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Development of Contingency Plans and Scientific Background Studies for Applying Weather Modification During Drought Periods in Utah

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DEVELOPMENT OF CONTINGENCY PLANS AND SCIENTIFIC BACKGROUND STUDIES FOR APPLYING WEATHER MODIFICATION DURING DROUGHT PERIODS IN UTAH

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16. ABSTRACT

A multi-disciplinary study of drought in Utah was conducted as a part of the Bureau of Reclamation's Southwest Drought Research Program. The study was administered by the Utah Division of Water Resources. Utah drought was investigated from a variety of viewpoints, including drought climatology, drought meteorology, hydrologic effects of drought, and economic effects of drought. A stand-by wintertime cloud seeding program was designed for all sections of the state. An economics model was then used to determine benefits to the state as a result of the seeding program.

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EXECUTIVE SUMMARY

Utah Droughts

An adequate definition of drought is very difficult to find since the impact and timing vary greatly with the individuals concerned and their location. After a thorough search of the literature, the definitions proposed by Wayne Palmer were accepted for this study because of the ready availability of these indices and the variety of byproducts that are part of the Palmer calculations.

Analysis of the Palmer indices for the seven climate divisions in Utah for the period 1931-1980 showed two significantly different drought periods: the 1934 and 1976-77 drought situations. The 1934 drought was a slowly developing situation over a period of years, while the 1976-77 drought developed very rapidly and ended almost as abruptly as it began. Summaries of all drought periods in each climate division have been included in the report.

To determine the potential for extending the indices into periods prior to 1931, the Palmer Index was calculated for the entire period of record at Logan USU (1893-1980) and Salt Lake City (1874-1980). The average of these two indices was then related to the calculated indices for the North Central Division to obtain an estimate of the Palmer Index for this division from 1894 to 1930.

The average value of the Palmer Index during the growing season (i.e. April through September) was found to have a very good correlation with the Range Condition Index published by the U. S. Department of Agriculture. To study the impact of cloud seeding on various aspects of the economy, the assumption was made that cloud seeding would increase the wintertime precipitation by certain increments. The Palmer indices were then recalculated using these incremental precipitation amounts. The values of the Range Condition were then recalculated for use by the economics group in their economic evaluation.

Meteorology And Weather Modification Potential During Droughts

The analysis of meteorological conditions during drought has shown that wintertime precipitation in Utah during moderate or worse drought periods (Palmer Index less than -2) is characterized chiefly by fewer days having precipitation. At locations on the windward side of the Wasatch Mountains, when winter precipitation does occur during drought, the average daily amounts are similar to those occurring during non-drought periods. However, to the lee of the mountains, daily precipitation amounts during drought are reduced.

The decrease in the number of precipitation events during drought is explained by a decrease in the number of precipitation-bearing low pressure systems (troughs) crossing the Western United States. The decrease in troughs is balanced by an increase in fair weather systems (ridges) and in zonal flow (a rapid west-to-east progression of relatively minor troughs and ridges). The percentage increase in zonal flow in drought compared to non-drought periods was larger than the increase in ridges.

In terms of storm-related parameters such as frequency of clouds and cloud base and top heights (inferred from rawinsonde observations), the storms that did occur during drought were very similar to those occurring during non-drought periods. However, some differences were detected. These included a reduction in the number of low-based precipitating clouds at lee-side sounding stations and stronger winds aloft during drought. The winds aloft were also more frequently from the west and northwest during drought. These differences could help explain the reduction in mean daily precipitation amounts in the lee of the mountains, since the stronger, more westerly, winds could enhance the naturally-occurring rain shadow.

From the standpoint of weather modification during drought, these analyses suggest that, whenever they do occur, the storms should be as seedable as those occurring during non-drought, especially on the windward side of the mountains.

Drought Hydrology And Weather Modification Augmentation Potential

Since the management of reservoir storage is a vital part of drought problems and many of the reservoirs in the state had not been constructed in the 30's, it was necessary to estimate evaporative losses that would have occurred from reservoirs during this drought period.

A rather rough method of estimating pan and lake evaporation from available climate data was developed. This method showed surprising accuracy where actual climate data were available. A modification of Dalton's evaporation equation was used.

Use of the evaporation equations and the Range Condition estimates are now being used in an operational program with the Bureau of Land Management. Predicted values of the Range Condition in each of the Climate Divisions of the state were prepared at the end of June and the end of July and sent to the BLM range managers. To date, their reports indicate that the predictions for 1982 were quite accurate.

Four reservoir-buffered river basins were selected for analysis by the hydrology team. Objectives with respect to these systems were twofold: 1) to determine how the quantity of water available for reservoir storage would be affected by weather modification, and 2) to determine the ownership of the developed water in accordance with established water rights and other institutional considerations.

A precipitation-reservoir inflow model was adapted and applied to the drought years of 1934 and 1977, yielding an estimate of runoff without cloud seeding. The model was then rerun to estimate runoff that would be expected under two seeding increments, M1 and M2. Since the observed runoff could not be perfectly predicted by the model, observed reservoir inflows for 1934 and 1977 were multiplied by the ratio of model-predicted runoff with seeding to model-predicted runoff without seeding. This provided an estimate of streamflows that would be expected to occur during the study years, had weather modification been practiced.

Once hydrographs of reservoir inflows for the "no seeding" and the "seeding" cases had been developed, the alternative water supplies were allocated according to whatever water rights currently pertain to the basin. Interviews were held with the river commissioners in each area to learn the water rights and rules governing reservoir operations and natural flow distribution.

The estimated increases in streamflow resulting from assumed increases in precipitation in different basins varies from three percent in the Sevier River Basin to 150 percent in the Weber River Basin for the M2 program. The small increase in the Sevier River Basin is explained by upstream diversion of developed water. The larger increases in the Wasatch range are attributable to the deeper snow accumulation and the lower consumptive losses in these northern drainage basins. The difference in the percent increase in streamflow between the two study years is very small, with the percentage for 1934 being slightly smaller in most cases.

During 1934 and 1977, streamflow was so low that most water which might have been developed through cloud seeding would be allocated to natural flow users rather than to reservoir storage. In each of the four basins studied, the developed water supply would be divided among a group of users in proportion to their right within a class of rights. Exactly which users benefit from cloud seeding depends on the unique water rights system within a basin, which reflects the history of settlement, agricultural and other development, and peculiar characteristics in the resolution of conflicts over water allocation.

Economic Assessment

The economic evaluation was completed in order to describe the economic impacts of drought of varying intensity and duration, and to evaluate the economic feasibility of modifying drought in Utah through cloud seeding. A qualitative evaluation was made of alternative policies to mitigate the adverse impacts of drought, comparing their usefulness with the cloud seeding alternative.

In order to evaluate the economic impacts of drought on the agricultural economy of Utah and to analyze the feasibility of cloud seeding to modify these impacts, a 10-region economic model of the Utah agricultural economy and other regional economies which interact with the Utah economy was developed. Seven regions were delineated in Utah following the Utah climatological regions, and then three other regions were specified to describe the agricultural economies of, respectively, the Western U.S., the Midwest, and the Eastern U.S. Various crop and livestock systems, yield-water availability relationships, feed-to-livestock conversion systems, precipitation and water availability limits by region, interregional trade routes, and cost-production components were specified as a constraint system of the model. The objective is to maximize the profit from producing and transporting crops, livestock and livestock products, subject to constraints caused by production relationships and resource availability.

Initially, the model was used to simulate base year production and resource use conditions to obtain optimal activity organization in each region. The year 1979 was chosen as the base year because of its currency in representing water delivery and storage technology in Utah, as well as being representative of current distributions of crops and livestock production activities. The resource limitations reflective of 1931-34 drought conditions, as imposed on the base year activities, were then integrated into the model constraint system and objective function parameter set. Then, a new optimal solution to the model was obtained to derive estimates of changes in the production activities, trade flows, water use patterns, and net revenues in order to describe the economic impacts of a drought of this intensity on the current agricultural economy in Utah. Another optimal solution was obtained by imposing new parameters in the model which reflect conditions of the 1976-77 shortages. Increased feed and liquidation costs were again the leading causes of the erosion of net revenues due to the drought conditions. Imports of hay and barley into Utah regions increase relative to the import position of the base year, but they are still only 46 percent of the import levels derived for the 1934-type conditions.

A Design Of A Standby Weather Modification Program

A stand-by cloud seeding program was designed for each climatological division of Utah. Programs for combined divisions were also developed. The seeding programs were based on previous experience, logistics, and numerical modeling guidance. Costs were estimated for each seeding program.

In most areas of the state, ground-based seeding was recommended due to economy of use, sufficient population density to allow a network of manually-controlled seeding devices, and mountainous terrain to provide vertical diffusion of the seeding material. However, in the far northwest part of the state, sparse population and relatively small mountains argue for aerial seeding. In addition, very sparse population in the southeast necessitates aerial seeding if storms with northwesterly flow are to be seeded efficiently.

Cost savings of 25 to 30 percent would be realized by combining seeding programs in several climatological divisions into one program. Combined seeding programs would be especially practical in divisions with shared water use (i.e., water flowing from one division and used in another division).

Benefit Cost Analysis

Again using the economic model, some important economic information about the feasibility of modifying the two known drought episodes as imposed on current production and water delivery activities in Utah was derived. The benefits of cloud seeding to achieve two different precipitation increments in the regions of Utah were generated using the model. Improvements in net revenues associated with simulations using increased precipitation were compared with the net revenues derived from the drought simulations.

The two modification increments represent a liberal and a conservative increment of precipitation anticipated through cloud seeding for each region in Utah. In general, the results of the economic modeling indicate that if only the more conservative increment can be achieved, then it appears that seeding would be infeasible, particularly in southwestern portions of Utah. There is also some question about seeding the Wasatch Front area to generate benefits for the agricultural sector since some price declines for specialty crops are induced in that area as their production is increased. The evaluation does suggest, however, that precipitation increments which are closer to the more liberal seeding increment would be the desirable seeding program to implement in Utah.

The benefits for employing the best practice (the most likely achievable increment) cloud seeding program for the entire state were estimated to be some $12.6 million for modification of the 1934-type drought conditions as imposed on current crop, livestock, and water delivery activities. Some $5.7 million in benefits were derived for modification of the less severe 1977 drought conditions. The static benefit/cost ratios for modifying these two droughts are, respectively, 9.7 and 4.4 for cloud seeding on a region-by-region basis in Utah. Considerable savings can be generated by administering the seeding program on a broader regional basis in the state, thus increasing the benefit/cost ratios to, respectively, 12.6 and 5.7 for modification of the same two droughts using the best practice design. Regional benefit/cost ratios without including the cost savings from operating on a broader regional basis range from 3.3 to 22.5 for modifying the impacts of the 1934-type drought, and range from 0.7 to 10.0 for modifying the 1977-type water shortage conditions. The greatest benefit/cost ratios are generated primarily in the southeastern portion of Utah and in the Uintah Basin area of the state.

The main economic objection to alternative relief policies such as grants, low interest loans, etc. is that they impose misallocative effects on existing markets and the investment process under certain conditions. If two economic activities are identical in every respect except in their degree of vulnerability to drought, then as the discounts rate (social rate of time preference) increases over time so does the investment in the more durable activity, since more is invested in the latter to bring about durability. This will also be the social ordering of preference for investment activities, since a higher present values of returns is derived from the activity with the lower initial cost. This preference is not changed with the implementation of a relief policy to aid investors who face damages from a natural hazard. There is no incentive provided for the shift to more durable investment and production activities. In fact, the relief policy alternative constitutes a direct disincentive to invest in durability.

It appears that more flexible ownership arrangements for water and clear opportunity to transfer water to its best and highest return use during drought conditions would improve economic efficiency under the appropriative doctrine of allocating water rights as practiced by most states in the arid West. In the short run, appropriative water rights systems clearly violate the conditions of economic efficiency. However, if water markets do exist and there is exchange between parties, a number of inefficiencies can be avoided if third party effects (external costs of inefficiencies imposed on third parties) are not induced by water transfers between two parties in the market place. More flexible ownership and the existence of water markets certainly work toward a more efficient water allocation process in the face of drought conditions.

1. THE CLIMATOLOGY OF DROUGHT

1.1 Introduction And Concepts

Since the time man first began to observe the changes which take place in his atmospheric environment, he has been subject to the impact of its extremes. The cyclical nature of the weather has been recorded in the width of tree rings, in deposits of soil on river flood plains, in the deposition of pollen in peat bogs, and even in the mass migrations of man himself as he tried to meet the challenges of his stressful environment. These records all indicate wide ranges in climatic conditions over the centuries.

Unlike hurricanes, tornadoes, and floods which have wreaked great havoc in the past, drought does little to stir people into action. Drought is a slowly developing, incidious thing whose significance may remain unrecognized until the opportunity for effective action is largely past. Drought is an important element of stress to man, animal, and plant in a semi-desert environment. Variations in rainfall from one season to another are the greatest under desert and semi-desert conditions. In a recent study by the State Climatologist, it was found that the coefficient of variation of monthly precipitation in Northern Utah was three times as large during the decade of the 70's as any previous decade back through the 30's. What is the cause of such extremes?

1.2 Literature Search

A comprehensive review of the literature related to drought in all areas of the world was published by Palmer and Denny of the National Weather Service as NOAA Technical Memorandum

EDS 20 in 1971. The authors list 3,150 references broken down into five major drought categories: 1. General, 2. Descriptive, 3. Causes, 4. Effects, and 5. Countermeasures. These references relate to agricultural, hydrological and meteorological drought in most areas of the world. Many of the references are accompanied by brief abstracts.

Earlier, Palmer (1965) made an excellent review of the literature related to drought in the United States when he developed his program to predict meteorological drought. Palmer considered drought as strictly a meteorological phenomena in its broadest sense. In this manner, he felt that he was avoiding many of the complicating biological factors and arbitrary definitions with which the literature is so replete.

Jensen (1978) in his work on his Doctor's Dissertation brought the subject down nearer to the Intermountain Area and Utah specifically. Jensen developed two drought indices in his study: 1) the drought severity index for describing the state of drought as it affects a water system and 2) the drought vulnerability index, which indicates the probability of water shortage in a water system.

While not exhaustive, these three references give an adequate overview of the problem of drought in each of the respective categories. The bibliographies in these publications enable one to cover most aspects of the problem of drought and relate to almost any desired area of interest. No attempt will be made to repeat their efforts in this report.

1.3 Drought Definitions

One of the more difficult problems associated with an analysis of drought conditions is related to the definition - what is drought? To a hydrologist, drought is when streamflow and/or lake and reservoir levels are reduced below normal. To a dryland farmer, drought is a shortage of moisture in the rooting zone of plants. To an economist, drought is related to water shortage that adversely affects the established business economy. To a meteorologist, drought may be related simply to a prolonged or abnormal deficiency of precipitation or rainfall. A completely adequate definition is very difficult to find. Not only is there disagreement as to the meaning of the word, even its spelling and pronunciation provide room for argument.

Palmer (1965) summarizes a number of definitions which may help to understand the complexity of the problem as related to meteorological drought alone:

1. A period with precipitation less than some small amount, such as 0.10 inches in 48 hours.
2. A period of more than some particular number of days with precipitation less than some specified amount.
3. A period of strong wind, low precipitation, high temperature, and unusually low relative humidity (this has been referred to as "atmospheric drought").
4. A day on which the available soil moisture was depleted to a small percentage of available capacity.
5. A period of time when one or all of the following conditions prevail: a) pasturage becomes scarce;

b) stock loses condition from fair order; c) hand feeding in vogue; d) agistment of stock.

6. Monthly or annual precipitation less than some particular percentage of normal.

7. A condition that may be said to prevail whenever precipitation is insufficient to meet the needs of established human activities.

Jensen (1978) reviewed other specific drought concepts which further illustrate the complexity of the problem.

Tannehill (1947) -- "But we have no good definition of drought. We may truthfully say that we scarcely know a drought when we see one. We welcome the first clear day after a rainy spell. Rainless days continue for a time and we are pleased to have a long spell of such fine weather. It keeps on and we are a bit worried. A few days more and we are really in trouble. The first rainless day in a spell of fine weather contributes as much to the drought as the last, but no one knows precisely how serious it will be until the last dry day is gone and the rains have come again ... We are not sure about it until the crops have withered and died ..."

Thornthwaite in 1947 noted that drought cannot be defined as a shortage of rainfall alone.

Deacon et al., in 1959, realizing that the problem was very involved, urged that definitions of drought be systemized in relation to the effectiveness of precipitation in different climates.

Subrahmanyam (1967) noted that, to the meteorologist, a drought is a rainless situation for an extended period. To the agriculturalist, drought is a shortage of moisture for crops. The economist view is that of a water shortage adversely affecting the established economy of the region. The hydrologist considers drought as dimunition of streamflow or lower surface and underground water levels.

Water shortage is basic to drought conditions and is a relative rather than an absolute condition. Jensen notes that practically every author on the subject defines drought in a different manner depending upon the particular interests of the individual. He lists over 35 different ideas under such groupings as: General Definitions; Concepts and Statements; Precipitation and Drought Concepts; Climatic and Evapotranspiration Concepts; Economic and Social Concepts; Methods of Analysis; and Specific Drought Indices.

To combine these various concepts into a workable definition is a complex problem. Drought severity may be a direct function of moisture demand as well as moisture supply. It may depend upon both current and antecedent weather conditions. It may take many months for a serious drought situation to develop, so a factor of time must also be considered. Any given situation departs from normal ("we never have an exactly normal year"). Thus a method is needed to combine all of these concepts.

1.4 Existing Climatic Summaries

Climatic data exists in an almost limitless variety of forms and locations. It seems that many researchers have a tendency to feel that the weather information they collect has to be superior to official information already being collected at the same site, regardless of the type of measurements being recorded and regardless of the accuracy of the equipment.

1.4.1 Data Limitations

There are many new types of exotic devices now on the market which are supposed to measure standard types of weather information. However, in many cases, these instruments are not measuring the same variables as are being measured at standard weather stations, and the data is thus not compatible with official weather station data. Many of the new measuring devices have different time constants, have not been adequately field tested, and are often not properly exposed to obtain representative measurements. Proper exposure to measure a given variable is extremely important. For example, there is an old cliche that "anyone can measure temperature but the question is what temperature is being measured". Some new equipment developed by the National Weather Service, for example, measured the temperature very well under laboratory conditions but failed completely when tested under Utah conditions because the plastic thermoscreen used by the developers was not uniformly opaque. Maximum temperatures as much as 10 to 15 degrees higher than those measured in the standard instrument shelter were recorded.

Similarly, the shape and dimensions of the orifice of a raingage, the characteristics of the exposure site, the installation of a wind shield, and other factors will influence the catch of precipitation in the gage.

The number of cups, the dimensions of the cups, the height of the mast, the location with respect to trees and buildings will modify the speed and direction of the wind at any given location. These differences may be further increased by use of different anemometer designs.

Hence, if one desires to collect data which is to be compared with the long-term records at standard climatological stations, only standard, pre-tested equipment with carefully selected exposure sites can be used.

1.4.2 Climatological Data Collection

A survey of potential new weather data sources for Utah, recently completed for the Bureau of Land Management by Science Applications, Inc., (1980) revealed that very little of the information being collected by research organizations and private consultants is compatible with existing climate stations and thus not satisfactory for this study. It had been hoped that by use of some of this additional data more accurate representation of the climate during drought conditions might be obtained, but, due to this incompatability of data we were unable to achieve this objective.

Magnetic tapes containing all of the currently available information that has been key punched by the National Climatic Center at Ashville had been previously purchased by the Office of the State Climatologist. Additional data from a few weather stations with compatible equipment have been key punched and added to these data tapes. On these tapes, daily data from 1948 or earlier, for a few stations, was recorded on one set of tapes and each following year on another set. The various data tapes for each station were combined to make a contiguous record for each station available for analysis. The resulting tapes total over 186 megabytes of weather information from all areas of the state. A few records began as early as 1893, but most records have been punched only back to August of 1948 when the National Climatic Center key punch program began.

1.5 Identification Of Drought In Utah

As was indicated earlier, one of the first objectives of this program was to develop a definition of drought severity that would meet the needs of the various members of the team.

1.5.1 Objectives And General Approach

After a review of the available literature and an analysis of the specific skills and interests of the various members of the interdisciplinary team, the following major objectives for the Southwest Drought Research Program were developed:

1. Perform background studies of the precipitation climatology of Utah.
2. Perform background studies of drought periods in the state.
3. Prepare an assessment of the potential and benefits of weather modification during drought periods as a means to augment water supplies.
4. Develop a design for a standby cloud seeding program for both winter and summer situations to be implemented for drought mitigation as required.

A general outline of the approach that was used to meet the above objectives is illustrated in Figure 1.1.

To limit the conditions which were to be considered in the study, the impact of drought on five aspects of Utah's economy were analyzed:

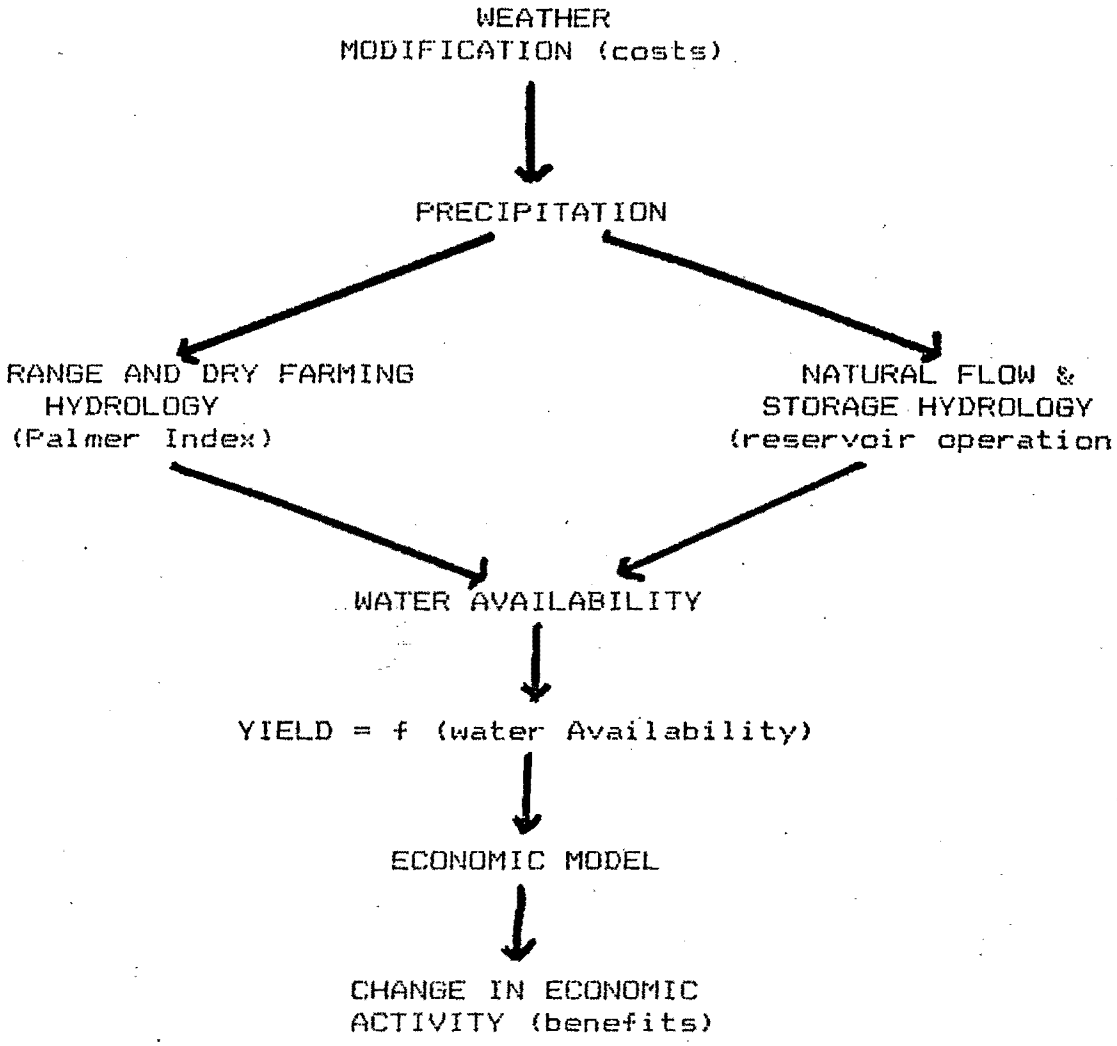

FIGURE 1.1 General Approach To Problem

1. Range and Dry Farming (as related to the current year's rainfall).
2. Winter Wheat (current year's precipitation as modified by summer following).
3. Natural streamflow rights (irrigation).
4. Storage rights (irrigation).
5. Groundwater.
   a. Full service - relatively unaffected by drought over the short term.
   b. Supplemental - does not significantly affect incremental benefits from winter modification but will affect costs.

1.5.2 The Palmer Drought Index

Logic For Selection. After a review of the objectives listed in 1.5.1 and the limitations imposed by the considerations of only five aspects of the economy, the decision was made to use the Palmer definition of drought. This decision was based upon the fact that this definition has already been accepted by the National Weather Service. Further, the calculations of the index are widely available, since they are distributed nationwide on a weekly basis during the growing season and on a monthly basis throughout the year. Also, records of the drought index for the seven climate divisions in Utah have been published by Magnusson (1968), beginning with 1931. These tabulations have been brought up to date by the addition of the more recent calculations for each climate division.

Description Of The Palmer Index. Palmer (1965) considers drought as a strictly meteorological phenomenon. His index evaluates the condition as strictly a meteorological anomaly characterized by a prolonged and abnormal moisture deficiency. His approach avoids many of the complicating biological factors and the arbitrary definitions described earlier. Within reasonable limits, the index permits time and space comparisons of drought severity.

The underlying concept of Palmer's approach assumes that the amount of precipitation required for the near-normal operation of the established economy of an area during some stated period is dependent upon the average climate of the area and upon the prevailing meteorological conditions both during the preceding month and the period in question. Palmer developed a method of estimating the required precipitation values. The difference between the actual precipitation and the computed precipitation requirement represents a fairly direct measure of the departure of the moisture aspect of the weather from normal. When these departures are properly weighted, the resulting index numbers appear to be of reasonably comparable significance both in space and time.

The precipitation requirement is actually derived from consideration of the evapotranspiration, the moisture recharge, and runoff, as well as the antecedent rainfall conditions. These data are normalized for each area of the state. Thus, the "average" moisture requirement is for normal rainfall, but individual periods may require above or below normal rainfall depending upon the character of the preceding weather and temperature during the period under study.

The basic input data for the index calculations are monthly temperature and precipitation figures, by climatic divisions, for the period January 1931 through December 1960. Thus the provides monthly index values that permit the comparison of any particular period with the average climatic conditions for the area in question.

Palmer Drought Classes. These index numbers have been related to certain descriptive classes of wet and dry periods as indicated in the table below:

TABLE 1.1
Classes For Wet And Dry Periods

Monthly Index Value			Class
	=>	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
.50	to	.99	incipient wet spell
.49	to	- .49	near normal
- .50	to	- .99	incipient drought
-1.00	to	-1.99	mild drought
-2.00	to	-2.99	moderate drought
-3.00	to	-3.99	severe drought
	=<	-4.00	extreme drought

These descriptive class values are used, since a descriptive classification is easier to relate to than the number classes. It should be pointed out that incipient drought corresponds to a sort of dry spell in which the need for rain becomes apparent. Extreme drought, on the other hand, is a very serious situation which results from many months, or sometimes even years, of abnormally dry weather. During an extreme drought, agricultural crops are a complete failure, industries and municipalities may face the need for rationing water, and the local and regional economy begins to become disrupted. Thus, extreme drought is essentially a disaster.

Palmer Drought Tabulations. The State of Utah has been divided into seven distinct climatic regions or zones. Each division has been designed to represent a fairly similar set of climatic conditions. However, in mountainous terrain which may react in a variety of ways to any given synoptic pattern, these zones are not as homogeneous as they are in the eastern section of the nation. The areas of the state covered by these zones are shown in Figure 1.2

Since anomalous weather conditions are often found at individual weather stations, the Palmer Index has been computed for each of these climate divisions in the state. The monthly values of the Palmer Index for the period of 1931 through 1980 have been tabulated for each division in Tables 1.2 through 1.8. In Table 1.9 weighted monthly values of the index averaged for the state as a whole have been tabulated.

Summary Of Drought Periods. In Tables 1.10 through 1.17, a summary of drought periods, as defined by the Palmer Index monthly values for the same period, is given for each division and for the weighted state average values. It is interesting to note that the worst drought periods are not necessarily the same in each of the climate divisions. For example, if we look at the largest number of months with extreme drought during any given drought period we find that a total of 43 months of extreme drought were recorded during the period October 1952 through July 1961 in the Western division. In

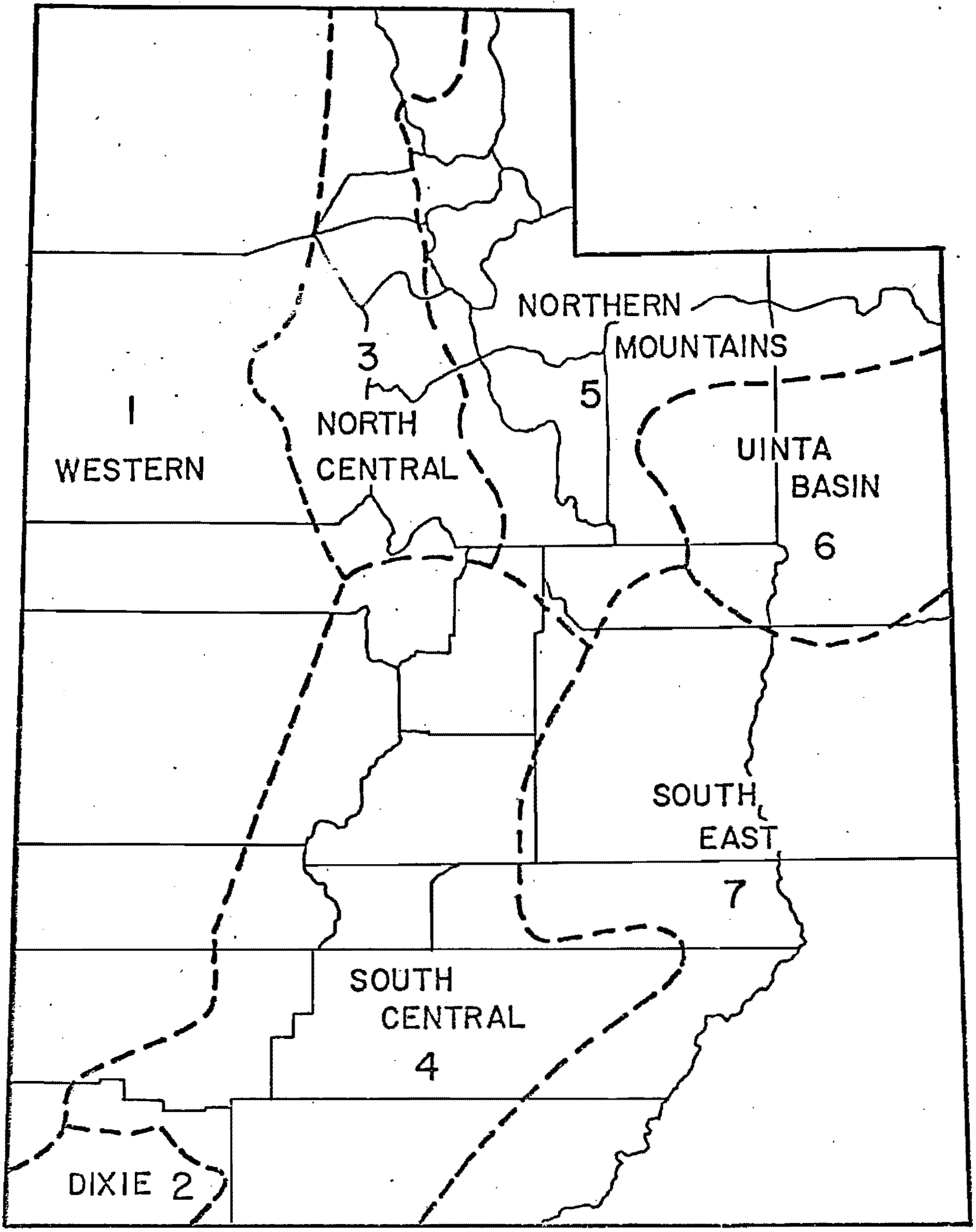

FIG. 1.2 Map Showing The Seven Climate Divisions In Utah

TABLE 1.2

Meteorological Drought In Utah, 1931-1980
(Western Division, 4201)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.26	-0.17	-0.17	-0.16	-0.14	-0.33	-0.55	-0.63	-0.64	-0.98	0.56	1.06
1932	1.40	1.85	1.96	2.37	2.63	3.57	4.57	5.27	4.48	3.88	2.89	2.77
1933	2.84	2.33	1.95	2.48	3.55	-0.02	-0.06	-0.37	-0.71	-1.25	-1.38	-1.31
1934	-1.52	-1.59	-2.62	-3.84	-5.00	-5.23	-5.29	-5.11	0.43	-0.53	0.43	0.45
1935	0.10	0.05	0.18	0.90	2.20	0.03	-0.03	-0.03	-0.29	-0.79	-0.85	-0.96
1936	0.21	1.23	1.18	-0.41	-0.89	0.47	1.53	2.09	1.73	2.29	1.96	2.46
1937	2.68	2.98	3.02	2.93	3.10	2.90	4.91	4.42	4.20	3.69	3.12	3.11
1938	2.73	2.86	3.80	3.81	4.72	5.06	5.23	5.06	4.23	4.49	4.29	3.80
1939	3.49	3.28	-0.38	-0.90	-1.19	-1.18	-1.40	-1.66	1.48	1.60	-0.78	-1.42
1940	0.90	1.59	1.15	1.55	-0.69	-1.14	-1.93	-2.56	2.29	2.25	2.14	2.32
1941	2.22	2.57	3.01	4.65	5.04	6.33	7.39	8.09	8.03	9.12	8.37	8.52
1942	7.80	7.61	7.49	7.18	7.54	7.82	7.93	7.59	6.55	5.68	5.81	5.20
1943	4.75	4.55	3.96	3.13	2.36	2.77	2.38	2.50	2.10	1.85	1.39	1.32
1944	1.42	1.24	1.61	2.50	2.55	3.42	3.08	2.06	1.44	0.64	1.79	1.45
1945	1.01	1.03	1.71	1.81	1.61	2.50	2.81	3.33	-0.04	0.08	-0.05	-0.06
1946	-0.35	-0.90	-0.97	-1.32	-1.35	-2.28	-2.47	-2.16	-2.47	3.12	3.91	4.03
1947	3.61	3.00	2.06	2.18	2.63	3.46	3.23	3.62	3.90	3.52	3.38	3.48
1948	-0.58	-0.62	-0.17	-0.32	-0.89	-0.54	-0.17	-0.18	-0.22	-0.34	-0.54	0.49
1949	1.51	1.73	1.90	1.32	1.80	2.23	2.26	-0.50	-0.57	-0.14	-0.81	-0.59
1950	-0.34	-0.84	-1.02	-1.27	-1.49	-1.95	-2.10	-2.69	-2.45	-2.79	-2.87	-2.96
1951	-2.77	-2.83	-2.81	-2.37	-2.28	-2.82	-2.93	0.35	-0.44	0.02	0.29	0.91
1952	1.12	0.89	1.56	-0.06	-0.21	-0.05	-0.17	-0.31	-0.80	-1.81	-1.55	-1.74
1953	-2.38	-2.81	-3.15	-2.80	-2.99	-3.75	-3.25	-3.49	-3.84	-3.44	-3.91	-4.11
1954	-3.53	-3.90	-3.38	-3.84	-4.56	-4.65	-4.89	-4.87	-4.23	-4.12	-4.15	-4.05
1955	-3.92	-3.74	-4.00	-4.05	-4.17	-4.06	-4.21	-2.53	-2.44	-2.77	-2.82	-2.96
1956	-2.75	-2.77	-3.35	-3.40	-3.55	-4.17	-4.61	-5.11	-5.34	-5.17	-5.05	-5.13
1957	-4.52	-4.93	-4.82	-4.39	-3.07	-3.61	-4.21	-4.42	-4.65	-4.00	-2.85	-2.96
1958	-3.05	-3.01	-2.04	-1.85	-2.15	-2.63	-3.21	-3.07	-2.78	-3.38	-2.77	-3.25
1959	-3.45	-3.04	-3.12	-3.49	-3.40	-3.89	-4.46	-3.90	-3.23	-3.51	-3.76	-3.24
1960	-3.38	-3.18	-3.50	-3.82	-4.46	-5.07	-5.52	-5.68	-5.04	-4.35	-3.79	-4.00
1961	-4.30	-4.69	-4.20	-3.94	-4.35	-5.24	-5.41	0.41	1.53	1.57	1.58	1.25
1962	0.90	1.61	1.56	0.87	1.05	1.16	-0.36	-1.06	-1.23	-1.19	-1.80	-2.15
1963	-2.52	-2.90	-2.79	0.97	0.32	1.11	0.02	0.19	1.16	-1.23	0.73	-0.45
1964	-0.87	-1.36	0.21	0.72	1.21	1.92	-0.58	-0.88	-1.12	-1.73	-1.21	-1.04
1965	-1.37	-1.56	-1.68	0.27	0.50	0.40	0.83	1.83	2.72	-0.77	-0.59	-0.25
1966	-0.70	-0.92	-1.47	-2.00	-2.86	-3.56	-4.21	-4.32	-3.88	-3.93	-4.05	-2.77
1967	-2.50	-2.96	-3.22	0.47	0.63	2.08	2.01	1.22	2.25	-0.61	-1.18	-1.30
1968	-1.79	-1.81	-2.12	-1.51	-1.52	-1.49	-1.71	1.31	-0.39	-0.45	-0.91	-0.92
1969	-0.83	-0.12	-0.38	-0.31	-1.32	0.62	0.61	-0.58	-0.94	-0.32	-0.54	-0.74
1970	-1.10	-1.81	-1.99	-1.46	-2.06	-2.18	-2.05	-2.03	-1.56	-1.62	-1.30	-1.18
1971	-1.31	-1.14	-1.66	0.77	1.22	-0.27	-0.95	0.24	0.32	0.95	0.81	0.82
1972	-0.66	-1.39	-2.56	-3.03	-4.10	-4.38	-5.16	-4.74	0.40	1.38	1.51	1.40
1973	1.01	0.86	1.64	2.01	1.83	1.95	2.62	-0.18	-0.13	-0.39	-0.13	-0.40
1974	-0.29	-0.66	-1.45	-1.81	-2.81	-3.80	-4.09	-4.48	-4.71	-3.61	-3.57	-3.61
1975	-3.58	-3.67	0.48	0.90	1.67	1.64	2.01	-0.33	-0.50	-0.28	-0.34	-0.75
1976	-1.30	-1.13	-1.20	-0.95	-1.50	-2.18	-2.43	-2.56	-2.09	-1.73	-2.21	-2.81
1977	-3.25	-3.83	-3.75	-4.65	-2.90	-3.49	-3.64	-2.52	-2.33	-2.82	-3.04	-3.25
1978	-2.85	-2.46	-2.04	-1.16	-0.93	-1.54	-2.19	-2.25	1.23	0.33	1.17	0.84
1979	1.23	1.25	1.48	-0.39	-0.35	-0.48	-0.79	-0.66	-1.32	-1.15	-1.09	-1.62
1980	1.01	1.56	2.06	1.64	3.16	3.63	3.60	2.98	3.74	3.19	2.70	1.79

TABLE 1.3

Meteorological Drought In Utah, 1931-1980
(Dixie Division, 4202)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.02	0.13	-0.40	-0.63	-0.54	-0.51	-1.24	-1.13	-1.50	-1.75	1.50	2.17
1932	1.89	3.58	2.93	3.06	3.84	5.11	5.94	6.20	-0.08	-0.56	-1.10	-1.21
1933	-0.65	-1.10	-1.53	-1.30	-1.27	-1.60	-1.86	-1.90	-1.60	-2.03	-1.99	-1.47
1934	-1.66	-1.81	-2.56	-3.20	-4.02	-3.99	2.75	2.49	1.88	1.45	1.35	1.40
1935	1.25	1.18	1.60	1.97	2.51	2.77	-0.66	-0.12	-0.17	-0.74	-0.43	-0.64
1936	-1.33	-0.66	-0.61	-0.96	-1.39	-1.94	-1.72	-1.86	-1.74	1.02	0.76	1.39
1937	1.81	2.14	2.57	2.14	2.43	2.37	-0.35	-1.09	-0.51	-0.84	-1.34	-1.25
1938	-1.30	0.04	1.14	0.98	1.49	2.00	-0.58	-0.78	-1.16	-0.99	-0.93	-1.09
1939	0.53	-0.19	-0.39	-0.53	-1.01	-1.54	-2.10	-2.35	3.67	3.70	-0.37	-1.17
1940	0.51	1.25	-0.53	-0.38	-0.67	-1.23	2.62	2.14	3.73	3.09	2.75	3.37
1941	3.41	3.73	3.99	5.29	5.44	6.04	10.00	9.99	8.94	9.78	8.83	8.57
1942	7.54	6.71	6.28	6.18	5.79	5.45	4.28	3.81	2.83	2.40	1.86	1.44
1943	2.46	2.18	2.72	2.70	2.63	2.33	1.54	1.80	1.84	1.87	1.32	0.98
1944	1.07	1.36	1.57	2.24	3.08	3.44	-0.28	-1.00	-1.53	-1.62	-0.76	-0.96
1945	-1.33	-1.31	0.72	-0.14	-0.23	-0.28	-0.74	0.68	-0.58	-0.15	-0.42	-0.19
1946	-0.50	-1.16	-1.46	-1.90	-2.47	-3.19	-3.62	-3.07	-3.33	1.16	2.37	2.84
1947	-0.18	-0.76	-1.36	-1.41	-1.04	-1.08	-1.61	-0.60	-1.24	-1.24	-1.25	-0.61
1948	-1.25	-1.12	-0.66	-0.60	-0.86	-0.63	-1.25	-1.64	-1.54	-1.50	-1.74	-0.04
1949	0.55	0.54	-0.21	-0.44	0.16	0.90	-0.61	-1.08	-1.14	-0.78	-1.07	-0.67
1950	-0.72	-1.10	-1.46	-2.13	-2.59	-3.07	-2.82	-3.01	-2.82	-3.32	-3.33	-3.90
1951	-4.07	-4.52	-4.69	-4.04	-3.90	-4.50	-4.75	1.21	1.19	0.99	0.99	1.38
1952	1.52	0.85	1.48	1.95	1.93	2.36	-0.13	-0.47	-0.49	-1.23	-1.04	-0.84
1953	-1.37	-2.12	-2.49	-2.63	-3.07	-3.48	-3.53	-2.99	-3.40	-3.12	-3.31	-3.31
1954	-2.96	-2.81	-2.03	-1.98	-2.02	-1.79	-1.69	-1.98	-1.35	-1.69	-1.98	-1.98
1955	-1.60	-1.70	-2.07	-2.32	-2.67	-2.82	-2.57	-1.45	-1.84	-2.00	-1.54	-1.80
1956	-1.81	-2.29	-2.31	-3.19	-3.55	-3.90	-3.61	-3.94	-4.21	-4.35	-4.35	-4.65
1957	0.75	-0.32	-0.71	0.12	0.56	0.92	-0.38	-0.33	-0.90	1.71	2.08	1.97
1958	1.52	2.10	3.64	3.95	5.03	5.68	5.05	4.00	4.55	-0.23	-0.15	-0.95
1959	-1.65	-0.79	-1.21	-1.70	-2.11	-2.54	-2.68	-2.08	-2.24	-2.26	-1.87	-1.46
1960	-1.09	-0.87	-0.93	-0.63	-0.68	-0.63	-1.33	-1.63	0.13	0.42	0.91	-0.44
1961	-0.61	-1.40	-1.09	-1.09	-1.50	-2.08	-2.15	1.35	1.50	1.14	1.37	0.96
1962	0.76	1.65	1.66	-0.34	0.05	0.46	-0.42	-1.01	0.46	-0.35	-0.64	-1.12
1963	-1.27	-1.33	-1.40	-0.80	-1.28	-1.58	-2.14	1.54	2.07	-0.30	-0.11	-0.79
1964	-1.25	-1.97	0.04	0.61	0.91	-0.36	-0.77	-0.92	-1.26	-1.85	-1.57	-1.82
1965	-2.33	-2.32	0.18	2.16	2.50	2.97	2.71	2.51	2.34	1.92	3.10	4.00
1966	3.59	3.47	2.77	2.47	2.45	2.30	1.91	1.26	1.21	1.18	1.18	2.17
1967	2.42	1.66	1.18	1.47	1.59	1.86	1.63	1.48	2.97	2.01	2.39	2.76
1968	2.39	2.00	1.79	1.74	1.67	1.84	1.60	1.86	-0.47	-0.92	-1.17	-1.19
1969	1.39	3.01	2.81	2.43	2.97	3.34	3.15	-0.40	-0.33	-0.64	-0.54	-1.20
1970	-1.68	-2.12	-1.73	-1.60	-2.25	-2.61	-2.25	-1.55	-1.50	-1.81	-1.05	-1.03
1971	26.14	23.51	20.60	18.41	17.30	15.35	13.27	13.43	11.54	10.85	9.71	9.31
1972	-0.62	-1.41	-2.33	-2.64	-3.25	-2.55	-3.08	0.77	1.75	2.87	3.94	3.69
1973	4.17	4.55	5.63	5.27	5.79	6.41	-0.07	-0.22	-0.72	-1.06	-0.70	-1.32
1974	-0.55	-1.19	-1.64	-1.73	-2.36	-2.96	-2.66	-2.42	-2.74	1.09	1.01	-0.44
1975	-0.86	-1.04	0.58	0.95	1.25	1.29	1.66	1.70	-0.29	-0.48	-0.42	-0.83
1976	-1.64	-1.07	-1.30	-0.82	-1.30	-1.79	-1.90	-2.18	-1.96	-1.36	-1.64	-2.23
1977	-2.51	-3.25	-3.56	-4.18	-2.93	-3.34	-3.44	-2.82	-2.39	-2.62	-2.75	-2.58
1978	1.35	1.92	3.86	4.76	5.19	6.02	5.27	4.24	4.10	3.34	4.45	4.55
1979	5.38	5.55	6.21	5.60	5.75	5.74	4.95	5.09	3.89	2.93	2.54	1.64
1980	4.01	5.77	5.84	5.45	6.05	6.72	6.47	5.89	5.86	5.45	4.55	3.29

TABLE 1.4

Meteorological Drought In Utah, 1931-1980
(North Central Division, 4203)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.38	-0.71	-0.94	-1.30	-1.37	-2.16	-2.62	-2.76	-2.62	-2.64	0.38	0.75
1932	1.06	1.41	1.73	2.26	1.62	1.78	1.91	2.80	-0.54	-0.80	-1.34	-1.39
1933	-1.25	-1.61	-2.00	-1.78	-0.78	-1.23	-1.70	-2.13	-2.22	-2.73	-3.34	-3.64
1934	-4.09	-4.35	-5.77	-7.06	-8.27	-8.83	-9.06	-8.61	-7.74	-7.26	0.65	0.82
1935	-0.51	-0.84	-0.93	0.62	1.67	-0.20	-0.33	-0.68	-0.98	-1.43	-1.37	-1.65
1936	0.40	1.78	1.98	-0.53	-1.06	-1.25	0.14	0.36	0.01	0.47	0.27	0.70
1937	1.02	1.80	1.94	2.07	-0.22	-0.67	-0.23	-0.60	0.30	0.54	-0.30	-0.32
1938	-1.06	-1.41	0.83	0.73	1.33	1.23	1.30	-0.13	-0.59	0.72	1.05	1.04
1939	1.14	1.18	-0.28	-0.66	-0.88	-0.89	-1.10	-1.50	0.65	0.79	-1.16	-2.00
1940	-1.37	-1.04	-1.30	-1.16	-2.15	-2.92	-3.73	-4.33	1.22	1.20	1.27	1.46
1941	1.32	1.62	1.91	2.87	2.64	2.96	3.69	4.11	3.96	4.89	4.56	4.93
1942	5.13	5.50	5.49	5.03	5.33	4.96	5.09	-0.32	-0.41	-0.66	-0.21	-0.27
1943	-0.58	-0.47	-0.69	-1.38	-1.60	0.88	1.00	1.13	-0.63	0.58	-0.74	-1.11
1944	-1.33	-1.78	0.26	1.85	1.82	3.13	3.80	-0.49	-0.69	-1.34	-0.69	-0.84
1945	-1.48	0.23	0.61	0.77	0.86	2.37	3.56	5.09	5.29	4.47	4.67	4.72
1946	4.29	3.48	3.30	2.74	3.10	2.51	2.02	1.83	1.33	3.49	3.86	4.43
1947	4.56	4.36	3.77	3.87	3.45	4.25	4.42	4.96	5.22	5.18	5.14	4.52
1948	3.60	2.95	3.06	2.83	2.17	2.60	2.42	2.09	1.63	1.30	1.42	1.94
1949	2.48	2.43	2.96	1.99	2.74	2.77	2.69	2.14	1.69	2.58	1.97	2.19
1950	2.48	2.23	2.13	1.59	1.96	1.70	1.90	1.30	1.74	0.99	1.35	1.27
1951	1.26	0.99	0.80	1.35	1.24	0.92	1.37	2.39	1.75	1.92	2.13	3.02
1952	3.78	4.20	5.39	-0.15	-0.37	-0.29	-0.31	-0.23	-0.88	-1.82	-1.80	-2.10
1953	-1.60	-2.12	-2.64	-1.74	-1.34	-1.18	-0.91	-0.84	-1.37	-1.66	-2.20	-2.56
1954	-2.99	-3.90	-4.05	-4.81	-5.16	-5.12	-5.32	-5.16	-4.12	-4.04	-3.73	-3.82
1955	-3.51	-3.01	-3.23	-2.95	-2.87	0.27	0.44	0.65	1.07	0.62	0.90	1.04
1956	1.69	1.67	-0.67	-0.90	-0.52	-0.90	-1.34	-1.94	-2.36	-2.03	-2.28	-2.24
1957	-2.34	-2.89	-2.80	0.89	2.28	2.68	3.10	2.93	2.33	1.91	1.92	1.78
1958	1.28	1.29	1.73	1.77	-0.77	-1.53	-2.34	-2.56	-2.55	-3.22	-2.75	-3.10
1959	-3.10	-2.84	-3.06	-3.08	-2.60	-2.46	-2.80	0.61	1.97	-0.60	-1.49	-1.64
1960	-2.00	-1.81	-1.74	-1.95	-2.30	-2.97	-3.74	-3.76	-3.49	-3.00	-2.40	-2.80
1961	-3.77	-4.20	-4.28	-4.59	-5.03	-5.95	-6.37	0.09	1.35	1.81	1.74	1.65
1962	1.30	1.88	2.39	2.30	2.80	2.69	3.20	-0.24	-0.47	-0.89	-1.65	-2.57
1963	-3.17	-4.28	-4.85	1.08	0.15	0.65	0.25	0.05	0.97	0.81	1.16	-0.39
1964	-0.72	-1.49	-1.41	0.63	1.53	3.27	4.43	4.07	3.38	2.50	2.44	3.55
1965	3.77	3.67	3.05	3.03	3.04	3.45	4.35	5.43	6.52	-0.64	0.36	0.70
1966	-0.47	-0.41	-0.81	-1.11	-1.39	-2.08	-2.74	-2.98	-2.48	-2.23	-2.42	-2.05
1967	-1.63	-2.08	-2.20	0.52	1.16	2.61	4.26	3.86	3.71	3.13	2.17	2.03
1968	1.06	0.98	0.85	1.60	1.86	2.70	3.39	5.43	4.82	4.72	4.19	3.98
1969	4.52	5.43	-0.15	-0.17	-1.16	0.87	0.98	0.66	0.25	0.99	-0.42	-0.58
1970	-0.34	-0.95	-1.29	0.51	0.41	1.04	1.74	1.57	2.75	3.08	3.66	4.07
1971	4.15	4.58	4.15	4.38	3.96	3.86	3.49	3.85	4.16	5.18	4.94	5.30
1972	4.98	-0.20	-0.70	0.64	-0.82	-1.10	-1.71	-1.92	0.67	1.74	1.96	2.21
1973	2.46	2.72	3.31	3.28	2.82	2.56	2.97	2.93	4.76	4.01	3.98	3.93
1974	3.77	3.47	2.62	3.15	-0.56	-1.10	-1.61	-2.09	-2.55	0.84	-0.40	-0.41
1975	-0.57	-0.85	0.76	1.38	2.04	2.83	4.12	3.61	2.90	3.36	3.28	2.78
1976	2.05	2.33	2.38	2.56	-0.45	0.05	0.36	0.47	-0.08	-0.22	-1.11	-2.20
1977	-3.19	-4.46	-5.00	-5.91	1.37	-1.13	-1.29	1.25	1.73	1.27	0.57	0.15
1978	0.28	0.59	1.36	2.33	2.04	1.48	0.76	0.93	2.44	1.31	1.90	1.80
1979	1.93	2.22	2.27	-0.44	-0.59	-0.96	-1.13	-0.85	-1.46	-1.05	-1.00	-1.71
1980	0.94	1.99	2.73	2.01	3.32	3.50	4.09	3.81	3.84	3.77	3.30	2.52

