vapor pressure is the partial pressure of the air due to water vapor. It is a measure of the absolute water vapor content of the air.

Table 5.2 gives the average relative humidity aloft as observed over International Falls for the 10 years from 1946 to 1955. Note the lowest values are from the surface to 850 millibars in the April-May time period. But in March-April it is at 800 and 750 millibars, and in August above 750 millibars. Highest values are in August at the surface; in November from 950 to 850 millibars (when low stratus at these pressures are present); in June from 800 to 700 millibars, when impact of moisture-laden air from the Gulf of Mexico is at a maximum; and in January, above 700 millibars.

CHAPTER 6
PRECIPITATION

INTRODUCTION

Most of the water furnishing the precipitation in the Region originates in the Gulf of Mexico, although appreciable quantities also come from the Pacific Ocean and Lake Superior. Very minor amounts originate from land surface vegetation, local lakes, Hudson Bay, and perhaps the Arctic Ocean and the Atlantic.

Information in this section is from analyses made of data published in References 7, 11, 12, and 13.

PRECIPITATION THROUGHOUT THE YEAR

There is a general wet season and dry season, corresponding closely to the warm season and cold season, respectively. From an analysis (Figure 6.1) of composite records made mostly at the city of Tower (other station's data were used when the station at Tower was not in operation) from 1894 to 1976, the wet season can be defined as beginning on April 14, when a sudden increase in average precipitation begins, and ending on October 15, when a sharp drop in average precipitation takes place. Interestingly, the dates are six months apart. Similar data are presented for Winton, Babbitt, and Virginia (Figures 6.2 to 6.4).

June and July are the wettest months in the Region; February the driest. Peak of raininess is around June 23, with a secondary peak around September 1. The period from mid-July to August 20 is relatively dry, except for an enhancement around August 8. Late September is also dry, with a wet period in mid-October. There is also a significant dry spell around Memorial Day.

June and July are nearly equal in precipitation, with August being perhaps insignificantly different, especially in the southeastern portion of the Region. June and July are so close in average rainfall that it becomes perhaps a moot point as to which is the wettest. To the west of the Region, in Virginia, June is slightly wetter than July, according to records since 1894; Babbitt has had slightly wetter Junes than Julys, according to records taken since 1921. However, the evidence indicates that if Babbitt records also had extended back to 1894, July would have averaged out the wettest.

At Virginia, July was the wettest month up through 1960. Since 1960 June has been much wetter than July, with the result that both Virginia and Babbitt, to 1976, have had the wettest month tipped to June for the lengths of record of both places. At other places, such as Winton, July has been the wettest month, however, even since 1960. There is, across Minnesota from west to east, a shift of the peak of rainfall toward occurrence later in the warm season. For example, the wettest month at Grand Marais, Grand Portage, and Beaver Bay is September.

Around August 20 the pressure systems orient themselves similar to the June pattern, and an increase in rainfall takes place which lasts until about September 20. As mentioned previously, from September 20 to October 20 the United States is under the dominance of a high pressure system. Due to the widespread sinking air associated with this high pressure, this is a period of high percentage of cloud free skies in the Region.

Late October brings an end to the high pressure regime over the United States as high pressure systems over Canada become more intense and generate more frequent northwesterly winds. The Upper Great Lakes' low pressure system is reborn and becomes very strong. At this time low stratus clouds cover the states of these Upper Lakes. The low remains strong through all but the last week of December, and the accompanying cloudiness makes November and December the cloudiest (perhaps dreariest and gloomiest) time of the year.

SPATIAL VARIATION

If we compare monthly rainfall total values at the various weather stations of northeastern Minnesota, as observed from 1960 to 1976, to those in Virginia, and then compare the 1960-1976 Virginia values with those from 1894 to 1960, we can arrive at an estimate as to what the 1894 to 1976 rainfall totals would have been at the various weather stations. This assumes that over time precipitation variation in the Region is identical with the variation observed at the Virginia station. Using this comparison July generally gets a slight nod as the wettest month in the region.

Figures 6.5 to 6.17 and table 6.1 depict the monthly and annual totals using the comparison method described above in this paragraph. The charts for the Beaver Bay record were derived with exception to this method, since the data are from records made between 1858 and 1874. This record was used since no concurrent data with virginia were available.

In using these values the reader should keep in mind that total average precipitation will vary from century to century and millenium to millenium, as well as over other time intervals such as decade to decade.

These data cannot show small-scale variations that likely exist since the rain gauges are so far apart. Important average differences can exist over distances as little as several miles. As an example, the difference between the city of Hibbing and the Hibbing airport illustrates the differences that can arise between closely adjacent stations. And, the differences between the two stations could be due in part to the problems caused by differences in rain gauge exposure. The reader should bear in mind that rain gauges chronically suffer from exposure problems. For example, differences may arise from vegetation, i.e. precipitation generally falls at an angle to the ground because of the wind. The trees may intercept the rain or snow, lowering the amount accumulated. This effect is greatest with wind-driven rain or snow.

In addition, hilly areas are preferred places for convergence of air and, consequently, precipitation. Areas downstream from hills may also be wetter due to passage of clouds formed or enhanced over hills. The records from Grand Marais, Grand Portage, and Two Harbors clearly show the effects of land, water, and topography. These places are drier than inland in the warm season due to enhanced convergence over the inland ridge about 30 kilometers west of the Lake. In the cold season they tend to be drier than the high ground around Isabella, but wetter than places to the northwest of the high ground. High winter values at Beaver Bay are likely associated with the very abrupt rise of the land above the lake in that area.

TEMPORAL VARIATION

Figure 6.18 gives the total monthly precipitation for 12-month periods at the end of each month at Virginia for the total period of record 1894 to 1977. The curve shows the variations that can be expected, and the cycles of wetness and dryness that can be expected. Values range from 1160 millimeters in the 12 months ending November 30, 1905, to 365 millimeters in the 12 months ending March 31, 1977. Of this total, it is rather startling to note that over half of the total, 208 millimeters occurred in June of 1976, with only 157 millimeters falling in the other 11 months.

The 1977 drought incident was the only time that the 12-month precipitation total dropped below 400 millimeters. On 12 previous occasions annual precipitation fell below 500 millimeters, but there were intervening years when annual precipitation was above 500 millimeters. Only once, however, was a dryness situation sustained around the 500-millimeter mark (at least until 1977), which was the long dry period between the spring of 1917 and the summer of 1919.

The wet mark for a twelve-month period was established in November, 1905, due to a very wet spell in the summer and autumn of that year. Precipitation for that period was 1160 millimeters. Years from 1895 to 1907 appear to have been unparalleled for wetness, but rains also were most generous from 1944 to 1953, and again from 1964 to 1973.

Evidence of the twenty-year drought cycle appears at Virginia, but not as strongly as forthe Great Plains. The 1917-1919 drought, however, and those of 1934, 1936, 1954, and 1956, and the current one appear rather clearly.
The inter-cycle dry years of 1910 and 1921-1923 appear in the record, albeit not as sharply as at other locations to the southwest of the Region.

HEAVY RAINS

Heaviest precipitation occurs here, as at most other places, when thunderstorms pass. Large amounts of rainfall may result over time periods of hours or a day if a line of thunderstorms moves en echelon over a point.

In the Region it is possible for a 10-square-mile area (9) to receive nearly 560 millimeters of rain in a 6-hour period. Such an event would be extremely unlikely, but it is important when considering the flood design of structures. Flood design of structures (dams, buildings) are commonly geared to return periods of flood rains which might occur once every 100 years.

Table 6.2 is a chart showing return periods of heavy rainfalls for a given point in the Region (9). As an example in reading the chart, a rain of 127 millimeters in 24 hours is to be expected once every 100 years. One caveat to be used in this table-a once-in-100-year rain could occur more than once even in a given week, or it may take centuries for it to ever happen. Examination of very long rainfall records reveals that in a given decade rare or unusual rain events tend to be followed closely by one or more subsequent unusual rain events. That is, rare rain events tend to cluster at times.

Table 6.3 gives some actual observed heavy rainfalls at International Falls (10) which is roughly applicable to the Region. The converse to rain events are non-events. For example, measurable precipitation has not occurred at Tower on February 7 since 1960, and only once on March 24 since 1953. Every September 21 has had precipitation at Tower since 1969, and it has failed to rain on that date only six times since 1946.

Appendix III gives the five wettest days for the period of record at Babbitt. Precipitation exceeding 70 millimeters in a single day has occurred on 9 occasions. See Table 6.4.

All but two of the nine heaviest rains occurred on or after August 25. The heaviest rains in the area generally are due to thunderstorms occurring in conjunction with sharp outbreaks of cold air. Ordinarily, air mass convective clouds (cumulonimbus) are generally too small to deliver extremely heavy rains. Such is not the case further south in Minnesota, where many of the heaviest rains come with air mass cumulonimbus. Note also that none of the heaviest late summer-early fall rains have occurred recently, giving further testimony to the relative dryness of August and September in recent times.

MONTHLY VARIATIONS

Table 6.5 and 6.6 give monthly rainfall statistics (other time intervals can be used as well) for Babbitt and Virginia, respectively. The long-term average for the Babbitt data are the adjusted data appearing in the monthly precipitation table (6.1). All other data in the tables are for the periods of record as shown. The Babbitt data give 56-year information for a station in the Copper-Nickel Study Region; the Virginia data give 83-year information for a station just west of the Region.

The percent of total annual rainfall for each month is listed in the column under the average monthly precipitation. For both Babbitt and Virginia the monthly precipitation is quite evenly distributed over the warm months. From 10 to 15 percent of the annual precipitation occurs each month from May through September.

These data cannot show small-scale variations that likely exist since the rain gauges are so far apart. Important average differences can exist over distances as little as several miles. As an example, the difference between the city of Hibbing and the Hibbing airport illustrates the differences that can arise between closely adjacent stations. And, the differences between the two stations could be due in part to the problems caused by differences in rain gauge exposure. The reader should bear in mind that rain gauges chronically suffer from exposure problems. For example, differences may arise from vegetation, i.e. precipitation generally falls at an angle to the ground because of the wind. The trees may intercept the rain or snow, lowering the amount accumulated. This effect is greatest with wind-driven rain and snow.

In addition, hilly areas are preferred places for convergence of air and, consequently, precipitation. Areas downstream from hills may also be wetter due to passage of clouds formed or enhanced over hills. The records from Grand Marais, Grand Portage, and Two Harbors clearly show the effects of land, water, and topography. These places are drier than inland in the warm season due to enhanced convergence over the inland ridge about 30 kilometers west of the lake. In the cold season they tend to be drier than the high ground around Isabella, but wetter than places to the northwest of the high ground. High winter values at Beaver Bay are likely associated with the very abrupt rise of the land above the lake in that area.

Over the cold months distribution is also fairly even, with all months from December through March contributing between 2.5 and 4.4 percent. Clearly, however, February is the driest month.

Cumulative percentages are instructive. The third row on the charts gives the percent of the annual precipitation occurring at the end of each month starting January 1. For Babbitt only 40.2 percent of the total annual precipitation has fallen by the end of June; at Virginia it is 43.2 percent. On the average, the half-way mark does not arrive until about mid-July.

The fourth row gives cumulative percentages of precipitation from May 1 onward. From May 1 to the end of August, slightly over half of the annual precipitation occurs; thus, slightly less than half of the annual precipitation occurs in the eight months from September 1 to April 30.

Note that September is wetter than May, however, so even a few percent less occurs in the eight months from October 1 to May 31. Stated differently, at Babbitt, 64.4 percent of the annual precipitation occurs during the five-month period from May 1 to September 30; at Virginia the value is 65.4 percent. Roughly, then, two-thirds of the precipitation occurs from May through September; one-third from October through April.

The next four rows give the wettest and driest months over the periods of record. The wettest month ever at either station was 278.9 millimeters, occurring in June, 1944, at Babbitt. Wettest for Virginia was August, 1900, with 257.6 millimeters. That August, incidentally, was followed by the wettest September and second-wettest month ever, with 254.8 millimeters. On the dry side, January, 1947, had no measurable precipitation in Virginia.

The driest month in Babbitt was April, 1926, when only a half-millimeter of precipitation occurred.

At Babbitt the wettest calendar year ever was 1928, with a total precipitation of 954.3 millimeters. Driest was 1923, with a 416.8 millimeter total, although 1976 was a close second with 436.1 millimeters. Virginia, with the longer record, recorded a high of 1087.9 millimeters in 1905. The driest calendar year ever in Virginia's 83-year weather history was 1976, with a total of only 408.7 millimeters. Of that year, over half of the precipitation fell in June (208.3 millimeters)--ironically, this was also one of the wettest Junes on record, only 28.2 millimeters short of the all-time record.

Further statistics are the longer-period precipitation values for the two stations. Babbitt data are presented for 10-year intervals plus the six odd years of the 1970s. The variations perhaps speak for themselves, as do the odd-period intervals for Virginia. More than anything, the data perhaps illustrate the chronic dryness of February and the switching around of June, July, August, and September as the wettest month of various periods, although September often falters badly. The comparative wetness of more recent Octobers is noteworthy.

TRENDS

One final note. Evidence suggest that a "drying out" of the Region may be occurring. The Virginia periodic averages give some support to this, showing that most of the decrease is occurring in the late summer. Other parts of Minnesota show a similar trend. We cannot be sure that this trend will continue, but the second major rainy peak (August-September) is not as strong as it was in the early years of the century. It is also possible that the August-September wetness of yesteryear was the anomaly. There is no evidence to suggest that the Copper-Nickel Study Region has a trend towards increased summer precipitation, and as such should not be expected.

CHAPTER 7
EVAPORATION

Evaporation has been measured in Hoyt Lakes since 1958 using a "standard-pan". The dimensions of the pan are 48 inches in diameter by 10 inches deep. The water is kept at a level varying between 7 and 8 inches and the pan is exposed to allow water to evaporate freely to the atmosphere.

The noticable results concerning pan evaporation values for the Region is that mean values are virtually the same as mean values for precipitation. Because of this, it is important to consider some of the more subtle aspects of the phenomenon-the relationships are not so simple.

At the outset it should be noted that for about 99 percent of the land area of the contiguous United States, evaporation exceeds precipitation. Thus, the Copper-Nickel Study Region is unusual in that the values are virtually identical.

Another vital point is that evaporation from lakes is approximately only 70 percent of that observed in pans. Thus, clearly, precipitation in the Region exceeds lake evaporation. This feature is important for the maintenance of the water levels of the lakes in the Study Region.

Precipitation and pan evaporation vary in their relative magnitudes in various parts of the Region. In the northeast, where precipitation is higher and pan evaporation is lower than for the Region as a whole, precipitation exceeds pan evaporation. In the southwest, where precipitation is lower and evaporation is higher than for the Region as a whole, pan evaporation exceeds precipitation. However, it must be borne in mind that over the entire Region, precipitation exceeds lake evaporation.

Evaporation is a function of temperature, humidity, sunshine, and wind speed. Consideration of the microclimate is, therefore, important to an understanding of the variation of evaporation across the Region. Microclimates are highly variable over the Region, with sunshine and wind accounting for the largest variation. In heavily-forested areas, values for sunshine and wind speed are on the order of 20 percent of the values for open areas. As such daytime temperatures tend to be slightly lower while daytime humidities tend to be slightly higher as compared to open areas. In such places there is, without a doubt, a great excess of precipitation over evaporation. The heavy growth of mosses, which enhances the beauty of the Minnesota climax forest, is undoubtedly a manifestation of this phenomenon.

The longer period of ice on lakes also influences evaporation. Data on the length of ice cover are normally not recorded in Weather Service observations. Fortunately, this is compensated for by the fact that no natural phenomenon is more closely watched by inhabitants of the Region than ice-in and ice-out times. From interviews, it is found that ice covers the lakes almost half of the year (see Table 7.1).

Let us now consider the pan evaporation data from Hoyt Lakes. The pan usually is operative from about May 1 to October 20, with existing data showing very little evaporation after the latter date--about 1 millimeter per day to the end of October. Figure 7.1 gives the mean daily pan evaporation at Hoyt Lakes based on data taken daily from 1958 to 1975 by the National Weather Service cooperative station located at the main entrance to the Erie mine. Peak evaporation appears a bit after mid-July. The inflection in May shown by the data is probably real, considering the tendency for cloudy, rainy weather in early May yielding to sunnier weather later in May. These data are compiled into monthly values (Table 7.2).

Evaporation data are not taken in November, but by my estimate, would show evaporation on the order of 0.5 millimeters per day. Applying all of the above information, we obtain evaporation values for the Region as a whole as indicated in Table 7.3.

Precipitation in the Region averages from near 700 millimeters in the southwest to 760 millimeters in the northeast, so it is quite evident that actual precipitation exceeds actual lake evaporation by a wide margin--around 200 millimeters. Virtually all of the precipitation that falls on lake surfaces through the year ends up in the lakes, since snow just stays on the ice and most of the rain that falls during freeze-up is simply absorbed in the snow. Often, the mixture becomes ice or frazil.

CHAPTER 8
SNOWFALL

INTRODUCTION

Snowfall is very much a part of the scene most of the year in the Region. Snow can probably fall any month of the year, but there have been no reports of snow in July that the author has been able to verify.

Data in this section are from original records on file in the State Climatology Office. Average annual snowfall in the Tower, Minnesota, area, based on long-term observations from 1894 to 1976, is 1426 millimeters. Average daily snowfall (calculated as 7-day running means) peaks on November 26, with a secondary peak on March 4 (Figure 8.1). The daily snowfall average increases from an average of less than a millimeter in mid-October to 13 millimeters on November 26, then declines sharply to average between 7 to 10 millimeters from December through early April. Thereafter, average daily snowfall is about 3 millimeters through the last three weeks of April. There is then a sharp drop to less than a millimeter by May 3. February days are definitely less snowy than those of January and March.

January exhibits the greatest monthly average snowfall with 283.5 millimeters. Other months in decreasing order are December, 275.6 millimeters; March, 259.8; November, 255.3: February, 215.4: April, 121.9; May 11.9; and October, 2.3 millimeters.

Seven-day running means of average daily snowfall were calculated for Winton, Hibbing, Babbitt and Isabella (Figures 8.2 to 8.5) also. These stations show greater variability of the average daily snowfall than are found at Tower, probably due to the shorter period of record for these stations. The peaks at all stations, including Virginia, tend to occur around the same dates, however.

The charts also show substantially higher snowfall at Isabella (just to the east of the Region) than at the other locations. This is due to the joint influence of Lake Superior and the high ridge on which Isabella is located. Since there is a general downward slope of the Copper-Nickel Study Region from east to west (away from the Lake), it is reasonable to expect that average snowfall decreases over the Region from east to west. Table 8.1 gives the average monthly and annual snowfall for the periods of record for the five stations discussed above.

HEAVY SNOWFALLS

In the Babbitt area between 1921 and 1976 there have been 48 days with a snowfall greater than 125 millimeters. This record refers to calendar days only and not to 24-hour totals.

The heaviest snowfall ever to occur was March 4-5, 1966, when a total of 546 millimeters fell during these two days. On March 4 the total was 406 millimeters. The second greatest one-day total was 302 millimeters on April 7, 1956. A one-day total of 279 millimeters occurred twice-once on April 25, 1950, and again on April 1, 1952.

Table 8.2 gives record snowfall data for Babbitt. Note that most of the heavy snows usually occur in March, with April following second. Heavy snows are weaker and less common in January and February than in

November, December, March, and April, and the heaviest snow for October and May are greater than for either January or February. Indeed, the heaviest snow in June is not all that far behind the heaviest snows of January or February. The reason for the lack of heavy snow in January and February is the sparse moisture supply in those months—there is simply not enough water vapor in the air to manufacture a really heavy snowfall.

CHAPTER 9
SNOW ACCUMULATION

The depth of snow on the ground is a function of snowfall, temperature, sunshine, wind speed, humidity, and the occurrence of other forms of precipitation. Snow depth data were compiled from original records in the State Climatology Office for Winton and Babbitt.

Figures 9.1 and 9.2 give mean snow depth for two sites (Winton and Babbitt). The deepest snow depth occurs on February 8 at Babbitt and on March 7 at Winton. The Winton snow depth curve is very flat from mid-February to about March 10, while there is a sharp peak up to the Babbitt maximum. This is most likely a reflection of the forest-site of Winton as compared to Babbitt.

Both locations have an average peak of 450 millimeters snow depth, with Winton being 451 millimeters by March 7 and Babbitt 434 millimeters by February 8.

The deepest snow cover ever recorded at Babbitt was 1270 millimeters from February 1 to 7, 1969; the deepest at Winton was 1016 millimeters from February 8-16, 1916.

We can also speak of the least amount of snow on the ground on a monthly basis for these stations. Over the periods of record, no January day ever had less than 25 millimeters of snow on the ground at Babbitt; and at Winton no day in January ever had less than 76 millimeters; and no day in February less than 102 millimeters. These data are presented in Tables 9.1 and 9.2.

The length of time that snow remains on the ground is also of importance. For example, at Babbitt snow was on the ground continuously from October 24 to April 15 during the winter of 1919-1920. In both instances this is nearly half the year.

In contrast, during the winter of 1930-1931 continuous snow cover at Babbitt lasted from only November 23 to February 23, a time base of 3 months; while at Winton minimum continuous cover lasted only from November 26 in 1913 to April 7 in 1914; and again from December 11, 1914, to March 23, 1915; in both cases about 3½ to 4 months.

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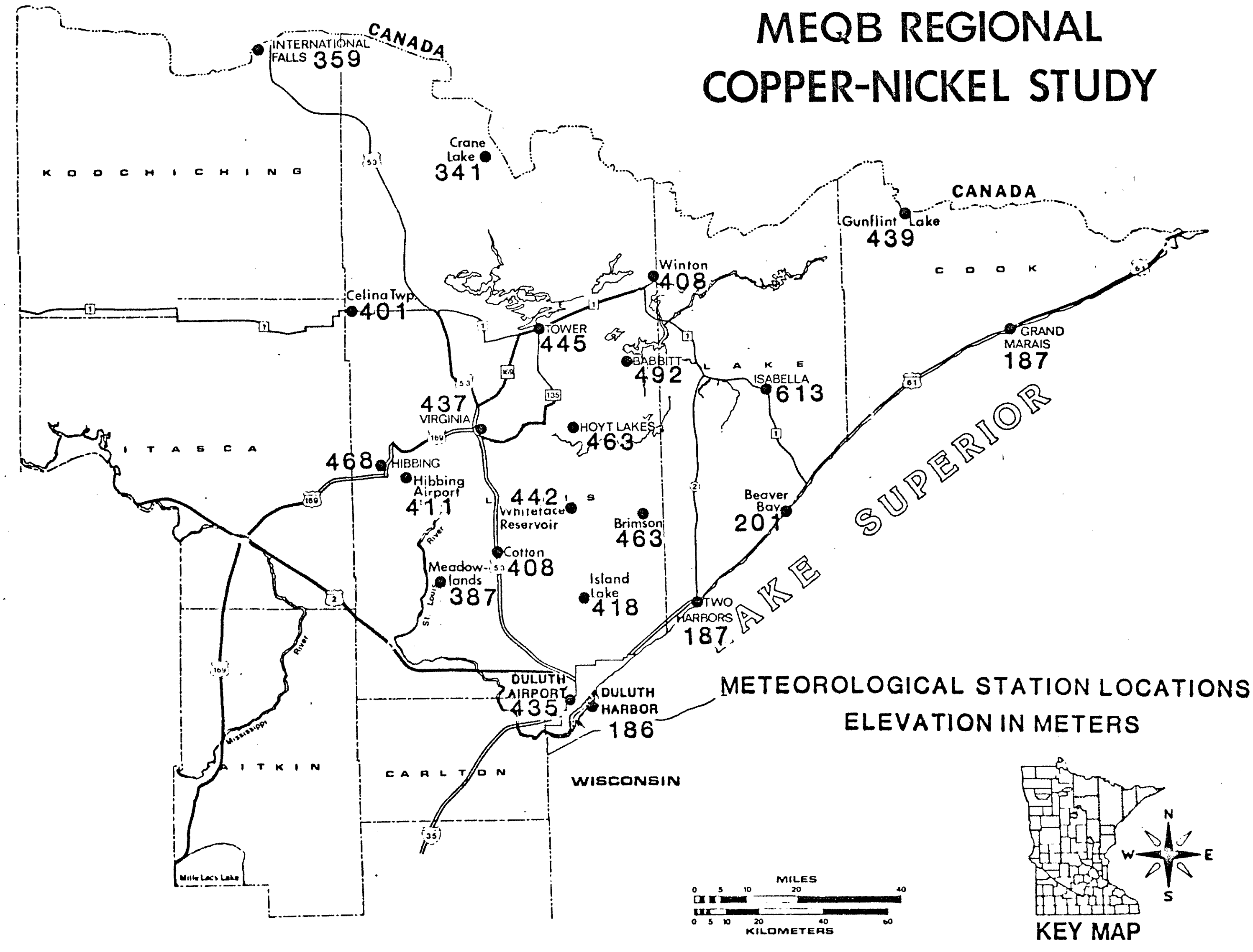
FIGURE 1.1.


MEQB REGIONAL
COPPER-NICKEL STUDY
METEOROLOGICAL STATION LOCATIONS
ELEVATION IN METERS
CANADA
INTERNATIONAL FALLS 359
Crane Lake 341
KOOCHICHING
Gunflint Lake 439
COOK
Winton 408
Celina Twp. 401
TOWER 445
BABBITT 492
LAKE
ISABELLA 613
GRAND MARAIS 187
437 VIRGINIA
HOYT LAKES 463
ITASCA
468 HIBBING
Hibbing Airport 411
442 Whiteface Reservoir
Brimson 463
Beaver Bay 201
LAKE SUPERIOR
Cotton 408
Meadowlands 387
Island Lake 418
TWO HARBORS 187
DULUTH AIRPORT 435
DULUTH HARBOR 186
AITKIN
CARLTON
WISCONSIN
Mille Lacs Lake
MILES
KILOMETERS
KEY MAP

AVERAGE SEA LEVEL PRESSURE
(MILLIBARS)

FIGURE 2.1 JANUARY

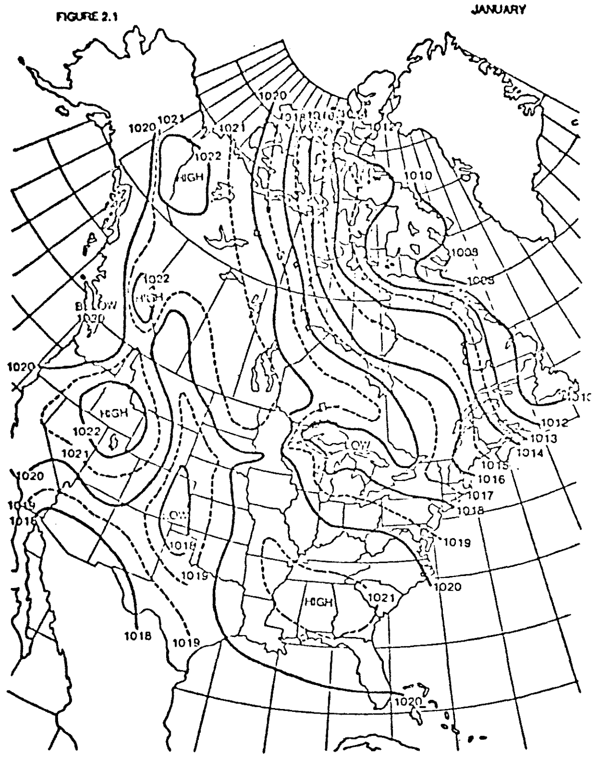


FIGURE 2.2 FEBRUARY

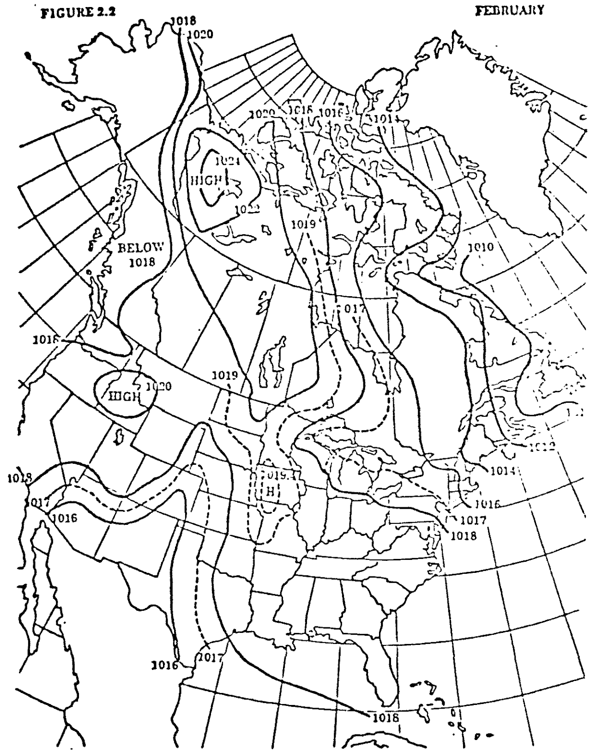


FIGURE 2.3 MARCH

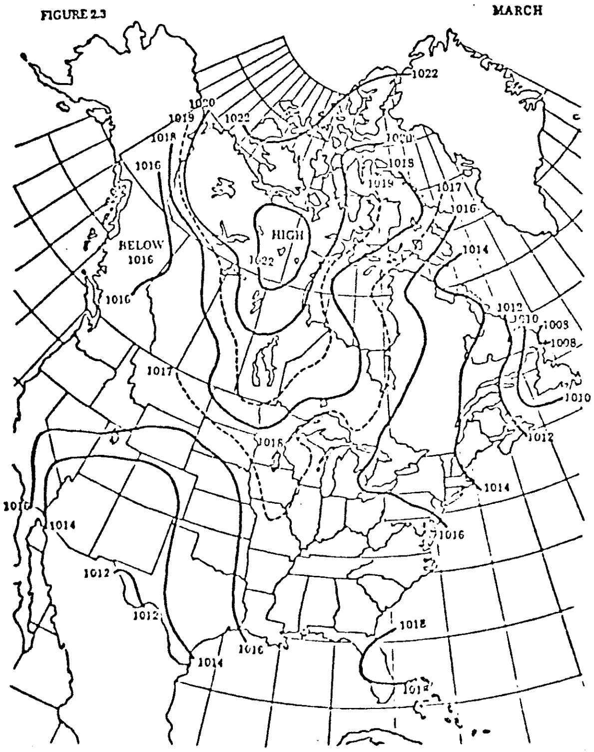
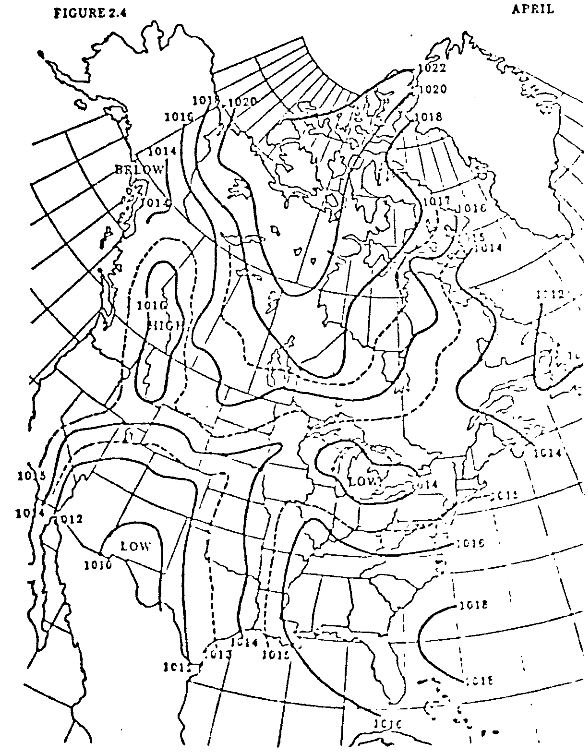


FIGURE 2.4 APRIL



AVERAGE SEA LEVEL PRESSURE,
(MILLIBARS)

