Precipitation Pattern Analysis

Uinta Basin - Wasatch Front

Office of the State Climatologist
Utah State University
Logan, Utah

D. T. Jensen, Gail E. Bingham, Gaylen L. Ashcroft,
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Report to Division of Water Resources, State of Utah
Under Contract Number 90-3078

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Executive Summary

In agreement with the Division of Water Resources, State of Utah, the climatology of winter storms in the Uinta Basin and along the Wasatch Front was investigated. The purpose of the study was to evaluate Utah terrain and its effect on orographic precipitation patterns.

The 1951-1980 normal precipitation calculations show that on the average, the Uinta Basin receives about 8 inches of precipitation annually. About half of the precipitation results from winter storms. At higher elevations, about three-quarters of all precipitation comes from winter storms. Because much of the precipitation at higher elevations in winter storms falls as snow, it becomes available as runoff in the spring and summer months and is therefore valuable to residents in the Basin for irrigation and other purposes.

This study presents the climatology of Utah and the Uinta Basin. Winter and spring storms were classified into four categories. The first represents a ridge position over the intermountain west and allows very little precipitation to be produced in the Utah area. The additional three categories reflect wind flow from the northwest, the southwest and the southeast. These studies show most storms which produce significant precipitation in the Basin come from the southwest through southeast. Relatively few storms from the west or northwest result in precipitation in the Basin. This climatology of storms was verified using correlations among precipitation stations and by modelling storm wind trajectories and precipitation patterns.

During periods of drought in the Basin, there is always concern about water availability for municipal and industrial systems and for irrigation. To show historical periods of water deficit or drought in the Basin and their relation with other areas, long-term meteorological drought indices are presented. Emphasis is placed on the last ten years of record. The present severity of drought in the Basin is presented and related directly to past droughts and drought severity in other areas of the State.

The Rhea orographic precipitation model was used to evaluate the effect of winter storms and their precipitation distribution patterns in the Basin. The model was calibrated to 1984 winter and spring storms. Results verify that much of the precipitation in the Uinta Basin results from storms from the southerly directions.

Introduction

This study was conducted in agreement with the Division of Water Resources, State of Utah. For several years Utah has maintained an active precipitation augmentation program that operates during the winter months. The intent of the program is to increase precipitation in the Wasatch Mountains and increase water harvest. There is concern in the Uinta Basin that precipitation augmentation in the Wasatch Mountains is depleting the Eastern Utah moisture source.

To address these concerns this study presents Utah in her Western United States climate setting, noting effects of terrain; average annual precipitation amounts and comparisons; historical and present drought relationships; storm types; precipitation station correlations; and orographic model results. In each of these topics we address the general western setting and then the very specific setting of the Uinta Basin.

Utah Climatic Setting

Utah is located about 500 miles inland from the Pacific Ocean. The State is a land of high mountains, elevated plateaus and deserts. Elevations in the State vary from near 2,350 feet in the southwest corner of Utah to 13,528 feet at Kings Peak in the Uinta Mountains. The Wasatch Range extends some two hundred miles from the northern border to Nephi in central Utah, and has several peaks in excess of 10,000 feet. The Uinta Mountains reach about 150 miles east from the Wasatch Mountains to the Colorado border with several peaks in excess of 12,000 feet.

South and east of the Wasatch and Uinta Mountains lie the Colorado Plateaus. The High Plateaus, the western portion of the Colorado Plateaus, extend southward from Nephi into Arizona and are about 40 miles across, with summits reaching elevations in excess of 11,000 feet. South of the Uinta Mountains lie the Tavaputs Plateaus and the great Canyonlands of the Colorado with elevations of 8,000 to 10,000 feet.

The Uinta Basin, except for the narrow Green River Canyon, resembles the Basin of an ancient sea or lake and is surrounded by the Uinta Mountains on the north, the Wasatch Mountains on the West and the high Colorado Plateaus on the south and east.

Although the Utah climate is classified as semiarid, there are enormous differences between the alpine climates of the Uinta Mountains and the desert climate in the Uinta Basin. Annual precipitation varies from over 40 inches in the high elevations of the Uintas to less than 6 inches near Ouray. The unique setting of the Uinta Basin, surrounded by mountainous terrain, is aptly shown on the satellite view of Utah in Figure 1.

The mountains and high plateaus (Figure 2) have a great influence upon the distribution of precipitation in Utah. This is shown on the annual normal precipitation map in Figure 3. Utah's Climatic Divisions are shown in Figure 4.

Annual normal precipitation by climatic division tabulated in Table 1 shows annual values for the Uinta Basin Division are lower than any other division in Utah. Differences in the 30-year averages reflect the droughts of the 1930's and 1970's.

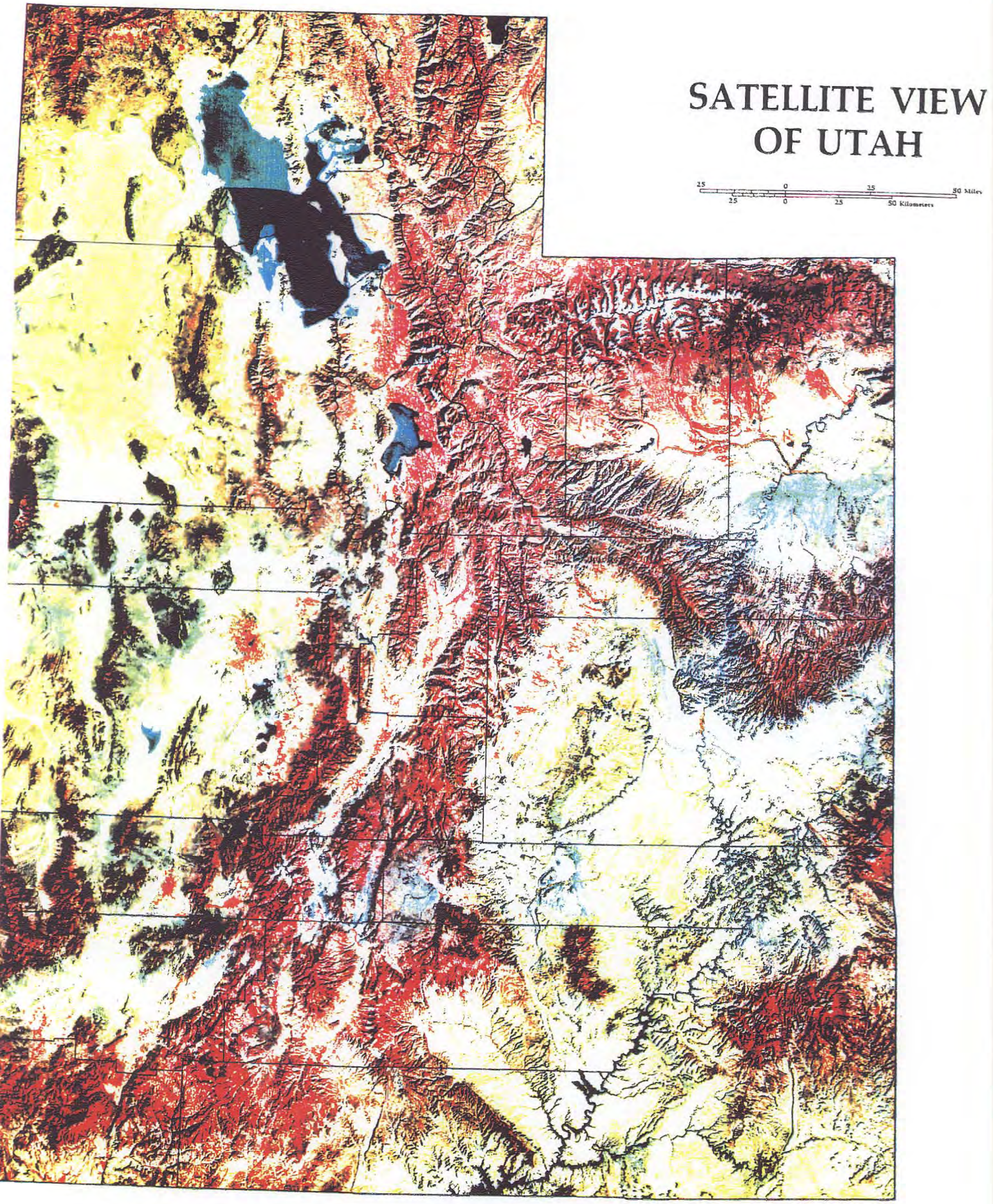


Figure 1. Satellite View of Utah (after Greer et al., 1981)

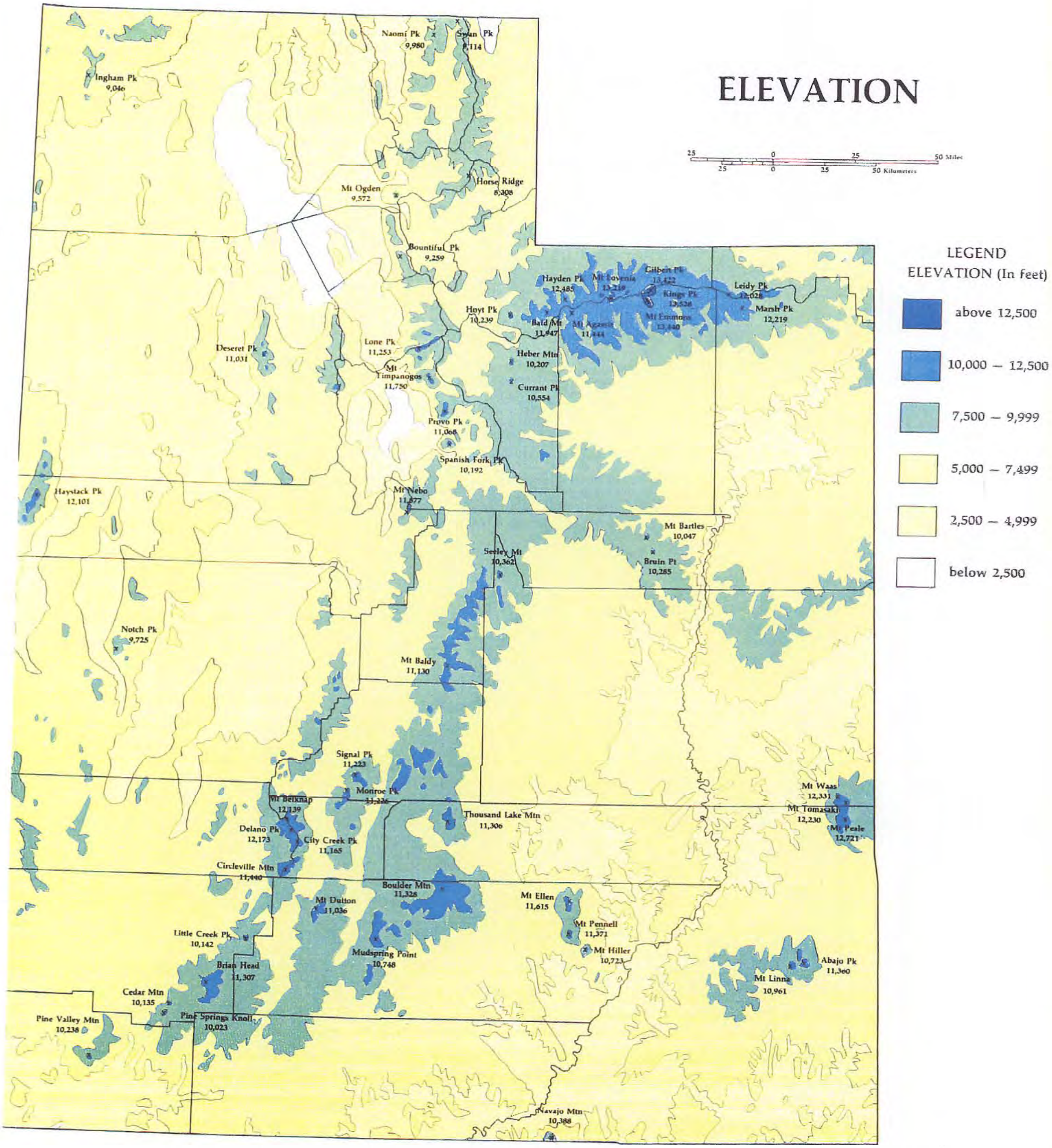


Figure 2. Elevation Map of Utah (after Greer et al., 1981)

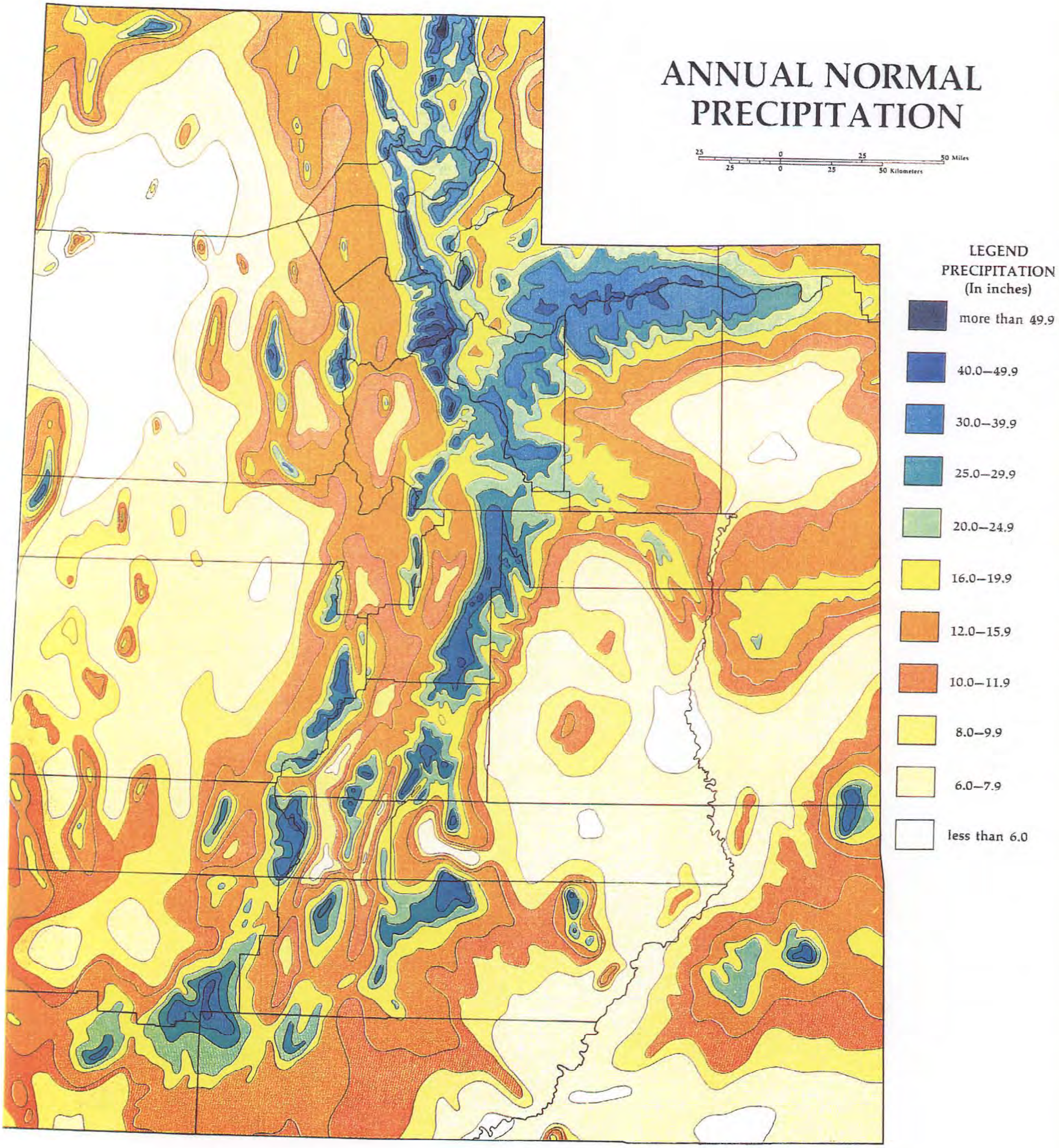


Figure 3. Annual Normal Precipitation, Utah (after Greer et al., 1981)