TABLE 1.5

Meteorological Drought In Utah, 1931-1980
(South Central Division, 4204)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.44	-0.67	-1.06	-1.19	-1.38	-1.84	-2.30	-2.85	-3.06	-3.14	0.85	1.12
1932	1.13	2.10	2.05	1.83	1.74	1.99	2.63	3.07	-0.34	-0.64	-1.36	-1.20
1933	-0.84	-1.31	-1.60	0.20	1.04	-0.41	-0.51	-0.97	-1.33	-1.82	-1.98	-1.85
1934	-2.16	-2.56	-3.63	-4.53	-5.36	-5.80	-6.28	-5.92	-5.89	-5.91	-5.10	-4.72
1935	-4.65	-4.55	-3.98	-3.19	-1.98	-2.13	-2.42	-2.41	-2.73	-3.11	-3.04	-2.83
1936	-3.12	-2.00	-1.90	-2.32	-2.70	0.28	1.88	2.44	2.09	2.38	1.78	2.62
1937	3.24	3.45	3.97	3.44	3.57	3.43	3.95	3.33	3.49	2.73	1.83	1.96
1938	1.76	1.91	2.80	2.59	3.18	3.54	3.25	3.13	2.80	2.62	2.70	2.25
1939	2.29	2.36	-0.23	-0.66	-0.96	-1.19	-1.50	-1.88	2.78	2.84	-0.58	-1.46
1940	-1.13	-0.48	-0.66	-0.57	-1.32	-1.81	-2.58	-2.86	1.90	1.72	1.78	2.01
1941	1.95	1.85	2.20	3.52	3.84	4.72	5.48	5.25	5.34	6.80	6.36	6.52
1942	5.81	5.75	5.67	5.58	5.24	4.95	4.68	-0.40	-0.74	-0.80	-0.58	-1.02
1943	-0.78	-0.97	-0.93	-1.46	-1.78	0.30	0.13	0.38	0.24	0.63	0.24	0.09
1944	0.67	0.97	1.49	2.45	2.54	3.45	3.52	-0.46	-0.98	-1.49	-1.04	-1.26
1945	-1.54	-1.50	0.91	1.41	1.41	1.96	2.38	3.29	3.02	3.04	-0.03	0.06
1946	-0.27	-0.89	-0.92	-1.22	-0.80	-1.43	-1.62	0.55	-0.54	2.09	3.26	3.49
1947	3.47	3.27	2.55	2.61	2.97	3.78	3.86	4.91	4.03	4.06	4.12	4.22
1948	3.31	3.41	3.67	3.45	2.81	3.32	2.89	2.65	1.81	1.65	1.24	1.56
1949	2.10	1.93	2.13	1.46	1.74	2.56	2.59	-0.42	0.29	0.42	-0.82	-0.37
1950	-0.21	-0.62	-1.05	-1.48	-1.83	-2.37	-1.81	-2.27	-2.27	-2.94	-2.98	-3.21
1951	-3.37	-3.78	-4.03	-3.32	-2.92	-3.48	-3.61	0.50	0.12	0.19	0.54	1.53
1952	2.14	1.98	2.89	2.95	2.84	3.40	3.58	3.51	-0.11	-1.07	-0.78	-0.76
1953	-1.19	-1.36	-1.79	-1.47	-1.30	-1.78	-1.18	-0.78	-1.30	-1.26	-1.47	-1.68
1954	-1.40	-1.97	-1.50	-1.95	-2.08	-2.23	-2.41	-2.80	-1.80	-1.83	-1.86	-1.88
1955	-1.57	-1.29	-1.77	-2.04	-2.32	-2.49	-2.38	-1.36	-1.54	-2.13	-1.75	-1.95
1956	-1.73	-2.00	-2.74	-2.61	-2.98	-3.42	-3.57	-3.88	-4.22	-4.11	-4.13	-4.40
1957	-3.28	-3.57	-3.43	0.92	1.94	2.23	2.38	2.46	1.62	2.58	3.33	3.08
1958	2.82	3.10	3.66	3.45	3.39	0.01	-0.47	-0.88	-0.08	-0.78	-0.84	-1.68
1959	-2.37	-1.94	-2.46	-2.75	-3.27	-3.98	-4.53	-3.97	-3.56	-3.59	-3.64	-3.21
1960	-3.33	-3.04	-3.25	-3.24	-3.56	-4.01	-4.65	-5.10	-4.18	-3.23	-2.56	-2.86
1961	-3.26	-3.86	-3.12	-2.69	-2.69	-3.22	-3.29	1.10	2.50	2.07	2.09	1.67
1962	1.42	2.56	2.74	2.11	2.35	2.42	-0.08	-0.87	-0.35	-0.63	-1.31	-1.73
1963	-2.20	-2.83	-3.00	-2.23	-2.98	-3.14	-3.88	-2.28	-1.51	-1.98	-1.62	-2.07
1964	-2.54	-3.23	-2.94	-1.98	-1.44	-1.41	-1.71	-1.52	-1.35	-2.08	0.59	0.91
1965	0.68	0.58	0.69	1.58	2.57	3.12	4.17	4.57	5.28	4.14	4.35	4.79
1966	-0.13	0.17	-0.47	-0.76	-0.98	-1.29	-1.48	-1.50	-1.35	-1.15	-1.43	1.39
1967	1.59	-0.40	-0.81	0.40	1.08	1.73	2.34	2.25	4.25	3.20	2.72	2.99
1968	2.35	2.00	1.61	2.30	2.24	2.10	2.24	3.08	2.59	1.82	1.27	1.00
1969	2.08	3.01	3.08	2.73	2.54	3.12	3.67	3.42	3.27	3.12	-0.07	-0.44
1970	-1.00	-1.82	-1.72	-1.32	-1.83	-0.01	0.42	0.63	0.70	0.44	0.92	-0.06
1971	-0.64	-0.53	-1.11	-1.05	-0.80	-1.18	-1.64	0.82	0.43	1.53	1.44	2.06
1972	-0.47	-1.15	-2.22	-2.36	-3.02	-2.76	-3.42	-0.01	0.81	2.52	3.24	3.77
1973	3.95	4.23	5.00	5.32	5.37	5.69	5.59	5.07	-0.24	-0.69	0.35	0.06
1974	0.74	-0.37	-0.84	-0.61	-1.30	-2.01	-2.07	-2.50	-2.68	-1.95	-1.83	-2.10
1975	-2.37	-2.55	0.31	0.71	1.46	1.66	2.43	-0.06	-0.11	-0.33	-0.23	-0.61
1976	-1.34	-1.08	-1.08	-0.60	-0.68	-1.13	-1.12	-1.74	-1.50	-1.51	-1.92	-2.60
1977	-3.15	-4.09	-4.13	-4.58	-4.70	-4.79	-4.70	-4.41	-4.33	-4.22	-4.35	-4.35
1978	0.59	1.10	1.73	2.16	2.32	2.30	1.80	1.02	1.63	1.04	3.00	3.36
1979	4.28	4.80	5.57	4.83	5.07	4.73	3.88	3.53	2.45	1.85	2.01	1.48
1980	2.90	4.43	5.02	4.46	5.24	5.27	5.11	4.97	5.48	5.13	4.27	2.81

TABLE 1.6

Meteorological Drought In Utah, 1931-1980
(Northern Mountains Division, 4205)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.96	-2.14	-2.80	-2.88	-3.01	-3.65	-4.01	-4.12	-4.10	-4.17	-3.93	-3.93
1932	-3.82	-3.62	-3.18	-3.06	-3.28	-3.18	-2.63	-1.95	-2.29	-2.44	-3.04	-3.25
1933	-3.49	-4.14	-4.48	-4.16	-3.42	-3.78	-3.80	-4.15	-4.18	-4.60	-5.04	-5.10
1934	-5.58	-6.21	-7.20	-7.84	-8.61	-8.87	-9.24	-8.76	-8.34	-8.16	-7.55	-7.29
1935	-7.54	-8.21	-7.93	-6.62	-5.25	-5.23	-5.25	-5.11	-5.12	-5.21	-5.15	-5.55
1936	0.04	1.98	1.88	1.36	0.68	0.27	0.99	1.17	1.08	1.16	0.59	0.54
1937	0.59	1.31	1.00	0.98	1.00	0.78	1.29	-0.21	0.16	0.17	-0.32	-0.61
1938	-1.05	-1.11	0.90	0.48	1.12	0.92	1.01	1.34	1.17	1.47	1.66	-0.21
1939	-0.42	-0.23	-0.56	-1.12	-1.29	-1.43	-1.78	-1.96	-0.92	-0.80	-1.79	-2.64
1940	-2.71	-2.74	-2.91	-2.47	-3.10	-3.48	-3.99	-4.23	1.30	1.18	0.00	-0.09
1941	-0.53	-0.57	-0.76	1.14	1.10	1.87	2.58	2.95	3.26	4.40	4.47	4.95
1942	4.77	4.59	-0.30	-0.29	-0.24	-0.54	-0.70	-1.05	-0.99	-1.18	0.34	0.47
1943	0.89	1.17	1.20	0.34	0.14	1.21	1.43	1.61	0.98	1.71	-0.45	-0.92
1944	-1.11	-1.56	0.76	1.78	1.49	2.58	2.56	-0.60	-0.92	-1.42	-1.15	-1.21
1945	-1.84	0.61	1.07	1.36	1.09	2.03	2.52	3.52	3.37	2.90	3.75	4.22
1946	3.94	3.27	3.20	2.85	3.05	2.28	1.84	1.52	0.84	3.16	3.97	4.12
1947	3.95	3.50	2.98	3.19	3.22	4.00	4.01	4.57	4.53	4.19	4.22	3.77
1948	3.06	2.81	3.33	3.64	2.77	2.68	2.15	2.05	1.38	1.33	1.30	2.00
1949	2.76	2.90	2.69	1.35	1.83	2.16	2.16	1.77	1.54	2.47	2.00	2.70
1950	4.18	3.85	4.11	3.43	3.53	3.04	3.03	2.18	2.53	1.66	2.48	2.85
1951	3.42	3.40	2.88	2.84	2.76	2.52	2.78	3.37	2.56	2.87	3.60	5.10
1952	5.56	5.40	6.50	5.74	5.08	4.97	4.78	4.78	-0.30	-1.29	-1.47	-1.57
1953	0.41	0.16	0.16	0.58	1.47	1.34	1.69	1.84	-0.58	-0.62	-0.80	-1.07
1954	-1.06	-1.41	-0.95	-1.50	-1.79	-1.70	-1.64	-1.77	-0.81	-1.02	-1.27	-1.64
1955	0.15	0.67	0.35	0.44	0.22	0.22	0.51	0.87	1.16	0.59	1.17	2.36
1956	3.47	3.26	-0.94	-1.10	-0.81	-1.09	-1.20	-1.72	-2.13	-1.93	-2.42	0.02
1957	0.22	0.16	0.25	1.34	2.45	2.79	3.03	3.30	2.62	2.45	2.76	2.79
1958	2.49	3.20	3.29	3.44	-0.53	-1.09	-1.86	-2.16	-2.11	-2.76	-2.64	-2.95
1959	-3.20	-2.74	-2.53	-2.49	0.26	0.54	0.37	0.62	1.97	-0.23	-0.87	-1.48
1960	-1.98	-1.75	-1.46	-1.58	-1.75	-2.00	-2.49	-2.97	-2.58	-2.05	-1.64	-2.19
1961	-3.23	-3.91	-3.42	-3.41	-3.58	-3.92	-4.09	0.48	1.80	2.31	2.30	2.16
1962	2.39	3.43	3.13	2.73	2.80	-0.05	0.09	-0.59	-0.66	-1.04	-1.77	-2.73
1963	-3.01	-3.77	-3.50	-1.56	-2.22	-1.88	-2.15	-1.37	-0.69	-1.07	-1.19	-1.91
1964	-2.13	-3.27	-3.03	0.64	1.00	1.93	2.15	-0.33	-0.65	-1.36	0.53	2.24
1965	2.76	2.35	1.61	1.96	2.09	2.62	3.70	4.15	5.09	3.93	4.11	3.98
1966	-0.30	0.32	-0.66	-0.89	-1.01	-1.28	-1.39	-1.65	0.19	0.26	-0.32	0.07
1967	0.41	-0.17	-0.38	0.78	1.62	2.60	3.07	-0.17	-0.11	-0.42	-0.97	-0.83
1968	-1.36	0.47	0.15	1.24	1.62	2.00	2.13	3.26	2.79	2.51	2.22	2.02
1969	2.75	3.69	2.49	2.21	1.08	2.00	2.10	1.66	1.28	2.16	1.67	1.35
1970	1.54	1.19	0.95	1.55	1.23	1.62	1.88	1.54	2.15	2.53	3.10	3.35
1971	3.19	3.06	2.22	2.30	2.36	2.14	1.70	1.63	1.76	2.79	2.97	3.58
1972	3.67	-0.26	-0.82	0.88	-0.64	-0.61	-1.09	-1.45	0.55	1.91	2.01	2.32
1973	2.15	2.14	1.92	2.29	1.95	1.57	1.97	1.77	2.65	1.84	2.19	2.24
1974	2.17	1.88	1.14	2.10	-0.67	-1.24	-1.43	-2.04	-2.51	-1.88	-2.10	-2.11
1975	-2.01	-1.95	0.52	1.25	2.45	3.09	3.59	2.97	2.45	2.76	2.92	-0.20
1976	-0.65	-0.30	-0.68	-0.57	-0.56	-0.53	-0.58	-0.95	-0.94	-1.28	-2.13	-3.22
1977	-4.31	-5.76	-5.67	-6.21	-4.67	-5.24	-5.00	-4.29	-3.60	-3.47	-3.51	-3.27
1978	-3.08	-2.70	-1.99	-0.74	-0.80	-1.07	-1.73	-1.68	-0.72	-1.59	-0.88	-0.92
1979	-0.88	-0.61	-0.83	-1.03	-1.16	-1.59	-1.89	-1.89	-2.51	-1.89	-1.71	-2.42
1980	1.59	2.90	3.07	2.51	3.36	2.79	2.60	2.09	2.10	2.08	1.63	0.82

TABLE 1.7

Meteorological Drought In Utah, 1931-1980
(Uinta Basin Division, 4206)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.24	-0.28	0.08	0.89	1.26	1.68	1.75	-0.25	-0.67	-0.97	0.32	0.43
1932	0.21	0.58	0.96	1.44	1.32	1.36	2.28	2.82	-0.59	-0.55	-0.98	-1.15
1933	-1.04	-1.35	-1.58	0.97	1.77	-1.00	-1.30	-1.87	-1.84	-2.26	-2.14	-2.02
1934	-2.05	-1.99	-2.98	-4.00	-4.82	-4.95	-5.07	-4.90	-5.04	-5.39	-4.49	-4.38
1935	-4.17	-3.66	-3.26	-1.82	-0.66	-1.10	-1.55	-1.29	-1.88	-2.23	-2.37	-2.67
1936	-2.95	-2.80	-2.16	-2.49	-3.09	-3.08	0.59	1.16	1.03	1.20	0.79	1.58
1937	1.96	2.68	2.92	2.44	3.57	3.68	5.04	5.50	4.83	3.78	2.74	2.85
1938	2.23	2.02	2.60	2.07	2.63	3.23	2.81	2.30	3.42	3.50	3.53	3.03
1939	2.74	2.69	2.81	-0.44	-0.59	-0.94	-1.37	-1.79	2.11	2.03	-0.59	-1.04
1940	-0.49	-0.11	-0.16	-0.21	-1.06	-1.95	-2.41	-2.85	1.75	1.35	1.49	1.32
1941	1.40	1.07	0.94	2.07	2.47	3.05	2.94	3.49	4.59	6.37	5.81	5.30
1942	4.59	4.00	3.75	3.76	3.45	-0.25	-0.01	-0.56	-0.51	-0.60	-0.76	-1.06
1943	-1.41	-1.41	-1.48	-2.21	-2.60	0.52	0.03	0.55	-0.67	-0.66	0.13	0.00
1944	0.95	1.38	1.86	2.78	3.31	4.22	4.13	-0.61	-1.10	-1.05	-0.84	-1.29
1945	-1.46	-1.26	-0.91	-0.58	-0.67	-0.04	-0.41	-0.51	-0.95	-0.96	-1.15	-1.23
1946	-1.63	-2.02	-2.34	-2.53	-2.96	-3.79	-4.32	-4.01	-4.31	1.03	1.95	1.92
1947	1.85	1.61	0.75	0.37	0.28	2.14	3.62	4.48	3.47	3.30	3.18	3.27
1948	2.56	2.57	2.66	-0.35	-0.86	-0.63	-0.62	-0.78	-1.17	-1.08	-1.10	0.57
1949	1.52	-0.13	-0.02	-0.56	0.97	1.89	2.54	1.69	1.47	2.37	1.78	2.52
1950	2.73	-0.22	-0.41	-0.28	-0.13	-0.57	-0.25	-1.13	-0.88	-1.83	-1.92	-1.98
1951	-2.25	-2.21	-2.41	-2.19	-2.58	-2.69	-2.93	-2.38	-2.81	1.37	1.28	2.85
1952	2.98	2.46	3.13	3.11	3.58	4.61	6.25	6.96	-0.39	-1.29	-1.40	-0.90
1953	-1.01	-1.21	-1.50	-1.36	-1.13	-1.57	-1.94	-1.90	-2.50	-2.53	-1.86	-2.13
1954	-2.03	-2.54	-2.14	-2.50	-3.11	-3.23	-3.46	-3.61	1.99	2.09	1.61	1.11
1955	0.95	1.35	-0.72	-0.79	-1.48	-1.87	-2.04	-1.06	-1.27	-2.00	-1.60	-1.61
1956	-0.94	-1.01	-1.53	-1.69	-2.04	-2.59	-3.02	-3.59	-3.93	-3.57	-3.54	-3.39
1957	0.44	-0.34	-0.43	0.51	1.81	1.79	1.41	2.40	1.47	1.66	3.24	-0.04
1958	-0.38	-0.43	0.62	-0.01	-0.15	-0.53	-1.07	-1.73	-1.41	-2.20	-2.20	-2.52
1959	-2.59	-1.85	-1.91	-2.17	-2.66	-2.64	-2.85	-2.28	-1.33	-1.23	-1.60	-1.45
1960	-1.30	-0.76	-1.07	-1.38	-1.78	-2.39	-2.82	-3.24	-2.77	-2.17	-1.91	-2.16
1961	-2.54	-2.86	-2.46	-2.39	-3.25	-4.26	-4.59	-4.29	1.83	2.65	2.71	2.33
1962	2.60	3.45	3.32	-0.52	-0.42	-0.46	-0.70	-1.43	-1.12	-1.31	-1.66	-2.08
1963	-2.35	-2.76	-2.95	-2.83	-3.89	-4.25	-4.74	-3.89	-3.39	-3.80	-3.69	-3.84
1964	-4.03	-4.05	-3.46	-2.68	-2.32	-2.53	-3.11	-3.25	-3.17	-3.76	1.16	2.45
1965	2.44	2.31	2.32	2.61	4.00	6.57	8.77	8.79	9.33	8.16	7.39	7.21
1966	6.01	5.45	4.33	3.42	3.09	2.28	1.86	1.41	1.31	1.07	0.63	1.95
1967	2.19	1.81	1.50	1.15	1.65	3.10	3.08	-0.45	-0.66	-1.29	-1.50	0.60
1968	0.15	0.66	0.49	1.84	2.50	2.54	-0.34	-0.13	-0.58	-0.97	-1.10	-1.16
1969	0.91	1.59	1.61	1.64	1.06	2.65	2.19	1.60	1.83	2.56	0.00	-0.12
1970	-0.23	-0.57	-0.55	-0.30	-0.68	1.45	1.39	-0.70	-0.76	-0.55	-0.60	-0.79
1971	-0.95	-0.62	-1.12	0.53	1.06	-0.91	-1.57	-2.26	-2.27	1.51	1.25	1.62
1972	-0.42	-0.82	-1.81	-2.19	-2.15	-2.30	-2.82	-3.04	0.17	1.36	1.75	2.06
1973	2.03	1.93	2.53	3.30	3.93	4.91	5.63	-0.04	-0.15	-0.53	0.64	0.55
1974	0.69	-0.32	-1.02	-1.26	-2.04	-2.65	-2.96	-3.64	-3.99	-3.31	-3.42	-3.61
1975	-3.25	-3.05	0.74	0.91	2.21	2.96	3.57	-0.55	-0.98	-1.12	-0.88	-1.27
1976	-1.69	0.15	0.25	0.58	0.57	-0.46	-1.07	-1.56	-1.37	-1.85	-2.19	-2.62
1977	-2.67	-2.46	-2.73	-3.10	-2.54	-3.92	-3.01	-2.51	-2.75	-2.99	-2.69	-2.73
1978	0.76	0.65	1.09	1.63	1.87	-0.24	-0.76	0.64	-0.92	-1.50	1.30	1.50
1979	1.67	1.53	3.10	2.87	3.48	3.46	3.25	3.19	2.04	2.12	1.89	1.44
1980	2.38	2.75	2.61	2.27	3.11	2.63	2.24	2.06	2.70	2.67	2.31	1.49

TABLE 1.8

Meteorological Drought In Utah, 1931-1980
(Southeast Division, 4207)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.40	-0.33	-0.32	-0.18	-0.21	-0.10	-0.29	-0.96	0.07	0.14	0.80	1.27
1932	1.11	1.59	1.18	1.22	1.17	1.29	2.72	3.66	-0.08	-0.54	-1.01	-0.85
1933	-0.38	-0.71	-0.95	0.34	0.85	0.24	1.37	-0.64	-0.29	-0.61	-0.22	-0.43
1934	-0.72	-0.75	-1.75	-2.52	-2.66	-3.06	-3.66	-3.86	-3.98	-4.42	0.23	0.17
1935	0.39	0.49	1.04	1.68	2.33	2.15	2.08	-0.16	-0.04	-0.52	-0.81	-0.81
1936	-1.27	-0.91	-1.03	-1.52	-2.10	-2.46	1.07	1.48	1.11	1.12	0.65	1.33
1937	1.37	1.61	2.25	1.88	2.04	2.07	3.18	2.93	2.78	1.83	1.15	1.00
1938	0.87	0.95	2.09	1.87	1.90	2.59	2.18	1.70	2.36	1.91	1.54	1.39
1939	1.61	1.56	1.71	-0.23	-0.57	-1.06	-1.55	-1.85	2.04	-0.27	-0.66	-1.30
1940	0.29	0.70	-0.52	-0.83	-1.45	-1.37	-1.91	-2.30	2.29	2.31	2.48	2.89
1941	2.99	3.19	3.50	4.94	6.33	8.23	8.70	8.47	8.33	10.03	8.91	8.29
1942	7.20	6.57	6.09	6.22	5.81	5.34	-0.06	-0.60	-0.58	-0.58	-1.03	-1.41
1943	-1.49	-1.94	-1.62	-2.14	-2.67	-2.60	-3.15	0.44	-0.25	-0.52	0.10	0.04
1944	0.26	0.58	0.46	1.60	2.01	2.62	2.50	-0.78	-1.40	-1.84	-1.55	-1.67
1945	-1.56	-1.62	0.39	0.70	-0.37	-0.13	-0.19	0.00	-0.67	-0.23	-0.52	-0.48
1946	-0.91	-1.45	-1.48	-1.68	-2.07	-2.95	-3.28	-2.57	-2.75	-2.15	-1.03	-1.08
1947	-1.39	-1.77	-2.16	-2.51	-2.41	-1.91	-2.53	2.02	1.05	1.69	1.93	2.42
1948	1.67	2.02	2.11	1.88	1.42	2.17	1.82	1.76	1.21	1.38	0.95	1.19
1949	2.40	2.21	2.29	2.04	2.57	3.68	3.74	-0.44	-0.53	0.60	-0.76	-0.51
1950	-0.80	-1.09	-1.38	-1.90	-2.41	-3.04	-2.09	-2.84	-2.56	-3.46	-3.67	-4.04
1951	-4.05	-4.03	-4.08	-4.26	-4.29	-4.77	-5.05	1.24	0.56	0.45	0.87	1.69
1952	2.18	1.79	2.17	2.49	2.75	3.25	3.16	2.61	2.69	-1.10	-0.82	-0.71
1953	-1.02	-1.22	-1.32	-1.30	-1.64	-2.22	-1.46	-0.80	-1.66	-0.78	-0.56	-0.81
1954	-1.00	-1.86	-1.37	-1.80	-2.19	-2.77	-3.26	-3.70	-2.51	-2.58	-2.53	-2.40
1955	-1.99	-1.30	-1.53	-1.62	-1.71	-1.87	-2.29	-1.84	-2.41	-3.13	-2.76	-2.80
1956	-2.35	-2.47	-2.81	-3.08	-3.49	-4.07	-3.75	-3.95	-4.45	-4.35	-4.20	-4.31
1957	1.05	0.75	0.37	1.37	3.04	3.44	3.72	4.82	3.63	4.75	5.95	5.39
1958	4.78	4.63	4.68	4.42	4.77	4.60	-0.39	-0.85	-0.32	-0.77	-0.82	-1.60
1959	-2.05	-1.56	-1.96	-2.21	-2.89	-3.51	-3.98	-3.48	-3.17	-2.82	-2.74	-1.84
1960	-1.73	-1.10	-1.16	-1.16	-1.16	-1.37	-1.89	-2.64	-0.02	1.14	1.04	-0.14
1961	-0.58	-1.16	0.75	1.11	-0.31	-0.97	-1.26	0.89	2.88	3.06	2.85	-0.09
1962	-0.47	0.61	-0.08	-0.40	-0.75	-0.95	-1.49	-2.27	-0.88	-0.82	-0.93	-1.29
1963	-1.41	-1.72	-1.69	-1.44	-2.57	-3.07	-3.66	-2.09	-1.59	-1.96	-2.18	-2.64
1964	-3.01	-3.40	-2.89	-2.26	-2.37	-2.95	-3.19	-3.00	-2.84	-3.57	0.26	0.44
1965	0.24	0.55	0.81	1.85	3.15	4.06	5.37	5.43	5.83	5.33	5.37	6.01
1966	-0.33	0.43	-0.57	-0.75	-0.50	-0.63	-0.16	-0.15	-0.20	-0.54	-0.73	0.90
1967	-0.27	-0.87	-1.60	-2.11	-1.57	-0.87	-0.57	-0.57	-0.70	-1.51	-1.82	1.01
1968	-0.42	-0.63	-0.75	0.51	0.58	0.10	0.55	1.48	-0.64	-0.96	-1.13	-1.17
1969	0.86	1.48	1.56	1.23	1.43	2.38	3.04	3.02	2.66	3.15	2.98	-0.38
1970	-0.74	-1.55	0.70	1.24	-0.45	-0.36	-0.71	-0.86	-0.08	-0.16	0.00	-0.16
1971	-0.67	-0.93	-1.38	-1.82	-1.89	-2.72	-3.35	0.13	-0.20	1.35	1.30	1.74
1972	-0.54	-1.25	-2.37	-3.06	-3.58	-3.19	-3.53	-3.80	0.13	3.74	4.18	4.92
1973	5.19	5.07	5.45	5.62	7.11	9.08	9.56	8.68	-0.19	-0.65	-0.59	-0.95
1974	1.02	-0.37	-1.06	-1.23	-1.94	-2.64	-2.31	-3.05	-3.32	0.94	1.15	-0.25
1975	-0.43	0.09	0.90	1.62	2.44	3.01	3.96	-0.70	-0.88	-1.24	-1.06	-1.14
1976	-1.64	-1.35	-1.26	-0.92	-0.63	-1.27	-1.35	-1.89	-1.33	-1.77	-2.24	-2.77
1977	-2.68	-3.15	-3.24	-4.02	-4.10	-4.83	-3.76	-3.67	-3.66	-3.79	-3.67	-3.71
1978	1.31	1.88	2.24	2.52	2.96	-2.85	-0.39	-1.34	-1.66	-1.84	1.64	2.94
1979	4.10	4.42	5.16	4.85	6.57	7.56	7.13	6.04	4.46	3.41	3.61	3.39
1980	4.27	5.14	5.76	5.83	7.22	8.10	7.52	6.42	6.37	5.92	5.07	3.61

TABLE 1.9

Meteorological Drought In Utah, 1931-1980
(Utah State, 42)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1931	-0.42	-0.60	-0.77	-0.74	-0.78	-1.01	-1.30	-1.75	-1.56	-1.69	0.09	0.44
1932	0.51	1.05	1.07	1.23	1.20	1.58	2.43	3.18	0.77	0.39	-0.30	-0.30
1933	-0.10	-0.55	-0.87	0.18	0.99	-0.69	-0.51	-1.29	-1.38	-1.83	-1.89	-1.91
1934	-2.20	-2.41	-3.46	-4.41	-5.18	-5.52	-5.75	-5.57	-3.97	-4.32	-2.05	-1.93
1935	-2.07	-2.12	-1.77	-0.88	0.21	-0.62	-0.80	-1.32	-1.49	-1.90	-1.96	-2.05
1936	-1.06	-0.09	-0.07	-0.99	-1.51	-0.70	1.21	1.65	1.34	1.66	1.21	1.77
1937	2.03	2.41	2.67	2.42	2.44	2.31	3.38	2.86	2.88	2.30	1.60	1.55
1938	1.23	1.28	2.48	2.28	2.83	3.18	3.02	2.73	2.61	2.68	2.60	2.06
1939	2.03	1.98	0.35	-0.66	-0.94	-1.15	-1.49	-1.80	1.58	1.09	-0.85	-1.57
1940	-0.38	0.09	-0.43	-0.31	-1.44	-1.82	-2.42	-2.85	1.99	1.90	1.78	1.97
1941	1.90	2.02	2.28	3.75	4.27	5.43	6.18	6.39	6.44	7.79	7.15	7.13
1942	6.45	6.19	5.38	5.27	5.21	4.80	3.45	1.72	1.36	1.05	1.23	0.87
1943	0.80	0.64	0.55	-0.12	-0.59	0.48	0.20	1.22	0.63	0.76	0.37	0.20
1944	0.42	0.45	1.11	2.15	2.28	3.16	3.03	0.12	-0.41	-0.94	-0.36	-0.58
1945	-0.87	-0.42	0.88	1.14	0.79	1.48	1.75	2.38	1.19	1.22	0.60	0.69
1946	0.34	-0.25	-0.33	-0.64	-0.64	-1.44	-1.75	-1.08	-1.58	1.50	2.44	2.57
1947	2.31	1.92	1.25	1.21	1.41	2.20	2.10	3.71	3.31	3.31	3.33	3.41
1948	1.72	1.74	2.02	1.71	1.11	1.53	1.37	1.25	0.80	0.75	0.51	1.17
1949	2.06	1.95	2.06	1.43	1.97	2.64	2.68	0.15	0.17	0.84	-0.07	0.30
1950	0.56	0.01	-0.19	-0.60	-0.81	-1.32	-0.98	-1.63	-1.40	-2.08	-2.03	-2.17
1951	-2.10	-2.22	-2.37	-2.09	-2.03	-2.48	-2.56	0.97	0.33	0.77	1.12	2.05
1952	2.47	2.25	2.99	2.14	2.07	2.41	2.43	2.30	0.27	-1.38	-1.21	-1.23
1953	-1.29	-1.59	-1.85	-1.56	-1.51	-1.99	-1.51	-1.30	-2.11	-1.80	-1.94	-2.18
1954	-2.03	-2.59	-2.15	-2.62	-3.04	-3.23	-3.47	-3.67	-2.43	-2.44	-2.49	-2.52
1955	-2.08	-1.67	-2.10	-2.16	-2.35	-2.18	-2.26	-1.34	-1.45	-1.99	-1.70	-1.64
1956	-1.19	-1.32	-2.46	-2.57	-2.75	-3.25	-3.39	-3.80	-4.16	-3.99	-4.01	-3.79
1957	-1.75	-2.11	-2.14	-0.41	0.89	0.98	0.93	1.24	0.52	1.16	2.07	1.63
1958	1.30	1.43	1.96	1.89	1.19	0.19	-1.47	-1.74	-1.34	-2.01	-1.81	-2.40
1959	-2.75	-2.30	-2.52	-2.76	-2.66	-3.04	-3.49	-2.77	-2.09	-2.56	-2.78	-2.41
1960	-2.52	-2.17	-2.30	-2.43	-2.74	-3.17	-3.71	-4.12	-3.00	-2.19	-1.80	-2.34
1961	-2.84	-3.36	-2.53	-2.30	-2.87	-3.57	-3.78	0.36	2.09	2.21	2.16	1.22
1962	1.00	1.93	1.78	1.05	1.12	0.75	-0.28	-1.22	-0.81	-0.94	-1.45	-1.94
1963	-2.27	-2.78	-2.80	-0.85	-1.63	-1.57	-2.26	-1.32	-0.58	-1.54	-0.96	-1.72
1964	-2.09	-2.67	-1.95	-0.79	-0.43	-0.15	-0.89	-1.24	-1.32	-2.02	0.15	0.69
1965	0.58	0.51	0.46	1.52	2.21	2.78	3.78	4.28	5.00	2.93	3.10	3.44
1966	0.07	0.30	-0.46	-0.82	-1.10	-1.52	-1.72	-1.84	-1.44	-1.48	-1.74	-0.24
1967	-0.32	-1.14	-1.53	-0.07	0.44	1.46	1.82	0.91	1.57	0.24	-0.24	0.62
1968	-0.17	-0.04	-0.30	0.60	0.71	0.69	0.64	2.18	0.93	0.61	0.24	0.13
1969	1.17	1.96	1.35	1.18	0.66	1.92	2.18	1.62	1.34	1.81	0.73	-0.28
1970	-0.55	-1.23	-0.76	-0.17	-0.93	-0.35	-0.22	-0.39	0.10	0.10	0.44	0.29
1971	0.40	0.40	-0.19	0.49	0.64	-0.24	-0.83	0.81	0.68	1.90	1.80	2.16
1972	0.40	-1.04	-2.03	-2.07	-2.93	-2.88	-3.45	-2.73	0.46	2.30	2.65	2.99
1973	2.98	2.99	3.52	3.81	4.11	4.69	5.00	3.51	0.54	0.08	0.50	0.27
1974	0.91	0.11	-0.57	-0.52	-1.80	-2.54	-2.63	-3.16	-3.45	-1.53	-1.58	-2.02
1975	-2.09	-2.03	0.59	1.12	1.97	2.33	3.02	0.37	0.09	0.08	0.16	-0.52
1976	-1.09	-0.73	-0.77	-0.46	-0.79	-1.25	-1.36	-1.73	-1.44	-1.53	-2.06	-2.74
1977	-3.17	-3.91	-3.97	-4.67	-3.44	-4.15	-3.84	-3.13	-2.95	-3.13	-3.22	-3.29
1978	-0.65	-0.23	0.31	0.98	1.18	-0.60	-0.47	-0.78	0.35	-0.30	1.50	1.80
1979	2.41	2.65	3.14	2.15	2.64	2.69	2.25	1.97	0.97	0.75	0.85	0.36
1980	2.38	3.35	3.82	3.46	4.64	4.91	4.72	4.15	4.49	4.14	3.50	2.37

TABLE 1.10

Meteorological Drought, Summary, 1931-1980
(Western Division, 4201)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	OCT	1933	AUG	1934	-23.14	141.0745	-5.29	JUL	1934	0	5	1	1	4	11
2	MAY	1939	AUG	1939	-1.43	12.0737	-1.66	AUG	1939	0	4	0	0	0	4
3	DEC	1939	DEC	1939	-0.42	2.6248	-1.42	DEC	1939	0	1	0	0	0	1
4	JUN	1940	AUG	1940	-2.63	12.0542	-2.56	AUG	1940	0	2	1	0	0	3
5	APR	1946	SEP	1946	-6.05	27.5118	-2.47	JUL	1946	0	2	4	0	0	6
6	MAR	1950	JUL	1951	-23.40	106.9102	-2.96	DEC	1950	0	4	13	0	0	17
7	OCT	1952	JUL	1961	-289.29	1559.4552	-5.68	AUG	1960	0	4	18	41	43	106
8	AUG	1962	MAR	1963	-7.64	34.5892	-2.90	FEB	1963	0	4	4	0	0	8
9	OCT	1963	OCT	1963	-0.23	1.5129	-1.23	OCT	1963	0	1	0	0	0	1
10	FEB	1964	FEB	1964	-0.36	2.8090	-1.36	FEB	1964	0	1	0	0	0	1
11	SEP	1964	MAR	1965	-2.71	15.0367	-1.73	OCT	1964	0	7	0	0	0	7
12	MAR	1966	MAR	1967	-28.73	145.6952	-4.32	AUG	1966	0	1	5	4	3	13
13	NOV	1967	JUL	1968	-5.43	24.1638	-2.12	MAR	1968	0	8	1	0	0	9
14	MAY	1969	MAY	1969	-0.32	4.7153	-1.32	MAY	1969	0	1	0	0	0	1
15	JAN	1970	MAR	1971	-9.45	43.9705	-2.18	JUN	1970	0	11	4	0	0	15
16	FEB	1972	AUG	1972	-18.36	104.1652	-5.16	JUL	1972	0	1	1	1	4	7
17	MAR	1974	FEB	1975	-29.19	152.6897	-4.71	SEP	1974	0	2	1	6	3	12
18	JAN	1976	AUG	1978	-45.10	213.0952	-4.65	APR	1977	2	7	15	7	1	32
19	SEP	1979	DEC	1979	-1.18	8.4421	-1.62	DEC	1979	0	4	0	0	0	4
NUMBER OF MONTHS										2	70	68	60	58	258
PERCENT OF TIME (600 MONTHS)											12%	11%	10%	10%	43%

TABLE 1.11

Meteorological Drought, Summary, 1931-1980
(Dixie Division, 4202)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	JUL	1931	OCT	1931	-1.62	9.2360	-1.75	OCT	1931	0	4	0	0	0	4
2	NOV	1932	JUN	1934	-18.20	87.6077	-4.02	MAY	1934	1	14	2	2	1	20
3	JAN	1936	SEP	1936	-3.98	20.2605	-1.94	JUN	1936	3	6	0	0	0	9
4	AUG	1937	JAN	1938	-0.93	7.3244	-1.34	NOV	1937	2	4	0	0	0	6
5	SEP	1938	DEC	1938	-0.25	5.3235	-1.16	SEP	1938	2	2	0	0	0	4
6	MAY	1939	AUG	1939	-3.00	13.7933	-2.35	AUG	1939	0	2	2	0	0	4
7	DEC	1939	DEC	1939	-0.17	1.5058	-1.17	DEC	1939	0	1	0	0	0	1
8	JUN	1940	JUN	1940	-0.23	2.3871	-1.23	JUN	1940	0	1	0	0	0	1
9	AUG	1944	FEB	1945	-1.79	11.0279	-1.62	OCT	1944	2	5	0	0	0	7
10	FEB	1946	SEP	1946	-12.20	58.5023	-3.62	JUL	1946	0	3	1	4	0	8
11	MAR	1947	NOV	1948	-5.27	31.3095	-1.74	NOV	1948	6	15	0	0	0	21
12	AUG	1949	JUL	1951	-42.31	225.4296	-4.75	JUL	1951	3	5	4	6	6	24
13	OCT	1952	DEC	1956	-78.39	372.7439	-4.65	DEC	1956	1	18	16	12	4	51
14	JAN	1959	AUG	1960	-11.85	57.0065	-2.68	JUL	1959	6	8	6	0	0	20
15	FEB	1961	JUL	1961	-3.31	16.1008	-2.15	JUL	1961	0	4	2	0	0	6
16	AUG	1962	AUG	1962	-0.01	1.3121	-1.01	AUG	1962	0	1	0	0	0	1
17	DEC	1962	JUL	1963	-3.12	16.4827	-2.14	JUL	1963	1	6	1	0	0	8
18	JAN	1964	FEB	1964	-1.22	6.1696	-1.97	FEB	1964	0	2	0	0	0	2
19	SEP	1964	FEB	1965	-5.15	23.1676	-2.33	JAN	1965	0	4	2	0	0	6
20	NOV	1968	DEC	1968	-0.36	3.8523	-1.19	DEC	1968	0	2	0	0	0	2
21	DEC	1969	DEC	1970	-9.38	42.3089	-2.61	JUN	1970	0	9	4	0	0	13
22	FEB	1972	JUL	1972	-9.26	41.3224	-3.25	MAY	1972	0	1	3	2	0	6
23	OCT	1973	SEP	1974	-10.08	46.0996	-2.96	JUN	1974	2	5	5	0	0	12
24	FEB	1975	FEB	1975	-0.04	2.0148	-1.04	FEB	1975	0	1	0	0	0	1
25	JAN	1976	DEC	1977	-31.74	147.3174	-4.18	APR	1977	1	9	9	4	1	24
NUMBER OF MONTHS										30	132	57	30	12	261
PERCENT OF TIME (600 MONTHS)											22%	10%	5%	2%	44%

TABLE 1.12

Meteorological Drought, Summary, 1931-1980
(North Central Division, 4203)

NO.	BEGAN MONTH	BEGAN YEAR	ENDED MONTH	ENDED YEAR	AREA	INDEX SQUARED	MAXIMUM SEVERITY INDEX	MAXIMUM SEVERITY MONTH	MAXIMUM SEVERITY YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
										NUMBER OF DROUGHT MONTHS					
1	APR	1931	OCT	1931	-8.49	38.1358	-2.76	AUG	1931	0	2	5	0	0	7
2	NOV	1932	OCT	1934	-74.40	596.2968	-9.06	JUL	1934	1	7	4	2	10	24
3	OCT	1935	DEC	1935	-1.45	10.0466	-1.65	DEC	1935	0	3	0	0	0	3
4	MAY	1936	JUN	1936	-0.31	2.9670	-1.25	JUN	1936	0	2	0	0	0	2
5	JAN	1938	FEB	1938	-0.47	4.2143	-1.41	FEB	1938	0	2	0	0	0	2
6	JUL	1939	AUG	1939	-0.60	5.9055	-1.50	AUG	1939	0	2	0	0	0	2
7	NOV	1939	AUG	1940	-11.16	57.1504	-4.33	AUG	1940	0	5	3	1	1	10
8	APR	1943	MAY	1943	-0.98	6.3209	-1.60	MAY	1943	0	2	0	0	0	2
9	DEC	1943	FEB	1944	-1.22	7.1139	-1.78	FEB	1944	0	3	0	0	0	3
10	OCT	1944	JAN	1945	-0.82	5.8839	-1.48	JAN	1945	2	2	0	0	0	4
11	OCT	1952	MAY	1955	-61.92	331.9392	-5.32	JUL	1954	2	8	8	6	8	32
12	JUL	1956	MAR	1957	-11.22	49.4727	-2.89	FEB	1957	0	2	7	0	0	9
13	JUN	1958	JUL	1959	-23.99	106.1836	-3.22	OCT	1958	0	1	8	5	0	14
14	NOV	1959	JUL	1961	-48.28	268.9118	-6.37	JUL	1961	0	5	5	5	6	21
15	NOV	1962	MAR	1963	-11.52	62.2878	-4.85	MAR	1963	0	1	1	1	2	5
16	FEB	1964	MAR	1964	-0.90	4.8787	-1.49	FEB	1964	0	2	0	0	0	2
17	APR	1966	MAR	1967	-13.39	58.3388	-2.98	AUG	1966	0	3	9	0	0	12
18	MAY	1969	MAY	1969	-0.16	1.3970	-1.16	MAY	1969	0	1	0	0	0	1
19	MAR	1970	MAR	1970	-0.29	3.1950	-1.29	MAR	1970	0	1	0	0	0	1
20	JUN	1972	AUG	1972	-1.73	9.0229	-1.92	AUG	1972	0	3	0	0	0	3
21	JUN	1974	SEP	1974	-3.35	14.9863	-2.55	SEP	1974	0	2	2	0	0	4
22	NOV	1976	APR	1977	-15.87	97.7007	-5.91	APR	1977	0	1	1	1	3	6
23	JUN	1977	JUL	1977	-0.42	2.9410	-1.29	JUL	1977	0	2	0	0	0	2
24	JUL	1979	DEC	1979	-1.35	10.6209	-1.71	DEC	1979	1	5	0	0	0	6
NUMBER OF MONTHS										6	67	53	21	30	177
PERCENT OF TIME (600 MONTHS)											11%	9%	4%	5%	30%

TABLE 1.13

Meteorological Drought, Summary, 1931-1980
(South Central Division, 4204)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	MAR	1931	OCT	1931	-8.82	41.1079	-3.14	OCT	1931	0	4	2	2	0	8
2	NOV	1932	MAR	1933	-1.47	8.7965	-1.60	MAR	1933	1	4	0	0	0	5
3	SEP	1933	MAY	1936	-80.90	466.3289	-6.28	JUL	1934	0	6	10	6	11	33
4	JUN	1939	AUG	1939	-1.57	8.6106	-1.38	AUG	1939	0	3	0	0	0	3
5	DEC	1939	AUG	1940	-5.16	24.5903	-2.86	AUG	1940	2	4	2	0	0	8
6	DEC	1942	MAY	1943	-1.26	10.4386	-1.78	MAY	1943	3	3	0	0	0	6
7	OCT	1944	FEB	1945	-1.83	10.6329	-1.54	JAN	1945	0	5	0	0	0	5
8	APR	1946	JUL	1946	-1.27	8.5100	-1.62	JUL	1946	1	3	0	0	0	4
9	MAR	1950	JUL	1951	-29.72	141.9520	-4.03	MAR	1951	0	4	6	6	1	17
10	OCT	1952	MAR	1957	-62.22	294.8353	-4.40	DEC	1956	3	28	13	6	4	54
11	DEC	1958	JUL	1961	-74.09	371.4043	-5.10	AUG	1960	0	2	7	18	5	32
12	NOV	1962	OCT	1964	-28.96	129.8097	-3.88	JUL	1963	0	11	9	4	0	24
13	JUN	1966	NOV	1966	-2.20	13.0702	-1.50	AUG	1966	0	6	0	0	0	6
14	JAN	1970	MAY	1970	-2.69	13.3768	-1.83	MAY	1970	0	5	0	0	0	5
15	MAR	1971	JUL	1971	-0.98	7.7507	-1.64	JUL	1971	1	4	0	0	0	5
16	FEB	1972	JUL	1972	-8.93	40.4759	-3.42	JUL	1972	0	1	3	2	0	6
17	MAY	1974	FEB	1975	-11.36	48.8765	-2.68	SEP	1974	0	3	7	0	0	10
18	JAN	1976	DEC	1977	-44.82	251.6942	-4.79	JUN	1977	2	9	1	1	11	24
NUMBER OF MONTHS										13	105	60	45	32	255
PERCENT OF TIME (600 MONTHS)											18%	10%	8%	5%	43%

TABLE 1.14

Meteorological Drought, Summary, 1931-1980
(Northern Mountains Division, 4205)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY				NUMBER OF DROUGHT MONTHS				
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	FEB	1931	DEC	1935	-231.64	1660.7695	-9.24	JUL	1934	0	1	6	16	36	59
2	JAN	1938	FEB	1938	-0.16	2.8532	-1.11	FEB	1938	0	2	0	0	0	2
3	APR	1939	AUG	1940	-22.64	109.1746	-4.23	AUG	1940	2	6	5	3	1	17
4	AUG	1942	OCT	1942	-0.23	5.6798	-1.18	OCT	1942	1	2	0	0	0	3
5	JAN	1944	FEB	1944	-0.67	4.7146	-1.56	FEB	1944	0	2	0	0	0	2
6	OCT	1944	JAN	1945	-1.62	9.3950	-1.84	JAN	1945	0	4	0	0	0	4
7	OCT	1952	DEC	1952	-1.33	6.3799	-1.57	DEC	1952	0	3	0	0	0	3
8	DEC	1953	DEC	1954	-4.87	26.6655	-1.79	MAY	1954	2	11	0	0	0	13
9	APR	1956	NOV	1956	-4.59	22.4544	-2.42	NOV	1956	1	5	2	0	0	8
10	JUN	1958	APR	1959	-15.53	67.6846	-3.20	JAN	1959	0	2	8	1	0	11
11	DEC	1959	JUL	1961	-31.48	148.9956	-4.09	JUL	1961	0	7	6	6	1	20
12	OCT	1962	MAR	1964	-20.60	96.4683	-3.77	FEB	1963	1	8	4	5	0	18
13	OCT	1964	OCT	1964	-0.36	2.3810	-1.36	OCT	1964	0	1	0	0	0	1
14	MAY	1966	AUG	1966	-1.33	8.6308	-1.65	AUG	1966	0	4	0	0	0	4
15	JAN	1968	JAN	1968	-0.36	3.9725	-1.36	JAN	1968	0	1	0	0	0	1
16	JUL	1972	AUG	1972	-0.54	4.8123	-1.45	AUG	1972	0	2	0	0	0	2
17	JUN	1974	FEB	1975	-8.27	34.7322	-2.51	SEP	1974	0	4	5	0	0	9
18	OCT	1976	DEC	1979	-60.56	349.8704	-6.21	APR	1977	8	13	4	6	8	39
NUMBER OF MONTHS										15	78	40	37	46	216
PERCENT OF TIME (600 MONTHS)											13%	7%	6%	8%	36%

TABLE 1.15

Meteorological Drought, Summary, 1931-1980
(Uinta Basin Division, 4206)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY				NUMBER OF DROUGHT MONTHS				
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	DEC	1932	MAR	1933	-1.12	9.9223	-1.58	MAR	1933	0	4	0	0	0	4
2	JUN	1933	JUN	1936	-69.06	365.7636	-5.39	OCT	1934	1	10	12	4	10	37
3	JUL	1939	AUG	1939	-1.16	6.5063	-1.79	AUG	1939	0	2	0	0	0	2
4	DEC	1939	AUG	1940	-4.31	20.6083	-2.85	AUG	1940	0	3	2	0	0	5
5	DEC	1942	MAY	1943	-4.17	20.5082	-2.60	MAY	1943	0	4	2	0	0	6
6	SEP	1944	SEP	1946	-20.45	111.4188	-4.32	JUL	1946	7	8	4	1	3	23
7	SEP	1948	NOV	1948	-0.35	5.9971	-1.17	SEP	1948	0	3	0	0	0	3
8	AUG	1950	SEP	1951	-16.36	70.9213	-2.98	JUL	1951	1	4	9	0	0	14
9	OCT	1952	AUG	1954	-23.95	109.4436	-3.61	AUG	1954	1	11	7	4	0	23
10	MAY	1955	DEC	1956	-23.83	115.0724	-3.93	SEP	1956	1	9	4	6	0	20
11	JUL	1958	AUG	1961	-48.32	224.8093	-4.59	JUL	1961	1	14	18	2	3	38
12	AUG	1962	OCT	1964	-55.34	276.1872	-4.74	JUL	1963	0	4	8	11	4	27
13	OCT	1967	NOV	1967	-0.79	4.5522	-1.50	NOV	1967	0	2	0	0	0	2
14	NOV	1968	DEC	1968	-0.26	3.9654	-1.16	DEC	1968	0	2	0	0	0	2
15	MAR	1971	MAR	1971	-0.12	6.1426	-1.12	MAR	1971	0	1	0	0	0	1
16	JUL	1971	SEP	1971	-3.10	13.5535	-2.27	SEP	1971	0	1	2	0	0	3
17	MAR	1972	AUG	1972	-8.31	36.0275	-3.04	AUG	1972	0	1	4	1	0	6
18	MAR	1974	FEB	1975	-22.20	107.7004	-3.99	SEP	1974	0	2	3	7	0	12
19	OCT	1975	JAN	1976	-1.08	7.7607	-1.69	JAN	1976	1	3	0	0	0	4
20	JUL	1976	DEC	1977	-26.76	119.3632	-3.92	JUN	1977	0	4	11	3	0	18
21	OCT	1978	OCT	1978	-0.50	3.7316	-1.50	OCT	1978	0	1	0	0	0	1
NUMBER OF MONTHS										13	93	86	39	20	251
PERCENT OF TIME (600 MONTHS)											16%	14%	7%	3%	42%

TABLE 1.16

Meteorological Drought, Summary, 1931-1980
(Southeast Division, 4207)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	NOV	1932	NOV	1932	-0.01	5.0551	-1.01	NOV	1932	3	1	0	0	0	4
2	MAR	1934	OCT	1934	-17.91	91.7041	-4.42	OCT	1934	0	1	2	4	1	8
3	JAN	1936	JUN	1936	-3.38	17.8837	-2.46	JUN	1936	1	3	2	0	0	6
4	JUN	1939	AUG	1939	-1.46	7.3264	-1.85	AUG	1939	0	3	0	0	0	3
5	DEC	1939	DEC	1939	-0.30	2.1985	-1.30	DEC	1939	0	1	0	0	0	1
6	MAY	1940	AUG	1940	-3.03	13.8768	-2.30	AUG	1940	0	3	1	0	0	4
7	NOV	1942	JUL	1943	-9.05	41.0845	-3.15	JUL	1943	0	5	3	1	0	9
8	SEP	1944	FEB	1945	-3.64	16.5363	-1.84	OCT	1944	0	6	0	0	0	6
9	FEB	1946	JUL	1947	-19.17	85.7867	-3.28	JUL	1946	0	8	9	1	0	18
10	FEB	1950	JUL	1951	-41.01	218.5507	-5.05	JUL	1951	0	3	4	3	8	18
11	OCT	1952	DEC	1956	-64.44	313.6372	-4.45	SEP	1956	6	19	14	7	5	51
12	DEC	1958	AUG	1960	-25.02	118.3403	-3.98	JUL	1959	0	11	6	4	0	21
13	FEB	1961	FEB	1961	-0.16	1.7016	-1.16	FEB	1961	0	1	0	0	0	1
14	JUL	1961	JUL	1961	-0.26	2.6246	-1.26	JUL	1961	0	1	0	0	0	1
15	JUL	1962	OCT	1964	-35.55	163.3564	-3.66	JUL	1963	3	8	10	7	0	28
16	MAR	1967	NOV	1967	-3.61	20.3518	-2.11	APR	1967	4	4	1	0	0	9
17	NOV	1968	DEC	1968	-0.30	5.1128	-1.17	DEC	1968	0	2	0	0	0	2
18	FEB	1970	FEB	1970	-0.55	3.0945	-1.55	FEB	1970	0	1	0	0	0	1
19	MAR	1971	JUL	1971	-6.16	30.3570	-3.35	JUL	1971	0	3	1	1	0	5
20	FEB	1972	AUG	1972	-13.78	66.7680	-3.80	AUG	1972	0	1	1	5	0	7
21	MAR	1974	SEP	1974	-8.55	40.8768	-3.32	SEP	1974	0	3	2	2	0	7
22	OCT	1975	DEC	1977	-39.59	203.9164	-4.83	JUN	1977	2	11	3	8	3	27
23	JUN	1978	OCT	1978	-3.69	16.2114	-2.85	JUN	1978	0	3	1	0	0	4
NUMBER OF MONTHS										19	102	60	43	17	241
PERCENT OF TIME (600 MONTHS)											17%	10%	7%	3%	40%

TABLE 1.17

Meteorological Drought, Summary, 1931-1980
(Utah State, 42)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	JUN	1931	OCT	1931	-2.31	13.3476	-1.75	AUG	1931	0	5	0	0	0	5
2	AUG	1933	MAR	1935	-41.03	234.6185	-5.75	JUL	1934	1	7	5	2	6	21
3	AUG	1935	MAY	1936	-4.29	21.5278	-2.05	DEC	1935	2	6	1	0	0	9
4	JUN	1939	AUG	1939	-1.44	8.1013	-1.80	AUG	1939	0	3	0	0	0	3
5	DEC	1939	DEC	1939	-0.57	3.3318	-1.57	DEC	1939	0	1	0	0	0	1
6	MAY	1940	AUG	1940	-4.53	19.6459	-2.85	AUG	1940	0	2	2	0	0	4
7	JUN	1946	SEP	1946	-1.85	12.6030	-1.75	JUL	1946	0	4	0	0	0	4
8	JUN	1950	JUL	1951	-13.48	57.6813	-2.56	JUL	1951	1	3	10	0	0	14
9	OCT	1952	MAR	1957	-68.73	314.0728	-4.16	SEP	1956	0	22	21	9	2	54
10	JUL	1958	JUL	1961	-59.64	266.8864	-4.12	AUG	1960	0	5	23	8	1	37
11	AUG	1962	OCT	1964	-15.84	73.4252	-2.80	MAR	1963	7	11	7	0	0	25
12	MAY	1966	MAR	1967	-4.51	21.8454	-1.84	AUG	1966	0	9	0	0	0	9
13	FEB	1970	FEB	1970	-0.23	3.8663	-1.23	FEB	1970	2	1	0	0	0	3
14	FEB	1972	AUG	1972	-10.13	46.5047	-3.45	JUL	1972	0	1	5	1	0	7
15	MAY	1974	FEB	1975	-12.83	56.4986	-3.45	SEP	1974	0	3	5	2	0	10
16	JAN	1976	DEC	1977	-36.07	182.6634	-4.67	APR	1977	4	6	3	9	2	24
NUMBER OF MONTHS										17	89	82	31	11	230
PERCENT OF TIME (600 MONTHS)											15%	14%	5%	2%	38%

the Dixie Division, the greatest number of months during any drought period is only six months, recorded during the period August 1949 through July 1951. In the North Central Division, the greatest number of months with extreme drought was ten, recorded during the drought period of November, 1932 to October, 1934. For these summaries, a drought severity of at least -1.00 (mild drought) was considered necessary to initiate the drought period. Once the drought period was underway, a month with incipient drought (-.50 to -.99) was allowed as long as the drought period returned to -1.00 or more. The number of months falling into each drought class have been totaled and expressed as a percent of the total period (600 months).

Drought Intensity Classifications. As a further analysis of drought conditions, the area between an index value of -1 and the curve obtained by plotting consecutive monthly Palmer Index values during each drought period has also been tabulated in Tables 10-17. The sum of the squares of the monthly index values below zero has also been tabulated as a better indication of the duration of drought periods. In addition, the maximum index value recorded during each drought period, and the month and year of occurrence is given. All of these values were considered in various ways to test different drought definitions. In looking at these different severity indices we find that in many cases the most severe drought varies in a given climate division depending upon the definition used.