FIGURE 2.5 MAY

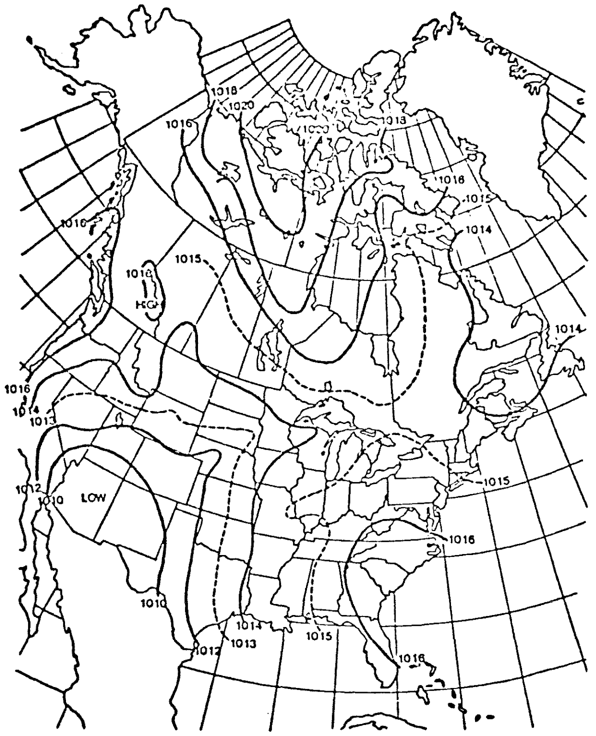


FIGURE 2.6 JUNE

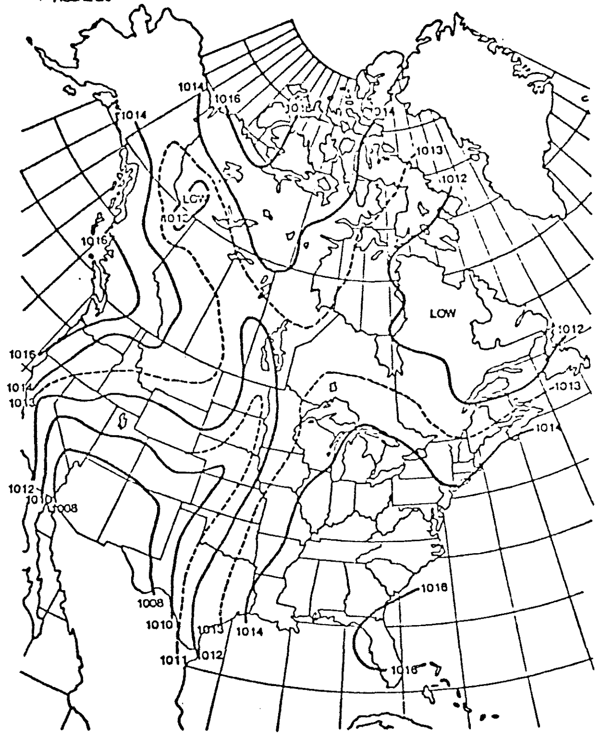


FIGURE 2.7 JULY

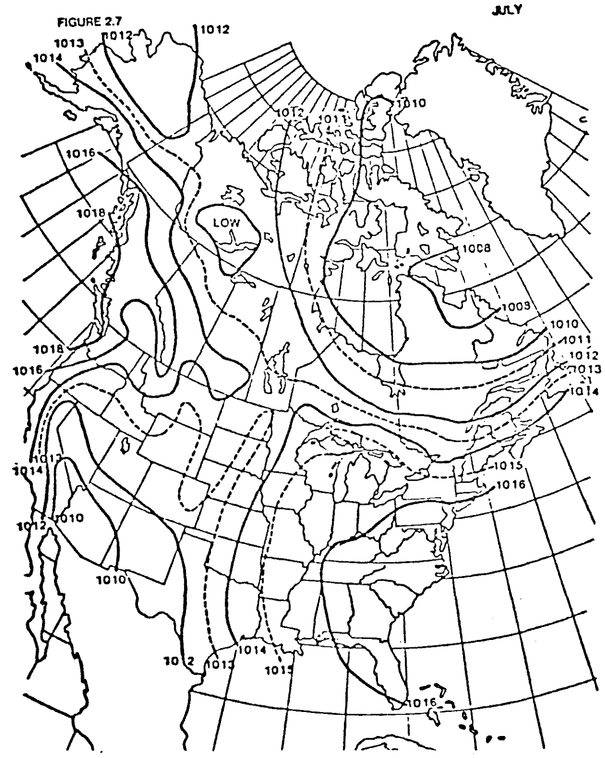
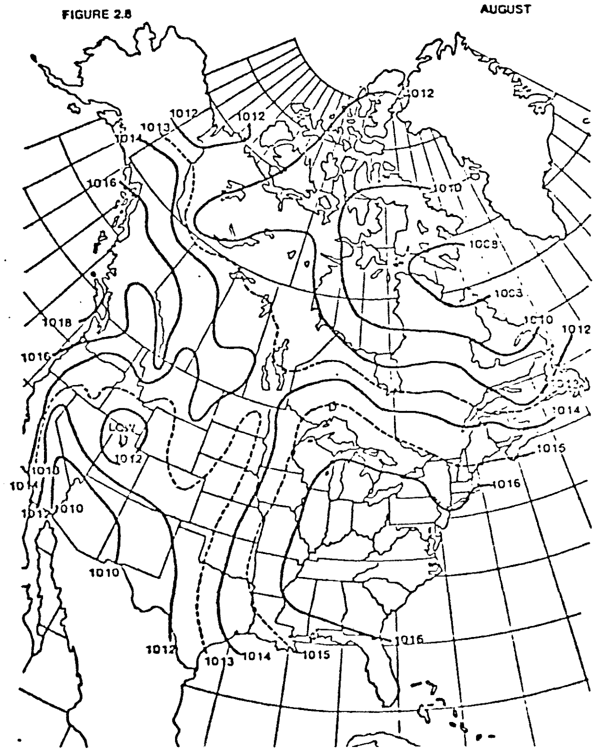


FIGURE 2.8 AUGUST



AVERAGE SEA LEVEL PRESSURE, MILLIBARS

FIGURE 2.9 SEPTEMBER

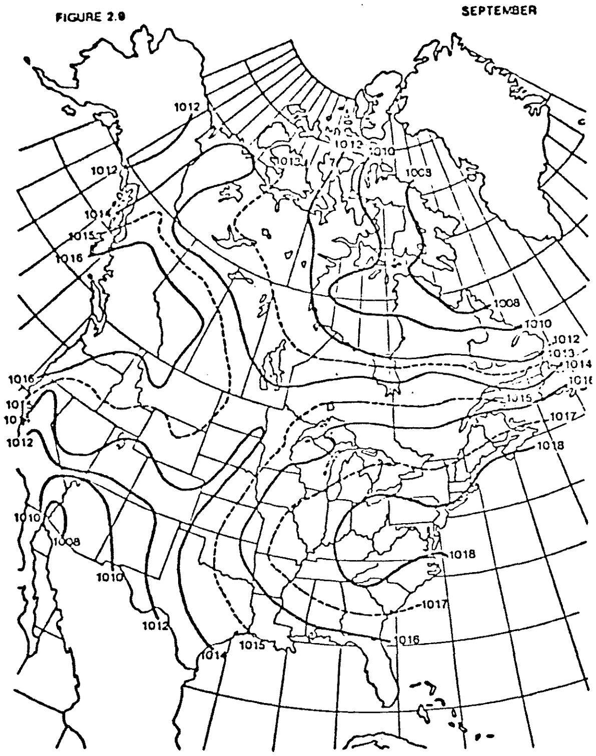


FIGURE 2.10 OCTOBER

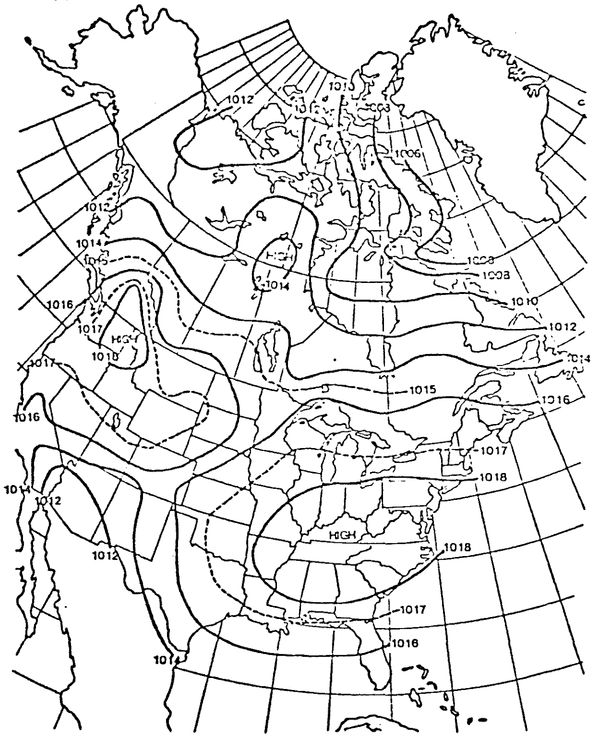


FIGURE 2.11 NOVEMBER

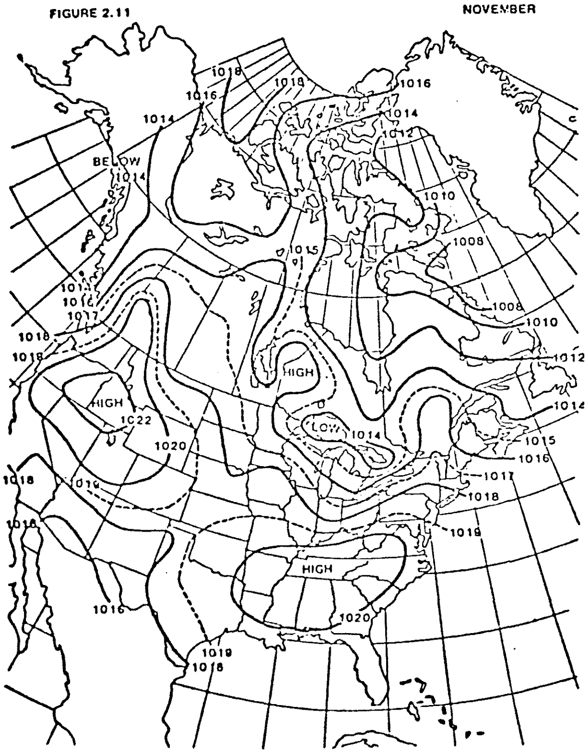
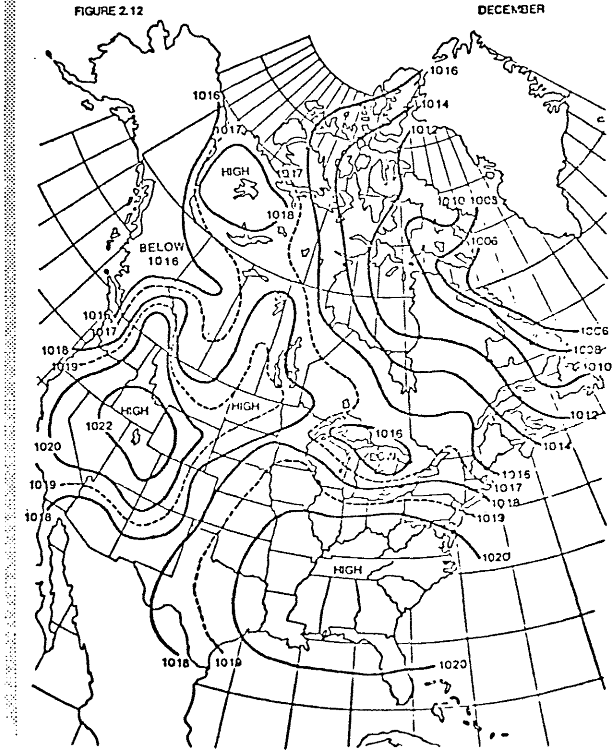


FIGURE 2.12 DECEMBER



HIBBING 1964-1973

FIGURE 2.13

WIND DISTRIBUTION
%FREQUENCY BY OCTANTS

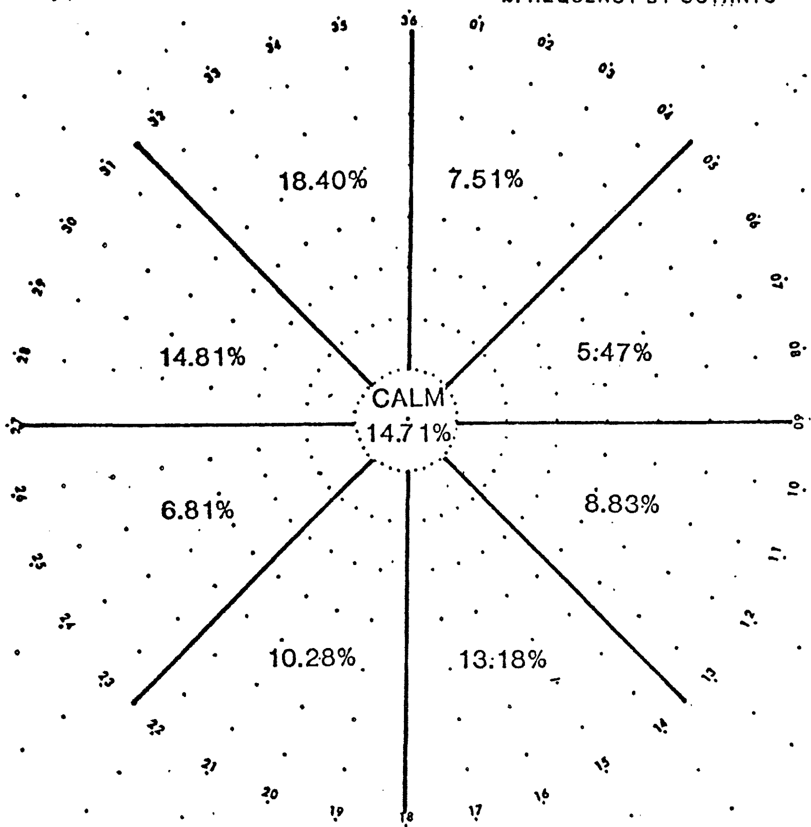
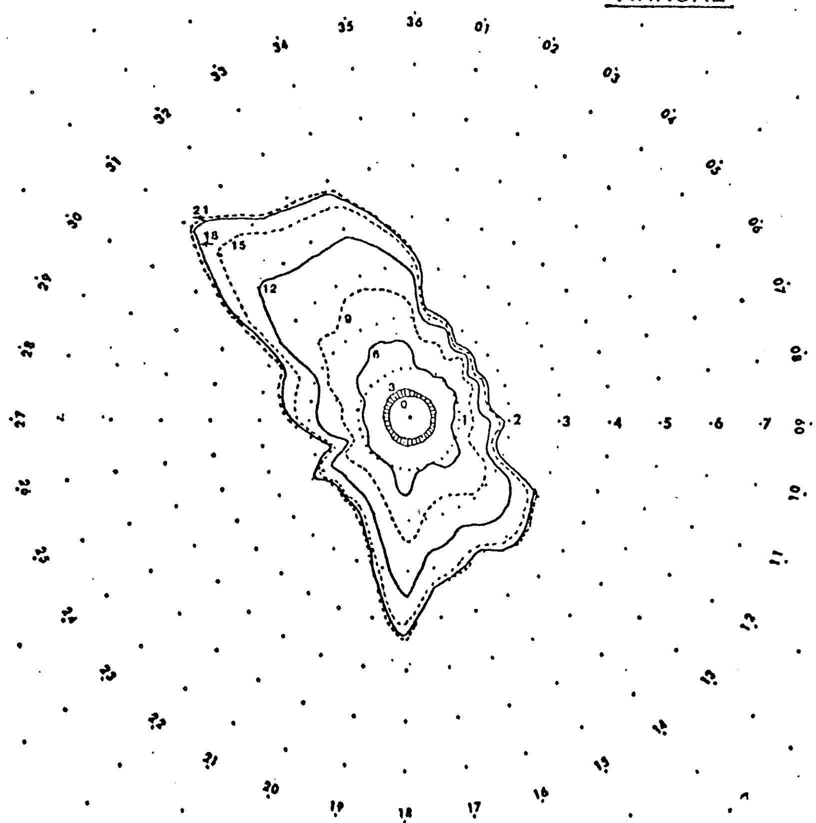


FIGURE 2.14

WIND ROSE
ANNUAL



NOTE: wind speeds are shown in knots on all isopleths. Divide by 2 to obtain meters/sec.

HIBBING 1964-1973

FIGURE 2.15

WIND ROSE
JANUARY

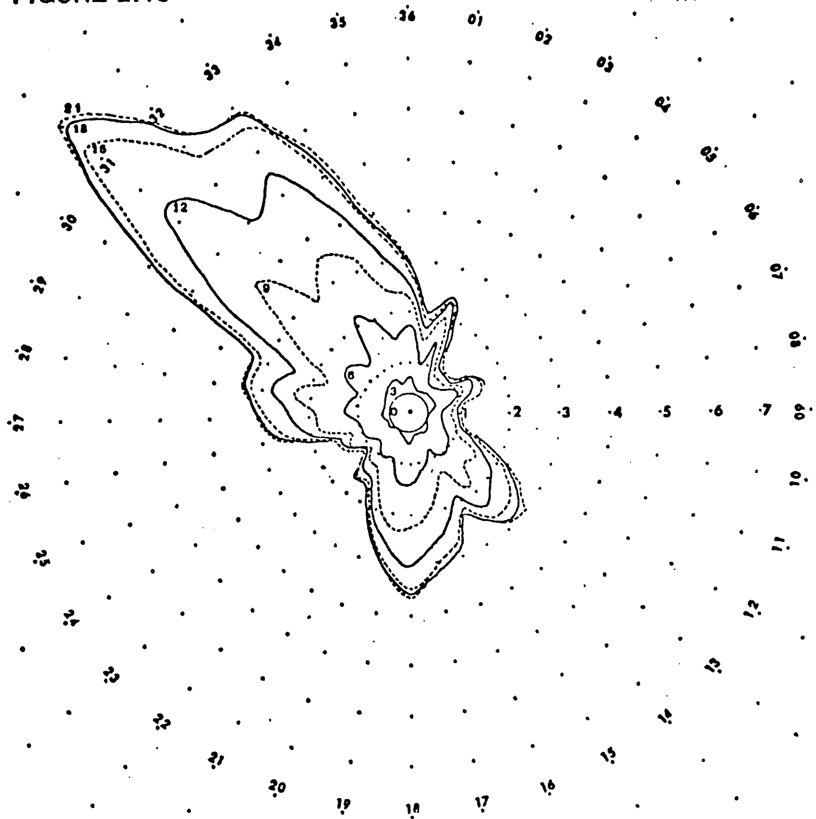
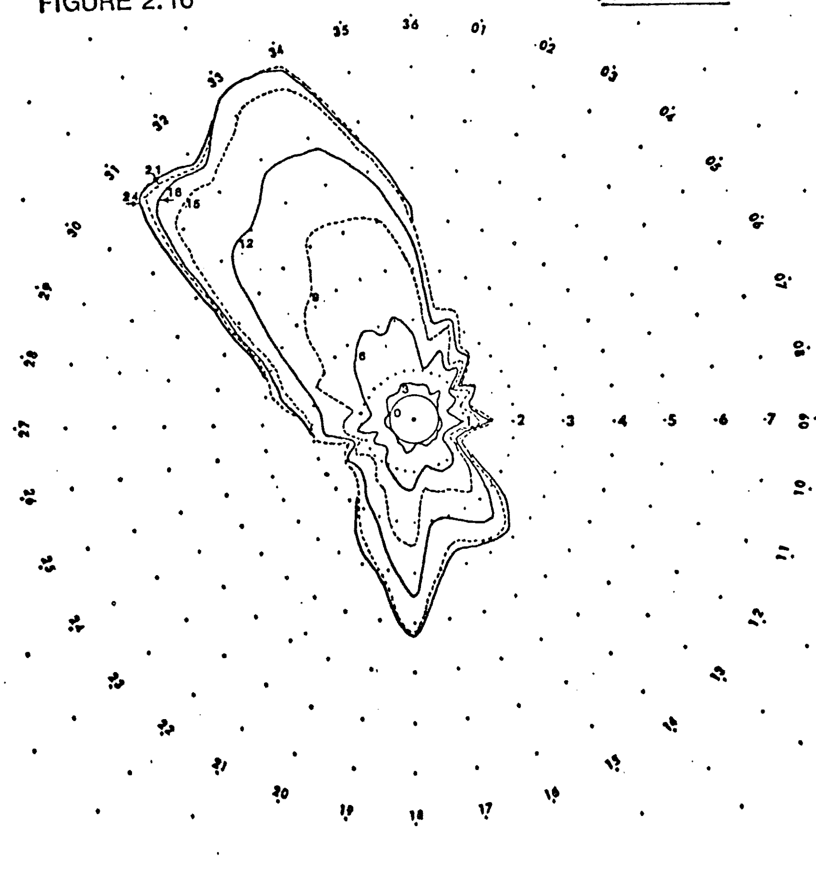


FIGURE 2.16

WIND ROSE
FEBRUARY



HIBBING 1964-1973

FIGURE 2.17

WIND ROSE
MARCH

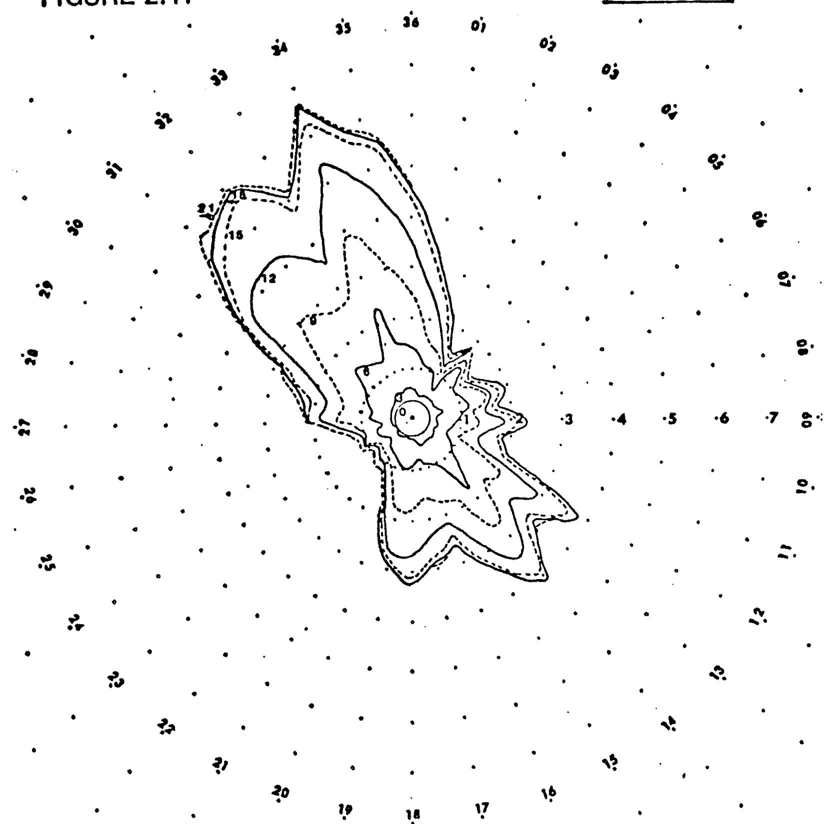
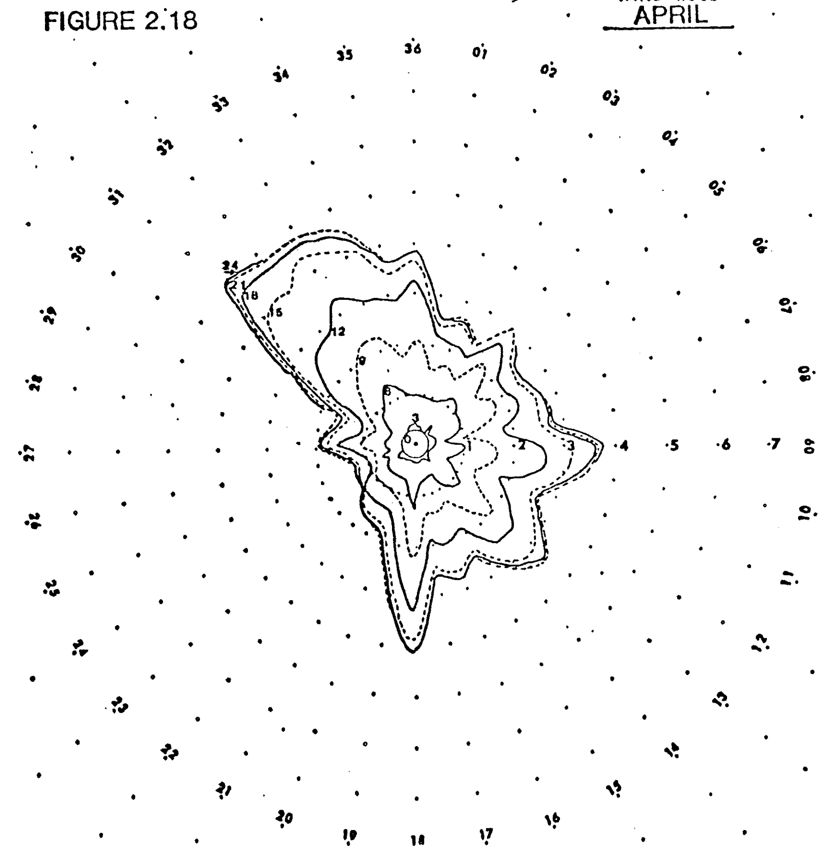


FIGURE 2.18

WIND ROSE
APRIL



HIBBING 1964-1973

FIGURE 2.19

WIND ROSE
MAY

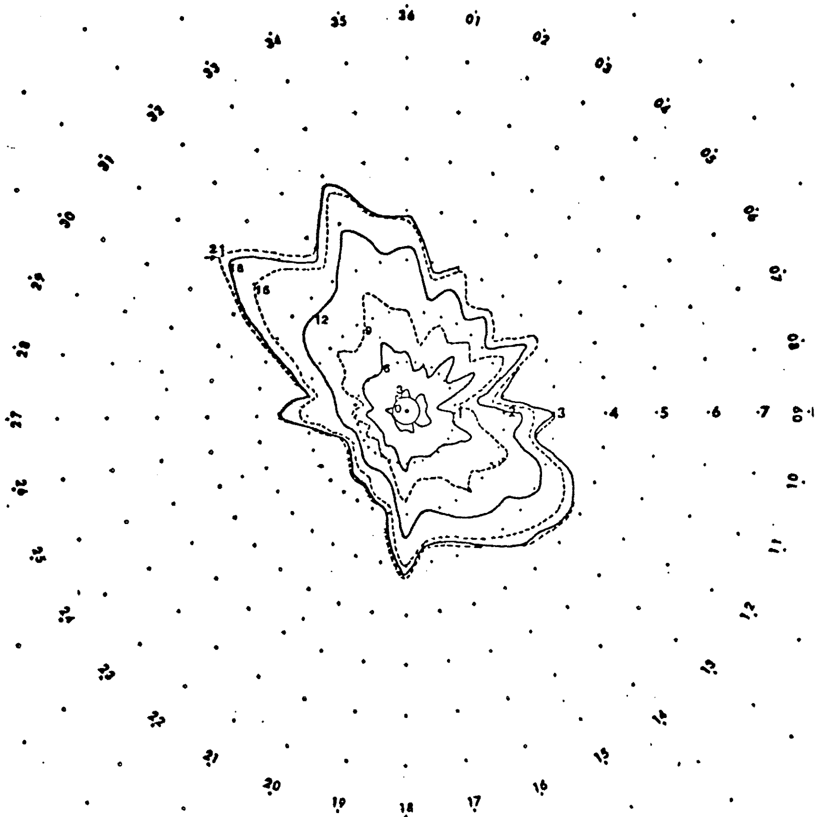
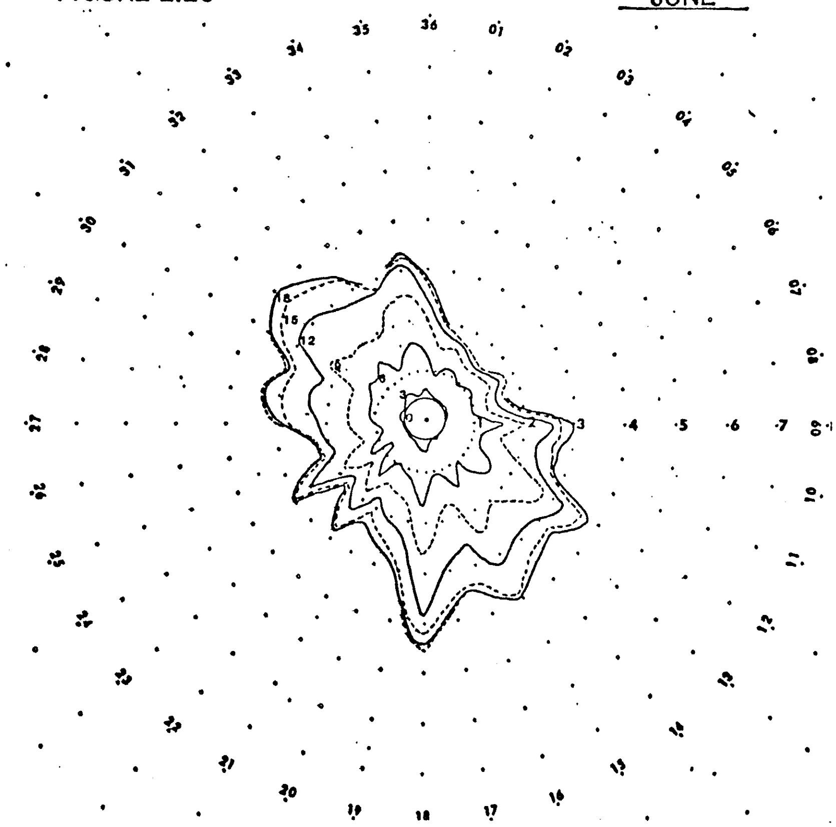


FIGURE 2.20

WIND ROSE
JUNE



HIBBING 1964-1973

FIGURE 2.21

WIND ROSE
JULY

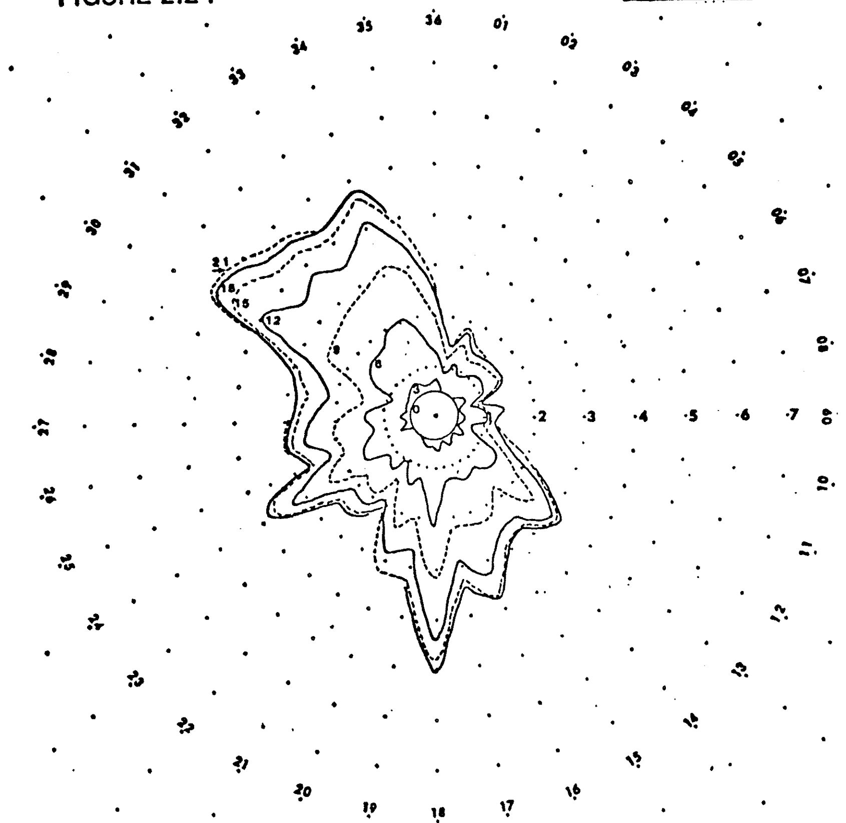
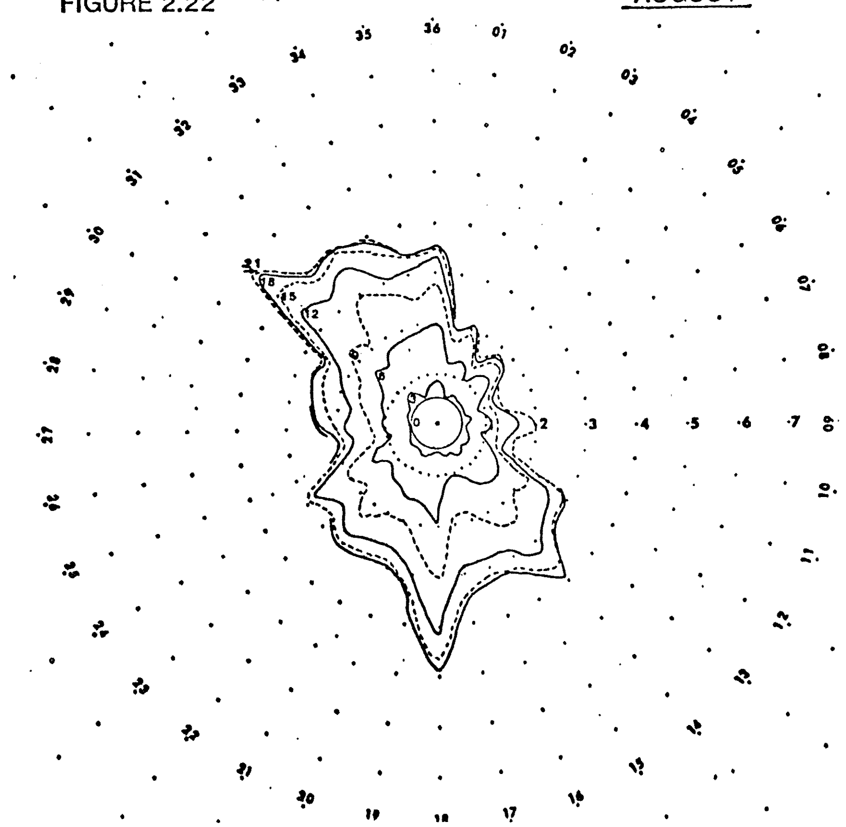