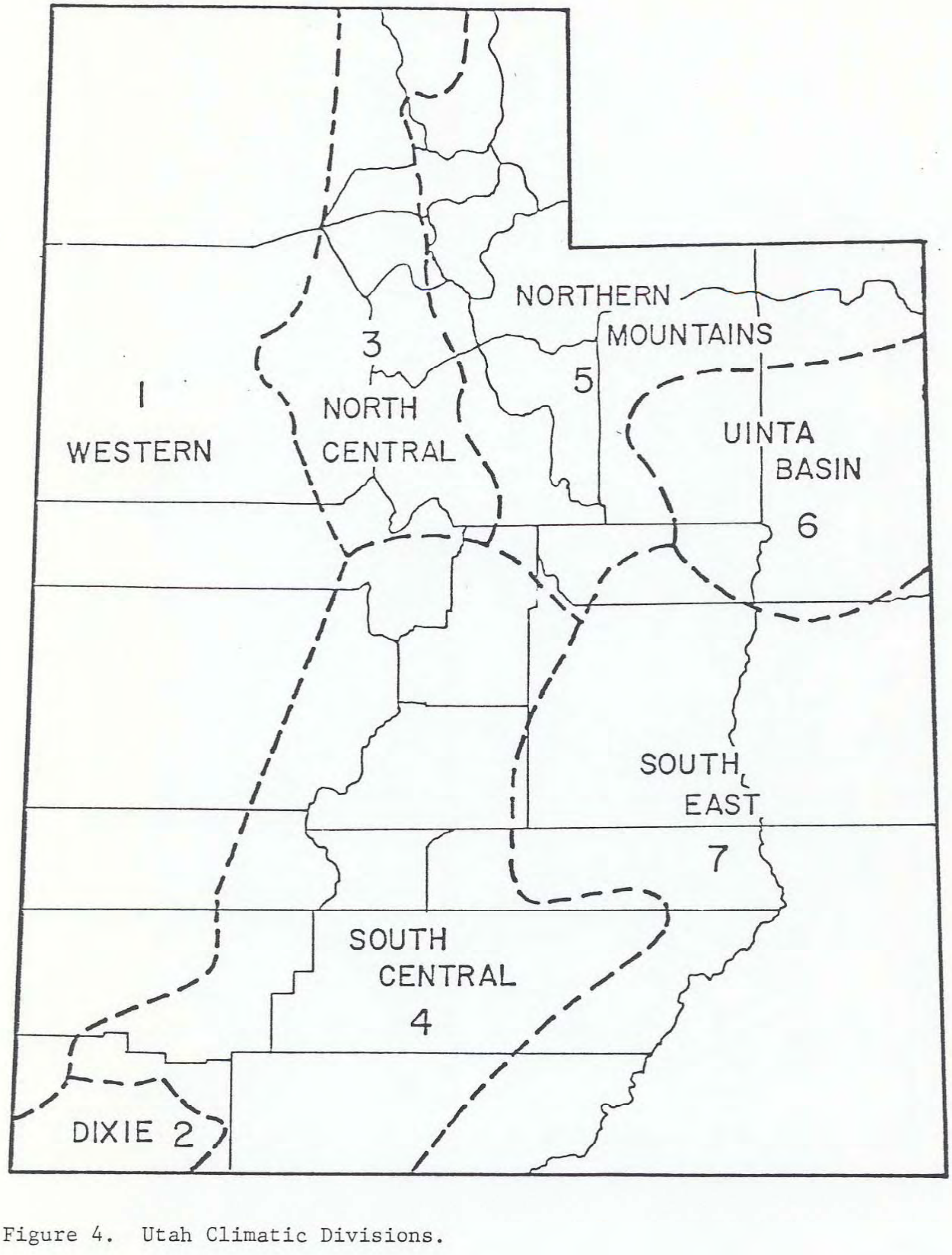


Figure 4. Utah Climatic Divisions.

Table 1. Annual Normal Precipitation by Climatic Division

	Utah Climatic Divisions						
Years Used	Western (01)	Dixie (02)	North Central (03)	South Central (04)	North Mtns (05)	Uinta Basin (06)	South East (07)
1931-80	8.77	11.71	16.06	12.23	18.61	7.90	8.78
1931-60	8.92	11.70	15.67	12.06	18.54	7.84	8.55
1941-70	8.49	10.95	16.33	12.23	19.91	8.05	8.75
1951-80	8.00	11.25	15.95	11.96	18.87	7.83	8.81

Climatology of Storms in Utah

General

The oceans are the primary source of moisture for the atmosphere, but it is also furnished by lakes, rivers, swamps, moist soil, snow, ice fields and vegetation. Moisture is introduced into the atmosphere as water vapor, and may be then carried great distances by winds before it is removed as liquid or solid precipitation.

There is a limit to the amount of water vapor the air can hold at a given temperature. When that limit is reached the air is said to be "saturated." The higher the air temperature, the more water vapor it can hold. For every 20 degree Fahrenheit increase in temperature, the capacity of a volume of air to hold water is doubled. On the other hand, unsaturated air containing a given amount of water vapor will become saturated if the temperature decreases sufficiently. Further cooling forces some of the water vapor to condense as fog, cloud or precipitation.

In general, clouds and precipitation result from lifting processes. As moist air is lifted by topography, storm fronts or large low pressure areas, clouds and precipitation result. Subsidence, or the downward movement of air, results in cloud dissipation. When air moves down the lee side of mountain barriers or subsides in large high pressure air masses, clouds and precipitation dissipate.

The Effects of Topography

Mountains are barriers to the horizontal movement of air masses and consequently lifting occurs when air approaches a mountain range. We refer to this lifting as orographic lifting and the precipitation that results, as orographic precipitation.

As air is forced over mountains it cools and moisture condenses out forming clouds and precipitation. After passing over the tops of the mountains, the air slides down the lee side. The downward movement of the air results in slight warming and the warmer air has more capacity to hold moisture as water vapor. Thus the cloud droplets evaporate and the clouds disappear.

When an air mass approaches the Uinta Basin from any direction, it must pass over mountains or high plateaus. The Wasatch Mountains to the west of the Basin form a barrier of about 8,000 to 10,000 feet. An air mass approaching from the west is lifted and cooled to the 8,000 level, and considerable moisture is condensed out. Although some moisture remains in the air mass, further lifting (above 8,000 feet) is required to continue cloud formation and precipitation. Further lifting occurs for the portion of the air mass that passes over the higher Uinta Mountains and precipitation is produced in those areas. The air passing over the southern slopes of the Uinta Mountains (less than 8,000 feet) or over the Uinta Basin, descends in elevation. Clouds dissipate and no precipitation results even though there is still moisture in the air. The moisture that is carried downwind will be deposited as precipitation when it is condensed out by further lifting processes (i.e., when the air mass is lifted above 8,000 feet as it passes over the Rocky Mountains of Colorado).

The Effects of Storm Fronts

Large air masses tend to take on and retain certain characteristics for relatively long periods of time. Air masses which stagnate over polar ice and snow fields are usually very cold and dry. Air masses that travel long distances over warm oceans are usually warm and moist. A "storm front" occurs when a warm air mass is pushed against a cold air mass. The warm air mass slides up and over the cold air mass. As the air rises and cools, moisture condenses and clouds are formed. Further cooling and condensation results in precipitation. For these reasons, clouds and precipitation are associated with storm fronts.

Winter and spring storm fronts pass over the Uinta Mountains, the Wasatch Mountains or the high plateaus into the Uinta Basin on a regular basis. These fronts are affected by topography. To understand the linkage between frontal storms and topography, net lifting can be divided into two components: (1) lifting within the storm system (warm moist air being lifted as it moves upward over the cold air mass) and (2) lifting of the storm system itself as it moves upward over a mountain range (or subsidence, as it descends mountainous slopes).

A frontal storm moving toward the Basin will be lifted as it approaches the Wasatch Mountains. The topographic lift of the storm system enhances the frontal lift of the storm. This lifting intensifies the storm and increases precipitation on the windward side of the mountains. As the storm moves into the Uinta Basin, it descends the mountains and the descent of the storm system tends to counteract the frontal lift that occurs within the storm. At times, the descent of the storm system may be rapid enough to negate the lifting within the storm and little or no precipitation results. At other times the frontal lifting within the storm is rapid enough that the slow topographical descent as the storm system moves down-slope, counterbalances only a small part of the frontal lifting within the storm system. Under this situation, precipitation may be copious, even though it is slightly reduced from what it would be if there were no mountainous descent.

The Effects of Large-scale, Low Pressure Lifting

In the Northern Hemisphere, air rotates counter-clockwise and toward the center of low pressure air masses. As air converges in the low pressure center, it is forced upward and as the air is lifted it cools, clouds form and precipitation may occur.

Large-scale low pressure systems are sometimes known as "closed lows," "cold lows," and when elongated, as "troughs" or "troughs aloft." These systems are not stationary, but travel in a general easterly direction, being guided by large-scale, hemispheric flow patterns and jet stream winds. These low pressure systems may occur at any time, but are most frequent during the weather transition periods (spring or fall). The low pressure systems are large enough in scale to cover most of the state with clouds and precipitation.

Storms resulting from large-scale air masses tend to decrease in intensity as they travel from the north and northwest toward the southeast. Storms travelling from the southwest and south toward the northeast tend to intensify. As the storms intensify, more air mass lifting takes place and this lifting process results in more precipitation.

When these low pressure systems pass over Utah, they bring wide-scale lifting, cloudiness and precipitation. Low pressure systems of this nature which cross the Wasatch Mountains from the northwest lose some of their intensity as they move into the Uinta Basin. However, the low pressure systems that approach from the south or southwest generally intensify and produce more precipitation and storminess as they move over the Basin.

Storm fronts may be imbedded in a low pressure system and may add some local intensity to the large-scale storm. Topography may also influence the storm and result in local differences in precipitation as noted above.

The Effects of Subsidence

Subsidence is the opposite of lifting. When air subsides, it descends. As it descends, it warms and the warming makes it possible to hold more moisture. Although significant amounts of moisture may still be in the air, clouds evaporate and revert to the invisible water vapor form. Without the clouds there is no precipitation.

Subsidence occurs in high pressure air masses. A high pressure air mass or ridge condition dominates large sections of Utah most of the time. This condition brings dry, sunny days, clear skies and fair weather.

Snow and Precipitation Correlations

Correlations Among Snow Courses

Snow courses have been established in several strategically located mountainous areas to provide assistance in forecasting available water supply for the irrigation season. Accumulated snow is measured monthly in the late winter and early spring of each year and is reported as inches of water equivalent.

Snow course measurements are expensive and difficult to make. Snow courses are located to measure snow information that is unique to an area. When correlations are high between two snow course stations, snow course data from one area can be used to estimate the other area. Over the past 30 years, the numbers of snow courses have been reduced to a minimum. Correlations among the remaining snow courses are therefore quite low but do show some correlation tendencies.

Correlations (see Table 2) were calculated for April 1 snow water equivalent values for 3 snow courses in the Uinta Mountains and representative snow courses in other parts of the State of Utah. Results show minor correlation among the 3 snow courses in the Uinta Mountains and weaker correlations between the Uinta snow courses and snow courses located in other areas of the State.

Table 2. Snow Course Correlations for 1931-1979

Snow Course	Sage	Silvr	Ree's	Buck	Corrl	Donk	LS L	LS U	Lk Fk	Msby	Para
Northwest											
Sagebrush Flat	1.0										
Silver Lake Brighton	.148	1.0									
Southwest											
Ree's Flat	.078	.378	1.0								
South											
Buckboard Flat	.095	.186	.295	1.0							
Corral	.163	.445	.396	.533	1.0						
Donkey Reservoir	.103	.144	.190	.335	.341	1.0					
LaSal Mtn. (Lower)	.036	.220	.515	.615	.487	.435	1.0				
LaSal Mtn. (Upper)	.009	.272	.421	.661	.581	.367	.828	1.0			
Uinta Mountains											
Lakefork Mountain #1	.173	.613	.338	.186	.459	.148	.324	.200	1.0		
Mosby Mtn.	.070	.510	.258	.455	.559	.105	.262	.276	.738	1.0	
Paradise Park	.043	.486	.224	.384	.452	.158	.215	.255	.686	.805	1.0

Correlations Among Several Precipitation Stations

Precipitation stations are generally located in valleys and close to population centers. Unlike the high mountain snow courses, collection of precipitation information is relatively inexpensive and quite popular.

Daily precipitation data for the 1928 through 1987 period was obtained for 13 stations. Where missing data existed for one station, that period was removed for all stations. Thus, the data used for correlations among precipitation stations were for the same time period for all stations. The daily precipitation data were summed and combined into 10-day periods.

Precipitation station data in the Uinta Basin show some correlation, although a large part of the variability among stations is not explained by the correlations. There is a weaker correlation between the Uinta Basin stations and the stations south of the Basin. Almost no correlation exists between the Basin stations and the stations located along the Wasatch Mountains. A correlation matrix for the precipitation stations is presented in Table 3.

Table 3. Precipitation Station Correlations for 10-Day Periods, 1928-1987

Stations	Cor	Logn	SLC	Hebr	Fill	Milf	Parn	Han	Duc	Ft.D	Myt	Roos	Ver
Northwest													
Corinne	1.0												
Logan USU	.642	1.0											
Salt Lake City	.430	.057	1.0										
Heber	.386	.407	.371	1.0									
Southwest													
Fillmore	.213	.226	.270	.261	1.0								
Milford	.254	.160	.160	.195	.425	1.0							
Parowan	.082	.078	.117	.122	.309	.394	1.0						
South													
Hanksville	.028	.003	.021	.031	.093	.154	.193	1.0					
Uinta Basin													
Duchesne	.088	.051	.126	.205	.154	.202	.187	.233	1.0				
Ft. Duchesne	.083	.064	.111	.225	.183	.195	.172	.149	.530	1.0			
Myton	.081	.057	.100	.187	.144	.213	.186	.202	.651	.649	1.0		
Roosevelt	.084	.051	.112	.212	.179	.227	.170	.149	.660	.733	.751	1.0	
Vernal	.121	.095	.163	.257	.173	.150	.120	.099	.428	.582	.472	.561	1.0

Storm Climatology

Precipitation in an area depends upon the large-scale hemispheric wind flow patterns, storm dynamics and local terrain. Figure 5 is a schematic showing the relative importance of each precipitation factor.

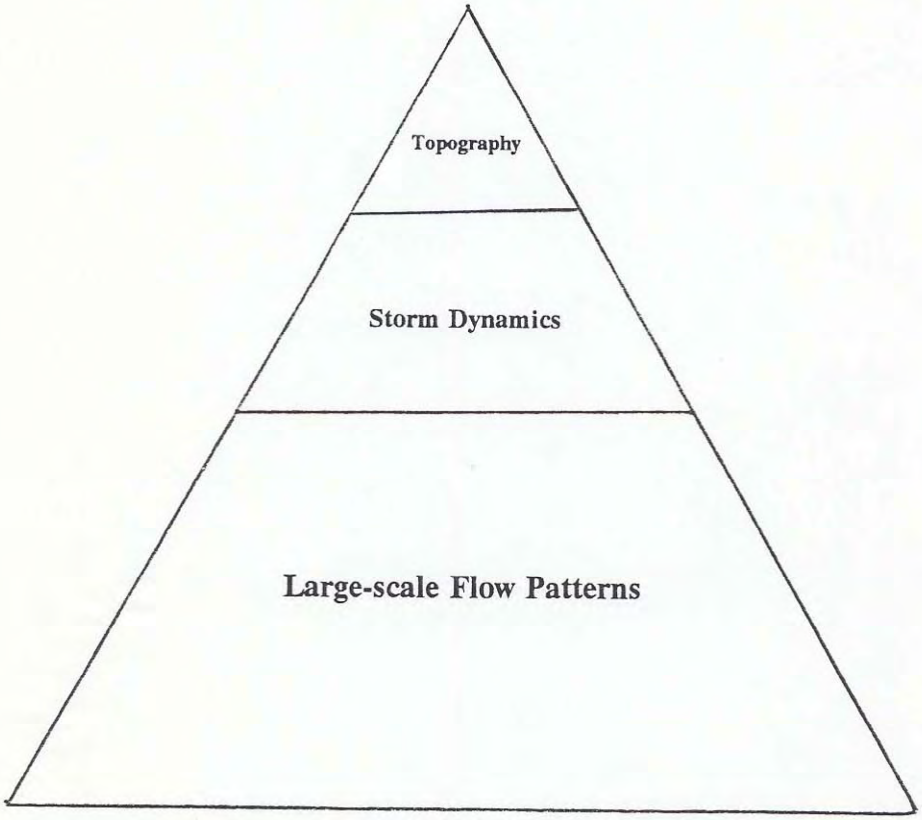


Figure 5. Schematic diagram showing relative importance of factors that result in precipitation

The large-scale hemispheric flow is the major factor that produced the deserts of the world located about 30 degrees north and south latitudes. It also interacts with other factors to produce the mild and wet climates around the earth. The large-scale flow associated with jet stream winds is the predominant factor that interacts with other atmospheric features and influences winter precipitation patterns in Utah. These patterns are large-scale guides to precipitation producing storms.