Extending The Palmer Index Record. Climate division records have been calculated only to 1931 in the State of Utah. To estimate drought conditions prior to this date, Palmer calculations were made beginning with 1896 at the Logan USU weather station and 1875 at the Salt Lake City station. These indices were then combined to obtain an estimate of drought conditions in Northern Utah for the period since 1896. Tabulations of these data can be found in Tables 1.18 through 1.20. The drought summaries are given in Tables 1.21 through 1.23.

1.5.3 Seasonal Palmer Index

Since it had been decided to limit this study to only five aspects of Utah's economy, it was necessary to relate the Palmer Index to each of these aspects (1.5.1). Aspect Number 1 deals with the range and dryland farming aspects of Agriculture. On the ranges and the dryland farms where summer fallowing is not practiced, the major control of production is the available soil moisture during the growing season.

Additional Output Of Palmer Analysis. The Index itself is only a small portion of the output obtained in the Palmer analysis. Several other interesting calculations are also output, as shown in Table 1.24.

It should be recognized that these additional results of the Palmer program may be far from the actual values occurring during any given month but they are of value as indices of the particular variables in question.

Thus the soil moisture at the beginning of the growing season combined with the amount of moisture added by precipitation during the remainder of the growing season will be an important factor of production. It is recognized that the Palmer calculations assume a special soil which has the potential for storing seven inches of available moisture and that, actually, every soil will have different characteristics. However, since we are only considering these calculations as indices

TABLE 1.18

Meteorological Drought In Utah, 1896-1980
(Logan USU, 42 5186)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1896	-0.29	-1.04	-1.22	0.20	1.32	1.02	1.65	2.39	2.30	-0.46	-0.11	-0.63
1897	-1.15	0.29	1.07	1.04	-0.85	-1.34	-1.42	-1.62	0.26	1.05	1.50	1.44
1898	-0.19	-0.50	-0.46	-0.82	1.96	1.83	1.93	-0.50	-0.98	-0.72	-1.06	-1.74
1899	-2.23	-2.93	-3.19	-3.63	-3.36	-3.61	-3.64	-3.25	-3.62	-2.40	-2.35	-2.48
1900	-2.95	-3.31	-4.47	-3.26	-3.18	-3.63	-4.01	-3.69	0.10	0.70	1.28	-0.54
1901	-0.78	-0.64	-0.72	-0.84	-0.60	-0.78	-1.00	-0.46	-0.24	-0.06	-1.03	-1.38
1902	-2.50	-3.40	-3.41	-2.97	-2.45	-2.50	-2.39	-2.39	-2.74	-2.97	-2.56	-2.64
1903	-1.94	-2.25	-2.77	0.00	0.77	-0.30	-0.31	-0.64	-0.44	-0.59	-0.09	-0.53
1904	-0.84	0.36	1.26	-0.59	-1.01	-1.35	-1.50	-1.29	-1.73	-1.51	-2.49	-2.93
1905	-3.90	-4.49	-4.92	-5.19	-4.59	-4.99	-5.45	-5.11	-3.77	-3.79	-4.13	-4.75
1906	-4.50	-4.17	0.30	0.45	2.37	2.62	3.84	6.58	6.55	5.54	4.61	4.26
1907	5.68	6.27	6.86	5.99	6.15	6.47	6.87	6.56	-0.47	-0.52	-1.39	-1.58
1908	-2.31	-3.03	-3.52	-4.45	1.13	1.89	2.59	2.98	3.16	4.57	4.44	3.64
1909	4.38	5.22	5.03	6.75	6.63	5.63	5.24	5.01	5.60	5.11	5.51	5.68
1910	5.67	5.96	-0.44	-1.55	-1.90	-2.83	-3.31	-3.66	-3.56	-2.95	-3.20	-3.11
1911	2.20	2.58	2.99	-0.11	0.16	-0.27	-0.56	-1.01	0.83	0.79	0.87	-0.49
1912	-1.03	-1.52	-1.51	0.27	0.68	0.69	1.86	2.75	2.57	3.50	3.91	3.33
1913	2.81	2.54	3.44	2.86	2.24	2.45	3.38	3.15	3.38	3.50	3.27	2.44
1914	3.38	3.55	3.46	3.32	2.37	3.04	4.15	3.75	3.95	4.00	-1.01	-1.75
1915	-2.44	-3.03	-4.48	-5.04	-3.99	-4.02	-4.32	-4.57	1.93	-0.75	-0.91	-1.42
1916	0.24	0.88	1.06	-0.27	-0.47	-0.49	-0.70	-1.18	-1.69	1.50	1.26	2.22
1917	2.16	4.41	4.48	4.85	5.90	5.21	5.19	-0.59	-0.20	-0.94	-1.50	-2.34
1918	-1.78	-1.27	-1.28	-1.67	-1.39	-1.74	-1.95	-2.08	-1.66	-0.87	-1.04	-1.67
1919	-2.76	-2.86	-3.77	-3.98	-4.29	-5.37	-6.10	-6.00	1.45	3.37	2.99	3.09
1920	2.46	2.40	3.04	3.67	2.95	2.23	1.63	1.95	2.35	4.25	4.18	4.31
1921	4.46	4.46	4.62	5.25	0.00	-0.46	-1.04	-1.03	-1.25	-1.32	-1.90	1.59
1922	1.62	2.12	2.33	2.54	-0.01	-0.25	-0.56	-0.19	-0.81	-1.36	-1.83	0.37
1923	0.89	0.49	0.24	0.97	0.78	1.18	1.64	1.46	1.64	2.12	-0.41	-0.84
1924	-1.76	-2.48	-2.52	-3.13	-3.46	-4.13	-4.55	-4.77	-4.41	0.43	0.23	1.17
1925	0.71	0.83	1.05	0.43	0.05	0.38	0.40	0.45	1.67	-0.61	-0.40	-0.59
1926	-1.09	0.50	-0.66	-1.24	-1.02	-1.64	-1.54	0.30	1.08	-0.55	-0.48	-0.80
1927	-1.21	0.06	0.02	0.51	1.09	0.77	0.95	1.01	1.71	-0.08	-0.14	-0.57
1928	-1.30	-2.19	-2.72	-3.13	-3.50	-3.48	-3.72	-3.98	-4.19	-3.78	-3.56	-3.79
1929	-3.59	-3.64	-3.35	-2.63	-3.15	-2.84	-2.82	-2.98	-1.07	-0.70	-0.94	-1.63
1930	-1.64	-1.78	-2.09	-2.35	0.50	0.17	0.38	1.30	2.33	3.09	0.03	-0.51
1931	-1.19	-1.83	-2.17	-2.76	-2.58	-3.47	-4.04	-4.28	-4.12	-0.02	-0.05	0.57
1932	1.01	1.23	2.21	2.76	1.92	1.62	1.60	2.17	-0.64	-1.09	-1.64	-2.03
1933	-1.89	-2.45	-3.15	-2.85	-1.97	-2.49	-3.04	-3.36	-3.04	-3.50	-4.06	-3.90
1934	-4.15	-4.38	-5.26	-6.11	-7.27	-7.71	-8.26	-7.97	-7.06	-6.67	-5.99	-5.64
1935	-5.53	-5.40	-5.10	-4.25	-3.12	-3.14	-3.12	-3.36	-3.71	-3.45	-3.20	-3.31
1936	-2.98	-1.85	-1.05	-1.01	-1.47	-1.85	-2.21	-1.96	-2.20	0.63	0.35	0.26
1937	0.18	1.10	1.25	2.05	-0.09	-0.41	0.52	0.00	0.29	0.32	0.35	0.43
1938	-0.52	-0.65	1.39	-0.87	-0.45	-0.37	-0.24	-0.55	-1.19	1.02	0.00	-0.04
1939	0.08	-0.19	-0.67	-1.09	-0.85	-0.77	-0.72	-1.18	0.64	-0.16	-1.33	-1.99
1940	-1.97	-2.21	-2.59	-2.66	-3.58	-4.24	-5.05	-5.44	1.69	1.71	1.37	1.38
1941	0.77	0.73	0.52	0.62	0.42	0.39	0.57	1.37	1.53	2.30	2.17	2.62
1942	3.00	3.51	3.36	3.32	3.54	3.34	3.44	2.94	2.63	1.98	2.70	2.32
1943	2.42	2.48	2.25	1.67	1.44	2.31	2.89	3.56	2.58	3.22	2.62	1.84
1944	1.20	0.76	1.09	2.57	1.84	2.93	3.37	-0.41	-0.68	-1.22	-0.60	-0.69
1945	-1.40	0.20	0.41	0.16	1.07	2.79	4.03	5.48	5.97	5.57	6.38	6.18
1946	5.50	4.94	5.50	4.49	4.63	3.91	3.61	3.04	3.16	5.06	4.99	5.41
1947	5.26	4.64	3.85	4.06	3.51	4.42	4.78	5.27	5.46	5.15	4.49	3.60
1948	2.49	1.55	0.94	1.79	1.83	2.43	2.64	2.01	1.75	1.30	1.55	1.52
1949	1.82	2.01	1.98	1.04	1.61	1.98	2.42	2.19	1.72	2.67	2.18	2.61
1950	3.68	3.48	3.56	3.11	3.79	3.46	3.93	3.54	3.92	3.31	3.33	3.18

TABLE 1.18

Continued

1951	3.04	3.23	3.10	3.09	3.07	2.51	2.24	3.23	2.64	2.42	2.69	2.98
1952	3.49	3.88	4.01	-0.17	-0.37	-0.17	-0.32	-0.56	-1.17	-2.04	-2.13	-2.67
1953	-2.16	-2.42	-2.82	0.39	1.17	1.38	1.82	-0.57	-1.25	-1.82	-2.54	-2.81
1954	-2.72	-3.26	-3.09	-3.86	-4.30	-4.21	-4.51	-4.70	-4.24	-4.29	-4.00	-3.87
1955	-0.05	0.29	0.17	0.51	0.23	0.51	0.57	0.89	1.13	0.70	1.03	2.75
1956	3.82	3.69	-0.70	-1.24	-1.13	-1.35	-1.63	-2.02	-2.49	-2.36	-2.30	-2.27
1957	-2.21	0.05	0.01	0.90	1.52	1.66	1.90	-0.16	-0.40	-0.60	-0.65	-0.73
1958	-1.14	-1.39	-0.94	-1.28	-1.94	-2.60	-3.00	-2.89	-2.94	-3.51	0.83	0.91
1959	0.98	1.38	1.20	1.30	1.29	1.35	0.98	2.13	2.94	-0.57	-1.45	-1.71
1960	-1.94	-1.97	-1.97	-2.05	-2.36	-2.91	-3.66	-3.42	-3.43	-2.98	-2.09	-2.36
1961	-3.18	-3.34	-3.16	-3.55	-3.93	-4.51	-5.13	-4.81	0.99	1.79	1.60	1.59
1962	1.29	2.32	2.65	2.07	2.25	2.04	2.31	-0.01	-0.46	-0.85	-1.61	-2.40
1963	-3.03	-3.70	-4.32	0.85	-0.48	-0.05	-0.07	-0.63	0.87	1.26	1.60	1.31
1964	1.14	0.65	0.78	0.69	1.11	2.99	4.13	3.75	2.95	2.15	2.02	3.09
1965	3.39	3.70	2.79	2.20	2.14	2.55	3.03	3.63	5.03	3.77	4.96	4.91
1966	-0.19	0.26	0.28	-0.20	-0.64	-1.07	-1.67	-1.92	-1.71	-1.99	-2.13	-1.99
1967	-1.98	-2.33	0.54	2.06	2.08	3.37	4.52	3.80	2.81	2.85	1.91	2.02
1968	1.56	2.09	2.56	2.62	2.25	3.21	3.66	5.56	4.75	4.69	4.51	4.06
1969	4.77	5.82	-0.38	-0.43	-1.48	0.96	1.22	1.09	0.70	0.94	-0.76	-1.05
1970	-1.09	-1.61	-2.06	0.00	0.35	0.45	0.91	0.69	1.10	1.89	2.97	3.95
1971	4.47	4.40	4.71	4.91	4.28	4.41	4.23	4.17	4.15	5.64	5.35	5.58
1972	5.22	4.61	3.56	4.27	2.95	2.70	1.98	1.39	1.82	2.28	2.14	2.07
1973	1.88	1.72	1.96	1.72	1.32	1.35	1.89	2.24	5.21	4.87	4.68	4.89
1974	4.83	5.14	4.40	4.45	-0.35	-0.65	-1.21	-1.59	-2.11	0.85	-0.38	-0.28
1975	-0.46	-0.61	0.71	1.31	1.54	1.91	3.06	2.64	1.92	3.35	3.41	3.38
1976	3.12	4.33	4.88	5.15	4.05	3.97	4.17	4.88	-0.13	-0.37	-1.39	-2.41
1977	-3.17	-4.23	-4.53	-5.46	-4.11	-4.86	-4.88	3.28	3.43	3.03	2.64	2.64
1978	2.19	2.38	1.91	2.70	2.73	2.10	1.63	1.82	3.16	-0.87	-0.79	-0.49
1979	-0.47	-0.16	-0.53	-1.06	-0.76	-0.85	-0.55	-0.83	-1.48	-0.93	-1.12	-1.64
1980	1.14	2.44	3.09	2.05	3.32	4.16	5.62	5.68	5.77	5.28	0.00	0.00

TABLE 1.19

Meteorological Drought In Utah, 1875-1980
(Salt Lake City, 42 7598)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1875	1.49	1.61	2.77	2.52	3.23	3.49	4.09	3.53	3.91	3.38	5.63	5.99
1876	6.13	6.16	7.46	7.01	8.04	7.37	7.24	6.77	6.05	6.57	5.61	5.45
1877	4.70	3.73	3.74	3.67	4.60	4.69	4.88	3.89	3.90	4.24	3.61	3.17
1878	2.58	3.53	3.67	3.93	4.34	4.18	4.50	4.13	6.51	6.12	-0.65	-1.44
1879	-1.47	-2.20	-3.39	-2.88	-3.58	-3.74	-4.39	-4.77	-4.89	-4.14	-4.29	1.05
1880	-0.59	-0.68	-1.05	-0.52	-0.05	-0.30	-0.48	-0.47	-0.32	-0.77	0.06	0.42
1881	0.34	0.98	0.64	0.76	1.35	1.26	0.74	1.25	1.15	1.67	1.75	1.65
1882	1.64	1.16	1.00	2.23	1.62	2.35	2.47	2.91	2.53	3.40	-0.26	-0.41
1883	-0.30	-0.47	-0.65	0.84	0.76	-0.03	-0.49	-0.75	-1.16	0.82	1.09	1.12
1884	0.77	1.47	2.83	3.40	3.44	3.24	2.74	2.43	3.73	2.81	1.82	1.97
1885	1.69	1.56	0.59	1.11	1.65	2.79	3.59	3.53	4.05	3.17	3.69	3.24
1886	3.35	3.04	3.66	4.99	3.84	3.34	2.41	1.79	3.02	3.19	3.32	3.00
1887	3.35	3.40	-0.75	-0.58	-0.85	-1.24	-0.98	-0.95	-0.79	-1.24	-1.99	-1.73
1888	-1.69	-1.84	-1.41	-1.99	-2.51	-2.71	-3.10	-3.07	-2.88	-2.90	-2.36	-1.57
1889	-1.68	-1.67	-1.83	-2.13	-1.25	-1.69	-2.34	-2.26	0.07	1.59	1.40	3.18
1890	4.65	5.27	4.87	-0.36	-0.93	-1.39	-1.96	-1.89	-2.23	-1.75	-2.52	-3.08
1891	-3.66	-4.06	1.42	1.16	0.66	0.67	0.68	0.41	1.10	0.98	0.34	0.79
1892	0.78	0.38	0.53	0.69	0.95	1.38	1.35	-0.67	-1.10	-0.75	-1.24	0.58
1893	0.11	0.30	0.99	1.75	1.99	1.84	2.17	2.04	2.73	2.35	1.95	2.31
1894	2.09	1.76	1.70	1.62	1.37	1.54	1.67	1.63	3.98	-0.15	-1.10	-1.10
1895	-1.28	-1.55	-2.05	-2.70	-2.35	-2.46	-2.59	-3.02	-2.24	-2.68	0.67	-0.09
1896	-0.15	-0.54	0.23	0.84	2.32	2.33	3.04	3.61	3.42	2.69	3.56	3.07
1897	2.81	4.40	4.97	4.77	-0.18	-0.30	-0.16	-0.44	-0.41	0.47	-0.26	-0.12
1898	-0.70	-1.41	-1.28	-1.77	1.38	1.77	1.85	2.09	1.53	1.73	1.98	1.92
1899	1.44	2.49	3.38	2.59	3.22	3.49	3.79	3.80	2.94	3.74	-0.02	-0.30
1900	-0.98	-1.01	-2.19	-1.61	-2.18	-3.21	-3.81	-3.65	-2.30	-1.61	-1.66	-2.33
1901	-2.78	-2.59	-2.02	-2.35	1.17	0.97	0.82	0.86	0.94	-0.27	-0.85	-0.98
1902	-1.56	-2.00	-2.23	-1.17	-1.65	-2.13	-2.30	-2.67	-2.85	-3.09	-2.97	-2.71
1903	-2.13	-2.09	-2.08	-2.18	1.20	1.32	0.02	-0.30	0.41	0.09	0.45	-0.40
1904	-0.43	0.52	2.00	2.15	3.02	2.97	3.37	-0.19	-0.53	-0.52	-1.57	-1.79
1905	-2.45	-2.63	-2.27	-2.32	0.70	-0.43	-0.54	-0.75	1.58	-1.13	-1.56	-1.79
1906	-2.07	0.15	0.78	1.53	2.54	3.25	4.24	5.23	5.86	4.77	4.70	3.98
1907	3.78	4.51	4.66	4.06	4.64	5.10	5.81	6.25	5.39	4.63	3.50	3.57
1908	2.64	2.11	1.86	0.91	3.15	3.98	5.15	5.42	7.29	7.22	6.89	5.89
1909	5.96	5.97	6.43	6.00	6.19	5.76	5.63	5.96	6.53	-0.08	-0.24	-0.09
1910	-0.39	-0.54	-1.07	-2.00	-2.72	-3.75	-4.24	-4.39	-3.79	-2.61	-2.81	-2.74
1911	-2.90	-2.31	-2.04	-1.80	-1.30	-1.28	-1.55	-2.08	1.14	1.36	1.35	-0.03
1912	-0.54	-0.68	1.04	1.54	1.82	2.18	2.92	2.89	3.28	4.11	3.94	3.47
1913	2.92	3.04	3.58	3.39	2.72	3.94	4.33	3.87	3.99	3.71	3.00	2.68
1914	3.21	2.87	2.29	2.57	2.06	2.94	3.75	3.21	2.61	3.06	-0.74	-1.34
1915	-2.03	-1.97	-2.37	-2.71	-2.44	-2.36	-2.78	-3.36	1.13	0.13	0.04	0.26
1916	0.55	0.48	1.07	-0.61	-0.76	-0.78	-0.66	-0.75	0.00	0.84	0.65	1.57
1917	1.44	1.59	2.62	2.54	3.68	3.51	3.96	3.53	3.84	-0.79	-0.98	-1.89
1918	-0.60	-0.30	-0.25	-0.71	-0.59	-1.05	-1.44	-1.54	1.58	-0.16	0.25	-0.42
1919	-1.38	-1.03	-1.77	-1.53	-1.80	-2.88	-3.92	-4.07	1.18	2.11	1.71	1.74
1920	1.59	1.36	2.69	3.61	3.66	3.35	2.96	3.01	3.79	4.93	4.91	4.83
1921	4.69	4.41	3.70	4.06	4.10	3.67	2.88	2.49	2.20	1.78	1.07	1.35
1922	1.13	1.74	2.43	3.30	3.57	3.74	3.45	3.93	2.99	2.21	3.19	4.19
1923	4.58	4.17	4.31	5.15	5.04	5.27	5.31	6.09	6.44	6.49	-0.25	-0.41
1924	-1.04	-1.67	-1.24	-1.66	-1.96	-2.53	-2.97	-3.26	-3.20	0.39	0.37	1.70
1925	1.38	1.51	1.45	1.14	1.59	2.01	3.40	4.27	4.49	-0.26	-0.25	-0.58
1926	-0.79	-0.27	-0.94	-1.36	-1.14	-1.83	-1.83	0.24	0.74	0.26	0.18	0.27
1927	0.21	0.17	0.97	0.69	2.09	2.50	2.85	2.60	3.99	3.45	3.55	3.72
1928	-0.17	-0.73	-0.24	-0.18	-0.28	-0.53	-0.72	-1.26	-1.54	0.32	0.49	-0.42
1929	-0.45	0.04	0.27	1.69	-0.54	-0.54	-0.66	-1.08	2.02	-0.24	-1.00	-1.80

TABLE 1.19

Continued

1930	-2.13	-2.01	-2.67	-3.27	-3.29	-4.09	-4.33	-3.18	-0.94	-0.63	-0.64	-1.04
1931	-1.59	-2.12	-2.54	-2.61	-3.14	-4.20	-4.81	-4.36	-3.91	-4.07	0.42	0.57
1932	0.53	0.45	0.49	0.62	0.32	0.61	0.67	2.16	-0.48	-0.48	-1.07	0.23
1933	0.47	0.34	0.24	0.09	1.25	-0.29	-0.87	-1.50	-1.62	-2.04	-2.77	-3.40
1934	-3.61	-3.45	-4.34	-5.57	-6.94	-7.44	-7.69	-7.03	-6.42	0.01	0.69	1.13
1935	-0.49	-0.86	-0.97	0.58	1.92	1.91	1.71	1.38	1.15	0.42	0.37	0.08
1936	0.64	2.25	2.18	-0.60	-1.19	-1.48	-1.13	-1.02	-1.27	0.25	0.07	0.54
1937	0.93	1.24	-0.01	-0.11	-0.22	-0.58	-0.36	-0.67	0.08	0.79	-0.59	-0.81
1938	-1.65	-2.15	1.03	0.80	1.14	-0.21	-0.59	-0.92	-1.38	0.11	0.65	0.83
1939	0.81	1.39	-0.19	-0.78	-0.97	-0.86	-1.21	-1.74	-1.54	-1.32	-2.36	-2.90
1940	1.09	1.49	1.18	1.38	-0.95	-1.77	-2.81	-3.57	1.15	1.38	2.07	2.09
1941	1.90	1.84	2.05	2.98	2.79	3.11	3.60	3.41	3.19	3.89	4.01	4.35
1942	4.49	4.78	4.97	4.39	5.06	5.05	5.98	-0.43	-0.81	-1.20	-0.93	-0.66
1943	-0.62	-0.13	-0.36	-0.96	-1.20	-0.63	-0.76	-0.97	-1.50	-0.67	-1.53	-1.86
1944	-1.98	-2.07	0.69	2.51	2.55	4.07	4.84	-0.67	-0.65	-1.43	-0.86	-1.18
1945	-1.76	-1.66	-1.58	-1.33	-1.51	0.94	1.44	3.77	3.76	3.13	3.47	-0.07
1946	-0.18	-0.88	-1.30	-1.90	-1.17	-1.90	-1.73	-1.68	-1.81	2.31	2.55	3.03
1947	3.16	2.95	2.21	2.44	2.50	3.77	4.33	4.36	4.45	4.58	4.56	3.92
1948	2.88	2.24	2.52	2.18	1.39	1.95	1.84	1.39	1.32	0.94	1.15	1.99
1949	2.66	2.54	3.35	2.65	3.11	2.74	2.30	1.83	1.77	2.68	2.06	2.02
1950	2.12	1.94	1.53	1.21	1.67	1.39	1.72	1.06	2.26	-0.59	-0.27	-0.78
1951	-0.69	-1.16	-1.21	-0.73	-0.93	-1.35	0.90	1.80	1.22	1.58	1.65	2.65
1952	3.28	3.94	5.36	4.89	4.33	4.14	4.23	-0.38	-0.87	-1.71	-1.59	-1.49
1953	-0.89	-1.35	-1.80	0.63	0.62	0.52	0.64	0.58	-0.43	-1.00	-1.49	-1.69
1954	-2.23	-2.75	-2.82	-3.63	-4.32	-4.10	-4.14	-3.02	-2.63	-2.77	-2.58	-2.71
1955	-2.69	-2.49	-2.96	0.21	-0.03	-0.15	-0.08	-0.39	0.48	0.22	0.81	0.59
1956	1.09	1.18	-0.72	-0.83	-0.33	-0.40	-0.85	-1.48	-1.76	-1.18	-1.42	-1.07
1957	-1.06	-1.59	0.06	0.90	2.04	2.79	3.58	4.02	3.51	2.89	2.72	2.68
1958	2.12	2.17	2.47	3.12	-0.58	-1.29	-2.02	-2.51	-2.55	-3.15	-3.00	-3.33
1959	-3.24	-3.10	-3.46	-3.48	-2.91	-2.86	-3.24	-2.24	-0.79	-1.27	-1.91	-1.99
1960	-2.37	-2.18	-1.74	-2.03	-2.31	-2.86	-3.70	-3.11	-2.91	-2.61	-2.22	-2.53
1961	-3.30	-2.99	-2.87	-3.18	-3.85	-4.92	-5.44	0.04	0.70	0.93	-0.03	-0.27
1962	-0.73	-0.68	0.59	1.12	1.56	1.70	3.03	-0.06	-0.20	-0.45	-1.11	-1.75
1963	-2.56	-3.33	-3.25	-1.72	-2.23	-1.75	-1.92	-2.16	-1.44	-1.60	-1.35	-1.50
1964	-1.77	-2.28	0.49	1.16	2.01	3.41	4.89	4.06	3.37	2.54	2.32	3.72
1965	4.25	4.34	3.59	3.57	3.81	4.57	5.97	7.05	8.18	-0.51	-0.87	-0.45
1966	-1.03	-1.05	-1.31	-1.45	-2.09	-2.97	-3.65	-3.96	-3.32	-2.92	-3.21	-3.27
1967	-2.88	-3.26	-3.15	0.24	0.64	1.72	2.69	-0.48	-0.23	-0.55	-1.13	-0.90
1968	-1.59	0.20	0.22	0.98	1.51	2.29	2.60	4.75	4.45	4.27	3.80	4.07
1969	3.96	4.86	4.23	3.68	2.66	3.30	3.91	3.30	2.58	2.92	2.39	2.44
1970	2.06	1.41	0.87	1.82	1.53	2.00	2.40	2.03	4.28	4.28	4.31	5.01
1971	4.74	5.18	4.68	4.63	4.36	4.17	4.21	4.95	5.87	6.66	6.03	5.73
1972	5.35	4.45	3.56	4.30	-0.54	-1.05	-1.82	-2.33	0.86	1.64	1.53	2.74
1973	2.97	2.98	3.60	3.41	3.33	2.88	2.70	2.68	6.11	5.37	5.44	5.64
1974	5.65	5.80	4.96	6.23	-0.36	-0.69	-1.44	-1.88	-2.23	-1.60	-1.94	-1.81
1975	-1.93	-1.99	0.90	1.56	2.32	3.23	4.32	3.34	2.57	2.68	2.65	2.27
1976	1.52	1.65	1.80	2.11	1.76	1.88	2.51	2.42	-0.31	-0.62	-1.52	-2.26
1977	-2.92	-3.60	-2.77	-3.56	1.52	0.88	0.48	1.19	2.42	1.82	1.35	1.05
1978	1.19	1.27	1.91	2.47	2.55	2.30	1.59	1.39	3.29	-0.86	-0.67	-1.01
1979	-1.51	-1.68	-2.30	-2.79	-3.32	-4.18	-4.73	-4.61	-4.77	-4.41	-4.14	-4.23
1980	0.59	1.14	1.70	1.02	1.72	1.71	2.18	1.62	1.68	1.81	0.00	0.00

TABLE 1.20

Meteorological Drought In Utah, 1896-1980
(Salt Lake, 7598, Logan USU, 5186)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1896	-0.22	-0.79	-0.50	0.52	1.82	1.67	2.35	3.00	2.86	1.12	1.73	1.22
1897	0.83	2.35	3.02	2.90	-0.52	-0.82	-0.79	-1.03	-0.08	0.76	0.62	0.66
1898	-0.44	-0.95	-0.87	-1.29	1.67	1.80	1.89	0.79	0.27	0.50	0.46	0.09
1899	-0.39	-0.22	0.10	-0.52	-0.07	-0.06	0.07	0.27	-0.34	0.67	-1.18	-1.39
1900	-1.97	-2.16	-3.33	-2.43	-2.68	-3.42	-3.91	-3.67	-1.10	-0.46	-0.19	-1.43
1901	-1.78	-1.62	-1.37	-1.59	0.28	0.10	-0.09	0.20	0.35	-0.17	-0.94	-1.18
1902	-2.03	-2.70	-2.82	-2.07	-2.05	-2.32	-2.35	-2.53	-2.80	-3.03	-2.77	-2.68
1903	-2.04	-2.17	-2.42	-1.09	0.99	0.51	-0.14	-0.47	-0.02	-0.25	0.18	-0.47
1904	-0.63	0.44	1.63	0.78	1.00	0.81	0.93	-0.74	-1.13	-1.01	-2.03	-2.36
1905	-3.18	-3.56	-3.60	-3.76	-1.95	-2.71	-2.99	-2.93	-1.10	-2.46	-2.85	-3.27
1906	-3.29	-2.01	0.54	0.99	2.45	2.93	4.04	5.91	6.21	5.16	4.66	4.12
1907	4.73	5.39	5.76	5.03	5.39	5.78	6.34	6.41	2.46	2.06	1.06	0.99
1908	0.17	-0.46	-0.83	-1.77	2.14	2.93	3.87	4.20	5.22	5.89	5.66	4.76
1909	5.17	5.59	5.73	6.38	6.41	5.70	5.43	5.49	6.07	2.52	2.64	2.79
1910	2.64	2.71	-0.76	-1.77	-2.31	-3.29	-3.77	-4.03	-3.67	-2.78	-3.01	-2.92
1911	-0.35	0.13	0.48	-0.95	-0.57	-0.77	-1.05	-1.54	0.99	1.08	1.11	-0.26
1912	-0.79	-1.10	-0.24	0.90	1.25	1.44	2.39	2.82	2.92	3.81	3.93	3.40
1913	2.87	2.79	3.51	3.13	2.48	3.20	3.86	3.51	3.69	3.61	3.13	2.56
1914	3.30	3.21	2.88	2.94	2.21	2.99	3.95	3.48	3.28	3.53	-0.88	-1.55
1915	-2.24	-2.50	-3.42	-3.88	-3.22	-3.19	-3.55	-3.97	1.53	-0.31	-0.44	-0.58
1916	0.40	0.68	1.07	-0.44	-0.62	-0.63	-0.68	-0.96	-0.85	1.17	0.95	1.90
1917	1.80	3.00	3.55	3.69	4.79	4.36	4.58	1.47	1.82	-0.87	-1.24	-2.12
1918	-1.19	-0.79	-0.76	-1.19	-0.99	-1.39	-1.70	-1.81	-0.04	-0.51	-0.39	-1.04
1919	-2.07	-1.94	-2.77	-2.76	-3.05	-4.13	-5.01	-5.04	1.32	2.74	2.35	2.41
1920	2.03	1.88	2.87	3.64	3.31	2.79	2.30	2.48	3.07	4.59	4.55	4.57
1921	4.58	4.43	4.16	4.66	2.05	1.61	0.92	0.73	0.48	0.23	-0.41	1.47
1922	1.38	1.93	2.38	2.92	1.78	1.75	1.45	1.87	1.09	0.43	0.68	2.28
1923	2.73	2.33	2.27	3.06	2.91	3.22	3.47	3.78	4.04	4.30	-0.33	-0.63
1924	-1.40	-2.08	-1.88	-2.39	-2.71	-3.33	-3.76	-4.01	-3.81	0.41	0.30	1.44
1925	1.04	1.17	1.25	0.79	0.82	1.20	1.90	2.36	3.08	-0.44	-0.33	-0.58
1926	-0.94	0.11	-0.80	-1.30	-1.08	-1.74	-1.69	0.27	0.91	-0.15	-0.15	-0.27
1927	-0.50	0.12	0.50	0.60	1.59	1.63	1.90	1.80	2.85	1.69	1.70	1.58
1928	-0.73	-1.46	-1.48	-1.66	-1.89	-2.01	-2.22	-2.62	-2.87	-1.73	-1.53	-2.11
1929	-2.02	-1.80	-1.54	-0.47	-1.85	-1.69	-1.74	-2.03	0.47	-0.47	-0.97	-1.72
1930	-1.89	-1.89	-2.38	-2.81	-1.39	-1.96	-1.98	-0.94	0.69	1.23	-0.31	-0.77
1931	-1.39	-1.98	-2.36	-2.68	-2.86	-3.84	-4.43	-4.32	-4.01	-2.05	0.18	0.57
1932	0.77	0.84	1.35	1.69	1.12	1.12	1.13	2.17	-0.56	-0.79	-1.36	-0.90
1933	-0.71	-1.06	-1.46	-1.38	-0.36	-1.39	-1.96	-2.43	-2.33	-2.77	-3.41	-3.65
1934	-3.88	-3.92	-4.80	-5.84	-7.11	-7.58	-7.98	-7.50	-6.74	-3.33	-2.65	-2.25
1935	-3.04	-3.13	-3.04	-1.84	-0.60	-0.62	-0.70	-0.99	-1.28	-1.51	-1.42	-1.62
1936	-1.17	0.20	0.57	-0.81	-1.33	-1.67	-1.67	-1.49	-1.74	0.44	0.21	0.40
1937	0.56	1.17	0.62	0.97	-0.16	-0.50	0.08	-0.34	0.19	0.56	-0.12	-0.19
1938	-1.09	-1.40	1.21	-0.03	0.34	-0.29	-0.41	-0.74	-1.29	0.56	0.32	0.39
1939	0.44	0.60	-0.43	-0.94	-0.91	-0.81	-0.97	-1.46	-0.45	-0.74	-1.85	-2.45
1940	-0.44	-0.36	-0.70	-0.64	-2.26	-3.00	-3.93	-4.51	1.42	1.55	1.72	1.74
1941	1.34	1.29	1.28	1.80	1.61	1.75	2.09	2.39	2.36	3.10	3.09	3.48
1942	3.74	4.14	4.16	3.86	4.30	4.20	4.71	1.25	0.91	0.39	0.89	0.83
1943	0.90	1.18	0.94	0.35	0.12	0.84	1.07	1.29	0.54	1.27	0.54	-0.01
1944	-0.39	-0.65	0.89	2.54	2.19	3.50	4.11	-0.54	-0.67	-1.33	-0.73	-0.94
1945	-1.58	-0.73	-0.59	-0.59	-0.22	1.87	2.74	4.63	4.86	4.35	4.93	3.05
1946	2.66	2.03	2.10	1.29	1.73	1.01	0.94	0.68	0.68	3.68	3.77	4.22
1947	4.21	3.80	3.03	3.25	3.01	4.10	4.56	4.82	4.95	4.87	4.53	3.76
1948	2.69	1.89	1.73	1.99	1.61	2.19	2.24	1.70	1.54	1.12	1.35	1.75
1949	2.24	2.28	2.66	1.85	2.36	2.36	2.36	2.04	1.75	2.68	2.12	2.32
1950	2.90	2.71	2.55	2.16	2.73	2.42	2.83	2.30	3.09	1.36	1.53	1.20

TABLE 1.20

Continued

1951	1.17	1.04	0.94	1.18	1.07	0.58	1.57	2.52	1.93	2.00	2.17	2.82
1952	3.38	3.91	4.69	2.36	1.98	1.98	1.96	-0.47	-1.02	-1.88	-1.86	-2.08
1953	-1.53	-1.89	-2.31	0.51	0.89	0.95	1.23	0.00	-0.84	-1.41	-2.02	-2.25
1954	-2.48	-3.01	-2.95	-3.75	-4.31	-4.16	-4.33	-3.86	-3.43	-3.53	-3.29	-3.29
1955	-1.37	-1.10	-1.39	0.36	0.10	0.18	0.25	0.25	0.81	0.46	0.92	1.67
1956	2.45	2.43	-0.71	-1.03	-0.73	-0.88	-1.24	-1.75	-2.13	-1.77	-1.86	-1.67
1957	-1.63	-0.77	0.04	0.90	1.78	2.22	2.74	1.93	1.55	1.15	1.04	0.98
1958	0.49	0.39	0.77	0.92	-1.26	-1.94	-2.51	-2.70	-2.75	-3.33	-1.09	-1.21
1959	-1.13	-0.86	-1.13	-1.09	-0.81	-0.75	-1.13	-0.05	1.08	-0.92	-1.68	-1.85
1960	-2.15	-2.08	-1.86	-2.04	-2.34	-2.88	-3.68	-3.27	-3.17	-2.80	-2.15	-2.44
1961	-3.24	-3.16	-3.02	-3.37	-3.89	-4.72	-5.29	-2.38	0.85	1.36	0.79	0.66
1962	0.28	0.82	1.62	1.60	1.90	1.87	2.67	-0.04	-0.33	-0.65	-1.36	-2.08
1963	-2.80	-3.54	-3.79	-0.44	-1.36	-0.90	-1.00	-1.40	-0.29	-0.17	0.13	-0.10
1964	-0.31	-0.81	0.63	0.93	1.56	3.20	4.51	3.90	3.16	2.35	2.17	3.40
1965	3.82	4.02	3.19	2.88	2.98	3.56	4.50	5.34	6.61	1.63	2.05	2.23
1966	-0.61	-0.39	-0.51	-0.83	-1.37	-2.02	-2.66	-2.94	-2.52	-2.46	-2.67	-2.63
1967	-2.43	-2.80	-1.31	1.15	1.36	2.55	3.61	1.66	1.29	1.15	0.39	0.56
1968	-0.02	1.14	1.39	1.80	1.88	2.75	3.13	5.16	4.60	4.48	4.16	4.07
1969	4.37	5.34	1.93	1.63	0.59	2.13	2.57	2.19	1.64	1.93	0.82	0.70
1970	0.48	-0.10	-0.59	0.91	0.94	1.23	1.66	1.36	2.69	3.09	3.64	4.48
1971	4.61	4.79	4.70	4.77	4.32	4.29	4.22	4.56	5.01	6.15	5.69	5.66
1972	5.28	4.53	3.56	4.29	1.21	0.83	0.08	-0.47	1.34	1.96	1.84	2.40
1973	2.42	2.35	2.78	2.57	2.33	2.12	2.30	2.46	5.66	5.12	5.06	5.26
1974	5.27	5.47	4.68	5.34	-0.36	-0.67	-1.33	-1.74	-2.17	-0.38	-1.16	-1.04
1975	-1.19	-1.30	0.81	1.43	1.93	2.57	3.69	2.99	2.24	3.02	3.03	2.83
1976	2.32	2.99	3.34	3.63	2.91	2.92	3.34	3.65	-0.22	-0.50	-1.46	-2.34
1977	-3.05	-3.91	-3.65	-4.51	-1.30	-1.99	-2.20	2.24	2.93	2.42	2.00	1.85
1978	1.69	1.83	1.91	2.59	2.64	2.20	1.61	1.61	3.23	-0.87	-0.73	-0.75
1979	-0.99	-0.92	-1.41	-1.92	-2.04	-2.51	-2.64	-2.72	-3.13	-2.67	-2.63	-2.93
1980	0.87	1.79	2.39	1.53	2.52	2.93	3.90	3.65	3.72	3.55	0.00	0.00

TABLE 1.21

Meteorological Drought, Summary, 1896-1980
(Logan, Utah, 42 5186)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	FEB	1896	MAR	1896	-0.26	2.6541	-1.22	MAR	1896	0	2	0	0	0	2
2	JAN	1897	JAN	1897	-0.15	1.9431	-1.15	JAN	1897	0	1	0	0	0	1
3	JUN	1897	AUG	1897	-1.38	7.1589	-1.62	AUG	1897	0	3	0	0	0	3
4	NOV	1898	AUG	1800	-45.99	225.8846	-4.47	MAR	1800	0	2	5	7	0	14
5	JUL	1901	MAR	1903	-25.29	116.0265	-3.41	MAR	1902	0	4	12	2	0	18
6	MAY	1904	FEB	1906	-55.56	323.4255	-5.45	JUL	1905	0	6	2	3	11	22
7	NOV	1907	APR	1908	-10.28	51.6297	-4.45	APR	1903	0	2	1	2	1	6
8	APR	1910	DEC	1910	-17.07	79.8549	-3.66	AUG	1910	0	2	2	5	0	9
9	AUG	1911	AUG	1911	-0.01	1.4187	-1.01	AUG	1911	0	1	0	0	0	1
10	JAN	1912	MAR	1912	-1.06	5.8915	-1.52	FEB	1912	0	3	0	0	0	3
11	NOV	1914	AUG	1915	-24.65	136.3169	-5.04	APR	1915	0	2	1	2	5	10
12	DEC	1915	DEC	1915	-0.42	3.4070	-1.42	DEC	1915	0	1	0	0	0	1
13	AUG	1916	SEP	1916	-0.87	5.2724	-1.69	SEP	1916	0	2	0	0	0	2
14	NOV	1917	AUG	1919	-35.50	204.9790	-6.10	JUL	1919	1	11	4	2	4	22
15	JUL	1921	NOV	1921	-1.54	9.2690	-1.90	NOV	1921	0	5	0	0	0	5
16	OCT	1922	NOV	1922	-1.19	6.2669	-1.83	NOV	1922	0	2	0	0	0	2
17	JAN	1924	SEP	1924	-22.21	118.2010	-4.77	AUG	1924	0	1	2	2	4	9
18	JAN	1926	JAN	1926	-0.09	2.0683	-1.09	JAN	1926	0	1	0	0	0	1
19	APR	1926	JUL	1926	-1.44	8.0748	-1.64	JUN	1926	0	4	0	0	0	4
20	JAN	1927	JAN	1927	-0.21	2.6370	-1.21	JAN	1927	0	1	0	0	0	1
21	JAN	1928	APR	1930	-43.90	236.9757	-4.19	SEP	1928	2	5	8	12	1	28
22	JAN	1931	SEP	1931	-17.44	87.6662	-4.28	AUG	1931	0	2	3	1	3	9
23	OCT	1932	SEP	1936	-132.25	852.7236	-8.26	JUL	1934	0	10	7	14	17	48
24	SEP	1938	SEP	1938	-0.19	3.7416	-1.19	SEP	1938	0	1	0	0	0	1
25	APR	1939	AUG	1939	-0.27	4.9009	-1.18	AUG	1939	3	2	0	0	0	5
26	NOV	1939	AUG	1940	-21.06	114.1934	-5.44	AUG	1940	0	3	3	1	3	10
27	OCT	1944	JAN	1945	-0.62	4.9150	-1.40	JAN	1945	2	2	0	0	0	4
28	SEP	1952	MAR	1953	-8.41	36.2814	-2.82	MAR	1953	0	1	6	0	0	7
29	SEP	1953	DEC	1954	-39.47	208.0265	-4.70	AUG	1954	0	2	3	4	7	16
30	APR	1956	JAN	1957	-9.00	38.9610	-2.49	SEP	1956	0	4	6	0	0	10
31	JAN	1958	OCT	1958	-11.69	56.0941	-3.51	OCT	1958	1	4	3	2	0	10
32	NOV	1959	AUG	1961	-43.91	219.8862	-5.13	JUL	1961	0	5	6	8	3	22
33	NOV	1962	MAR	1963	-10.06	50.8196	-4.32	MAR	1963	0	1	1	2	1	5
34	JUN	1966	FEB	1967	-7.79	33.4711	-2.33	FEB	1967	0	7	2	0	0	9
35	MAY	1969	MAY	1969	-0.48	2.5197	-1.48	MAY	1969	0	1	0	0	0	1
36	DEC	1969	MAR	1970	-1.81	9.7039	-2.06	MAR	1970	0	3	1	0	0	4
37	JUL	1974	SEP	1974	-1.91	8.9893	-2.11	SEP	1974	0	2	1	0	0	3
38	NOV	1976	JUL	1977	-26.04	151.3009	-5.46	APR	1977	0	1	1	1	6	9
39	APR	1979	DEC	1979	-1.30	12.5629	-1.64	DEC	1979	5	4	0	0	0	9
NUMBER OF MONTHS										14	116	80	70	66	346
PERCENT OF TIME (1020 MONTHS)											11%	8%	7%	6%	34%

TABLE 1.22

Meteorological Drought, Summary, 1875-1980
(Salt Lake City, 42 7598)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY			NUMBER OF DROUGHT MONTHS					
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	DEC	1878	NOV	1879	-29.18	157.5683	-4.89	SEP	1879	0	2	2	3	5	12
2	MAR	1880	MAR	1880	-0.05	3.4225	-1.05	MAR	1880	2	1	0	0	0	3
3	SEP	1883	SEP	1883	-0.16	3.1182	-1.16	SEP	1883	0	1	0	0	0	1
4	JUN	1887	AUG	1889	-25.08	112.2434	-3.10	JUL.	1888	3	14	8	2	0	27
5	JUN	1890	FEB	1891	-13.54	64.0917	-4.06	FEB	1891	0	4	2	2	1	9
6	SEP	1892	NOV	1892	-0.34	3.7590	-1.24	NOV	1892	1	2	0	0	0	3
7	NOV	1894	OCT	1895	-13.12	57.5785	-3.02	AUG	1895	0	4	7	1	0	12
8	FEB	1898	APR	1898	-1.46	8.1633	-1.77	APR	1898	0	3	0	0	0	3
9	FEB	1900	APR	1901	-20.30	92.4602	-3.81	JUL	1900	0	4	8	3	0	15
10	JAN	1902	APR	1903	-19.81	86.0289	-3.09	OCT	1902	0	3	12	1	0	16
11	NOV	1904	APR	1905	-7.03	30.1460	-2.63	FEB	1905	0	2	4	0	0	6
12	OCT	1905	JAN	1906	-2.55	12.2385	-2.07	JAN	1906	0	3	1	0	0	4
13	MAR	1910	AUG	1911	-27.38	132.1562	-4.39	AUG	1910	0	5	9	2	2	18
14	DEC	1914	AUG	1915	-12.36	54.6021	-3.36	AUG	1915	0	2	6	1	0	9
15	DEC	1917	AUG	1918	-1.92	14.6252	-1.89	DEC	1917	3	4	0	0	0	7
16	JAN	1919	AUG	1919	-10.38	52.1068	-4.07	AUG	1919	0	5	1	1	1	8
17	JAN	1924	SEP	1924	-10.53	48.3253	-3.26	AUG	1924	0	5	2	2	0	9
18	APR	1926	JUL	1926	-2.16	11.8941	-1.83	JUN	1926	0	4	0	0	0	4
19	AUG	1928	SEP	1928	-0.80	5.4837	-1.54	SEP	1928	0	2	0	0	0	2
20	AUG	1929	AUG	1929	-0.08	2.5641	-1.08	AUG	1929	0	1	0	0	0	1
21	NOV	1929	OCT	1931	-41.16	211.6661	-4.81	JUL	1931	3	4	6	5	6	24
22	NOV	1932	NOV	1932	-0.07	1.6057	-1.07	NOV	1932	0	1	0	0	0	1
23	AUG	1933	SEP	1934	-49.82	357.1956	-7.69	JUL	1934	0	2	2	3	7	14
24	MAY	1936	SEP	1936	-1.09	9.8173	-1.48	JUN	1936	0	5	0	0	0	5
25	JAN	1938	FEB	1938	-1.80	9.3247	-2.15	FEB	1938	0	1	1	0	0	2
26	SEP	1938	SEP	1938	-0.38	3.1430	-1.38	SEP	1938	0	1	0	0	0	1
27	JUL	1939	DEC	1939	-5.07	24.9103	-2.90	DEC	1939	0	4	2	0	0	6
28	JUN	1940	AUG	1940	-5.15	24.6764	-3.57	AUG	1940	0	1	1	1	0	3
29	OCT	1942	FEB	1944	-4.34	25.0941	-2.07	FEB	1944	8	6	1	0	0	15
30	OCT	1944	MAY	1945	-3.45	17.4469	-1.76	JAN	1945	1	7	0	0	0	8
31	MAR	1946	SEP	1946	-4.49	20.1820	-1.90	APR	1946	0	7	0	0	0	7
32	FEB	1951	JUN	1951	-0.72	7.5355	-1.35	JUN	1951	2	3	0	0	0	5
33	OCT	1952	MAR	1953	-2.94	14.4282	-1.80	MAR	1953	1	5	0	0	0	6
34	OCT	1953	MAR	1955	-32.02	152.4463	-4.32	MAY	1954	0	3	10	2	3	18
35	AUG	1956	FEB	1957	-2.56	15.8740	-1.76	SEP	1956	0	7	0	0	0	7
36	JUN	1958	JUL	1961	-67.67	322.8996	-5.44	JUL	1961	1	5	17	13	2	38
37	NOV	1962	FEB	1964	-15.77	70.5335	-3.38	FEB	1963	0	10	4	2	0	16
38	JAN	1966	MAR	1967	-24.52	118.7849	-3.96	AUG	1966	0	4	4	7	0	15
39	NOV	1967	JAN	1968	-0.72	5.2008	-1.59	JAN	1968	1	2	0	0	0	3
40	JUN	1972	AUG	1972	-2.20	10.1354	-2.33	AUG	1972	0	2	1	0	0	3
41	JUL	1974	FEB	1975	-6.82	28.4713	-2.23	SEP	1974	0	7	1	0	0	8
42	NOV	1976	APR	1977	-10.63	49.7314	-3.60	FEB	1977	0	1	3	2	0	6
43	DEC	1978	DEC	1979	-30.68	169.7385	-4.77	SEP	1979	0	3	2	1	7	13
NUMBER OF MONTHS										26	162	117	54	34	393
PERCENT OF TIME (1272 MONTHS)											13%	9%	4%	3%	31%

TABLE 1.23

Meteorological Drought, Summary, 1896-1980
(Salt Lake, 7598, Logan USU, 5186)

	BEGAN		ENDED			INDEX	MAXIMUM SEVERITY				NUMBER OF DROUGHT MONTHS				
NO.	MONTH	YEAR	MONTH	YEAR	AREA	SQUARED	INDEX	MONTH	YEAR	INCIPIENT	MILD	MODERATE	SEVERE	EXTREME	TOTAL
1	AUG	1897	AUG	1897	-0.03	3.5567	-1.03	AUG	1897	0	1	0	0	0	1
2	APR	1898	APR	1898	-0.29	3.5171	-1.29	APR	1898	0	1	0	0	0	1
3	NOV	1899	APR	1801	-19.03	90.7960	-3.91	JUL	1800	0	2	0	0	0	2
4	DEC	1901	APR	1903	-22.05	95.2607	-3.03	OCT	1902	0	2	14	1	0	17
5	SEP	1904	FEB	1906	-28.19	132.9527	-3.76	APR	1905	0	4	8	6	0	18
6	APR	1908	APR	1908	-0.77	4.0334	-1.77	APR	1908	0	1	0	0	0	1
7	APR	1910	DEC	1910	-18.55	89.2308	-4.03	AUG	1910	0	1	3	4	1	9
8	JUL	1911	AUG	1911	-0.59	5.2944	-1.54	AUG	1911	0	2	0	0	0	2
9	FEB	1912	FEB	1912	-0.10	1.9593	-1.10	FEB	1912	0	1	0	0	0	1
10	DEC	1914	AUG	1915	-18.52	90.1032	-3.97	AUG	1915	0	1	2	6	0	9
11	NOV	1917	AUG	1919	-22.45	125.3041	-5.04	AUG	1919	4	8	4	1	3	20
12	JAN	1924	SEP	1924	-16.37	79.3736	-4.01	AUG	1924	0	2	3	3	1	9
13	APR	1926	JUL	1926	-1.81	10.9026	-1.74	JUN	1926	0	4	0	0	0	4
14	FEB	1928	AUG	1929	-16.25	68.7462	-2.87	SEP	1928	0	11	7	0	0	18
15	DEC	1929	JUL	1930	-8.02	35.4026	-2.81	APR	1930	1	6	2	0	0	9
16	JAN	1931	OCT	1931	-19.92	100.7886	-4.43	JUL	1931	0	2	4	1	3	10
17	NOV	1932	JAN	1936	-72.83	487.0368	-7.98	JUL	1934	6	12	5	8	7	38
18	MAY	1936	SEP	1936	-2.90	13.2505	-1.74	SEP	1936	0	5	0	0	0	5
19	JAN	1938	FEB	1938	-0.49	3.5898	-1.40	FEB	1938	0	2	0	0	0	2
20	SEP	1938	SEP	1938	-0.29	2.4648	-1.29	SEP	1938	0	1	0	0	0	1
21	AUG	1939	AUG	1940	-12.46	66.9157	-4.51	AUG	1940	3	2	2	2	1	10
22	OCT	1944	JAN	1945	-0.91	8.2745	-1.58	JAN	1945	5	2	0	0	0	7
23	SEP	1952	MAR	1953	-5.57	23.8308	-2.31	MAR	1953	0	5	2	0	0	7
24	OCT	1953	MAR	1955	-33.93	170.2353	-4.33	JUL	1954	0	4	4	7	3	18
25	APR	1956	JAN	1957	-5.08	24.6405	-2.13	SEP	1956	3	7	1	0	0	11
26	MAY	1958	JUL	1959	-9.27	47.2244	-3.33	OCT	1958	3	8	3	1	0	15
27	NOV	1959	AUG	1961	-41.46	202.1512	-5.29	JUL	1961	0	3	9	8	2	22
28	NOV	1962	AUG	1963	-9.33	47.3709	-3.79	MAR	1963	1	4	2	2	0	9
29	MAY	1966	MAR	1967	-14.81	65.8207	-2.94	AUG	1966	0	2	9	0	0	11
30	JUL	1974	FEB	1975	-2.93	16.3410	-2.17	SEP	1974	0	6	1	0	0	7
31	NOV	1976	JUL	1977	-15.41	76.6489	-4.51	APR	1977	0	3	2	3	1	9
32	MAR	1979	DEC	1979	-14.60	66.6106	-3.13	SEP	1979	0	2	7	1	0	10
NUMBER OF MONTHS										26	117	94	54	22	313
PERCENT OF TIME (1020 MONTHS)											11%	9%	5%	2%	31%

TABLE 1.24

Selected Additional Output From Palmer Calculations

1.	SP	Available soil moisture at beginning of month.
2.	SS	Amount of available soil moisture in surface layer at beginning of month.
3.	SU	Amount of available soil moisture in underlying soil at beginning of month.
4.	PE	Potential evapotranspiration (Thornthwaite method).
5.	PL	Monthly potential moisture loss.
6.	PR	Potential recharge; at the start of a month. This is the number of inches required to bring the soil to field capacity.
7.	R	Monthly recharge; net gain in the surface and underlying soil.
8.	L	Monthly moisture loss from the surface and underlying soil.
9.	ET	Monthly evapotranspiration.
10.	RO	Monthly runoff.

of each particular variable, and the calculations are based upon the average temperature and precipitation for each month, comparisons of the calculated values for various drought periods seem reasonable. It was therefore decided to relate the average Palmer Index over the growing season to the production of range crops and non-fallowed dryland crops. For winter wheat, grown on fallowed land, the calculated soil moisture values gave a better relationship when corrected by precipitation during the previous fallow season.

To obtain the information needed to relate the seasonal Palmer Index to production on the range, average values for the winter season (October through March) and the growing season (April through September) were calculated. Tabulations of these average indices can be found in Tables 1.25 through 1.35.