FIGURE 2.22

WIND ROSE
AUGUST



HIBBING 1964-1973

FIGURE 2.23

WIND ROSE
SEPTEMBER

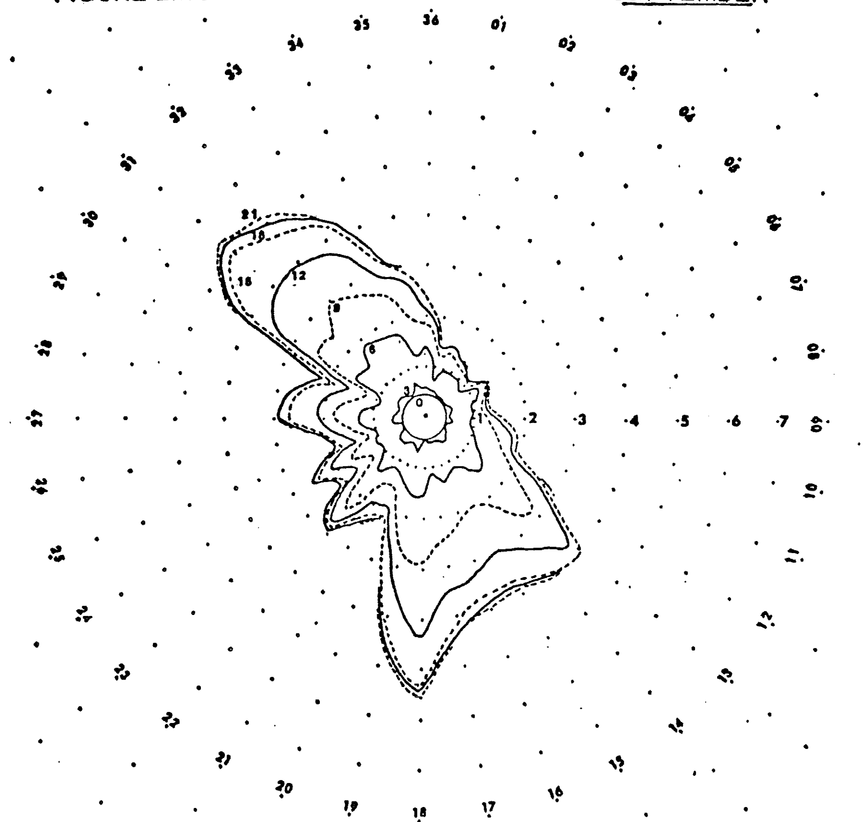
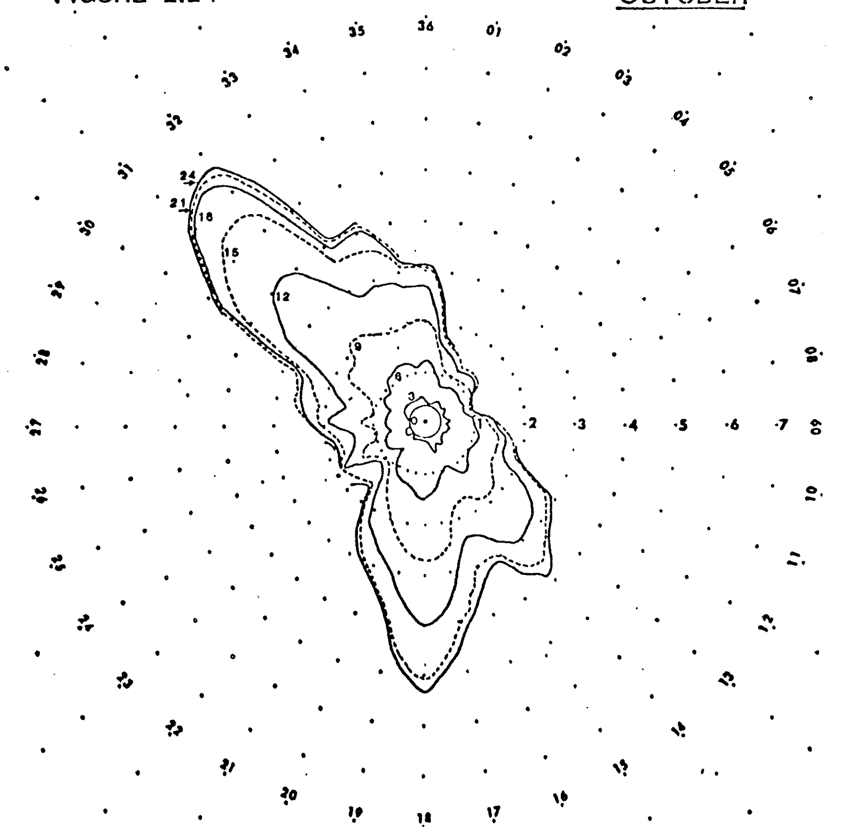


FIGURE 2.24

WIND ROSE
OCTOBER



HIBBING 1964-1973

FIGURE 2.25

WIND ROSE
NOVEMBER

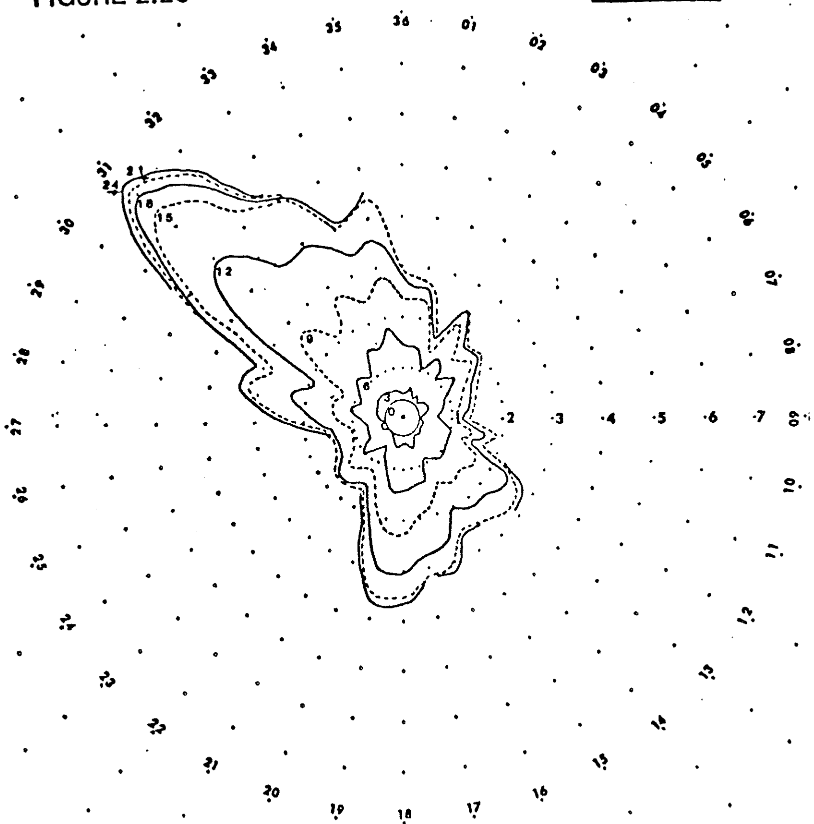
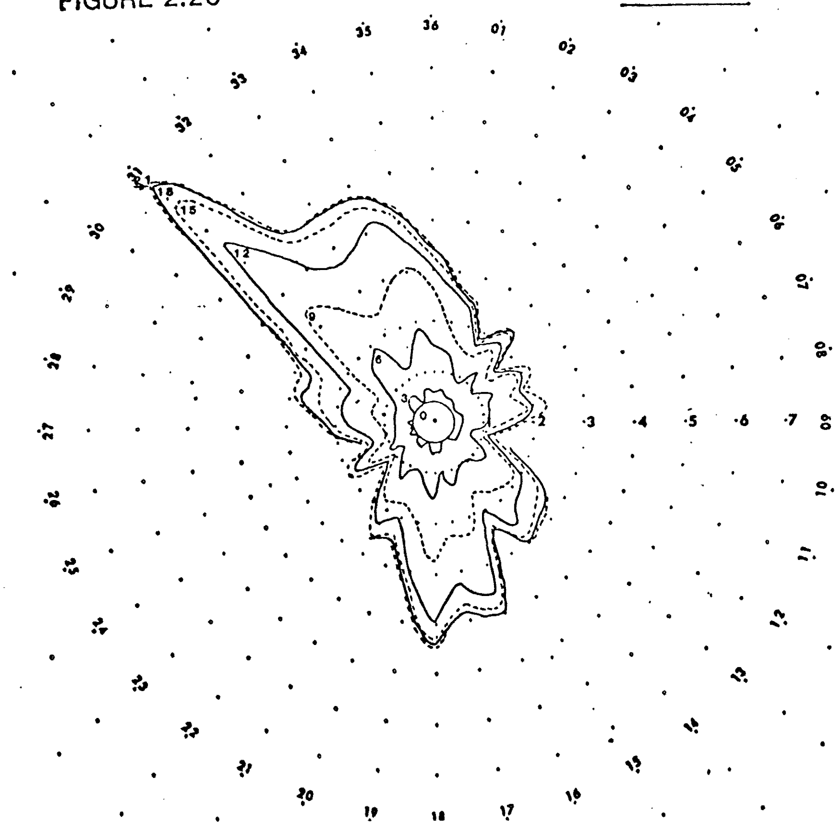


FIGURE 2.26

WIND ROSE
DECEMBER



HIBBING 1964-1973

FIGURE 2.27

WIND ROSE JAN 1-10

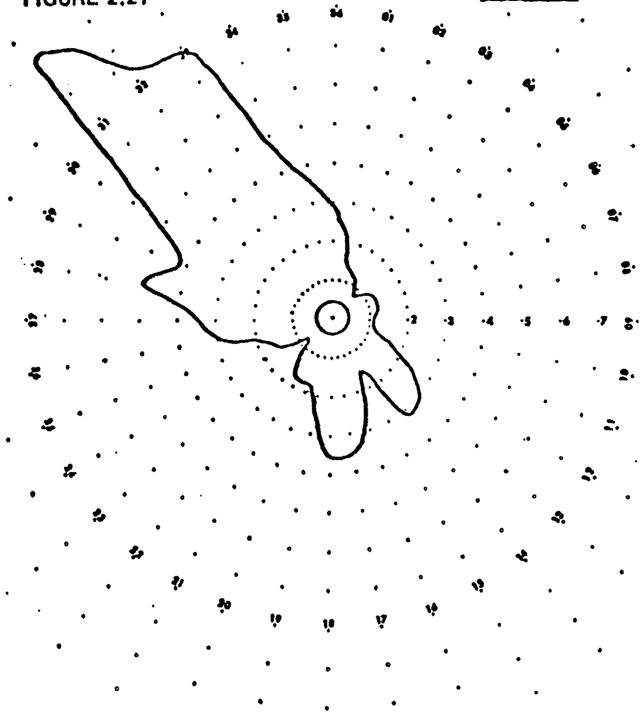


FIGURE 2.28

WIND ROSE JAN 11-20

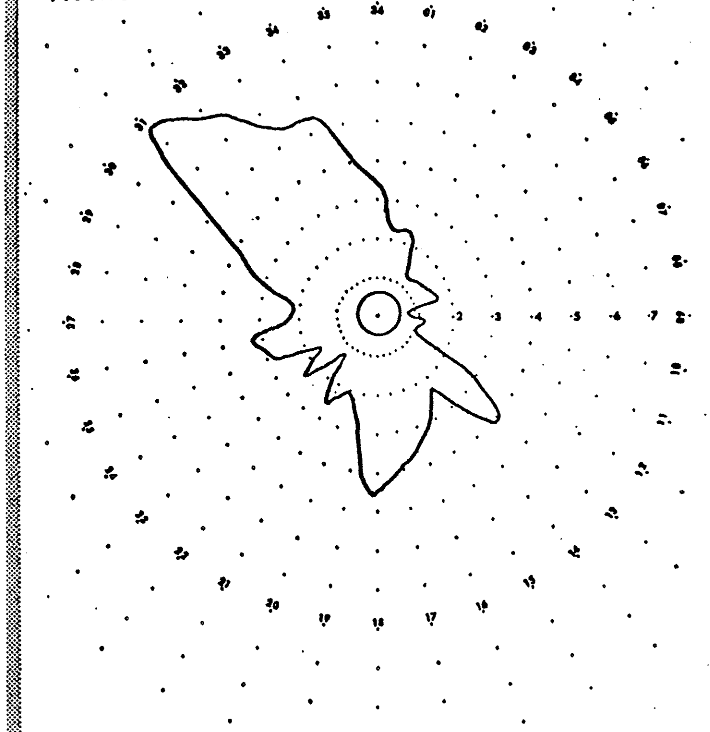


FIGURE 2.29

WIND ROSE JAN 21-30

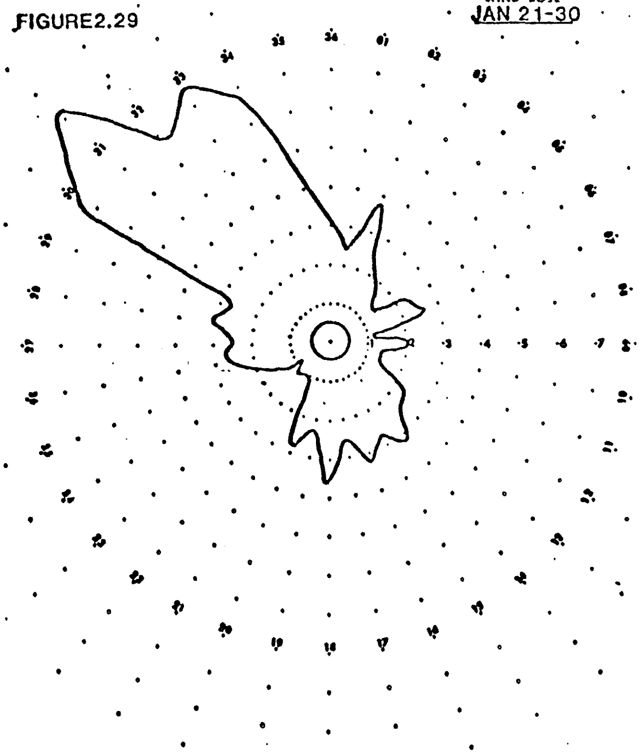
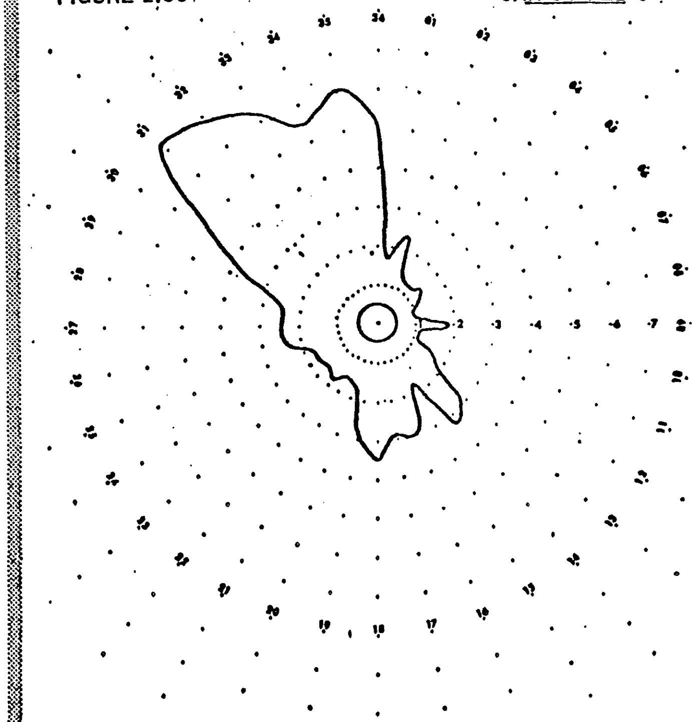


FIGURE 2.30

WIND ROSE JAN 31-FEB 9



HIBBING 1964-1973

FIGURE 2.31

WIND ROSE FEB 10-19

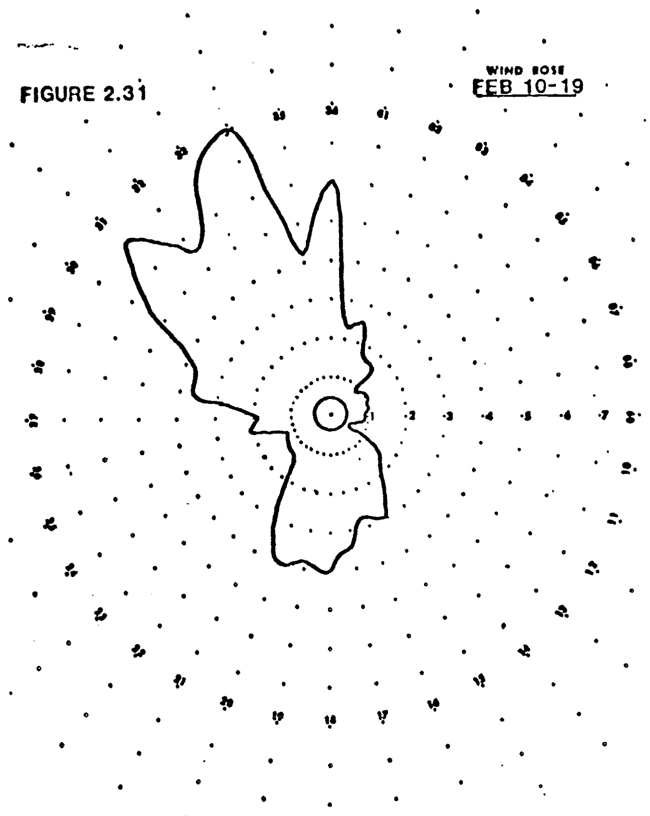


FIGURE 2.32

WIND ROSE FEB 20-MAR 1

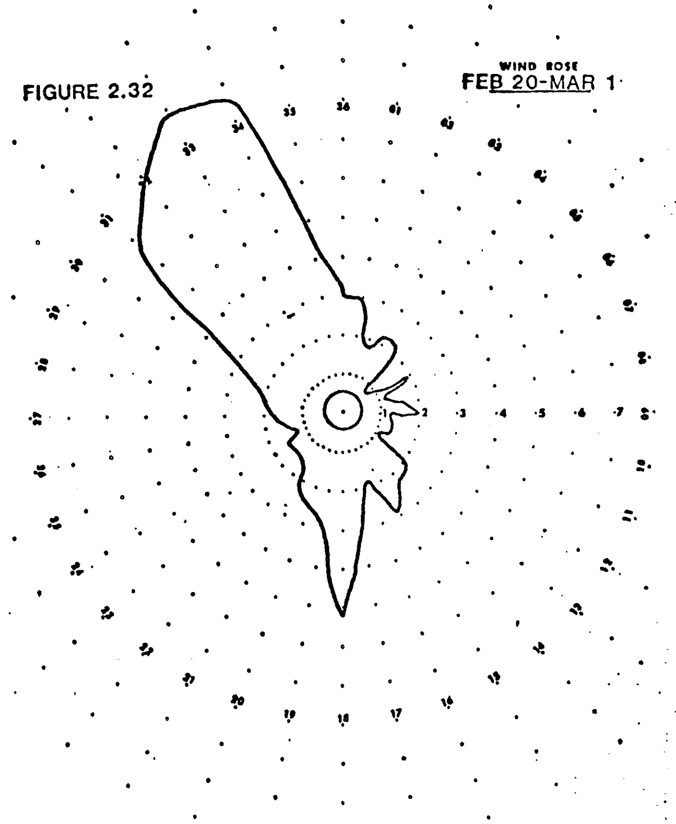


FIGURE 2.33

WIND ROSE MAR 2-11

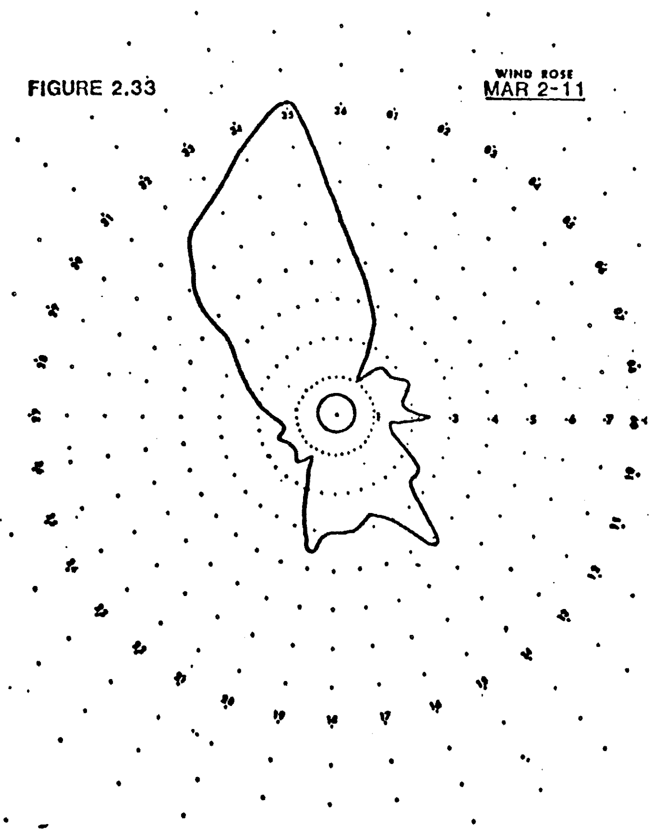
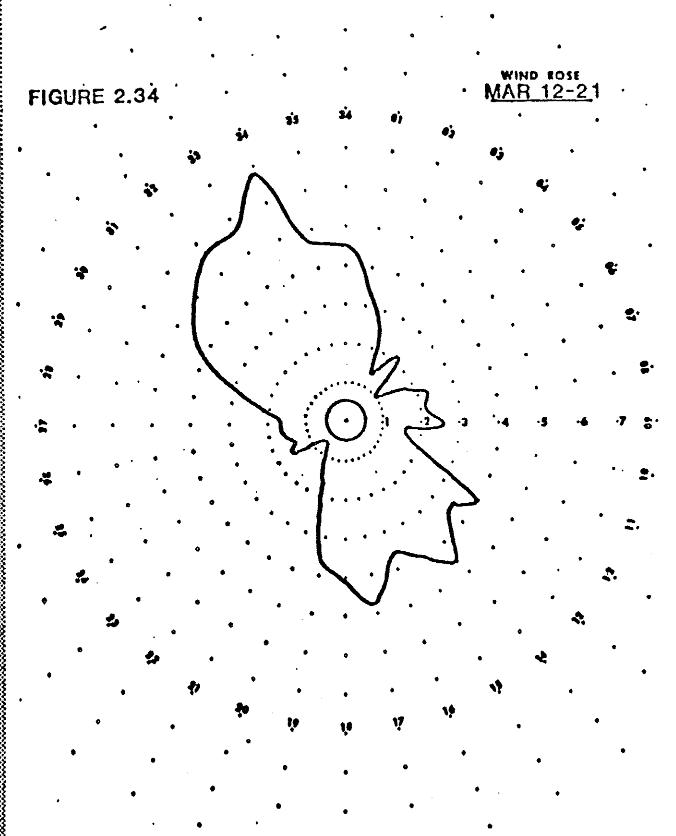


FIGURE 2.34

WIND ROSE MAR 12-21



HIBBING 1964-1973

FIGURE 2.35

WIND ROSE
MAR 22-31

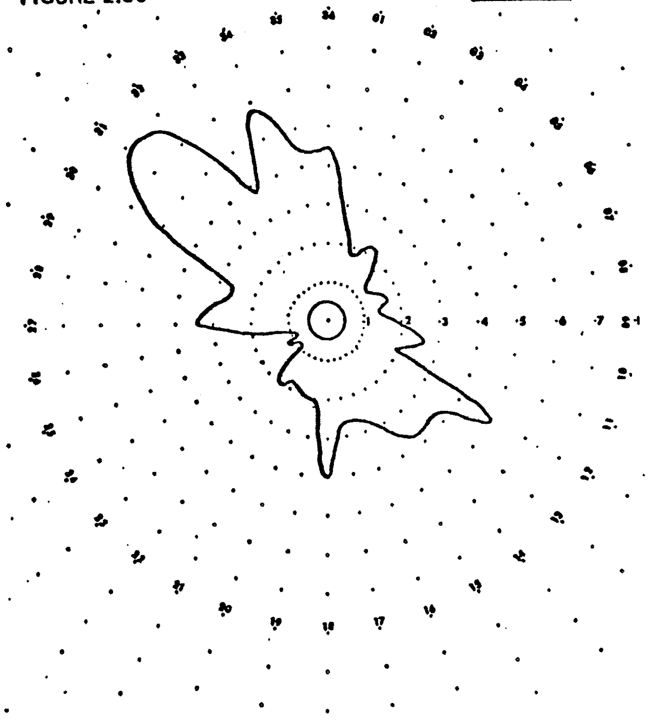


FIGURE 2.36

WIND ROSE
APR 1-10

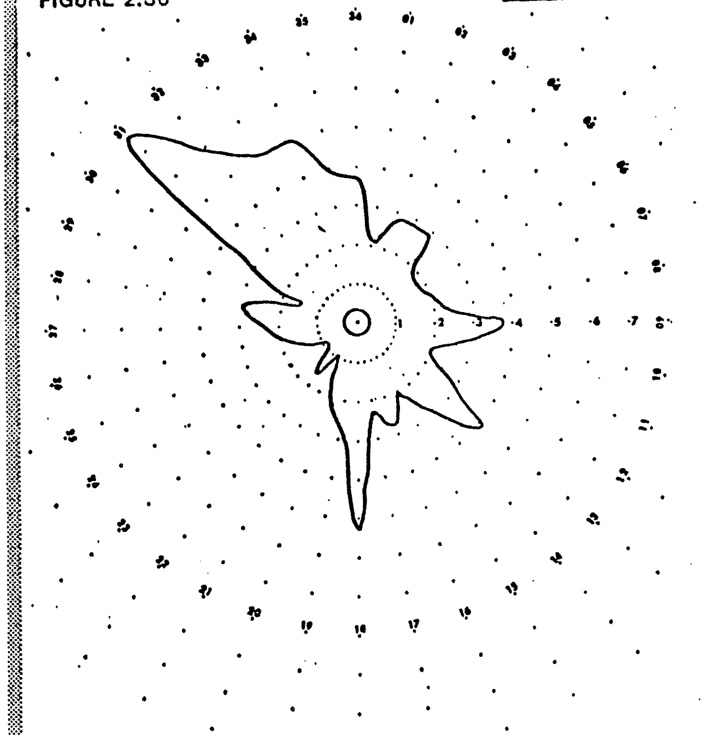


FIGURE 2.37

WIND ROSE
APR 11-20

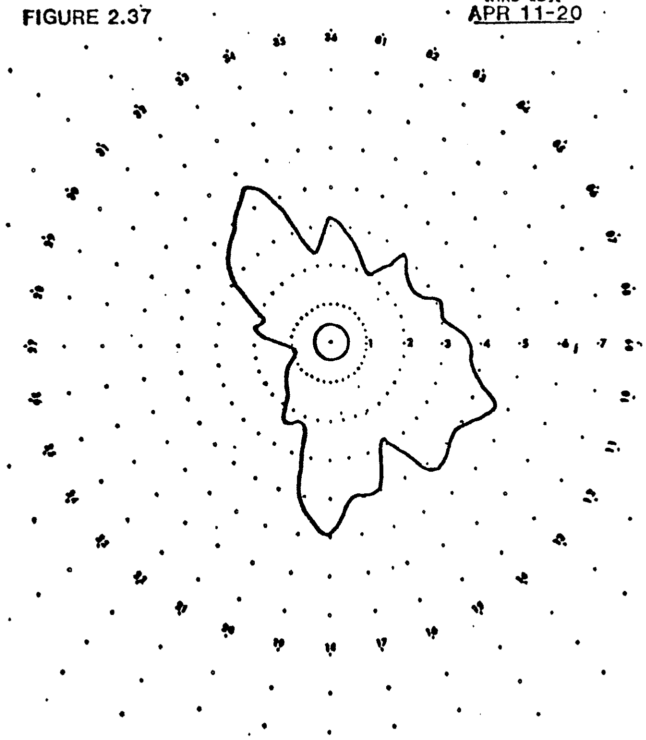
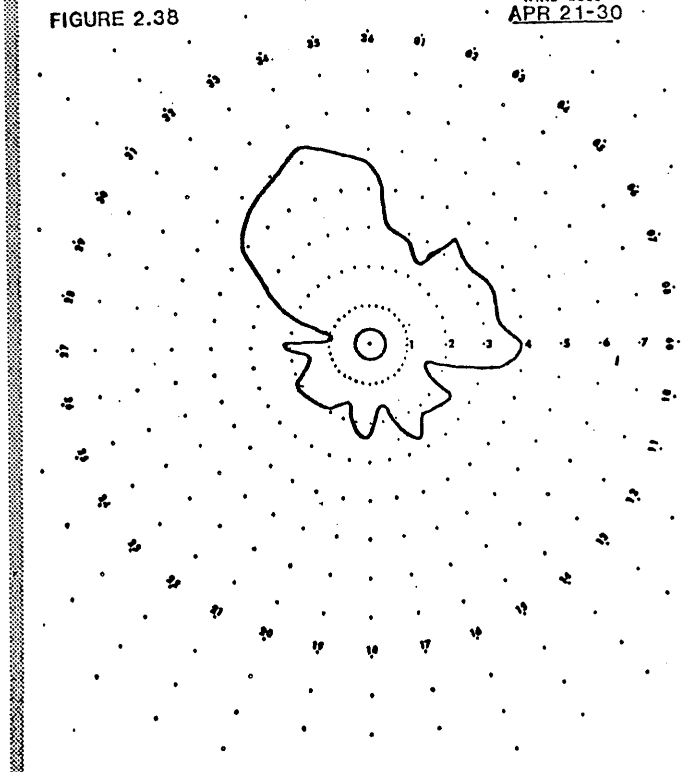