Figures 6 and 7 show schematics of general large-scale hemispheric flow over the Western United States. Figure 6 represents the type of large-scale flow that persisted during the wet, 1971-1975 and 1979-1988 winters. Figure 7 represents the large-scale flow patterns that persisted during the dry winters of 1976-1977 and 1989-1990.

Droughts and wet spells in the State of Utah are inter-related with events on a global scale. The position and movement of the Intertropical Convergence Zone (ITCZ), El Nino, ocean water surface

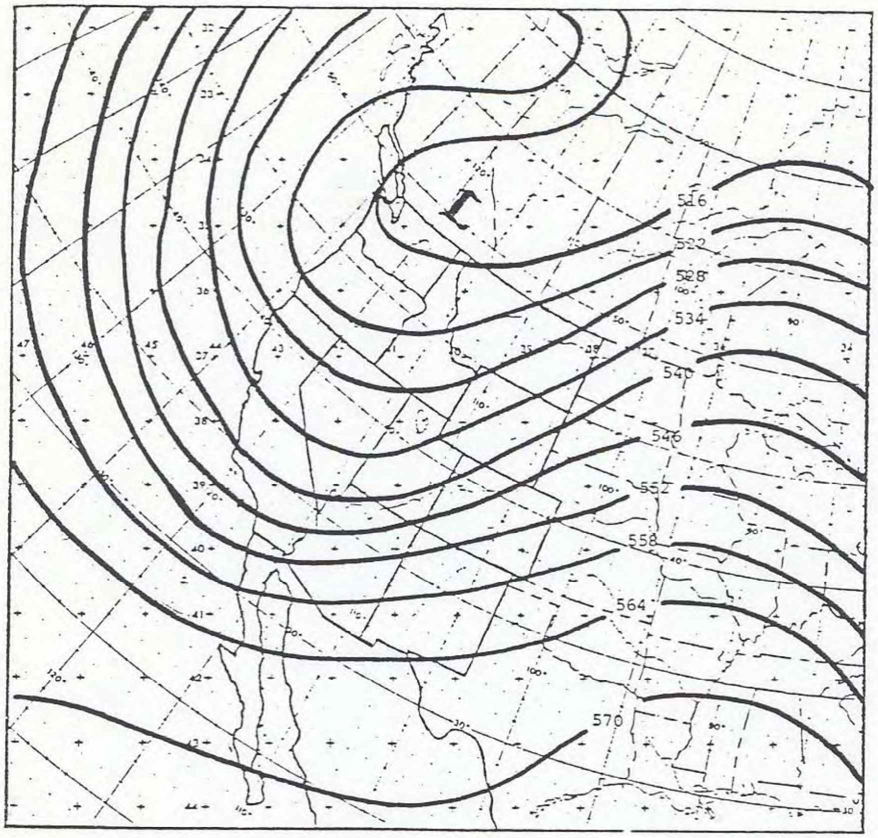


Figure 6. 500 mb Trough Flow Pattern Schematic

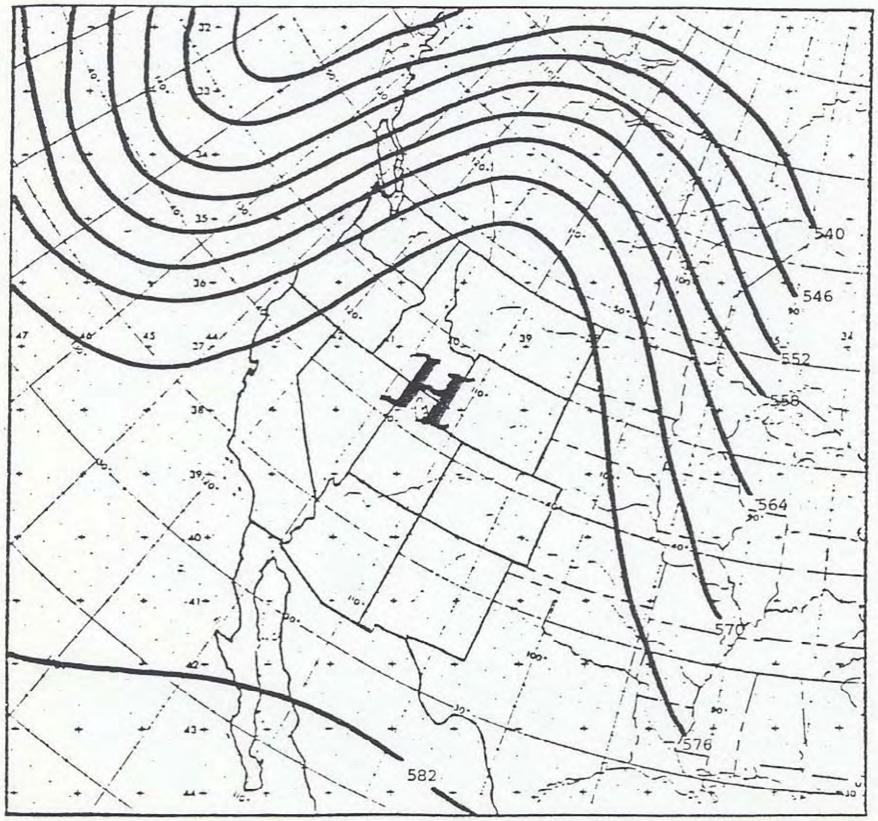


Figure 7. 500 mb Ridge Flow Pattern Schematic

temperatures, ocean currents, winds and atmospheric blocking patterns are only a few of the features that interact with weather and climate in Utah. These features provide guidance for storm systems that enter the State and control the speed and general makeup of the system.

Storm Classification

We evaluated methods of classifying storm types by the California Institute of Technology (1943); Williams and Peck (1962); the Western Region, National Weather Service (Rasch and MacDonald, 1975); and the Office of the State Climatologist, State of Colorado (1990).

Weather types shown in Elliott (1951) were developed after the California Institute of Technology system. They portray ten different weather types that affect Utah and neighboring states. Type Bn-c, which is included in our large-scale low pressure pattern shown in Figure 6, produces much below average temperatures and copious precipitation amounts through Utah and Colorado. Other storm types shown produce little to no precipitation for the Utah area, though their effect on temperature is varied.

To evaluate terrain influences in Utah, Williams and Peck (1962) classified storms in the Utah area as those having large-scale vertical motion ("cold lows"), cold frontal storms, storms with warm fronts over-running, and all other storms. They found that precipitation produced in storms with large-scale vertical motion has relatively little dependence on topographic lifting as compared to other storm types. The Williams and Peck study addressed only the Wasatch Front area because it is orthogonal to many general storm paths during the winter months. Storms classified by this system are included in the classifications in our study.

The State Climatologist for Colorado classified storms into seven types for the Western United States. These storm types fit well within the classification techniques noted above.

The Rasch and MacDonald technique was developed to increase ability to forecast probabilities of precipitation. This system classifies storms according to season and storm type. Ten storm types were classified for the winter and ten were classified for the spring season.

Using data provided in the Rasch and MacDonald study, we classified storms into four major types. The first type is a dry classification, placing the mean ridge position over the intermountain west as shown in Figure 7. The other three classifications fit within the large-scale low pressure pattern shown in Figure 6. These three general patterns are: 1) west through north flow; 2) southwest flow; and 3) southeast flow.

Using precipitation data and upper level flow patterns shown in Rasch and MacDonald (1975), there are 113 winter and 119 spring patterns that fit into the dry classification. Less than two percent of these 232 patterns produced precipitation. One storm produced precipitation in the Uinta Basin and 4 of the storms produced precipitation along the Wasatch Front.

For the west through north flow, 766 winter patterns and 247 spring patterns were evaluated. The combined 1,013 patterns produced precipitation only 58 times (6 percent) in the Uinta Basin. The Wasatch Front received precipitation 173 times (17 percent) from the storm patterns.

The southwest flow pattern, which included cut-off low pressure systems and split flow patterns, occurred in 440 winter patterns and in 756 spring patterns. The 1,196 patterns produced precipitation 192 times (16 percent) in the Uinta Basin and 329 times (28 percent) along the Wasatch Front.

The southeast flow occurred only 4 times. This flow pattern produced precipitation each time (100 percent) in the Uinta Basin and produced precipitation only once along the Wasatch Front (25 percent). It is significant to note that this type of storm pattern which was favorable to the Uinta Basin occurred only 4 times in the 2,441 events studied.

Of the 2,441 storms examined, 251 (10 percent) produced precipitation in the Uinta Basin and 506 (21 percent) produced precipitation along the Wasatch Front (i.e., twice as many storms produced precipitation along the Wasatch Front as in the Uinta Basin). This ratio is verified another way by comparing the same two areas on the annual normal precipitation map (Figure 3) and noting that the Wasatch Front receives about twice the annual normal precipitation as does the Uinta Basin. These values also verify the schematic of the influence of the large-scale flow patterns and storm dynamics shown in Figure 7 above.

Present Water Deficit

A water deficit or drought is normally perceived in terms of its problems and impacts. Generally, drought is spoken of as a function of one or a combination of many variables. These data may range between specific point measurements and averages of data for large areas. Variables that have historically been used to measure drought include radiation, precipitation, evapotranspiration, effective precipitation, stream flow, tree rings, varves, natural storage, artificial storage, and economic, social and psychological indicators.

In Utah, any one or a combination of these variables may be used to describe conditions in and around a drought stricken area (Jensen, 1978). One water deficit indicator is the Palmer Drought Index (Palmer, 1965). This drought indicator is a function of meteorological parameters and soil moisture. This index is the most accepted drought indicator in the United States and much of the world (Orville, 1990). Although it does not address many of the water deficit parameters in Utah, it is a good objective indicator of the general status of drought. It has been used in this study to show the relation of the present water deficit in the State with past wet and dry periods.

Both the Department of Agriculture and the National Weather Service have used the terms "mild," "moderate," " severe" and "extreme" to describe droughts. The severity of drought is a function of both the value of z, (short-term severity index) and also of the duration of the drought, because a drought situation tends to deteriorate with time. The Palmer Drought Severity Index (PDSI) is a long-term index. Its value, X, is given by the equation

$$X_i=\sum_{t=1}^{i} \frac{z_t}{0.309t+2.691}$$

where t is time in months. Palmer assigned values of X to different categories of drought, listed in Table 5. These values may be used to determine the start and finish of a drought and its severity at any time during its occurrence.

Table 5. **Classes for wet and dry periods of drought (after Palmer, 1965)**

Monthly Index Value	Class
More than 4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
Less than -4.00	Extreme drought

Drought Severity

Drought Severity is indicated by the length-of-time the drought continues, the water deficit (shown as negative PDSI index values) and by the areal extent of the drought conditions.

The PDSI for the Uinta Basin Climatological Division is presented in Figure 8 for the period 1895 through July of 1990. Figures for Utah's other climatological divisions can be found in Appendix A. These figures graphically show several droughts that have affected the Utah area.

It is of interest to examine drought conditions in the Uinta Basin for the period 1895-1990, in terms of length-of-drought and water deficit (negative values). The drought of 1899 through 1906 appears to be the most severe, lasting 7 years with index values as low as -5 in 1900. The early 1930's showed drought conditions in the Basin as did the 1953-1965 period and the mid-1970's.

The period 1979 through 1988, with the exception of a 3-month moderate drought during the summer of 1981, has been near normal to very wet. With the lack of fall and early winter snow in October 1988, the Uinta Basin fell into a moderate drought. By March and April of 1989, the Basin began to feel the effects of severe drought. That drought continues through the fall of 1990.

The indication of the severity of drought is also reflected by the length-of-time the area continues in drought conditions. That is, the longer the drought conditions persist, the more precipitation is required to pull the area out of drought. Table 6, calculated for September 1990, shows the precipitation necessary to return each climatic division to near normal conditions.

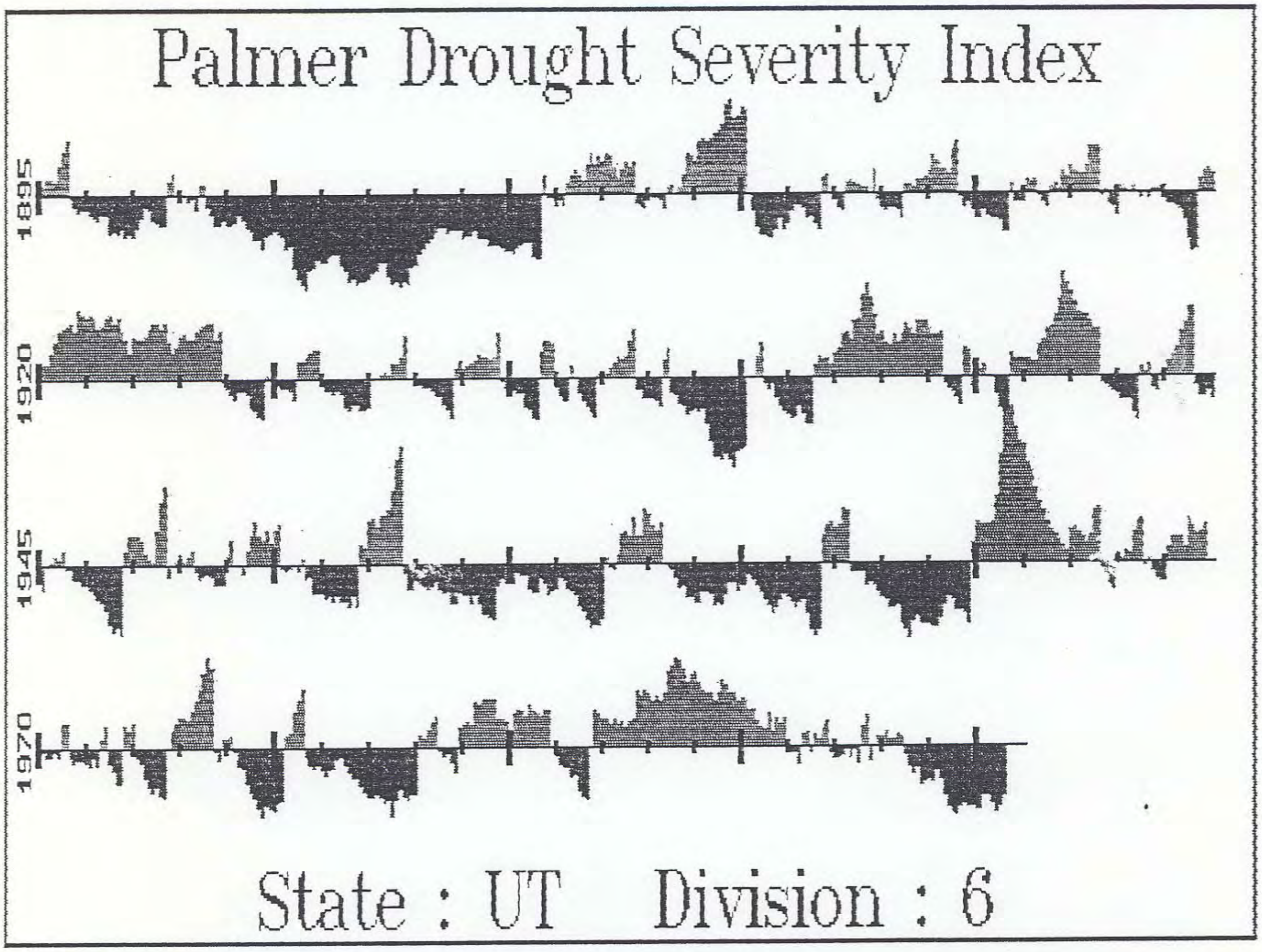


Figure 8. Palmer Drought Severity Index for the Uinta Basin Climate Division, 1895-1990.