TABLE 1.25

Division 1 Seasons

Summer	
APR 1931 to SEP 1931	-0.4
APR 1932 to SEP 1932	3.8
APR 1933 to SEP 1933	0.8
APR 1934 to SEP 1934	-4.0
APR 1935 to SEP 1935	0.4
APR 1936 to SEP 1936	0.7
APR 1937 to SEP 1937	3.7
APR 1938 to SEP 1938	4.6
APR 1939 to SEP 1939	-0.8
APR 1940 to SEP 1940	-0.4
APR 1941 to SEP 1941	6.5
APR 1942 to SEP 1942	7.4
APR 1943 to SEP 1943	2.5
APR 1944 to SEP 1944	2.5
APR 1945 to SEP 1945	2.0
APR 1946 to SEP 1946	-2.0
APR 1947 to SEP 1947	3.1
APR 1948 to SEP 1948	-0.3
APR 1949 to SEP 1949	1.0
APR 1950 to SEP 1950	-1.9
APR 1951 to SEP 1951	-1.7
APR 1952 to SEP 1952	-0.2
APR 1953 to SEP 1953	-3.3
APR 1954 to SEP 1954	-4.5
APR 1955 to SEP 1955	-3.5
APR 1956 to SEP 1956	-4.3
APR 1957 to SEP 1957	-4.0
APR 1958 to SEP 1958	-2.6
APR 1959 to SEP 1959	-3.7
APR 1960 to SEP 1960	-4.9
APR 1961 to SEP 1961	-2.8
APR 1962 to SEP 1962	0.0
APR 1963 to SEP 1963	0.6
APR 1964 to SEP 1964	0.2
APR 1965 to SEP 1965	1.0
APR 1966 to SEP 1966	-3.4
APR 1967 to SEP 1967	1.4
APR 1968 to SEP 1968	-0.8
APR 1969 to SEP 1969	-0.3
APR 1970 to SEP 1970	-1.8
APR 1971 to SEP 1971	0.2
APR 1972 to SEP 1972	-3.5
APR 1973 to SEP 1973	1.3
APR 1974 to SEP 1974	-3.6
APR 1975 to SEP 1975	0.9
APR 1976 to SEP 1976	-1.9
APR 1977 to SEP 1977	-3.2
APR 1978 to SEP 1978	-1.1
APR 1979 to SEP 1979	-0.6
APR 1980 to MAR 1980	3.1

Winter	
OCT 1931 to MAR 1932	0.9
OCT 1932 to MAR 1933	2.7
OCT 1933 to MAR 1934	-1.6
OCT 1934 to MAR 1935	0.1
OCT 1935 to MAR 1936	0.0
OCT 1936 to MAR 1937	2.5
OCT 1937 to MAR 1938	3.2
OCT 1938 to MAR 1939	3.1
OCT 1939 to MAR 1940	0.5
OCT 1940 to MAR 1941	2.4
OCT 1941 to MAR 1942	8.1
OCT 1942 to MAR 1943	4.9
OCT 1943 to MAR 1944	1.4
OCT 1944 to MAR 1945	1.2
OCT 1945 to MAR 1946	-0.3
OCT 1946 to MAR 1947	3.2
OCT 1947 to MAR 1948	1.5
OCT 1948 to MAR 1949	0.7
OCT 1949 to MAR 1950	-0.6
OCT 1950 to MAR 1951	-2.8
OCT 1951 to MAR 1952	0.8
OCT 1952 to MAR 1953	-2.2
OCT 1953 to MAR 1954	-3.7
OCT 1954 to MAR 1955	-4.0
OCT 1955 to MAR 1956	-2.9
OCT 1956 to MAR 1957	-4.9
OCT 1957 to MAR 1958	-2.9
OCT 1958 to MAR 1959	-3.1
OCT 1959 to MAR 1960	-3.4
OCT 1960 to MAR 1961	-4.2
OCT 1961 to MAR 1962	1.4
OCT 1962 to MAR 1963	-2.2
OCT 1963 to MAR 1964	-0.5
OCT 1964 to MAR 1965	-1.4
OCT 1965 to MAR 1966	-0.7
OCT 1966 to MAR 1967	-3.2
OCT 1967 to MAR 1968	-1.4
OCT 1968 to MAR 1969	-0.6
OCT 1969 to MAR 1970	-1.0
OCT 1970 to MAR 1971	-1.3
OCT 1971 to MAR 1972	-0.3
OCT 1972 to MAR 1973	1.3
OCT 1973 to MAR 1974	-0.5
OCT 1974 to MAR 1975	-2.9
OCT 1975 to MAR 1976	-0.8
OCT 1976 to MAR 1977	-2.9
OCT 1977 to MAR 1978	-2.7
OCT 1978 to MAR 1979	1.0
OCT 1979 to MAR 1980	0.1

TABLE 1.26

Division 2 Seasons

Summer	
APR 1931 to SEP 1931	-0.9
APR 1932 to SEP 1932	4.0
APR 1933 to SEP 1933	-1.5
APR 1934 to SEP 1934	-0.6
APR 1935 to SEP 1935	1.0
APR 1936 to SEP 1936	-1.6
APR 1937 to SEP 1937	0.8
APR 1938 to SEP 1938	0.3
APR 1939 to SEP 1939	-0.6
APR 1940 to SEP 1940	1.0
APR 1941 to SEP 1941	7.6
APR 1942 to SEP 1942	4.7
APR 1943 to SEP 1943	2.1
APR 1944 to SEP 1944	0.9
APR 1945 to SEP 1945	-0.2
APR 1946 to SEP 1946	-2.9
APR 1947 to SEP 1947	-1.1
APR 1948 to SEP 1948	-1.0
APR 1949 to SEP 1949	-0.3
APR 1950 to SEP 1950	-2.7
APR 1951 to SEP 1951	-2.4
APR 1952 to SEP 1952	0.8
APR 1953 to SEP 1953	-3.1
APR 1954 to SEP 1954	-1.8
APR 1955 to SEP 1955	-2.2
APR 1956 to SEP 1956	-3.7
APR 1957 to SEP 1957	0.0
APR 1958 to SEP 1958	4.7
APR 1959 to SEP 1959	-2.2
APR 1960 to SEP 1960	-0.8
APR 1961 to SEP 1961	-0.6
APR 1962 to SEP 1962	-0.1
APR 1963 to SEP 1963	-0.3
APR 1964 to SEP 1964	-0.3
APR 1965 to SEP 1965	2.5
APR 1966 to SEP 1966	1.9
APR 1967 to SEP 1967	1.8
APR 1968 to SEP 1968	1.3
APR 1969 to SEP 1969	1.8
APR 1970 to SEP 1970	-1.9
APR 1971 to SEP 1971	14.8
APR 1972 to SEP 1972	-1.5
APR 1973 to SEP 1973	2.7
APR 1974 to SEP 1974	-2.4
APR 1975 to SEP 1975	1.0
APR 1976 to SEP 1976	-1.6
APR 1977 to SEP 1977	-3.1
APR 1978 to SEP 1978	4.9
APR 1979 to SEP 1979	5.1
APR 1980 to MAR 1980	6.0

Winter	
OCT 1931 to MAR 1932	1.7
OCT 1932 to MAR 1933	-1.0
OCT 1933 to MAR 1934	-1.9
OCT 1934 to MAR 1935	1.3
OCT 1935 to MAR 1936	-0.7
OCT 1936 to MAR 1937	1.6
OCT 1937 to MAR 1938	-0.5
OCT 1938 to MAR 1939	-0.5
OCT 1939 to MAR 1940	0.5
OCT 1940 to MAR 1941	3.3
OCT 1941 to MAR 1942	7.9
OCT 1942 to MAR 1943	2.1
OCT 1943 to MAR 1944	1.3
OCT 1944 to MAR 1945	-0.8
OCT 1945 to MAR 1946	-0.6
OCT 1946 to MAR 1947	0.6
OCT 1947 to MAR 1948	-1.0
OCT 1948 to MAR 1949	-0.4
OCT 1949 to MAR 1950	-0.9
OCT 1950 to MAR 1951	-3.9
OCT 1951 to MAR 1952	1.2
OCT 1952 to MAR 1953	-1.5
OCT 1953 to MAR 1954	-2.9
OCT 1954 to MAR 1955	-1.8
OCT 1955 to MAR 1956	-2.0
OCT 1956 to MAR 1957	-2.2
OCT 1957 to MAR 1958	2.1
OCT 1958 to MAR 1959	-0.8
OCT 1959 to MAR 1960	-1.4
OCT 1960 to MAR 1961	-0.3
OCT 1961 to MAR 1962	1.2
OCT 1962 to MAR 1963	-1.0
OCT 1963 to MAR 1964	-0.7
OCT 1964 to MAR 1965	-1.6
OCT 1965 to MAR 1966	3.1
OCT 1966 to MAR 1967	1.6
OCT 1967 to MAR 1968	2.2
OCT 1968 to MAR 1969	0.6
OCT 1969 to MAR 1970	-1.3
OCT 1970 to MAR 1971	11.0
OCT 1971 to MAR 1972	4.2
OCT 1972 to MAR 1973	4.1
OCT 1973 to MAR 1974	-1.0
OCT 1974 to MAR 1975	0.0
OCT 1975 to MAR 1976	-0.9
OCT 1976 to MAR 1977	-2.4
OCT 1977 to MAR 1978	-0.1
OCT 1978 to MAR 1979	4.9
OCT 1979 to MAR 1980	3.7

TABLE 1.27

Division 3 Seasons

Summer	
APR 1931 to SEP 1931	-2.1
APR 1932 to SEP 1932	1.6
APR 1933 to SEP 1933	-1.6
APR 1934 to SEP 1934	-8.2
APR 1935 to SEP 1935	0.0
APR 1936 to SEP 1936	-0.3
APR 1937 to SEP 1937	0.1
APR 1938 to SEP 1938	0.6
APR 1939 to SEP 1939	-0.7
APR 1940 to SEP 1940	-2.1
APR 1941 to SEP 1941	3.3
APR 1942 to SEP 1942	3.2
APR 1943 to SEP 1943	-0.1
APR 1944 to SEP 1944	1.5
APR 1945 to SEP 1945	2.9
APR 1946 to SEP 1946	2.2
APR 1947 to SEP 1947	4.3
APR 1948 to SEP 1948	2.2
APR 1949 to SEP 1949	2.3
APR 1950 to SEP 1950	1.7
APR 1951 to SEP 1951	1.5
APR 1952 to SEP 1952	-0.3
APR 1953 to SEP 1953	-1.2
APR 1954 to SEP 1954	-4.9
APR 1955 to SEP 1955	-0.5
APR 1956 to SEP 1956	-1.3
APR 1957 to SEP 1957	2.3
APR 1958 to SEP 1958	-1.3
APR 1959 to SEP 1959	-1.3
APR 1960 to SEP 1960	-3.0
APR 1961 to SEP 1961	-3.4
APR 1962 to SEP 1962	1.7
APR 1963 to SEP 1963	0.5
APR 1964 to SEP 1964	2.8
APR 1965 to SEP 1965	4.3
APR 1966 to SEP 1966	-2.1
APR 1967 to SEP 1967	2.6
APR 1968 to SEP 1968	3.3
APR 1969 to SEP 1969	0.2
APR 1970 to SEP 1970	1.3
APR 1971 to SEP 1971	3.9
APR 1972 to SEP 1972	-0.7
APR 1973 to SEP 1973	3.2
APR 1974 to SEP 1974	-0.7
APR 1975 to SEP 1975	2.8
APR 1976 to SEP 1976	0.4
APR 1977 to SEP 1977	-0.6
APR 1978 to SEP 1978	1.6
APR 1979 to SEP 1979	-0.9
APR 1980 to MAR 1980	3.4

Winter	
OCT 1931 to MAR 1932	0.4
OCT 1932 to MAR 1933	-1.4
OCT 1933 to MAR 1934	-3.9
OCT 1934 to MAR 1935	-1.3
OCT 1935 to MAR 1936	-0.0
OCT 1936 to MAR 1937	1.0
OCT 1937 to MAR 1938	-0.2
OCT 1938 to MAR 1939	0.8
OCT 1939 to MAR 1940	-1.0
OCT 1940 to MAR 1941	1.4
OCT 1941 to MAR 1942	5.0
OCT 1942 to MAR 1943	-0.4
OCT 1943 to MAR 1944	-0.6
OCT 1944 to MAR 1945	-0.5
OCT 1945 to MAR 1946	4.1
OCT 1946 to MAR 1947	4.0
OCT 1947 to MAR 1948	4.0
OCT 1948 to MAR 1949	2.1
OCT 1949 to MAR 1950	2.2
OCT 1950 to MAR 1951	1.1
OCT 1951 to MAR 1952	3.4
OCT 1952 to MAR 1953	-2.0
OCT 1953 to MAR 1954	-2.8
OCT 1954 to MAR 1955	-3.5
OCT 1955 to MAR 1956	0.8
OCT 1956 to MAR 1957	-2.4
OCT 1957 to MAR 1958	1.6
OCT 1958 to MAR 1959	-3.0
OCT 1959 to MAR 1960	-1.5
OCT 1960 to MAR 1961	-3.4
OCT 1961 to MAR 1962	1.8
OCT 1962 to MAR 1963	-2.9
OCT 1963 to MAR 1964	-0.3
OCT 1964 to MAR 1965	3.1
OCT 1965 to MAR 1966	-0.2
OCT 1966 to MAR 1967	-2.1
OCT 1967 to MAR 1968	1.7
OCT 1968 to MAR 1969	3.7
OCT 1969 to MAR 1970	-0.4
OCT 1970 to MAR 1971	3.9
OCT 1971 to MAR 1972	3.2
OCT 1972 to MAR 1973	2.4
OCT 1973 to MAR 1974	3.6
OCT 1974 to MAR 1975	-0.1
OCT 1975 to MAR 1976	2.7
OCT 1976 to MAR 1977	-2.7
OCT 1977 to MAR 1978	0.7
OCT 1978 to MAR 1979	1.9
OCT 1979 to MAR 1980	0.3

TABLE 1.28

Division 4 Seasons

Summer		Winter	
APR 1931 to SEP 1931	-2.1	OCT 1931 to MAR 1932	0.6
APR 1932 to SEP 1932	1.8	OCT 1932 to MAR 1933	-1.1
APR 1933 to SEP 1933	-0.3	OCT 1933 to MAR 1934	-2.3
APR 1934 to SEP 1934	-5.6	OCT 1934 to MAR 1935	-4.8
APR 1935 to SEP 1935	-2.4	OCT 1935 to MAR 1936	-2.6
APR 1936 to SEP 1936	0.2	OCT 1936 to MAR 1937	2.9
APR 1937 to SEP 1937	3.5	OCT 1937 to MAR 1938	2.1
APR 1938 to SEP 1938	3.0	OCT 1938 to MAR 1939	2.0
APR 1939 to SEP 1939	-0.5	OCT 1939 to MAR 1940	-0.2
APR 1940 to SEP 1940	-1.2	OCT 1940 to MAR 1941	1.9
APR 1941 to SEP 1941	4.6	OCT 1941 to MAR 1942	6.1
APR 1942 to SEP 1942	3.2	OCT 1942 to MAR 1943	-0.8
APR 1943 to SEP 1943	-0.3	OCT 1943 to MAR 1944	0.6
APR 1944 to SEP 1944	1.7	OCT 1944 to MAR 1945	-0.9
APR 1945 to SEP 1945	2.2	OCT 1945 to MAR 1946	0.1
APR 1946 to SEP 1946	-0.8	OCT 1946 to MAR 1947	3.0
APR 1947 to SEP 1947	3.6	OCT 1947 to MAR 1948	3.8
APR 1948 to SEP 1948	2.8	OCT 1948 to MAR 1949	1.7
APR 1949 to SEP 1949	1.3	OCT 1949 to MAR 1950	-0.4
APR 1950 to SEP 1950	-2.0	OCT 1950 to MAR 1951	-3.3
APR 1951 to SEP 1951	-2.1	OCT 1951 to MAR 1952	1.5
APR 1952 to SEP 1952	2.6	OCT 1952 to MAR 1953	-1.1
APR 1953 to SEP 1953	-1.3	OCT 1953 to MAR 1954	-1.5
APR 1954 to SEP 1954	-2.2	OCT 1954 to MAR 1955	-1.7
APR 1955 to SEP 1955	-2.0	OCT 1955 to MAR 1956	-2.0
APR 1956 to SEP 1956	-3.4	OCT 1956 to MAR 1957	-3.8
APR 1957 to SEP 1957	1.9	OCT 1957 to MAR 1958	3.1
APR 1958 to SEP 1958	0.9	OCT 1958 to MAR 1959	-1.6
APR 1959 to SEP 1959	-3.6	OCT 1959 to MAR 1960	-3.3
APR 1960 to SEP 1960	-4.1	OCT 1960 to MAR 1961	-3.1
APR 1961 to SEP 1961	-1.3	OCT 1961 to MAR 1962	2.0
APR 1962 to SEP 1962	0.9	OCT 1962 to MAR 1963	-1.9
APR 1963 to SEP 1963	-2.6	OCT 1963 to MAR 1964	-2.4
APR 1964 to SEP 1964	-1.5	OCT 1964 to MAR 1965	0.2
APR 1965 to SEP 1965	3.5	OCT 1965 to MAR 1966	2.1
APR 1966 to SEP 1966	-1.2	OCT 1966 to MAR 1967	-0.1
APR 1967 to SEP 1967	2.0	OCT 1967 to MAR 1968	2.4
APR 1968 to SEP 1968	2.4	OCT 1968 to MAR 1969	2.0
APR 1969 to SEP 1969	3.1	OCT 1969 to MAR 1970	-0.3
APR 1970 to SEP 1970	-0.2	OCT 1970 to MAR 1971	-0.1
APR 1971 to SEP 1971	-0.5	OCT 1971 to MAR 1972	0.2
APR 1972 to SEP 1972	-1.7	OCT 1972 to MAR 1973	3.7
APR 1973 to SEP 1973	4.4	OCT 1973 to MAR 1974	-0.1
APR 1974 to SEP 1974	-1.8	OCT 1974 to MAR 1975	-1.7
APR 1975 to SEP 1975	1.0	OCT 1975 to MAR 1976	-0.7
APR 1976 to SEP 1976	-1.1	OCT 1976 to MAR 1977	-2.9
APR 1977 to SEP 1977	-4.5	OCT 1977 to MAR 1978	-1.5
APR 1978 to SEP 1978	1.8	OCT 1978 to MAR 1979	3.6
APR 1979 to SEP 1979	4.0	OCT 1979 to MAR 1980	2.9
APR 1980 to MAR 1980	5.0		

TABLE 1.29

Division 5 Seasons

Summer		Winter	
APR 1931 to SEP 1931	-3.6	OCT 1931 to MAR 1932	-3.7
APR 1932 to SEP 1932	-2.7	OCT 1932 to MAR 1933	-3.4
APR 1933 to SEP 1933	-3.9	OCT 1933 to MAR 1934	-5.6
APR 1934 to SEP 1934	-8.6	OCT 1934 to MAR 1935	-7.7
APR 1935 to SEP 1935	-5.4	OCT 1935 to MAR 1936	-2.0
APR 1936 to SEP 1936	0.9	OCT 1936 to MAR 1937	0.8
APR 1937 to SEP 1937	0.6	OCT 1937 to MAR 1938	-0.3
APR 1938 to SEP 1938	1.0	OCT 1938 to MAR 1939	0.2
APR 1939 to SEP 1939	-1.4	OCT 1939 to MAR 1940	-2.2
APR 1940 to SEP 1940	-2.6	OCT 1940 to MAR 1941	-0.1
APR 1941 to SEP 1941	2.1	OCT 1941 to MAR 1942	3.8
APR 1942 to SEP 1942	-0.6	OCT 1942 to MAR 1943	0.4
APR 1943 to SEP 1943	0.9	OCT 1943 to MAR 1944	-0.2
APR 1944 to SEP 1944	1.1	OCT 1944 to MAR 1945	-0.6
APR 1945 to SEP 1945	2.3	OCT 1945 to MAR 1946	3.5
APR 1946 to SEP 1946	2.0	OCT 1946 to MAR 1947	3.6
APR 1947 to SEP 1947	3.9	OCT 1947 to MAR 1948	3.5
APR 1948 to SEP 1948	2.4	OCT 1948 to MAR 1949	2.1
APR 1949 to SEP 1949	1.8	OCT 1949 to MAR 1950	3.2
APR 1950 to SEP 1950	2.9	OCT 1950 to MAR 1951	2.7
APR 1951 to SEP 1951	2.8	OCT 1951 to MAR 1952	4.8
APR 1952 to SEP 1952	4.1	OCT 1952 to MAR 1953	-0.6
APR 1953 to SEP 1953	1.0	OCT 1953 to MAR 1954	-0.9
APR 1954 to SEP 1954	-1.5	OCT 1954 to MAR 1955	-0.4
APR 1955 to SEP 1955	0.5	OCT 1955 to MAR 1956	1.6
APR 1956 to SEP 1956	-1.3	OCT 1956 to MAR 1957	-0.6
APR 1957 to SEP 1957	2.5	OCT 1957 to MAR 1958	2.8
APR 1958 to SEP 1958	-0.7	OCT 1958 to MAR 1959	-2.8
APR 1959 to SEP 1959	0.2	OCT 1959 to MAR 1960	-1.3
APR 1960 to SEP 1960	-2.2	OCT 1960 to MAR 1961	-2.7
APR 1961 to SEP 1961	-2.1	OCT 1961 to MAR 1962	2.6
APR 1962 to SEP 1962	0.7	OCT 1962 to MAR 1963	-2.6
APR 1963 to SEP 1963	-1.6	OCT 1963 to MAR 1964	-2.1
APR 1964 to SEP 1964	0.7	OCT 1964 to MAR 1965	1.3
APR 1965 to SEP 1965	3.2	OCT 1965 to MAR 1966	1.9
APR 1966 to SEP 1966	-1.0	OCT 1966 to MAR 1967	-0.0
APR 1967 to SEP 1967	1.3	OCT 1967 to MAR 1968	-0.4
APR 1968 to SEP 1968	2.1	OCT 1968 to MAR 1969	2.6
APR 1969 to SEP 1969	1.7	OCT 1969 to MAR 1970	1.4
APR 1970 to SEP 1970	1.6	OCT 1970 to MAR 1971	2.9
APR 1971 to SEP 1971	1.9	OCT 1971 to MAR 1972	1.9
APR 1972 to SEP 1972	-0.3	OCT 1972 to MAR 1973	2.0
APR 1973 to SEP 1973	2.0	OCT 1973 to MAR 1974	1.9
APR 1974 to SEP 1974	-0.9	OCT 1974 to MAR 1975	-1.5
APR 1975 to SEP 1975	2.6	OCT 1975 to MAR 1976	0.6
APR 1976 to SEP 1976	-0.6	OCT 1976 to MAR 1977	-3.7
APR 1977 to SEP 1977	-4.8	OCT 1977 to MAR 1978	-3.0
APR 1978 to SEP 1978	-1.1	OCT 1978 to MAR 1979	-0.9
APR 1979 to SEP 1979	-1.6	OCT 1979 to MAR 1980	0.2
APR 1980 to MAR 1980	2.5		

TABLE 1.30

Division 6 Seasons

Summer		Winter	
APR 1931 to SEP 1931	0.7	OCT 1931 to MAR 1932	0.2
APR 1932 to SEP 1932	1.4	OCT 1932 to MAR 1933	-1.1
APR 1933 to SEP 1933	-0.5	OCT 1933 to MAR 1934	-2.2
APR 1934 to SEP 1934	-4.8	OCT 1934 to MAR 1935	-4.2
APR 1935 to SEP 1935	-1.3	OCT 1935 to MAR 1936	-2.5
APR 1936 to SEP 1936	-0.9	OCT 1936 to MAR 1937	1.8
APR 1937 to SEP 1937	4.1	OCT 1937 to MAR 1938	2.7
APR 1938 to SEP 1938	2.7	OCT 1938 to MAR 1939	3.0
APR 1939 to SEP 1939	-0.5	OCT 1939 to MAR 1940	-0.0
APR 1940 to SEP 1940	-1.1	OCT 1940 to MAR 1941	1.2
APR 1941 to SEP 1941	3.1	OCT 1941 to MAR 1942	4.9
APR 1942 to SEP 1942	0.9	OCT 1942 to MAR 1943	-1.1
APR 1943 to SEP 1943	-0.7	OCT 1943 to MAR 1944	0.6
APR 1944 to SEP 1944	2.1	OCT 1944 to MAR 1945	-1.1
APR 1945 to SEP 1945	-0.5	OCT 1945 to MAR 1946	-1.5
APR 1946 to SEP 1946	-3.6	OCT 1946 to MAR 1947	1.5
APR 1947 to SEP 1947	2.3	OCT 1947 to MAR 1948	2.9
APR 1948 to SEP 1948	-0.7	OCT 1948 to MAR 1949	-0.0
APR 1949 to SEP 1949	1.3	OCT 1949 to MAR 1950	1.4
APR 1950 to SEP 1950	-0.5	OCT 1950 to MAR 1951	-2.1
APR 1951 to SEP 1951	-2.6	OCT 1951 to MAR 1952	2.3
APR 1952 to SEP 1952	4.0	OCT 1952 to MAR 1953	-1.2
APR 1953 to SEP 1953	-1.7	OCT 1953 to MAR 1954	-2.2
APR 1954 to SEP 1954	-2.3	OCT 1954 to MAR 1955	1.0
APR 1955 to SEP 1955	-1.4	OCT 1955 to MAR 1956	-1.4
APR 1956 to SEP 1956	-2.8	OCT 1956 to MAR 1957	-1.8
APR 1957 to SEP 1957	1.5	OCT 1957 to MAR 1958	0.7
APR 1958 to SEP 1958	-0.8	OCT 1958 to MAR 1959	-2.2
APR 1959 to SEP 1959	-2.3	OCT 1959 to MAR 1960	-1.2
APR 1960 to SEP 1960	-2.4	OCT 1960 to MAR 1961	-2.3
APR 1961 to SEP 1961	-2.8	OCT 1961 to MAR 1962	2.8
APR 1962 to SEP 1962	-0.7	OCT 1962 to MAR 1963	-2.1
APR 1963 to SEP 1963	-3.8	OCT 1963 to MAR 1964	-3.8
APR 1964 to SEP 1964	-2.8	OCT 1964 to MAR 1965	1.1
APR 1965 to SEP 1965	6.6	OCT 1965 to MAR 1966	6.4
APR 1966 to SEP 1966	2.2	OCT 1966 to MAR 1967	1.5
APR 1967 to SEP 1967	1.3	OCT 1967 to MAR 1968	-0.1
APR 1968 to SEP 1968	0.9	OCT 1968 to MAR 1969	0.1
APR 1969 to SEP 1969	1.8	OCT 1969 to MAR 1970	0.1
APR 1970 to SEP 1970	0.0	OCT 1970 to MAR 1971	-0.7
APR 1971 to SEP 1971	-0.9	OCT 1971 to MAR 1972	0.2
APR 1972 to SEP 1972	-2.0	OCT 1972 to MAR 1973	1.9
APR 1973 to SEP 1973	2.9	OCT 1973 to MAR 1974	0.0
APR 1974 to SEP 1974	-2.7	OCT 1974 to MAR 1975	-2.6
APR 1975 to SEP 1975	1.3	OCT 1975 to MAR 1976	-0.7
APR 1976 to SEP 1976	-0.5	OCT 1976 to MAR 1977	-2.4
APR 1977 to SEP 1977	-2.9	OCT 1977 to MAR 1978	-0.9
APR 1978 to SEP 1978	0.3	OCT 1978 to MAR 1979	1.2
APR 1979 to SEP 1979	3.0	OCT 1979 to MAR 1980	2.2
APR 1980 to MAR 1980	2.5		

TABLE 1.31

Division 7 Seasons

Summer	
APR 1931 to SEP 1931	-0.2
APR 1932 to SEP 1932	1.6
APR 1933 to SEP 1933	0.3
APR 1934 to SEP 1934	-3.2
APR 1935 to SEP 1935	1.3
APR 1936 to SEP 1936	-0.4
APR 1937 to SEP 1937	2.4
APR 1938 to SEP 1938	2.1
APR 1939 to SEP 1939	-0.5
APR 1940 to SEP 1940	-0.9
APR 1941 to SEP 1941	7.5
APR 1942 to SEP 1942	2.6
APR 1943 to SEP 1943	-1.7
APR 1944 to SEP 1944	1.0
APR 1945 to SEP 1945	-0.1
APR 1946 to SEP 1946	-2.5
APR 1947 to SEP 1947	-1.0
APR 1948 to SEP 1948	1.7
APR 1949 to SEP 1949	1.8
APR 1950 to SEP 1950	-2.4
APR 1951 to SEP 1951	-2.7
APR 1952 to SEP 1952	2.8
APR 1953 to SEP 1953	-1.5
APR 1954 to SEP 1954	-2.7
APR 1955 to SEP 1955	-1.9
APR 1956 to SEP 1956	-3.8
APR 1957 to SEP 1957	3.3
APR 1958 to SEP 1958	2.0
APR 1959 to SEP 1959	-3.2
APR 1960 to SEP 1960	-1.3
APR 1961 to SEP 1961	0.3
APR 1962 to SEP 1962	-1.1
APR 1963 to SEP 1963	-2.4
APR 1964 to SEP 1964	-2.7
APR 1965 to SEP 1965	4.2
APR 1966 to SEP 1966	-0.4
APR 1967 to SEP 1967	-1.0
APR 1968 to SEP 1968	0.4
APR 1969 to SEP 1969	2.2
APR 1970 to SEP 1970	-0.2
APR 1971 to SEP 1971	-1.6
APR 1972 to SEP 1972	-2.8
APR 1973 to SEP 1973	6.6
APR 1974 to SEP 1974	-2.4
APR 1975 to SEP 1975	1.5
APR 1976 to SEP 1976	-1.2
APR 1977 to SEP 1977	-4.0
APR 1978 to SEP 1978	-0.1
APR 1979 to SEP 1979	6.1
APR 1980 to MAR 1980	6.9

Winter	
OCT 1931 to MAR 1932	1.0
OCT 1932 to MAR 1933	-0.7
OCT 1933 to MAR 1934	-0.7
OCT 1934 to MAR 1935	-0.3
OCT 1935 to MAR 1936	-0.8
OCT 1936 to MAR 1937	1.3
OCT 1937 to MAR 1938	1.3
OCT 1938 to MAR 1939	1.6
OCT 1939 to MAR 1940	-0.2
OCT 1940 to MAR 1941	2.8
OCT 1941 to MAR 1942	7.8
OCT 1942 to MAR 1943	-1.3
OCT 1943 to MAR 1944	0.1
OCT 1944 to MAR 1945	-1.3
OCT 1945 to MAR 1946	-0.8
OCT 1946 to MAR 1947	-1.6
OCT 1947 to MAR 1948	1.9
OCT 1948 to MAR 1949	1.7
OCT 1949 to MAR 1950	-0.6
OCT 1950 to MAR 1951	-3.8
OCT 1951 to MAR 1952	1.5
OCT 1952 to MAR 1953	-1.0
OCT 1953 to MAR 1954	-1.0
OCT 1954 to MAR 1955	-2.0
OCT 1955 to MAR 1956	-2.7
OCT 1956 to MAR 1957	-1.7
OCT 1957 to MAR 1958	5.0
OCT 1958 to MAR 1959	-1.4
OCT 1959 to MAR 1960	-1.9
OCT 1960 to MAR 1961	0.1
OCT 1961 to MAR 1962	0.9
OCT 1962 to MAR 1963	-1.3
OCT 1963 to MAR 1964	-2.6
OCT 1964 to MAR 1965	-0.2
OCT 1965 to MAR 1966	2.7
OCT 1966 to MAR 1967	-0.5
OCT 1967 to MAR 1968	-0.6
OCT 1968 to MAR 1969	0.1
OCT 1969 to MAR 1970	0.6
OCT 1970 to MAR 1971	-0.5
OCT 1971 to MAR 1972	0.0
OCT 1972 to MAR 1973	4.7
OCT 1973 to MAR 1974	-0.4
OCT 1974 to MAR 1975	0.4
OCT 1975 to MAR 1976	-1.2
OCT 1976 to MAR 1977	-2.6
OCT 1977 to MAR 1978	-0.9
OCT 1978 to MAR 1979	2.7
OCT 1979 to MAR 1980	4.2

TABLE 1.32

State Seasons

Summer	
APR 1931 to SEP 1931	-1.1
APR 1932 to SEP 1932	1.7
APR 1933 to SEP 1933	-0.4
APR 1934 to SEP 1934	-5.0
APR 1935 to SEP 1935	-0.8
APR 1936 to SEP 1936	0.1
APR 1937 to SEP 1937	2.7
APR 1938 to SEP 1938	2.7
APR 1939 to SEP 1939	-0.7
APR 1940 to SEP 1940	-1.1
APR 1941 to SEP 1941	5.4
APR 1942 to SEP 1942	3.6
APR 1943 to SEP 1943	0.3
APR 1944 to SEP 1944	1.7
APR 1945 to SEP 1945	1.4
APR 1946 to SEP 1946	-1.1
APR 1947 to SEP 1947	2.3
APR 1948 to SEP 1948	1.3
APR 1949 to SEP 1949	1.5
APR 1950 to SEP 1950	-1.1
APR 1951 to SEP 1951	-1.3
APR 1952 to SEP 1952	1.9
APR 1953 to SEP 1953	-1.6
APR 1954 to SEP 1954	-3.0
APR 1955 to SEP 1955	-1.9
APR 1956 to SEP 1956	-3.3
APR 1957 to SEP 1957	0.6
APR 1958 to SEP 1958	-0.2
APR 1959 to SEP 1959	-2.8
APR 1960 to SEP 1960	-3.1
APR 1961 to SEP 1961	-1.6
APR 1962 to SEP 1962	0.1
APR 1963 to SEP 1963	-1.3
APR 1964 to SEP 1964	-0.8
APR 1965 to SEP 1965	3.2
APR 1966 to SEP 1966	-1.4
APR 1967 to SEP 1967	1.0
APR 1968 to SEP 1968	0.9
APR 1969 to SEP 1969	1.4
APR 1970 to SEP 1970	-0.3
APR 1971 to SEP 1971	0.2
APR 1972 to SEP 1972	-2.2
APR 1973 to SEP 1973	3.6
APR 1974 to SEP 1974	-2.3
APR 1975 to SEP 1975	1.4
APR 1976 to SEP 1976	-1.1
APR 1977 to SEP 1977	-3.7
APR 1978 to SEP 1978	0.1
APR 1979 to SEP 1979	2.1
APR 1980 to MAR 1980	4.3

Winter	
OCT 1931 to MAR 1932	0.2
OCT 1932 to MAR 1933	-0.2
OCT 1933 to MAR 1934	-2.2
OCT 1934 to MAR 1935	-2.3
OCT 1935 to MAR 1936	-1.1
OCT 1936 to MAR 1937	1.9
OCT 1937 to MAR 1938	1.7
OCT 1938 to MAR 1939	1.9
OCT 1939 to MAR 1940	-0.3
OCT 1940 to MAR 1941	1.9
OCT 1941 to MAR 1942	6.6
OCT 1942 to MAR 1943	0.8
OCT 1943 to MAR 1944	0.5
OCT 1944 to MAR 1945	-0.3
OCT 1945 to MAR 1946	0.3
OCT 1946 to MAR 1947	2.0
OCT 1947 to MAR 1948	2.5
OCT 1948 to MAR 1949	1.4
OCT 1949 to MAR 1950	0.2
OCT 1950 to MAR 1951	-2.1
OCT 1951 to MAR 1952	1.9
OCT 1952 to MAR 1953	-1.4
OCT 1953 to MAR 1954	-2.1
OCT 1954 to MAR 1955	-2.2
OCT 1955 to MAR 1956	-1.7
OCT 1956 to MAR 1957	-2.9
OCT 1957 to MAR 1958	1.5
OCT 1958 to MAR 1959	-2.3
OCT 1959 to MAR 1960	-2.4
OCT 1960 to MAR 1961	-2.5
OCT 1961 to MAR 1962	1.7
OCT 1962 to MAR 1963	-2.0
OCT 1963 to MAR 1964	-1.8
OCT 1964 to MAR 1965	0.0
OCT 1965 to MAR 1966	1.5
OCT 1966 to MAR 1967	-1.0
OCT 1967 to MAR 1968	0.0
OCT 1968 to MAR 1969	0.9
OCT 1969 to MAR 1970	-0.0
OCT 1970 to MAR 1971	0.2
OCT 1971 to MAR 1972	0.5
OCT 1972 to MAR 1973	2.9
OCT 1973 to MAR 1974	0.2
OCT 1974 to MAR 1975	-1.4
OCT 1975 to MAR 1976	-0.4
OCT 1976 to MAR 1977	-2.9
OCT 1977 to MAR 1978	-1.7
OCT 1978 to MAR 1979	1.8
OCT 1979 to MAR 1980	1.9

TABLE 1.33

USU Seasons

Summer		Winter	
APR 1896 to SEP 1896	1.4	OCT 1896 to MAR 1897	-0.1
APR 1897 to SEP 1897	-0.6	OCT 1897 to MAR 1898	0.4
APR 1898 to SEP 1898	0.5	OCT 1898 to MAR 1899	-1.9
APR 1899 to SEP 1899	-3.5	OCT 1899 to MAR 1900	-2.9
APR 1900 to SEP 1900	-2.9	OCT 1900 to MAR 1901	-0.1
APR 1901 to SEP 1901	-0.6	OCT 1901 to MAR 1902	-1.9
APR 1902 to SEP 1902	-2.5	OCT 1902 to MAR 1903	-2.5
APR 1903 to SEP 1903	-0.1	OCT 1903 to MAR 1904	-0.0
APR 1904 to SEP 1904	-1.2	OCT 1904 to MAR 1905	-3.3
APR 1905 to SEP 1905	-4.8	OCT 1905 to MAR 1906	-3.5
APR 1906 to SEP 1906	3.7	OCT 1906 to MAR 1907	5.5
APR 1907 to SEP 1907	5.2	OCT 1907 to MAR 1908	-2.0
APR 1908 to SEP 1908	1.2	OCT 1908 to MAR 1909	4.5
APR 1909 to SEP 1909	5.8	OCT 1909 to MAR 1910	4.5
APR 1910 to SEP 1910	-2.8	OCT 1910 to MAR 1911	-0.2
APR 1911 to SEP 1911	-0.1	OCT 1911 to MAR 1912	-0.4
APR 1912 to SEP 1912	1.4	OCT 1912 to MAR 1913	3.2
APR 1913 to SEP 1913	2.9	OCT 1913 to MAR 1914	3.2
APR 1914 to SEP 1914	3.4	OCT 1914 to MAR 1915	-1.4
APR 1915 to SEP 1915	-3.3	OCT 1915 to MAR 1916	-0.1
APR 1916 to SEP 1916	-0.8	OCT 1916 to MAR 1917	2.6
APR 1917 to SEP 1917	3.3	OCT 1917 to MAR 1918	-1.5
APR 1918 to SEP 1918	-1.7	OCT 1918 to MAR 1919	-2.1
APR 1919 to SEP 1919	-4.0	OCT 1919 to MAR 1920	2.8
APR 1920 to SEP 1920	2.4	OCT 1920 to MAR 1921	4.3
APR 1921 to SEP 1921	0.2	OCT 1921 to MAR 1922	0.7
APR 1922 to SEP 1922	0.1	OCT 1922 to MAR 1923	-0.2
APR 1923 to SEP 1923	1.2	OCT 1923 to MAR 1924	-0.9
APR 1924 to SEP 1924	-4.0	OCT 1924 to MAR 1925	0.7
APR 1925 to SEP 1925	0.5	OCT 1925 to MAR 1926	-0.4
APR 1926 to SEP 1926	-0.6	OCT 1926 to MAR 1927	-0.4
APR 1927 to SEP 1927	1.0	OCT 1927 to MAR 1928	-1.1
APR 1928 to SEP 1928	-3.6	OCT 1928 to MAR 1929	-3.6
APR 1929 to SEP 1929	-2.5	OCT 1929 to MAR 1930	-1.4
APR 1930 to SEP 1930	0.3	OCT 1930 to MAR 1931	-0.4
APR 1931 to SEP 1931	-3.5	OCT 1931 to MAR 1932	0.8
APR 1932 to SEP 1932	1.5	OCT 1932 to MAR 1933	-2.0
APR 1933 to SEP 1933	-2.7	OCT 1933 to MAR 1934	-4.2
APR 1934 to SEP 1934	-7.4	OCT 1934 to MAR 1935	-5.7
APR 1935 to SEP 1935	-3.4	OCT 1935 to MAR 1936	-2.6
APR 1936 to SEP 1936	-1.7	OCT 1936 to MAR 1937	0.6
APR 1937 to SEP 1937	0.3	OCT 1937 to MAR 1938	0.2
APR 1938 to SEP 1938	-0.6	OCT 1938 to MAR 1939	0.0
APR 1939 to SEP 1939	-0.6	OCT 1939 to MAR 1940	-1.7
APR 1940 to SEP 1940	-3.2	OCT 1940 to MAR 1941	1.0
APR 1941 to SEP 1941	0.8	OCT 1941 to MAR 1942	2.8
APR 1942 to SEP 1942	3.2	OCT 1942 to MAR 1943	2.3
APR 1943 to SEP 1943	2.4	OCT 1943 to MAR 1944	1.7
APR 1944 to SEP 1944	1.6	OCT 1944 to MAR 1945	-0.5
APR 1945 to SEP 1945	3.2	OCT 1945 to MAR 1946	5.6
APR 1946 to SEP 1946	3.8	OCT 1946 to MAR 1947	4.8
APR 1947 to SEP 1947	4.5	OCT 1947 to MAR 1948	3.0
APR 1948 to SEP 1948	2.0	OCT 1948 to MAR 1949	1.7
APR 1949 to SEP 1949	1.8	OCT 1949 to MAR 1950	3.0
APR 1950 to SEP 1950	3.6	OCT 1950 to MAR 1951	3.2
APR 1951 to SEP 1951	2.8	OCT 1951 to MAR 1952	3.2
APR 1952 to SEP 1952	-0.4	OCT 1952 to MAR 1953	-2.3
APR 1953 to SEP 1953	0.4	OCT 1953 to MAR 1954	-2.7
APR 1954 to SEP 1954	-4.3	OCT 1954 to MAR 1955	-1.9
APR 1955 to SEP 1955	0.6	OCT 1955 to MAR 1956	1.8

TABLE 1.33

Continued

APR 1956 to SEP 1956	-1.6	OCT 1956 to MAR 1957	-1.5
APR 1957 to SEP 1957	0.9	OCT 1957 to MAR 1958	-0.9
APR 1958 to SEP 1958	-2.4	OCT 1958 to MAR 1959	0.3
APR 1959 to SEP 1959	1.6	OCT 1959 to MAR 1960	-1.6
APR 1960 to SEP 1960	-2.9	OCT 1960 to MAR 1961	-2.8
APR 1961 to SEP 1961	-3.4	OCT 1961 to MAR 1962	1.8
APR 1962 to SEP 1962	1.3	OCT 1962 to MAR 1963	-2.6
APR 1963 to SEP 1963	0.0	OCT 1963 to MAR 1964	1.1
APR 1964 to SEP 1964	2.6	OCT 1964 to MAR 1965	2.8
APR 1965 to SEP 1965	3.1	OCT 1965 to MAR 1966	2.3
APR 1966 to SEP 1966	-1.2	OCT 1966 to MAR 1967	-1.6
APR 1967 to SEP 1967	3.1	OCT 1967 to MAR 1968	2.1
APR 1968 to SEP 1968	3.6	OCT 1968 to MAR 1969	3.9
APR 1969 to SEP 1969	0.3	OCT 1969 to MAR 1970	-0.9
APR 1970 to SEP 1970	0.5	OCT 1970 to MAR 1971	3.7
APR 1971 to SEP 1971	4.3	OCT 1971 to MAR 1972	4.9
APR 1972 to SEP 1972	2.5	OCT 1972 to MAR 1973	2.0
APR 1973 to SEP 1973	2.2	OCT 1973 to MAR 1974	4.8
APR 1974 to SEP 1974	-0.2	OCT 1974 to MAR 1975	-0.0
APR 1975 to SEP 1975	2.0	OCT 1975 to MAR 1976	3.7
APR 1976 to SEP 1976	3.6	OCT 1976 to MAR 1977	-2.6
APR 1977 to SEP 1977	-2.1	OCT 1977 to MAR 1978	2.4
APR 1978 to SEP 1978	2.3	OCT 1978 to MAR 1979	-0.5
APR 1979 to SEP 1979	-0.9	OCT 1979 to MAR 1980	0.5
APR 1980 to MAR 1980	4.4		

TABLE 1.34

SLC Seasons

Summer		Winter	
APR 1875 to SEP 1875	3.4	OCT 1875 to MAR 1876	5.7
APR 1876 to SEP 1876	7.0	OCT 1876 to MAR 1877	4.9
APR 1877 to SEP 1877	4.2	OCT 1877 to MAR 1878	3.4
APR 1878 to SEP 1878	4.6	OCT 1878 to MAR 1879	-0.5
APR 1879 to SEP 1879	-4.0	OCT 1879 to MAR 1880	-1.6
APR 1880 to SEP 1880	-0.3	OCT 1880 to MAR 1881	0.2
APR 1881 to SEP 1881	1.0	OCT 1881 to MAR 1882	1.4
APR 1882 to SEP 1882	2.3	OCT 1882 to MAR 1883	0.2
APR 1883 to SEP 1883	-0.1	OCT 1883 to MAR 1884	1.3
APR 1884 to SEP 1884	3.1	OCT 1884 to MAR 1885	1.7
APR 1885 to SEP 1885	2.7	OCT 1885 to MAR 1886	3.3
APR 1886 to SEP 1886	3.2	OCT 1886 to MAR 1887	2.5
APR 1887 to SEP 1887	-0.9	OCT 1887 to MAR 1888	-1.6
APR 1888 to SEP 1888	-2.7	OCT 1888 to MAR 1889	-2.0
APR 1889 to SEP 1889	-1.6	OCT 1889 to MAR 1890	3.4
APR 1890 to SEP 1890	-1.4	OCT 1890 to MAR 1891	-2.2
APR 1891 to SEP 1891	0.7	OCT 1891 to MAR 1892	0.6
APR 1892 to SEP 1892	0.4	OCT 1892 to MAR 1893	0.0
APR 1893 to SEP 1893	2.0	OCT 1893 to MAR 1894	2.0
APR 1894 to SEP 1894	1.9	OCT 1894 to MAR 1895	-1.2
APR 1895 to SEP 1895	-2.5	OCT 1895 to MAR 1896	-0.4
APR 1896 to SEP 1896	2.5	OCT 1896 to MAR 1897	3.5
APR 1897 to SEP 1897	0.5	OCT 1897 to MAR 1898	-0.5
APR 1898 to SEP 1898	1.1	OCT 1898 to MAR 1899	2.1
APR 1899 to SEP 1899	3.3	OCT 1899 to MAR 1900	-0.1
APR 1900 to SEP 1900	-2.7	OCT 1900 to MAR 1901	-2.1
APR 1901 to SEP 1901	0.4	OCT 1901 to MAR 1902	-1.3
APR 1902 to SEP 1902	-2.1	OCT 1902 to MAR 1903	-2.5
APR 1903 to SEP 1903	0.0	OCT 1903 to MAR 1904	0.3
APR 1904 to SEP 1904	1.8	OCT 1904 to MAR 1905	-1.8
APR 1905 to SEP 1905	-0.2	OCT 1905 to MAR 1906	-0.9
APR 1906 to SEP 1906	3.7	OCT 1906 to MAR 1907	4.4
APR 1907 to SEP 1907	5.2	OCT 1907 to MAR 1908	3.0
APR 1908 to SEP 1908	4.3	OCT 1908 to MAR 1909	6.3
APR 1909 to SEP 1909	6.0	OCT 1909 to MAR 1910	-0.4
APR 1910 to SEP 1910	-3.4	OCT 1910 to MAR 1911	-2.5
APR 1911 to SEP 1911	-1.1	OCT 1911 to MAR 1912	0.4
APR 1912 to SEP 1912	2.4	OCT 1912 to MAR 1913	3.5
APR 1913 to SEP 1913	3.7	OCT 1913 to MAR 1914	2.9
APR 1914 to SEP 1914	2.8	OCT 1914 to MAR 1915	-0.9
APR 1915 to SEP 1915	-2.0	OCT 1915 to MAR 1916	0.4
APR 1916 to SEP 1916	-0.5	OCT 1916 to MAR 1917	1.4
APR 1917 to SEP 1917	3.5	OCT 1917 to MAR 1918	-0.8
APR 1918 to SEP 1918	-0.6	OCT 1918 to MAR 1919	-0.7
APR 1919 to SEP 1919	-2.1	OCT 1919 to MAR 1920	1.8
APR 1920 to SEP 1920	3.4	OCT 1920 to MAR 1921	4.5
APR 1921 to SEP 1921	3.2	OCT 1921 to MAR 1922	1.5
APR 1922 to SEP 1922	3.5	OCT 1922 to MAR 1923	3.7
APR 1923 to SEP 1923	5.5	OCT 1923 to MAR 1924	0.3
APR 1924 to SEP 1924	-2.6	OCT 1924 to MAR 1925	1.1
APR 1925 to SEP 1925	2.8	OCT 1925 to MAR 1926	-0.5
APR 1926 to SEP 1926	-0.8	OCT 1926 to MAR 1927	0.3
APR 1927 to SEP 1927	2.4	OCT 1927 to MAR 1928	1.6
APR 1928 to SEP 1928	-0.7	OCT 1928 to MAR 1929	0.0
APR 1929 to SEP 1929	0.1	OCT 1929 to MAR 1930	-1.6
APR 1930 to SEP 1930	-3.1	OCT 1930 to MAR 1931	-1.4
APR 1931 to SEP 1931	-3.8	OCT 1931 to MAR 1932	-0.2
APR 1932 to SEP 1932	0.6	OCT 1932 to MAR 1933	-0.0
APR 1933 to SEP 1933	-0.4	OCT 1933 to MAR 1934	-3.2
APR 1934 to SEP 1934	-6.8	OCT 1934 to MAR 1935	-0.0

TABLE 1.34

Continued

APR 1935 to SEP 1935	1.4	OCT 1935 to MAR 1936	0.9
APR 1936 to SEP 1936	-1.1	OCT 1936 to MAR 1937	0.5
APR 1937 to SEP 1937	-0.3	OCT 1937 to MAR 1938	-0.5
APR 1938 to SEP 1938	-0.1	OCT 1938 to MAR 1939	0.6
APR 1939 to SEP 1939	-1.1	OCT 1939 to MAR 1940	-0.4
APR 1940 to SEP 1940	-1.1	OCT 1940 to MAR 1941	1.8
APR 1941 to SEP 1941	3.1	OCT 1941 to MAR 1942	4.4
APR 1942 to SEP 1942	3.2	OCT 1942 to MAR 1943	-0.6
APR 1943 to SEP 1943	-1.0	OCT 1943 to MAR 1944	-1.2
APR 1944 to SEP 1944	2.1	OCT 1944 to MAR 1945	-1.4
APR 1945 to SEP 1945	1.1	OCT 1945 to MAR 1946	0.7
APR 1946 to SEP 1946	-1.7	OCT 1946 to MAR 1947	2.7
APR 1947 to SEP 1947	3.6	OCT 1947 to MAR 1948	3.4
APR 1948 to SEP 1948	1.6	OCT 1948 to MAR 1949	2.1
APR 1949 to SEP 1949	2.4	OCT 1949 to MAR 1950	2.0
APR 1950 to SEP 1950	1.5	OCT 1950 to MAR 1951	-0.7
APR 1951 to SEP 1951	0.1	OCT 1951 to MAR 1952	3.0
APR 1952 to SEP 1952	2.7	OCT 1952 to MAR 1953	-1.4
APR 1953 to SEP 1953	0.4	OCT 1953 to MAR 1954	-2.0
APR 1954 to SEP 1954	-3.6	OCT 1954 to MAR 1955	-2.7
APR 1955 to SEP 1955	0.0	OCT 1955 to MAR 1956	0.5
APR 1956 to SEP 1956	-0.9	OCT 1956 to MAR 1957	-1.0
APR 1957 to SEP 1957	2.8	OCT 1957 to MAR 1958	2.5
APR 1958 to SEP 1958	-0.9	OCT 1958 to MAR 1959	-3.2
APR 1959 to SEP 1959	-2.5	OCT 1959 to MAR 1960	-1.9
APR 1960 to SEP 1960	-2.8	OCT 1960 to MAR 1961	-2.7
APR 1961 to SEP 1961	-2.7	OCT 1961 to MAR 1962	-0.0
APR 1962 to SEP 1962	1.1	OCT 1962 to MAR 1963	-2.0
APR 1963 to SEP 1963	-1.8	OCT 1963 to MAR 1964	-1.3
APR 1964 to SEP 1964	3.1	OCT 1964 to MAR 1965	3.4
APR 1965 to SEP 1965	5.5	OCT 1965 to MAR 1966	-0.8
APR 1966 to SEP 1966	-2.9	OCT 1966 to MAR 1967	-3.1
APR 1967 to SEP 1967	0.7	OCT 1967 to MAR 1968	-0.6
APR 1968 to SEP 1968	2.7	OCT 1968 to MAR 1969	4.2
APR 1969 to SEP 1969	3.2	OCT 1969 to MAR 1970	2.0
APR 1970 to SEP 1970	2.3	OCT 1970 to MAR 1971	4.7
APR 1971 to SEP 1971	4.7	OCT 1971 to MAR 1972	5.3
APR 1972 to SEP 1972	-0.1	OCT 1972 to MAR 1973	2.5
APR 1973 to SEP 1973	3.5	OCT 1973 to MAR 1974	5.4
APR 1974 to SEP 1974	-0.0	OCT 1974 to MAR 1975	-1.4
APR 1975 to SEP 1975	2.8	OCT 1975 to MAR 1976	2.1
APR 1976 to SEP 1976	1.7	OCT 1976 to MAR 1977	-2.2
APR 1977 to SEP 1977	0.4	OCT 1977 to MAR 1978	1.4
APR 1978 to SEP 1978	2.2	OCT 1978 to MAR 1979	-1.3
APR 1979 to SEP 1979	-4.0	OCT 1979 to MAR 1980	-1.5
APR 1980 to MAR 1980	1.6		

TABLE 1.35

SLC & USU Seasons

Summer		Winter	
APR 1896 to SEP 1896	2.0	OCT 1896 to MAR 1897	1.7
APR 1897 to SEP 1897	-0.0	OCT 1897 to MAR 1898	-0.0
APR 1898 to SEP 1898	0.8	OCT 1898 to MAR 1899	0.0
APR 1899 to SEP 1899	-0.1	OCT 1899 to MAR 1900	-1.5
APR 1900 to SEP 1900	-2.8	OCT 1900 to MAR 1901	-1.1
APR 1901 to SEP 1901	-0.1	OCT 1901 to MAR 1902	-1.6
APR 1902 to SEP 1902	-2.3	OCT 1902 to MAR 1903	-2.5
APR 1903 to SEP 1903	-0.0	OCT 1903 to MAR 1904	0.1
APR 1904 to SEP 1904	0.2	OCT 1904 to MAR 1905	-2.6
APR 1905 to SEP 1905	-2.5	OCT 1905 to MAR 1906	-2.2
APR 1906 to SEP 1906	3.7	OCT 1906 to MAR 1907	4.9
APR 1907 to SEP 1907	5.2	OCT 1907 to MAR 1908	0.5
APR 1908 to SEP 1908	2.7	OCT 1908 to MAR 1909	5.4
APR 1909 to SEP 1909	5.9	OCT 1909 to MAR 1910	2.0
APR 1910 to SEP 1910	-3.1	OCT 1910 to MAR 1911	-1.4
APR 1911 to SEP 1911	-0.6	OCT 1911 to MAR 1912	-0.0
APR 1912 to SEP 1912	1.9	OCT 1912 to MAR 1913	3.3
APR 1913 to SEP 1913	3.3	OCT 1913 to MAR 1914	3.1
APR 1914 to SEP 1914	3.1	OCT 1914 to MAR 1915	-1.1
APR 1915 to SEP 1915	-2.7	OCT 1915 to MAR 1916	0.1
APR 1916 to SEP 1916	-0.7	OCT 1916 to MAR 1917	2.0
APR 1917 to SEP 1917	3.4	OCT 1917 to MAR 1918	-1.1
APR 1918 to SEP 1918	-1.1	OCT 1918 to MAR 1919	-1.4
APR 1919 to SEP 1919	-3.1	OCT 1919 to MAR 1920	2.3
APR 1920 to SEP 1920	2.9	OCT 1920 to MAR 1921	4.4
APR 1921 to SEP 1921	1.7	OCT 1921 to MAR 1922	1.1
APR 1922 to SEP 1922	1.8	OCT 1922 to MAR 1923	1.7
APR 1923 to SEP 1923	3.4	OCT 1923 to MAR 1924	-0.3
APR 1924 to SEP 1924	-3.3	OCT 1924 to MAR 1925	0.9
APR 1925 to SEP 1925	1.6	OCT 1925 to MAR 1926	-0.5
APR 1926 to SEP 1926	-0.7	OCT 1926 to MAR 1927	-0.0
APR 1927 to SEP 1927	1.7	OCT 1927 to MAR 1928	0.2
APR 1928 to SEP 1928	-2.2	OCT 1928 to MAR 1929	-1.7
APR 1929 to SEP 1929	-1.2	OCT 1929 to MAR 1930	-1.5
APR 1930 to SEP 1930	-1.4	OCT 1930 to MAR 1931	-0.9
APR 1931 to SEP 1931	-3.6	OCT 1931 to MAR 1932	0.2
APR 1932 to SEP 1932	1.1	OCT 1932 to MAR 1933	-1.0
APR 1933 to SEP 1933	-1.6	OCT 1933 to MAR 1934	-3.7
APR 1934 to SEP 1934	-7.1	OCT 1934 to MAR 1935	-2.9
APR 1935 to SEP 1935	-1.0	OCT 1935 to MAR 1936	-0.8
APR 1936 to SEP 1936	-1.4	OCT 1936 to MAR 1937	0.5
APR 1937 to SEP 1937	0.0	OCT 1937 to MAR 1938	-0.1
APR 1938 to SEP 1938	-0.4	OCT 1938 to MAR 1939	0.3
APR 1939 to SEP 1939	-0.9	OCT 1939 to MAR 1940	-1.0
APR 1940 to SEP 1940	-2.1	OCT 1940 to MAR 1941	1.4
APR 1941 to SEP 1941	2.0	OCT 1941 to MAR 1942	3.6
APR 1942 to SEP 1942	3.2	OCT 1942 to MAR 1943	0.8
APR 1943 to SEP 1943	0.7	OCT 1943 to MAR 1944	0.2
APR 1944 to SEP 1944	1.8	OCT 1944 to MAR 1945	-0.9
APR 1945 to SEP 1945	2.2	OCT 1945 to MAR 1946	3.1
APR 1946 to SEP 1946	1.0	OCT 1946 to MAR 1947	3.7
APR 1947 to SEP 1947	4.1	OCT 1947 to MAR 1948	3.2
APR 1948 to SEP 1948	1.8	OCT 1948 to MAR 1949	1.9
APR 1949 to SEP 1949	2.1	OCT 1949 to MAR 1950	2.5
APR 1950 to SEP 1950	2.5	OCT 1950 to MAR 1951	1.2
APR 1951 to SEP 1951	1.4	OCT 1951 to MAR 1952	3.1
APR 1952 to SEP 1952	1.1	OCT 1952 to MAR 1953	-1.9
APR 1953 to SEP 1953	0.4	OCT 1953 to MAR 1954	-2.3
APR 1954 to SEP 1954	-3.9	OCT 1954 to MAR 1955	-2.3
APR 1955 to SEP 1955	0.3	OCT 1955 to MAR 1956	1.2

TABLE 1.35

Continued

APR 1956 to SEP 1956	-1.2	OCT 1956 to MAR 1957	-1.2
APR 1957 to SEP 1957	1.8	OCT 1957 to MAR 1958	0.8
APR 1958 to SEP 1958	-1.7	OCT 1958 to MAR 1959	-1.4
APR 1959 to SEP 1959	-0.4	OCT 1959 to MAR 1960	-1.7
APR 1960 to SEP 1960	-2.9	OCT 1960 to MAR 1961	-2.8
APR 1961 to SEP 1961	-3.1	OCT 1961 to MAR 1962	0.9
APR 1962 to SEP 1962	1.2	OCT 1962 to MAR 1963	-2.3
APR 1963 to SEP 1963	-0.9	OCT 1963 to MAR 1964	-0.1
APR 1964 to SEP 1964	2.8	OCT 1964 to MAR 1965	3.1
APR 1965 to SEP 1965	4.3	OCT 1965 to MAR 1966	0.7
APR 1966 to SEP 1966	-2.0	OCT 1966 to MAR 1967	-2.3
APR 1967 to SEP 1967	1.9	OCT 1967 to MAR 1968	0.7
APR 1968 to SEP 1968	3.2	OCT 1968 to MAR 1969	4.0
APR 1969 to SEP 1969	1.7	OCT 1969 to MAR 1970	0.5
APR 1970 to SEP 1970	1.4	OCT 1970 to MAR 1971	4.2
APR 1971 to SEP 1971	4.5	OCT 1971 to MAR 1972	5.1
APR 1972 to SEP 1972	1.2	OCT 1972 to MAR 1973	2.2
APR 1973 to SEP 1973	2.9	OCT 1973 to MAR 1974	5.1
APR 1974 to SEP 1974	-0.1	OCT 1974 to MAR 1975	-0.7
APR 1975 to SEP 1975	2.4	OCT 1975 to MAR 1976	2.9
APR 1976 to SEP 1976	2.7	OCT 1976 to MAR 1977	-2.4
APR 1977 to SEP 1977	-0.8	OCT 1977 to MAR 1978	1.9
APR 1978 to SEP 1978	2.3	OCT 1978 to MAR 1979	-0.9
APR 1979 to SEP 1979	-2.4	OCT 1979 to MAR 1980	-0.5
APR 1980 to MAR 1980	3.0		

Drought Periods For Analysis. After reviewing the agricultural production information, streamflow, and reservoir data available for analysis, two drought periods were selected. These were the 1976-77 drought, which was a very rapid developing situation, and the 1934 drought, which was the culmination of several years of deteriorating conditions. In the southern part of the state, the 1934 drought was already well established by the beginning of 1931 and continued to intensify through 1934. The 1976 drought developed very rapidly and then ended almost as abruptly as it began. These two periods were selected as being representative of two types of drought conditions that had occurred in the Utah area.