FIGURE 2.38

WIND ROSE
APR 21-30



HIBBING 1964-1973

FIGURE 2.39

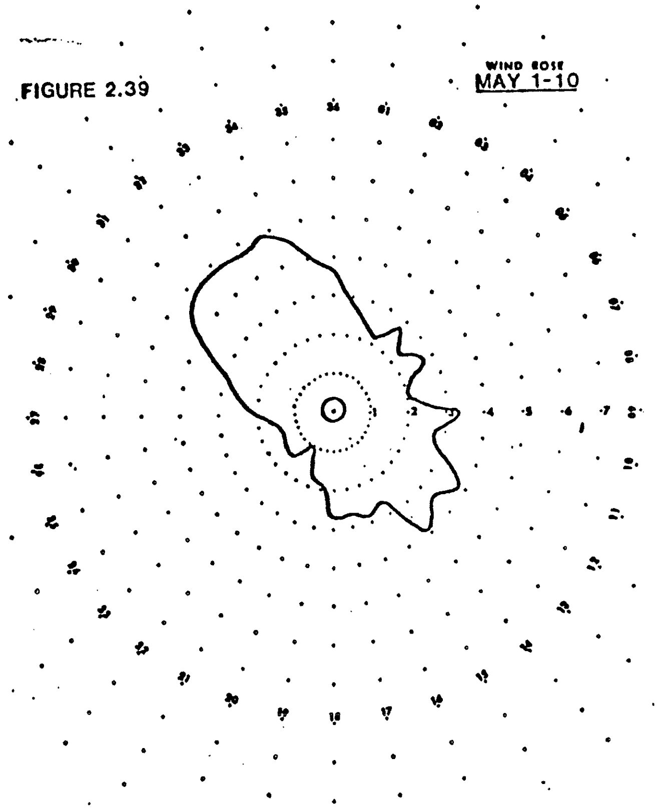


FIGURE 2.40

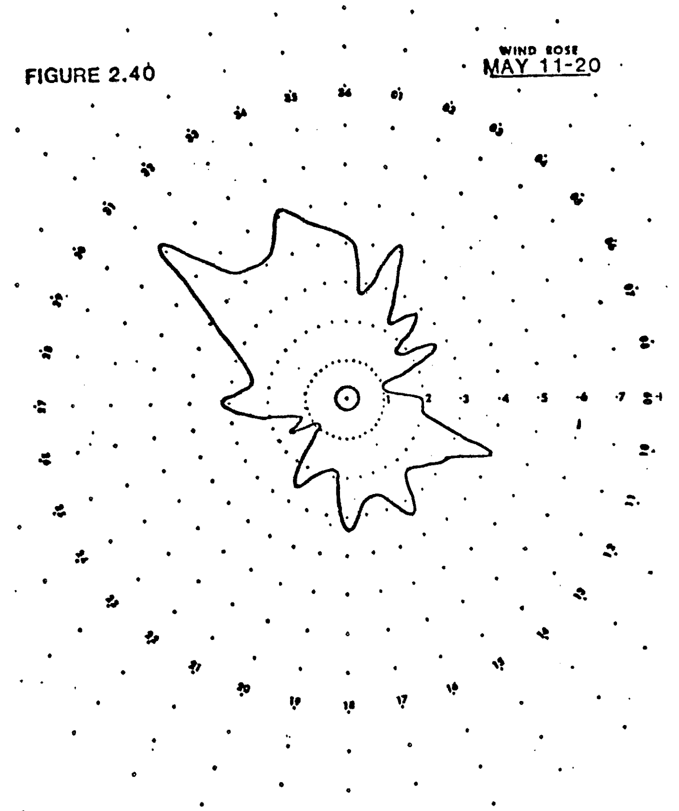


FIGURE 2.41

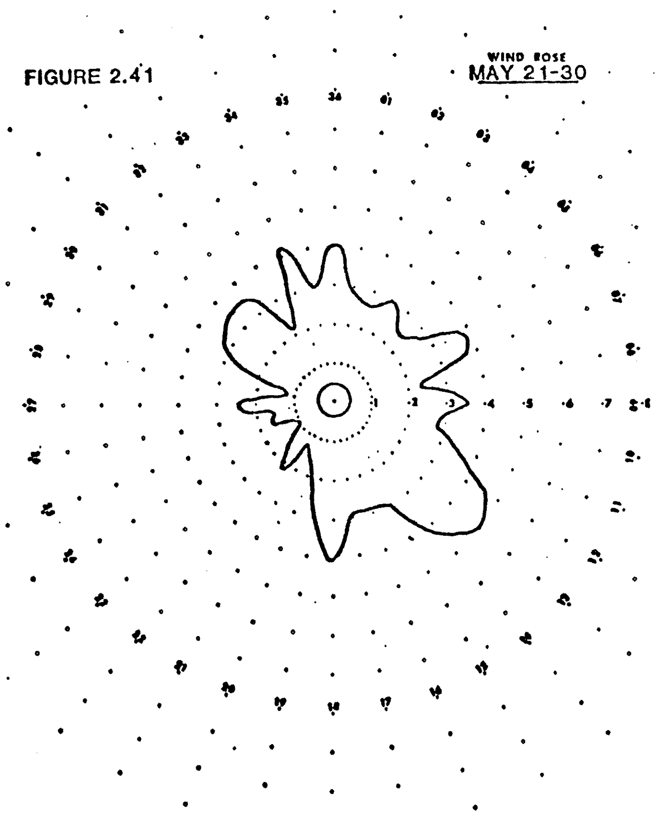
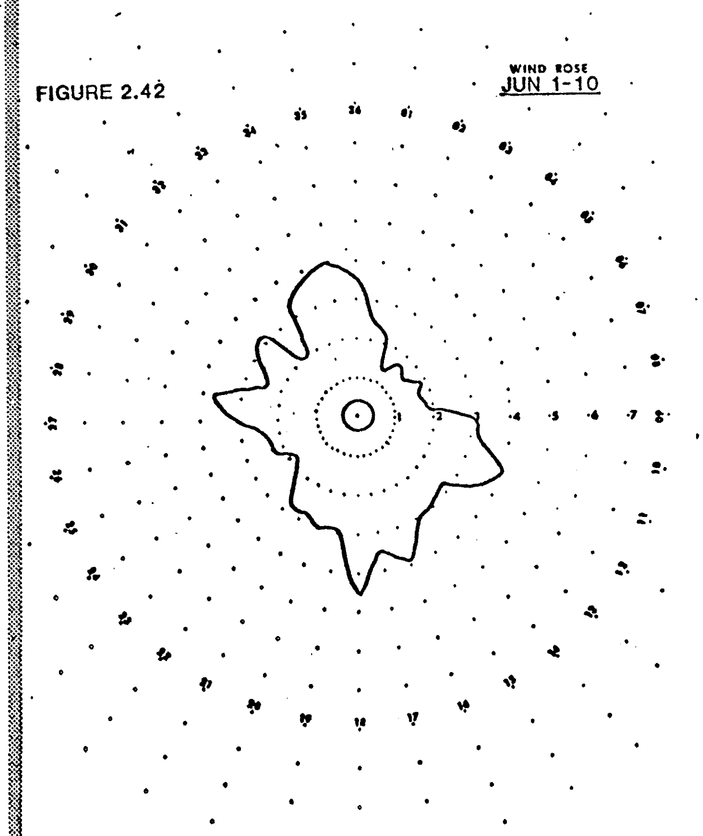


FIGURE 2.42



HIBBING 1964-1973

FIGURE 2.43

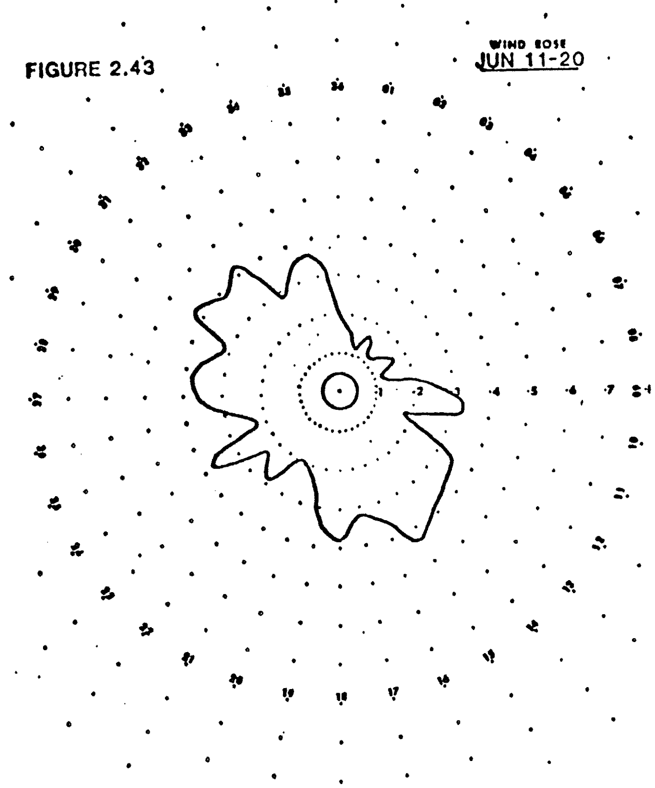


FIGURE 2.44

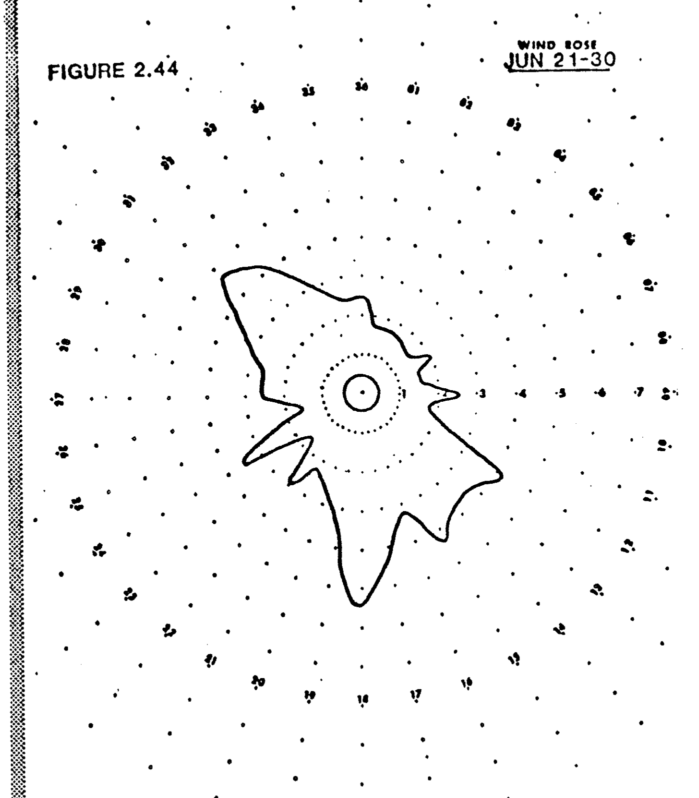


FIGURE 2.45

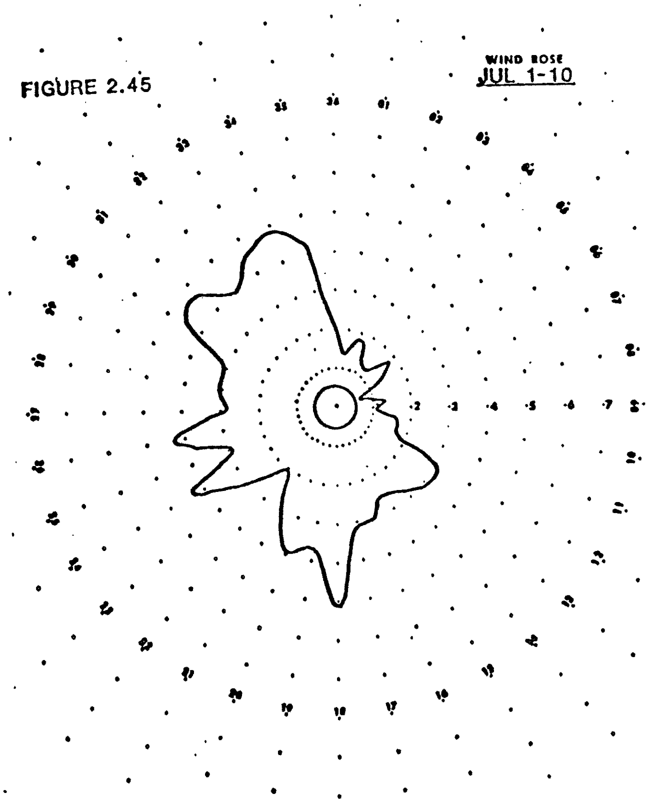
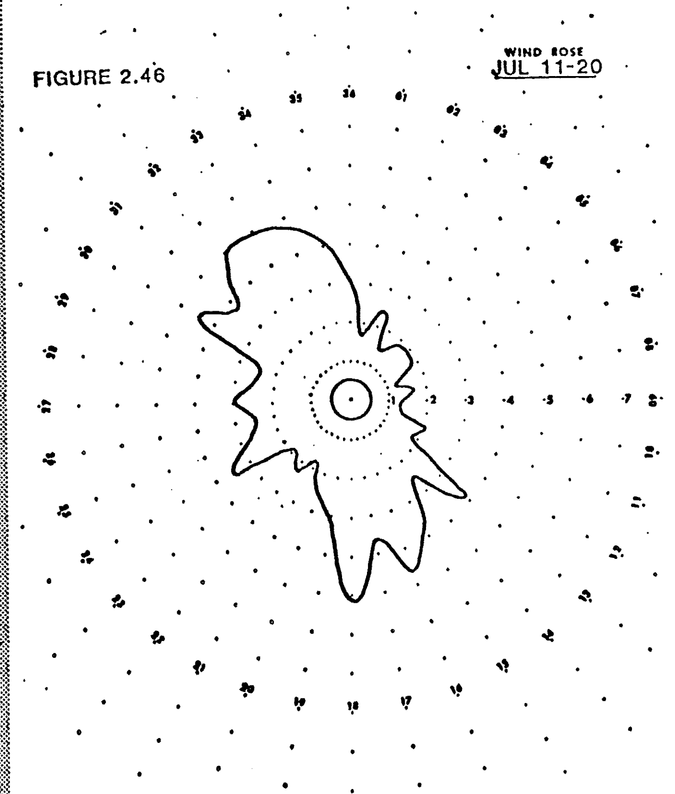


FIGURE 2.46



HIBBING 1964-1973

FIGURE 2.47

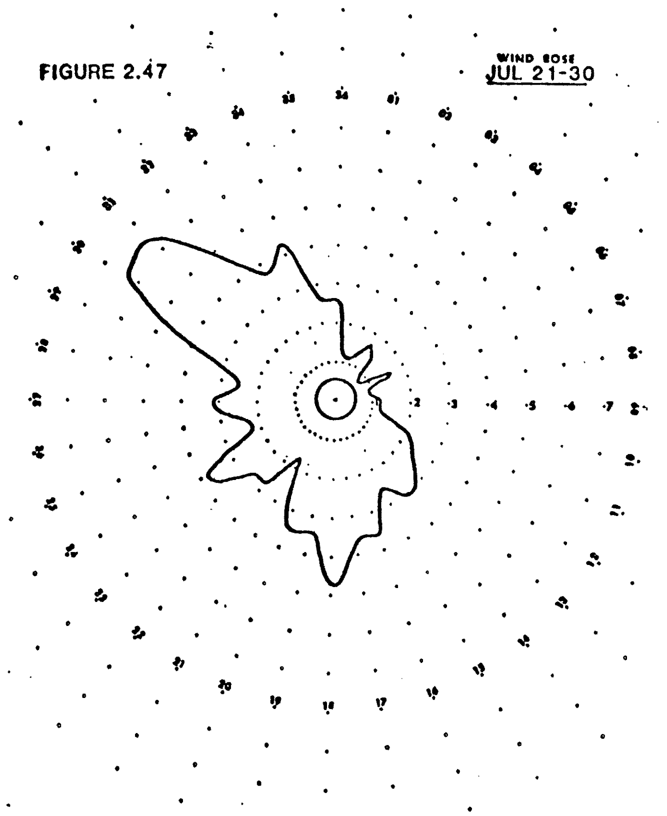


FIGURE 2.48

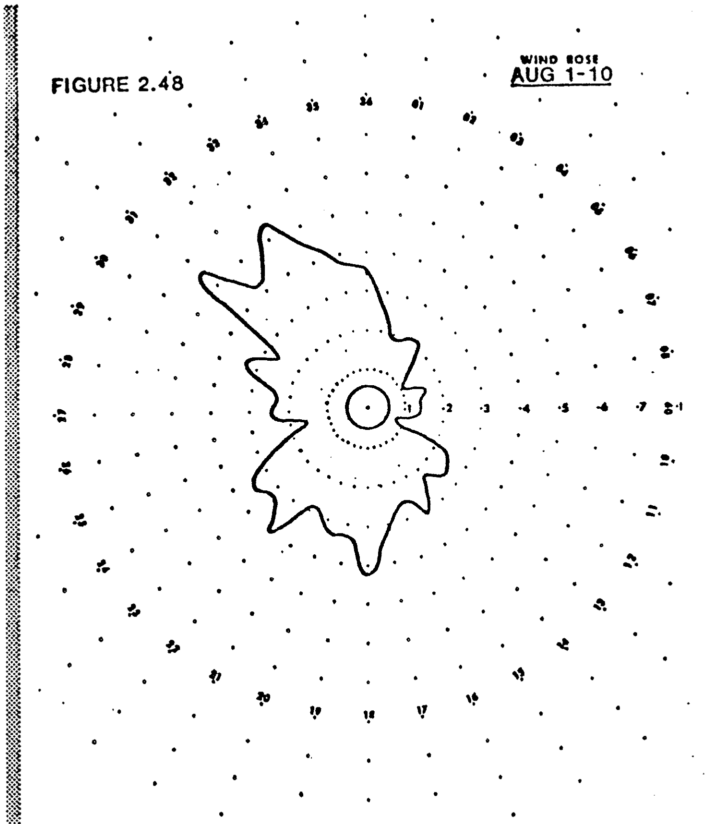


FIGURE 2.49

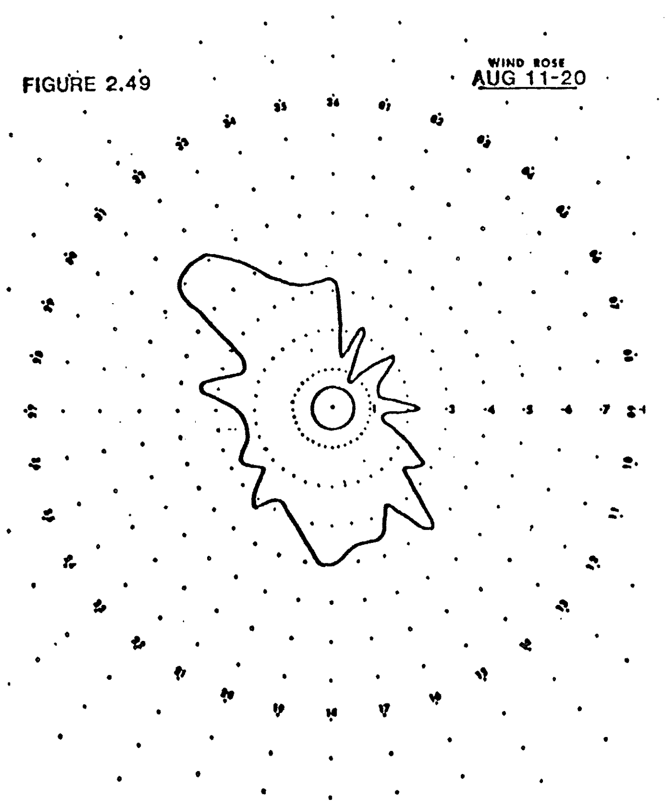
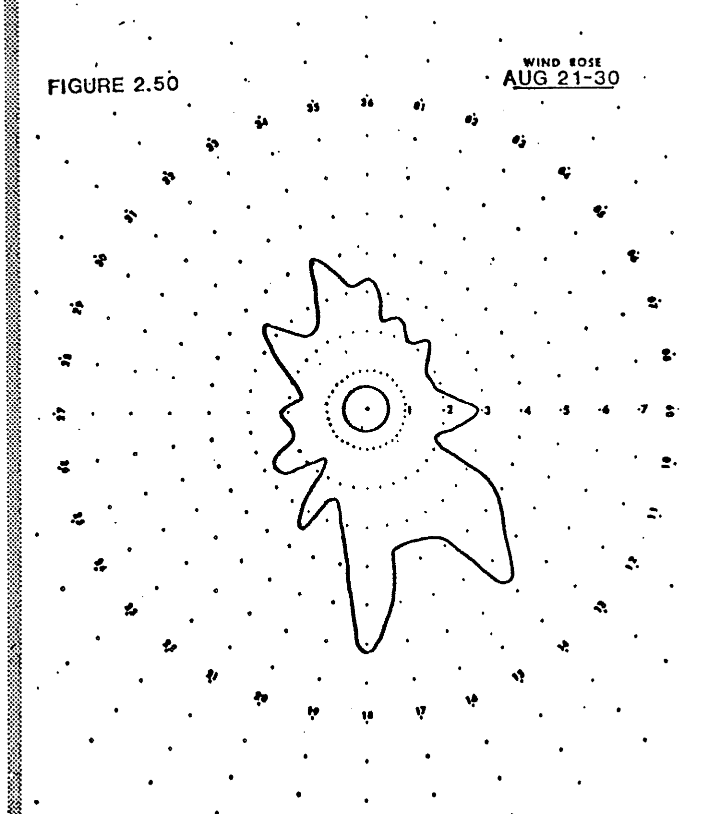


FIGURE 2.50



HIBBING 1964-1973

FIGURE 2.51

FIGURE 2.52

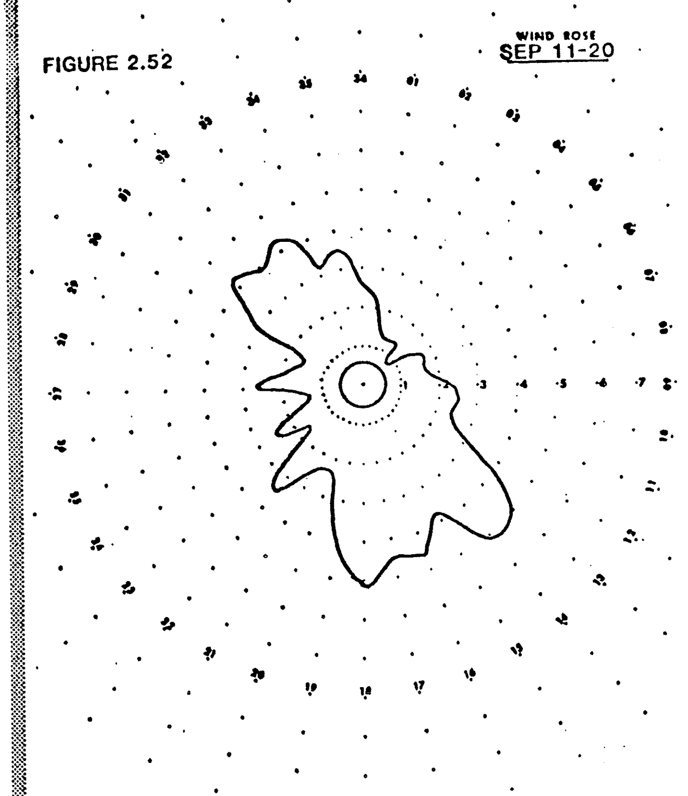


FIGURE 2.53

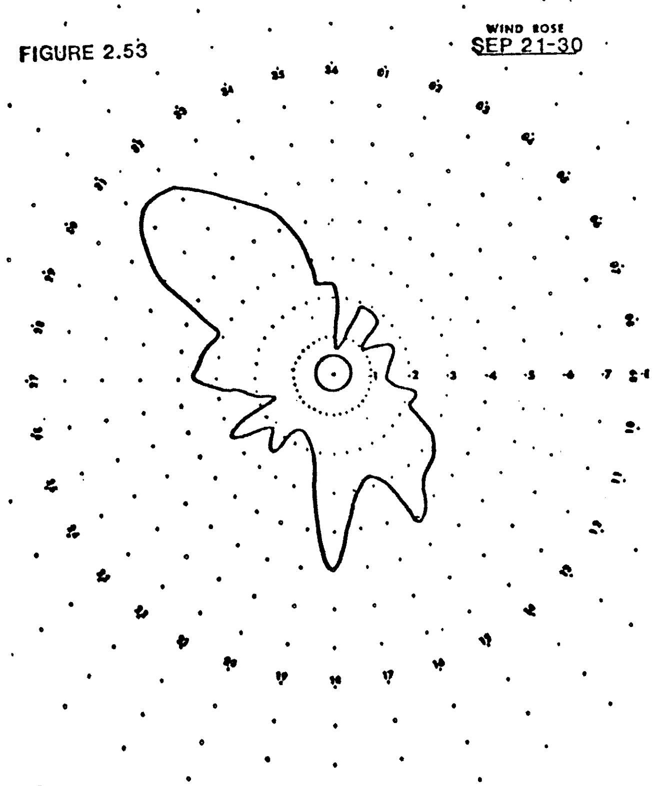
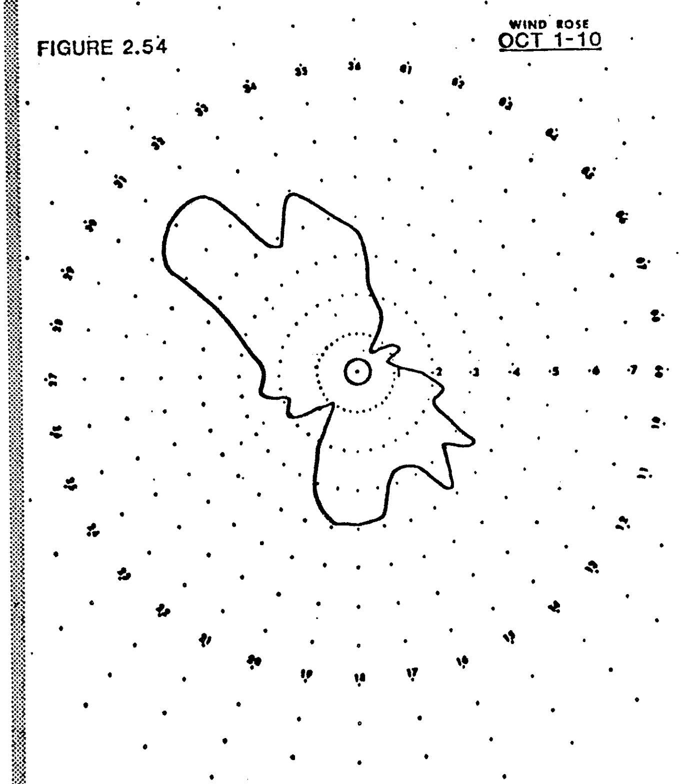


FIGURE 2.54



HIBBING 1964-1973

FIGURE 2.55

WIND ROSE OCT 11-20

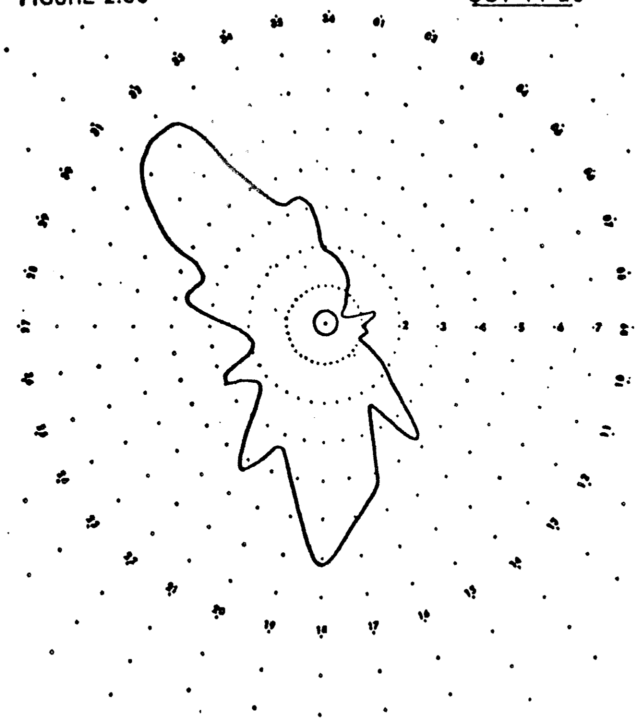


FIGURE 2.56

WIND ROSE OCT 21-30

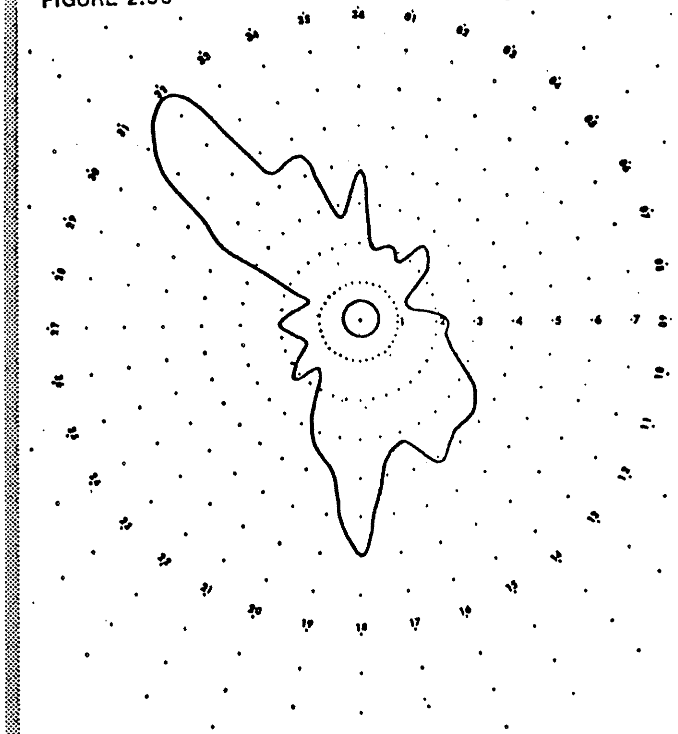


FIGURE 2.57

WIND ROSE NOV 1-10

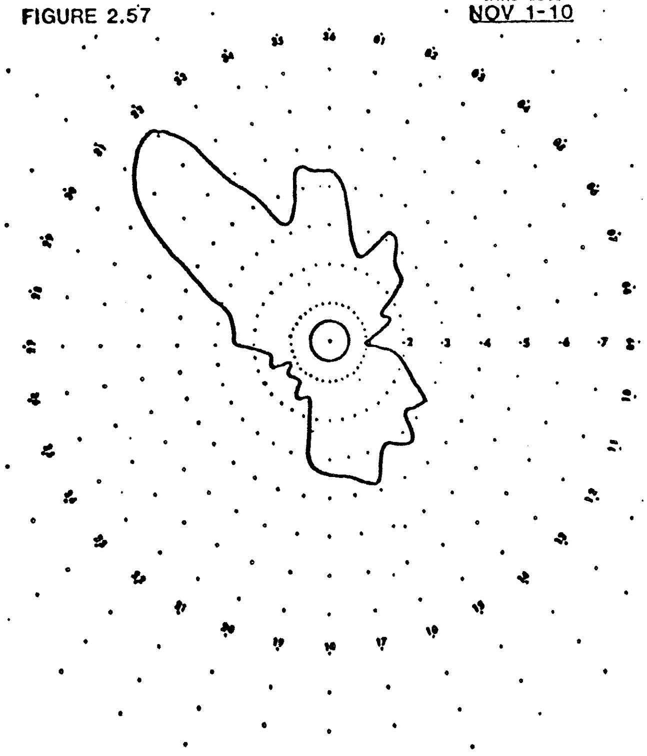
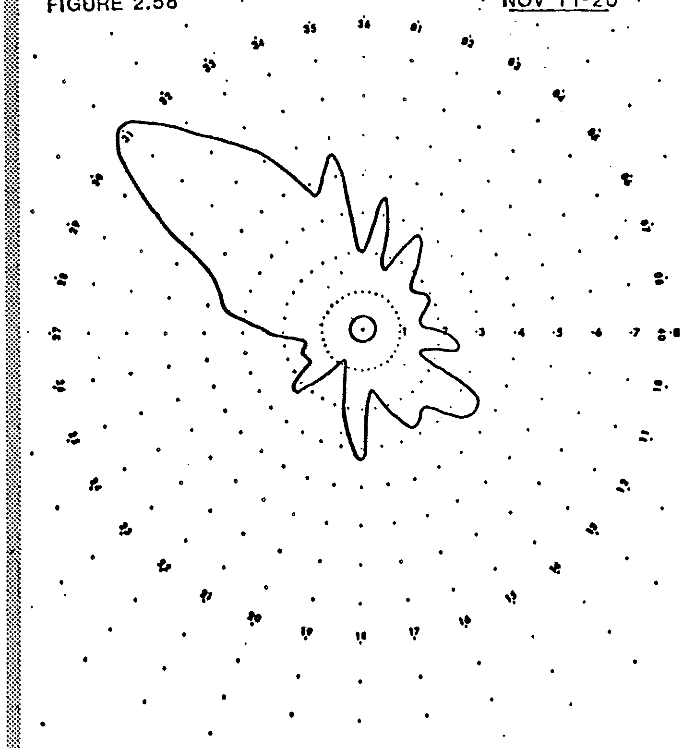