Table 6. Precipitation Necessary at the end of September 1990, to Bring Palmer Drought Severity Index Near Normal

	Precipitation needed to reduce PDSI to near normal in				
Division	1 month	2 months	3 months	6 months	1 year
Western	4.92	5.11	5.33	6.96	11.16
Dixie	5.82	6.69	7.43	11.04	14.90
No. Central	10.06	10.49	11.49	14.98	21.45
So. Central	7.23	7.65	8.22	10.97	16.23
No. Mountains	5.28	6.57	8.47	13.76	20.42
Uinta Basin	4.48	4.42	4.79	5.70	10.01
Southeast	5.58	5.54	5.85	7.03	11.29

Normal precipitation (1951-1980) for the Basin is 7.83 inches and the 12-month requirement to return the Basin to normal is 10.01 inches. The amount of precipitation necessary to fill the drought requirement is the difference, or 2.18 inches for the year. This can be compared to the deficit of 1.86 inches during the recent drought in 1977, the 2.61 inch deficit in 1935 and the 2.90 inch deficit in 1900.

Figures 9 and 10 show the areal extent of drought in the Western United States. It is obvious that drought conditions are wide-spread and reflect the large-scale weather pattern that has dominated the West for the past two years.

In the Uinta Basin, drought conditions are forestalled by two factors. The first is the amount of snow received in the mountains during winter months and available as snowmelt runoff during the Spring and early Summer months. In this particular drought, even the mountains are suffering from severe to extreme drought conditions, as are other areas in the State.

The second is the extensive reservoir and water distribution system in the Basin that collect water during periods of high flow and, through a complex management system, augment low flows. Through these processes the severity of drought is mitigated for at least a year, and with careful management, additional years. The PDSI considers only meteorological conditions and not reservoir or management decisions.

Orographic Precipitation Model Verification Study

One objective of this study is to show the effect the topography of the Uinta Basin on storm systems that approach the Basin from several different directions. In addition to empirical studies of storm systems, the orographic precipitation model developed by J. Owen Rhea (1978) was used to determine precipitation patterns from various wind trajectories. The resulting precipitation patterns

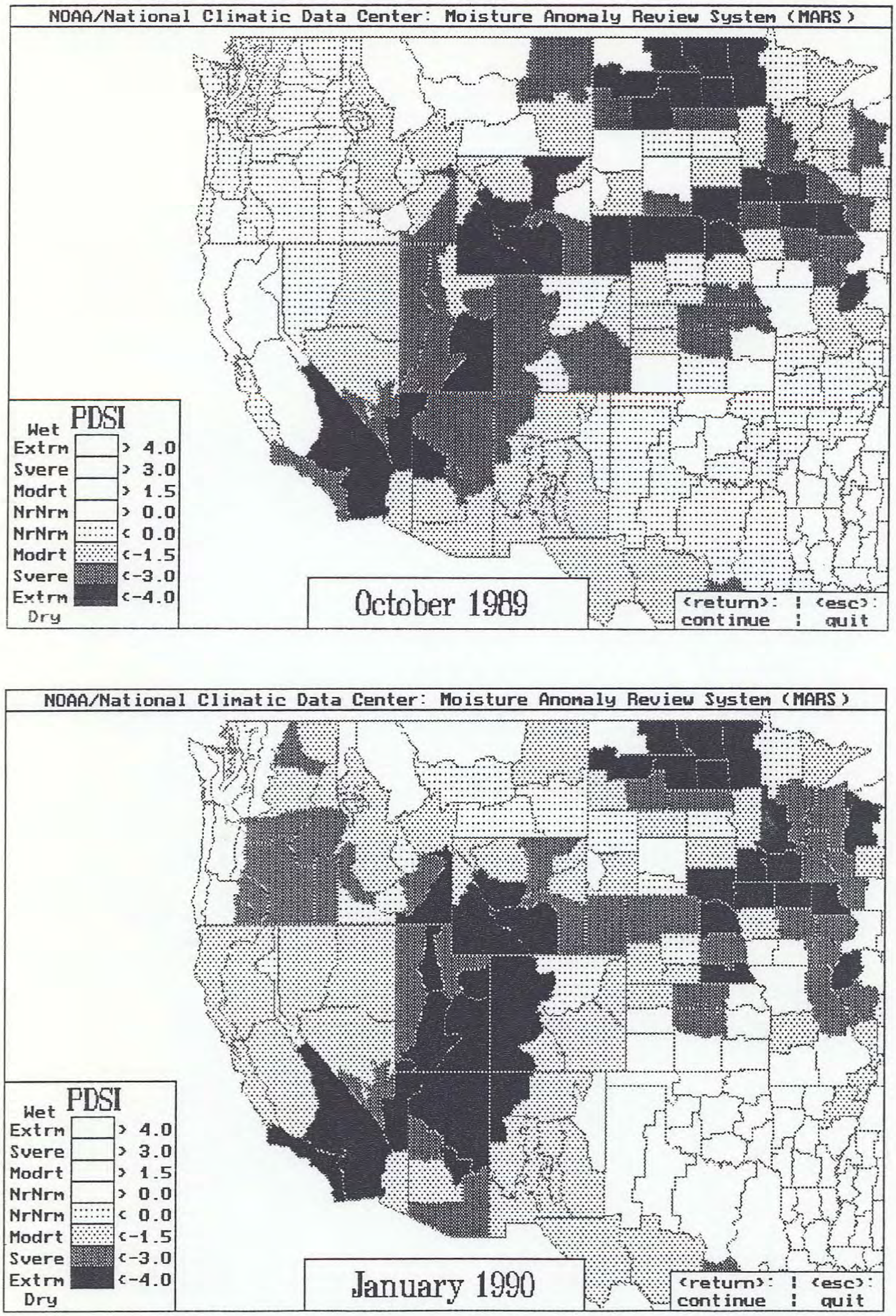
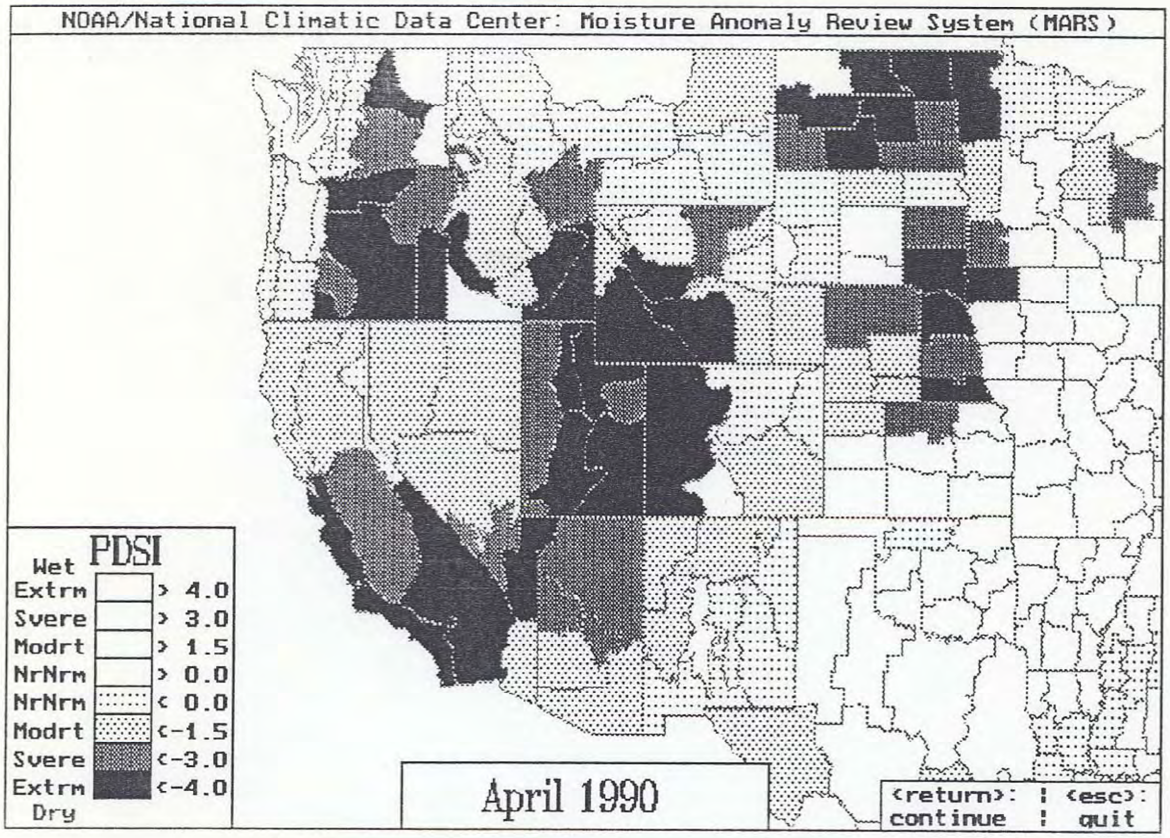


Figure 9. Spatial Distribution of Palmer Drought Severity Index for the Western United States (October 1989 and January 1990)



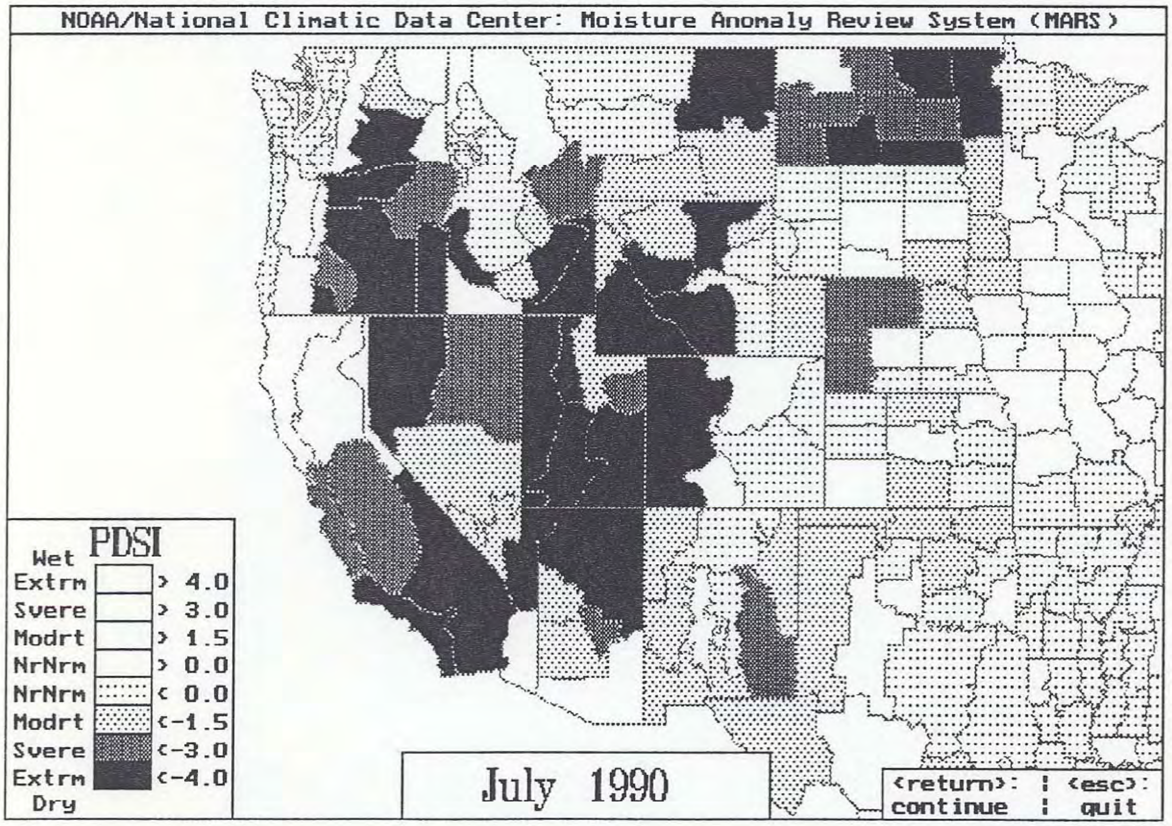


Figure 10. Spatial Distribution of Palmer Drought Severity Index for the Western United States (April 1990 and July 1990).

show the amounts and the locations where precipitation will tend to fall given specific wind trajectories and topography.

Another objective of the study was to provide a spatial representation of the convection/orographic ratio for the mountain areas. In this study the convection component was held constant. The spatial distribution of the orographic component is shown as isohyet contours for equal precipitation values mapped from a 10 by 10 kilometer grid for eight points of the compass.

Model Components

The Rhea model simplifies atmospheric dynamics and lumps precipitation causes into three categories. The first is large-scale vertical motion (large-scale low pressure lifting or high pressure subsidence), the second is convective motion and the third is the orographic component (lifting and descent associated with air passing over mountains and plateaus). This study held the large-scale vertical motion and convective motion parameters constant. The orographic component was evaluated by varying wind directions and computing resulting precipitation patterns and point precipitation amounts.

Model Initialization

To evaluate the effect of topography on atmospheric motion, topography was set up on a 10 kilometer grid having 51 rows and 48 columns. The grid center was at 40 degrees north Latitude and 111.5 degrees west Longitude, near Thistle, Utah. Terrain values (elevations) were derived from a digital terrain data set. A plot of 1,000 foot contour intervals is presented in Figure 11. The overlay found on the back cover may be used for orientation. The projection is a tangential plane with radial distances determined by great circle navigation.

Upper air data were based on the upper air sounding station at Salt Lake City, Utah. Other stations located at Lander, Wyoming; Denver, Colorado; Desert Rock, Nevada; and Winslow, Arizona, were considered but not used because of their distance and direction from the Basin.

Problems

The Rhea model does have some inherent problems. Some of the problems we dealt with in the model resulted from the use of the 10 kilometer grid spacing. The large grid spacing tended to smooth areas in mountainous terrain that would have been better served by a more dense grid. It is our understanding that the model will operate with a 2.5 kilometer grid spacing. At this time we are not, however, equipped to operate a grid of that density.

There were four major problems encountered in using the Rhea model for this study. Underestimation of point data in a low area surrounded by higher ridges is probably the result of the sparse grid. Underestimation of calculated precipitation data for isolated peaks and terrain funneling are also probably associated the grid density. Underestimation of precipitation for ridges aligned with wind vectors may or may not be associated with the grid density. Underestimation of precipitation data when using observed winds that were light and variable was also a weakness of the model.