Range Condition Equations. As will be discussed in detail in the Economic Section, good correlations between the growing season average Palmer Index and the Range Condition Index published by the Department of Agriculture were obtained. Due to differences in area of coverage of the climate divisions and the county Range Condition Index areas, some adjustments had to be made. However, R^2 values ranging from .605 in Northern Mountains to .852 in the Western Division were obtained. Averaged over the state the R^2 value was .902. R^2 values above .60 were obtained in most of the states west of the Mississippi River. Only Wyoming, Kansas and Iowa had lower R_2 values (Table 1.36).

The relationship which best fit the Range Condition Index can be expressed by the equation:

$$RC = 100/(1+ e^{(A + B1P + B2P)})$$

Where:

RC = Range Condition Index
P = Average Seasonal Palmer Index
A, B1 and B2 = Equation Constants of Proportionality.

TABLE 1.36

Regression Constants For Range Condition Equation

Division	Constant	B1	B2	R^2	D-W
Western	-1.6327	-.31785	-------	.852	1.79
Dixie	-1.509	-.27727	.04281	.626	2.22
North Central	-1.204	-.25318	--------	.737	1.64
South Central	-1.1843	-.26513	--------	.785	1.33
North Mountains	-1.1908	-.1796	--------	.605	1.46
Uinta Basin	-1.4321	-.27004	--------	.747	1.39
South East	-1.7657	-.37448	.04031	.788	1.81
State of Utah	-1.477	-.2563	.02917	.904	1.58
Washington	-1.4621	-.3094	--------	.718	2.33
Oregon	-1.6185	-.29359	--------	.601	2.00
California	-1.5434	-.40562	--------	.791	1.36
Early California	-1.8059	-.5024	--------	.845	1.63
Early Arizona	-1.3514	-.27632	--------	.660	2.48
Nevada	-1.338	-.3458	.05118	.886	1.55
Idaho	-1.5245	-.3137	.04365	.754	1.83
New Mexico	-1.1321	-.29316	.037085	.796	1.48
Early New Mexico	-.9433	-.23245	--------	.819	.92
Montana	-1.1457	-.256	--------	.736	1.74
Wyoming	-1.624	-.1702	--------	.591	2.05
Colorado	-1.144	-.1631	--------	.609	1.06
North Dakota	-.89958	-.3348	--------	.839	1.94
South Dakota	-.79786	-.3529	--------	.838	1.54
Nebraska	-1.133	-.4866	1.97	.676	2.11
Kansas	-1.295	-.2063	--------	.526	2.07
Texas	-.97711	-.2312	--------	.681	1.16
Minnesota	-1.1986	-.25286	--------	.555	1.39
Iowa	-1.486	-.1861	--------	.460	1.11
Missouri	-1.300	-.25113	.04773	.488	1.57
Oklahoma	-1.2783	-.20161	--------	.690	1.76
Illinois	-1..5226	-.16031	--------	.401	1.58

The equation constants for the state RC equations were obtained by multiplying the seasonal division average Palmer Indices by the areal percentages for each division used by Asheville, North Carolina (Table 1.36).

Seeding Increments. To evaluate the impact of cloud seeding on range production, two incremental precipitation increases were used for each climate division. These incremental increases were based upon results predicted by North American Weather Consultants.

The first increment (M1) was a minimal increase of only five to ten percent as shown in Table 1.37. M1 assumed seeding during the period November 15 through March 31. M2 is a more liberal increment and assumes seeding during the period November 1 through May 31.

To determine the monthly accumulation of precipitation for the Palmer calculations, the normal precipitation for each month was multiplied by the appropriate M1 or M2 incremental percentages. These precipitation values as shown in Tables 1.38 and 1.39 were then inserted into the monthly accumulative Palmer calculations. The average seasonal April through September Palmer index values were then used in each of the RC equations to determine the new RC index for each M1 and M2 incremental increases.

TABLE 1.37

Precipitation Increments For Drought Periods

Division	Nov M1/M2	Dec M1/M2	Jan M1/M2	Feb M1/M2	Mar M1/M2	Apr M1/M2	May M1/M2
Western	2.5/15	5/15	5/15	5/15	5/15	0/15	0/15
Dixie	5/20	10/20	10/20	10/20	10/20	0/20	0/20
N Central	5/20	10/20	10/20	10/20	10/20	0/20	0/20
S Central	5/20	10/20	10/20	10/20	10/20	0/20	0/20
N Mtns	5/20	10/20	10/20	10/20	10/20	0/20	0/20
Uinta Basin	0/10	0/10	0/10	0/10	0/10	0/10	0/10
S East	2.5/15	5/15	5/15	5/15	5/15	0/15	0.15

M1 = Conservative increment for seeding November 15 - March 31
M2 = Liberal increment for seeding November 1 - May 31

TABLE 1.38

Precipitation Estimates 1933-34

Division	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Western												
Base	.50	.83	.49	.94	.30	.35	.22	.49	.73	.63	.79	.40
M_1	.51	.87	.51	.99	.32	.37	.23	.49	.73	.63	.79	.40
M_2	.58	.95	.56	1.08	.35	.40	.25	.49	.73	.63	.79	.40
Dixie												
Base	.70	2.01	.80	1.22	.18	.32	.03	.64	6.01	.96	.33	.99
M_1	.74	2.21	.88	1.34	.20	.32	.03	.64	6.01	.96	.33	.99
M_2	.84	2.41	.96	1.46	.22	.38	.04	.64	6.01	.96	.33	.99
North Central												
Base	.32	1.16	1.11	1.98	.58	.44	.11	.74	.87	.71	.72	1.01
M_1	.34	1.28	1.22	2.18	.58	.44	.11	.74	.87	.71	.72	1.01
M_2	.38	1.39	1.33	2.38	.64	.53	.13	.74	.87	.71	.72	1.01
South Central												
Base	.65	1.26	.67	1.09	.42	.46	.61	.32	.64	1.29	.22	.41
M_1	.68	1.39	.74	1.20	.46	.46	.61	.32	.64	1.29	.22	.41
M_2	.78	1.51	.80	1.31	.50	.55	.73	.32	.64	1.29	.22	.41
Northern Mountains												
Base	.38	1.54	.98	1.63	.44	.41	.26	.60	.65	1.28	.45	.65
M_1	.40	1.69	1.08	1.79	.48	.41	.26	.60	.65	1.28	.45	.65
M_2	.46	1.85	1.18	1.96	.53	.49	.31	.60	.65	1.28	.45	.65
Uinta Basin												
Base	.37	.52	.33	.52	.00	.24	.20	.43	.45	.75	.07	.09
M_1	.37	.52	.33	.52	.00	.24	.20	.43	.45	.75	.07	.09
M_2	.41	.57	.36	.57	.00	.26	.22	.43	.45	.75	.07	.09
Southeast												
Base	.97	.46	.38	.89	.01	.41	.85	.18	.24	.67	.27	.08
M_1	.99	.48	.40	.93	.01	.41	.85	.18	.24	.67	.27	.08
M_2	1.12	.53	.44	1.02	.01	.47	.98	.18	.24	.67	.27	.08

TABLE 1.39

Precipitation Estimates 1976-77

Division	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.
Western												
Base	.13	.01	.26	.09	.51	.13	2.88	.47	.89	1.47	.49	.21
M_1	.13	.01	.27	.09	.54	.13	3.02	.47	.89	1.47	.49	.21
M_2	.15	.01	.30	.10	.59	.15	3.31	.47	.89	1.47	.49	.21
Dixie												
Base	.25	.03	.57	.08	.39	.07	2.33	.49	.88	1.24	.92	.35
M_1	.26	.03	.63	.09	.43	.07	2.33	.49	.88	1.24	.92	.35
M_2	.30	.04	.68	.10	.47	.08	2.80	.49	.88	1.24	.92	.35
North Central												
Base	.18	.08	.74	.59	1.46	.52	4.31	.17	1.35	2.39	1.39	.93
M_1	.19	.09	.81	.65	1.61	.52	4.31	.17	1.35	2.39	1.39	.93
M_2	.22	.10	.89	.71	1.75	.62	5.17	.17	1.35	2.39	1.39	.93
South Central												
Base	.26	.04	.43	.23	.63	.13	1.37	.52	1.38	1.27	.50	.76
M_1	.27	.04	.47	.25	.69	.13	1.37	.52	1.38	1.27	.50	.76
M_2	.31	.05	.52	.28	.76	.16	1.64	.52	1.38	1.27	.50	.76
Northern Mountains												
Base	.07	.05	.58	1.25	1.19	.34	2.75	.24	1.57	1.90	1.43	1.26
M_1	.07	.06	.64	1.38	1.31	.34	2.75	.24	1.57	1.90	1.43	1.26
M_2	.08	.06	.70	1.50	1.43	.41	3.30	.24	1.57	1.90	1.43	1.26
Uinta Basin												
Base	.00	.01	.31	.33	.19	.48	.93	.20	1.49	1.21	.31	.44
M_1	.00	.01	.31	.33	.19	.48	.93	.20	1.49	1.21	.31	.44
M_2	.00	.01	.34	.36	.21	.53	1.02	.20	1.49	1.21	.31	.44
Southeast												
Base	.04	.01	.63	.14	.14	.19	.64	.16	1.61	.95	.52	.55
M_1	.04	.01	.66	.15	.15	.19	.64	.16	1.61	.95	.52	.55
M_2	.05	.01	.72	.16	.16	.22	.74	.16	1.61	.95	.52	.55

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2. POTENTIAL EFFECTS OF WEATHER MODIFICATION ON WATER SUPPLY FROM SELECTED UTAH RESERVOIRS

2.1 Introduction

2.1.1 Relationship To Project

An important output from this project is an evaluation of the agricultural benefits of weather modification. These benefits were estimated using an economic model which requires as an input the quantity of water available to agriculture under drought conditions, both when cloud seeding is predicted and when it is not. The purpose of the work reported in this chapter was to estimate the amount and ownership of the additional useable water supply from several representative Utah reservoirs that would be expected to result from cloud seeding. We refer to such water as "developed water". These estimates were made because they were needed as an input to the economic model and also to better understand the fate of water developed from cloud seeding.

The nature of drought, as discussed in Chapter 1, makes it difficult to define a generalized "design drought", as one might for floods. Therefore, two actual years, 1934 and 1977, were selected as examples of the last year of a multiyear drought and a single-year drought, respectively. The effects on precipitation and snowpack of two emergency seeding programs, as estimated by North American Weather Consultants (NAWC), were imposed on the non-seeded droughts to obtain the input for the model under seeded conditions. The two emergency program designs, described fully in Chapter 5, represented a conservative and an optimistic estimate of the percentage increase in natural precipitation. They are referred to as the "M1" and "M2" designs, respectively.

The quantity of water available for irrigation is a function of both the physical hydrology and the water rights allocation system. For instance, permeability, consumptive use, groundwater flow patterns, and evaporation all affect the timing and quantity of water entering the river. Furthermore, the seniority of water rights of agricultural users and their stockholdings in reservoirs determine how much water is available to them. The problem, then, was to determine for the meteorological and hydrological conditions observed in 1934 and 1977, how much water was available to agriculture; and to estimate the increases in that quantity which would result from each of two cloud seeding programs. Since the goal of the overall project was to predict how cloud seeding might be used to mitigate drought impacts in the 1980's, current water resources facilities and operating policies were assumed. Thus, in this study, runoff resulting from the 1934 and 1977 droughts were analyzed within the context of modern water resources development.

2.1.2 Objectives

Four rerservoir-buffered river basins were selected for analysis in this study. Objectives with respect to these systems were twofold: 1) to determine how the quantity of water available for reservoir storage would be affected under weather modification; and 2) to determine the ownership of the developed water in accordance with established water rights and other institutional considerations.

A precipitation-reservoir inflow model was adapted and applied to the drought years of 1934 and 1977, yielding an estimate of runoff with no cloud seeding program. The model was then rerun to estimate runoff that would be expected under the two seeding program designs. Since the observed runoff could not be perfectly predicted by the model, observed reservoir inflows for 1934 and 1977 were multiplied by the ratio of model-predicted runoff with seeding to model-predicted runoff without seeding. This provided an estimate of streamflow that would be expected to occur during the study years, had weather modification been practiced.

Once hydrographs of reservoir inflows for the "no seeding" and the "seeding" cases had been developed, the alternative water supplies were allocated according to whatever water rights currently pertain to the basin. Interviews were held with the River Commissioners in each area to learn the water rights and rules governing reservoir operations and natural flow distribution.

2.1.3 Chapter Outline

Section 2.2 describes the selection of four study basins, and contains a description of each of the river systems included in the study. The methodology used to estimate the effects of cloud seeding on the volume of reservoir inflow is presented in Section 2.3. This is followed in Section 2.4 by a description of the methodology used to estimate the timing of the reservoir inflows under alternative cloud seeding design programs. Section 2.5 treats special considerations which arose in the application of the described methodology. Results of the estimation procedures are presented in Section 2.6. Section 2.7 describes the allocation of developed water, and estimates of total supply. This is done for each river basin in turn. Chapter 2 is summarized in Section 2.8.

2.2 Study Reservoirs

Since project resources did not permit the study of all Utah reservoirs, a small sample of carefully chosen reservoir systems was selected for use as indicators of the changes in water supply resulting from cloud seeding in several Utah climate divisions. The selection of these systems is detailed below, and is followed by description of each basin in which the study reservoirs are located.

2.2.1 Selection Of Reservoir

A list of Utah reservoirs was acquired from the Dam Safety Section of the Utah Division of Water Rights. Four reservoirs or reservoir systems were selected on the basis of their size, importance as an irrigation water supply, and representativeness of Utah's various climate divisions (see Figure 2.1). The availability of hydrometeorological data in and around the watershed was also taken into consideration. It was originally proposed to select only five individual reservoirs. However, the scope was expanded to include reservoir systems because in basins where the operations of several reservoirs are coordinated, it is difficult to consider single reservoirs independently.

Two single-reservoir systems, Ashley Creek in Eastern Utah and the Price River drainage in Central Utah, were selected together with two multiple-reservoir systems, the Weber River and the Sevier River. A third multiple-reservoir system, the Utah Lake drainage, which encompasses both the Provo and the Spanish Fork River basins, was also selected. This system was later eliminated because 1) insufficient time was available to consider it, 2) the Weber River basin also represents the same climate division and a similar service areas along the

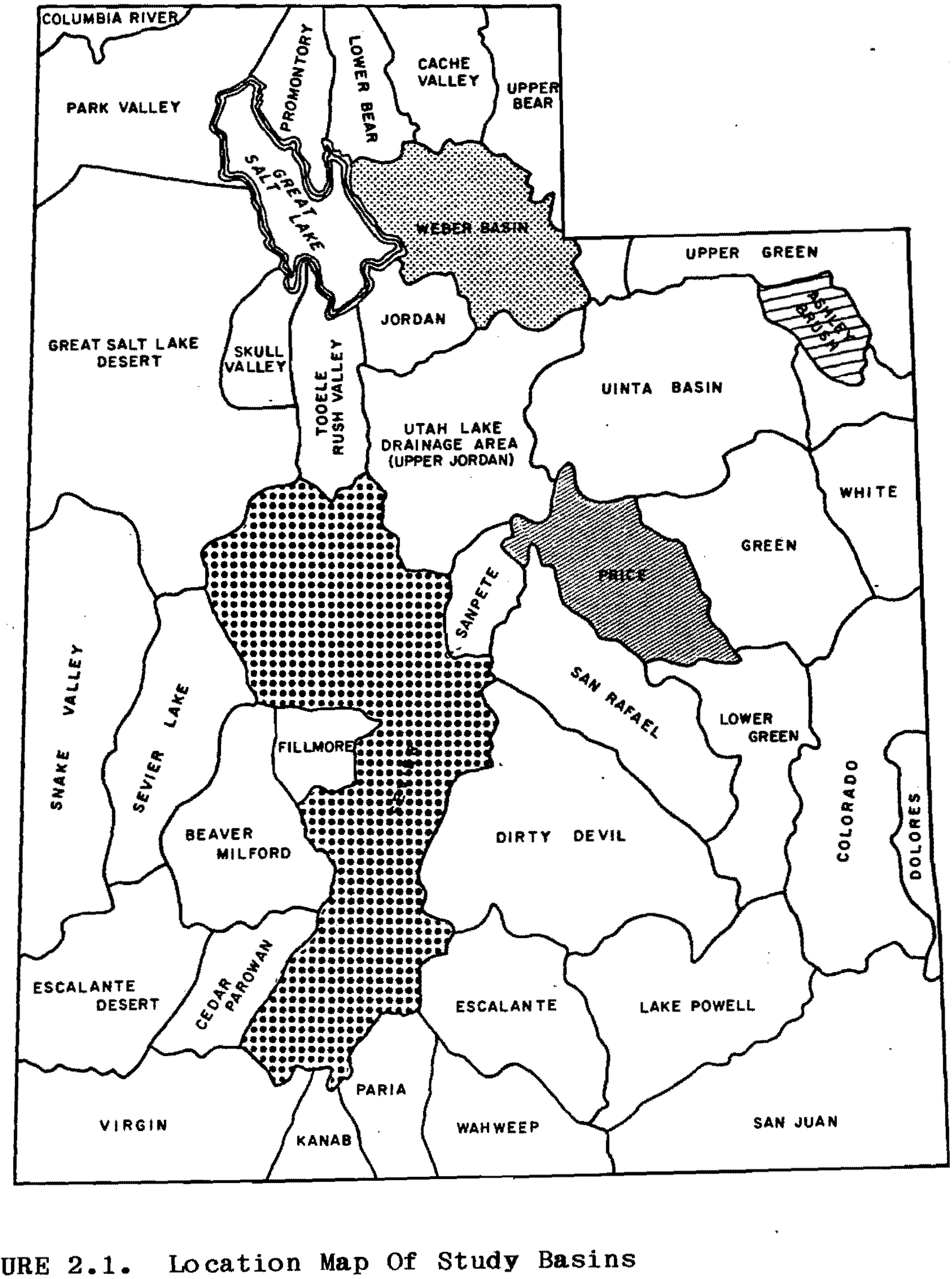


FIGURE 2.1. Location Map Of Study Basins

Wasatch Front, and 3) it appears that this system is relatively insensitive to drought, due to the enormous storage of over a million acre-feet (ac-ft) provided by the enlarged Strawberry Project, and 900,000 ac-ft provided by Utah Lake. The location of each river basin selected for study is shown on Figure 2.1.

2.2.2 Weber Basin

The Weber River rises among 12,000-foot peaks in Northern Utah's Wasatch Range. It flows northwesterly through Summit and Morgan Counties, emerging from its mountain canyon at Gateway, Utah, at an elevation of 4800 feet above mean sea level (ft, msl). From there it proceeds across the gently sloping plain formed by Lake Bonneville, is joined by its principal tributary, the Ogden River, and flows into the Great Salt Lake. The abruptly rising slopes of the Wasatch Front delineate the boundary between the North Central and Northern Mountains Climate Division in this area. The mountain barrier is also responsible for a considerable range in normal annual precipitation over the basin, from twelve inches at the lowest elevations to 50 inches in the mountains. As might be expected, the greater concentration of population, agriculture, and water demand lies in the plain between the mountains and the lake. Fortunately, the high valleys and canyons have provided numerous reservoir sites, five of which have been developed and were included in this study. The mountain reservoirs are supplemented by Willard Bay, a freshwater impoundment on the shores of the Great Salt Lake.

East Canyon Reservoir, on East Canyon Creek, was the first of the five dams constructed in the Weber basin. Originally, a private enterprise, the impoundment was built in the late 1800's to regulate the irrigation supply to farmers on the east shore of the Great Salt Lake. Further major structural development did not proceed until the early 1930's, when Echo Reservoir was constructed by the Weber Water Users Association. This consortium consisted of irrigators in both the upper and lower Weber drainage area, as well as users on the Provo River, who export water via the Weber-Provo Canal. This development was followed shortly after by construction of Pineview Dam on the Ogden River, the Ogden-Brigham Canal, and the South Ogden Canal. The Ogden River Water Users Association, as the sponsoring organization was known, sold stock primarily to irrigators in Weber and Box Elder Counties, although the present stockholders include several municipalities.

The mid-forties saw the development of Deer Creek Reservoir on the Provo River. Although outside the Weber basin, this project filled on winter flows above Echo Reservoir, which are diverted through the Weber-Provo Canal during the spring runoff period through an exchange with storage in Echo and Wanship reservoirs.

In June, 1950, the Weber Basin Conservancy District (WBCD), comprising Weber, Davis, and Morgan Counties, and a small portion of Summit County, was organized. Its purpose was to operate the Weber Basin Project and to pay back loans to the federal government. The storage components of the project are Wanship Reservoir, Pineview Dam enlargement, Willard Bay, Causey Reservoir, Lost Creek Reservoir, and East Canyon Reservoir enlargement. From these facilities, the project provides water for irrigation and domestic use in the mountain valleys along the South Fork of the Ogden River, as well as along the Weber River, either by direct release or by exchange. The bulk of the supply, however, serves irrigation, municipal, and industrial users along the east shore of the Great Salt

Lake. In accordance with the "first in time, first in right" principle of the appropriation system of water rights, WBCD rights are filled only after the senior natural flow and storage rights have been met. Two of the WBCD reservoirs were not analyzed for changes in inflow due to cloud seeding. The first was Causey Reservoir, which has a capacity of less than 10,000 ac-ft. Changes in inflow were expected to be relatively insignificant in comparison to the large projects in the basin. Willard Bay, which is the largest reservoir, is more sensitive to upstream operations than to the timing of snowmelt. Since it was easily filled by winter flows and was able to supply all demands made upon it in 1977, it is evident that the supply from Willard Bay is relative unaffected by drought.

A map of the Weber River basin is presented in Figure 2.2.

2.2.3 Scofield Rerservoir

Scofield Reservoir is located in the headwaters of the Price River basin in Central Utah. Figure 2.3 is a map of the Price River basin. While the reservoir and its drainage are situated in the Northern Mountains Climate Division, the irrigated acreage serviced by the reservoir is located in both the Northern Mountains and the Southeastern Divisions (see Figure 2.1). At an elevation of 7600 ft msl, Scofield Reservoir captures winter and spring flows from the high-yield area of the basin. Normal annual precipitation above Scofield Dam ranges from 22 to 30 inches, with all but 8 inches occurring between October and April. Along the Price River between Castle Gate and Wellington, which is the major use area, normal annual precipitation is only 8 to 12 inches. This lower elevation rainfall is more evenly distributed across the year.

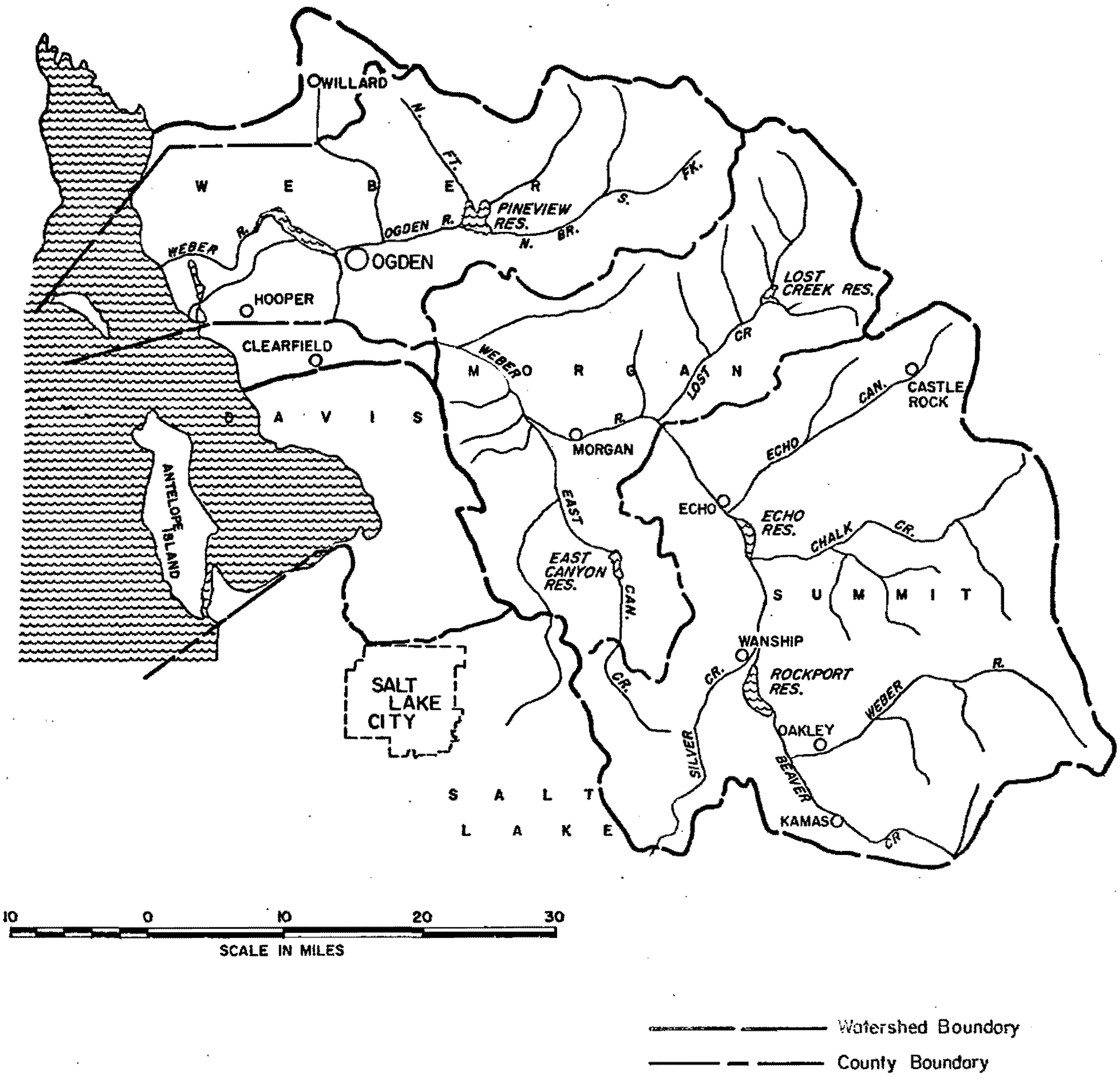


FIGURE 2.2. Map Of Weber River Basin

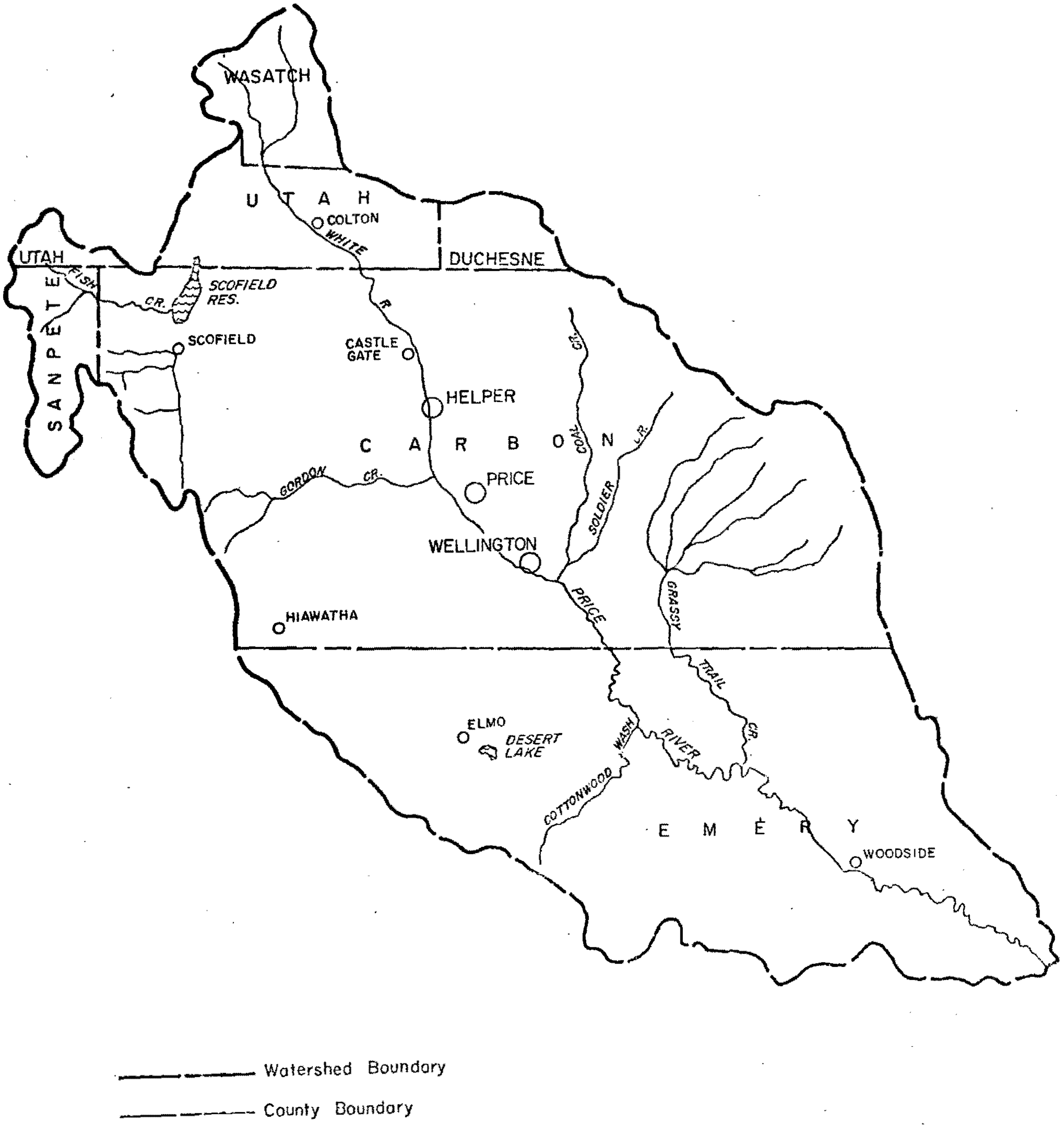


FIGURE 2.3. Map Of Price River Basin

Scofield Reservoir, with a capacity of 66,000 ac-ft, is the only major impoundment on the Price River. It supplies culinary water to the cities of Helper, Price, and several smaller communities. In addition, Utah Power and Light and several coal mining operations divert water for industrial purposes. The principal use, however, is for agriculture, with over 22,000 acres being irrigated in years of full supply. All interests are stockholders in the Price River Water Users Association.

2.2.4 Steinaker Reservoir

Steinaker Reservoir is the principal feature of the Vernal unit of the Central Utah Project. Located four miles north of Vernal, Utah, it provides offstream storage of flood flows from Ashley Creek, which drains the south flank of the Uinta County. As with the first two study systems, the source area is located in the Northern Mountains Climate Division, but in this case the service area is divided between the Northern Mountains and the Uinta Basin. Normal annual precipitation is only 8 inches in the lowlands near Vernal, but is 30 inches in the headwaters. The reservoir provides water for agricultural and municipal use.

With an active capacity of 33,100 ac-ft, Steinaker Reservoir is the smallest reservoir system selected in this study. It is also the system for which hydrometeorological data was most limited. However, the reservoir was included in order to represent the climatology and economics of Eastern Utah. A map of the Ashley Creek drainage area and Steinaker Reservoir is included as Figure 2.4.

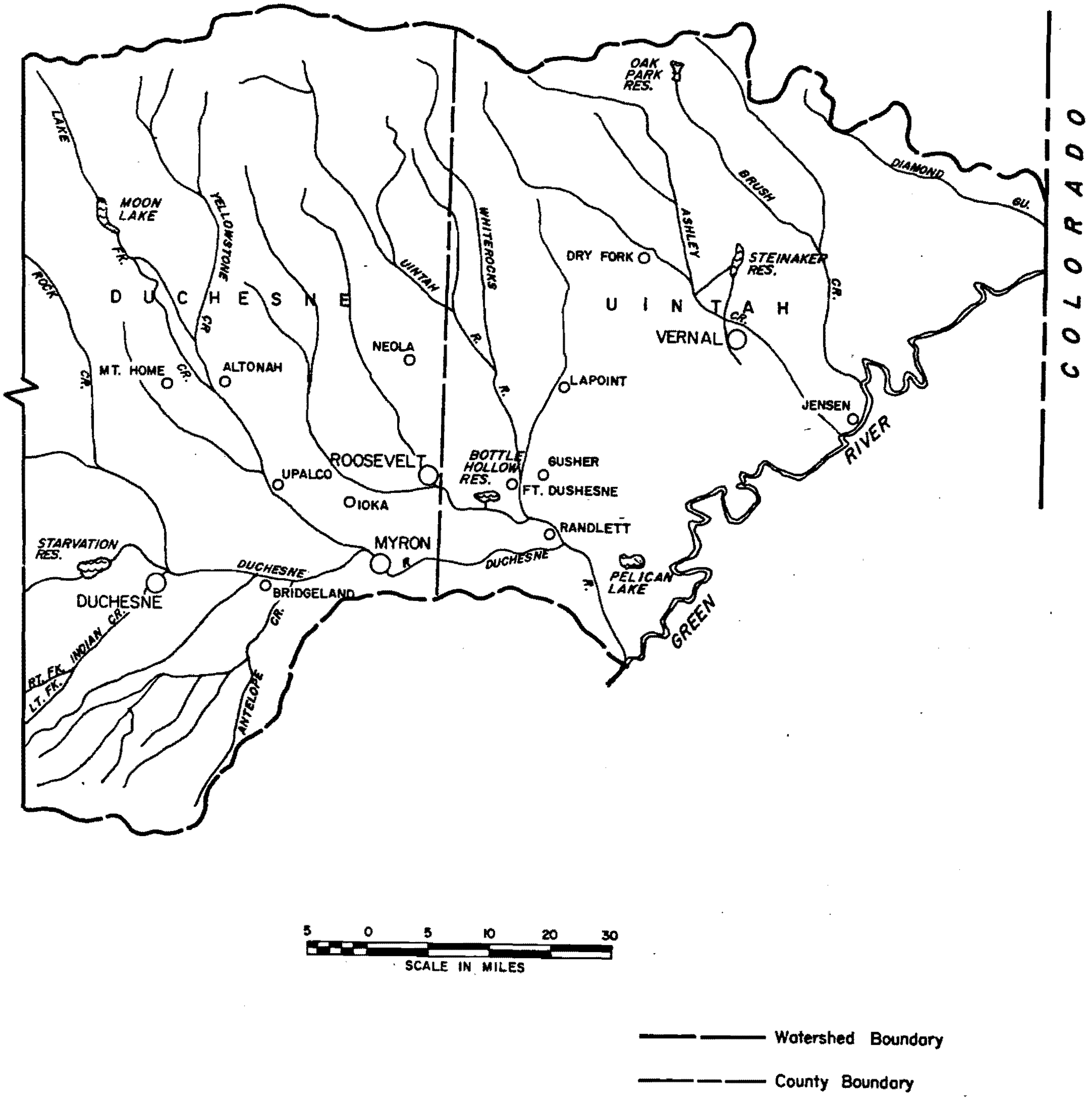


FIGURE 2.4. Map Of Ashley Creek Basin

2.2.5 Sevier Basin

The Sevier River basin is a major closed drainage of the Great Basin located in South Central Utah (see Figure 2.1). Before the arrival of white settlers, the Sevier River discharged perennially into Sevier Lake. Irrigation developments since the early 1900's have depleted the river until the only water now reaching Sevier Lake is occasional flood flow, drainage effluent, and groundwater.

The basin is 5,200,000 acres in area and includes portions of Garfield, Iron, Juab, Kane, Millard, Piute, Sanpete, Sevier, and Tooele Counties. Most of the irrigation water rises in the highlands, which constitutes 50 percent of the basin. Mountain ranges trend in a southwesterly-northeasterly direction; most are plateaus with elevations ranging from 4,550 to 12,173 ft, msl. The climate of the cropland area is semi-arid to arid. Average annual precipitation on irrigated land varies from 13.0 inches at Levan and Tropic in the uplands to 6.4 inches at Delta in the lowlands (see Figure 2.5). Average monthly valley precipitation is distributed nearly equally during the year although precipitation during the winter is greater in the northern part of the basin while during the summer it is greater in the south. Precipitation ranges up to a maximum of 40 inches annually at the highest elevations with the major portion falling in winter (USDA, 1969).

Storage on the Sevier River is provided by three major reservoirs: Otter Creek, Piute, and Sevier Bridge. Unlike most of the reservoirs previously described, Piute and Sevier Bridge are valley rather than mountain reservoirs. Piute Reservoir is located midway down the mainstem, just below the confluence of the East Fork with the main channel. Offstream

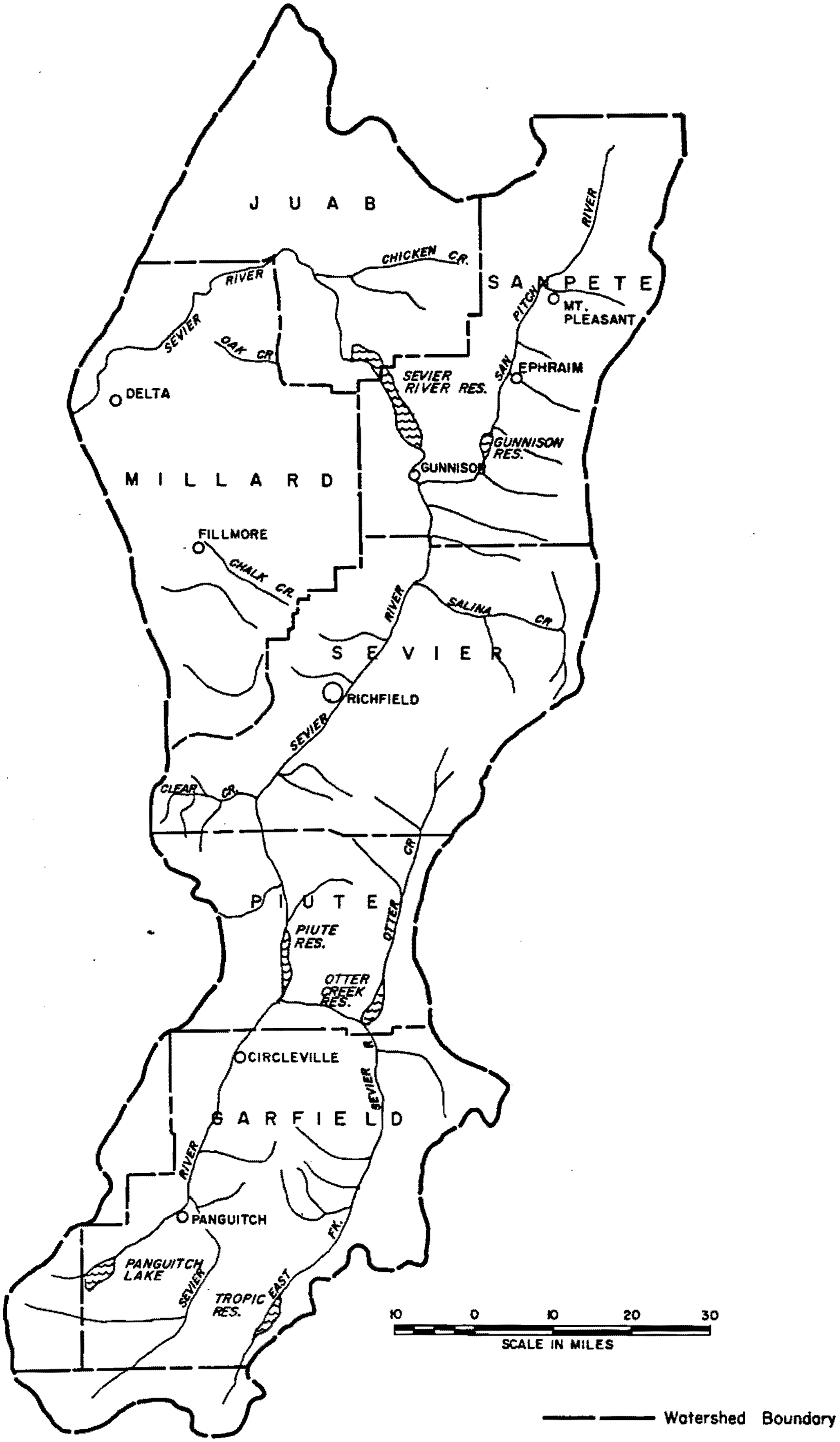


FIGURE 2.5. Map Of Sevier River Basin

storage of East Fork flows is provided by Otter Creek Reservoir just above this point. While irrigation is not heavily practiced in the upper East Fork, the main channel flows can be completely used above Piute Reservoir. The timing and quantity of water which reaches Piute Reservoir bears little resemblance to natural flow. The largest reservoir, Sevier Bridge, is also the lowest. Like Piute Reservoir, Sevier Bridge is filled by heavily managed flows. It provides irrigation water to farmers in the Western Climate Division, in and around Delta.

2.3 Methodology For Predicting Effects Of Weather Modification On Inflow Volumes

Several methods for predicting the effects of weather modification on inflow volumes were investigated. A parametric hydrology model was considered to be the most desirable approach but was eliminated from consideration because the level of effort required to properly calibrate and validate such a model for four river basins was beyond the scope of this project. Existing National Weather Service (NWS) water supply forecasting procedures were adapted to predict inflow volumes with and without cloud seeding. This section is divided into subsections describing the various methods investigated, the selected procedure, its application, and its data base.

2.3.1 Methods Investigated

In this subsection two attempts to develop methods for predicting runoff occurring as reservoir inflow from precipitation and snowpack data are described. Linear regressions of streamflow peak on precipitation and snowcourse data were explored as a possible index of the differences in reservoir inflow with and without weather modification. The Weber basin, with its extensive data network and snowmelt-controlled runoff, offered the best prospect for attempting this procedure. A stepwise regression model-building approach was taken, using a variety of climatological and hydrological parameters as candidates for inclusion. Maximum snowcourse water equivalents, regionalized mean monthly temperatures for March through June, regionalized April and May precipitation, and previous autumn streamflow were used as independent variables for the prediction of peak flow at USGS gaging stations "Chalk Creek at Coalville" and "Weber River at Oakley" (see Figure 2.2). The coefficient of determination (R^2) for the best Chalk Creek model was .76, while that for the Weber River was .60 based on lengths of record of 26 and 47 years, respectively. Since in the other basins, which have less extensive data networks, the coefficients of determination for similar regressions could only be expected to be poorer than these, this approach was abandoned.

An attempt was made to simulate April through July daily flows at the Oakley gage in 1934 and 1977 using a weighted degree-day model. The drainage area above the gage was divided into 1000-foot elevation bands. Data from four snowcourses were used to estimate the April 1 snowpack water equivalent for each of these bands. An assumed lapse rate was applied to daily temperatures at Kamas to estimate temperatures at the median elevations for each elevation band. It was assumed that melting could occur at a rate of 0.03 inches per degree-day, and the volume melted each day under this assumption was converted to a flow rate. This simple model was not without potential, although in this form it vastly overestimated stream response during warm periods. With considerably more work, it may have provided the basis for a parametric hydrology model of the Weber basin. However, resources were not available to extend this level of effort to all four basins and more importantly, data were found to be inadequate in the Sevier River, Ashley Creek, and Price River drainages.

As a result of these attempts to create new models, it was decided to adapt existing NWS precipitation-runoff models that had already been applied to the study basins.

2.3.2 National Weather Service Method

In 1969 and 1970, seasonal volume forecasting models for most Utah rivers were developed at the NWS Colorado River Forecast Center in Salt Lake City. Personnel at the center willingly made their work available for use in this study. The models are multiple linear regressions in the following form:

$$Q_t = b_o + b_1 P_f + b_2 P_w + b_3 P_s + b_4 SWE + b_5 Q_{t-1} \qquad (2.1)$$

in which

Q_t = seasonal flow volume
P_f = fall precipitation
P_w = winter precipitation
P_s = spring precipitation
SWE = April 1 snowpack water equivalent
Q_{t-1} = previous year flow volume

Generally, the runoff season used is April 1 through September 30. All regression and weighting coefficients are constrained to have positive values, thereby avoiding effects that are difficult to explain from physical principles. The NWS models do, however, have negative constant terms.

Input data used by NWS are more carefully screened and calibrated than for the regression techniques in Section 2.3.1.

The NWS regression equations utilize April 1 snow water content equivalent from up to five snowcourses on or near the basin. Data from these stations are weighted to reflect the representativeness of the gage and the quality of the record. Likewise, seasonal precipitation readings from four or five rain gages are weighted and combined before entering into the regression equation. Recorded precipitation from the entire snow accumulation season (November through April or May) is utilized.

2.3.3 Procedure For Applying National Weather Service Models

Although the NWS method was developed for real-time forecasting of water supply volumes, it was applied in this study for off-line prediction of reservoir inflow volumes. The NWS precipitation-runoff relationships are available for predicting upstream flow or inflow to nearly all the selected reservoirs. It was first supposed that historic values of the independent variables for 1934 and 1977 could be input to the regression models to obtain estimates of inflow without cloud seeding; next the historic values of the independent variables would be increased by factors representing the precipitation and snowpack increases induced by cloud seeding to provide estimates of inflow with cloud seeding. The ratio of these estimates would then be computed and used to adjust the observed runoff, resulting in a predicted inflow under cloud seeding for each drought year. Two problems complicated this procedure:

1. Since the State of Utah operated a seeding program in 1977, historic values of precipitation and streamflow would first have to be decremented to natural conditions as a base against which to compare inflow under the proposed cloud seeding program.

2. The NWS models, which were developed using 20 to 30 years of data prior to 1970, are not good predictors of inflow volumes in extremely dry years, and in some cases, yielded negative runoff values. Clearly, the second problem was the more serious of the two since whatever technique was employed to cope with the second problem could be operated in reverse in order to manage the first.

Resolution of the second problem was achieved by plotting predicted increases in inflow volumes for several dry years against the observed inflow volumes and then extrapolating a trend line to the observed inflows for 1934 and 1977. A sample of the 10 to 12 driest years of record, excluding those for which the NWS models yielded a negative forecast, was used to prepare such plots for each location. Runoff was estimated using historic and augmented values of the independent variables and the difference between these two estimates was calculated as a prediction of the increase in inflow volume due to cloud seeding. Separate calculations and plots were prepared for the 1977 operational seeding program and for the two proposed seeding programs, M1 and M2. The trend lines were either linear or parabolic in form and in most cases were forced to pass through the origin.

Estimates of the increases in precipitation under different seeding designs were provided by North American Weather Consultants and are described in Chapter 5 of this report. These estimates are based on two proposed cloud seeding programs, having different periods of application and different degrees of effectiveness. A third set of precipitation increases representing the actual seeding program in 1977 was also supplied by NAWC. Table 2.1 contains estimates of the augmented seasonal precipitation expressed as a percentage of observed precipitation

TABLE 2.1

Estimated Percent Increase In Precipitation Under Three Cloud Seeding Programs

	Cloud Seeding Program					
	M1		M2		1977	
Basin	Percent	Period of Application	Percent	Period of Application	Percent	Period of Application
Weber River	10	Dec. 15- Mar. 31	10 20	Nov. 1-Dec 31 Jan. 1-May 31	15	Feb. 1-May 31
Price River	10	Dec. 15-Mar. 31	10 20	Nov. 1-Dec. 31 Jan. 1-May 31	15	Jan. 1-May 31
Ashley River	-	-	5 10	Nov. 1-Dec. 31 Jan. 1-May 31	10	Mar. 1-May 31
Sevier River	10	Dec. 15-Mar. 31	10 20	Nov. 1-Dec. 31 Jan. 1-May 31	15	Jan. 1-May 31

for each study basin. Monthly precipitation input to the NWS equations was increased in accordance with these percentages for the appropriate cloud seeding program. Snowcourse terms were augmented by the percentage corresponding to the January-to-April period.

2.3.4 Data For The Inflow Volume Prediction Model

Sources of each data type needed for the NWS equations are described in this subsection. Also, steps taken to fill in missing data are described. Snow water equivalent data were obtained from Summary of Snow Survey Measurements for Utah (Whaley and Lytton, 1980). Approximately 10 observations at each of 13 snowcourses were required. Of these, only two readings, from the same snowcourse, were missing. The ratio of water content at the missing station to that at a nearby station was found to be quite stable. Therefore, an average ratio between the two stations was computed and used to fill in the missing values.

Precipitation data were obtained primarily from monthly compilations of NWS 24-hour observer stations, but some mountain storage gages were used also. At least one month of data was missing in each of eight seasons for the regressive pairs. The normal ratio method, as used by NWS (Paulhus and Kohler, 1952), was employed using as predictive gages the other precipitation stations in the model for which records were complete.

Observed values for inflow volumes, the dependent variable, came from one of two sources for the selected dry years. For those NWS forecast points which coincide with USGS streamflow stations, mean daily flow data from these stations were used. However, generally reservoir inflow is not gaged because of the multiple influences of evaporation, bank storage, and other sources of inflow such as local runoff and inundated seeps and springs. NWS estimates inflow as gaged outflow plus or minus changes in storage, with adjustments for transbasin diversion and change in storage of upstream reservoirs. These NWS estimates provided the second source of inflow volume data.