FIGURE 2.58

WIND ROSE NOV 11-20



HIBBING 1964-1973

FIGURE 2.59

WIND ROSE
NOV 21-30

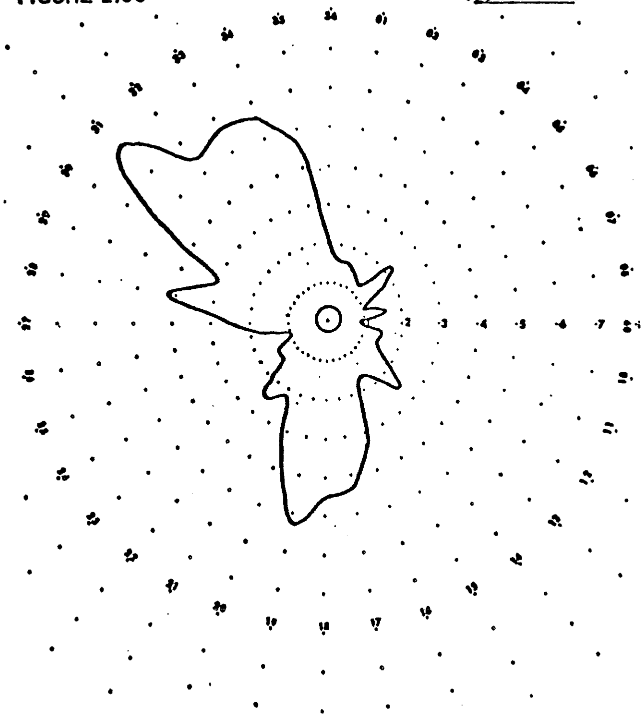


FIGURE 2.60

WIND ROSE
DEC 1-10

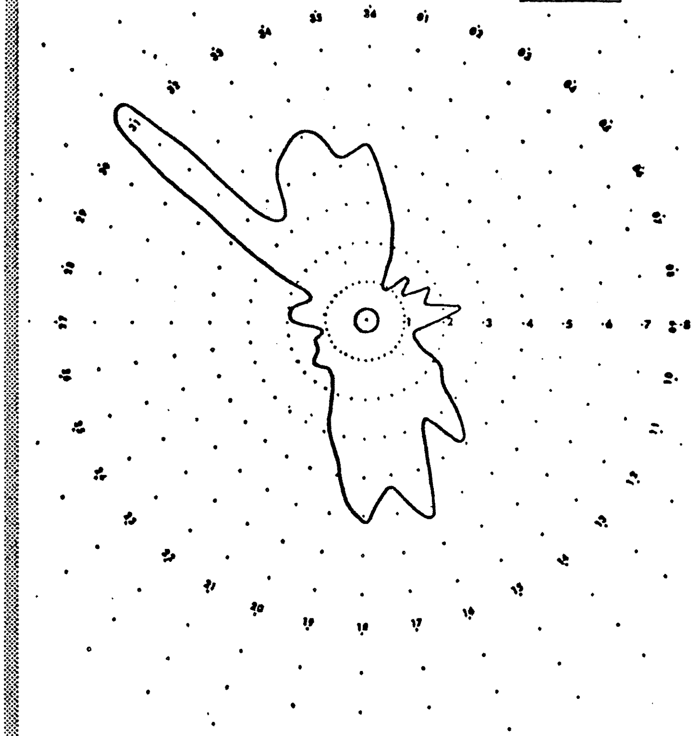


FIGURE 2.61

WIND ROSE
DEC 11-20

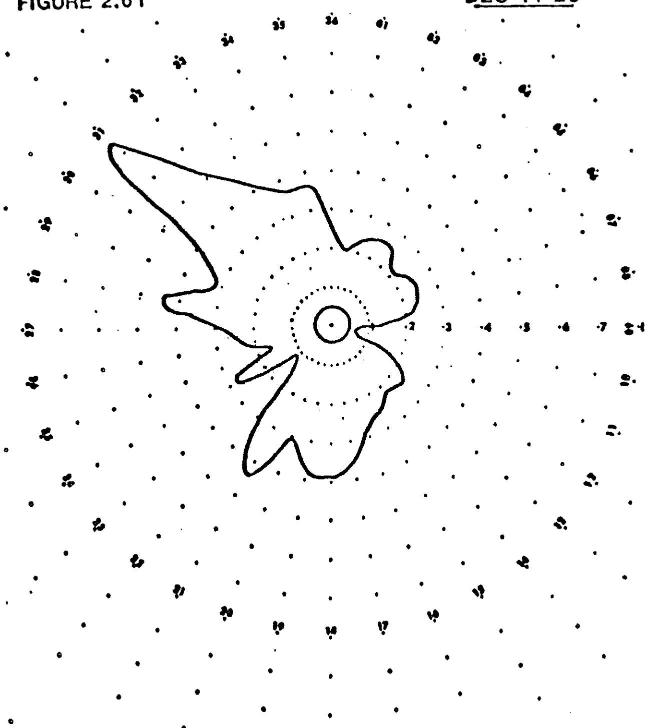


FIGURE 2.62

WIND ROSE
DEC 21-30

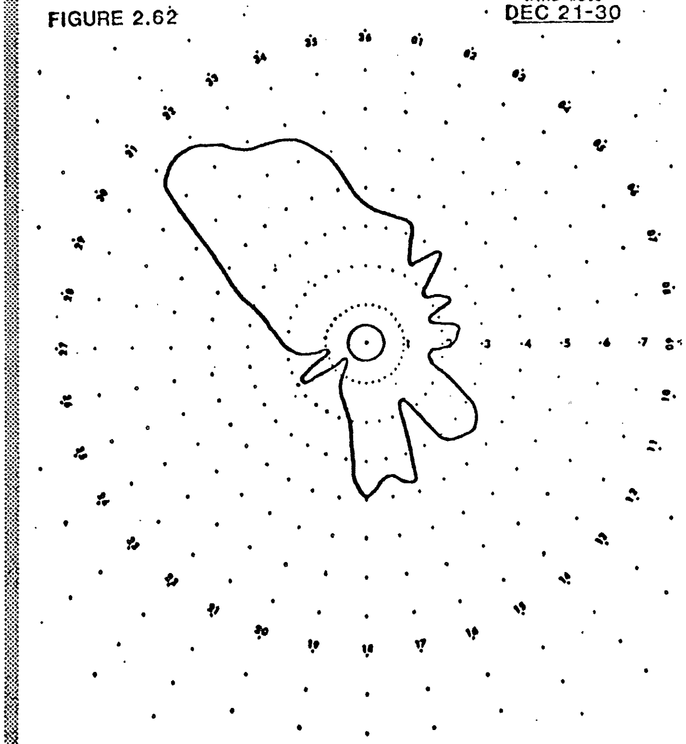
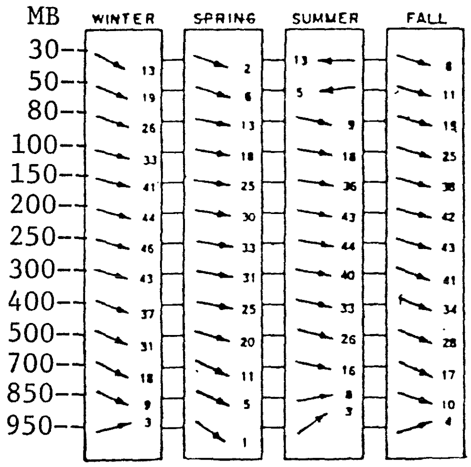


Figure 2.63

Seasonal vertical wind profile over International Falls, Minnesota at various Barometric Pressure Levels

(Wind Speed in Knots)



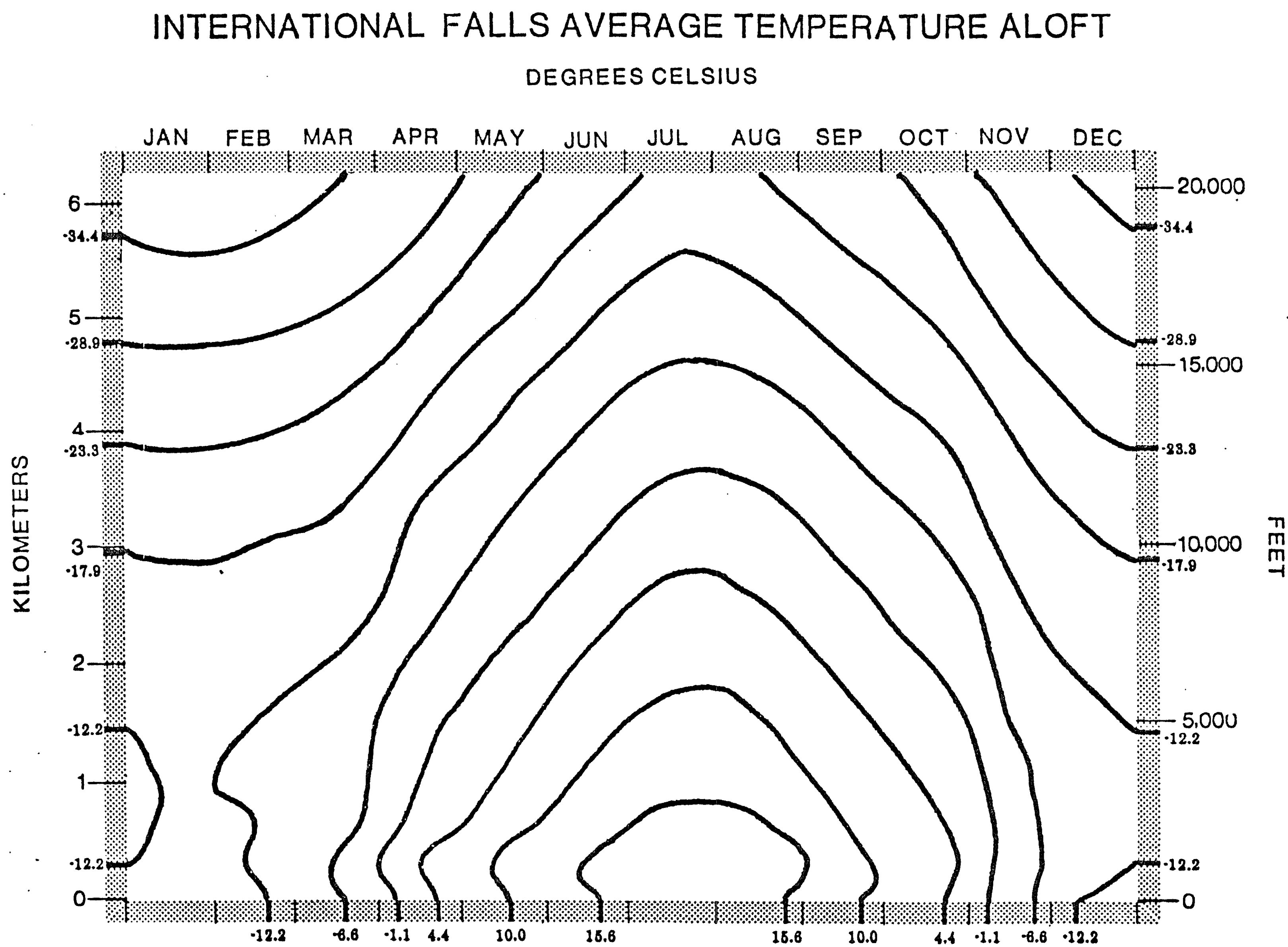

INTERNATIONAL FALLS AVERAGE TEMPERATURE ALOFT
DEGREES CELSIUS
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
KILOMETERS
6
5
4
3
2
1
0
-34.4
-28.9
-23.3
-17.9
-12.2
-12.2
FEET
20,000
15,000
10,000
5,000
0
-34.4
-28.9
-23.3
-17.9
-12.2
-12.2
-12.2 -6.6 -1.1 4.4 10.0 15.6 15.6 10.0 4.4 -1.1 -6.6 -12.2

FIGURE 4.1

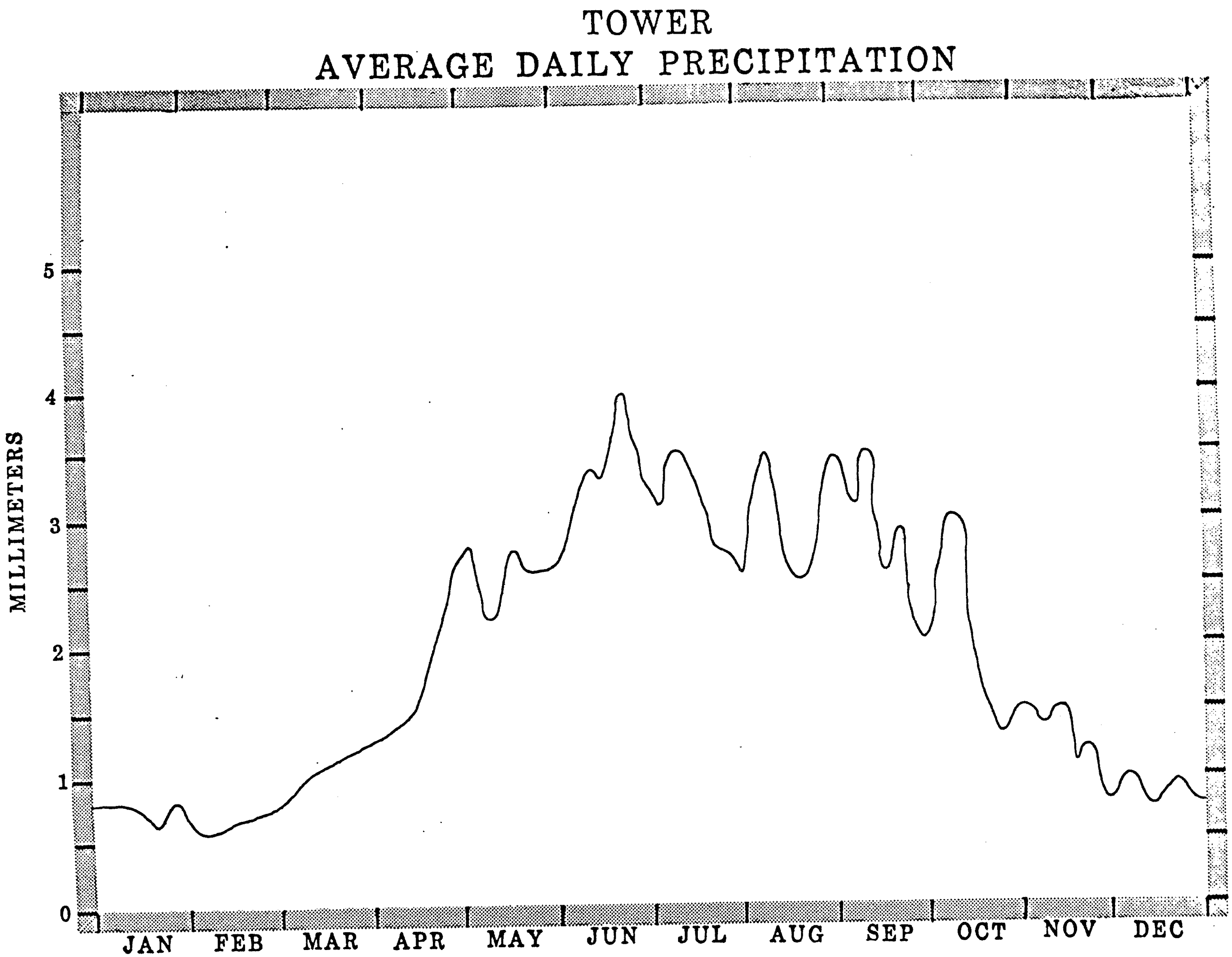

TOWER
AVERAGE DAILY PRECIPITATION
MILLIMETERS
0
1
2
3
4
5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 6.1

WINTON
AVERAGE DAILY PRECIPITATION

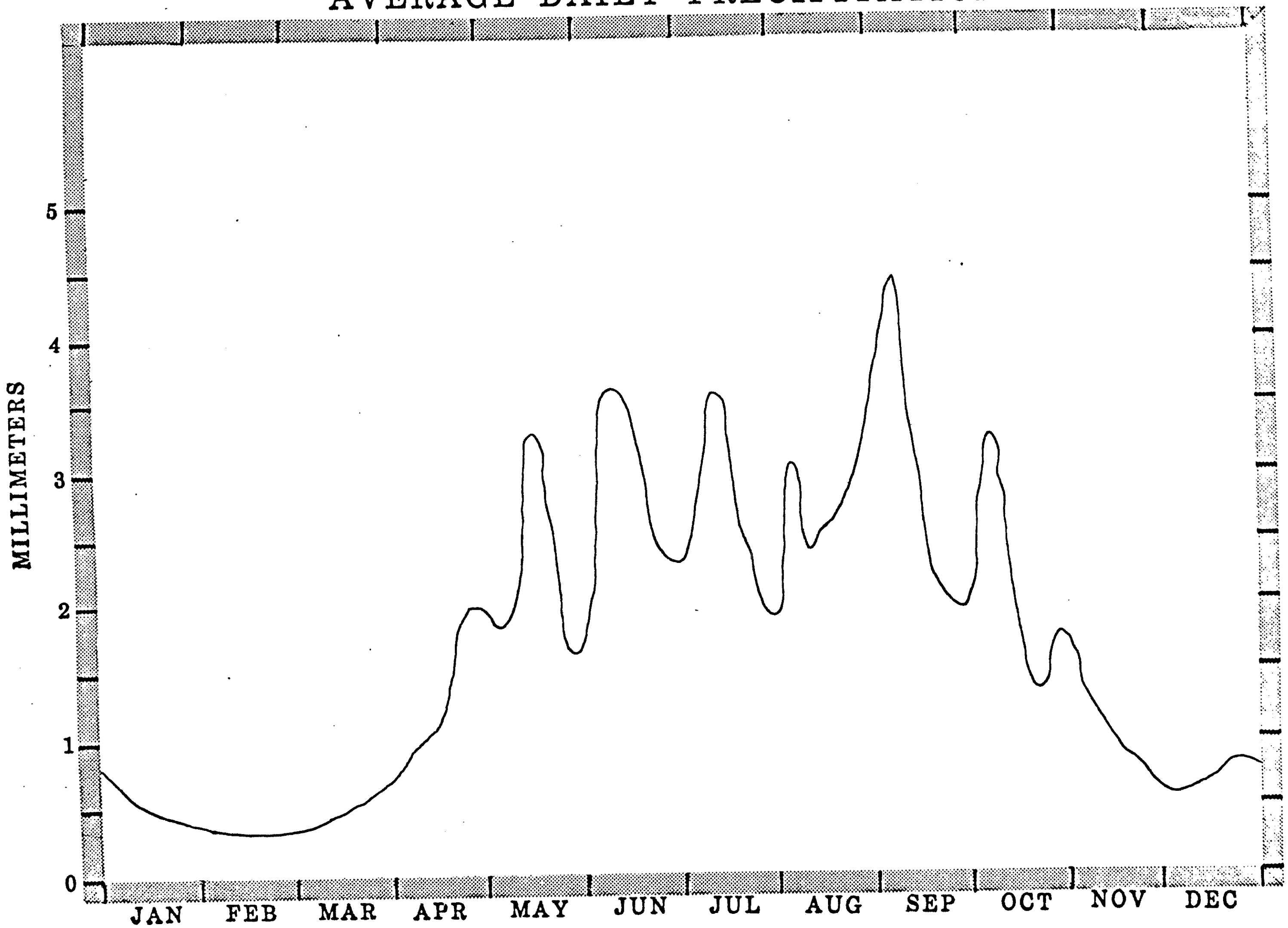


FIGURE 6.2

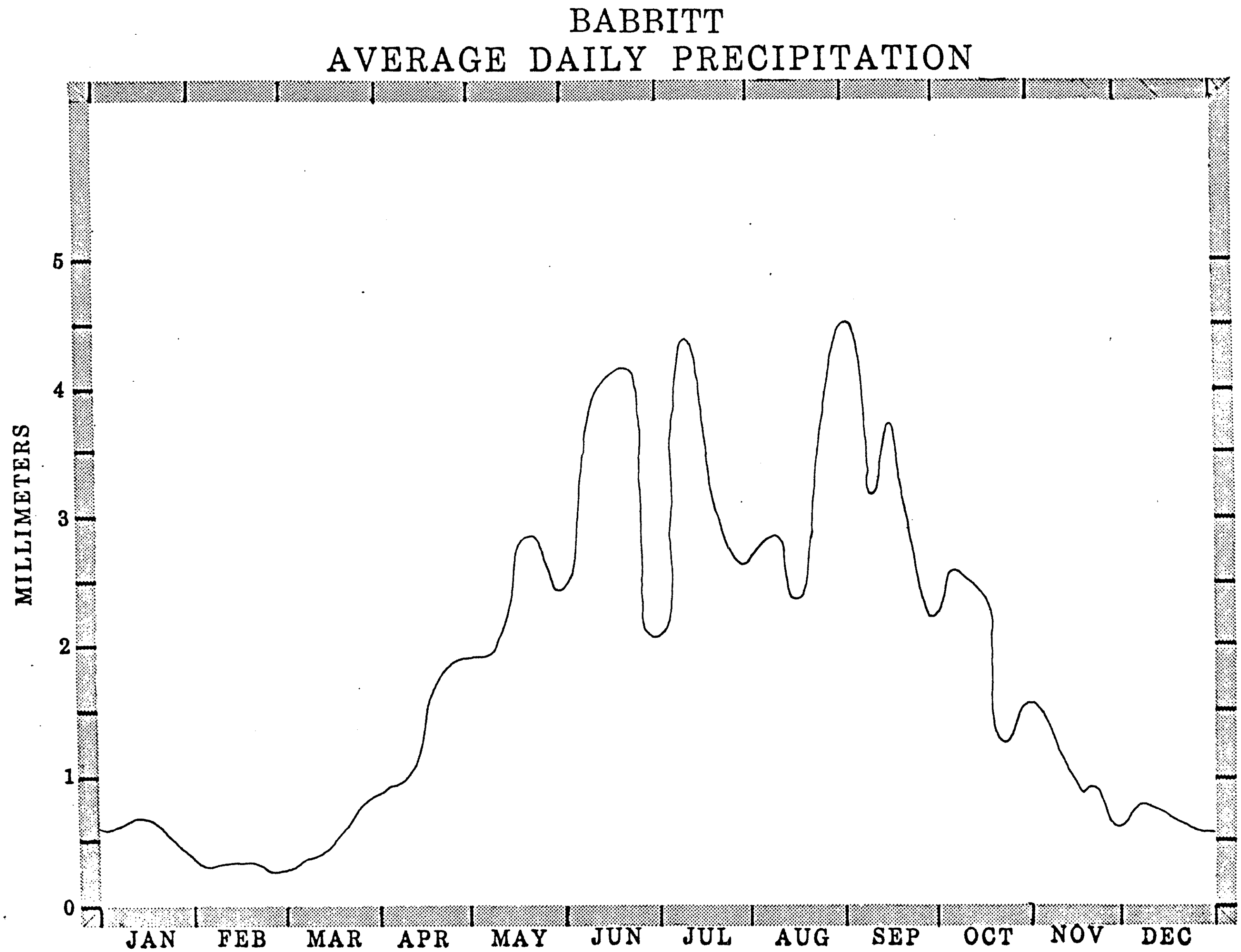

BABBITT
AVERAGE DAILY PRECIPITATION
MILLIMETERS
0
1
2
3
4
5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 6.3

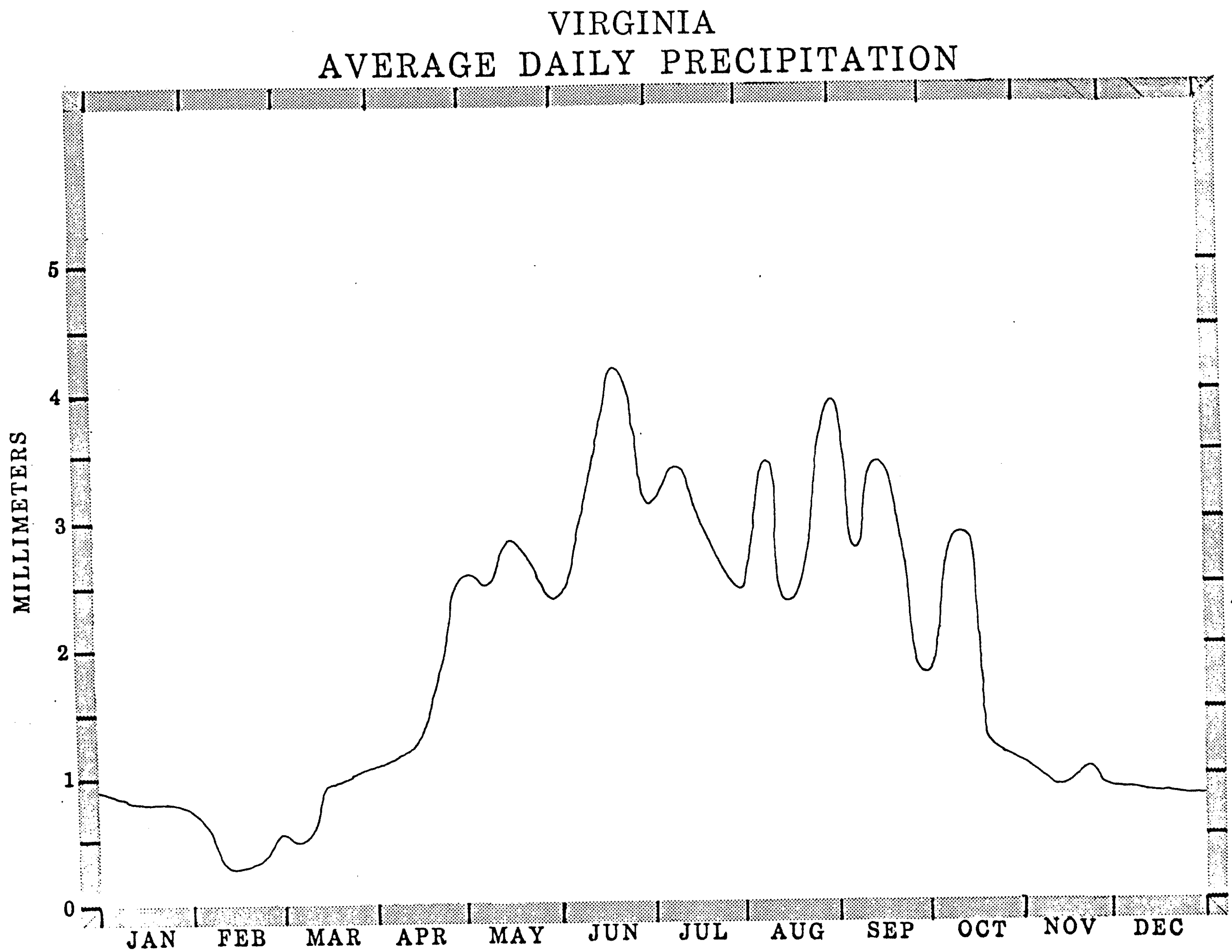

VIRGINIA
AVERAGE DAILY PRECIPITATION
MILLIMETERS
0
1
2
3
4
5
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 6.4

AVERAGE MONTHLY PRECIPITATION

FIGURE 6.5
JANUARY

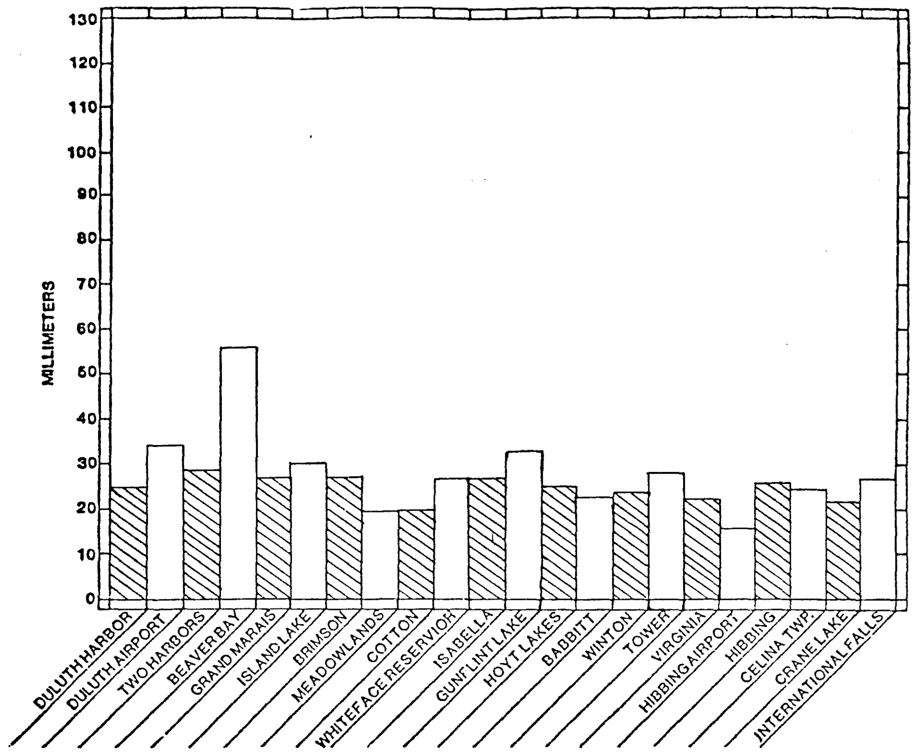
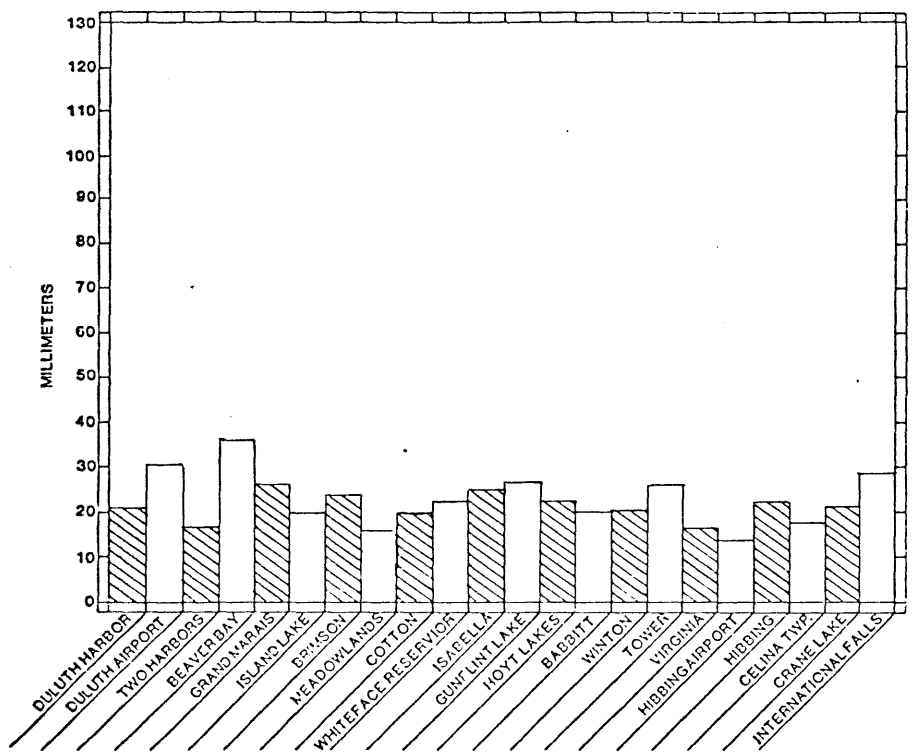


FIGURE 6.6
FEBRUARY



AVERAGE MONTHLY PRECIPITATION

FIGURE 6.7
MARCH

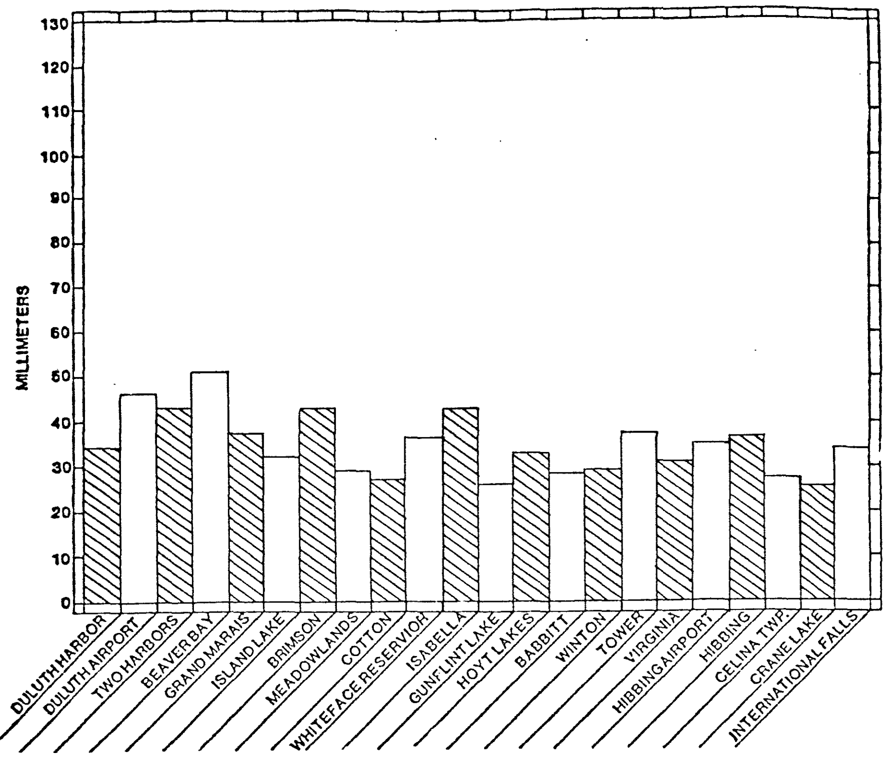
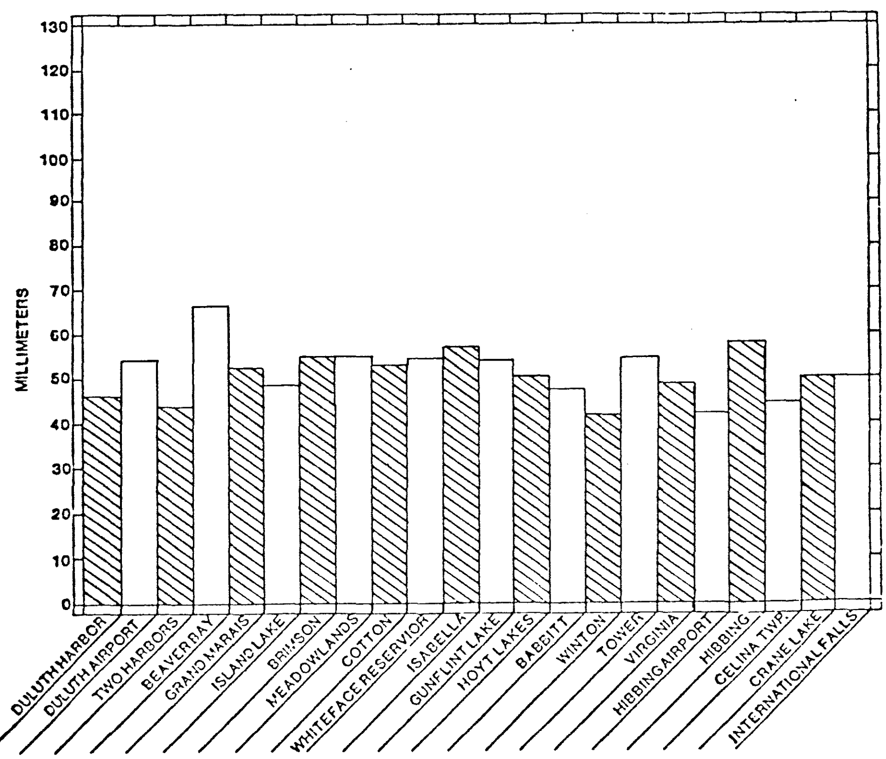