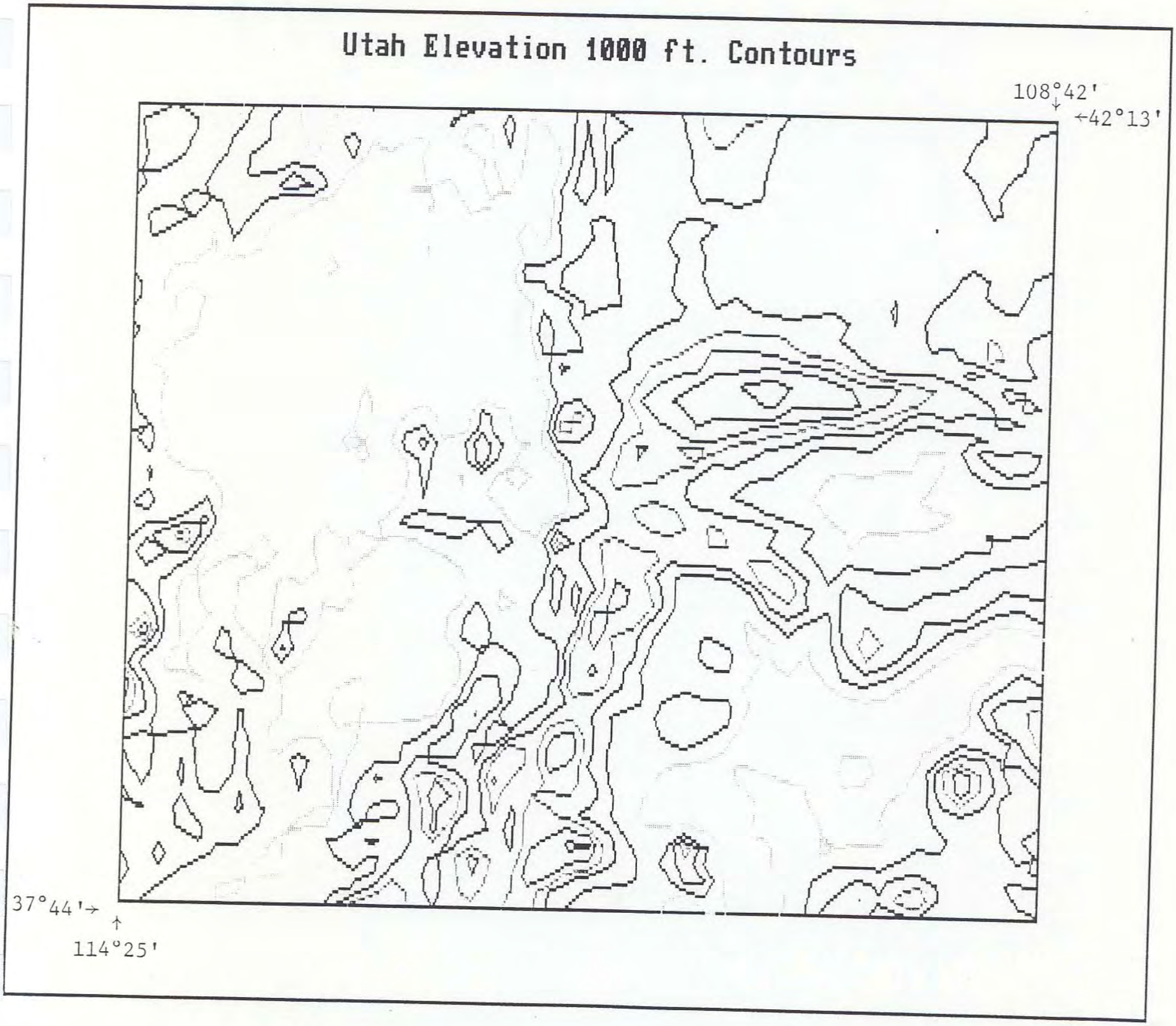


Figure 11. 1000 Foot Elevation Contours from Terrain Grid.

Orographic Precipitation Model Results

The Rhea model, using only the orographic component, was calibrated using upper air data and precipitation amounts from winter and spring storms of 1984. During this very wet period, the level of the Great Salt Lake was rising and all forms of weather modification in the Utah mountains had ceased. As far as we could determine, the storms were uncontaminated by man's intervention.

To show the effects of topography, various wind directions and resulting precipitation patterns, all parameters of the calibrated model were held constant and the model wind component was varied. This study produced 36 precipitation patterns for successive 10 degree increments. Orographic precipitation patterns for wind trajectories from the northwest and southwest are shown in Figure 12. Resulting calculated 12-hour precipitation amounts for several stations are also included in Table 7 for quantitative comparison. Patterns for the north, northeast, east, southeast and south are shown in Appendix B. An overlay with State and County boundaries is attached to the back cover so that precipitation patterns in Appendix B may be properly oriented.

Evaluation of the precipitation patterns and the point precipitation amounts verify that the Uinta Basin receives most of its topography related precipitation from storms from the southwest through southeast. Evaluations also verify that storms from other directions, particularly the west and northwest, result in little precipitation in the Basin.

Summary and Conclusions

There has been concern that winter precipitation augmentation projects along the Wasatch Front have depleted the amount of precipitation in the Uinta Basin. In agreement with the Division of Water Resources, State of Utah, the climatology of winter storms in the Uinta Basin was evaluated. Several winter storm types were studied. It was shown that winter and spring storms that produce precipitation in the Uinta Basin and on the southern slopes of the Uinta Mountains have southerly wind trajectories. Precipitation along the Wasatch Front is generally produced by storms with a westerly or northwesterly wind flow pattern. It was also shown that large-scale atmospheric conditions are inter-related with wet and dry periods and are very significant in determining wet and dry periods in the Western United States.

Correlations of precipitation stations and snow courses in the Uinta Basin and in other areas of Utah showed that when stations in southern Utah received precipitation, the Uinta Basin was also likely to receive precipitation. Storms from the southwest through southeast are therefore likely to produce precipitation for the Basin. There was no correlation between the stations along the Wasatch Front and those in the Uinta Basin. Storms from the west or northwest are not as likely to produce precipitation for the Basin.

The lifting caused by mountains and subsequent subsidence on the lee side is responsible for precipitation distribution patterns. The west through northwest storm trajectories favor precipitation along the Wasatch Front. Southerly storm trajectories favor precipitation in the Uinta Mountains.

Cyclonic, large-scale storms provide the lifting mechanism that produces general precipitation regardless of terrain features. These storms tend to diminish in intensity as they move from the north and northwest toward the southeast. Storms which move from the southwest and south toward the northeast tend to intensify.

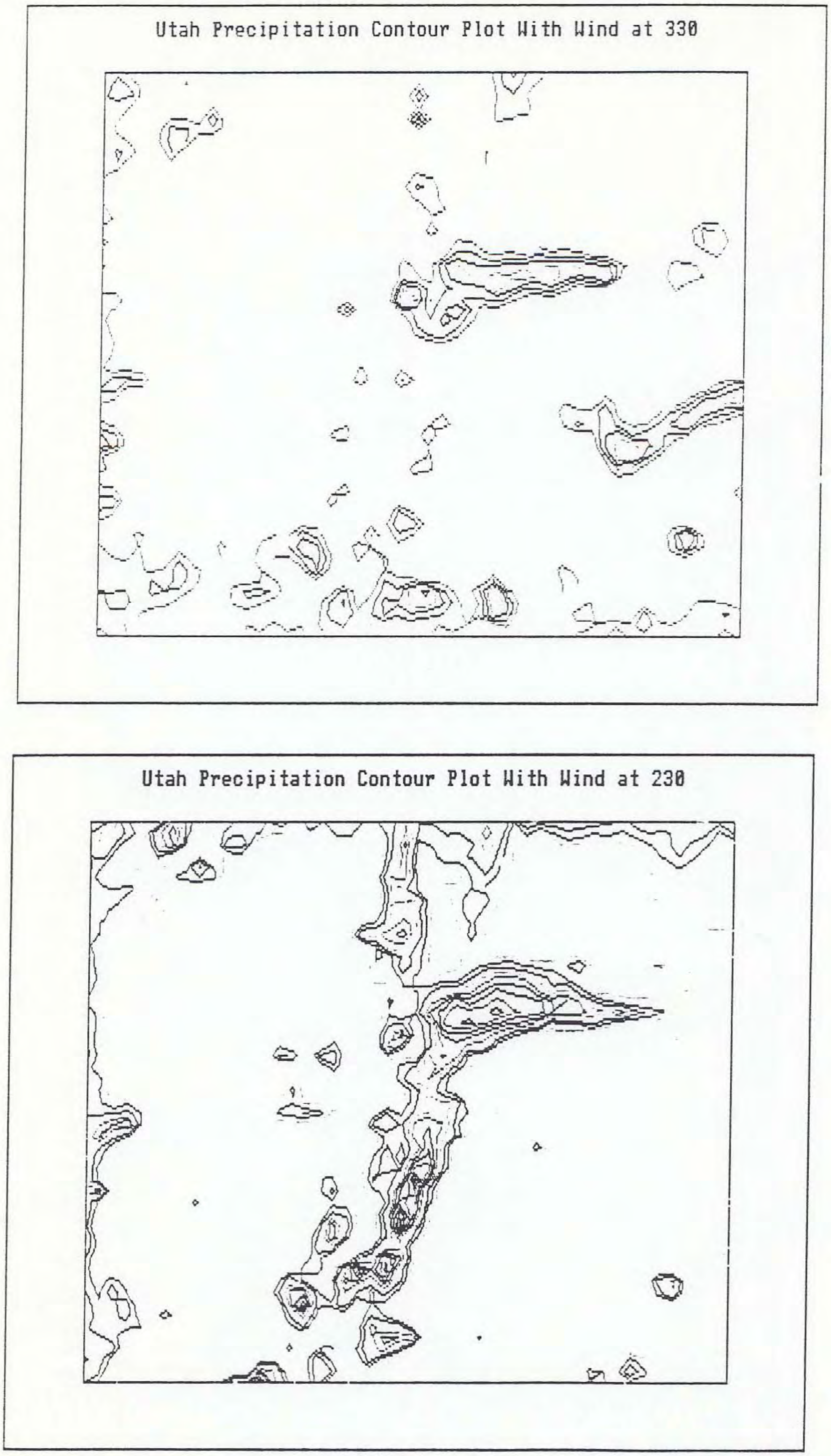


Figure 12. Orographic precipitation patterns for wind trajectories from the northwest and southwest.

Table 7. Synthetic Precipitation 12 Hour Amounts (inches) from Orographic Precipitation Model.

	WIND DIRECTION							
Station	N	NE	E	SE	S	SW	W	NW
ALLENS RANCH	.00	.00	.00	.03	.00	.00	.00	.00
ALTA	.00	.00	.04	.16	.13	.57	.02	.29
ALTAMONT	.33	.24	.05	.02	.00	.00	.00	.00
BEAVER CANYON PH	.00	.00	.00	.00	.00	.01	.00	.00
BRIGHAM WASTE PLT	.34	.13	.21	.03	1.70	.78	.81	.04
BONANZA	.00	.00	.00	.11	.00	.00	.00	.00
CITY CREEK WATER PLT	.00	.00	.00	.00	.00	.25	.00	.00
COALVILLE	.45	.64	.52	.00	.00	.00	.21	.27
CORINNE	.05	.09	.11	.08	.79	.16	.02	.00
COTTONWOOD WEIR	.00	.00	.00	.00	.00	.26	.18	.08
CUTLER DAM UP&L	.19	.00	.13	.00	.17	.34	.15	.00
DEER CREEK DAM	.00	.00	.12	.00	.26	.97	.37	.29
DELTA	.00	.00	.00	.00	.00	.00	.00	.00
DINOSAUR QUARRY	.02	.65	.16	.28	.00	.00	.00	.00
DUCHESNE	.02	.02	.24	.00	.00	.00	.00	.00
ECHO DAM	.54	.54	.80	.00	.00	.07	.47	.33
ELECTRIC LAKE UP&L	.13	.35	.09	.00	.37	1.00	.66	.36
FARMINGTON USU FIELD	.00	.00	.00	.00	.00	.15	.00	.00
FLAMING GORGE	.00	.00	.01	.00	.00	.00	.00	.02
FORT DUCHESNE	.00	.00	.00	.00	.00	.00	.00	.00
GREEN RIVER AVN	.00	.00	.05	.11	.57	.02	.09	.00
HEBER	.30	.38	.61	.13	.59	.89	.80	.17
JENSEN	.00	.35	.00	.47	.00	.00	.00	.00
LOGAN UTAH STATE UNI	.03	.22	.57	.43	.00	.40	.04	.00
MAESER 9 NW	.00	.01	.06	.35	.00	.00	.00	.00
MANILA	.00	.00	.07	.00	.00	.00	.00	.30
MORGAN	.01	.03	.70	.09	.38	1.34	.17	.00
MOUNTAIN DELL DAM	.00	.00	.00	.00	.00	.32	.00	.06
MYTON	.00	.00	.00	.00	.00	.00	.00	.00
NEOLA	.00	.00	.08	.20	.00	.00	.00	.00
NUTTERS RANCH	.00	.00	.00	.00	.00	.00	.00	.00
OGDEN PIONEER PH	.00	.00	.00	.00	.03	.03	.00	.02
OGDEN SUGAR FACTORY	.00	.00	.00	.00	.00	.00	.00	.14
OURAY 4NE	.00	.00	.00	.00	.00	.00	.00	.00
RANDOLPH	.00	.00	.00	.00	.00	.00	.00	.00
RICHMOND	.23	.73	.44	1.36	.21	.54	.65	.13
RIVERDALE	.00	.00	.00	.00	.01	.00	.00	.07
ROOSEVELT	.00	.00	.00	.00	.00	.00	.00	.00
SCOFIELD DAM	.18	.08	.55	.00	.00	.25	.60	.67
SLC NWSFO AP R	.00	.00	.00	.00	.09	.25	.00	.00
SILVER LAKE BRIGHTON	.00	.00	.07	.26	.26	.86	.09	.16
SNAKE CREEK P H	.06	.20	.41	.26	.37	.96	.25	.05
TRENTON	.01	.04	.17	.79	.53	.71	.14	.02
UINTALANDS	.02	.00	.00	.00	.00	.00	.00	.00
VERNAL AIRPORT	.00	.20	.01	.43	.00	.00	.00	.00
WANSHIP DAM	.28	.66	.27	.00	.00	.41	.22	.71
WEBER BASIN PUMP PL	.00	.00	.00	.00	.00	.08	.00	.00
WOODRUFF	.06	.00	.00	.00	.00	.00	.00	.00

The study noted that wet and dry periods in Utah and the Uinta Basin are inter-connected with large-scale atmospheric conditions. Storm types developed from upper level wind flow patterns show that Utah receives almost no precipitation when a ridge position is located over the intermountain west. Storms that approach Utah from the west through north, produce precipitation about 17 percent of the time along the Wasatch Front and about 6 percent of the time in the Uinta Basin. Storms from the southwest produce more precipitation, about 28 percent of the time, along the Wasatch and 16 percent of the time in the Uinta Basin. Storms from the southeast produce almost no precipitation along the Wasatch. These storms produce precipitation in the Uinta Basin, and of the patterns studied, they produced precipitation 100 percent of the time in the Basin.

Historical graphs of drought indices were presented to show the relation of the present drought to past occurrences. These show that Utah, the Uinta Basin and much of the Western United States have been suffering from water shortages for a long period of time.

A winter regime, orographic precipitation computer model was calibrated for the winter and spring storms of 1984. During that season no precipitation augmentation projects were active. Depth-area isohyetal patterns were developed which show the spatial distribution of precipitation for various wind flow trajectories. These distributions verified that the Uinta Basin receives the major amount of its winter precipitation from storms from southerly directions.