2.4 Methodology For Predicting Inflow Hydrology

Water allocation rules are based on daily flows, and therefore, daily inflow hydrographs were required for each reservoir. In general, reservoir inflow can be estimated from gaged outflow by the following mass balance equation:

$$I = O \pm S + E \qquad (2.2)$$

in which

I = reservoir inflow
O = gaged reservoir outflow
S = change in reservoir contents
E = evaporation loss

Pan evaporation data did not exist at most study reservoir sites for the selected years. The pan evaporation estimation procedure described in Appendix A was used to obtain values for E in Equation 2.2. Pan coefficients for each month were estimated for the Northern Mountain Climate Division using published nomographs (Linsley, Kohler and Paulhus, 1975) which give lake evaporation as a function of Class A pan evaporation and heat transfer through the pan. This procedure was applied using average values of wind movement, air temperature, water temperature, and pan evaporation recorded at Wanship Reservoir. For reasons discussed in Section 2.5, it was not necessary to obtain pan coefficients for other climate divisions. Reservoir evaporation loss was computed as the depth indicated by the pan data adjusted by the pan coefficient and multiplied by the area associated with the average reservoir contents for the month.

Storage contents are recorded only bi-monthly or monthly for most study reservoirs. Therefore, Equation 2.2 was solved on a monthly basis only. A nearby station, preferably upstream but in some cases a well-correlated gage in a different basin, was selected to characterize the distribution of daily flows. Specifically, the ratio of reservoir inflow to the nearby station flow was computed for each month. Ordinates of the nearby station hydrograph were multiplied by this ratio to provide an estimated daily reservoir inflow hydrograph. In order to avoid abrupt jumps in estimated daily flows at changes between calendar months, ratios in successive months were linearly interpolated to provide a ratio which changed smoothly from day to day.

In 1934, few of the study reservoirs were in existence. Therefore, the approach as outlined above was altered. The five driest years of the period held in common by reservoir inflow estimates and the nearby station were identified. Ratios of the inflow volumes, as determined by backrouting through the reservoir, to the nearby station flows were calculated for each month. The average of the five ratios for each month was then used as described previously to distribute the monthly flow on a daily basis.

The method described above was used to construct reservoir inflow hydrographs under historic conditions. To distribute the increase in inflow resulting from cloud seeding, it was assumed that cloud seeding would have negligible effects on the timing of runoff. Each daily flow rate from the beginning of the snowmelt season through the end of the water year was multiplied by the ratio of augmented seasonal inflow volume to observed seasonal inflow based on the procedure described in Section 2.3.3. For 1934, this resulted in two new hydrographs, one for the M1 design and another for the M2 design. For 1977, three hydrographs were generated: one representing streamflows which would have occurred in the absence of any cloud seeding (smaller in volume than the historic runoff), and one for each of the M1 and M2 designs superimposed on the non-seeded hydrograph.

2.5 Special Cases

In summary, the procedure described in the previous two sections can be condensed into five steps:

1. Compute seasonal runoff estimates under various seeding designs for a sample of dry years.
2. Plot the predicted changes against the observed seasonal volumes and fit a curve.
3. Enter the fitted curve with observed 1934 or 1977 seasonal volume and read the volume of the newly developed reservoir inflow water.
4. Construct historic daily hydrograph by backrouting through the reservoir on a monthly basis, and distributing the flows based on those recorded at a well-correlated nearby gage.
5. Multiply ordinates of the hydrograph obtained in Step 4 by the ratio of the inflow volume with seeding to the inflow volume without seeding based on the results of Step 3.

Several reservoirs did not conform perfectly to the sequence outlined above, and the special considerations involved in these cases are explained below.

1) The NWS does not forecast inflows to either Echo or Lost Creek Reservoirs in the Weber basin. Therefore, the augmented reservoir inflows could not be estimated by the procedure described above. Instead augmented reservoir inflow volumes were estimated based on the increase in seasonal inflow volumes predicted for several neighboring reservoirs. These increases were normalized with respect to observed inflow volumes in order to provide a basis of comparison for the different-sized streams. Deer Creek and Strawberry Reservoirs in the Upper Jordan Basin were included in the regional estimates for 1977. For 1934, only the Weber Basin reservoirs, Wanship, East Canyon, and Pineview, were available. A simple arithmetic mean of the normalized values was then used at Echo and Lost Creek.

2) Echo and Wanship Reservoirs are in series. The inflow hydrographs developed for Echo represent local inflows between Wanship and Echo Dam, rather than all flows from the drainage above Echo. In addition to the Weber River, Chalk Creek is a major tributary to Echo Reservoir. Both streams are gaged just above their entry into the reservoir. The daily distribution of the monthly inflow was here characterized by the sum of Chalk Creek and Weber River daily flows at these locations.

3) Steinaker Reservoir is unique among the study reservoirs in that it is an offstream impoundment which stores water from Ashley Creek. Backrouting through the reservoir was unnecessary, as the relevant hydrograph, for water allocation purposes, was at the site of the diversion from Ashley Creek. These flows were gaged by the USGS from 1938 to 1965. In recent years, the Ashley Creek River Commissioner's reports have included daily streamflow here during the irrigation season. The methods described previously for generating hydrographs prior to the existence of the reservoir were used to transfer flows from an upstream gage ("Ashley Creek near Vernal") to this point during 1934 and the winter of 1977.

4) Exceptions to Steps 4 and 5 were taken in the Sevier basin. The Sevier River is a highly managed stream. Inflows to the reservoirs are as much the result of operational decisions as they are a response to natural hydrologic processes. The procedure which has been devised for allocating the water

supply attempts to distinguish the contributions of runoff and return flow, called "primary" water, from reservoir releases in defined reaches of the river. Computations of primary flow provide the basis for water allocation. NWS forecasts seasonal flow volumes in three of the river's administrative zones. The augmented inflow volume estimated in Steps 1 through 3 was added to primary flow rather than to the reservoir inflow hydrograph. Furthermore, no attempt was made to produce daily inflow hydrographs at the Sevier River reservoirs for three reasons:

a) The time distribution of the developed water is unknown. Because of upstream diversions, it is unlikely that the hydrograph of the developed supply would resemble the historic inflow. It is also unlikely that the developed supply would reach the reservoirs in the typical pattern of snowmelt runoff, due to use above the reservoirs.

b) The amount of developed water was small in comparison to the deficit to a large class of common priority rights. Even if the developed water peaked very suddenly, it probably would not be enough to exceed the decreed right of this group of users.

c) Because primary flow was in such short supply during the study years, and because nearly all users have the privilege of storing their primary flow in one reservoir or another, it is unlikely that any users would waive their primary flow right, thereby changing the ownership of the supply. For reasons b and c, the allocation of the developed supply was insensitive to the timing of the runoff on a daily scale.

2.6 Estimates Of Reservoir Inflow

The results of the application of the methods, described above, are presented in this section. The first subsection deals with estimates of increases in seasonal inflow volumes, obtained using the techniques detailed in Section 2.3. The second subsection presents the development of daily inflow hydrographs using the procedure described in Section 2.4.

Interpretation and discussion of the results are included in each subsection.

2.6.1 Seasonal Volume Changes

Table 2.2 summarizes the predictions of increases in seasonal inflows at each reservoir under the three seeding program designs (i.e., M1, M2, and 1977). The regression equation presented in Table 2.2 was fitted to the plots of predictions of developed water versus observed inflow. Units for the equations are thousand acre-feet. Although most of these equations are parabolic or linear in form, the data were most satisfactorily fit with hand-drawn curves in three cases. Examples of a parabolic, a linear, and a hand-drawn curve are shown in Figure 2.6 through 2.8, respectively.

The number of data points on which each curve was based (N) is given in Table 2.2. The data set was smaller than ten points for several reservoirs where precipitation data were missing from most of the gages used in the NWS model.

The 1977 and 1934 observed inflows presented in Table 2.2 were determined using the mass balance of Equation 2.1. For 1934, observed inflow conditions are also the no-seeding conditions. The estimated effects of the 1977 seeding program on reservoir inflow were subtracted from observed inflow to obtain estimates of the 1977 inflow under no-seeding conditions. The values of inflow under the M1 and M2 programs were computed by adding the quantity of developed water, as predicted using the curves presented in Table 2.2, to the "no-seeding" inflow volumes.

TABLE 2.2

Observed And Predicted Seasonal Reservoir Inflow Values In Thousands Of Ac-Ft

Site and Seeding Design	Regression Equation[1]	N[2]	1977 observed	1977 no seeding	1977 seeding	1934 observed[3]	1934 seeding
Weber River Basin							
Weber River at Oakley (Wanship Reservoir Inflow)			42.86			39.54	
M1	$Y = .195X - .00103X^2$	12			41.82		45.64
M2	$Y = .491X - .00229X^2$	12			50.87		55.37
1977	$Y = .222X - .000983X^2$	12		36.12			
Pineview Reservoir			21.17			20.59	
M1	$Y = .442X - .00315X^2$	11			21.10		28.36
M2	$Y = .966X - .00609X^2$	11			28.35		37.90
1977	$Y = .439X - .00261X^2$	11		15.13			
East Canyon Reservoir			7.83			4.80	
M1		11			8.79		7.50
M2	Curves drawn by hand	11			13.06		11.25
1977		11		5.70			
Echo Reservoir			16.99			9.91	
M1	Increment determined				17.39		13.52
M2	by regionalized values				23.58		18.45
1977				12.59			
Lost Creek Reservoir			5.02			2.57	
M1	Increment determined				5.14		3.51
M2	by regionalized values				6.97		4.78
1977							

TABLE 2.2

Continued

Site and Seeding Design	Regression Equation[1]	N[2]	1977 observed	1977 no seeding	1977 seeding	1934 observed[3]	1934 seeding
<u>Utah Lake Drainage</u>							
Deer Creek Reservoir			33.3				
M1	$Y = .460X - .00267X^2$	9			34.4		
M2	$Y = .911X - .00434X^2$	9			44.5		
1977	$Y = .391X - .00167X^2$	9		24.7			
Strawberry Reservoir			11.2				
M1		9			11.1		
M2	Curves drawn by hand	9			15.8		
1977		9		7.6			
<u>Price River Basin</u>							
Scofield Reservoir			7.14			9.77	
M1	Curves drawn by hand	9			5.65		15.77
M2		9		3.83	8.47		19.57
1977		9					
<u>Ashley Creek Basin</u>							
Ashley Creek near Vernal[4] (Steinaker Reservoir diversion)			23.66			24.87	
M2	$Y = .226X - .00245X^2$	7			25.34		28.97
1977	$Y = .137X - .00193X^2$	7		21.60			
<u>Sevier River Basin</u>							
Sevier River at Hatch (Upper Sevier increment)			108.61			122.72	
M1	$Y = .110X$	10			100.91		136.22
M2	$Y = .305X$	10			118.64		160.15
1977	$Y = .195X$	10		90.91			

TABLE 2.2

Continued

Site and Seeding Design	Regression Equation[1]	N[2]	1977 observed	1977 no seeding	1977 seeding	1934 observed[3]	1934 seeding
Piute Reservoir			65.90			68.91	
M1	$Y = .176X - 10.99$	11			64.65		70.04
M2	$Y = .527X - 31.71$	11			66.50		
1977	$Y = .296X - 17.45$	11		64.32			73.51
Sevier River at Gunnison			49.2			29.6	
M1	$Y = .0837X$	10			46.97		32.09
M2	$Y = .222X$	10			52.95		36.20
1977	$Y = .152X$	10		43.33			

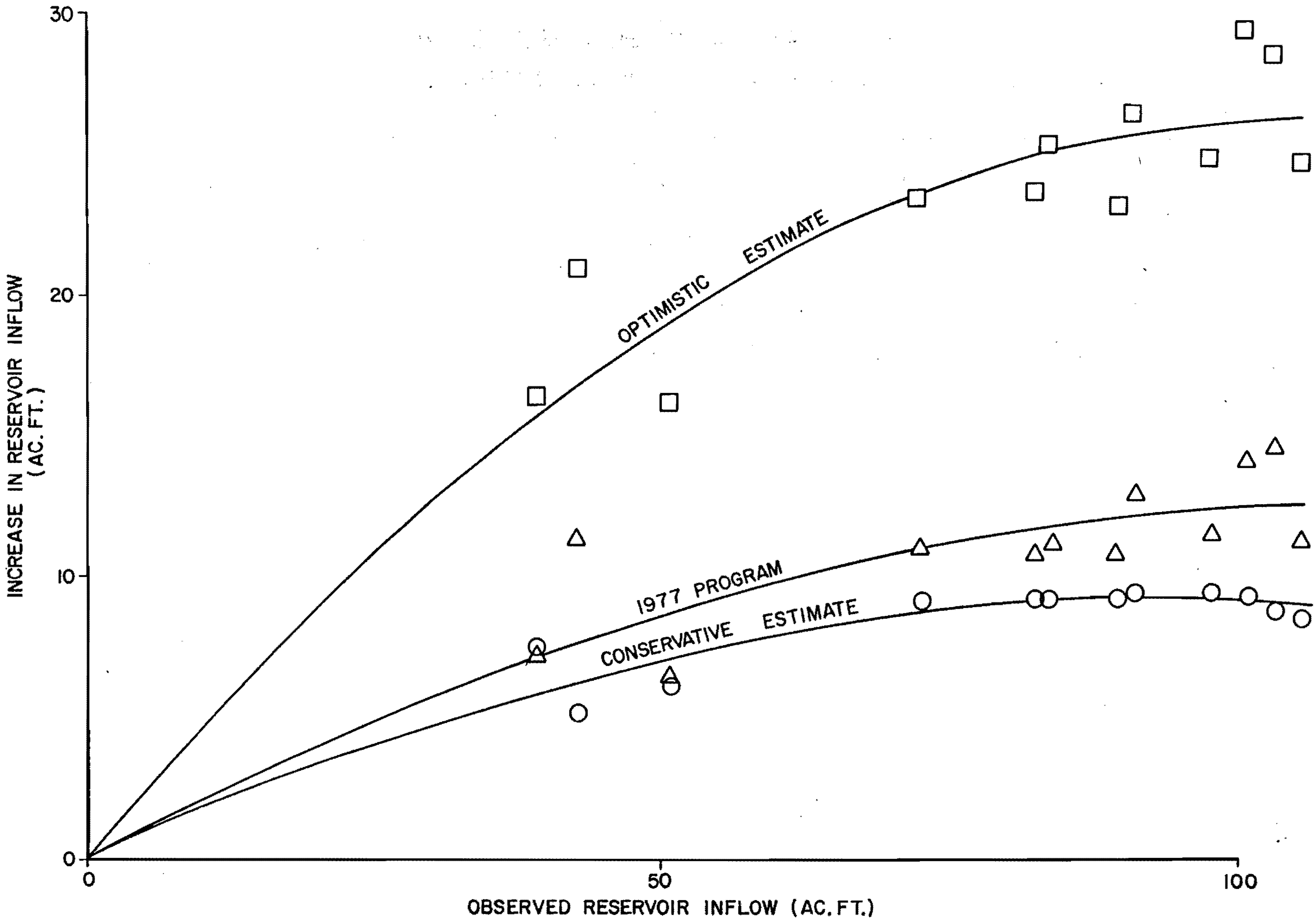
---

[1] X = seasonal flow volume in thousand ac-ft; Y = estimated increase in seasonal flow volume under cloud seeding.

[2] N = number of data points used to develop regression.

[3] Observed flows in 1934 are identical to no seeding design.

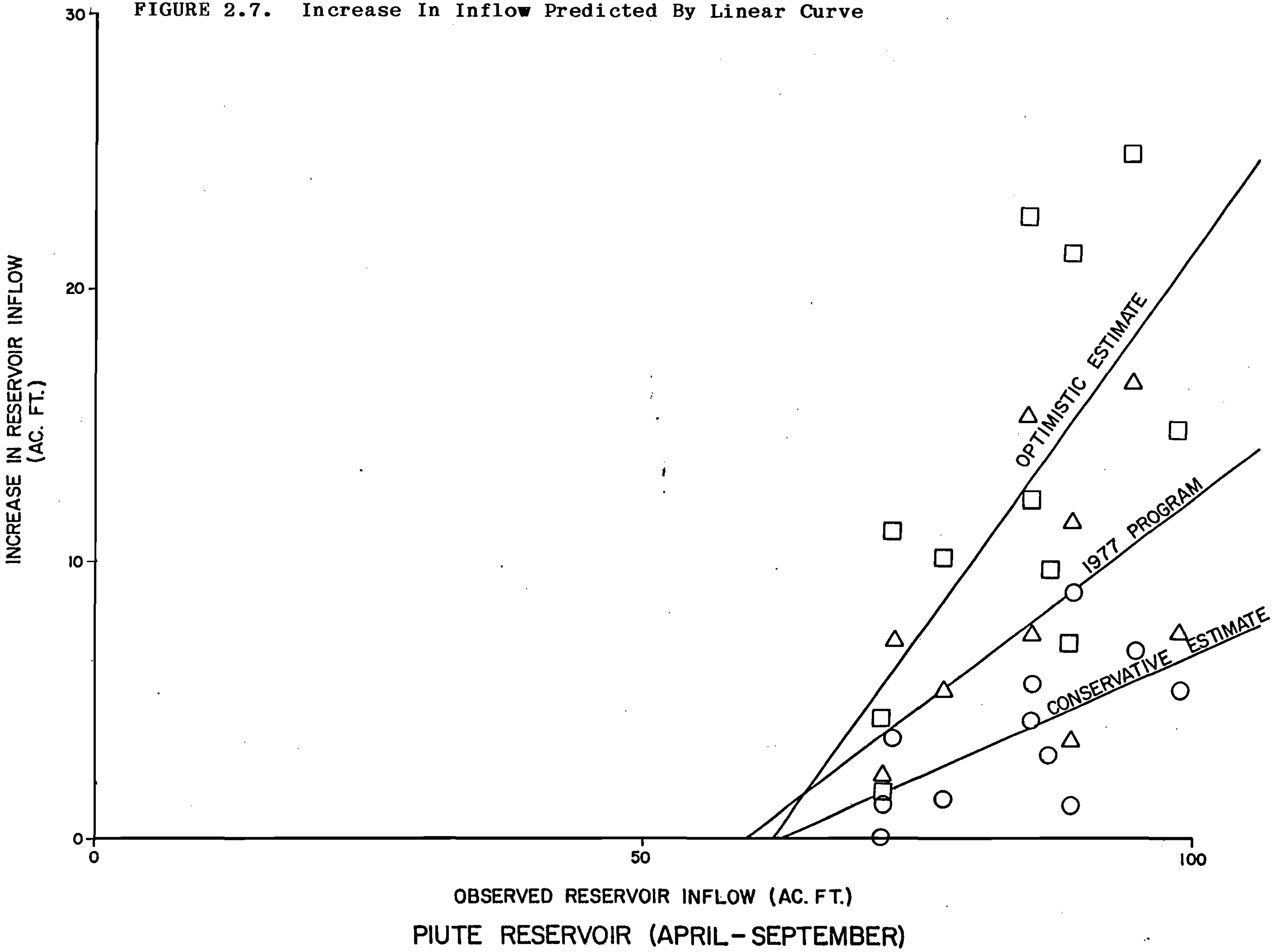
[4] No M1 design is proposed for Ashley Creek (see Table 2.1).



WANSHIP RESERVOIR (APRIL - SEPTEMBER)

FIGURE 2.6. Increase In Inflow Predicted By Parabolic Curve

FIGURE 2.7. Increase In Inflow Predicted By Linear Curve



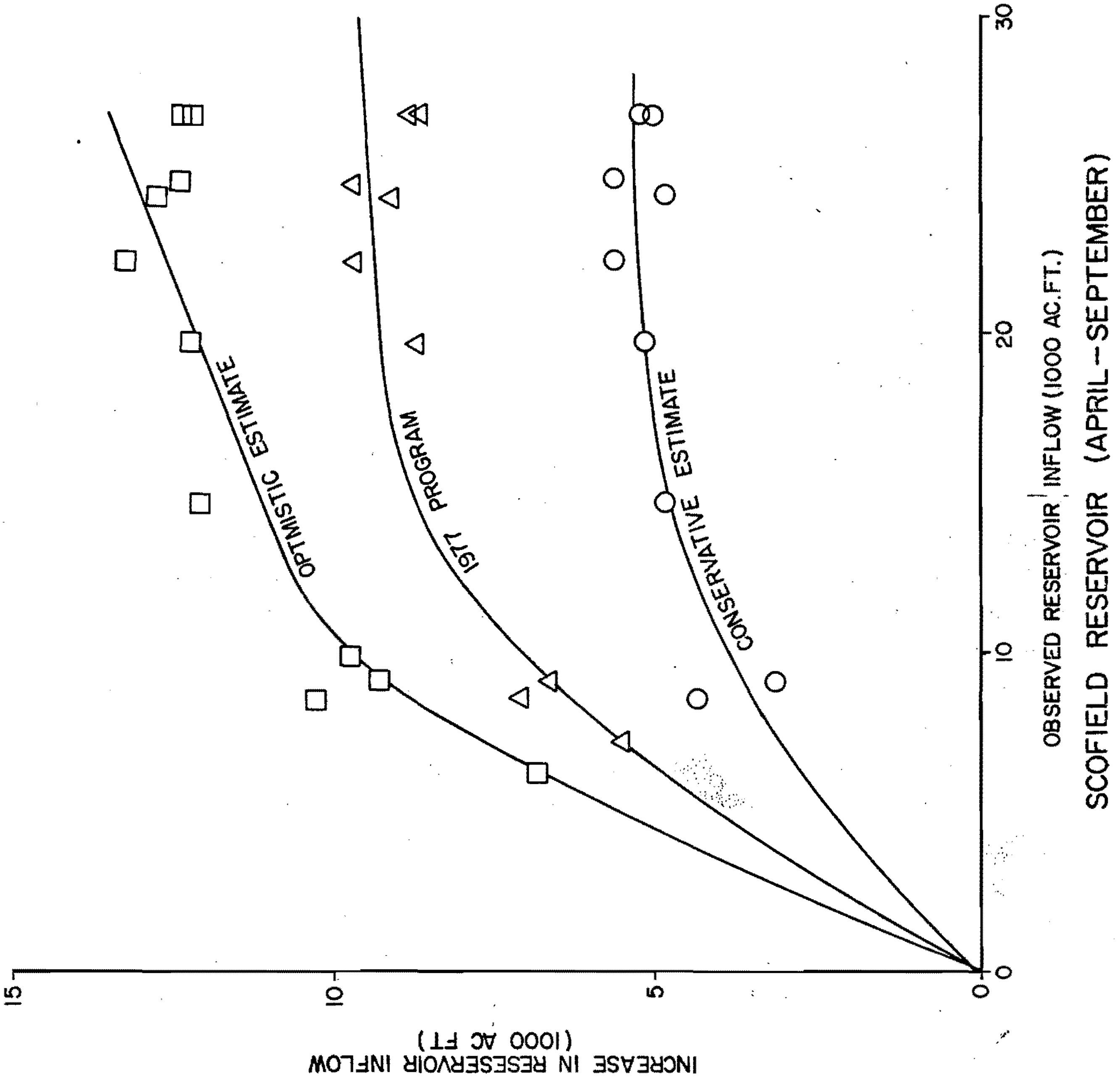


FIGURE 2.8. Increase In Inflow Predicted By Hand-Drawn Curve

It is interesting to note the similar magnitude of the effects of the M1 design and the 1977 program. The difference in the two seeding designs is a later startup date for the 1977 program, and a greater estimated percent increase in precipitation than for the M1 design.

Table 2.3 presents the percent increases in inflow, based on the non-seeded seasonal runoff, for each seeding design and for each of the study years. Clearly, the basins of the Wasatch Mountains appear to be most responsive to weather modification. This would be expected, given the higher elevation of the catchment areas contributing to these reservoirs, and therefore the greater influence of snowpack on runoff and the smaller relative losses at higher elevations. Also larger proportions of these drainage areas are subject to the orographic storms to which seeding technology is suited.

The comparatively small increases for Ashley Creek flows are explained by the smaller proportion of high elevation, high yield area in its catchment area, and by other physical and meteorological factors which make the area less conducive to successful weather modification. These are discussed in more detail in Chapter 4 of this report but are reflected in the lower percentages of precipitation augmentation presented in Table 2.1. A third influence on Ashley Creek results may be a limitation in the NWS model for Ashley Creek. The model does not include snow water equivalent as an independent variable presumably because of the lack of representative stations in or near the drainage. To compensate for this, model parameters weight precipitation for the winter months more heavily than in other forecast equations. On the average, January-to-March precipitation in the Ashley Creek model account for 65 percent of the non-constant portion of the forecast, compared to,

TABLE 2.3

Percent Increases In April-September Reservoir Inflows

	1934		1977	
	M1	M2	M1	M2
Weber River Basin				
East Canyon Reservoir	54	129	56	134
Pineview Reservoir	37	84	40	87
Wanship Reservoir	15	40	16	41
Utah Lake Drainage				
Strawberry Reservoir[1]	-	-	52	97
Deer Creek Reservoir[1]	-	-	34	90
Price River Basin				
Scofield Reservoir	61	100	48	121
Ashley Creek Basin				
Ashley Creek near Vernal	-	17	-	17
Sevier River Basin				
Sevier River at Hatch	11	31	11	31
Piute Reservoir	1.6	6.7	0.5	3.4
Sigurd Gunnison	8.4	22	8.4	22

[1] Analysis not carried out for 1934 (see Section 2.2.1).

for example, 74 percent for Pineview Reservoir and 76 percent for Scofield, for which both precipitation and snow water equivalent variables are included. Since the January-to-March period is the most sensitive in terms of the incremental effects of weather modification, it can be seen that any predictions for Ashley Creek will be less responsive to perturbations in winter precipitation. Whether this reflects actual characteristics of the basin, or is simply the lack of snowcourse data, is unknown.

The Sevier River models indicate moderate gains in flow compared to those in the northern highlands. These are partly due to the diversions and consumptive use above the forecast points. Water generated in the mountainous boundaries of the basin may never reach Piute or Sevier Bridge Reservoirs. Another factor is the relative importance of groundwater and return flow in the Sevier basin. Some benefits from seeding in the Sevier basin would be expected in years following the year of seeding, but these were not explored in this study.

2.6.2 Daily Inflow Hydrographs

Table 2.4 lists the nearby gaging stations used as a basis for estimating each daily inflow hydrograph. Superscripts indicate instances where 1) the nearby station was outside the drainage area or 2) the reservoir contents or outflow gage does not exist and so an average relation between a nearby station and reservoir inflow was used. It is expected that the greatest accuracy was achieved for those station-year combinations for which reservoir contents and outflow were measured, and for which the daily distribution of flows was derived from an upstream gage.

TABLE 2.4

Gaging Stations Used As Basis For Estimating The Distribution Of Daily Reservoir Inflows

Reservoir		Gaging station used for daily flow distribution
Wanship Inflow	1934[1]	Weber River near Oakley
	1977	Weber River near Oakley
Wanship to Echo Local Inflow	1934	
	1977	Chalk Creek at Coalville & Echo Diversion-Inflow
East Canyon Inflow	1934	Creek Creek at Coalville[2]
	1977	Chalk Creek at Coalville[2]
Lost Creek Inflow	1934[1]	Chalk Creek at Coalville[2]
	1977	Chalk Creek at Coalville[2]
Pineview Inflow	1934[1]	South Fork Ogden River near Huntsville
	1977	South Fork Ogden River near Huntsville
Scofield Inflow	1934[1]	Huntington Creek near Huntington[2]
	1977	Fish Creek above reservoir
Ashley Creek at Thornburgh Diversion	1934[1]	Ashley Creek near Vernal
	1977	Ashley Creek near Vernal

[1] Daily station outside catchment

[2] No outflow gage; average of dry-year ratios used to transfer hydrograph and distribute on daily basis.

Inflow hydrographs were plotted for each reservoir for both study years. Each graph showed reservoir inflow as it would have occurred without seeding, and as it was predicted to occur with the M1 or M2 seeding designs. A sample plot is included as Figure 2.9.

2.7 Allocation Of Developed Water

2.7.1 Background

Knowledge of the physical effects of cloud seeding on streamflow needs to be converted into economic benefits if the feasibility of weather modification is to be assessed and the value of such a program justified. Such an economic evaluation, in turn, requires that one knows which users are entitled to use the developed water. Although many authors have attempted to determine the quantity of water that might be induced by cloud seeding, few if any have analyzed its ownership. For the purpose of the economic model utilized in this project, the developed water was divided both by climate division and by use sector (i.e., agricultural and non-agricultural).

This section opens with general information regarding the procedure selected to determine ownership of developed water, along with its legal justification. In the following subsections, basin-specific rules and other water allocation policies are briefly described for each reservoir system for the study years 1977 and 1934. Presentations for each basin are not exactly parallel because the pertinent information differs from system to system. In some cases, river commissioner reports provided a basis for segregating agricultural from non-agricultural use, and for assigning use to each climate

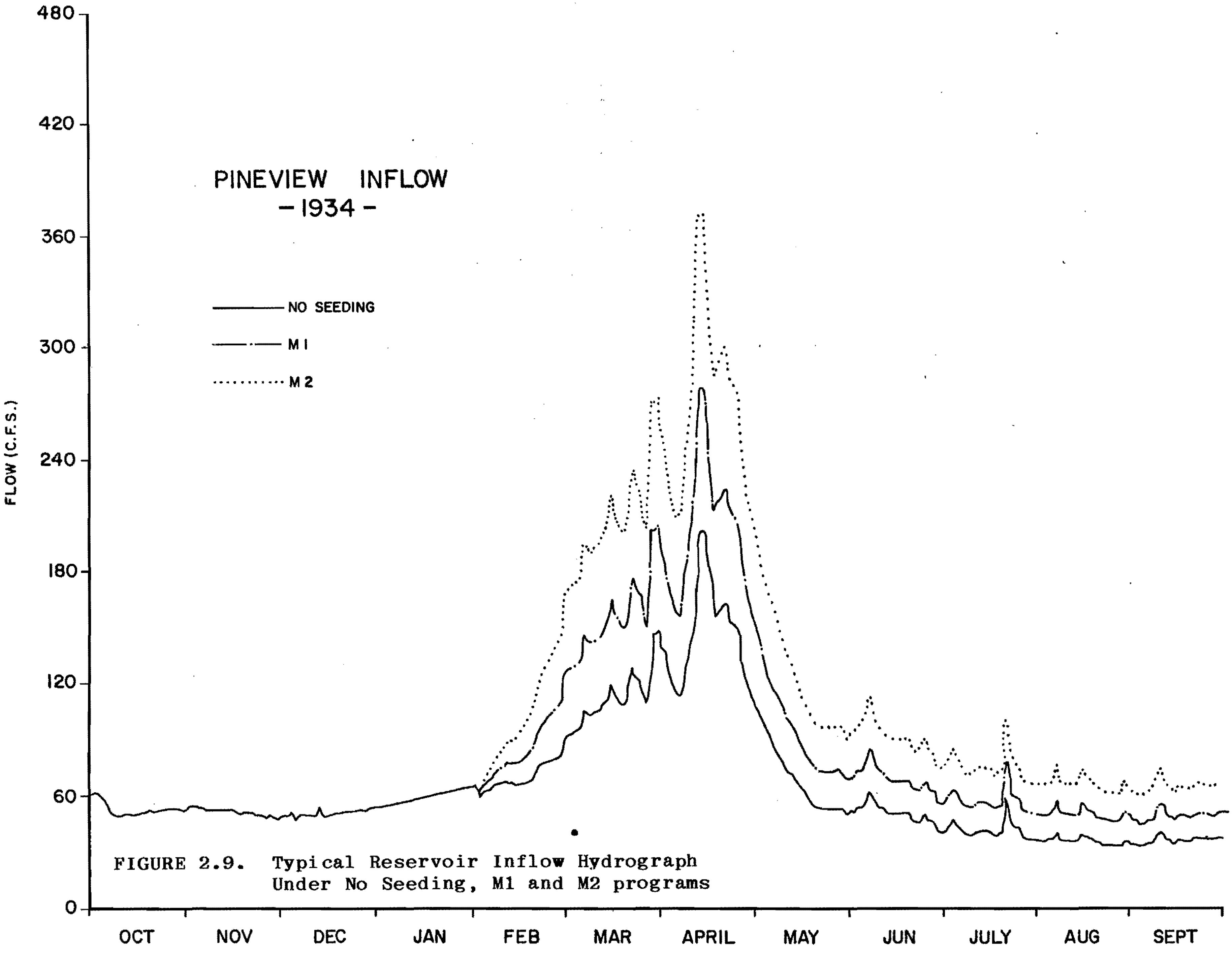


FIGURE 2.9. Typical Reservoir Inflow Hydrograph Under No Seeding, M1 and M2 programs

division in the basin; in other instances the quantities were left in their aggregated condition. Other bases for dividing the supply by use sector and climate division incorporating previous economic studies are presented in Chapter 3 of this report.

The allocation of developed water poses some interesting legal questions. Particularly where privately-sponsored projects are undertaken, it would be desirable to separate developed water from the natural supply, and permit the weather modifier to make use of water which results from his investment. Utah statute, however, treats pragmatically the obvious difficulties in proving the precise volume of water creditable to seeding, and resolving conflicting claims of cloud seeders who believe that their areas of influence have overlapped. The Utah Weather Modification Act (Utah Code Annotated 1953, 73-15-4) states that developed rainfall "... shall be considered as a part of Utah's basic water supply the same as all natural precipitation ..., and all statutory provisions that apply to water from natural precipitation shall also apply to water derived from cloud seeding". Thus, it is clear that hydrographs of augmented reservoir inflow should be allocated under the established rules which apply under non-seeded conditions.

Utah water rights, although administered by the states and based on doctrine accepted throughout the Western U.S., are locally variable. The rules reflect the historical development of a basin, its physical and geographical features, and the tradition and desires of the local users. In each basin, it was necessary to interview individuals familiar with the daily procedures of allocating water. Usually this was the river commissioner, but help was also received from employees of water users group. Despite variations in the details, the general approach taken was to examine records of the actual allocation in 1977, which revealed the limits of the historical supply, and areas of shortfall. The changes with respect to the historical water supply were then allocated. These changes were negative for the no-seeding alternative, and, occasionally, for the M1 seeding design where it was predicted to be less effective than the 1977 program. Changes for the M2 design, being more effective than the 1977 program, were always positive. The amount of use recorded in the river commissioners reports was also noted. Basinwide use was then adjusted by the allocation of the developed water. Since the same kinds of records did not exist for 1934, the predicted supply for both the observed or non-seeded conditions was allocated using the same relative distribution of water among users as occurred in 1977.

2.7.2 Weber Basin Reservoirs

Water rights on the Weber basin reflect the history outlined in Section 2.2.2. Direct flow or natural flow rights are honored first during the irrigation season. Winter flows accumulate in the reservoir into which they drain, with the theoretical stipulation that Echo Reservoir must fill before the two more recent developments, Deer Creek and Wanship Reservoirs, may store water. In practice, water is diverted to the Provo River during spring flows, coinciding with the filling of Echo; in dry years it is possible to export water under an agreement with Utah Power and Light without Echo being filled. Pineview and East Canyon Reservoirs, which were enlarged by WBCD, must store the capacity of the original reservoir before any water accrues to the WBCD. The Ogden River Water Users (ORWU) own the first 44,000 ac-ft of Pineview Reservoir while WBCD owns the remaining 66,000 ac-ft. Of the 48,000 ac-ft capacity of East Canyon, the first 28,000 ac-ft belong to the Davis and Weber Canal Company (D&W), and the remaining 20,000 ac-ft belong to WBCD. Once the irrigation season begins, exchanges can be made through the downstream users to insure that prior storage rights are filled.

Estimated changes in reservoir inflows for the two study years are given in Table 2.5 and 2.6. It is emphasized that these are changes from observed inflows. Since cloud seeding was practiced in 1977, estimated inflows without seeding and in some cases under the M1 program are smaller than observed flows. This accounts for the negative entries in Table 2.5. Inflow to Wanship Reservoir is combined with the inflow to the Wanship-Echo reach and labeled "Above Echo" in Tables 2.5 and 2.6 because all contributions above Echo are credited to Echo until it fills. This is because Echo has the prior rights. The basis for allocating the developed water is explained below for each year, and the ownership of the developed water is given on a month-by-month basis.

1977

In order to determine the allocation of the changes from observed supply for 1977, river commissioners reports were consulted to determine which reservoir or storage rights were only partially filled, and at what time irrigators were calling for their stored water. For both seeding designs and for the no-seeding case, the changes from the observed supply in each month were allocated following water rights and operating rules for the Weber basin. At the suggestion of the Weber River Commissioner, water use during April, May, and a portion of June under all conditions was assumed to stay at observed levels, with more or less of calls being provided by storage

TABLE 2.5

Predicted Changes In 1977 Observed Weber Basin Reservoir Inflows (Ac-ft)

Reservoir/Seeding Program	Oct.-Mar.	April	May	June	July	Aug.	Sept.
Above Echo							
No seeding	-701	-1738	-2772	-2827	-1023	-832	-1014
M1	-36	-83	+116	-254	-36	-17	12
M2	+925	+2326	+3689	3592	1370	1130	1419
Net Change							
M1	665	1655	2888	2573	987	815	1026
M2	1626	4064	6461	6419	2393	1962	2433
East Canyon							
No seeding	-566	-683	-717	-363	-262	-217	-217
M1	+254	+306	+322	163	119	97	98
M2	+1391	+1146	+1761	892	653	532	534
Net Change							
M1	820	989	1039	526	381	314	315
M2	1957	1829	2478	1255	915	749	751
Lost Creek							
No seeding	-96	-272	-276	-188	-174	-179	-209
M1	+9	+25	+26	17	16	17	19
M2	+144	+408	+414	282	262	269	314
Net Change							
M1	105	297	302	205	190	196	228
M2	240	680	690	470	436	448	523
Pineview							
No seeding	-506	-1230	-1992	-1262	-1114	-899	-781
M1	-5	-13	-21	-13	-12	-10	-8
M2	+600	+1458	2361	1496	1321	1063	926
Net Change							
M1	501	1217	1971	1249	1102	889	773
M2	1106	2688	4353	2758	2435	1962	1707

TABLE 2.6

Predicted Changes In 1934 Observed Weber Basin Reservoir Inflows (Ac-Ft)

Reservoir/Seeding Program	Oct.-Mar.	April	May	June	July	August	September
Above Echo							
M1	2115	2222	3339	1166	413	464	591
M2	5095	5537	8335	2879	1027	1149	235
East Canyon							
M1	2213	1068	654	305	432	447	203
M2	5292	2553	1564	729	1033	1070	486
Lost Creek							
M1	136	335	184	130	92	99	107
M2	322	794	436	307	217	209	252
Pineview							
M1	2607	3319	1605	1117	944	822	783
M2	5815	7404	3580	2491	2106	1834	1748

water. Flow increase during the latter half of the summer were assumed to result in increased use. Records showed which users drew on reservoir storage in the spring. Where the increase was used to offset this reservoir use, the assignment to a climate division was certain because the point of diversion was known. Where the increase was only known to provide natural flow over the entire basin, the new supply was divided between the climate divisions in the same ratio as the observed supply.

Specific considerations for water allocations in various periods within 1977 are presented below. Quantities of the allocation supported by these considerations are summarized in Table 2.7.

October to March

This being the storage season in the Weber basin, positive changes in reservoir inflow (Table 2.5) represent increases in reservoir storage above 1977 levels. Negative changes indicate reductions in winter storage, or increases in shortfalls at the end of the storage season.

April

In 1977, irrigation began in the third week of April. No diversions were made from reservoir water during this month, so it can be assumed that natural flow was sufficient to meet the early season demand. Had more water been available due to more effective cloud seeding programs, it would have been stored. In the absence of the 1977 cloud seeding program, a reduction in supply would have diminished the quantity of water stored during April.

TABLE 2.7

Allocation Of Changes In 1977 Weber Reservoir Inflows (Ac-Ft)

	Echo			Lost Creek			East Canyon (WBCD)			East Canyon (D & W)		
	NO SEEDING	M1	M2	NO SEEDING	M1	M2	NO SEEDING	M1	M2	NO SEEDING	M1	M1
Observed	65,974	65,974	65,974	14,150	14,150	14,150	12,920	12,920	12,920	22,100	22,100	22,100
Oct-March	-701	-36	925	-96	9	144	0	0	0	-566	254	1,391
April	-1,738	-83	2,326	-272	25	408	0	0	0	-683	306	1,146
May	0	0	263	0	0	0	0	0	0	0	0	124
June 1-15	0	0	942	0	0	0	0	0	0	0	0	235
June 16-Sept	0	0	0	0	0	0	0	0	0	0	0	0
	63,535	65,855	70,430	13,782	14,184	14,702	12,920	12,920	12,920	20,851	22,660	24,996

	Pineview (ORWU)			Pineview (WBCD)			Natural Flow Use			Storage Use		
	NO SEEDING	M1	M2	NO SEEDING	M1	M2	NO SEEDING	M1	M2	NO SEEDING	M1	M2
Observed	31,189	31,189	31,189	33,490	33,490	33,490	0	0	0	0	0	0
Oct-March	-506	-5	600	0	0	0	0	0	0	0	0	0
April	-1,230	-13	1,458	0	0	0	0	0	0	0	0	0
May	0	0	2,361	0	0	0	-5,757	+211	5,477	5,757	-211	-5,477
June 1-15	0	0	0	0	0	0	-3,378	-49	2,000	+3,378	49	-2,000
June 16-Sept	0	0	0	0	0	0	-8,185	257	12,878	0	0	0
	29,453	31,171	35,608	33,490	33,490	33,490	-17,320	419	20,355			

May

By May, several irrigation water users were calling for more water than natural flow could supply. Thus they were beginning to deplete their reservoir storage. Use of this type came to 5034 ac-ft in the North Central Climate Division and 443 ac-ft in the Northern Mountains. According to the Weber River Water Commissioner, this is a very unusual occurrence, and any increase in flows during May would have been used to offset the reservoir draft. Assuming that demand remains the same under different scenarios, positive adjustments would imply increased natural flow use up to the amount charged to reservoir storage. Reservoir use would be diminished by the same amount to complete the transfer.

It should be noted that the total quantity of storage is not increased by this transaction between natural flows and storage; that is, shortfalls in the reservoir are not reduced, because the user is simply postponing the consumption of water already accumulated. However, positive changes in excess of the quantities withdrawn from storage in May would be stored, and would therefore represent additional accumulation in the reservoir. Decreases in runoff would reduce the natural flow supply, inducing irrigators to rely on reservoir supplies.

June

After inspecting the hydrographs developed for the Weber Basin reservoirs, the River Commissioner suggested that June be divided into two equal periods. Flow during the first fifteen days amounted to roughly two-thirds of the June runoff. The commissioner indicated that about 2000 ac-ft of reservoir draft in early June should be handled as the May drafts were handled: positive increments in supply would be used to offset storage use, and developed water beyond this amount could be credited to storage. Negative increments would reduce natural flow use and increase reservoir draft.

Late Summer

During the remainder of the season, flows were low enough that developed water attributed to cloud seeding would be allocated to natural flow users. Similarly, reductions in supply are charged against natural flow.

In determing the total delivered supply for each climate division, it must be remembered that the five sub-watersheds above the Weber River reservoirs cover only a portion of the basin. Additional runoff is yielded below the dams and the supply from Willard Bay must be accounted for. Total basin supply for 1977 under the proposed seeding programs was calculated by adjusting the observed natural flow and storage uses, as recorded in the river commissioners annual report, by the quantities of the allocated increments. Since observed uses are recorded by location, it was possible to estimate use by climate division.

In Table 2.8 use is presented by location for 1977. These use estimates exclude interbasin transfers and non-irrigation uses. Observed use was combined with estimates of the developed water to obtain the total use for each seeding design. In estimating WBCD and non-WBCD storage uses it is assumed that the additional water stored is used in the 1977 irrigation season. The transfers from storage use to natural flow use appear in the final column of Table 2.8 as supply which could

TABLE 2.8

Predicted And Observed Weber Basin Water Use By Climate Division For Alternative Seeding Designs In 1977

	Natural Flow	WBCD Storage	Other Storage	Change to 1977 Carryover or Use
Northern Mountains Climate Division				
Measured Use	87,088	11,552	12,049	
No Seeding	80,143	11,184	13,593	-2,715
M1 Seeding	87,174	11,586	11,992	0
M2 Seeding	92,712	12,104	13,745	443
North Central Climate Division				
Measured Use	84,132	86,853	70,589	
No Seeding	73,757	86,853	70,764	-4,428
M1 Seeding	84,465	86,853	70,886	183
M2 Seeding	98,861	86,853	73,187	7,034

potentially be used in the 1977 irrigation season, or held over until the following year.

1934

The procedure for allocating the 1934 developed water supply was similar to that taken for 1977. Two simplifying assumptions had to be made where data were either unavailable or irrelevant for the allocation of 1934 flows according to present technology. The first was that carryover at the end of the 1933 water year existed only in East Canyon and Echo Reservoirs. The historical end-of-the-water-year contents of 5800 ac-ft, were used for East Canyon Reservoir and this was assumed to belong entirely to the Davis and Weber Canal Company. The implication here is that all storage in the WBCD's mountain reservoirs was depleted by the previous three dry years. The validity of this assumption cannot be verified without a rather sophisticated operational study but it seems reasonable in light of the prolonged drought in the early 1930's. In any case, it makes a convenient distinction between the single year drought in 1977 and the multi-year drought in the early 1930's. Judging from the ease with which Willard Bay was replenished during the winter of 1977, it is likely that the deficit at the end of water year 1931 would be filled with early snowmelt flows in 1932. A "worst case" scenario for 1933 might call for 50,000 ac-ft. evaporation loss and a 50,000 ac-ft pumping loss during the season. If only half of that were replaced in the winter of 1934, Willard Bay would have held 165,000 ac-ft in the spring of 1934 and this would have been sufficient to meet all the WBCD needs that can physically be met from Willard Bay using the currently available distribution system.

The second assumption suggested by the River Commissioner was that all flows during April, May, and the first part of June in the non-seeded cases would be diverted as natural flow, and that the increases due to seeding would go to storage. Although most water is decreed to be natural flow during this period, significant quantities of flood flows are often captured for late summer use. Therefore this assumption is based upon practices in the basin.

Cropping patterns and cultivated acreage have changed so much since 1934 that the observed use is irrelevant to an assessment of how the 1934 water supply would be used under current conditions. In order to determine water use in 1934 by climate division and use sector, the collective inflow above the five reservoirs for April through early June of 1934 was compared to the same quantity for 1977. During this period, diversions are usually from natural flow rights rather than from storage. The ratio of these two inflows were multiplied by 1977 natural flow use in the Northern Mountain Climate Division and in the North Central Climate Division to obtain an estimate of total natural flow use in 1934 in each area. Likewise, the water stored in all reservoirs, other than those owned by WBCD, was summed for both years. An equivalent fraction of the 1977 Northern Mountain and North Central irrigation supplies from these reservoirs was assumed to represent reservoir use in 1934. It should be noted that this procedure implies that similar proportions of the supply were held over in reservoir storage at the end of both drought years. WBCD reservoir water was treated similarly but separately because the partitioning of irrigation use from non-irrigation use was different for this supply. Once the allocation of the non-seeded supply was made for 1934, the developed water under the M1 and M2 programs was added to obtain estimates of delivered water under the two proposed programs.

The detailed allocation for 1934 is presented in Table 2.9 followed by the estimates of total use by climate division in Table 2.10. Specific considerations for water allocations in various periods within 1934 are presented below.

October-April 20

All winter inflows are assumed to be stored in Pineview and Lost Creek Reservoirs. Storage in East Canyon would be the inflow volume, less a volume equivalent to a 5 cfs release for the maintenance of fish on East Canyon Creek for a 202-day period during the winter season. Storage in Echo Reservoir would be 3793 ac-ft less than the inflow during this period, based on the proportion of winter flows that were delivered to the Provo water users under their winter diversion right in 1977. None of the Weber reservoirs would fill under non-seeded conditions and neither East Canyon nor Pineview would fill to their pre-expansion capacity. Therefore, developed water under both the M1 and M2 seeding programs during this period would be allocated to storage.

April 21 - June 10

Without cloud seeding, all reservoir inflows would be delivered to natural flow users. Additional inflow developed by cloud seeding would probably be stored. Under the M1 program, all reservoirs fall short of filling, but the M2 program would be expected to yield enough runoff so that 2851 ac-ft would be stored in Wanship Reservoir. Eleven hundred ac-ft would accrue to WBCD in East Canyon Reservoir, and 5500 ac-ft would

TABLE 2.9

Allocation Of Changes In 1934 Weber Reservoir Inflows (Ac-Ft)

	Echo		Lost Creek		East Canyon (WBCD)		East Canyon (D & W)	
	M1	M2	M1	M2	M1	M2	M1	M2
Observed (no seed)	54,865	54,865	4,195	4,195	0	0	18,386	18,386
Oct-Mid June	7,970	16,849	720	1,706	0	1,093	4,088	8,681
Mid June-Sept	0	0	0	0	0	0	0	0
	62,835	71,714	4,915	5,901	0	1,093	22,474	27,067

	Pineview (ORWU)		Pineview (WBCD)		Wanship		Natural Flow Use	
	M1	M2	M1	M2	M1	M2	M1	M2
Observed (no seed)	27,509	27,509	0	0	0	0		
Oct-Mid June	8,877	14,292	0	5,509	0	2,851	0	0
Mid June-Sept	0	0	0	0	0	0	6,391	14,927
	36,386	41,801	0	5,509	0	2,851	6,391	14,927

TABLE 2.10

Predicted And Observed Weber Basin Water Use By Climate Division For Alternative Seeding Designs In 1934

	Natural Flow	WBCD	Other Storage
Northern Mountains Climate Division			
No Seeding	65,316	965	9,201
M1 Seeding	73,153	1,130	11,022
M2 Seeding	83,629	3,531	12,195
North Central Climate Division			
No Seeding	63,099	3,230 non Willard Bay up to 115,000 Willard Bay	60,072
M1 Seeding	70,671	3,785 non Willard Bay up to 115,000 Willard Bay	71,693
M2 Seeding	80,767	11,823 non Willard Bay up to 115,000 Willard Bay	79,615

accumulate in Pineview Reservoir. Lost Creek Reservoir would not fill. Deliveries to Provo users would increase with cloud seeding as Echo inflow increases. An estimate of seasonal evaporation loss, based on estimated pan evaporation and the average reservoir surface area during the season, was subtracted from total storage in each reservoir.

Late Summer

Both the non-seeded inflows and the augmented inflows would be distributed as natural flow supply.

2.7.3 Scofield Reservoir

Scofield Reservoir has an unusually short storage season, lasting from December 1 to the end of February. Since irrigation does not begin until later in the spring, agricultural users typically waive their March direct flow right, and this water also becomes storage water. Like the Weber River reservoirs, Scofield Reservoir drains a high-yield subwatershed within the basin, but some of the irrigation supply is contributed on the main stem below the dam, and by six tributaries below the reservoir. Primary or natural flow is determined through the irrigation season by adding flow above Scofield Reservoir to those from the six lower tributaries, some of which are gaged, and some of which are estimated by the Price River Commissioner. This sum is then allocated to eight classes of users, the first class being fully satisfied before anything is allocated to the second class and so on. All users in a partially satisfied class receive the same portion of their allotment. The first class rights amount to 74 cfs. The next 16 cfs are spread across Classes 2 through 7, and Class 8 consists of an additional 80 cfs. Several levels of allocation, including some for summer storage in Scofield Reservoir, exist beyond Classes 1 through 8, but they were not in effect at any time during 1977 or 1934, and therefore are not described herein.

The changes to observed reservoir inflows for 1977 and 1934 are presented in Table 2.11. The allocation of the changes is described below.

1977

The Price River Commissioner in his 1977 report stated that the first seven classes received full allotments during April, but that only fractions of first class water were available during the subsequent months. With this information, the developed water for each month was successively assigned to the unsatisfied users until the developed water was fully allocated.

Specific considerations for water allocations in various periods within 1977 are presented below.

December - March

All increments add to or subtract from storage in Scofield Reservoir.

April

Natural flow was sufficient to meet demand for the first seven classes. The positive increment of developed water generated by the M2 program would be decreed to the eigth class of rights, but it probably would have been waived by

TABLE 2.11

Changes To Observed Scofield Reservoir Inflows (Ac-Ft)

	Dec.-Mar.	April	May	June	July	Aug.	Sept.
1977							
No seeding	-151	-1,476	-1,618	-825	-619	-599	-356
M1	0	-674	-727	-371	-278	-267	-161
M2	61	596	654	333	250	242	144
Net Change							
M1	151	802	891	454	341	332	195
M2	212	2,072	2,272	1,158	869	841	500
1934							
M1	0	3,800	2,818	815	196	194	393
M2	1,088	6,202	4,600	1,330	320	315	640

its owners, and therefore stored. This is because most users with the eigth class right also own a more senior right, which would have provided their early season needs. The negative increments would have reduced storage during April.

May - September

Reservoir contents declined continuously throughout this period, implying that all negative increments reduce direct flow supply. The positive increments would be allocated to first class rights. During May, when the deficit was 30 percent of the first class right, the increment is 654 ac-ft, roughly half of the quantity needed for full allotment within this class. As the summer progresses, the deficit grows as the increment dwindles, which means that no other groups of rights can receive water.

The available natural flow supply over the reservoir drainage and the six contributing streams was inferred from the commissioner's account of the distribution of waters for 1977. The difference between this natural flow supply and the inflow to Scofield is attributable to the net effect of transmission losses and small incoming streams. The simplifying assumption was made that other subwatersheds of the Price River drainage would not be significantly affected by the proposed seeding programs, since thev are lower in elevation, lower in recorded precipitation, and further from the target area for cloud seeding. Thus, the difference in basinwide supply under each seeding design, compared to basinwide supply under observed conditions was the change to Scofield inflow. The commissioner also included a seasonal irrigation use estimate in his report, since industry and several municipalities number among the direct flow users. The ratio of seasonal irrigation use to the estimated direct flow supply for observed conditions was applied to the estimated direct flow without seeding, with the M1 program, and with the M2 program. Since all additional water was allocated within one class, the division was correct. This procedure isolated agricultural use for the purposes of input to the economic models.

1934

For 1934, the available direct flow supply was estimated for the observed, no-seeding condition. The entire supply was allocated to the eight classes, revealing where the shortfall would occur, given the hydrologic conditions of 1934. The developed water was then allocated as for 1977.

Records of reservoir contents in mid-October, 1933, indicate that Scofield Reservoir entered the 1934 storage season with useable contents of about 8000 acre-feet. Total storage for 1934 is taken to be this 1933 carryover, plus inflows through March. Direct flow supply for 1934 was estimated by examining the relationship during 1977, of estimated Scofield inflow to basinwide direct flow. This was done on a monthly basis, and the same ratios were assumed to hold for 1934. In this manner the direct flow supply for each month was estimated.

December - March

All increments increase the storage supply in Scofield Reservoir.

April

Under historic conditions, the basin yielded water well in excess of the first several classes. All the excess would have been available for storage, as would any of the developed water.

May

The historic basinwide flow barely filled the first seven classes. Increments would go to eigth class rights but would not satisfy them.

June - September

In 1934, flows decreased quite rapidly in the summer months. Runoff was insufficient to meet the first class and all seeding-generated water would be awarded to this right.

The ratio of seasonal irrigation use to the estimated direct flow for 1977 was used with 1934's values to yield a division of agricultural use from other uses. Since water was, for the most part, allocated to the same classes for the two years, the error induced is minimal.

The allocation of total water supply for the two study years is summarized in Table 2.12.