FIGURE 6.8
APRIL



AVERAGE MONTHLY PRECIPITATION

FIGURE 6.9
MAY

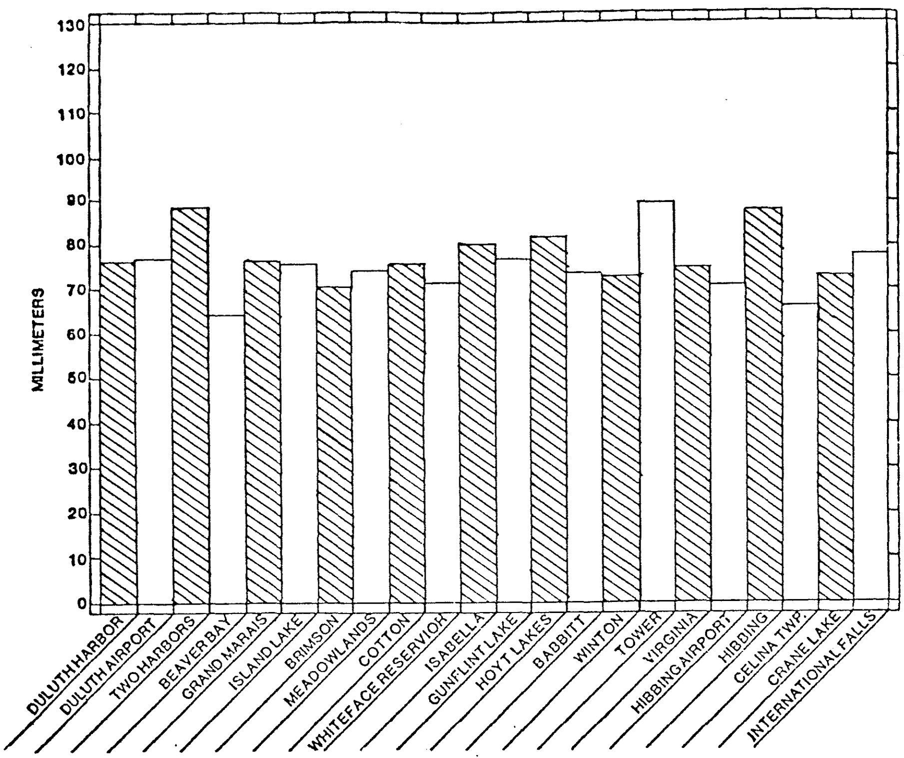
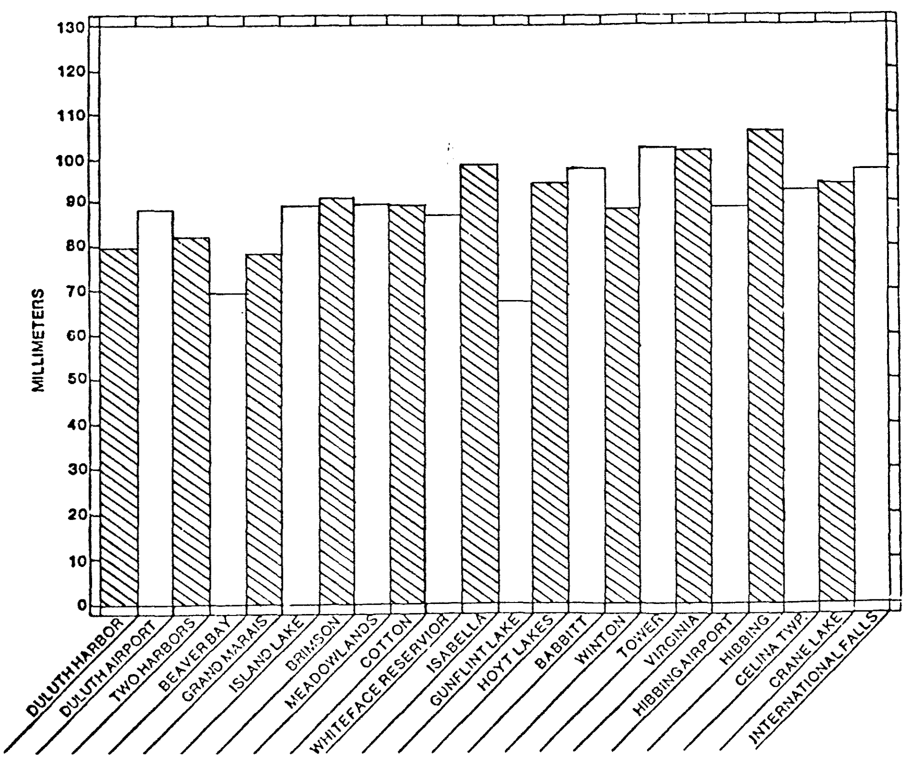


FIGURE 6.10
JUNE



AVERAGE MONTHLY PRECIPITATION

FIGURE 6.11
JULY

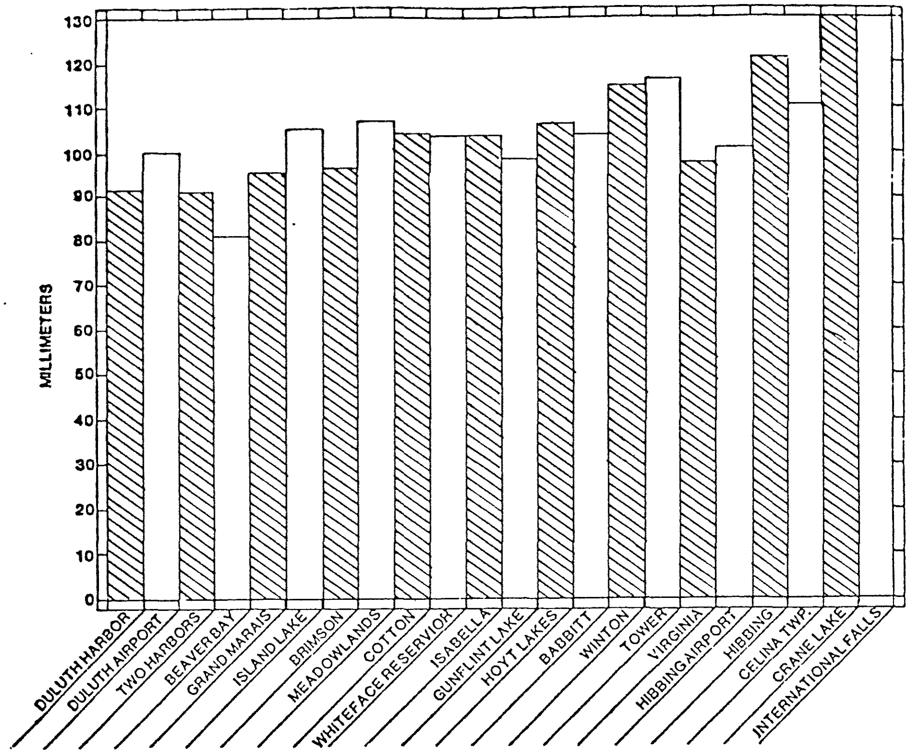
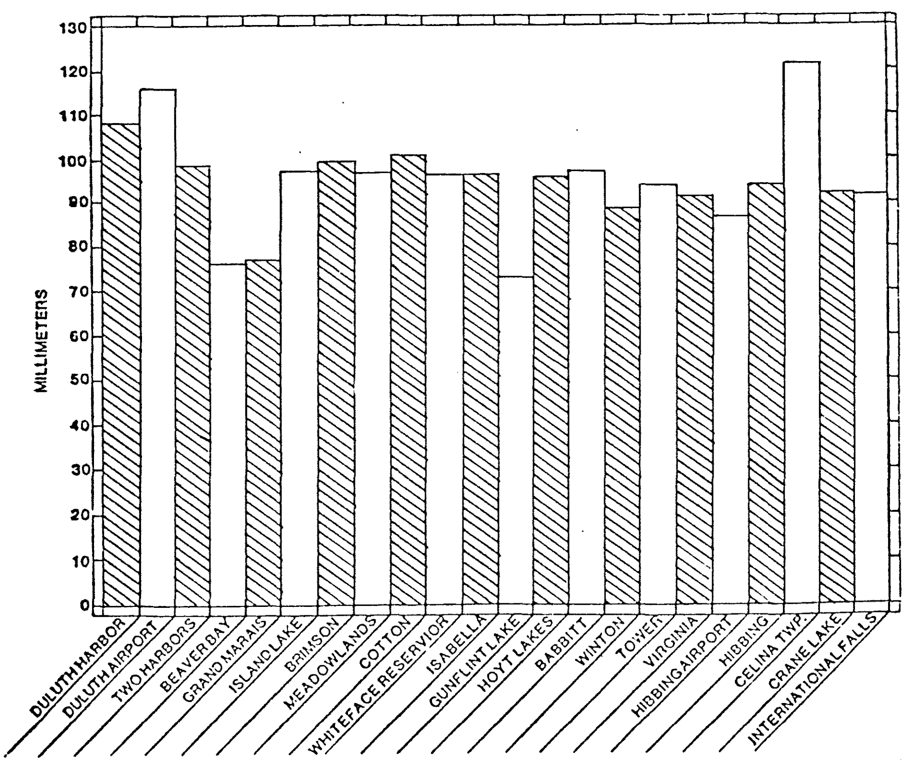


FIGURE 6.12
AUGUST



AVERAGE MONTHLY PRECIPITATION

FIGURE 6.13
SEPTEMBER

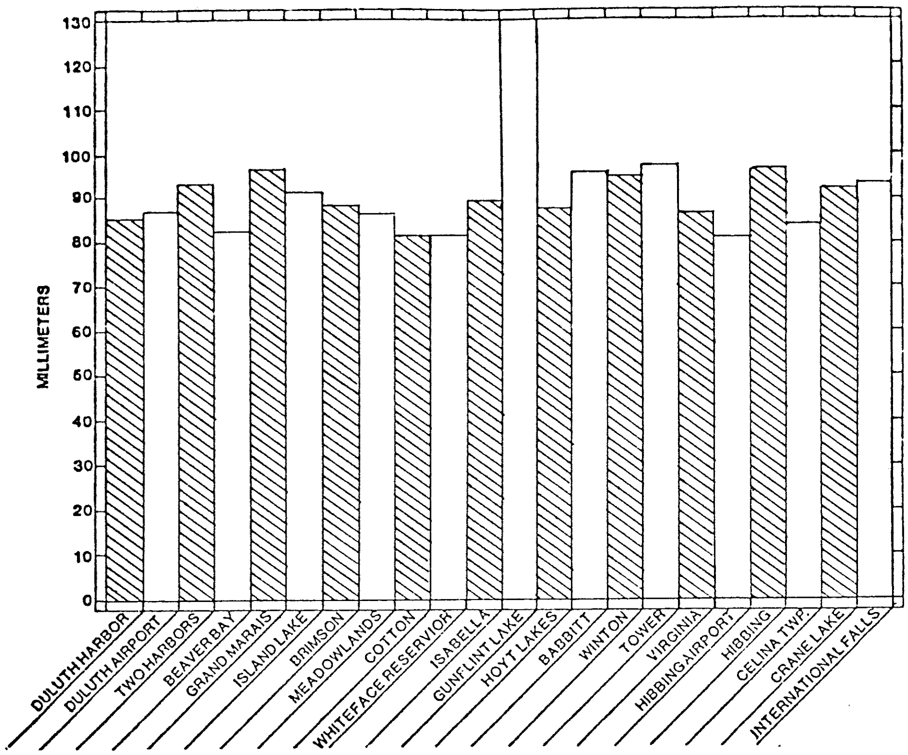
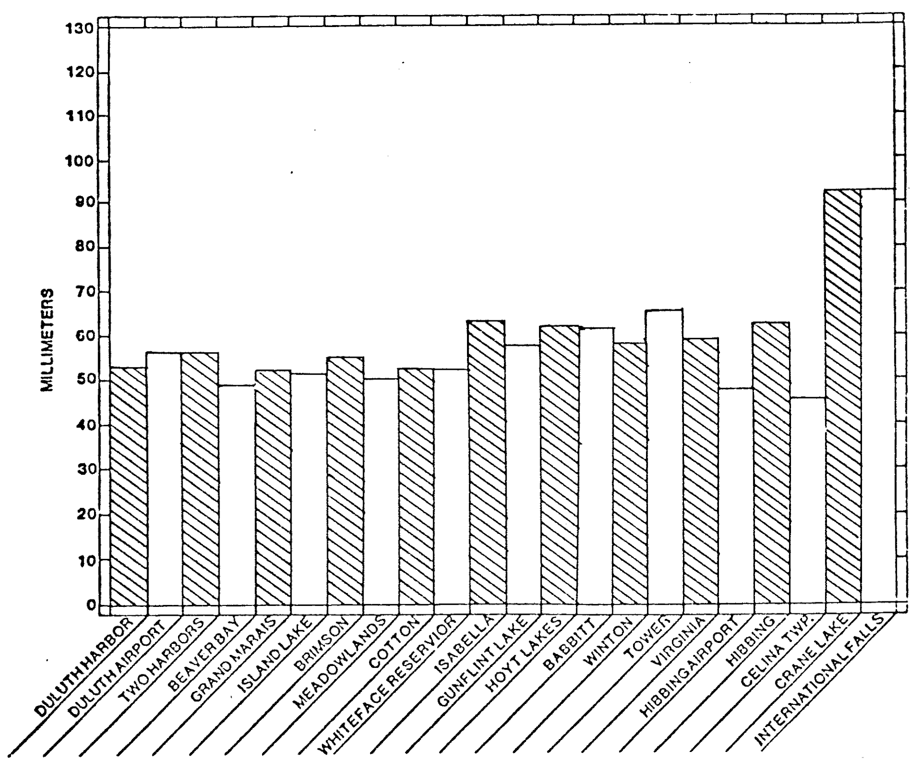


FIGURE 6.14
OCTOBER



AVERAGE MONTHLY PRECIPITATION

FIGURE 6.15
NOVEMBER

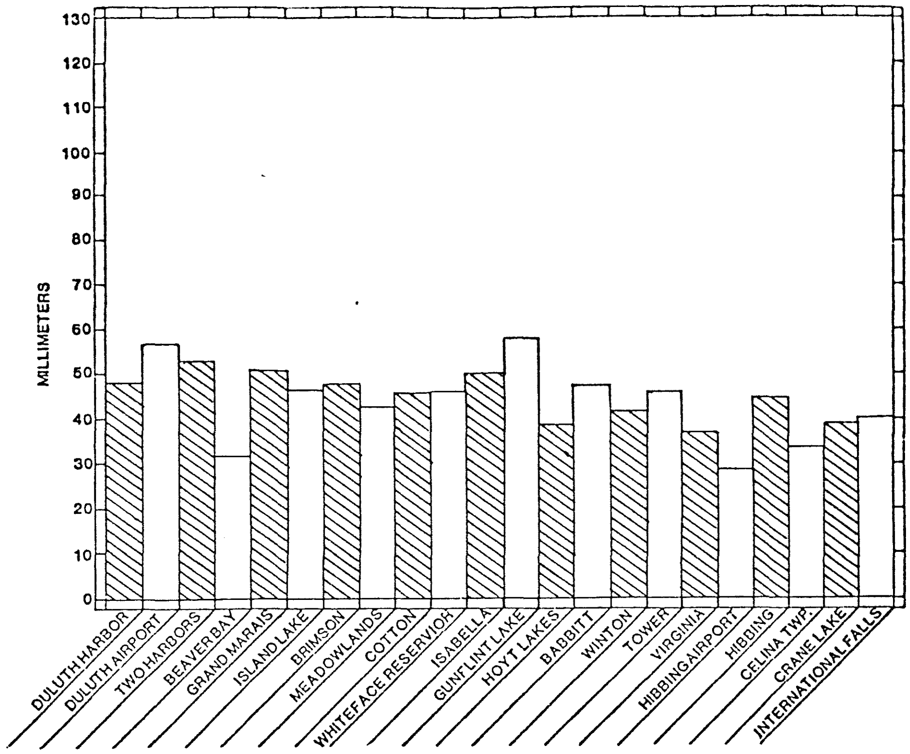
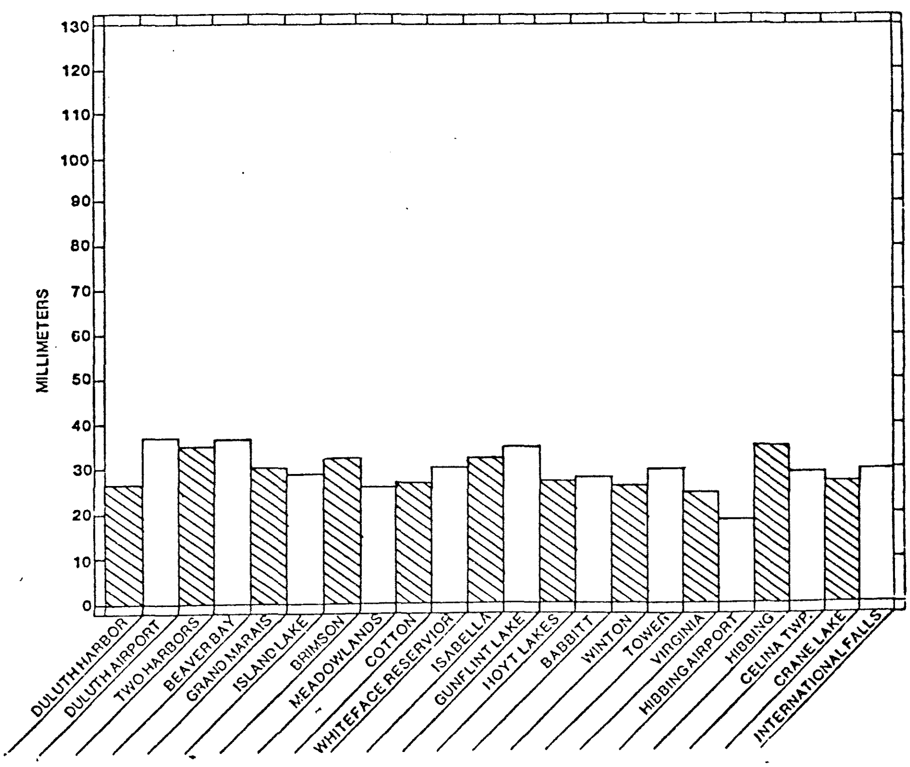


FIGURE 6.16
DECEMBER



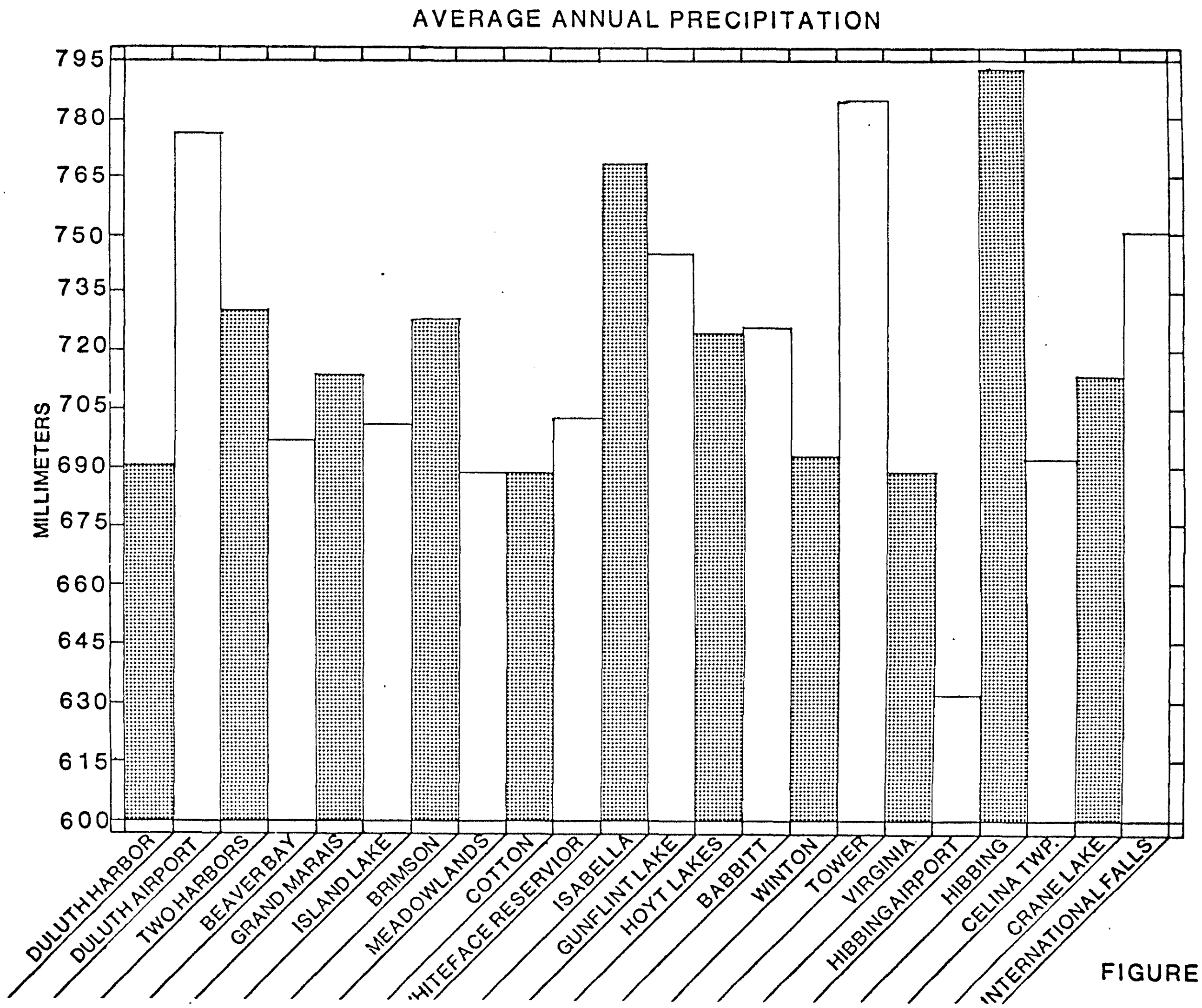
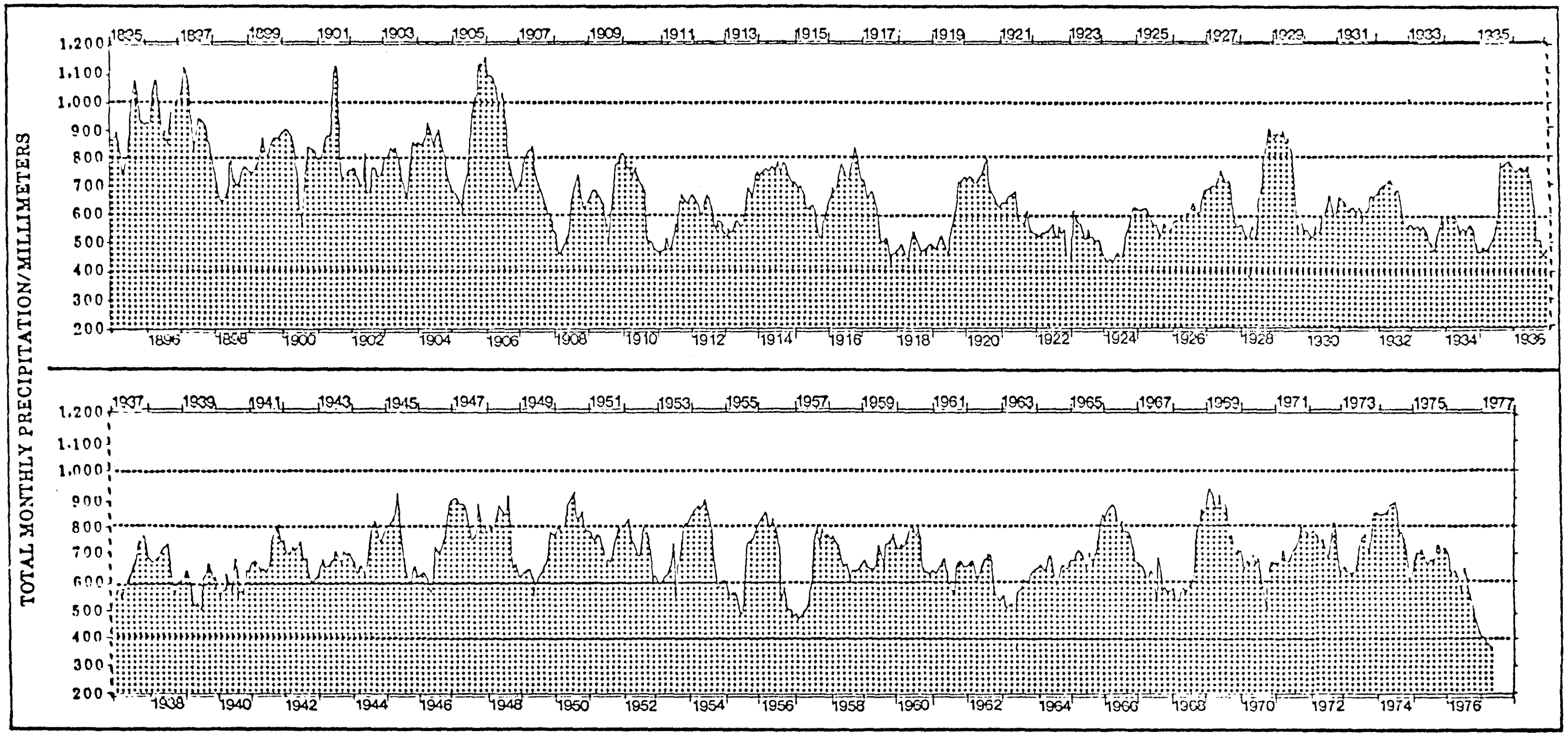
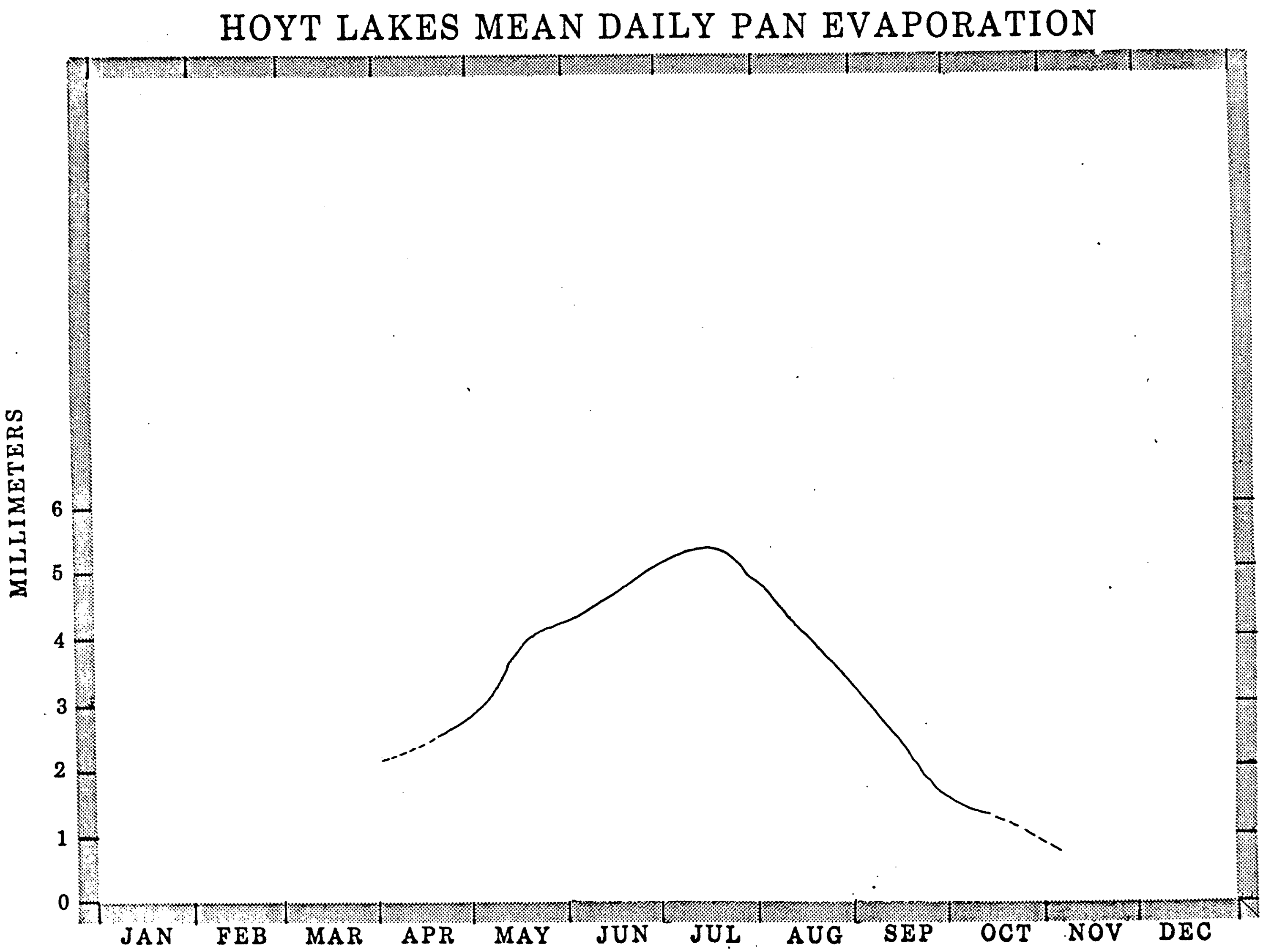

AVERAGE ANNUAL PRECIPITATION
MILLIMETERS
795
780
765
750
735
720
705
690
675
660
645
630
615
600
DULUTH HARBOR
DULUTH AIRPORT
TWO HARBORS
BEAVER BAY
GRAND MARAIS
ISLAND LAKE
BRIMSON
MEADOWLANDS
COTTON
WHITEFACE RESERVIOR
ISABELLA
GUNFLINT LAKE
HOYT LAKES
BABBITT
WINTON
TOWER
VIRGINIA
HIBBING AIRPORT
HIBBING
CELINA TWP.
CRANE LAKE
INTERNATIONAL FALLS

FIGURE 6.17

FIGURE 6.18 VIRGINIA PRECIPITATION TOTALS FOR TWELVE MONTH PERIODS AT THE END OF EACH MONTH 1895-1977





HOYT LAKES MEAN DAILY PAN EVAPORATION
MILLIMETERS
0
1
2
3
4
5
6
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 7.1