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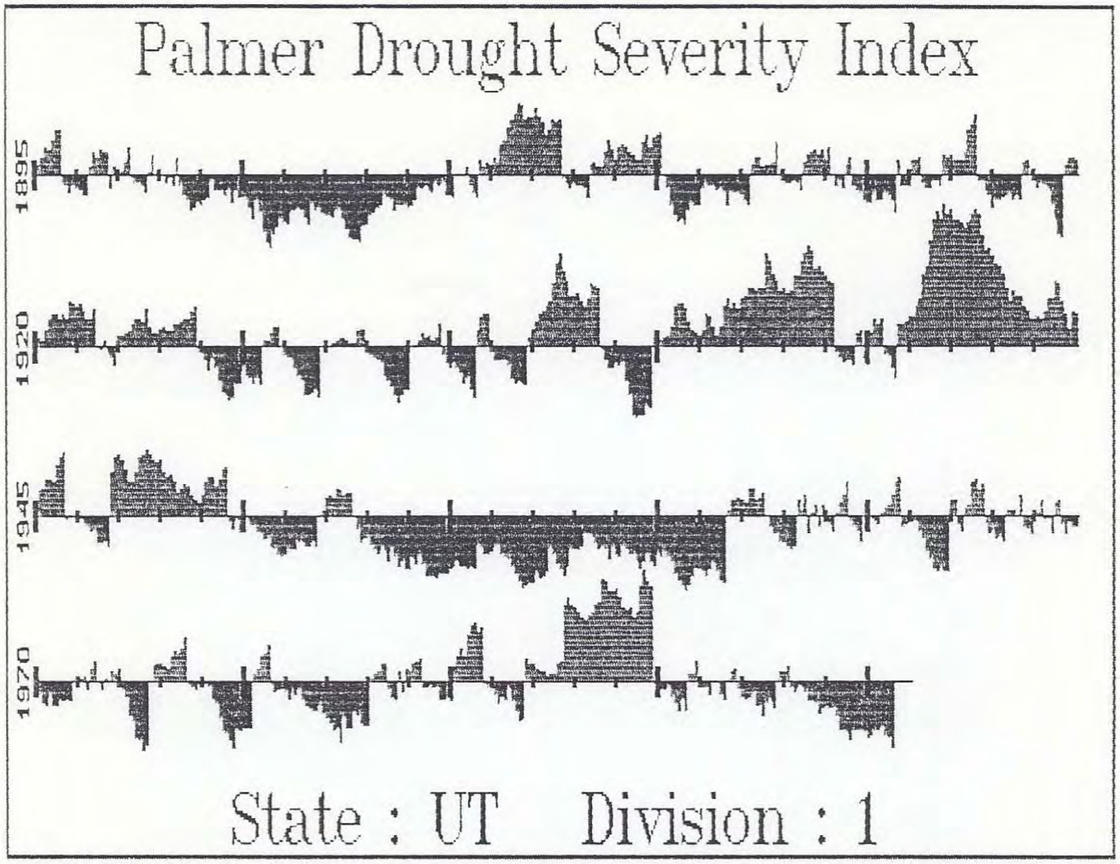
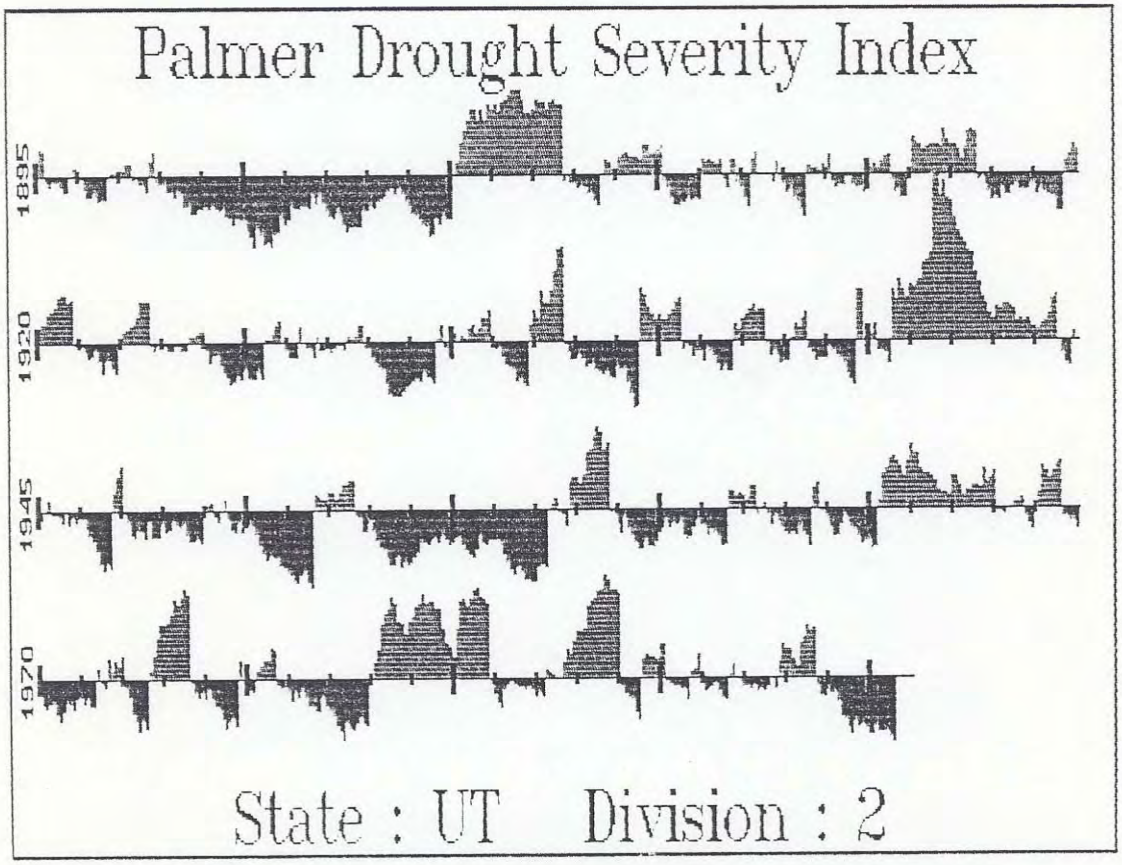
APPENDICES

Appendix A

Palmer Drought Severity Index Information



Division 1: Western



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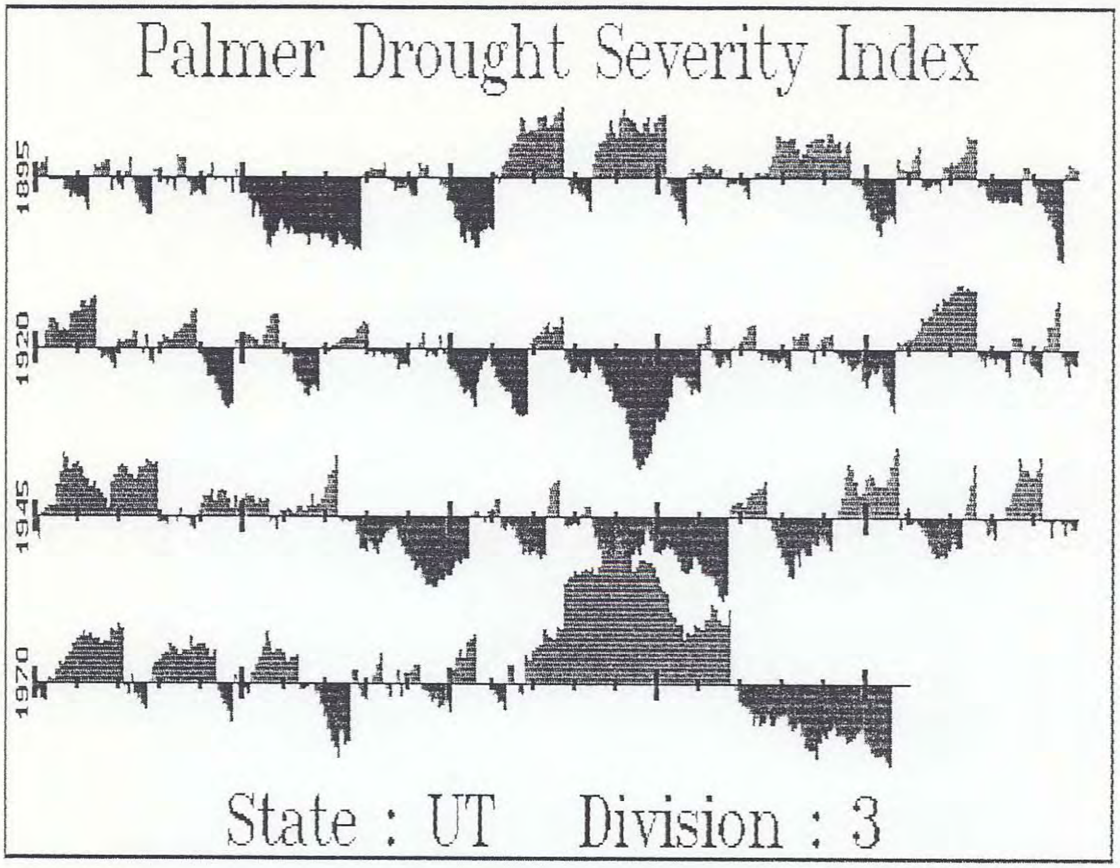

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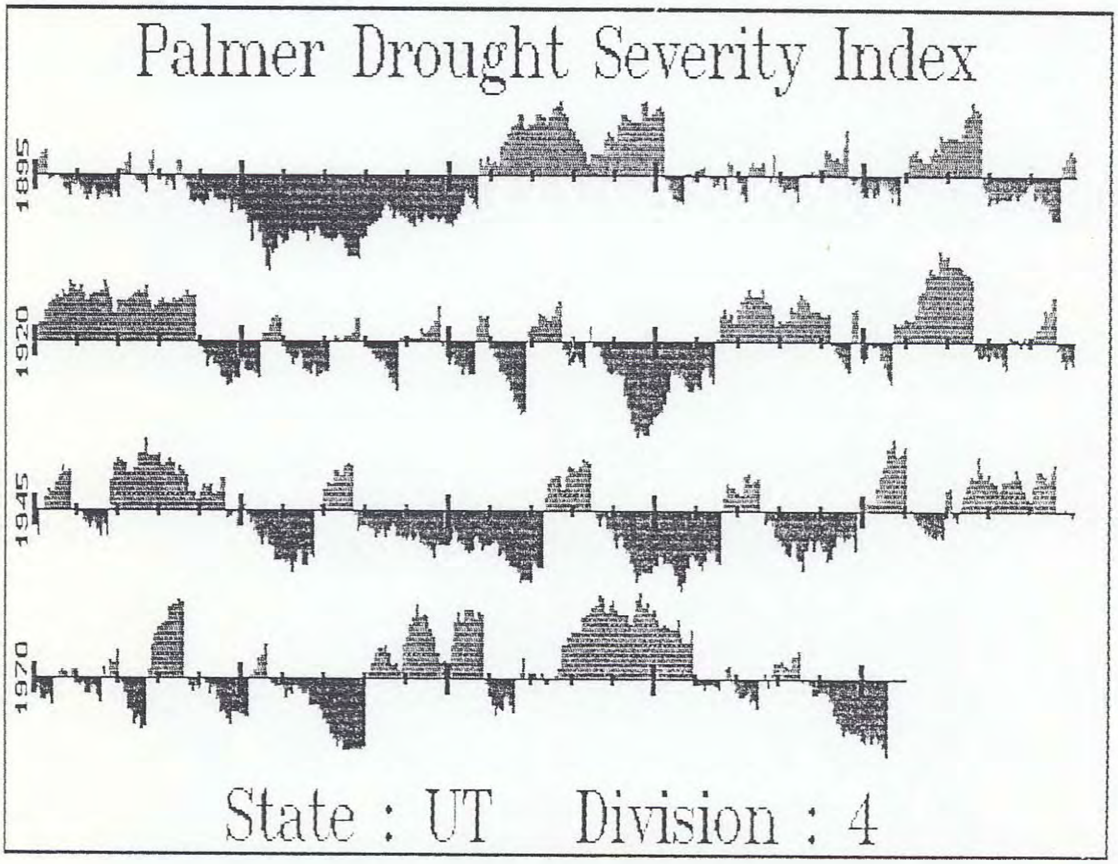

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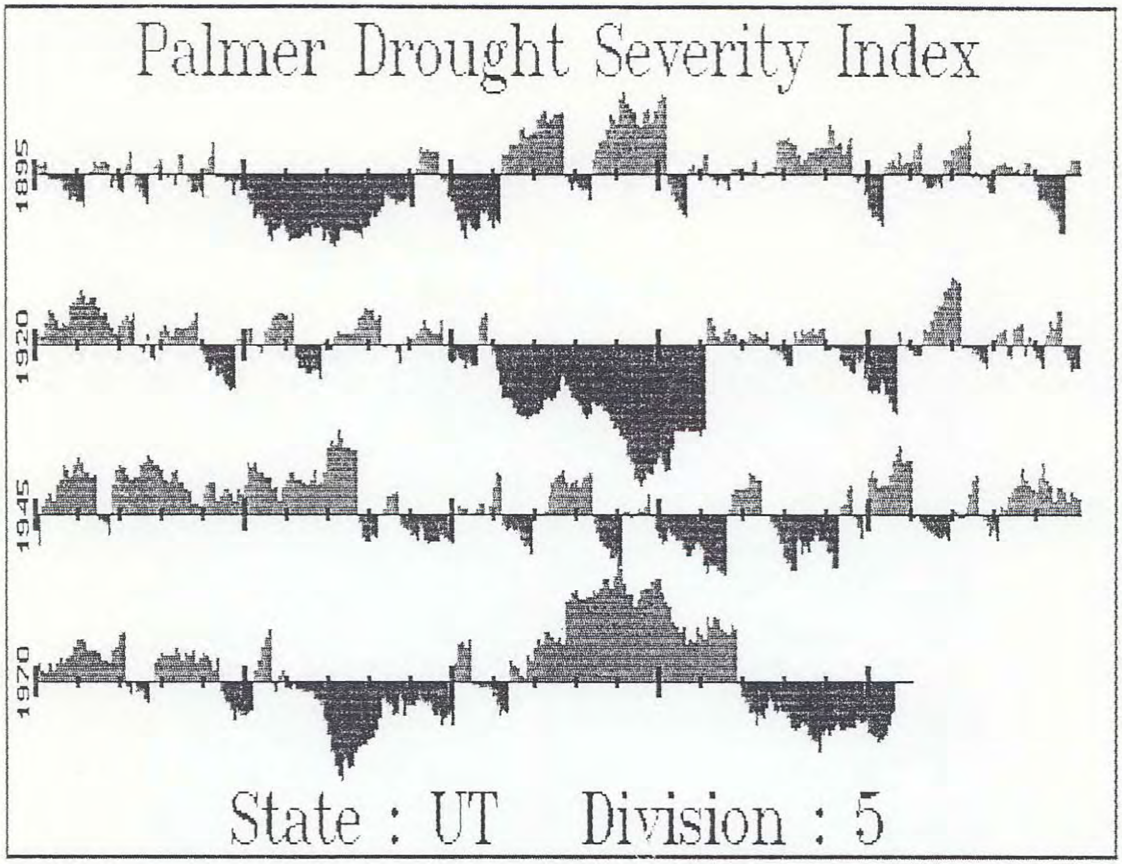