2.7.4 Steinaker Reservoir

The allocation of water on Ashley Creek is relative straight forward. Steinaker Reservoir is entitled to store all flows from November 1 to April 1. Thereafter, natural flow rights

TABLE 2.12

Allocation Of Total Water Supply For Price River (Ac-Ft)

	1977			1934		
	No Seeding	M1	M2	No Seeding	M1	M2
Observed Storage	31,100	31,100	31,100	12,831	12,831	12,831
	-1,552	-674	+627	0	+3,800	+7,882
	29,548	30,426	31,727	12,831	16,631	20,713
Observed Direct Flow	13,000	13,000	13,000	20,144	20,144	20,144
	-4,017	-1,804	1,623	0	4,416	7,205
	8,983	11,196	14,623	20,144	24,560	27,349
x Irrigation Use	x.736	x.736	x.736	x.736	x.736	x.736
Direct Flow Supply	6,611	8,240	10,762	14,826	18,076	20,129

take precedence. Although there is some use in the canyons well upstream from the Vernal area, the major diversions are all made within a short reach of the main channel in the area of the diversion to Steinaker Reservoir. Six water companies divide the total flow in Ashley Creek when stream discharge is 500 cfs or less. Natural flow may be waived under these low flow conditions, in which case it is stored in Steinaker Reservoir. Flows above 500 cfs belong to the Highline Canal which, with the other six companies, constitutes the ownership of Steinaker Reservoir. Any water not taken by the Highline Canal can be diverted to Steinaker Reservoir. Once the water enters the reservoir, it becomes part of a commonly shared pool. That is, when a given company uses less than its decreed share of natural flow, the balance becomes storage water, and is divided among all stockholders. Since all of the natural flow users are also stockholders in the reservoir, it is in the interest of each company to conserve for the sake of storing water in dry years. The limit of the reservoir diversion is the capacity of the feeder canal, or approximately 350 cfs.

Changes to observed flow for 1934 and 1977 are summarized by month in Table 2.13. Since only one seeding design was included by NAWC for the Uinta Basin, there is no "M1" entry. It was necessary to consult the daily hydrograph in order to interpret flows in terms of water rights. During both 1934 and 1977, spring runoff fell far short of the 500 cfs necessary to fulfill the first group of natural flow rights. Nonetheless, 512 ac-ft were diverted to Steinaker Reservoir during the first four days of June 1977. This illustrates the flexibility available to the irrigation in managing their water, and the degree of speculation involved in estimating how users would use developed water from cloud seeding. For this study, it was assumed that all streamflow would be used

TABLE 2.13

Predicted Changes In Observed Flows At Diversion To Steinaker Reservoir (Ac-Ft)

	Nov.- Mar.	Apr.	May	June	July	Aug.	Sept.
1977 not seeding	-14	-174	-460	-530	-257	-279	-341
1977 M2	+12	142	375	433	210	228	279
Net change M2	26	316	835	963	467	507	620
1934 M2	+27	+674	+1455	+617	+401	+501	+418

TABLE 2.14

Allocation Of Total Water Supply For Ashley Creek

	1977			1934	
	Observed	No Seeding	M2	No Seeding	M2
Nov. 1 storage	14180	14180	14180	0	0
Winter storage	5762	5748	5774	7474	7501
Summer storage	512	375	607	867	1500
Evaporation	-1175	-1175	-1175	-400	-400
Total storage	19279	19128	19386	7941	8601
Natural flow	23144	21240	24717	24001	27434

without being stored, except for the period immediately following the runoff peak. During this period, natural flow use of 135 cfs would be maintained, with flow in excess of this level being allocated to storage. The diversion to storage would end when flows fell below 135 cfs, which was the use maintained during the first days of June, 1977, when farmers were presumably being conservative in order to save some of the supply for the late summer use.

The allocation of the total water supply for Ashley Creek under the various seeding designs is given in Table 2.14. For 1934 it was assumed that the reservoir was dry at the beginning of the storage season. This appears to be reasonable given the sequence of dry years which preceded 1934, and considering the experience of 1977. Carryover storage at the end of 1977 was less than 2000 ac-ft. If another dry winter had followed, spring storage would not have been close to the 19,500 ac-ft necessary to award a full allotment of 1.0 ac-ft per share to the reservoir stockholders (Personal Communication, L. Y. Siddoway, May 20, 1982). By the following autumn, the reservoir would probably be dry.

The evaporation estimate given in Table 2.14 represents the net effects of evaporation and local inflow from Steinaker Draw, the drainage contributing to the offstream facility. For 1977, it is the difference between inflow estimated from the outflow gage and reservoir contents, and inflow measured above the reservoir by the Bureau of Reclamation. For 1934, the same loss rate was applied to the smaller reservoir surface area to obtain evaporation.

The distinction between natural flow supply and storage supply is relatively unimportant in this basin, except for lands irrigated by the Highline Canal. These users benefit only from the minor additions to storage since most of the developed water (3700 ac-ft in 1977, and 4100 ac-ft in 1934) is supplied as natural flow and would be shared by the canal companies in the same proportion as the first 500 cfs are shared. Allocation of use by sector and climate division is presented in Chapter 3 of this report.

2.7.5 Sevier Basin Reservoirs

Of all Utah river systems the Sevier River has the longest history of development and perhaps the most complex and intriguing system of allocation. The river is divided administratively into a series of zones or reaches (see Figure 2.10). Users above and including Circleville divert irrigation season flows on a "use-or-lose" basis, as there are no major impoundments in this area, and no provisions for exchange with downstream reservoirs. In dry years the river may be fully allocated in the upper zone, meaning that all flow below Circleville is either from irrigation return flow or from local contributions. Just below Circleville, the East Fork of the Sevier joins the main stem. Flows from the East Fork are stored in Otter Creek Reservoir, the oldest of the three major impoundments in the system. A somewhat unique feature of storage rights in Otter Creek Reservoir is that they persist through the summer at a varying fraction of the flow in East Fork. Thus, Otter Creek Reservoir is filled by winter flow on the East Fork plus two-thirds, one-half, or one-third of summer flows, depending on the month. The first 10,760 ac-ft in Otter Creek are used to supply irrigators in the Kingston area, just above Piute Reservoir. This fulfills the terms of the agreement by which Kingston irrigators gave up their natural flow right to owners of Otter Creek Reservoir in exchange for a guaranteed

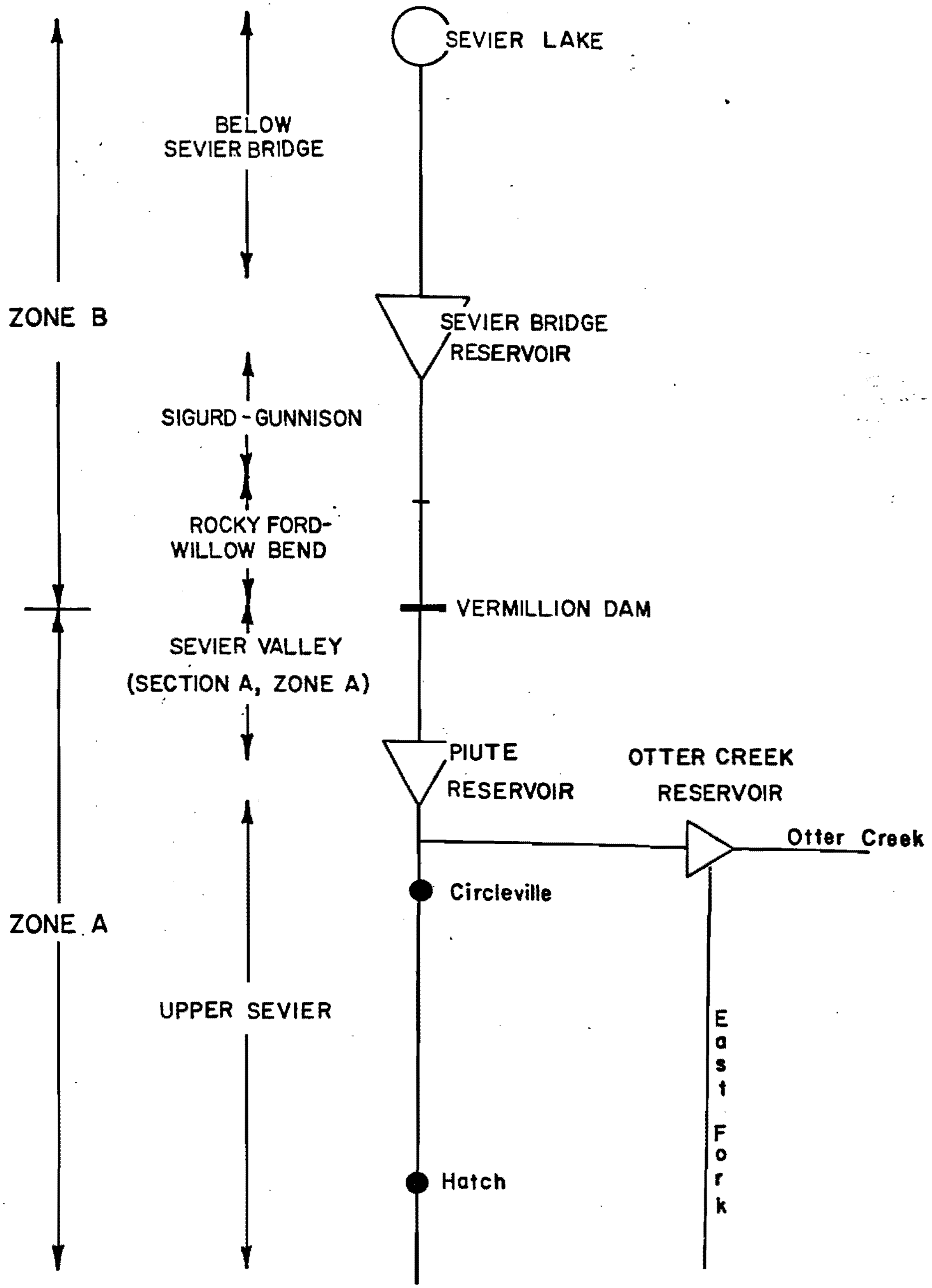


FIGURE 2.10. Schematic Diagram Of Sevier River Basin

35 cfs flow throughout the irrigation season. Ownership of the balance of Otter Creek's contents is held by the irrigators in the Sevier Valley, the area between Piute Reservoir and Vermillion Dam. In addition to Otter Creek storage water, the Sevier Valley users own natural flow rights and the storage provided by Piute Reservoir. Sevier Valley natural flow or "primary water" is that which reaches Piute Reservoir after April 1, less storage releases from Otter Creek, plus local contributions within the Sevier Valley. Since a sizeable portion of this quantity enters the river above Piute Reservoir, it may be stored there, provided that space exists. As a result, Sevier Valley users have a natural flow right with the advantages of reservoir water. Storage water in Piute Reservoir is largely winter flow. However, water that is collected in Piute by April 1 must be shared with Sevier Bridge Reservoir, the largest of the three major reservoirs, and the furthest downstream. Each year on April 1, winter additions to the two reservoirs are summed. The total quantity is divided according to the following algorithm which is designed to fill both reservoirs at the same time if enough water is available:

1) the first 89,280 ac-ft to Sevier Bridge;
2) the next 40,000 ac-ft to Piute;
3) of the next 32,000 ac-ft, 75 percent to Sevier Bridge and 25 percent to Piute;
4) the next 13,720 ac-ft to Sevier Bridge;
5) of the next 75,000 ac-ft, 75 percent to Sevier Bridge and 25 percent to Piute;
6) of all further water, 85 percent to Sevier Bridge and 15 percent to Piute.

If necessary, transfers are made from Piute to Sevier Bridge, in order to allocate storage water correctly. These transfers may be made during the winter months, as the River Commissioner is able to anticipate approximately the winter accumulations of both reservoirs.

Primary water in Zone B (Vermillion Dam to Sevier Lake) is defined as the additions to the river from Vermillion Dam downstream between March and October. In dry years, the primary flow in Sevier Valley is completely diverted; in wet seasons, primary flow may be waived, but as soon as it passes Vermillion Dam, it becomes storage water credited to Sevier Bridge Reservoir. Therefore, Zone B primary water is computed entirely independently of the Sevier Valley primary water. The irrigation companies between Vermillion Dam and Sevier Bridge Reservoir are not owners of the reservoir. However, they may store natural flow water in the reservoir commencing April 15 and exchange it for flows later in the irrigation season. Thus, their rights are nearly as versatile as storage water, although in very dry seasons they are subject to the limits of low, late summer flows. Irrigation companies below Sevier Bridge Reservoir own varying combinations of Sevier Bridge storage water and natural flow water. In addition, the supply can be manipulated through several small storage and regulating reservoirs in this area. The result is that nearly all water, whether classified storage or primary, can be held in storage and called for when it is needed. This has been referred to as a "banking system" in that water allocated to each user is held for disbursement at the user's request. The account is balanced at the end of each month, with primary flow being credited to the user, and diversions being debited.

Assumptions

Assumptions made for 1934 and 1977 are enough alike that they are presented together here. The first paragraph treats assumptions regarding the developed water and the second paragraph deals with the assumptions necessary to estimate total use divided by climate division.

As explained in Section 2.5, it was not necessary to produce daily hydrographs of the inflows to the Sevier reservoirs. Changes from observed local inflow were estimated using the NWS models and are presented by reach in Table 2.15. The cloud seeding programs would have negligible effect in the Rocky Ford reach, a short section fed by irrigation return and base flow. Similarly, the local inflow below Sevier Bridge Reservoir is not subject to snowmelt, and would not be greatly influenced by seeding. It was assumed that the developed runoff occurred during the non-storage season. In Zone B, this is entirely reasonable because most primary rights become effective on March 1. In the upper zone, where storage can continue until April 1, some error with respect to the division of waters between Piute and Sevier Bridge Reservoirs may be introduced by this assumption. However, the quantities involved over the entire season are small, and the volume of runoff occurring before April 1 would be only a fraction of that. With this assumption in mind, the allocation of the relatively small flow increases due to cloud seeding during 1977 and 1934 became fairly simple, since all increments were primary rather than storage water.

Total water use for 1977 was determined from diversion records reported by the River Commissioner. Without more complete records for 1934, it was necessary to make estimates

TABLE 2.15

Predicted Changes In Observed Sevier River Local Inflows (Ac-Ft)

	1977	1934
Upper Sevier		
No seeding	-7,000	-
M1	2,400	12,400
M2	18,500	32,800
Net change		
M1	9,400	-
M2	25,500	-
Sevier Valley		
No seeding	-1,600	-
M1	300	1,100
M2	2,200	4,600
Net change		
M1	1,900	-
M2	3,800	-
Rocky Ford		
No seeding	0	0
M1	0	0
M2	0	0
Gunnison		
No seeding	-6,600	-
M1	-3,000	2,500
M2	2,900	6,000
Net change		
M1	3,600	-
M2	9,500	-
Below Sevier Bridge		
No seeding	0	-
M1	0	0
M2	0	0

of use in some reaches. For example, few of the Upper Sevier ditches were gaged in 1934. Of those that were gaged, the average diversion was 126 percent of their 1977 flows. On this basis the supply available was assumed to be 126 percent of the observed 1977 flow. Use for the remaining reaches of the river was interrelated by the winter storage which is divided between Piute and Sevier Bridge Reservoirs. Actual records of April 1 storage in the two reservoirs were adjusted using present-day allocations rules to determine the ownership of the water. Primary flow in the Sevier Valley was computed from daily records for the summer months. The components of the Sevier Valley supply, winter storage in Otter Creek and Piute Reservoirs, Otter Creek's summer storage right, and summer primary water, were summed to obtain the total supply.

Diversion by Rocky Ford and Willow Bend Canal Companies were taken directly from historical records, and it was verified that this volume was all that the two canals would have been entitled to under present-day allocation rules. Supply below Vermillion Dam was taken to be the winter storage in Sevier Bridge, plus summer primary flow in Zone B.

Allocation

Since the basis for allocating supply for the two study years is quite similar, specific considerations are presented by reach rather than by year. Moving downstream from the Upper Sevier, each administrative zone is treated in turn. Allocations finally determined using the logic developed here are summarized in Table 2.16.

TABLE 2.16

Allocation Of Predicted And Observed Sevier Basin Supply By Climate Division For Alternative Seeding Designs (Ac-Ft)

	1977	1934
South Central Climate Division		
Upper Sevier		
No seeding	35,700	53,800
M1	45,100	66,200
M2	61,200	86,600
Sevier Valley		
No seeding	81,700	52,300
M1	82,000	53,400
M2	84,200	56,900
Rocky Ford - Willow Bend		
No seeding	17,600	15,400
M1	17,600	15,400
M2	17,600	15,400
Sigurd-Gunnison		
No seeding	12,400	13,200
M1	13,200	13,800
M2	14,400	14,600
Western Climate Division		
Below Sevier Bridge		
No seeding	149,900	99,400
M1	157,500	101,400
M2	152,800	104,600

Allocation of the developed water in the area above Circleville on the main stem and above Otter Creek on the East Fork was inferred from the NWS models. The NWS model for the Sevier River at Hatch indicates that for the M2 seeding program in 1934 over 35,000 ac-ft might be generated over the area. At the same time, increases of less than 5,000 ac-ft are predicted for Piute Reservoir inflow. The difference is attributed to diversions in the Upper Sevier. Even with the large additions resulting from the M2 seeding program in 1934, the Upper Sevier seasonal supply is approximately 24,000 ac-ft less than diversions recorded there in 1979. This indicates that the upper limit of water right is not exceeded under any of the seeding designs, for either of the study years.

Zone A, Section A primary, which is diverted by Sevier Valley irrigators, was computed from daily records for both 1977 and 1934. The algorithm for these calculations has been documented by Roger Walker, the Sevier River Commissioner, in Analysis of Water Rights in the Sevier River Basin, (1976). The first priority right, amounting to 30 cfs through April and 1.25 cfs thereafter, belongs to the Monroe South Bend Company, and was filled during both years. The next right, in terms of priority, is actually a large class of rights designated "First Class" rights. When a 100 percent allotment is not available, all users in this group must reduce their demand. For example, if primary flow is 72 percent of full allotment, each owner receives 72 percent of his right available by the river. The full allotment for this right is met when primary flow reaches 297 cfs above the first priority right. During June 1977, 34 percent of the First Class rights were filled. During all other months, the supply was lower, amounting to 22 percent of the right in May, and less than 20 percent in all other months. The deficit in terms of their right, for First Class users during June 1977 was 11,600 ac-ft. Clearly, all of the seasonal increment would go to the First Class users in proportions that reflect their appropriation within this class of rights. The situation in 1934 is similar. The first priority right was available throughout the season. First Class water was supplied at 20 percent of the full allotment during June 1934, and at lower proportions during all other months. Deficits during any month of the April-to-September period are greater in magnitude than the predicted quantity of developed water from seeding.

While it is not expected that inflow below Sevier Bridge Reservoir would be affected by cloud seeding, the primary flow canal companies throughout Zone B would be beneficiary of any additional flow in the Sigurd-to-Gunnison reach. This is because users throughout Zone B have rights with a common priority. The highest priority group of the Zone B primary rights are designated "AA" rights, and are followed by several "Well" rights. Together these represent 18 cfs, a quantity easily met by the local contributions below Sigurd in both years. The next group of rights are known as "Class A" rights. Their total diversion right is 295 cfs above the first 18 cfs for the "AA" right. This large group of users, like the First Class users in the Sevier Valley, have agreed to pro-rata their allocations when the river cannot supply 313 cfs.

To put the increments presented in Table 2.15 into perspective, consider that a full allotment of Class A water, which at 295 cfs for the 214 days of the irrigation season is equivalent to 125,218 ac-ft. The Sevier River Commissioner reported that Zone B primary was allocated at 42.1 percent of full allotment in 1977. The positive increments of several thousand ac-ft in the Sigurd-to-Gunnison reach would thus increase the supply to Class A rights, but would not bring any lower priority rights into effect. Negative increments would reduce the Class A rights, but would not deplete them entirely.

The irrigated acreage above Sevier Bridge Reservoir is in the South Central Climate Division region, while the area below the reservoir is in the Western Division. Therefore, the increments of Zone B primary were allocated to the correct climate division by alloting to each in proportion to the Class A rights in each division (see Table 2.16).

In order to determine the Class A allotment in Zone B for 1934, the diversions of five different non-storage companies were examined. The quantities diverted ranged from 29 percent to 64 percent of the present Class A allotment. The two canals that diverted relatively large portions of their allotments were in the Gunnison reach, which is the more upstream section. This suggests that Class A water was not divided uniformly among the users either because the adjudication now known as the Cox Decree had not been completed, or because no enforcement of the traditional patterns had been provided for. In any case, Class A water in 1934 was assumed to be 40 percent of the full allotment, which is the average of the sample of five non-storage companies. As in 1977, the magnitude of the changes to the primary supply would not be great enough to affect any other class of rights. Again, the developed water was divided between the two climate divisions, as presented in Table 2.16.

2.7.6 Discussion

An interesting conclusion that comes out of the water allocation study is that in extreme drought years, the natural flow users are allocated more of the water developed by weather modification than are reservoir stockholders. The division of waters between natural flow versus storage is summarized in Table 2.17.

The anomalous allocation for 1934 in the Weber Basin is a result of the assumptions necessitated by a lack of information for that year. The Weber River Basin is a physically complex system. In practice, the River Commissioner decides to permit more or fewer diversions depending on the response of the river to diversions currently being made. For instance, an upstream user may divert water under a low priority right until a more senior, downstream right cannot be filled by the low flows which result from the upstream use. The allocation is conditioned on the demands made by users, which in turn are influenced by expectations as to the dryness of the year. This is in contrast to less complex basins like Ashley Creek and Price River, where natural flow is computed, and for the first class of rights, a fixed percent of the total is allocated to each user. Since user demand in the Weber River Basin for 1934 was not known, it was assumed that all flow without seeding would be allocated as natural flow and that the developed water during April, May and half of June would be stored. A more realistic approach would require that demand be modeled as a function of the supply, but a dynamic procedure of this type was beyond the scope of the project.

The allocations in the Sevier Basin for both 1934 and 1977, and the economic benefits associated with them, reflect

TABLE 2.17

Percent Of Developed Water Which Is Allocated To Natural Flow Use

	1977		1934	
	M1	M2	M1	M2
Weber	74%	68%	23%	23%
Scofield	72%	72%	54%	48%
Steinaker	-	93%	-	84%
Sevier	100%	100%	100%	100%

only the first year effects of the developed water supply. It has been known for years that the Sevier River Basin is underlain by huge groundwater reservoirs. These are recharged by irrigation excesses which eventually return to the channel at some downstream point. In this fashion, water may be diverted several times on its course from the southern highlands to Sevier Lake. Table 2.16 indicates that most of the developed water is diverted in the Upper Sevier. This is in keeping with the irrigators' practice of diverting all the water to which they are entitled, in spite of the fact that their allocation substantially exceeds consumptive use. Water which would not be lost to evapotranspiration would recharge the groundwater reservoirs, and resurface the following winter. At that point it would most probably become storage water in Piute or Sevier Bridge Reservoir, and would have some beneficial value in the second irrigation season after seeding. Without modeling groundwater flow, the quantity and timing of the increased returnflows are unknown, and no attempt was made to estimate them. It should be observed that the estimates of the benefits of seeding in the Sevier Basin are conservative to the extent that they ignore secondary use of the developed water.

2.8 Summary And Conclusions

Ten reservoirs in four Utah river basins were selected based on their size, importance for irrigation supply, and representativeness of Utah's climate divisions. National Weather Service seasonal volume forecast procedures were adapted so that they could be used to estimate the volume change in runoff which might be expected under two different cloud seeding programs under the 1934 and 1977 conditions. The adaptation involved fitting a curve to plots of predicted volume increases versus observed flows for approximately ten low flow years.

Hydrographs of reservoir inflows in 1934 and 1977 were generated by backrouting through the reservoir on a monthly basis, and using a nearby daily station to distribute the reservoir inflows on a daily basis. Ordinates of the daily hydrograph from the beginning of the snowmelt season until the end of September were multiplied by the ratio of the seasonal volume as predicted with cloud seeding to observed seasonal volume. In this manner, reservoir inflow hydrographs for two cloud seeding design programs, and without seeding, were obtained for the two study years. The water supplies represented by the alternative hydrographs were allocated in accordance with current water allocation practices, based on water rights, in order to determine the ownership of the developed water. Insofar as possible from the records of the river commissioners, the supply was further divided by use sector and by climate division for use a input to an economic model.

The estimated increases in streamflow resulting from assumed increases in precipitation in different basins varies, from 3 percent in the Sevier River Basin to 150 percent in the Weber River Basin for the M2 program. The small increase in the Sevier River Basin is explained by upstream diversion of developed water. The larger increases in the Wasatch Range are attributable to the deeper snow accumulation and the lower consumptive losses in these northern drainage basins. The difference in the percent increase in streamflow between the two study years is very small, with the percentage for 1934 being slightly smaller in most cases.

During 1934 and 1977, streamflow was so low that most water which might have been developed through cloud seeding would be allocated to natural flow users rather than to reservoir storage. In each of the four basins studied, the developed water supply would be divided among a group of users in proportion to their right within a class of rights. Exactly which users benefit from cloud seeding depends on the unique water rights system within a basin, which reflects the history of settlement, industrialization, and peculiar characteristics in the resolution of local conflicts.

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3. THE ECONOMIC EVALUATION OF DROUGHT

3.1 Overview

Change in today's world is one event that we can rely on occurring with probability very close to one. Change is a pervasive force affecting people, organizations, methods and values. There are several physical, lifestyle, and policy changes which affect our economic lives and organization. Population growth increases the demand for goods and services. When values change, policies may change which restrict the production of some products while enhancing the production of others. Technological advances that create new and better methods of production influence tastes for consumption and economic organization for production.

Weather and its change is a physical phenomenon which affects our economic organization to produce and our seasonal consumption habits. Because water is an essential input to the crop and livestock production process, the agricultural sector and, indirectly, other sectors of the economy are highly affected by weather change. In order to remain in an economically viable operation, the successful farmer must adjust to changes in natural phenomena such as drought, storms and floods, and also operate within the changing governmental and marketing policy environments.

In recent years, new technological advances have been developed to alter the effects of weather and presumably alter the adjustments that have to be made as natural phenomena may be altered. As a result, both policy makers and those sectors of the economy which are highly dependent on weather as a production input are now concerned about what adjustments can be made and to what extent the new technology is beneficial. These concerns are particularly apparent in the arid agriculture regions of the U.S. and in areas where severe and damaging storms occur frequently.

Policy makers were recently confronted with a drought problem where some understanding of the adjustment process would have been useful. The effects of the 1976-77 drought in Utah and much of the Western States caused considerable concern and reaction. In Utah, the Governor organized a special committee to recommend alternative courses of action to ease the situation. A special session of the legislature was convened to consider governmental action to relieve the situation. Nationally, both houses of Congress gave attention to various drought relief measures. Among the alternatives considered were weather modification technology, easing of grazing restrictions on federal and state lands, transporting water to livestock, improvements in irrigation technology and water delivery, loans for water projects and/or conservation, and direct loans and grants to secure feed for livestock and to buoy up the financial situation of farmers in particular.

The success of solutions implemented in Utah varied, in part because the impact and consequences of drought on Utah economic organization were largely unknown. Considering the recurring nature of weather patterns, drought will continue as a periodical situation in Utah and much of the arid West. Adjustment to drought and its consequences are not new to Utahns. The drought of the late 1950's and again in 1961 in certain regions of Utah caused production problems. Certainly, the extensive drought of 1931-34, which not only occurred in Utah but to a much greater extent in the Great Plains states, was one of the more severe weather events experienced in the country. Drought also occurred around the turn of the century, which affected agricultural production. Just how we should adjust to such events is the subject of great concern and debate.

The purpose of this economic study of drought in Utah is to shed some light on the definition of drought as drought affects economic organization, and to provide some measures of the impact of drought and the feasibility of altering weather patterns to modify the impact of drought in Utah. Some discussion is devoted to other alternatives for providing drought relief, and their consequences are compared to the weather modification technology alternative.

The specific objectives that were outlined for the study included the following:

1. Provide a useful definition of drought in terms of its economic effects.
2. Estimate some specific impacts of drought on Utah agriculture and the adjustments which are and can be made.
3. Evaluate the economic feasibility of a standby cloud seeding program for the State of Utah and various regions within the state.
4. To evaluate the feasibility and impacts of alternative drought relief programs and to provide some information on "optimum" effectiveness of weather modification in Utah and other locations.

This study reviews some relevant literature which helps to provide an economic definition of drought. Then this definition is outlined and the economic impacts primarily on Utah agriculture of specific known droughts (1931-34, 1976-77) are derived from a modeling system. These are all contained in this chapter. In Chapter 6, the economic feasibility of a standby seeding program is evaluated and reported. This work was completed in a joint effort with North American Weather Consultants who developed a weather modification design for the climatological regions of Utah and developed the cost base used in the feasibility evaluation. The design and costs are reported in Chapter 5, while the economic evaluation is given in Chapter 6. Relief programs and alternatives to weather modification as applied in Utah are discussed in Chapter 6.

3.2 Literature Search

The literature on the economics of weather modification is rather limited. In fact, the reporting of the economic effects of drought in general is limited relative to the vast literature dealing with floods and their economic impacts. As was discussed earlier in Chapter 1, drought is a phenomenon which creeps up on an economy; it does not stir action until it produces relatively extensive effects on production and local or larger economy. The result is that little is known about the consequences of drought and the adjustments which are, or can be, made.

Considerable discussion of the impacts of technological change is in the economics literature such as the classic work of Griliches (1958, 1964) on agricultural production shifts due to technological change, the research impact study of Ayer and Schuh (1972), and the summary of technological impact literature found in Arndt et al. (1977). However, not until the early 1970's did reports of studies of the feasibility and impacts of weather modification appear in the economics literature. The works by Swanson et al. (1972), Stroup and

Townsend (1973), and the Bureau of Reclamation (1974) were some of the earlier studies in this area. Later studies extended both the meteorological and economic evaluation of weather modification, such as studies by the South Dakota Agricultural Experiment Station (1973), Allaway (1975), Inman (1976), Johnson (1974), and recently the Southwest Drought Research Program under the sponsorship of the Bureau of Reclamation (summarized in the Bureau of Reclamation, 1981) and the Kansas studies (Bark, 1978; Bark et al., 1979; and Buller et al., 1981). Two recent studies of weather modification as a technology for hail suppression have been completed by Swanson et al. (1978) and von Blockland et al. (1978).

These studies, completed for the states of North Dakota, South Dakota, Montana, Oklahoma, and Texas, have considered the impact of cloud seeding on the state agricultural economies. All these studies suggest that estimated rainfall augmentation has a positive effect on crop production and farm income in general. However, for the wheat production case in Central and Eastern Kansas, as reported by Buller et al. (1981), spring season cloud seeding and subsequent increased rainfall reduces crop production because planting is delayed.

There are two other important results which are derived out of these studies which are relevant to the current evaluation. First, the definition of drought and the measurement of drought impacts and modification of drought, via weather modification technology, is necessarily explained as a phase of drought or modification effects. Second, one has to be quite specific and precise in measuring the effects or benefits of cloud seeding. That is, one has to capture as nearly as possible all the economic interactions that take place and also interrelate the natural and economic impact relationships. A modeling system is helpful in accounting for these interrelationships, and it is also useful for making simulations of the interrelationships involved.

Drought can be measured as a meteorological effect, which consequently impacts on precipitation. Precipitation changes affect changes in biomass and crop growth. Crop growth affects the productivity of land, livestock production, and income derived from agricultural activity. The agricultural sector in turn impacts on other sectors of the economy. The extent of drought can be measured at any one phase of impact delineated above, but to capture the direct impacts of drought, one needs to evaluate each phase of effect. Hence, in this study we have tried to capture this more "fluid" definition of drought, and we have made our evaluation of drought and drought modification impacts at each of the major stages of effect, i.e., meteorological, precipitation-hydrological, and economical.

Water provided through rainfall, directly or indirectly through storage and subsequent irrigation, is an input to biomass or crop production. Additional water input, up to a critical point, increases production or shifts the supply of output. Weather modification alters the supply of water and is thereby a crop and livestock supply-increasing technology. Increases in supply are usually measured during one of two approaches: a firm-level or an industry-level estimate of impact. The effect of the technology on prices and total revenue is evaluated assuming a perfectly elastic demand for any commodity for the firm. However, if the industry impact is evaluated, particularly the agricultural industry, a highly inelastic demand for commodities is usually assumed. The elastic demand at the firm level of analysis implies that the firm can sell all that can be produced at a given price assuming the price covers variable costs. If the firm adopts an output-augmenting technology such as weather modification, the manager foresees no perceptible influence on price and subsequently visualizes an increase in total revenue, i.e., increased volume of sales for a given price. However, a decrease in total revenue occurs at the industry level (for inelastic demand at the industry level) because the increase in supply on an inelastic demand curve results in a greater price reduction than in associated quantity demanded. That is, the demand curve is downward sloping at the industry level. If all firms in the industry increase supply or if a particularly dominating firm, whose share of industry output is large relative to the total industry output, increases supply, then of course industry prices are depressed by the output-augmenting technology.

These supply-increasing technologies are generally available without regard to regional or state boundaries. However, cloud seeding is an exception, since permission to seed to augment crop or rangeland production is granted by the states. Thus, the evaluation of this state-controlled technology is based on the production or economic activity increase within the state, but with recognition that externalities in the form of increased production and perhaps depressed prices accrue to other parties outside of the state. Firms who produce the same commodities or their substitutes in other states will be influenced by the output-augmentation policy via the price effect, but they receive no benefit if their crop production is unaffected. It may be feasible for one state to rationalize the adoption of a supply-increasing technology even though the commodity affected may have an inelastic demand. In this case the adverse price effect is shared by all farmers in the total market for the commodities affected. However, only those farmers in the state granting the permission for the cloud seeding receive the benefit of the supply augmentation. Consequently, total revenue may increase for farmers in the state doing the cloud seeding, yet the remaining farmers experience decreases in total revenue and the adversity has been shifted to them. Therefore, it is important to clearly define the benefits and delineate who benefits.

The nature of cloud seeding is such that the technology is somewhat uniformly applied to all acreage in the area underlying cloud seeding and is not, therefore, farm or ranch specific. One has to be concerned about the region's or state's share of commodity output relative to the total market for the commodity to evaluate the accrual or benefits. More on this point will be developed in the discussion which outlines the economic modeling system.

There is also some relevant literature on relating crop yields and acreage to measures of water availability, precipitation and temperature. The studies which contribute to the conceptual base of this current effort are those by Sim and Araji (1981) and Thompson (1969) on wheat yields and technological change and Koo et al. (1978) on weather and grain yields in general. These studies extended some weather index-crop yield relationship studies in economics by Stallings (1960) and Oury (1965). These studies have served as a guide to relationship specification and variable delineation in yield-weather relationship estimation that has been done at the Utah Agricultural Experiment Station in conjunction with research on the impacts of production changes on Utah's agriculture (Nef, 1979; Bailey, 1980; and Perry, 1982). The previously mentioned studies by Swanson et al. (1972) and Buller et al. (1981) also contained yield-weather relationship specifications.

The modeling work by Buller et al. (1981), Koo et al. (1978), Nef (1979), Bailey (1980), and Perry (1982) has direct input into the current study. The spatial equilibrium-linear programming systems and indices developed in these studies outline the economic modeling system followed in our work. These systems capture the direct impacts which result from production changes, and these types of systems can be used to delineate benefits of shifts in supply due to technological change such as weather modification.

3.3 The Economic Definition Of Drought

Changes in economic activity ultimately occur as changes in precipitation and water availability for crop and range forage are experienced. The agricultural sector experiences the direct economic impact of drought along with households in the economy. All water-using sectors experience change economically as a result of drought, but the initiation of impacts is generally felt in food production. Therefore, we have centered our efforts in measuring drought impacts and shifts which occur as a result of modification on the agricultural sector.

For dryland agriculture there is an apparent immediate effect of drought, i.e., reduced precipitation, hence reduced biomass production. The main effects are reduced soil moisture from lack of winter precipitation and reduced production in the growing season if precipitation during the growing season does not occur in a timely manner. Economically, in the U.S., the lack of timely precipitation reduces primarily grain (food and feed) supply and alters the grain and feeding industries of the agricultural sector. That impact is felt almost immediately if soil moisture during early spring and in June is reduced. Irrigated agriculture is buffered from such effects until the drought extends into the summer in the case of irrigation from natural flow supply sources, but this sector usually avoids drought experience for at least one growing season if water storage systems are involved. Reduction of winter precipitation for more than one season induces supply reduction in irrigated agriculture. The grain, fruit and vegetable, and other speciality crop subsectors of the economy are affected in this case, but economic changes are delayed relative to changes that take place in the dryland crop production sectors. Extended drought (time extended) and winter drought initiate change in the irrigated agricultural economy, while short period droughts initiate change in dryland agriculture. Livestock production profits are affected by both types of drought since the feed input is a major share of total livestock production costs. The livestock sector generally experiences declining profits even in a single growing drought period because feed costs increase, but because of the livestock production cycle and resources associated with breeding stock as live capital, the prices for finished or feeder livestock are not altered except for seasonal variations. During extended drought, however, some liquidation of breeding stock does take place to maintain profit levels in the livestock industries, or to minimize losses.

In the case of rangeland agriculture, particularly where public grazing lands are involved, grazing restrictions are imposed during both short and extended droughts. The price per grazing animal unit month (AUM) has not been increased to reflect the public forage scarcity, but the rancher has to move the herd off the public land and onto more expensive private pasture and supplemental feed which is higher in cost. This is the typical adjustment in Utah since the range livestock economy is the dominant economic activity in the agricultural sector of the state. More hay and barley are demanded, and in the Utah case, these feeds have to be imported from nearby states.

For Utah, it is claimed that grazing restrictions are implemented, feed imports are triggered, and the cost-price squeeze gets tighter even during a short drought period, and the situation gets worse during extended drought. It is also claimed that if drought exists in the Western states, then profits for feed producers in the West and Midwest increase because of increased feed demand and the backward shifting of supply on an inelastic grain industry demand schedule. These propositions need to be examined and tested. The modeling system used and outlined later allows for such adjustments and other adjustments that might occur under optimum (profit-maximizing) conditions. Drought of varying intensity is imposed on the model in the form of feed and water availability restrictions. Impacts and adjustments due to drought are modeled by assuming that agricultural firms operate to maximize profit. Operation of the model to solve for optimum conditions and activities under drought helps us to define drought in economic terms and aids in the impacts and the adjustments which take place under optimization. Propositions about adjustments and impacts can be evaluated using the modeling tool.

3.4 Modeling For The Simulation Of Drought Impacts

3.4.1 Model Development

For this particular study, a model was constructed for simulating the impacts of drought and/or its modification. The modeling system used is a linear programming-spatial equilibrium system which follows the same basic modeling structure to estimate the effects of changes in agricultural production on the livestock economy of Utah, developed through some economic studies at the Utah Agricultural Experiment Station (Grimshaw, 1972; Nef, 1979; Bailey, 1980; and Perry, 1982).

Several changes were made in the structure of the modeling system to allow for various adjustments that could be made by representative firms and regions as drought situations were imposed on the model via changes in precipitation, water availability, yield, acreage and prices. First, a regionalized crop rotation section was added to the objective function and constraint sets of the model, and feeds produced were linked to livestock production alternatives. Second, regional delineations were changed to approximate Utah's climatological regions and major non-Utah production regions, such as the Western U.S. The Midwest which is west of Mississippi River, and the rest of the U. S. regional livestock and crop activities outside of Utah were included, since there are interregional trade activities that exist in the agricultural sector. In particular, Utah livestock enterprises depend on imports of feeds, primarily corn, barley, hay, protein, and milo for the beef, sheep, layer, turkey and dairy industries. These import activities, or export activities, are all impacted by drought conditions within Utah, but are also significantly impacted by production conditions in the major-feed producing regions. Drought in any of these other regions conditions the drought impacts which occur in Utah. In addition to these changes, other constraint systems and activities were included, such as beef and dairy cattle backgrounding activities, sheep and cow/calf herd liquidation, and allowance for animal movement between regions to utilize least cost grazing or feeding. Backgrounding is an intermediate feeding activity, i.e., the process of feeding, for example, a 350 lb calf to produce an additional 200-300 lb before the calf is sold to go into the finish feeding phase of development.

The objective function of the linear programming-spatial equilibrium system is to maximize the profit from producing and transporting crops (and crops fed to livestock), livestock, and livestock products interregionally in the U.S., with the Utah region delineated by the climatological divisions of the State. Solutions to the model (profit maximum solutions) are then derived, subject to various constraint sets which are representative of the producing, transporting, interregional routing, and consumption activities that take place within the agricultural sector. The solutions represent a constrained optimum, i.e., profit for each region is constrained by various activities and availability of resources, including water availability in the form of both precipitation and irrigation water available.

The optimal solution then derives the production levels, the input use levels, the optimum spatial trading or transporting routes between regions, herd liquidation levels, and the optimum conversion of feed to livestock, and livestock-to-livestock product levels. These levels are determined for given price levels, given consumption needs, and for imposed levels of resource availability. In simulating drought impacts and/or modification, it is the precipitation and water availability constraints which are altered, and then the economic impacts of a particular drought are simulated, assuming profit maximizing adjustments occur as new equilibrium solutions to the model are obtained. These solutions are compared to a base year or base level of economic activity solution of the model to obtain cost, production, or net profit differentials with their associated changes in economic activity levels. It is through these comparisons that the impacts and the benefits of weather modification are estimated.

The model was constructed to represent current-year economic functions in the agricultural sector. Using this construction, the impact of a drought was evaluated as if it occurs in the current crop-livestock year. Current crop rotations, live capital base, and water source conditions and distribution were modeled, and the impact of various drought intensities on that current system of activities were simulated. The year 1979 was chosen as the base of current year because it was the most recent year for which a complete data set was available to construct the constraint systems of the model, and 1979 was generally typical of production conditions for each region under recent "normal" conditions.

3.4.2 Symbolic Description Of The Model

The general mathematical formulation of the model is as follows:

Maximize

$$(1) \quad \sum_{kj}\sum P_{kj}Q_{kj} - \sum_{ikg}\sum\sum A_{ikg}B_{ikg} - \sum_{ikhg}\sum\sum\sum R_{ikhg}S_{ikhg} - \sum_{kj}\sum F_{kj}Q_{kj} - \sum_{jkh}\sum\sum Y_{jkh}Z_{jkh} - \sum_{mk}\sum H_{mk}U_{mk}$$

Subject to

$$(2) \quad V_{ikg} = A_{ikg} + \sum_{hk} R_{ihkg} - \sum_{hk} R_{ikhg} \quad \text{for all i and k}$$

$$(3) \quad T_{jk} = Q_{jk} + \sum_{hk} Y_{jhk} - \sum_{hk} Y_{jkh} \quad \text{for all j and i}$$

$$(4) \quad \sum_{ikg}\sum\sum K_{ijkg}V_{ikg} = \sum_{jkg}\sum\sum L_{jkg}Q_{jkg}$$

$$(5) \quad \sum_{ikg}\sum\sum M_{ijkg}V_{ikg} \geq \sum_{jkg}\sum\sum N_{jkg}Q_{jkg}$$

(6) $Q_{jk} \geq E_{jk} - U_{mk}$ for $j = 7, 9$ for all k and m

(7) $A_{ikg}, C_{ijkg}, Q_{jkg}, R_{ikhg}, Y_{jkhg} \geq 0$

Where

A_{ikg} = the quantity of the ith feed or nonfeed crop produced in region k during season g.

B_{ikg} = the per unit cost of producing the ith feed or nonfeed crop in region k during season g.

C_{ijkg} = the quantity of the ith feed fed to the jth class of livestock in region k during season g.

E_{jk} = the 1979 production level of the jth livestock produced in region k.

F_{jk} = the nonfeed costs of producing one unit of the jth livestock product in region k.

H_{mk} = the cost of liquidating production of the mth livestock in region k.

K_{ijkg} = the metabolizeable energy supplied per unit of the ith feed when fed to the jth class of livestock in region k during season g.

L_{jkg} = the metabolizable energy required per unit of product produced by the jth class of livestock in region k during season g.

M_{ijkg} = the digestable protein supplied by the ith feed when fed to the jth class of livestock in region k during season g.

N_{jkg} = the digestable protein required per unit of product by the jth class of livestock in region k during season g.

P_{kj} = the revenue received for production of the jth livestock product in region k.

$Q_{jk}6$ = the quantity of the jth livestock product produced in region k.

R_{ihkg} = the quantity of the ith feed or nonfeed crop shipped from region k to region h during season g.

S_{ikhg} = the per unit cost of transporting the ith feed or nonfeed crop from region k to region h in season g.

T_{jk} = the quantity of the jth livestock product consumed in region k.

U_{mk} = the number of the mth livestock liquidated in region k.

V_{ikg} = the quantity of the ith feed available for feeding in region k during season g.

Y_{jkh} = the quantity of the jth livestock produced that is shipped from region k to region h.

Z_{jkh} = the per unit cost of transporting the jth livestock product from region k to region h.

The subscripts i, j, h, k, and g represent the following:

$i = 1, 2, 3 \ldots, 16$

where

1 -	Barley	2 -	Wheat
3 -	Grain Corn	4 -	Silage Corn
5 -	Oats	6 -	Sorghum
7 -	Hay	8 -	Protein Supplement
9 -	Private Pasture	10 -	Aftermath (Post crop harvest grazing)
11 -	Private Range	12 -	BLM Rangeland
13 -	Forest Service Rangeland	14 -	State Rangeland
15 -	State Rangeland	16 -	Vegetable Crops

$j = 1, 2, 3 \ldots, 11$

where

1 -	Fed Beef	2 -	Hogs
3 -	Broilers	4 -	Turkeys
5 -	Layers (eggs)	6 -	Milk Cows (milk)
7 -	Cow/Calf	8 -	Backgrounders
9 -	Sheep	10 -	Dairy Calves
11 -	Dairy Backgrounder		

$g = 1, 2, 3, 4, 5, 6$

where

1 - Season I   2 - Season II
3 - Season III   4 - Season IV
5 - Season V   6 - Season VI

$kh = 1, 2, 3 \ldots, 10$

where

1 - Region I   2 - Region II
3 - Region III   4 - Region IV
5 - Region V   6 - Region VI
7 - Region VII   7 - Region VIII
9 - Region IX   10 - Region X

$m = 1, 2$

where

1 - Cow/Calf   2 - Sheep

As indicated, the model is representative of various seasonal producing activities. For livestock grazing and feeding operations, seasonal delineations are important. Certain grazing permits are issued for winter cattle or sheep grazing, some for only spring or summer grazing, and still others for fall grazing. Differential feed values and prices per nutrient unit occur seasonally and are accounted for in the seasonal delineation of the model. The seasonal structure also accounts for the grazing rotation which takes place in range livestock operations in Utah and most of the Western states.

Other specific assumptions used by the modeling system are listed below.

1) The base year (1979) is considered a "normal" year for feed and livestock production.

2) Only livestock classes within the model are considered to be competing for the available feed.

3) Transportation costs within a region are zero.

4) Wheat in the model represents five per cent of the total wheat production in the U. S. and is the maximum amount allowed to be consumed by livestock (Srack, 1980).

5) Production of livestock products is limited between an upper and lower bound in each region. These bounds were determined by the highest percentage increase or decrease in production of each livestock product in each region over the last 20-25 years. This percentage increase or decrease was then assigned as the acceptable deviation for each individual region from actual 1979 production. These values were obtained from Nef, 1979.

6) Corn silage is not transferred between regions, but is consumed in the region of production.

7) Protein supplement is not produced but is available in each region at the average price in the region.

8) A five per cent decrease in calf numbers is assumed to account for death losses.

9) The cow/calf and dairy calf activities produce a 400 lb calf which serves as an input for the beef backgrounding and dairy backgrounding activities.

10) The sheep activity produces ten lambs or 100 pounds of lamb per ewe, making the lambs ready for immediate slaughter. No revenue from wool is considered in the model.

11) Of the total number of livestock actually produced, 25 percent of beef calves, 55 percent of dairy calves, and 20 percent of lambs are produced as replacements. Neither costs of replacements nor revenues from animals culled are considered in the model.

12) The beef backgrounding activity adds 250 lbs to a calf and produces a 650 lb animal. The dairy backgrounding activity adds 400 lbs to a calf and produces an 800 lb animal. Both beef and dairy backgrounders serve as inputs for the beef activity.

13) The beef activity adds 400 lbs to a backgrounder, generating a 1050 lb beef animal and a 1200 lb dairy animal. Final demand for beef is limited to only fed beef.

14) Only fluid milk is produced and consumed in the model. Demand for milk products is converted to the equivalent amount of fluid milk (cheese, butter, etc.) required to produce the milk product. Therefore, transportation costs for all milk products are the same as the cost of transporting fluid milk.

15) Because livestock production by county during 1979 was not readily available for Utah, production by county was calculated using the 1978 Agricultural Census. For example, if Utah County had 40 percent of the laying hens in the state it was assumed that Utah County produced 40 percent of the eggs in the state.

16) Pasture and range feeds are only available for consumption by the cow/calf, dairy backgrounder, beef backgrounder,and sheep livestock activities.

17) Non-grazing feeds produced in the year are assumed to be available for use during any season.

18) The number of AUM's feed available during any season for BLM, Forest Service, and aftermath feeds is constrained to represent actual consumption patterns. Feeds not used within a season are assumed to be lost. Consumption of private pasture, private range, and forage from state lands is limited to 5-12 percent of the year's production in December, 10-20 percent in April, and 20-30 percent in May, depending on the region. The lowest limits are placed on feeds in mountainous regions while the least stringent bounds are placed on feeds in regions which are largely made up of low elevation valleys.

19) Livestock prices do not change as a result of changes in feed availability or price. This is because the lag between culling of brood herds and the subsequent shortage of livestock products is longer than the time period considered in the model.

20) The amount of hay and corn silage available for consumption is assumed to be equal to the amount demanded in the base year. Production, therefore, was decreased to the level consumed in the base year. This was done by adding up the total amount of hay and corn silage consumed in an initial run of the base simulation, finding what percentage that total was of the amount actually produced, and reducing production to that percentage.

21) No limits are placed on the number of AUM's which can be transferred between regions by the model. Consequently, the current grazing permit system is assumed to not exist and feed is allocated between regions so as to maximize total profit to the model.

22) No limits are placed on the number of AUM's which can be transfered between regions by the model. Consequently, the current grazing permit system is assumed not to exist, and feed is allocated between regions so as to maximize total profit to the model.

23) All hay produced in the model is Alfalfa hay.

To show the specific transfers and matrix for the feed and livestock sectors of the model, a summary of these sectors of the linear programming system is given in Figure 3.1. The acronym RHS is given for right-hand-side or resource availability vectors.

3.4.3 Regionalization In The Model

The State of Utah was divided into seven regions following county boundaries to approximate as closely as possible the climatological divisions of the state. Three other regions, namely, the Western, Midwestern, and Eastern regions, were also added to represent the rest of the U.S. livestock-feed economy. Utah agricultural activities are not isolated from these other regions, and drought conditions in these areas are thought to significantly affect the Utah situation because of the importance of feed imports and the fact that large numbers of Utah range livestock feeder animals are shipped to Idaho, Colorado, and California for finish feedings. These

Activities Restraints	Production of Feed	Feed Transfer	Feed Conversion	Production of Livestock	Liquidation of Livestock	Livestock Transfer	RHS
Seasonal feed production account	+1	-1					= 0
Yearly feed production account	+1						≤ Act. Prod.
Feed available account		+1	-1				= 0
Mega Calorie/ metabolized energy (MCAL/M.E.)			+a	-a			= 0
Tons of Digestable Protein (DP)			+a	-a			= 0
Yearly livestock production account				+1		-1	= 0
Total livestock production account				+1	+1		≥ Act. Prod.
Consumption of livestock products						+1	≥ Reg. Dmd.
Objective function	-c	-c		+P	-c	-c	
Bounds	b		b	b			

a = data coefficient; c = cost of activity; p = profit of activity

FIGURE 3.1. **Condensed Tabular Illustration Of Linear Programming Matrix For One Region**

operations are accounted for in the regional structure. Given this structure, the model can be used for national as well as interregional production change estimation. The regional structure for Utah is given in Figure 3.2, and the entire regional structure is outlined in Figure 3.3.

A city in each region was chosen to represent the central point of the region from which interregional transportation costs were calculated. These points are listed by region in Table 3.1. Note that two cities are given for Region VIII. Most of the exports for Utah, i.e., livestock product exports, are received in Los Angeles, California and therefore Los Angeles was chosen as the consumption center for Region VIII. However, the primary source of imported feeds into Utah comes from Idaho, Montana and Colorado, with the bulk of hay and barley coming in from Idaho. Therefore, Blackfoot, Idaho was chosen as the supply center for Region VIII as oriented for supply to Utah.

3.4.4 Livestock And Feed Structure Of The Model

Eleven livestock classes were identified for inclusion in the model to produce seven livestock products which are listed in Table 3.2. Similarily, Table 3.3 gives the fourteen grazing and non-grazing feed classifications included in this study.

Because grazing is not equally available to livestock throughout the year, the grazing resource was disaggregated into seasons of production in order to determine the value of feed in any one season as explained previously. The seasons used are listed in Table 3.4.