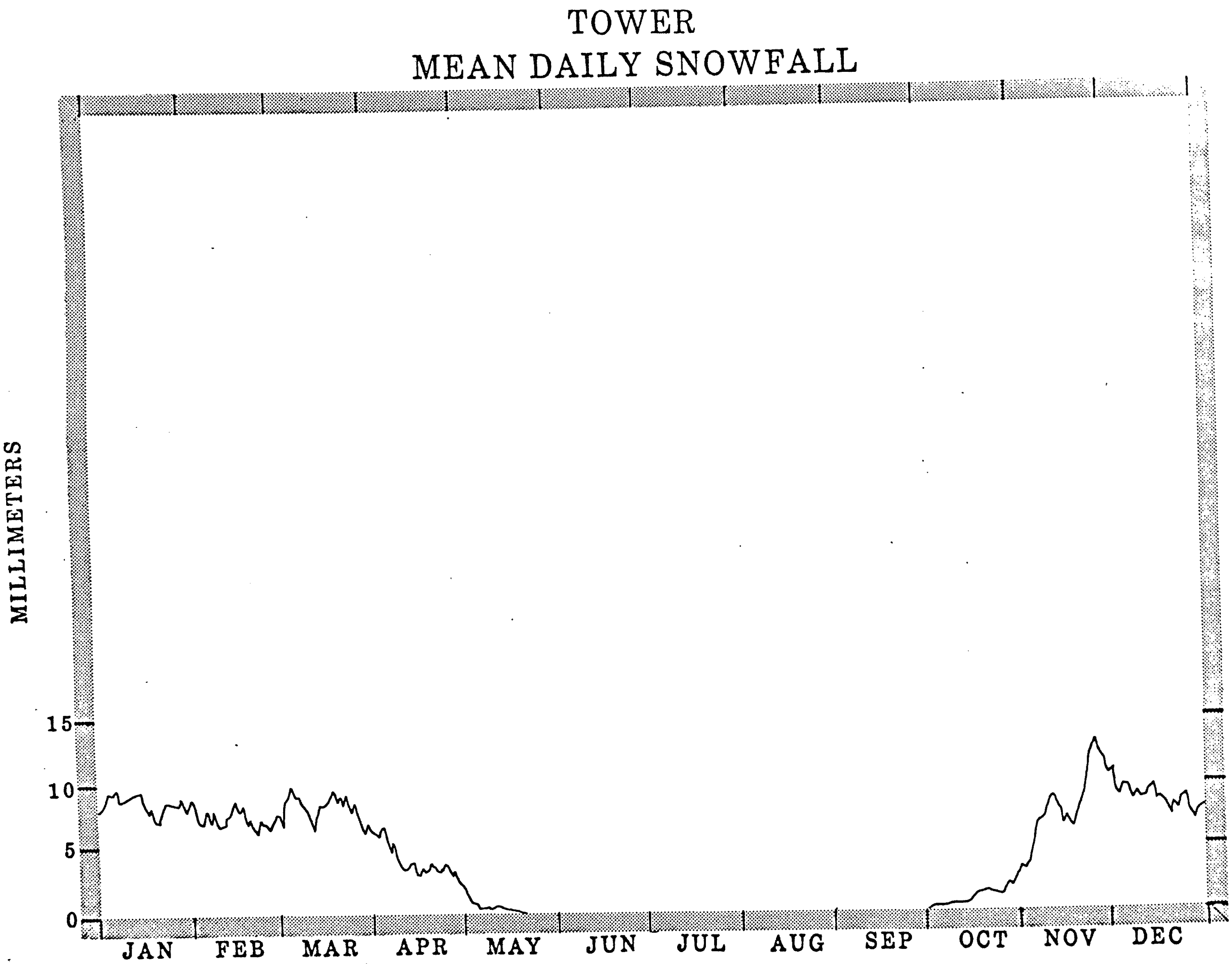

TOWER
MEAN DAILY SNOWFALL
MILLIMETERS
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 8.1

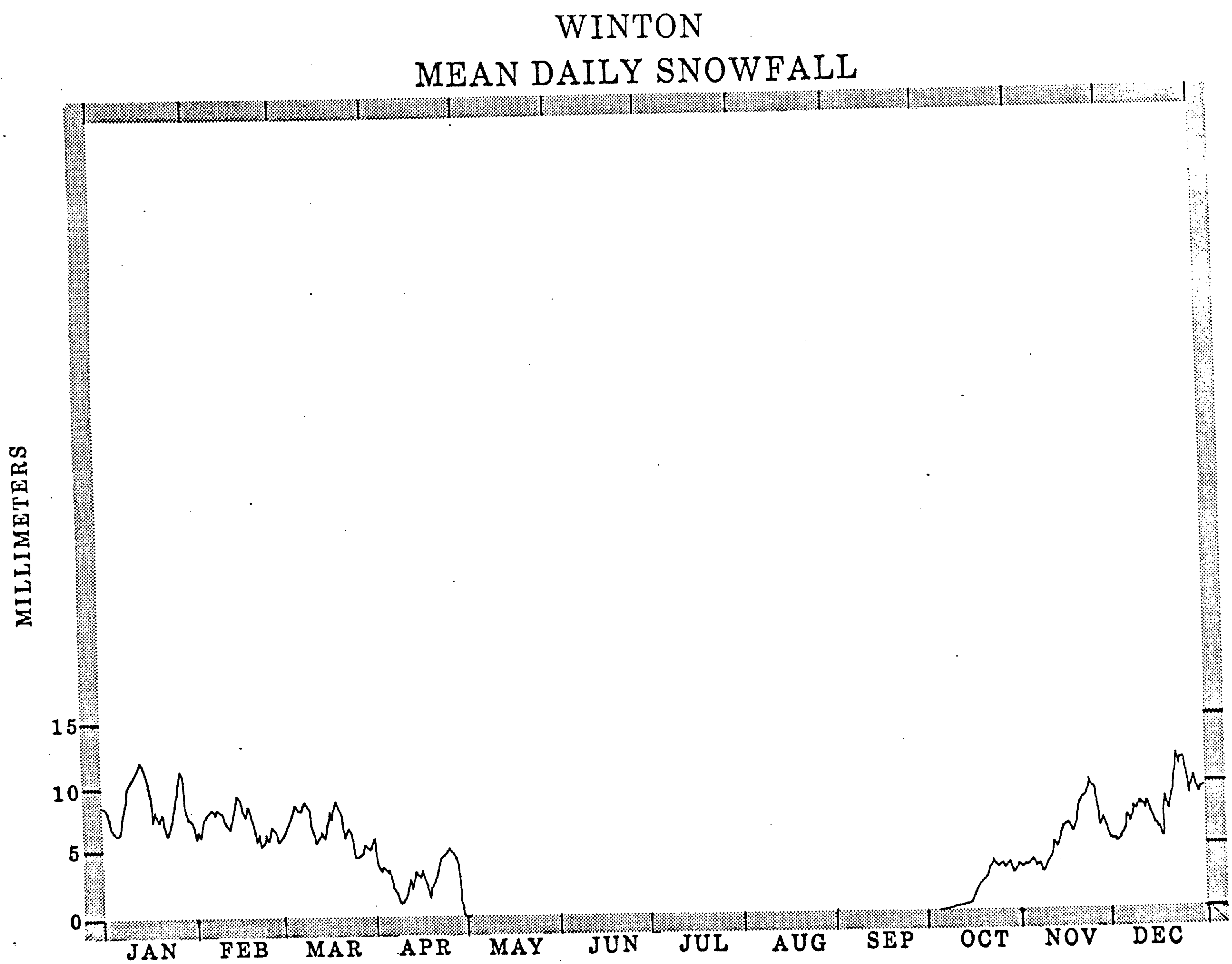
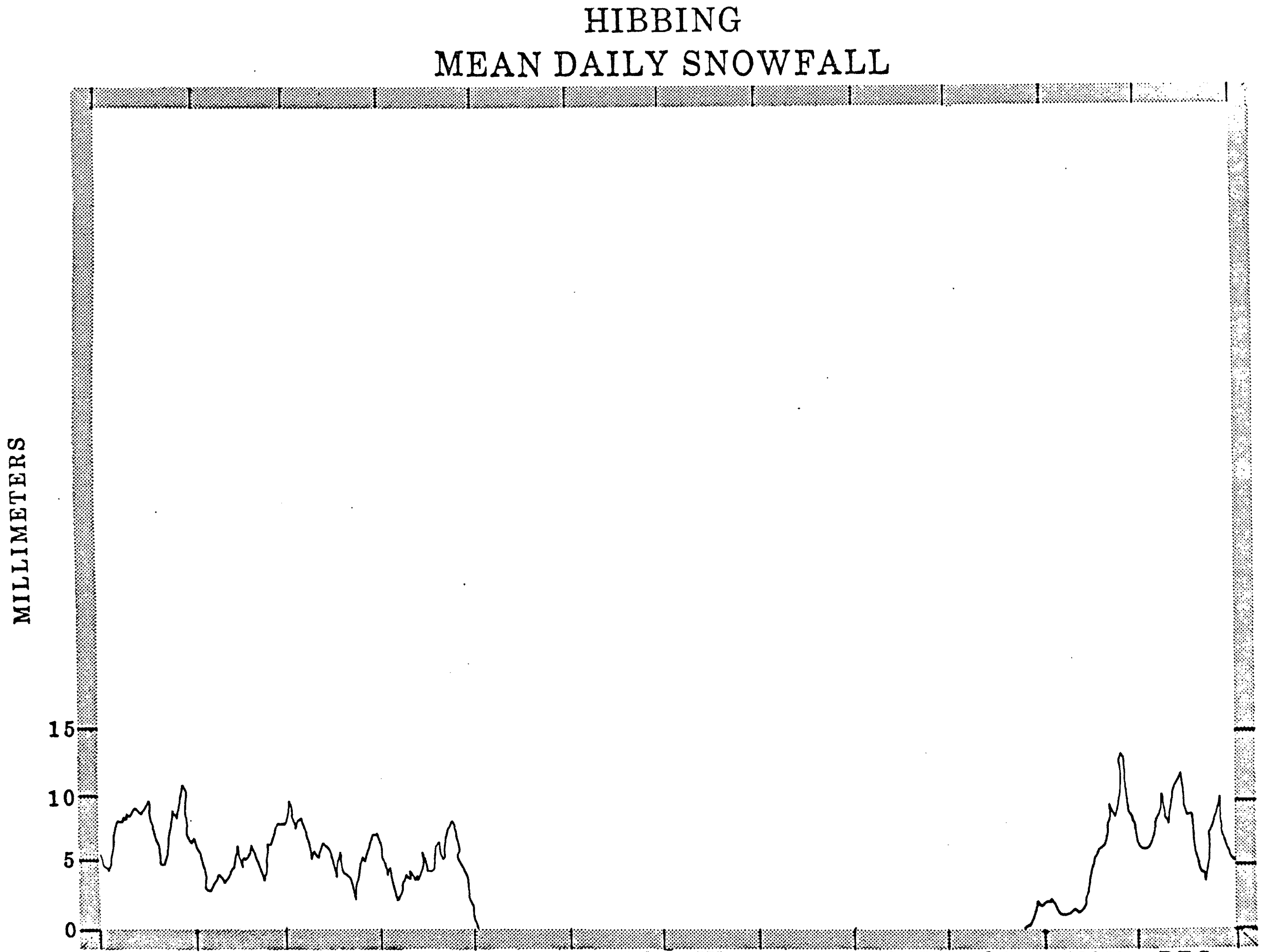

WINTON
MEAN DAILY SNOWFALL
MILLIMETERS
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 8.2



HIBBING
MEAN DAILY SNOWFALL
MILLIMETERS
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 8.3

BABBITT
MEAN DAILY SNOWFALL

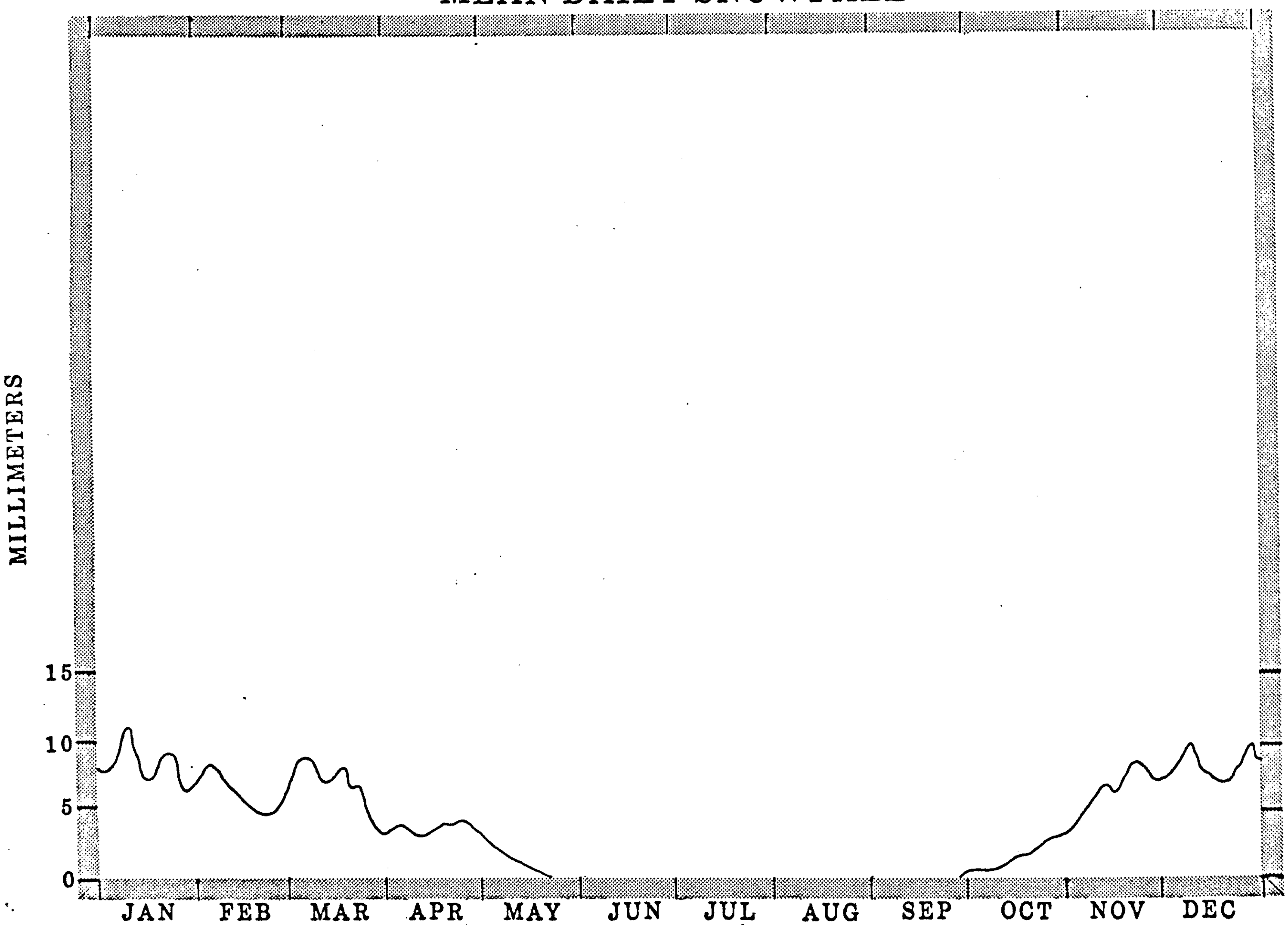


FIGURE 8.4

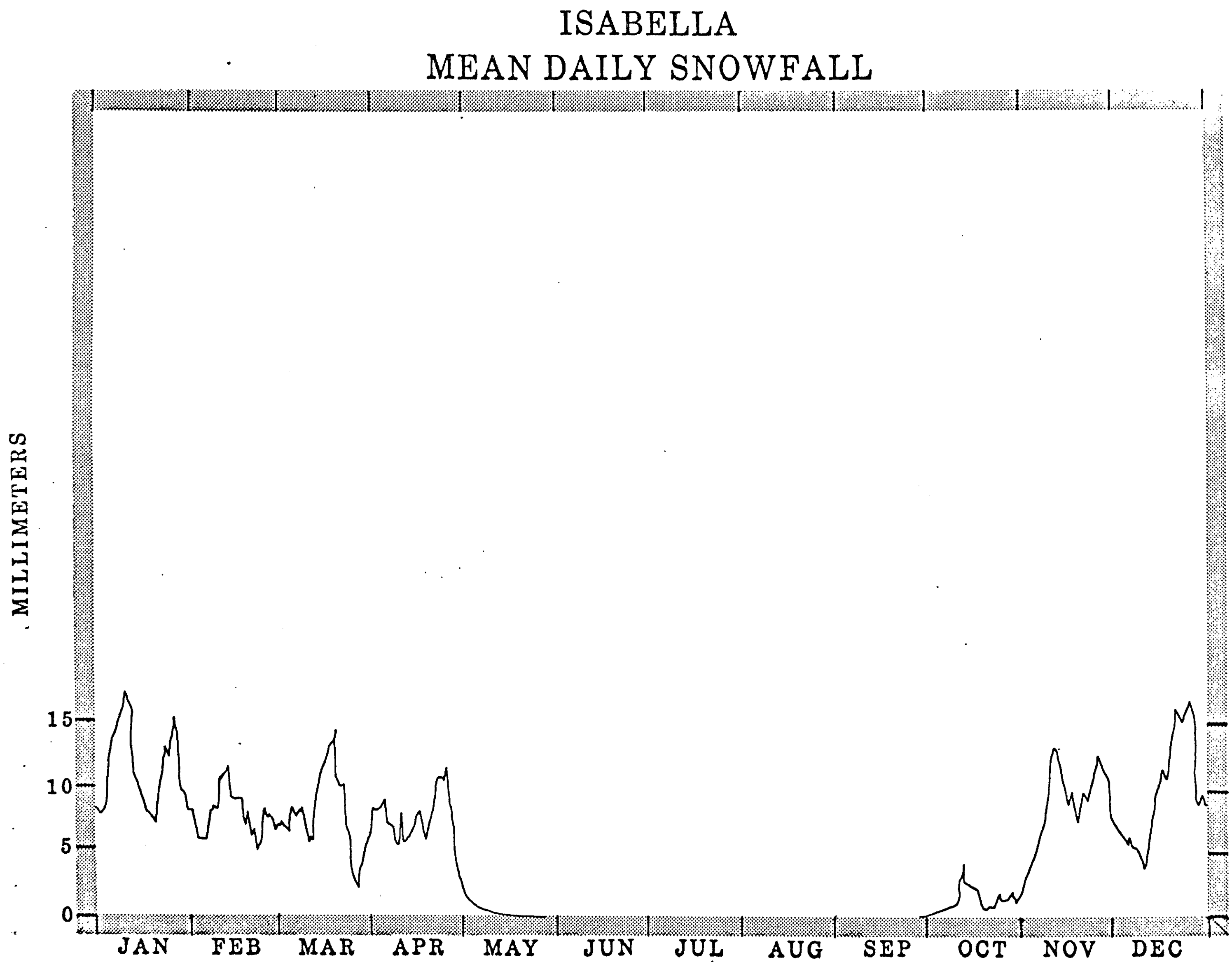

ISABELLA
MEAN DAILY SNOWFALL
MILLIMETERS
15
10
5
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 8.5

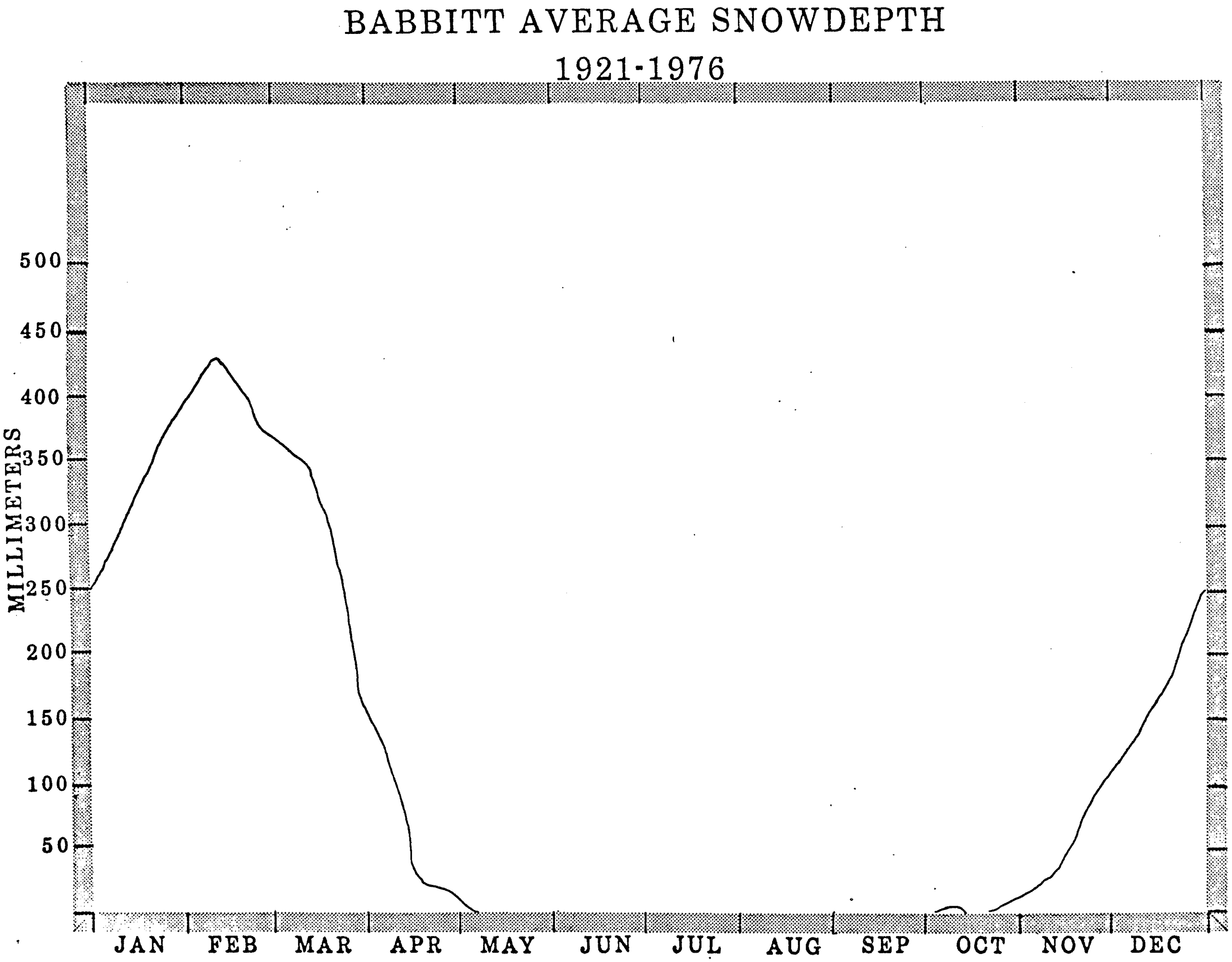

BABBITT AVERAGE SNOWDEPTH
1921-1976
MILLIMETERS
500
450
400
350
300
250
200
150
100
50
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 9.2

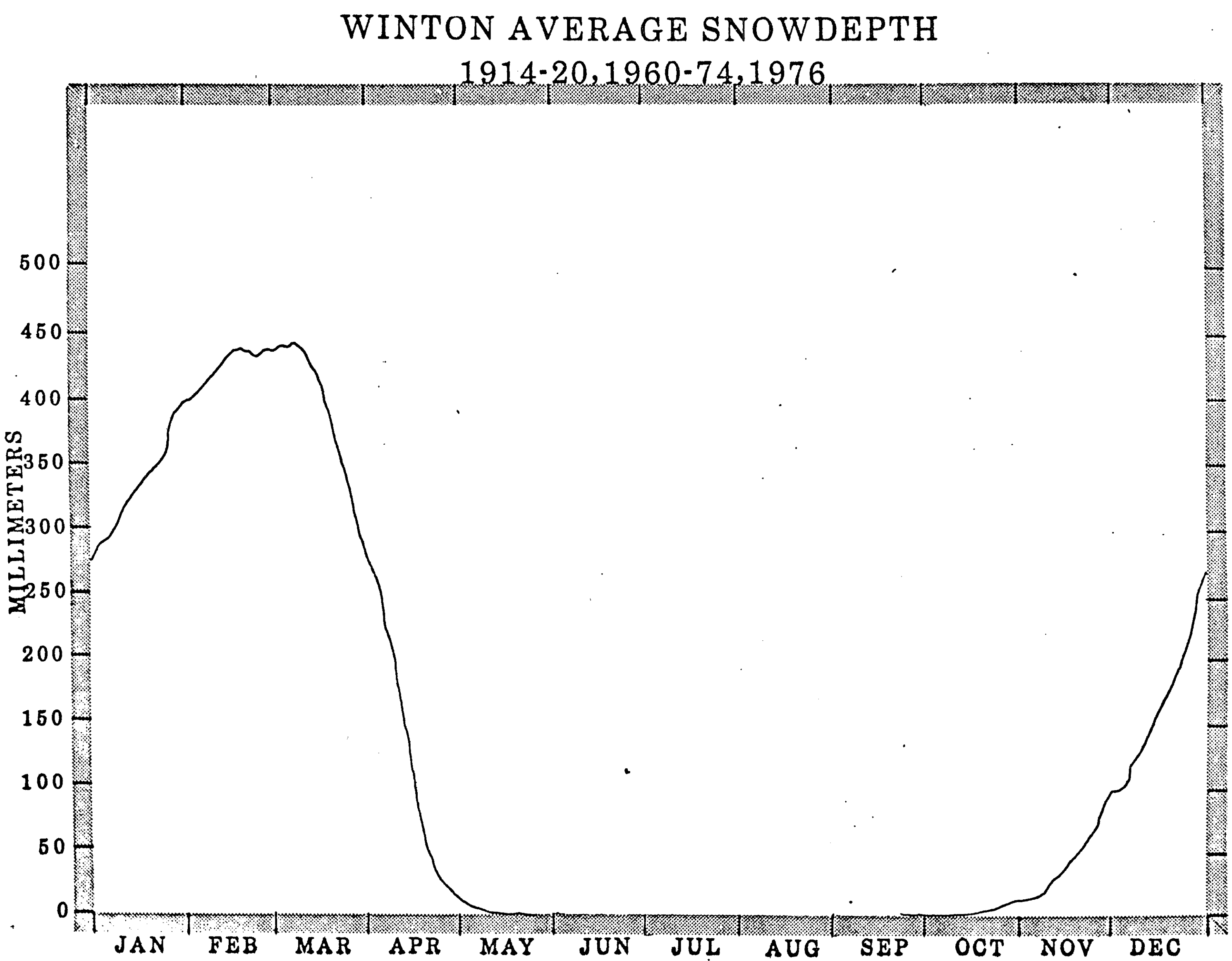

WINTON AVERAGE SNOWDEPTH
1914-20,1960-74,1976
MILLIMETERS
500
450
400
350
300
250
200
150
100
50
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

FIGURE 9.1

TABLE 2.1

MONTHLY MEAN HEIGHT VERSUS PRESSURE LEVELS ABOVE

International Falls, Minnesota
(Elevation 360 meters). Period of
Record Jan 1945-Dec 1955

PRESSURE[a]	AVERAGE HEIGHT G.P.M.* JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SFC	973	974	973	972	971	970	972	973	972	972	971 9	973 9
1000	151	154	159	127	114	97	111	123	121	126	124 9	145 9
950	541	549	543	545	545	537	558	567	556	551	532 9	540 9
900	948	960	964	982	992	994	1019	1027	1006	993	956 9	951 9
850	1383	1397	1407	1440	1461	1473	1504	1510	1480	1489	1405 9	1390 9
800	1845	1861	1874	1922	1953	1975	2013	2017	1977	1950	1870 9	1856 9
750	2342	2359	2377	2436	2477	2509	2554	2558	2508	2472	2387 9	2355 9
700	2857	2876	2895	2968	3020	3062	3114	3116	3058	3016	2914 9	2874 9
650	3419	3439	3463	3546	3607	3659	3719	3718	3651	3603	3487 9	3439 9
600	4003	4025	4050	4149	4222	4287	4353	4353	4277	4221	4085 9	4027 9
550	4641	4664	4693	4805	4889	4966	5039	5038	4952	4888	4735 9	4669 9
500	5322	5346	5379	5504	5602	5693	5775	5771	5676	5603	5430 9	5355 9
450	6069	6095	6131	6269	6380	6488	6579	6575	6468	6386	6194 9	6105 9
400	6875	6903	6942	7094	7222	7348	7447	7439	7322	7227	7016 9	6917 9
350	7772	7802	7844	8011	8155	8300	8408	8399	8270	8164	7928 9	7818 9
300	8780	8811	8854	9039	9198	9365	9486	9472	9330	9213	8957 9	8829 9
250	9953	9984	10028	10220	10398	10581	10715	10696	10542	10415	10145 9	10003 9
200	11390	11414 9	11459	11641	11829	12019	12169	12147	11983	11854	11587 9	11438 9
175	12259	12276 9	12317	12497 9	12676	12874	13026	13002	12838	12707	12445 9	12298 9
150	13266 9	13281 9	13319	13487 9	13660	13860	14006	13989	13825 9	13686	13413 8	13291 8
125	14461 9	14451 8	14515 9	14659 8	14828	15028	15166	15143	14961 8	14814 8	14562 7	14473 8
100	15902 7	15883 7	15942 7	16095 8	16280 8	16459 9	16572 9	16545 9	16375 8	16218 8	15993 6	15889 7
80	17307 6	17293 6	17341 5	17517 8	17698 6	17862 7	17990 7	17954 6	17782 5	17618 6	17408 6	17324 7
60	19147 5	19120 5	19177 5	19333 4	19527 6	19716 6	19823 5	19792 5	19617 5	19428 5	19229 6	19166 5
50	20315 5	20328 5	20344 5	20500 4	20675 6	20879 6	20999 5	20966 5	20793 5	20575 5	20399 6	20336 5
40			21779 5	21936 4	22104 4	22315 4	22451 5	22413 5	22219 5	21983 5	21792 4	21749 5
30					23954 4	24194 4	24330 5	24288 5	24063 5	23812 5		

*Geopotential height, measured in geopotential meters (G.P.M.), is virtually identical to geometric height.

a Pressure in millions

Table 2.2

Extreme heights and Standard Deviation of heights versus Pressure Levels above International Falls, Minnesota (elevation 360 meters). Period of Record Jan. 1945-Dec. 1955.

Pressure Level (mb)		Extreme Heights *											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
950	MAX	770	730	780	700	710	640	680	680	730	710	710	710
	MIN	343	360	350	330	230	390	390	410	370	300	310	280
850	MAX	1596	1579	1630	1558	1599	1595	1617	1609	1635	1594	1592	1551
	MIN	1193	1230	1218	1238	1139	1321	1337	1353	1264	1216	1191	1142
700	MAX	3051	3073	3110	3166	3187	3196	3221	3229	3248	3187	3140	3042
	MIN	2640	2691	7694	2772	2699	2888	2961	2934	2797	2770	2697	2668
500	MAX	5569	5674	5673	5818	5858	5870	5937	5945	5923	5794	5752	5618
	MIN	4988	5078	5038	5177	5273	5440	5559	5529	5372	5238	5117	5074
300	MAX	143	9732	9274	9493	9578	9663	9730	9757	9648	9503	9409	9212
	MIN	8394	8449	8445	8543	8698	8964	9165	9098	8894	8853	8499	8408
700	MAX	11728	11779	11986	12139	12224	12373	12488	17560	12367	12160	12039	11817
	MIN	11037	11099	11084	11138	11429	11675	11795	11735	11577	11360	11181	11044
150	MAX	13580	13568	13714	13876	14011	14158	14267	14442	14179	13951	13740	13638
	MIN	12957	17944	12936	13014	13413	13587	13678	13652	13465	13234	13083	12900
100	MAX	16211	16180	16258	16381	16531	16650	16757	16709	16683	16405	16257	16748
	MIN	15478	15526	15643	15656	16079	16199	16331	16379	16102	15851	15680	15499

	STANDARD DEVIATIONS OF HEIGHTS											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
950	72	69	69	58	56	52	45	43	62	64	76	74
850	62	64	65	58	56	50	42	41	59	61	74	66
700	68	77	76	73	70	55	50	49	73	77	88	75
500	107	120	118	116	107	78	75	74	111	123	131	112
300	153	167	170	171	159	122	120	122	165	181	190	164
200	137	141	151	156	148	129	138	143	167	174	173	151
150	132	130	140	132	117	111	115	119	143	153	139	147
100	133	132	114	115	95	86	81	73	115	130	112	150

*Geopotential height, measured in geopotential meters (G.P.M.), is virtually identical to geometric height.

Table 3.1

Monthly Averages of percent of possible sunshine and cloudiness, for the Copper-Nickel Study Area

		Month											
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Percent possible sunshine		46	57	59	53	55	58	67	61	50	42	33	40
% of sky clear	Hr.	32	37	33	31	32	34	42	39	31	31	20	23
"	at 00	36	38	34	34	40	42	51	51	40	36	25	27
"	at 06	31	40	38	35	33	29	41	41	31	37	27	24
"	at 12	26	27	28	26	26	30	38	34	26	27	11	15
"	at 18	34	33	31	31	28	30	40	38	27	26	17	23
% of sky overcast		68	63	67	69	68	66	58	61	69	69	80	77
"	at 00	64	62	66	66	60	58	49	49	60	64	75	73
"	at 06	69	60	62	65	67	71	59	65	69	63	73	76
"	at 12	74	73	72	74	74	70	62	66	74	73	89	85
"	at 18	66	66	69	69	72	70	60	62	73	74	83	77

Table 4.1

Monthly mean, Mean minimum and Mean maximum temperatures for the Copper-Nickel Region sites.