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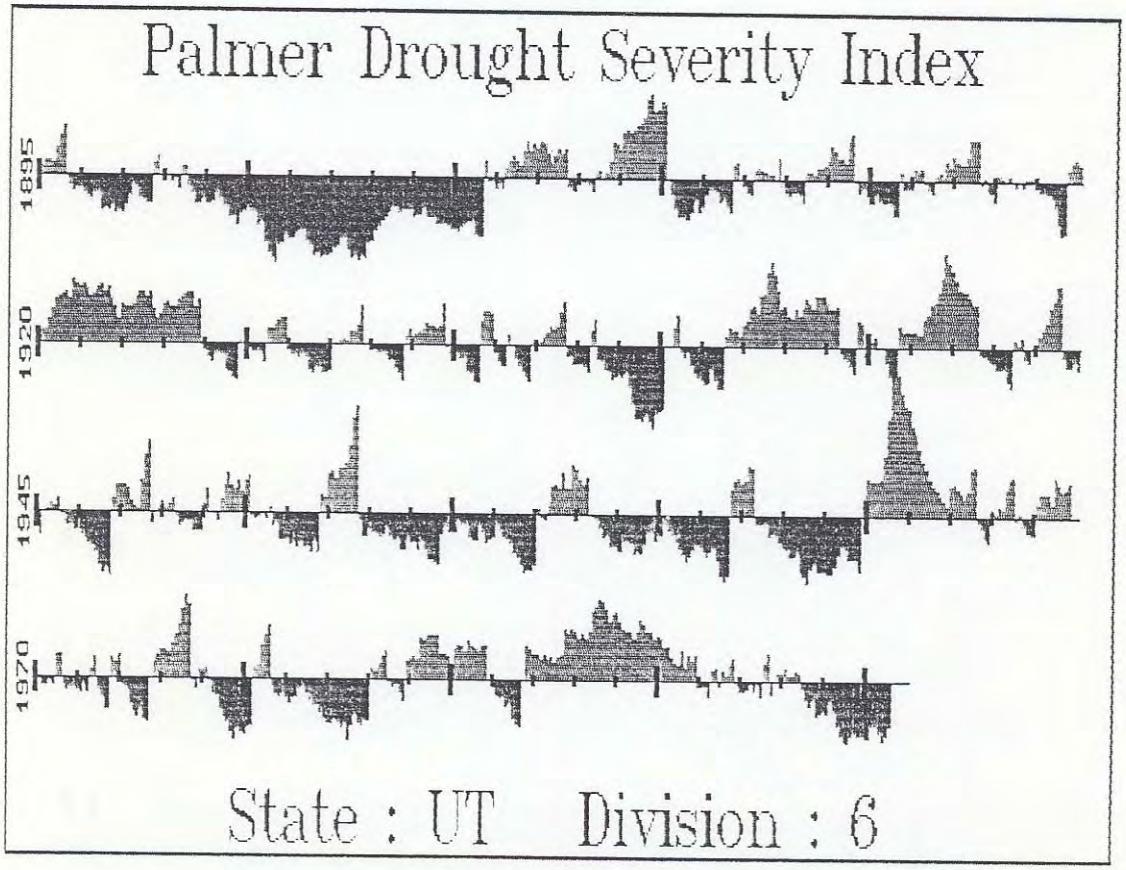
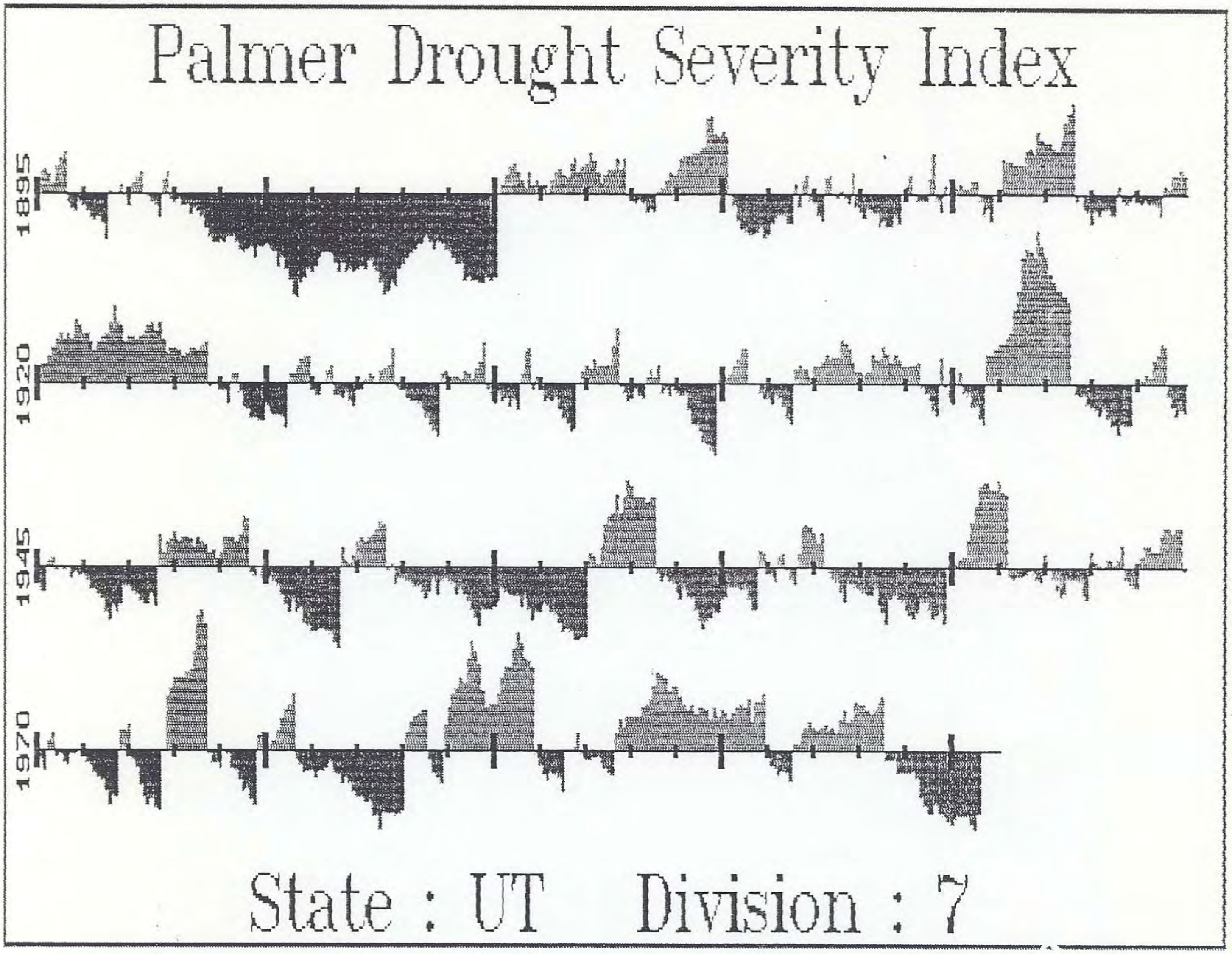


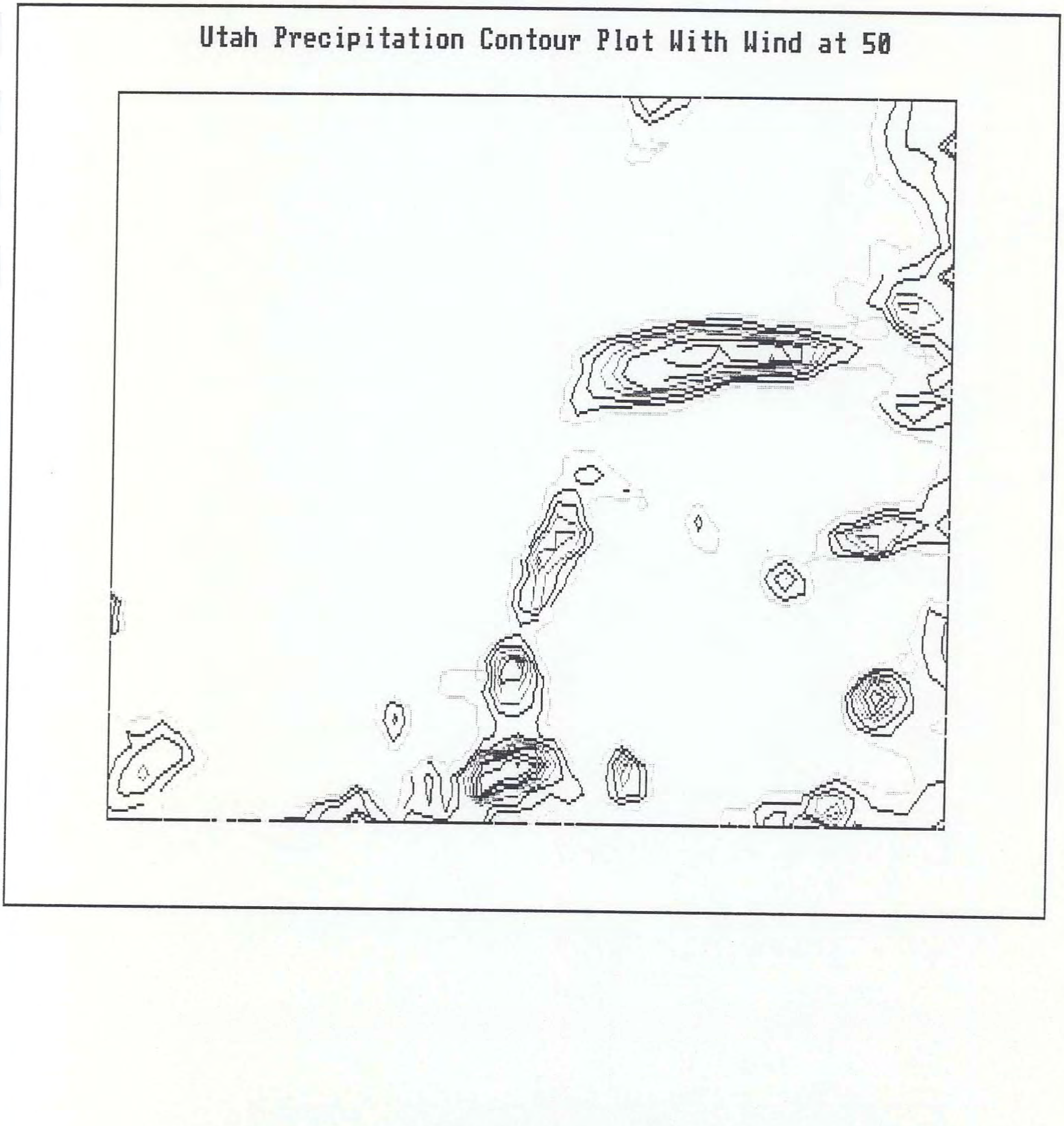
Division 6: Uinta Basin



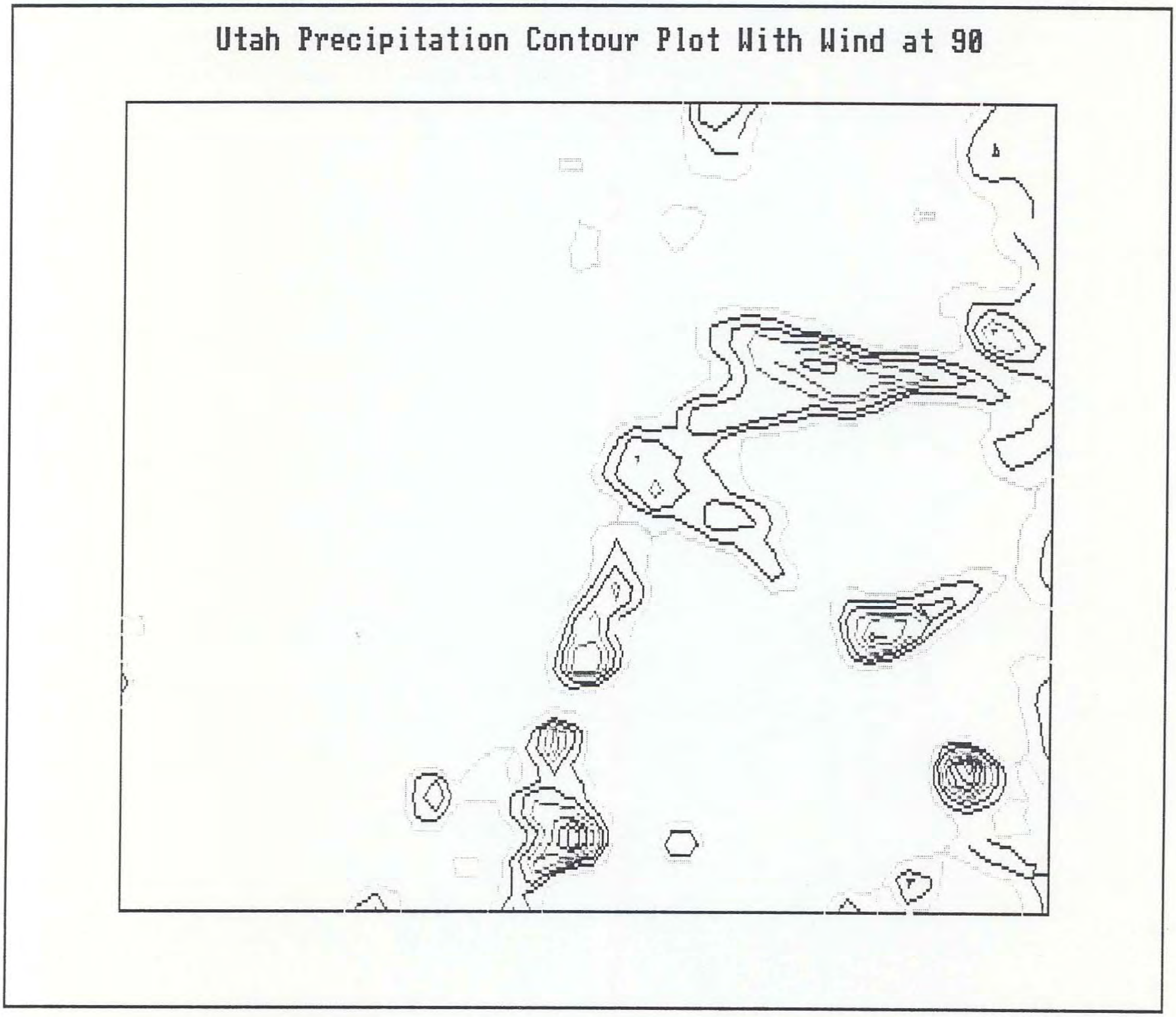
Division 7: South East

Appendix B

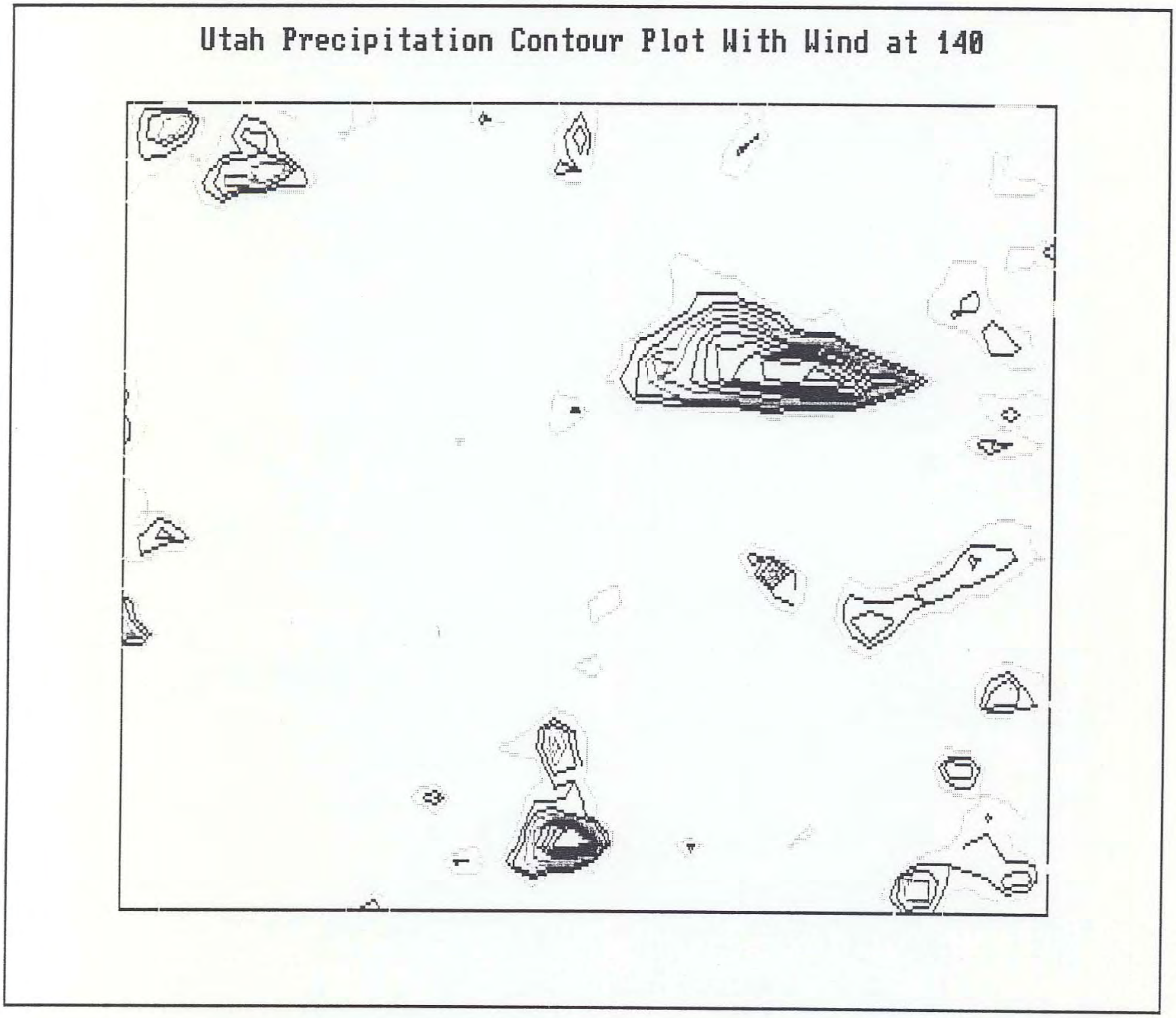
Orographic Precipitation Distributions for 6 Wind Flow Patterns