(^{o}C)

	JANUARY			FEBRUARY			MARCH			APRIL			MAY			JUNE		
	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN
DULUTH AIRPORT	-12.2	-7.1	-17.3	-11.2	-6.3	-16.1	-4.5	0.1	-9.2	2.0	6.4	-2.5	8.1	13.3	3.0	12.2	17.7	6.8
BEAVER BAY	-11.9	-6.8	-17.0	-11.3	-6.4	-16.2	-4.8	-0.2	-9.5	2.2	6.7	-2.2	9.0	13.9	4.1	12.8	17.5	6.0
GRAND MARAIS	-11.7	-6.6	-16.8	-11.3	-6.4	-16.2	-5.0	-0.4	-9.7	2.6	7.1	-1.8	9.5	14.3	4.6	11.5	17.4	5.5
BRIMSON	-15.5	-10.2	-20.8	-13.4	-7.9	-18.8	-6.4	-1.2	-11.6	1.4	7.2	-4.5	8.7	15.1	2.3	13.2	19.4	7.1
MEADOWLANDS	-14.4	-9.1	-19.7	-12.2	-6.8	-17.7	-5.5	-0.3	-10.1	3.4	9.2	-2.5	10.9	17.3	4.5	15.6	21.0	8.7
COTTON	-14.7	-9.7	-20.0	-12.6	-7.2	-18.1	-5.6	-0.4	-10.2	2.8	8.6	-3.1	10.0	16.4	3.6	14.8	21.0	8.7
WHITEFACE RESERVOIR	-15.1	-9.8	-20.4	-13.0	-7.9	-18.5	-5.8	-0.6	-10.4	2.5	8.3	-3.4	9.7	16.1	3.3	14.4	20.6	8.3
ISABELLA	-16.2	-10.9	-21.5	-14.6	-9.1	-20.0	-7.0	-1.8	-12.2	0.7	6.5	-5.2	7.6	14.0	1.2	12.0	18.1	5.8
HOYT LAKES	-15.6	-10.3	-20.9	-13.6	-8.2	-19.1	-5.7	-0.5	-10.3	2.6	8.4	-3.3	11.0	17.4	4.6	15.8	21.9	9.6
BABBITT	-16.0	-10.7	-21.3	-14.0	-8.6	-19.5	-5.5	-0.3	-10.3	1.3	7.1	-4.6	9.7	16.1	3.3	14.0	20.1	8.8
WINTON	-15.2	-9.9	-20.5	-13.6	-8.2	-19.1	-5.5	-0.3	-10.1	2.0	7.8	-3.9	10.1	16.5	3.7	15.2	21.4	9.1
TOWER	-15.4	-10.1	-20.7	-13.2	-7.8	-18.7	-5.6	-0.4	-10.2	2.6	8.4	-3.3	10.9	17.3	4.5	15.2	21.4	9.1
VIRGINIA	-15.4	-10.1	-20.7	-13.2	-7.8	-18.7	-5.8	-0.6	-10.4	2.4	8.3	-3.4	10.2	16.6	3.8	15.2	21.3	9.0
HIBBING AIRPORT	-15.4	-10.1	-20.7	-13.3	-7.9	-18.8	-5.8	-0.6	-11.0	2.7	8.5	-3.0	10.6	17.0	4.2	15.4	21.6	9.3
HIBBING	-15.4	-10.1	-20.7	-13.2	-7.7	-18.6	-5.8	-0.6	-11.0	2.8	8.6	-3.1	10.6	17.0	4.2	15.2	21.3	9.0
CELINA TWP.	-15.1	-9.8	-20.4	-12.8	-7.4	-18.3	-4.3	0.9	-9.5	3.0	8.8	-2.9	10.6	17.0	4.2	15.6	21.7	9.4
CRANE LAKE	-15.9	-10.6	-21.2	-12.8	-7.4	-18.3	-4.7	0.5	-9.9	2.6	8.5	-3.2	10.7	17.1	4.3	15.6	21.7	9.4

	JULY			AUGUST			SEPTEMBER			OCTOBER			NOVEMBER			DECEMBER		
	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN	MEAN	$\bar{X}$-MAX	$\bar{X}$-MIN
DULUTH AIRPORT	16.7	23.1	10.3	15.9	22.2	9.6	14.0	18.2	9.8	7.6	11.7	3.4	-1.3	2.8	-5.4	-8.1	-3.7	-12.5
BEAVER BAY	15.8	21.7	10.0	15.6	20.9	10.2	12.4	16.9	8.0	7.1	11.2	3.0	-1.9	2.4	-5.8	7.7	-3.2	-12.2
GRAND MARAIS	15.5	21.2	9.9	15.4	20.2	10.5	12.1	16.3	7.9	6.9	11.0	2.7	-1.9	2.2	-6.0	-7.4	-3.0	-11.8
BRIMSON	17.0	23.4	10.6	15.4	21.8	9.0	10.4	16.7	4.1	4.1	10.2	-2.0	-4.8	0.1	-9.9	-12.3	-7.2	-17.4
MEADOWLANDS	18.8	25.2	12.4	16.8	23.2	10.9	12.4	18.7	6.1	5.8	11.9	-0.3	-3.7	1.2	-8.6	-10.4	-5.3	-15.5
COTTON	18.6	25.0	12.2	16.7	23.1	10.8	11.9	18.2	5.6	5.5	11.6	-0.6	-4.1	0.8	-9.0	-10.9	-5.3	-15.5
WHITEFACE RESERVOIR	18.3	24.5	11.9	16.4	22.8	10.0	11.6	17.9	5.3	5.2	11.3	-0.9	-4.3	0.6	-9.2	-11.3	-6.2	-16.4
ISABELLA	15.8	22.2	9.4	14.0	20.4	7.6	9.4	15.7	3.1	3.2	9.3	-2.9	-5.3	-0.4	-10.2	-12.8	-7.7	-17.9
HOYT LAKES	18.3	24.7	11.9	16.2	22.6	9.8	11.6	17.9	5.3	5.0	11.1	-1.1	-4.8	0.1	-9.7	-11 9	-6.8	-17.0
BABBITT	16.8	23.2	10.4	14.5	20.9	8.1	10.6	16.9	4.3	3.6	9.7	-2.5	-5.3	-0.4	-10.2	-12.3	-7.2	-17.4
WINTON	18.5	24.9	12.1	16.0	22.4	9.6	11.3	17.6	5.0	4.5	10.6	-1.6	-5.0	-0.1	-9.9	-12.0	-6.9	-17.1
TOWER	18.0	24.4	11.6	15.5	21.9	9.1	11.0	17.3	4.7	4.9	11.0	-1.2	-4.3	0.6	-9.2	-12.4	-7.3	-17.5
VIRGINIA	18.1	24.5	11.7	15.7	22.1	9.3	11.3	17.6	5.0	5.0	11.1	-1.1	-4.3	0.6	-9.2	-11.4	-6.3	-16.5
HIBBING AIRPORT	18.7	25.1	12.3	16.5	22.9	10.1	11.8	18.1	5.5	5.0	11.1	-1.1	-4.3	0.6	-9.2	-11.7	-6.6	-16.8
HIBBING	18.6	25.0	12.2	16.4	22.8	10.0	11.8	18.1	5.5	5.0	11.1	-1.1	-4.3	0.4	-9.4	-11.9	-6.8	-17.0
CELINA TWP.	18.3	24.7	11.9	16.3	22.7	9.9	10.7	17.0	4.4	5.0	11.1	-1.1	-4.3	0.6	-9.2	-11.9	-6.8	-17.0
CRANE LAKE	18.7	25.1	12.3	16.4	22.8	10.0	11.5	17.8	5.2	5.0	11.1	-.1	-4.5	0.4	-9.4	-12.3	-7.2	-17.4

Table 4.2

Monthly Mean temperatures versus Pressure Levels above International Falls, Minnesota (elevation 360 meters-mel). Period of Record, January 1946-December 1955.

(°C)

PRESSURE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
					AVERAGE TEMPERATURE C							
SFC	16.1-	12.8-	6.7-	2.9	9.7	15.2	18.1	16.5	11.0	5.9	3.9-	12.9-
950	15.3-	11.7-	5.8-	4.0	10.8	16.3	19.7	18.6	12.6	7.4	3.9-	12.2-
900	14.2-	12.3-	7.9-	1.3	8.0	13.6	16.8	15.9	10.4	5.6	5.0-	11.5-
850	12.8-	11.7-	9.3-	1.1-	4.9	10.4	13.5	12.7	7.7	3.6	5.7-	10.8-
800	12.9-	12.1-	10.5-	3.5-	1.9	7.2	10.5	9.9	5.3	1.6	6.8-	11.3-
750	14.2-	13.7-	12.1-	5.7-	.9-	4.2	7.6	7.0	2.8	.6-	8.6-	12.6-
700	16.3-	15.7-	14.4-	8.4-	3.8-	1.3	4.5	3.8	.0	3.3-	11.0-	14.8-
650	18.9-	18.4-	17.1-	11.5-	7.0-	2.0-	1.1	.5	3.2-	6.6-	13.5-	17.6-
600	22.2-	21.7-	20.2-	15.0-	10.5-	5.5-	2.7-	3.3-	6.9-	10.1-	16.9-	20.7-
550	26.0-	25.5-	24.0-	19.1-	14.7-	9.6-	7.0-	7.6-	10.9-	14.2-	20.9-	24.4-
500	30.3-	29.9-	28.5-	23.9-	19.4-	14.4-	11.7-	12.3-	15.6-	18.8-	25.3-	28.8-
450	35.3-	34.8-	33.6-	29.2-	24.9-	19.9-	17.1-	17.7-	21.0-	24.1-	30.5-	34.0-
400	40.9-	40.3-	39.4-	35.3-	31.1-	26.0-	23.3-	24.0-	27.2-	30.2-	36.3-	39.6-
350	47.0-	46.2-	45.5-	41.9-	38.1-	33.2-	30.6-	31.3-	34.3-	37.0-	42.7-	45.8-
300	52.2-	52.1-	51.5-	48.9-	45.4-	41.1-	38.6-	39.4-	42.1-	44.3-	48.8-	51.4-
250	54.3-	55.1-	54.5-	54.5-	52.1-	49.4-	46.9-	48.0-	49.7-	51.2-	52.9-	54.2-
200	52.4-	52.6-	52.9-	54.7-	55.0-	54.1-	53.0-	53.2-	53.8-	55.3-	53.4-	53.0-
175	51.4-	51.5-	51.7-	53.4-	54.3-	54.2-	54.7-	54.2-	54.7-	55.9-	53.2-	52.4-
150	51.9-	51.7-	51.7-	52.8-	53.6-	53.9-	55.9-	55.7-	56.0-	56.4-	53.2-	52.6-
125	53.0-	53.1-	52.1-	53.1-	54.1-	54.8-	57.2-	57.2-	56.4-	57.1-	53.9-	53.1-
100	54.6-	54.4-	53.8-	54.2-	55.7-	56.2-	57.2-	57.0-	56.4-	57.5-	54.8-	54.0-
80	55.6-	55.0-	54.7-	55.5-	56.2-	55.9-	56.0-	56.1-	55.8-	57.6-	55.6-	54.6-
60	56.7-	57.6-	56.0-	56.3-	55.7-	54.5-	54.0-	54.1-	55.1-	57.4-	56.6-	54.6-
50	57.2-	56.5-	56.1-	55.1-	54.6-	53.7-	52.4-	52.7-	54.9-	57.2-	57.4-	54.5-
40			55.9-	54.8-	53.6-	51.9-	50.8-	50.9-	54.0-	56.9-	58.1-	54.8-
30					52.0-	49.2-	48.4-	48.9-	52.1-	55.1-		

Table 4.3

Monthly extreme temperatures (^{o}C.) and standard deviation of temperature versus pressure level (millibars) above International Falls, Minnesota (WBO elevation 360 meters). Period of Record, Jan. 1946-Dec. 1955.

Extreme Temperature

Pressure		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
950	Max	1	3	17	28	26	27	29	30	25	24	14	5
	Min	34-	31-	28-	18-	7-	3	7	8	0	7-	22-	31-
850	Max	10	5	13	20	19	20	21	24	23	21	12	8
	Min	34-	30-	30-	23-	11-	2-	1	0	7-	14-	22-	28-
700	Max	1-	1-	1	6	9	11	13	15	11	9	2	1
	Min	33-	31-	30-	28-	19-	10-	7-	8-	18-	23-	31-	32-
500	Max	18-	18-	15-	12-	9-	6-	3-	3-	7-	8-	12-	16-
	Min	45-	43-	42-	39-	35-	28-	22-	22-	31-	36-	41-	46-
300	Max	41-	39-	43-	39-	36-	31-	30-	27-	31-	34-	37-	40-
	Min	61-	63-	60-	61-	53-	53-	48-	49-	54-	57-	58-	60-
200	Max	39-	39-	43-	40-	42-	38-	41-	41-	41-	39-	39-	40-
	Min	68-	68-	70-	66-	67-	62-	62-	61-	62-	66-	68-	66-
150	Max	42-	41-	44-	44-	43-	44-	46-	47-	45-	44-	43-	42-
	Min	65-	62-	62-	68-	69-	65-	68-	65-	68-	65-	54-	65-
100	Max	48-	44-	47-	46-	45-	50-	50-	51-	48-	45-	47-	44-
	Min	65-	64-	60-	60-	63-	65-	63-	65-	65-	64-	63-	71-

Standard Deviation

Pressure	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
950	7.6	7.4	7.1	7.0	6.6	4.5	4.0	4.0	5.3	6.3	7.0	7.3
850	7.7	7.4	7.3	7.2	6.4	4.6	4.0	4.6	6.1	7.2	7.4	7.2
700	6.5	6.3	6.4	6.0	5.3	4.2	4.0	4.1	5.6	6.4	6.5	6.5
500	5.5	5.5	5.5	5.2	4.8	3.8	3.5	3.5	4.5	5.3	5.8	5.5
300	3.5	3.5	2.9	3.6	3.5	3.7	3.7	3.7	3.7	3.6	3.4	3.4
200	5.3	5.9	5.2	5.9	6.0	4.7	3.9	3.6	4.7	5.2	5.5	5.5
150	4.0	4.2	3.4	4.1	4.2	4.2	4.2	3.9	4.6	4.2	4.1	4.2
100	3.1	4.2	3.0	3.2	2.9	3.1	3.2	3.2	3.3	3.4	3.5	3.7

Table 5.1 Monthly Mean Values of Relative Humidity for the Copper-Nickel Study Region
Period of Record, 1921-1976
(%)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
HOUR												
0600	79	79	80	78	77	84	89	89	91	89	86	81
1200	67	67	65	58	52	58	60	61	65	62	71	74
1800	68	67	64	57	50	56	59	61	67	65	75	76
2400	77	77	76	72	72	80	86	84	86	82	83	79
Mean	73	73	72	66	62	69	74	75	78	75	79	79
Mean Water Vapor Pressure (MB)	2.5	2.8	4.6	6.0	7.9	11.7	11.7	12.9	10.8	7.0	4.9	3.3
Dew Point (°C)	-19	-18	-9	-4	4	8	12	10	7	-1	-8	-15

<u>Table 5.2</u>

Monthly mean relative humidity versus pressure level above International Falls, Period of Record, 1946-1955.

Month

Pressure	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	77	75	70	66	66	73	79	83	82	76	81	78
950	76	74	64	59	58	64	66	69	71	67	78	77
900	73	72	65	60	59	63	66	67	67	64	76	73
850	66	66	63	59	62	67	68	67	65	60	69	66
800	61	61	58	58	63	68	64	61	61	56	63	60
750	58	56	54	55	58	64	57	56	55	51	59	55
700	56	54	53	54	55	58	50	51	50	49	56	51
650	54	52	52	52	51	52	48	46	49	48	52	49
600	54	51	50	51	48	48	43	41	47	46	49	48
550	54	51	50	51	45	46	40	39	44	44	49	48
500	53	50	48	50	42	43	37	37	41	43	48	48
450	53	48	49	49	43	42	35	35	41	43	48	48
400	52	50	51	48	43	42	36	34	40	43	47	49

Table 6.1

AVERAGE MONTHLY PRECIPITATION FOR THE SITES INDICATED

(Millimeter Units)

Site	JAN	FEB	MAR	APR	—Month— MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
Duluth Harbor	24.0	21.4	34.8	46.2	76.0	79.9	91.8	108.3	84.2	52.7	48.1	26.4	691.2
Duluth Airport	33.3	31.4	47.2	54.8	77.0	87.1	100.2	115.3	86.7	54.6	56.6	36.3	776.2
Two Harbors	28.6	17.3	42.9	43.4	88.2	81.9	91.2	98.8	92.9	54.6	52.0	34.3	729.5
Beaver Bay	54.8	35.1	51.6	67.6	63.8	69.6	80.8	75.9	82.6	49.3	30.7	36.1	697.7
Grand Marais	26.1	26.3	37.1	52.4	76.0	78.6	95.1	76.5	96.0	52.0	50.5	30.2	714.6
Island Lake	30.6	20.0	32.3	49.3	75.2	88.3	105.0	97.6	90.4	51.8	45.9	29.2	701.6
Brimson	26.5	23.5	42.9	55.7	70.2	90.6	96.0	99.9	87.9	53.9	47.8	32.3	726.9
MeadowLands	19.5	16.2	29.7	55.7	73.5	89.0	107.1	96.1	85.6	50.1	42.5	25.1	689.6
Cotton	20.0	15.9	28.2	52.6	75.0	88.5	104.1	101.4	80.8	52.4	45.0	26.2	689.6
Whiteface Reservoir	26.5	22.5	36.3	54.8	70.7	85.2	103.5	95.6	80.8	52.2	45.3	30.2	703.4
Isabella	26.5	25.9	41.1	58.4	79.7	99.3	103.5	95.6	89.8	63.2	50.2	32.2	768.1
Gunflint Lake	33.6	26.9	26.8	54.2	76.0	76.7	98.7	72.1	132.2	56.5	58.8	34.3	744.1
Hoyt Lakes	24.5	22.8	32.5	50.9	81.0	93.7	106.8	95.3	87.3	62.5	38.0	27.2	724.0
Babbitt	23.4	20.0	29.2	48.7	73.0	98.1	103.8	97.9	94.9	61.7	46.8	28.2	726.4
Winton	23.8	21.1	29.7	41.4	72.5	88.3	114.5	88.3	93.5	56.5	41.0	25.6	693.5
Tower	28.6	26.3	36.8	55.3	88.5	102.1	116.0	93.0	96.6	64.7	45.6	30.2	785.4
Virginia	23.4	17.3	30.7	49.8	75.2	101.9	97.5	91.2	85.6	57.2	35.8	24.4	689.8
Hibbing Airport	16.3	14.8	35.1	41.6	70.2	88.5	101.7	86.3	80.3	48.6	29.7	19.0	632.2
Hibbing	26.1	22.8	36.3	58.8	87.5	106.3	121.7	93.0	96.3	62.7	44.7	34.5	793.7
Celina Twp.	25.6	18.7	28.2	43.8	67.7	91.8	110.9	122.2	83.4	44.9	33.7	29.7	693.2
Crane Lake	22.9	21.8	26.6	50.6	72.5	93.7	130.3	92.1	92.6	50.9	38.6	26.9	714.9
International Falls	27.4	29.7	33.0	50.6	77.5	98.8	130.9	91.5	92.9	58.0	40.1	30.2	751.7

Table 6.2

Rainfall amounts in inches for various return periods and durations.

Duration	Return period, years 2	10	25	50
30 minutes	0.8-0.9	1.2-1.4	1.3-1.6	1.5-1.8
1 hour	0.9-1.2	1.5-1.8	1.7-2.0	1.9-2.2
6 hours	1.6-1.8	2.4-2.7	2.8-3.1	3.1-3.4
12 hours	2.0-2.2	2.9-3.2	3.3-3.8	3.6-4.1
24 hours	2.3-2.5	3.4-3.7	3.9-4.3	4.3-4.6

Table 6.3

Heaviest rainfalls observed for various time intervals at International Falls, Minnesota

Time Interval	Year	Amount (mm)	Rate (mm/min)
5 minutes	1953-1961	20.3	4.06
10 minutes	"	26.2	2.62
15 minutes	"	29.0	1.93
30 minutes	"	34.0	1.13
1 hour	1946-1961	36.8	0.61
2 hours	"	54.6	0.46
3 hours	"	68.1	0.38
6 hours	"	68.3	0.19
12 hours	"	74.7	0.10
24 hours	"	122.4	0.085

SOURCE: Maximum Recorded United States Rainfall, National Weather Service, 1967.

TABLE 6.4

Past Record of Precipitation Events when Total Rainfall Exceeded 70 mm.

DATE	PRECIPITATION, mm.
October 8, 1949	91.9
June 8, 1968	91.4
September 3, 1953	84.6
July 28, 1940	81.5
August 30, 1924	81.5
August 25, 1959	76.2
August 28, 1936	74.9
September 19, 1925	72.4
September 12, 1930	71.6

Table 6.5 Monthly Precipitation Statistics, Babbitt, Minnesota (1921-1976)
(Values in Millimeters)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Long-term average	23.4	20.0	29.2	48.7	73.0	98.1	103.8	97.9	94.9	61.7	46.8	28.2	726.4
% of annual precipitation in month	3.2	2.8	4.0	6.7	10.0	13.5	14.3	13.5	13.1	8.5	6.4	3.9	-
% of annual total by end of month from Jan 1	3.2	6.0	10.0	16.7	26.7	40.2	54.5	68.0	81.1	89.6	96.1	100.0	-
% of annual total by end of month from May 1	86.4	89.2	93.3	100.0	10.0	23.5	37.8	51.3	64.4	72.9	79.3	83.2	-
Wettest	72.1	49.3	66.8	109.5	149.1	278.9	185.7	212.9	214.4	181.6	83.1	65.0	954.3
Year	1969	1939	1966	1968	1930	1944	1935	1928	1925	1971	1965	1968	1928
Driest	0	1.5	2.3	1.3	7.5	23.9	30.0	15.0	7.4	11.2	5.6	4.1	416.8
Year	1947	1928	1959	1944	1976	1956	1964	1976	1948	1938	1921	1940	1923
Decade Average:													
1921-1930	14.0	14.2	22.9	34.8	58.2	97.5	107.7	88.6	119.4	37.8	30.2	21.3	646.7
1931-1940	21.3	17.0	24.4	43.9	82.8	102.6	86.4	95.3	77.5	51.3	41.9	21.1	665.7
1941-1950	21.8	12.7	23.1	51.3	83.1	137.2	98.3	113.8	86.1	53.3	30.2	20.1	730.8
1951-1960	20.8	18.0	26.2	52.1	76.2	97.3	107.2	107.7	80.8	43.9	42.9	23.9	697.0
1961-1970	22.1	14.2	29.7	66.8	80.3	113.5	85.3	86.1	100.6	67.6	38.9	31.2	736.1
1971-1977	23.1	17.8	32.8	33.3	58.2	105.7	89.9	93.0	72.1	83.8	37.8	22.6	674.9
1921-1976	20.9	15.9	26.1	48.0	74.1	109.2	96.2	97.7	90.6	54.3	36.9	23.4	693.3

Table 6.6 Monthly Precipitation Statistics, Virginia, Minnesota (1894-1976)
(Values in Millimeters)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Average	23.4	17.3	30.7	49.8	75.2	101.9	97.5	91.2	85.6	57.2	35.8	24.4	689.9
	3.4	2.5	4.4	7.2	10.9	14.8	14.1	13.2	12.4	8.3	5.2	3.5	-
	3.4	5.9	10.3	17.5	28.4	43.2	57.3	70.5	82.9	91.2	96.5	100.0	-
	85.9	88.3	92.8	100.0	10.9	25.7	39.8	53.0	65.4	73.7	78.9	82.4	-
Wettest	83.8	76.2	97.3	142.2	173.0	236.5	240.0	257.6	254.8	177.8	143.3	69.3	1087.9
	1897	1897	1894	1896	1896	1944	1905	1900	1900	1970	1909	1903	1905
Driest	0.8	2.0	3.8	0.5	6.3	8.9	16.5	15.0	7.4	5.6	2.0	3.3	408.7
	1957	1957	1900	1926	1917	1910	1939	1976	1948	1923	1916	1954	1976
Period Averages:													
1894-1930	21.3	19.1	29.5	43.2	75.9	103.4	105.4	92.2	96.3	57.9	31.2	25.4	700.8
1931-1952	25.1	18.3	34.8	54.4	68.3	98.3	86.9	98.0	73.1	53.8	43.7	24.1	678.9
1894-1960	22.6	18.3	30.7	47.8	74.9	99.8	101.1	94.0	87.6	54.6	37.3	24.4	693.2
1960-1976	26.2	12.7	30.7	57.4	76.2	110.5	83.1	80.0	77.5	67.6	29.7	24.4	671.6

Table 7.1. Freeze dates and duration of ice on Copper-Nickel Study Region lakes.

	FREEZETIME	DURATION
Ponds, Small Lakes	November 5-April 20	166 days
Medium Lakes	November 15-April 25	161 days
Large Lakes	November 25-April 30	156 days

Table 7.2 Mean monthly pan evaporation values for Hoyt Lakes.

MONTH	PAN EVAPORATION (mm)
April	75
May	112
June	138
July	161
August	127
September	72
October	40
Season	725

Table 7.3. Mean annual actual evaporation considering the freezing of lake surfaces.

(Millimeters)

	PAN EQUIVALENT	LAKE EVAPORATION
Ponds, Small Lakes	677	474
Medium Lakes	669	468
Large Lakes	662	463

Table 8.1. Average monthly and annual snowfall (Millimeters)

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	YEAR
Virginia	23	255	276	283	215	260	122	12	1446
Babbitt	40	198	256	251	172	220	107	10	1254
Winton	63	168	252	283	215	228	91	10	1310
Isabella	47	251	315	370	226	256	229	20	1714
Hibbing	16	145	252	236	144	251	145	5	1194

Table 8.2. Record snowfall data from Babbitt area

MONTH	NUMBER OF DAYS WITH A FALL OVER 125 mm 1921-1976	HEAVIEST FALL IN MONTH (in millimeters)
September	0	25
October	4	203
November	7	254
December	7	178
January	4	178
February	4	254
March	13	406
April	8	302
May	1	191
June	0	102

Table 9.1. Greatest recorded depth of snow on ground (millimeters/year).

MONTH	BABBITT	WINTON
October	241/(1932)	127/(1919)
November	533/(1965)	508/(1965)
December	635/(1965)	483/(1965)
January	1270/(1969)	991/(1916)
February	1320/(1969)	1016/(1916)
March	914/(1971)	965/(1916)
April	762/(1971)	1737/(1971)
May	76/(1966)	51/(1966)

Table 9.2. Least recorded depth of snow on ground (millimeters/year).

MONTH	BABBITT	WINTON
October	0	0
November	0	0
December	0	0
January	25/(1932)	76/(1915)
February	0	102/(1917)
March	0	0
April	0	0
May	0	0

Appendix I

Historical Weather Stations -- Northeast Minnesota

Site	Parameter	Period of Record	Observer
Babbitt*	TP	Feb. 1, 1920-Sep. 10,1951	Mesabi Iron Co.
	TP	Sep. 11, 1951 - Present	Reserve Mining Co.
Brimson	P	Aug. 1, 1923 -Present	MP&L
Crane Lake	P	Jan. 1, 1926 -Sep. 30, 1927	W.G. Randolph
	P	Oct. 30, 1942 -June 3, 1947	U.S. Customs
	P	June 4, 1947 -Present	DNR
	T.	Oct. 1, 1961 -Present	DNR
Cotton	TP	Aug. 21, 1962 -Sep. 30, 1963	Reynold E. Syria
	TP	Jul. 2, 1964 -Nov. 30, 1967	Hugh Wilson
	TP	Jul. 26, 1968 -Jan. 31, 1971	Bruno Lasko
	TP	Sep. 4, 1971 -Aug. 29, 1975	Henry Moberg
	TP	Sep. 1, 1975 -Present	Roy Tarbell
Ely	TP	Mar. 1, 1911 -Oct. 31, 1913	W.H. Farrell and J.Wista
Grand Marais	TP	May 1, 1900 -July 31, 1902	2 observers
	TP	May 13, 1913 -Dec. 22, 1913	3 observers
	TP	Aug. 13, 1914 -Apr. 30, 1915	2 observers
	TP	Aug. 23, 1915 -Aug. 31, 1915	C.G. Strikler
	TP	Aug. 21, 1916 -Jan. 31, 1921	J. Woods
	TP	Aug. 11, 1921 -Present	Many observers (Glenn Bergstrom,1978)
Hibbing	P	Dec. 1, 1923 -Present	MP&L
Hibbing-Mahoning	TP	Dec. 1, 1920 -Apr. 30, 1962	Mahoning Ore & Steel Co.
Hibbing Airport *	TP+	Nov. 1, 1962 -Present	U.S.F.A.A.
Hoyt Lakes *	TPE	Mar. 1, 1958 -Present	Erie Mining Co.

Appendix I cont'd.

Isabella	P	Dec. 1, 1925 -June 30, 1928	Sophia Russka
Isabella FS	TP	Aug. 1, 1957 -Present	U.S.F.S.
Isabella Elc *	TP	Feb. 1, 1975 -Present	ELC Staff
Stephens Mine *	TP	Nov. 9, 1906 -Mar. 31, 1914	Oliver Mining Co.
Tofte	P	Nov. 7, 1942 -Present	USFS
Tower*	TP	Jan. 1, 1895 -Present	Many observers A few breaks
Wales	P	Apr. 3, 1936 -May 26, 1941	USFS
	P	Oct. 20, 1943 -June 10, 1946	A.H.Gillson
	P	June 10, 1946 -Present	Mabel Larson
Virginia *	TP	Sept. 1, 1910 -Present	Oliver Mining Co.
Whiteface Res.	P	Aug. 1, 1923 -Present	MP&L
Winton *	TP	Nov. 1, 1913 -Mar. 31, 1920	Several observers
		May 10, 1940 -Present	Power plant

T = Temperature, Max. and Min.

P = Precipitation, daily. Often with snow, snow depth, and time of precipitation occurrence, depending on discretion of observer.

+ = Complete hourly aviation weather observations

E = Evaporation

* Stations considered to have better records

APPENDIX II

Explanation of Wind Roses

The wind roses are plotted on polar coordinate paper where the radials are direction from which the wind blows and the concentric circles are percent frequency of wind occurrence on each of 36 radials. On the monthly and annual wind roses envelopes are drawn for 1½ meter per second (wind speed) intervals, while on the 10-day wind roses, only the total frequency of occurrence envelope is drawn.

To make the annual and monthly roses, points were plotted along each radial corresponding to the observed percent of time that the wind came from the corresponding direction for velocity intervals of 1.5 meters per second. The distance from the data point to the origin represents the percent of time that a wind from a certain direction blows at a given speed <u>or less</u>. The distance <u>between</u> the points along the radial is the percent of time that the wind blows from the indicated direction in the speed category defined by the speeds represented by the two points.

Except for speeds of 1.5 meters per second, lines were drawn connecting points representing equal speeds at 1.5 meters per second speed intervals around the 360 degree arc. The data points are obscured by the lines drawn over them. The first solid line from origin represents 3 meters per second; the first dashed line 4.5 meters per second; the second solid line 6 meters per second; the lone hash line 7.5 meters per second; the third solid line 9 meters per second; the second dashed line 10.5 meters per second; the fourth solid line 12 meters per second, etc. In most cases, winds over 10.5 meters per second are so rare that the lines may seem to merge.

APPENDIX III

Temperature and Precipitation Data for Babbitt

The data in this appendix were compiled from the original Babbitt records by Ms. Susan Richter under contract to the author. The data were computer analyzed by Dr. Donald Baker and Mr. John Enz of the Soils Science Department of the University of Minnesota, whose cooperation is gratefully acknowledged.

Temperature values are in degrees Fahrenheit, and precipitation values are in inches.

In the computer analysis no correction was made for mean temperature and mean maximum-minimum temperature error due to observing time. The correction values for mean maximum temperature for each month appear at the top of the monthly columns on pages 1 and 2 of the appendix. These correction values were derived from a model devised by the author. In the model, no observing time correction is applied to the minimum temperature. The correction to the average daily, weekly, or monthly temperature is equal to one-half the correction value for mean maximum temperature. In all cases for Babbitt, the correction value is to be subtracted.