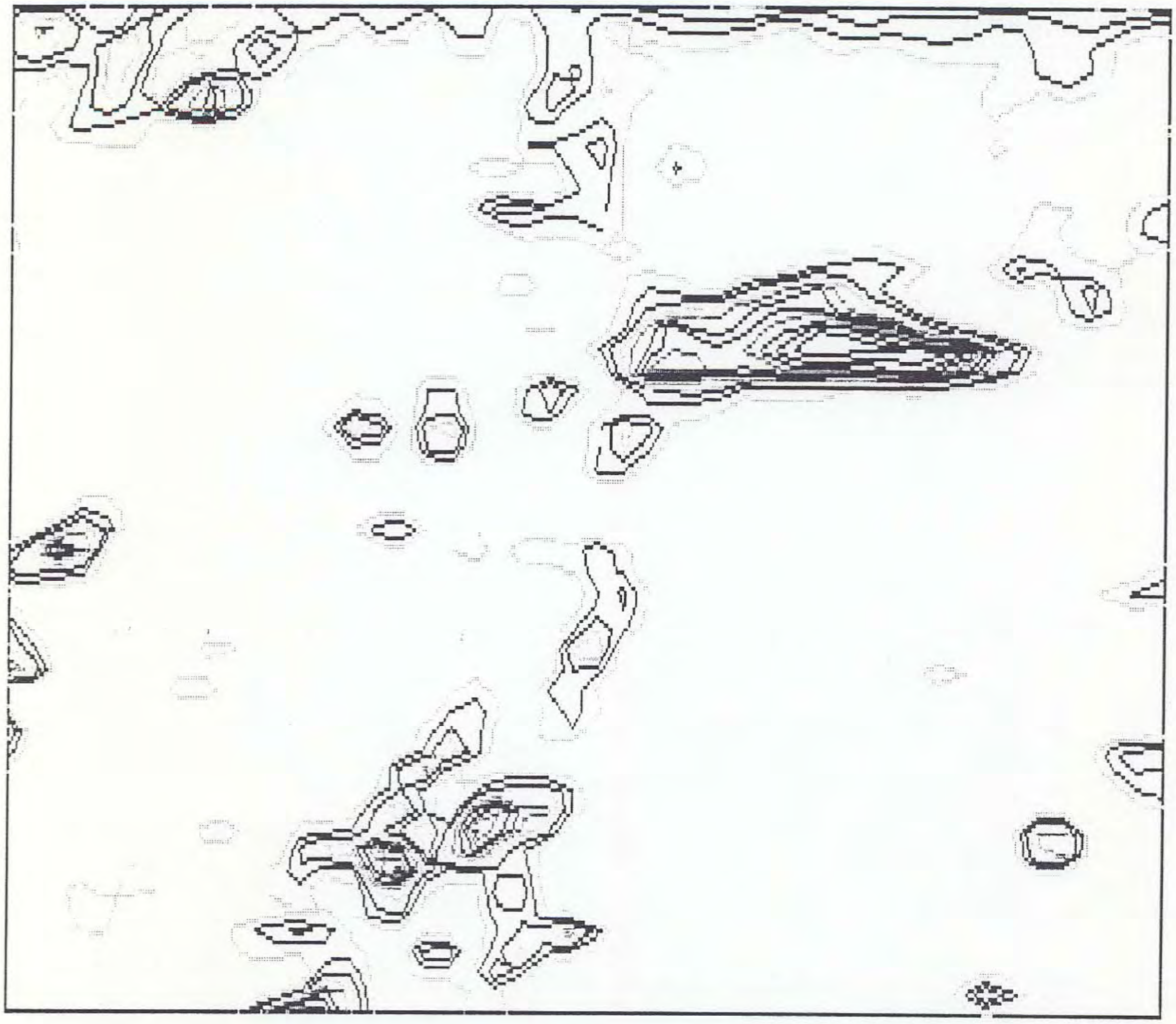
Utah Precipitation Contour Plot With Wind at 50

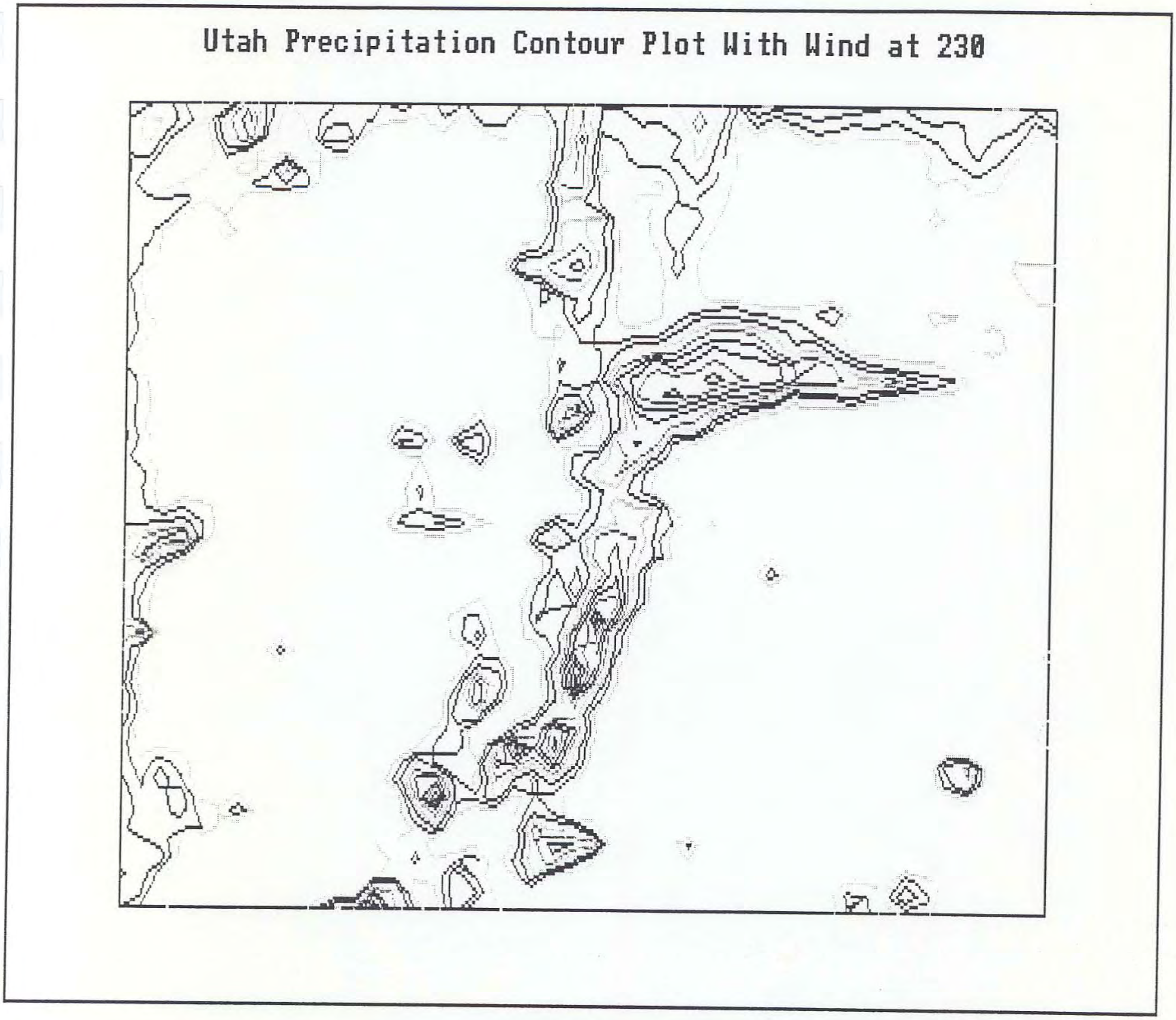


Utah Precipitation Contour Plot With Wind at 90


Utah Precipitation Contour Plot With Wind at 140

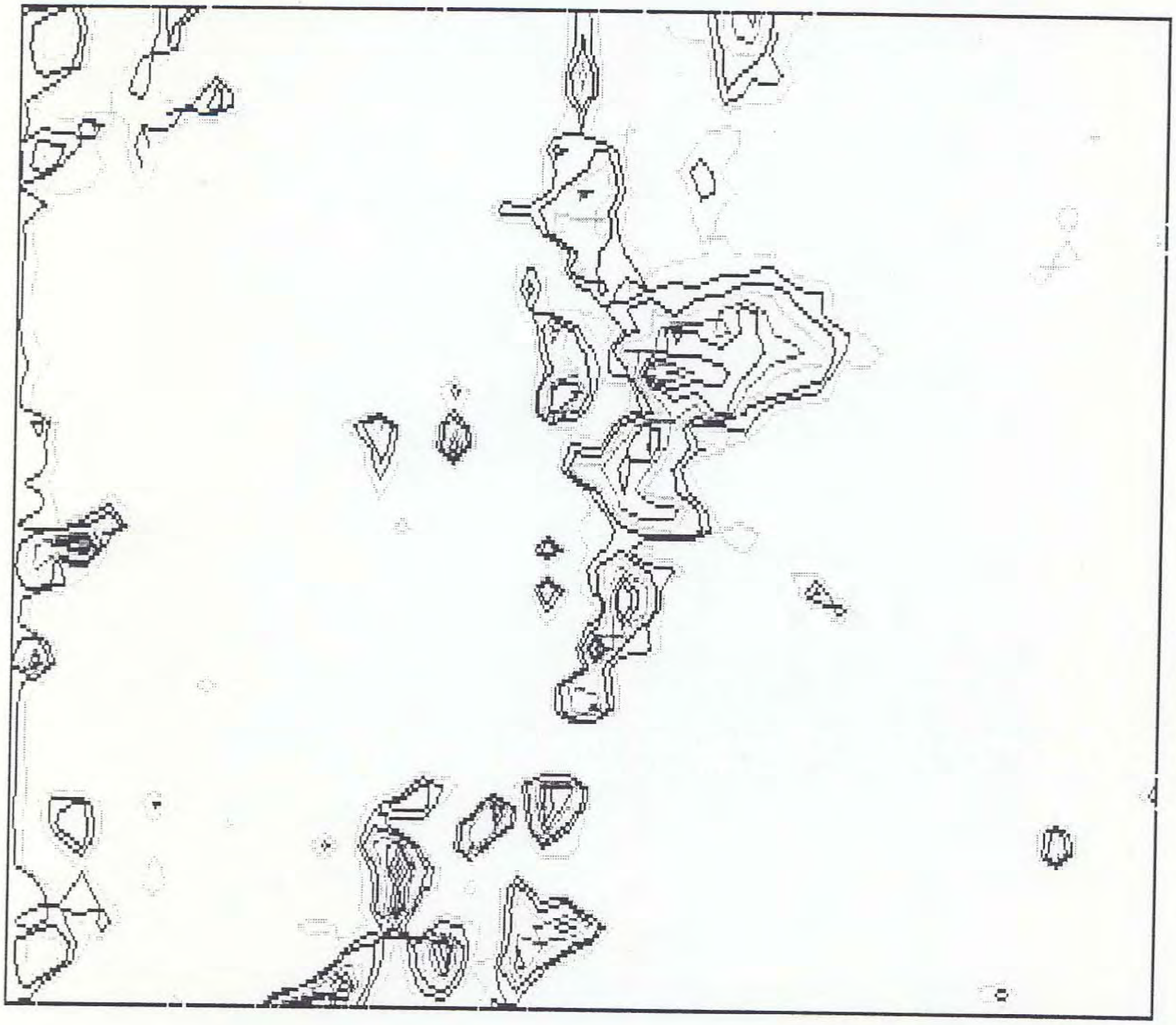
Utah Precipitation Contour Plot With Wind at 180

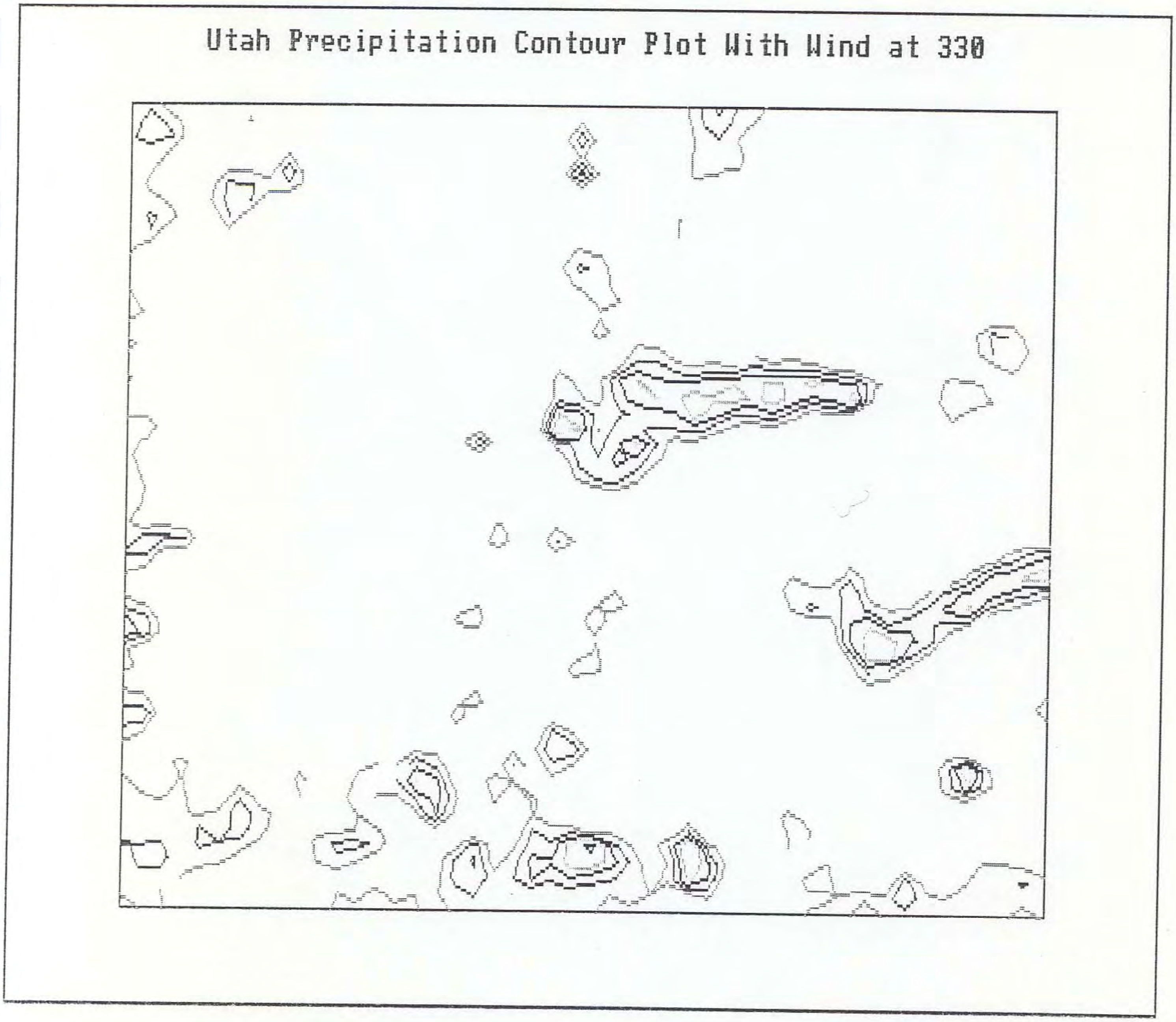




Utah Precipitation Contour Plot With Wind at 230

Utah Precipitation Contour Plot With Wind at 270





Utah Precipitation Contour Plot With Wind at 330

Utah Precipitation Contour Plot With Wind at 360