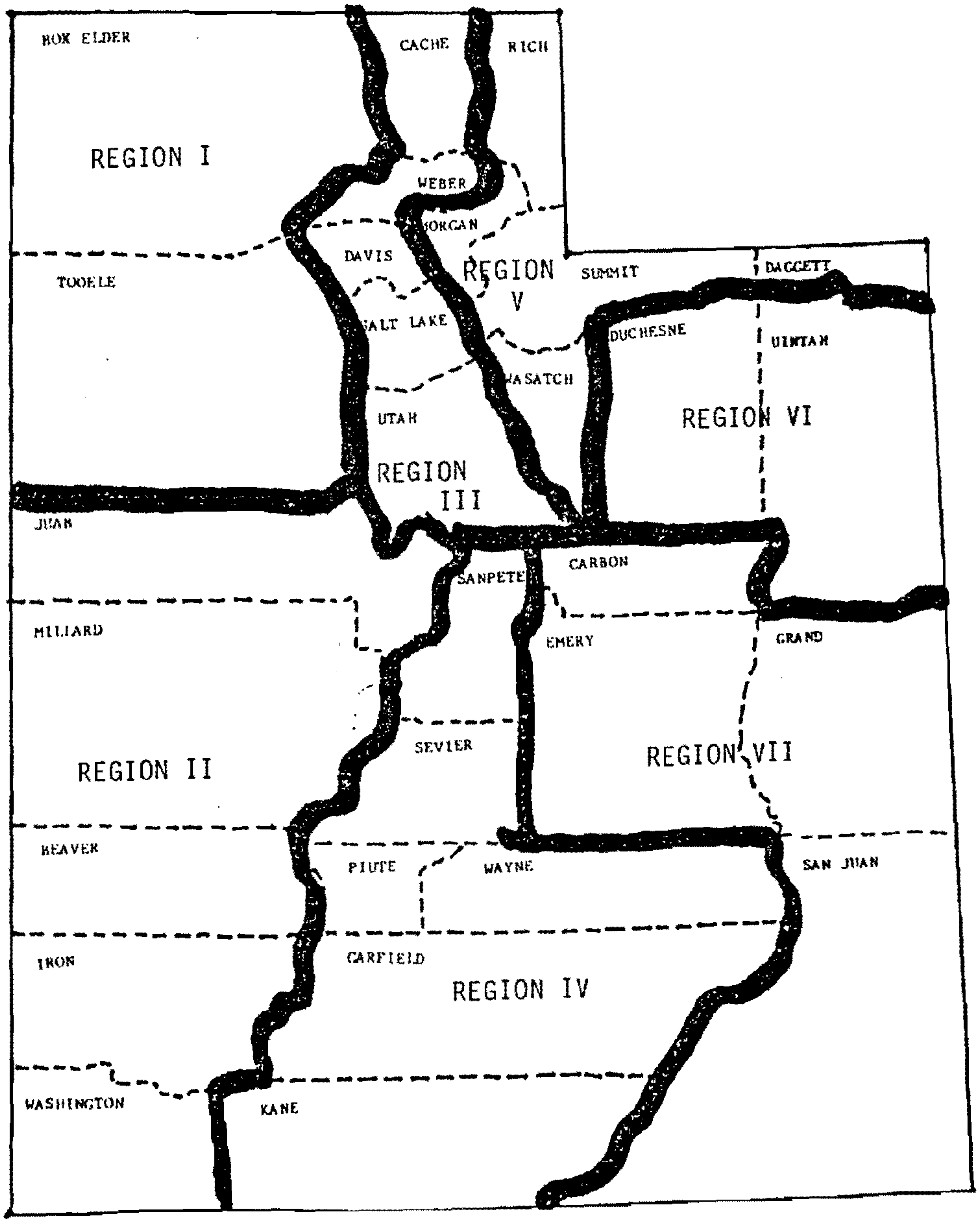

FIGURE 3.2. Regions Of Utah Used In This Study

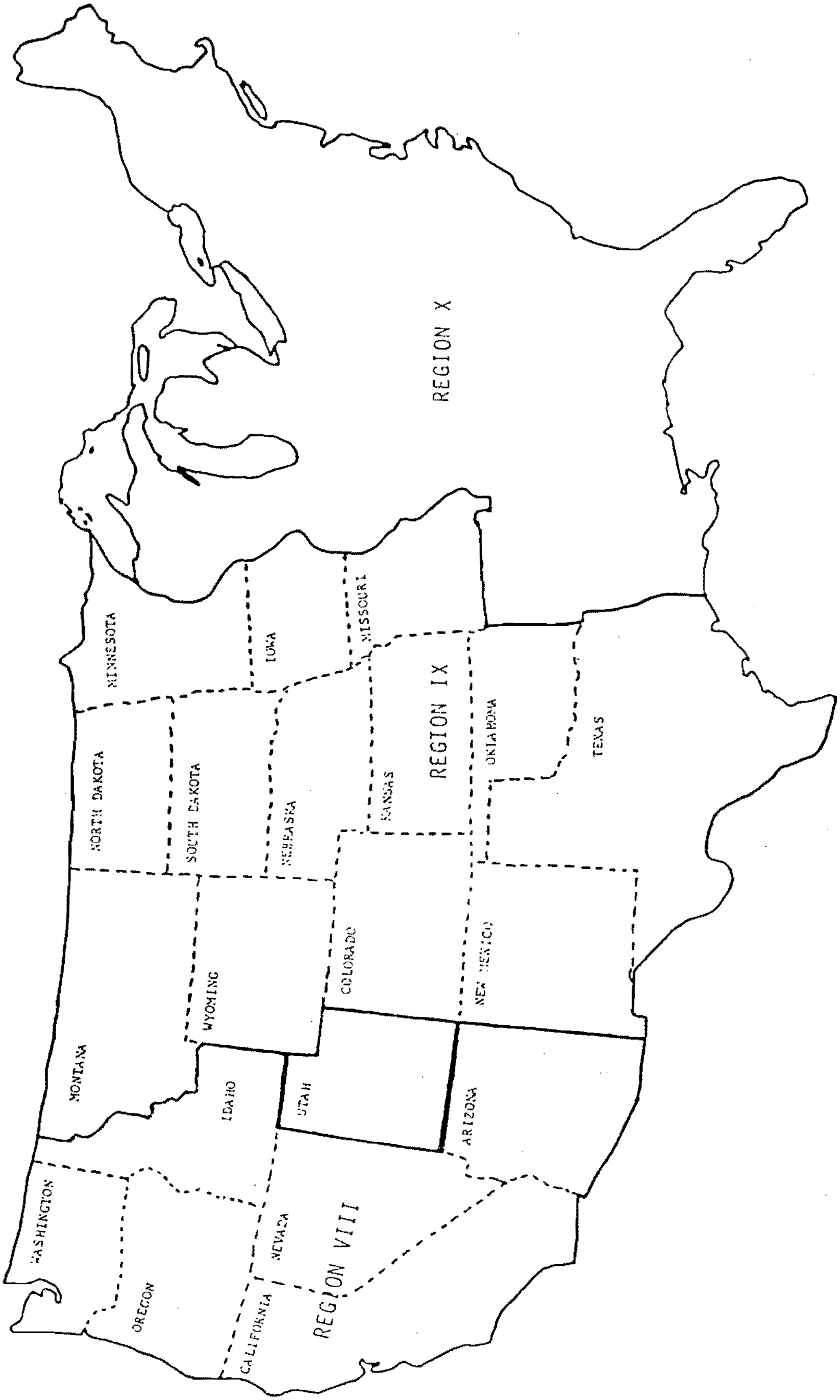

FIGURE 3.3. Regions Outside Of Utah Used In This Study

TABLE 3.1

Regions And Regional Centers Used In The Study

Region	Counties/States	Regional Center
I	Box Elder, Tooele Counties	Brigham City
II	Beaver, Iron, Juab, Millard, Washington Counties	Cedar City
III	Cache, Davis, Salt Lake, Utah, Weber Counties	Ogden
IV	Kane, Garfield, Piute, Sanpete, Sevier, Wayne Counties	Richfield
V	Daggett, Morgan, Rich, Summit, Wasatch Counties	Echos
VI	Duchesne, Uinta Counties	Vernal
VII	Carbon, Emery, Grand, San Juan Counties	Moab
VIII	Arizona, California, Idaho, Nevada, Oregon, Washington	Blackfoot Los Angeles
IX	Colorado, Iowa, Kansas, Minnesota, Missouri, Montana Nebraska, New Mexico, North Dakota, Oklahoma, South Dakota, Texas, Wyoming	Omaha
X	All Eastern States not mentioned above	Chicago

TABLE 3.2

Livestock Classes And Products Defined For The Study

Livestock Classes	Livestock Product Produced
Fed Beef	Beef
Hogs	Pork
Broilers	Chicken
Turkeys	Turkey
Layers	Eggs
Milk Cows	Milk
Dairy Calves*	
Cow/Calf*	
Dairy Backgrounders*	
Beef Backgrounders*	
Sheep	Lamb

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* The Dairy Calves, Cow/Calf, and Backgrounding activities are intermediate steps to the Fed Beef category and Fed Beef is the only beef product available for consumption in the model.

TABLE 3.3

Feeds Available To Be Fed To Livestock

Non-Grazing	Grazing
1. Barley	1. Private Pasture (PP)
2. Wheat	2. Aftermath (Aft)
3. Grain Corn	3. Private Range (PR)
4. Silage Corn	4. Bureau of Land Management Range (BLM)
5. Oats	5. Forest Service Range (FS)
6. Sorghum	6. State-Owned Range (ST)
7. Hay	
8. Protein Supplement	

TABLE 3.4

Seasons Of Production As Used In The Model

Season	Time Of Year
I	December, January February, March
II	April
III	May
IV	June, July, August, September
V	October
VI	November

Both feed supplies and livestock demands for feed were converted into equivalents of Metabolizable Energy (M.E.) and tons of Digestable Protein (D.P.). The feeds were then mixed to make an industry least-cost feed ration. The factors used to convert feed into energy are given in Table 3.5. Tables 3.6 and 3.7 list, respectively, M. E. - D. P. requirements to produce one unit of livestock product using seasonal feeds, and the nutrients available in grazing feeds. The latter requirements given in Table 3.7 are calculated from Nutrient Requirements for Cattle (National Academy of Sciences, 1976) and from Cook and Harris (1977). Nonfeed costs of livestock production are given in Table 3.8.

3.4.5 Transportation Structure Of The Model

The model represents a spatial equilibrium framework and the optimal solutions to the model derive the optimal routing of products to maximize profit to the agricultural sectors represented in the model. The transportation cost structure for transporting fed beef, hogs, and sheep was developed from a way bill study by Dietrich (1971) and used information from Webb (1980) and the U.S. Senate Committee on the Judiciary (1978) transport cost index to update the cost structure. Transportation costs for turkeys and broilers were obtained from Moroni Feed Company (1981) and milk product transport costs were given by Cache Valley Cheese, Inc. (1981). A study by Witt (1965) indicated egg transport costs. Transport costs for backgrounder animals and calves were derived from data given by Miller Transport Company (1981).

TABLE 3.5

Nutrients Furnished By One Ton Of Feed In MCAL M. E. Or Tons Of DP When Fed To Various Classes Of Livestock*

Class of Livestock	Variables	Barley	Western Barley	Wheat	White Wheat	Corn	Oats	Western Oats	Silage Corn	Alfalfa Hay	Sorghum	Protein Supplement
Beef Cow/Calf Background	MCal M.E.	2428	2399	2575	2580	2572	2224	2308	920	1686	2423	2794
	Tons D.P.	.087	.073	.100	.077	.065	.088	.067	.019	.114	.063	.373
Hogs	MCal M.E.	2322	2379	2671	2744	2690	2159	--	--	--	2613	2446
	Tons D.P.	.082	.075	.117	.091	.070	.099	--	--	--	.079	.394
Broilers Turkeys Layers	MCal M.E.	2405	--	2800	--	3106	2305	--	--	--	3000	2449
	Tons D.P.	.116	--	.108	--	.088	.118	--	--	--	.111	.438
M. Cows	MCal M.E.	2428	2399	2575	2580	2572	2224	2308	920	1686	2423	2794
	Tons D.P.	.087	.073	.085	.077	.065	.088	.067	.019	.114	.114	.373
Sheep	MCal M.E.	2515	2311	2575	2580	2770	2195	2398	907	1715	2515	2455
	Tons D.P.	.092	.069	.100	.077	.069	.092	.070	.018	.130	.075	.394

*Source: Calculated by author from NRC Tables (National Academy of Science, 1975,1976,1977,1978,1979).

TABLE 3.6

Tons Of Digestable Protein Available In Non-Irrigated Grazing Feeds

	December	April	May	June	October	November
I	.01575	.01575	.03330	.03240	.02250	.01575
II	.01575	.01575	.03330	.03240	.02250	.01575
III	.01125	.01125	.03330	.03240	.02250	.01125
IV	.01575	.01575	.03330	.03240	.02250	.01575
V	.00945	.01125	.03330	.03240	.02250	.00945
VI	.01395	.01395	.03330	.03240	.02250	.01395
VII	.01395	.01395	.03330	.03240	.02250	.01395
VIII	.01620	.01800	.03375	.03330	.02250	.01350
IX	.01575	.02250	.03375	.03240	.02250	.01665
X	.02025	.02700	.03600	.03600	.02700	.02250

Source: Calculated by author from NRC Tables (National Academy of Sciences, 1976).

TABLE 3.7

Metabolizeable Energy And Digestable Protein Requirement In Each Season To Produce Indicated Livestock Products*

		Cow/Calf		Beef Backgrounders		Sheep		Calves		Dairy Backgrounders	
		Mcal ME	Tons DP	MCal ME	Tons DP	MCal ME	Tons DP	MCal ME	Tons DP	MCal ME	Tons DP
Regions I-VIII	Dec	2926	.0470	1395	.0435	4899	.1725	381	.0140	1096	.0380
	Apr	714	.0215	0	0	1740	.0735	95	.0035	274	.0095
	May	913	.0275	0	0	1740	.0835	95	.0035	274	.0095
	June	3513	.1200	0	0	8069	.2905	381	.0140	1096	.0380
	Oct	524	.0008	269	.0085	731	.0265	95	.0035	274	.0095
	Nov	567	.0009	364	.0115	792	.0295	95	.0035	274	.0095
Regions IX-X	Dec	3052	.0777	676	.0212	4899	.1725	381	.0140	1096	.0380
	Apr	763	.0194	169	.0053	1740	.0735	95	.0035	274	.0095
	May	763	.0194	169	.0053	1740	.0835	95	.0035	274	.0095
	June	3052	.0777	676	.0212	8069	.2905	381	.0140	1096	.0380
	Oct	763	.0194	169	.0053	731	.0265	95	.0035	274	.0095
	Nov	763	.0194	169	.0053	792	.0295	95	.0035	274	.0095

*Source: Calculated from NRC Tables (National Academy of Sciences, 1975 and 1976).

TABLE 3.8

Non-Feed Costs Of Livestock Production 1979 (Per Livestock Unit)

	Milk	Turkey	Broiler	Layers	Hogs	Fed Beef	Beef Calf	Back-grounders	Sheep	Dairy Calves
I	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
II	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
III	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
IV	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
V	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
VI	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
VII	59.86	367.50	--	279.70	256.80	615.50	176.60	410.51	454.40	181.15
VIII	70.68	297.50	182.30	326.70	312.80	625.05	114.10	408.62	450.20	181.15
IX	61.61	310.60	148.00	264.70	297.90	640.53	174.80	409.76	533.00	181.15
X	64.85	349.14	211.30	408.60	294.10	609.89	111.00	390.82	328.10	181.15

Sources: Bailey (1980); USDA, Firm Enterprise Data System, 1979 Budgets (1979); and Perry (1980).

$/1000 lbs. live weight fed beef, hogs, broilers, turkeys, milk, and sheep; $/1000 dozen eggs; $/head beef calf, dairy calf, and backgrounders.

3.5 Drought Condition Input To The Model

The spatial equilibrium model is used to simulate the impacts of drought and also to estimate the benefits of weather modification in altering the impacts of drought. Therefore, certain data inputs are needed which represent drought conditions and which can be imposed in the model to obtain restricted optimal solutions under assumed drought and/or modified drought conditions. In a linear programming model of this nature, the optimal solutions are altered by changing the fixed or given parameters of the model such as output and input prices in the objective function, input-output coefficients in the constraint system, or the resource availabilities of the constraint system sometimes referred to as the right-hand-sides (RHS).

Drought conditions affect precipitation and water availability, which in turn affect supply elements such as yield and acreage in the agricultural sector. For fixed demand, the supply change causes a change in prices, which depends on the elasticities of demand of the commodities affected. Therefore, the drought-condition inputs to the model are projections of changes in precipitation, water availability, yield, acreage, and prices.

Precipitation affects both range forage and dryland crop production as well as runoff for water storage and future water availability. Precipitation is a resource used in the model for the production of each crop and is therefore in the input-output coefficient set of the model and as a given resource available at a certain level. Alteration of that level alters the optimal production of crops and range forage. Changes in precipitation for the growing season and for the water year (October-September of each year) were calculated using the precipitation and Palmer Index series previously developed in Chapter 1. These changes were incorporated in the model for each drought condition.

Water is available for crop and livestock production via surface and ground water sources. Changes in precipitation affect the levels of surface water and ground water availability through runoff, storage, and recharge. Changes in water availability were calculated using information from the hydrological study of changes in inflows to major storage reservoirs, reported in Chapter 2, and from information obtained from mutual water companies, river commissioners, the state engineer's office, and various state water record publications (Utah Division of Water Resources, 1975, 1978, 1980; Utah Consortium for Energy Research and Education, 1981a, 1981b; Lewis, 1980). These changes alter the water resource availability constraints in the modeling system.

Yield and acreage changes for Utah were derived by using yield-acreage-precipitation relationships which were estimated using data for Utah range condition, dryland wheat production, and yields and acreages of other dryland crops in Utah. The range condition relationship was described briefly in Chapter 1. Several functional forms for representing growth relationships were specified and estimated using data series for the Range Condition Index (U.S. Department of Agriculture, 1977) and the Palmer Index described and listed in Chapter 1. The specification of these growth functions follows previous developments of growth and phenological relationships by Shoemaker (1973), Talpaz and Borash (1974), and Regev et al. (1976) which modify the classical close response relationship of the bioassay literature reported by Finney (1952).

The response relationships developed followed in general the relationship given by

$$G\ (x,t) = P(t)f(x) \qquad (3.1)$$

where

G (x,t) is growth as a function of x, some force influencing growth, some time period, t, and population level at t. f(x) can be viewed as an attrition or growth function,

where

$$f(o) = o \qquad (3.2)$$

and

$$\lim_{x} f(x) \leq 1 \qquad (3.3)$$

If f(x) is an attrition relationship, then equation (3.1) is the familiar close response relationship. In this study we use the general relationship f(x) as a growth relationship assuming P(t) is given. The general function then maps a general sigmoid shaped curve in G(x,t) as x is increased. Several empirical functional forms satisfy (3.2) and (3.3) or are hybrid functions of the system (3.1) - (3.3), such as the arctangent, logistic and other functions describing the Weibul distribution (Thompson and Gaver, 1973, Talpaz and Borash, 1974).

The modified function we used for this study was of the form,

$$G(x,t) = 100/ \left[1 + e^{(a + b_1 P + b_2 P^2)}\right] \qquad (3.4)$$

where

G (x,t) is range condition measured as percent of optimal range forage production, e is the exponential operator, P is the Palmer Index, and a, b_1, b_2, 1 and 100 are parameters with a, b_1, and b_2 estimated using the range condition and Palmer Index data and using Ordinary Least Squares (OLS) estimation.

The best statistical results were obtained when average range conditions for the months of April through September were regressed on the corresponding average of the Palmer Indices. The function estimated derives a modified sigmoid curve. The estimated coefficients (3-4) are given in Table 1.36. Estimates were derived for all of the climatological regions in Utah and for several states outside of Utah. The relationships were used to project range condition (range yield) for varying Palmer Index values to describe rangeland drought conditions for the various regions involved.

Dryland crop production changes in Utah were estimated using a yield-weather relationship similar in concept to the relationships used by Swanson et al. (1972), Koo et al. (1978), and Buller et al. (1981). Dryland wheat production was separated from other dryland crops. The yield-weather relationship is of the following form:

$$y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 \quad (3.5)$$

where,

y = yield per planted acre

X_1 = evapotranspiration for March

X_2 = the ratio of actual evapotranspiration to evapotranspiration potential for June

X_3 = June precipitation

X_4 = Total precipitation for the previous water year (October-September) for the lag periods beginning with 1960.

Yield per planted acre was used as the yield measure to more accurately reflect the effect of abandoned acreage that appeared to increase as drought conditions dominated the growing season weather patterns for the period 1931-1980, particularly in 1931-1934, 1957-1961, and to some degree in 1977. The evapotranspiration measures were used to reflect the forces of water demand by the plant as temperatures vary, as well as to reflect water availability to the plant under varying temperature conditions. Some experimentation was done to arrive at acceptable statistical performance of the model expressed in (3.5), using various seasonal evapotranspiration measures. Following Hanks (1974), the ratio of actual evapotranspiration to potential evapotranspiration at varying temperatures is an indexed measure of water demand-availability forces of actual production in ratio to potential production. The level of evapotranspiration is a component of the Palmer Index and is therefore related to that measure of drought condition primarily used in this study. Some experimentation with relating dryland crop yields to the Palmer Index was done in this study but did not meet with the same success as relating range condition to the Palmer Index. A more finely defined measure of plant water demand and availability was needed as reflected by evapotranspiration. What is probably needed are measures of both transpiration and evaporation, but the data do not exist for the crops and regions involved.

Precipitation in the month of June is reflective of moisture availability, particularly for grain and forage crops which require adequate water during that particular part of the growing season. The precipitation levels for the previous water year (October-September) reflect the influence of fallow operations on yield. A plot of the yield data suggested that the fallow effect has been particularly strong in the past two decades in the case of dryland wheat production. Therefore, previous water year precipitation, as a measure of the effect of fallow and carryover moisture, was entered in the model as an interaction effect (dummy variable specification following Gujuradi, 1970). No experimentation with the lag and water carryover structure was performed. Such experimentations might be justified to fine tune the model in the future.

The best fit of the model for dryland wheat given by (3.5) is given below in equation (3.6).

$$y = 2.351 + 3.102X_1 + 15.701X_2 + 0.609X_3 + 0.1610X_4 \qquad (3.6)$$

$$(1.197) \quad (2.864) \qquad (6.660) \qquad (1.555) \qquad 4.117$$

for $D = 1$ for 1960-1980 observations
$= 0$ otherwise.

The t-statistics for each estimated coefficient are given in parentheses. The adjusted R^2 (coefficient of determination) is equal to 0.785, or approximately 78.5 percent of the variation in tons of wheat per planted acre is explained by the evapotranspiration and precipitation forces, X_1, X_2, X_3, and X_4. The F-statistic of 23.969 indicates overall statistical significance of the model, though the t-statistic for the June precipitation coefficient in the estimated model is not significantly different from zero at the five percent level of probability. Data were used for the period 1931-1980 as found in Perry (1982). This model was used to estimate the yield effect of various drought conditions as captured by precipitation and evapotranspiration.

For other dryland crops combined, a similar relationship was estimated, but the fit was not as good as for the dryland wheat. The estimated model is given in (3.7).

$$y = 1.392 + 0.991X_1 + 5.021X_2 + 0.195X_3 + 0.052X_4 \qquad (3.7)$$

$$(1.112) \quad (1.891) \qquad (3.213) \qquad (1.206) \qquad (1.012)$$

Data observations on dryland alfalfa, oats, barley and beans were only available for 1963-1978 to be used in the estimation. The adjusted coefficient of determination of the model is $R^2 = 0.439$, while the F-statistic is 3.338. With the exception of the actual to potential evaporation ratio, the t-statistics indicated relatively little influence of the defined independent variables, X_1, X_2, X_3, X_4, on yield per planted acre. The model overall was just barely a significant explanation of yields as indicated by the F-statistic.

For changes in dryland and irrigated crops in regions outside of Utah, weather indices for food and feed grains developed by Koo et al. (1978) were used. The index developed for each state showed the variability of crops due to weather influences corrected for technological change effects on yield. The index is a ratio of another index indicating the variability of crop yields due to weather in each state to the same variability over the entire U.S. For example, an index of 80 indicates production is 80 percent as volatile as the national average, while an index of 120 shows a particular state's production fluctuates 1.2 times the national average, i.e., weather has a greater influence. This index appeared to account for the influence of irrigation as a buffer to weather volatility, but use of the index for the particularly arid production areas seemed to underestimate the effects of drought on crop yield (Nef, 1979 and Perry, 1982). Therefore, the index was not used to alter Utah yields in the economic model. It was used for changing yield relationships in other arid states under drought conditions and thereby underestimated drought effects in those states, particularly Region VIII (the Western U.S.). The index could have more conveniently been used to change yields in all regions associated with the model as was done by Nef (1979) and is probably a quicker model change operation by far if rough estimates of drought effects for each state or general region of the U.S. are to be obtained. We desired in this study to more accurately reflect changes in Utah specifically, so the indices were used to specify outside region drought conditions while the equations (3.6) and (3.7) were used to alter Utah yields. Irrigated crop production in Utah was not imposed exogenously on the model simulations, but production levels were derived in the optimal solutions since they are related to water and land availability resource constraints in the model.

The weather indices derived by Koo et al. (1978) for the states involved in the regional delineations of this study are given in Table 3.9. Koo et al. (1978) and Nef (1979) estimated similar indices for various drought conditions experienced in various regions and for the U.S. The drought conditions used were assumed to be the worst weather expected for crop production in a certain ten-, twenty-, and forty-year period, measured as actually occurred in a given year during each of these periods. The worst expected in the last ten-year period was 1977, while the worst expected in forty years corresponded to the 1934 drought of the Great Plains region. Reductions in production for these years for the U.S. were combined with the indices of Table 3.9 and an estimate of percentage reduction of the crops involved was derived for each state and region.

We used these same calculations but assumed the reductions in alfalfa and private pasture were similar in nature and, therefore, in magnitude to the feed grain reductions to arrive

TABLE 3.9

Estimated Weather Indices By Region And State For Feed And Food Grains

Region	State	Grains a/	Grains a/
Utah	Utah	54	70
VII	Oregon	72	71
	Washington	70	61
	California	71	74
	Nevada	57	60
	Idaho	58	55
	Arizona	63	67
IX	Montana	101	100
	Wyoming	81	128
	Colorado	95	144
	New Mexico	151	167
	North Dakota	119	129
	South Dakota	148	160
	Nebraska	139	133
	Kansas	139	120
	Oklahoma	122	134
	Texas	101	146
	Minnesota	90	76
	Iowa	83	67
	Missouri	109	92

TABLE 3.9

Continued

Region	State	Grains[a]	Grains[a]
X	Alabama	116	123
	Arkansas	98	106
	Connecticut	b/	b/
	Delaware	135	131
	Florida	120	114
	Georgia	125	102
	Illinois	88	64
	Indiana	78	64
	Kentucky	92	66
	Louisiana	103	78
	Maine	36	b/
	Maryland	87	96
	Massachussetts	b/	b/
	Michigan	79	64
	Mississippi	108	105
	New Hampshire	b/	b/
	New Jersey	104	88
	New York	84	51
	North Carolina	99	84
	Ohio	72	71
	Pennsylvania	82	61
	Rhode Island	b/	b/
	South Carolina	95	113
	Tennessee	82	91
	Vermont	53	b/
	Virginia	100	85
	West Virginia	75	62
	Wisconsin	70	85

a/ Indices for specific grain crops are aggregated.

b/ Not computed

Source: Koo et al., 1978.

at percentage changes in yields of crops outside of Utah from yields achieved during the base year for the drought conditions assumed, 1931-1934 and 1977.

Orchard and vegetable crops were not incorporated in the model for other regions outside of Utah since the interdependency effects of most of the crops produced in Utah to production levels of similar crops produced elsewhere is small in magnitude, with the possible exception of cherries and apples where Idaho, California and Washington production effects on prices in Utah may be experienced. A measure of production reduction due to lack of water availability is difficult to separate from temperature damage (frost) but some separation was made using U.S. Department of Ariculture data on specialty crop production in Utah for 1977, 1979 and a 1950-1978 historical average. Agricultural Census data had to be used to define reductions that took place in specialty crop production in Utah for 1934.

A review of the Agricultural Census and Utah Agricultural Statistics (Utah Department of Agriculture, 1978) suggests that acreage changes result during drought periods. We attempted without success to relate acreage changes to weather forces such as the Palmer Index, precipitation and evapotranspiration variables. Therefore, the acreage changes were estimated using the Census and Utah Agricultural Statistics estimates of acreage in crops during 1934 and 1977 relative to the base year. These estimates were then imposed in the drought simulations using the economic model.

The model used to simulate economic impacts of drought conditions or the modification of these conditions required that prices be exogenously determined. Given the variation in quantity as described above (via yield and acreage changes), the variation in price was estimated using specific commodity own-price elasticities of demand, a measure of percentage change in quantity for a given percentage change in price. Actually the reciprocal, the price flexibility measure, was used since quantity changes are originally imposed. these elasticities were taken from Womack (1981) and Glover (1978). The elasiticity magnitudes used were: Barley -0.666; Wheat -2.627; Corn Silage -0.317; Oats -0.750; Sorghum -0.605; Corn Grain -0.500; and a combined orchard crop-vegetable crop group elasticity of -0.938. Little is known about the elasticities of alfalfa hay, private pasture and alfalfa seed. Therefore, an elasticity of -1.0 was assumed, reflecting that price and quantity movements are similar. The reciprocal of these elasticities was then applied to the changes in production to obtain the needed price changes which were in turn imposed on the objective function of the economic model.

It is important to note that benefits of supply shifts, such as those induced by cloud seeding and augmentation of precipitation, depend significantly on the price-quantity relationship for the particular commodity of interest. Increasing the production of commodities which have an inelastic demand (the case for most agricultural commodities) reduced the total revenue to all producers in the market because the price impacts are greater than the quantity change. However, if the increase in production is restricted to a small region of the market, total revenue to the producers in this region may increase because for them the percentage increase in their production may be greater than the percentage decrease in the price in the total market, the price received in the region. If such a case exists, the region's producers have shifted the adverse effect of the price decline on total revenue to all producers excluding themselves. The extent to which this shift can occur depends upon the share of the region's production in the total production in the market and the increase in production that takes place in the region. In the case of inelastic demand, whether a region receives an increase in total revenue after a shift in supply depends on the region's share in total production in relation to the absolute value of the elasticity of demand for the output. If this share is equal to the elasticity of demand, then a change in supply leaves total revenue in the region unchanged. If the share is less than the value of the demand elasticity, then the increased supply can effect an increase in the region's total revenue. If the share is greater than the demanded elasticity, then total revenue is decreased in the region.

For the most part, Utah's share of production of livestock and crops is small relative to the total market. The exceptions would possibly be sweet and sour cherries and alfalfa seed which are produced within a western region market. At different times during the harvest season, Utah cherries may dominate local western markets, while at other times Idaho, California or Washington cherries may dominate production in the western market. Alfalfa seed is produced in Utah, California, Idaho, Nebraska and some other western states for a western states market. Just what effects that revenue shifts in the production of these crops have is determined by the economic model with the appropriate elasticities imposed. There are a number of price-quantity-revenue interactions that the model is capable of accounting for. It is for this reason that the activity analysis economic modeling approach was chosen to estimate supply shift impacts.

3.6 Simulated Economic Impact Of The 1931-34 And 1976-77 Droughts

The linear programming-spatial equilibrium model and the drought condition inputs previously described were used to simulate the economic impacts and interactions that take place during drought periods. The modeling system is particularly useful in accounting for all of the many economic activities of a local economy as it interacts with other regional economies in which the local economy is imbedded. The optimization procedure and the constrained optimal solution to the model provides a trace or a recipe of all the changes in economic activity which are triggered by changes in the parameters or given values of the model. The major changes imposed on the model as used in this study were those associated with water availability and precipitation and associated yield-water availability relationships imposed on the model.

The model was first used to simulate base or "normal" conditions which we assume relate to 1979 production and precipitation conditions. Then a constrained optimum for the model was obtained for imposed changes in water availability, precipitation, and price-quantity relationships associated with static conditions for 1934, assuming 1979 distribution of production. The changes made assumed the changes in water availability as the drought of that period progressed from 1931 to 1934. Therefore, we have attempted to capture an extended drought situation. Next, a constrained optimum was obtained for the 1976-77 drought period which was a different kind of drought in timing, effect, and extent than the 1931-34 period. These drought simulations provided some information for describing the drought effects and therefore provided an economic definition of the two types of drought. Later, as reported in Chapter 6, the model was used to evaluate the benefits of modifying these same drought situations through cloud seeding.

3.6.1 The Base Year (1979) Simulation

The year 1979 was chosen as the base year because it was the most current year for which data were available on the distributions of crop production, livestock production and water use which could be allocated to the climatological regions delineated for Utah. The choice of the base year was therefore, in part, dictated by data considerations. The choice was also made so as to represent a current year water-use pattern which was reflective of the current water storage and delivery technology in each of the climatological regions of the State. Information is needed on the impacts that a variety of water flow conditions have on the local economy, given that current storage and delivery systems are in place. The year 1979 was, at the initiation of the study, the most current year for which data on most economic interactions such as livestock grazing and movement within the State and feed and food grain trade were available. This particular year was not representative of a "normal" weather year. The year was somewhat representative of crop production and livestock operations in Utah over the period of 1967-1979. A "normal" year base could only be developed from a moving average of all weather, production, and distribution data over a designated period such as 1931-1979. Detailed data for such a derivation do not exist.

Production and distribution data for the delineated regions in Utah (i.e., Regions I-VII and those representative of the rest of the U.S. Regions VIII-X) were used to construct the base year objective function and constraint system of the linear programming-spatial equilibrium model. Then a constrained optimum solution to the model was obtained. We term this solution to the model the base year simulation of economic activity in the crop, range forage, and livestock sectors of the regions involved. Profit or returns to fixed cost were maximized subject to the various constraints on crop production, livestock production (feed intake and availability), water availability, and feed and livestock trade routes. The solution not only gave the maximum returns to fixed costs, production costs, and transport costs associated with the various activities of the crop and livestock sectors, but also generated a recipe for the various interactions in the sectors, such as feed production, utilization by region and the trade in feed between regions, which is optimal. Similarly, livestock production and transport activities were given. The levels of these activities help us to describe the impacts of drought in addition to the monetary effects when drought conditions were imposed on the model through water availability constraints and given price-quantity relationships.

A description of base year activities is useful in order to understand the effects of changes in the optimal solution when drought conditions are imposed. Therefore, in what follows, a description of the base year solution is given. Only major production activities are outlined in this report, since they are the major sectors which are impacted when drought conditions occur. These major activities for Utah are the grain and forage production and livestock production activities. Optimal feed production levels, as derived by the model for the base year, are given in Table 3.10. Actual production is also shown in the table. For the most part, production demanded for most feeds as derived from the model was the same as the

TABLE 3.10

Feed Production Levels Required In The Base Year As Compared To Actual Production Level in Each Region

		Tons							AUMS			
									Private Pastures		Private Range	
Region		Corn	Oats	Barley	Wheat	Sorghum	Hay	Corn S.	Cattle	Sheep	Cattle	Sheep
I	Opt	8,861	1,361	41,621	4,006	-0-	105,917	116,794	92,740	31,661	106,100	36,283
	Actual	8,681	1,361	41,621	4.006	-0-	105,917	125,133	92,740	31,661	106,100	36,283
II	Opt	2,421	2,033	53,371	1,751	-0-	265,294	88,440	106,700	48,508	109,300	16,543
	Actual	2,421	2,033	53,730	1,751	-0-	265,294	96,030	106,700	48,508	109,300	16,543
III	Opt	21,800	2,033	58,971	22,784	-0-	231,373	283,668	119,300	11,192	58,330	41,792
	Actual	21,800	2,033	64,803	22,784	-0-	231,373	283,668	119,300	11,244	58,330	41,792
IV	Opt	-0-	2,276	38,607	291	-0-	158,205	154,454	132,500	28,546	38,260	13,504
	Actual	-0-	2,276	38,030	291	-0-	158,205	168,156	132,500	28,546	38,260	28,928
V	Opt	-0-	-0-	8,807	203	-0-	94,460	-0-	70,390	5,752	80,520	87,722
	Actual	-0-	759	9,406	203	-0-	74,163	-0-	70,390	5,920	80,520	87,722
VI	Opt	3,270	-0-	5,614	127	-0-	73,324	27,167	183,576	12,432	44,360	26,940
	Actual	3,270	2,260	5,784	127	-0-	87,128	28,940	149,800	12,432	44,360	27,793
VII	Opt	-0-	-0-	1,693	791	-0-	54,309	8,653	61,870	1,334	45,050	-0-
	Actual	-0-	1,384	1,721	791	-0-	50,782	10,929	61,870	4,571	45,050	2,687
VIII	Opt	1,471,540	206,000	2,850,000	478,200	143,080	8,348,000	4,025,700	6,637,000	415,463	12,906,000	2,815,400
	Actual	1,472,000	206,000	3,030,000	478,200	479,100	8,851,000	3,655,000	6,637,000	415,463	12,403,000	2,746,388
IX	Opt	109,264,092	3,320,653	4,986,190	2,089.000	21,434,160	34,974,330	22,775,200	73,233,864	1,723,060	145,300,000	10,413,120
	Actual	109,264,092	5,395,632	5,184,960	2,293,817	21,432,348	34,291,000	23,995,000	31,400,000	1,723,030	150,000,000	7,092,121
X	Opt	106,618,500	2,894,535	641,600	320,700	888,723	22,948,800	20,586,600	-0-	-0-	139,943,600	2,053,364
	Actual	87,650,000	2,949,000	641,600	430,600	889,100	25,471,000	28,452,000	-0-	-0-	139,800,000	2,958,073

actual production for the base year. Some exceptions did occur, such as the low production of sorghum demanded in Region VIII (Western U.S.) relative to the actual production. More production of corn silage was demanded in the same region relative to the actual production of corn silage for 1979. The excess feed produced can be explained by recognizing that 1) not all the details of livestock for every region are included in the coefficient set of the model, 2) some livestock are produced inefficiently and therefore, require more feed, and 3) some waste does occur in the process of production transport and conversion to livestock products. The excess demanded may reflect some differences in the input-output processes modeled and what actually exists in various regions. If all activities and input-output relationships were represented in exact detail in the model, then the optimal solution should give some direction to regional producers as to how to overcome some inefficiences by following the recipe of feed input, trade routes, and production levels, given the costs and prices involved. Production of forage feeds from public lands such as the Forest Service, Bureau of Land Management and state grazing lands was equal to the actual 1979 levels in all cases and is, therefore, not listed here. Exact detail of animal unit month (AUM) utilization for the base year was obtained, and this provided for more accuracy in the model representation of these feeds. An animal unit month is the amount of forage utilized by one cow and her calf or ten sheep in one month.

The most important industry in Utah is the livestock industry, including both sheep and cow/calf operations. These activities rely heavily on grazing feeds from the public lands and private range and pasture. Feed allocation in each season to the cow/calf and sheep activities in each region are presented in Tables 3.11 and 3.12, respectively. In most regions within

TABLE 3.11

Allocation Of Feed To The Cow/Calf Activity By Season And Region For The Base Year Simulation Of The Economic Model

The seasons are indicated by the letter symbols: D (Dec-Mar); A (April); M (May); J (June-Sept); O (Oct); and N (Nov).

		Feed									
Region	Season	IS	BLM	State	PR	AFT.	PP	Hay	Corn S.	Barley	Protien
I	D	---	-0-	1,288	-0-	---	-0-	45,816	1,674	-0-	-0-
	A	648	6,474	1,013	10,310	---	7,508	2,051	418	-0-	-0-
	M	-0-	4,244	2,146	20,620	---	13,723	-0-	418	-0-	-0-
	J	16,436	20,720	5,683	75,170	---	38,621	-0-	1,674	-0-	-0-
	O	391	1,755	-0-	-0-	-0-	-0-	7,459	418	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	11,140	418	-0-	-0-
II	D	---	53,215	-0-	-0-	---	-0-	57,567	2,544	-0-	-0-
	A	---	12,706	2,467	10,930	---	10,270	5,716	636	-0-	-0-
	M	2,267	15,655	-0-	21,860	---	20,905	2,361	636	-0-	-0-
	J	66,452	54,772	2,620	765,510	---	49,600	3,180	2,544	-0-	-0-
	O	4,769	5,769	-0-	-0-	-0-	-0-	9,852	636	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	18,504	-0-	-0-	-0-
III	D	---	-0-	261	-0-	---	-0-	55,985	2,036	-0-	-0-
	A	---	-0-	261	-0-	---	-0-	13,586	507	-0-	-0-
	M	609	1,383	522	11,666	---	29,825	1,846	620	-0-	-0-
	J	44,505	7,076	1,564	46,664	---	89,475	-0-	2,384	-0-	-0-
	O	-0-	-0-	-0-	-0-	7,216	-0-	7,396	507	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	13,586	-0-	-0-	-0-

TABLE 3.11

Continued

		Cow/Calf									
Region	Season	FS	BLM	State	PR	AFT.	PP	Hay	Corn S.	Barley	Protein
IV	D	---	-0-	-0-	-0-	---	-0-	70,142	2,322	-0-	-0-
	A	381	8,716	1,875	-0-	---	-0-	13,204	580	-0-	-0-
	M	1,874	10,823	3,750	7,652	---	29,877	2,756	580	-0-	-0-
	J	119,516	-0-	-0-	30,608	---	87,230	-0-	2,322	-0-	-0-
	O	8,749	-0-	-0-	-0-	-0-	-0-	9,358	580	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	16,964	-0-	-0-	-0-
V	D	---	25,204	217	-0-	---	-0-	35,491	-0-	-0-	-0-
	A	---	661	413	8,042	---	-0-	7,616	-0-	-0-	-0-
	M	-0-	4,529	867	16,107	---	17,548	-0-	-0-	-0-	-0-
	J	29,079	12,499	-0-	55,837	---	52,842	-0-	-0-	-0-	-0-
	O	3,709	1,353	2,818	434	4,365	-0-	3,463	-0-	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	10,580	-0-	-0-	-0-
VI	D	---	11,591	785	4,436	---	-0-	46,399	2,362	-0-	-0-
	A	---	3,484	785	4,436	---	14,980	4,420	454	-0-	-0-
	M	278	4,087	1,570	8,872	---	29,960	481	1,814	-0-	-0-
	J	26,680	5,540	-0-	7,435	---	138,636	-0-	-0-	-0-	-0-
	O	1,937	2,387	4,711	17,278	-0-	-0-	-0-	454	-0-	-0-
	N	---	1,284	-0-	-0-	-0-	-0-	12,593	-0-	-0-	-0-

TABLE 3.11

Continued

					Cow/Calf						
Region	Season	FS	BLM	State	PR	AFT.	PP	Hay	Corn S.	Barley	Protein
VII	D	---	21,245	3,338	-0-	---	-0-	35,301	1,344	-0-	-0-
	A	---	18,780	2,782	3,851	---	-0-	1,700	336	-0-	-0-
	M	---	19,560	-0-	6,817	---	12,374	-0-	336	-0-	-0-
	J	41,248	18,650	4,450	34,382	---	49,496	-0-	1,867	-0-	-0-
	O	-0-	4,771	17,250	-0-	-0-	-0-	-0-	336	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	10,639	-0-	-0-	-0-
VIII	D	---	-0-	---	1,390,950	---	-0-	3,246,806	136,900	-0-	-0-
	A	---	365,188	---	927,300	---	663,700	216,469	34,232	-0-	-0-
	M	97,943	535,493	---	1,854,600	---	805,807	-0-	34,232	-0-	-0-
	J	2,422,358	1,676,081	---	6,210,368	---	2,313,360	-0-	165,455	-0-	-0-
	O	---	-0-	---	1,868,078	-0-	-0-	-0-	34,232	-0-	-0-
	N	---	-0-	---	-0-	-0-	-0-	906,656	-0-	-0-	-0-
IX	D	---	638,078	---	22,515,000	---	-0-	18,565,047	983,100	998,613	-0-
	A	---	171,708	---	4,530,942	---	-0-	-0-	312,700	249,486	-0-
	M	177,015	348,482	---	14,278,072	---	5,388,165	-0-	-0-	-0-	-0-
	J	2,561,784	-0-	---	58,451,232	---	19,808,051	-0-	312,700	249,486	-0-
	O	144,147	246,264	---	19,321,849	---	-0-	-0-	312,700	249,486	-0-
	N	---	221,940	---	18,492,792	---	-0-	-0-	312,700	249,486	-0-

TABLE 3.11

Continued

					Cow/Calf						
Region	Season	FS	BLM	State	PR	AFT.	PP	Hay	Corn S.	Barley	Protein
X	D	6,890	---	---	20,970,000	---	---	5,130,787	670,000	-0-	-0-
	A	1,723	---	---	9,097,612	---	---	-0-	-0-	-0-	-0-
	M	10,335	---	---	9,089,000	---	---	-0-	-0-	-0-	-0-
	J	37,895	---	---	36,383,840	---	---	-0-	-0-	-0-	-0-
	O	10,335	---	---	9,089,000	---	---	-0-	-0-	-0-	-0-
	N	1,722	---	---	9,097,613	---	---	-0-	-0-	-0-	-0-

TABLE 3.12

Allocation Of Feed To The Sheep Activity By Season And Region For The Base Year Simulation Of The Economic Model

The season are indicated by the letter symbols: D (Dec-Mar); A (April); M (May); J (June-Sept); O (Oct); and N (Nov).

		Feed									
Region	Season	Fs	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protein
I	D	---	27,641	-0-	4,354	---	-0-	2,576	531	-0-	-0-
	A	-0-	3,870	-0-	3,628	---	2,311	1,488	132	-0-	-0-
	M	77	1,677	-0-	5,978	---	6,332	-0-	132	-0-	-0-
	J	34,282	83	-0-	18,603	---	11,857	-0-	875	-0-	-0-
	O	1,469	388	-0-	3,720	-0-	-0-	76	132	-0-	-0-
	N	---	5,076	-0-	-0-	-0-	-0-	426	132	-0-	-0-
II	D	---	29,203	-0-	-0-	---	-0-	2,327	616	-0-	-0-
	A	-0-	4,553	-0-	-0-	---	4,851	1,217	154	-0-	-0-
	M	-0-	522	-0-	2,656	---	9,705	-0-	154	-0-	-0-
	J	13,407	3,643	-0-	13,887	---	28,952	-0-	616	-0-	-0-
	O	---	2,488	-0-	-0-	-0-	-0-	976	154	-0-	-0-
	N	---	4,612	-0-	-0-	-0-	-0-	394	154	-0-	-0-
III	D	---	7,839	-0-	4,179	---	-0-	6,016	436	-0-	-0-
	A	---	6,080	-0-	-0-	---	-0-	1,527	109	-0-	-0-
	M	-0-	-0-	-0-	8,358	---	2,087	-0-	109	-0-	-0-
	J	15,811	1,161	-0-	22,710	---	8,534	-0-	651	-0-	-0-
	O	---	-0-	-0-	3,720	-0-	573	-0-	109	-0-	-0-
	N	48	390	-0-	2,825	-0-	-0-	490	109	-0-	-0-

TABLE 3.12

Continued

		Sheep									
Region	Season	FS	BLM	State	PR	AFT.	PP	Hay	Corn S.	Barley	Protein
IV	D	---	11,789	9,559	2,893	---	-0-	7,262	685	-0-	-0-
	A	---	7,745	-0-	2,893	---	173	1,847	171	-0-	-0-
	M	-0-	3,168	-0-	5,786	---	7,137	-0-	171	-0-	-0-
	J	58,442	-0-	-0-	-0-	---	16,207	-0-	773	-0-	-0-
	O	243	1,338	-0-	-0-	-0-	5,030	-0-	171	-0-	-0-
	N	---	3,852	-0-	-0-	-0-	-0-	490	171	-0-	-0-
V	D	---	29,561	-0-	4,386	---	-0-	5,694	-0-	-0-	-0-
	A	---	2,496	-0-	7,997	---	-0-	2,570	-0-	-0-	-0-
	M	-0-	621	-0-	17,217	---	-0-	-0-	-0-	-0-	-0-
	J	30,970	-0-	-0-	46,535	---	5,217	-0-	-0-	-0-	-0-
	O	177	233	-0-	6,548	---	535	-0-	-0-	-0-	-0-
	N	---	430	-0-	5,039	-0-	-0-	927	-0-	-0-	-0-
VI	D	---	22,582	-0-	-0-	---	-0-	2,434	535	-0-	-0-
	A	---	6,882	-0-	-0-	---	-0-	1,163	-0-	-0-	-0-
	M	-0-	483	-0-	5,559	---	2,486	716	134	-0-	-0-
	J	11,140	25	-0-	16,697	---	21,309	-0-	535	-0-	-0-
	O	-0-	4	-0-	3,685	-0-	637	-0-	134	-0-	-0-
	N	---	2,563	-0-	1,000	-0-	400	134	-0-	-0-	

TABLE 3.12

Continued

					Sheep						
Region	Season	FS	BLM	State	PN	AFT	PP	Hay	Corn S.	Barley	Protein
VII	D	---	3,247	-0-	-0-	---	-0-	350	76	-0-	-0-
	A	---	989	-0-	-0-	---	-0-	196	-0-	-0-	-0-
	M	---	634	-0-	-0-	---	914	-0-	-0-	-0-	-0-
	J	7,128	53	-0-	-0-	---	-0-	-0-	-0-	-0-	-0-
	O	72	159	-0-	-0-	-0-	420	-0-	-0-	-0-	-0-
	N	---	543	-0-	-0-	-0-	-0-	57	-0-	-0-	-0-
VIII	D	---	135,437	-0-	336,958	---	-0-	345,327	22,155	-0-	-0-
	A	-0-	33,407	-0-	224,638	---	41,546	77,762	5,539	-0-	-0-
	M	7,208	45,641	-0-	449,278	---	19,733	-0-	5,539	-0-	-0-
	J	325,541	133,720	-0-	1,594,242	---	354,184	-0-	33,921	-0-	-0-
	O	18,885	22,361	-0-	164,693	-0-	-0-	2,966	5,539	-0-	-0-
	N	---	22,383	-0-	45,579	-0-	-0-	57,741	5,539	-0-	-0-
IX	D	---	148,213	---	1,033,818	---	-0-	709,874	59,654	37,015	-0-
	A	---	32,995	---	538,063	---	-0-	202,534	14,921	13,147	-0-
	M	12,158	54,097	---	812,301	---	344,606	-0-	-0-	-0-	-0-
	J	280,892	176,134	---	3,873,499	---	1,341,714	-0-	-0-	-0-	-0-
	O	14,386	36,549	---	426,223	---	36,710	-0-	-0-	-0-	-0-
	N	14,386	34,168	—	408,218	—	-0-	32,120	14,921	-0-	-0-

TABLE 3.12

Continued

Sheep											
Region	Season	FS	BLM	State	PN	AFT	PP	Hay	Corn S.	Barley	Protein
X	D	361	---	---	443,711	---	---	54,879	9,151	-0-	-0-
	A	90	---	---	218,260	---	---	-0-	-0-	-0-	-0-
	M	540	---	---	217,810	---	---	-0-	-0-	-0-	-0-
	J	1,983	---	---	1,010,582	---	---	-0-	-0-	-0-	-0-
	O	541	---	---	91,191	---	---	-0-	-0-	-0-	-0-
	N	90	---	---	99,297	---	---	-0-	-0-	-0-	-0-

Utah, private range is consumed more heavily during the winter and spring seasons and little is consumed during the fall. Therefore, winter and early spring moisture is important in producing this forage. Private pasture is consumed by cow/calf operations beginning in the spring, with a peak in the summer and declining use in the fall. Sheep operations generally follow this same pattern, except more range is consumed relative to pasture than in cattle operations. Backgrounder activities consume mostly hay and corn silage, although some grazing forage is used in these activities in Utah. In general, these patterns were simulated in the base year optimal solution.

The movement of livestock to different regions for grazing purposes is appropriately represented in the base year simulation relative to movement patterns which do exist. This can be detected by following the seasonal grazing activities changes that were generated by the model. These changes are reflected in Tables 3.11 and 3.12. Livestock is moved onto grazing land in the mountains during the summer months, then they are moved to the desert floors for the winter. Grazing on ranch lands is generally done during the early spring and in the fall. There is usually greater movement of sheep in this seasonal grazing pattern than cattle, and this was also reflected in the simulation.

One of the more useful variables derived from linear programming was the shadow price which is computed by the model. The shadow price represents the value of an additional unit of a given resource to producers demanding that particular resource as derived by the model. The producer can pay up to the shadow price value for another unit of the resource and, thereby, increase profits. In some cases, depending on the nature of the constraint imposed on the model, this value reflects the value at which the price of the resource would have to fall in order for the producer to find it profitable to use more of the particular resource. The shadow prices also change with different economic conditions which may be imposed on the model and which, in turn, alter the optimal solution, i.e., alter the profit position. In fact, various physical constraints which were altered in the model also altered the profit position and use of resources. Use was made of the shadow prices here and later to interpret comparative advantage of various regions in producing livestock and crops, and to evaluate the effects of drought on the profit position and comparative advantage.

The shadow prices for the non-grazing feeds are presented in Table 3.13, along with the actual prices which existed in the base year. Some shadow prices are higher than the actual prices. These differences are particularly noticeable for grain, corn and barley, and in some regions there was divergence between the price of wheat and its shadow value. Sorghum shadow prices were all considerably lower than the actual prices paid for sorghum in the base year. The closeness of these two values indicates that the cost of transportation of the feed between the regional points was quite representative of the actual costs faced by producers who purchase the feeds.

The shadow prices for the Bureau of Land Management (BLM) grazing AUM's are given in Table 3.14. These values are given for the six seasons imposed on the model structure. Grazing operations depend heavily on a grazing rotation system that takes place throughout the year. Shortage of forage in any part of that rotation imposes some costs on the livestock operations, since supplemental feed has to be either purchased or diverted as a supplement in some other season to be used

TABLE 3.13

Shadow Prices And Actual Prices For Non-Grazing Feeds On Each Region In The Base Year Simulation

Region	Price	Corn	Oats	Barley	Wheat	Sorghum	Hay	Corn S.
I	Shadow	114.29	106.33	116.93	114.42	---	56.75	18.08
	Actual	105.40	106.33	92.08	111.00	---	52.92	18.00
II	Shadow	124.68	107.81	122.65	124.83	---	52.92	18.00
	Actual	105.40	106.33	92.08	111.00	---	52.92	18.00
III	Shadow	112.73	98.43	116.70	125.43	---	52.17	18.88
	Actual	105.40	106.33	92.08	11.00	---	52.92	18.00
IV	Shadow	121.05	113.09	199.26	121.19	---	53.89	18.00
	Actual	105.40	106.33	92.08	111.00	---	52.92	18.00
V	Shadow	115.28	105.87	115.38	115.42	---	62.82	18.95
	Actual	105.40	106.33	92.08	111.00	---	52.92	18.00
VI	Shadow	122.53	105.95	120.64	122.67	---	52.92	19.27
	Actual	105.40	106.33	92.08	111.00	---	52.92	18.00
VII	Shadow	125.94	108.90	123.83	126.09	---	52.92	19.80
	Actual	105.40	106.33	92.08	111.00	---	52.92	18.00
VIII	Shadow	123.88	115.92	110.26	133.66	121.53	30.50	20.69
	Actual	107.10	103.10	102.08	117.30	167.00	58.00	18.50
IX	Shadow	82.14	74.18	91.56	114.90	79.79	65.77	31.43
	Actual	82.14	81.87	81.67	114.90	127.10	44.00	
X	Shadow	87.92	90.16	126.32	103.56	96.25	59.50	20.58
	Actual	87.92	90.00	123.43	124.90	118.80	59.50	18.00

TABLE 3.14

Shadow And Actual Prices On Each Season For Bureau Of Land Management And Private Pasture Grazing Feeds In The Base Year Simulation

		BLM			Private Pastures		
Region	Season	Cattle	Sheep	Actual	Cattle	Sheep	Actual
I	D	10.71	9.32	2.84	13.05	12.03	14.25
	A	11.44	7.16	2.06	13.45	9.84	10.36
	M	9.38	4.72	1.26	10.64	5.98	6.34
	J	8.81	5.19	1.42	10.23	6.61	7.13
	O	7.12	6.59	1.89	9.01	8.98	9.50
	N	5.71	7.75	2.52	9.08	10.65	12.66
II	D	7.17	6.53	2.84	10.54	9.16	14.25
	A	9.33	4.56	1.62	10.94	6.91	8.14
	M	7.83	4.20	1.33	9.16	5.83	6.71
	J	7.88	4.72	1.51	9.38	6.23	7.60
	O	4.61	4.50	1.89	6.49	6.38	9.50
	N	7.88	3.41	2.52	10.43	6.59	12.66
III	D	11.03	9.91	2.84	12.74	13.83	14.25
	A	11.23	8.08	2.27	13.14	13.83	14.25
	M	10.03	6.16	1.33	11.36	6.29	6.71
	J	8.54	5.05	1.33	9.87	6.29	6.71
	O	7.44	6.40	1.62	11.30	7.72	8.14
	N	6.43	8.47	2.52	10.11	11.40	12.66
IV	D	8.78	8.59	2.84	11.62	11.42	14.25
	A	9.50	7.73	2.52	12.02	10.50	12.66
	M	8.82	8.18	1.42	10.24	9.60	7.13
	J	6.07	2.93	1.26	7.33	4.18	6.34
	O	5.95	4.36	1.62	7.59	5.98	8.14
	N	8.59	7.48	2.52	13.66	10.21	12.66
V	D	11.78	10.41	2.84	14.62	13.44	14.25
	A	12.18	8.49	2.84	15.02	12.62	14.25
	M	11.29	5.02	1.51	12.80	6.53	7.60
	J	7.89	4.27	1.26	9.14	5.53	6.34
	O	8.96	5.34	1.62	10.57	7.33	8.14
	N	4.91	8.01	2.52	15.47	11.68	12.66

TABLE 3.14

Continued

		BLM			Private Pasture		
Region	Season	Cattle	Sheep	Actual	Cattle	Sheep	Actual
VI	D	11.04	7.16	2.84	13.88	9.47	14.25
	A	12.00	2.56	2.27	14.28	6.75	11.40
	M	11.17	10.96	1.33	12.50	12.28	6.71
	J	4.73	4.21	1.42	6.15	5.63	7.13
	O	5.70	5.18	1.74	7.44	7.27	8.77
	N	2.27	7.48	2.52	11.68	11.16	12.66
VII	D	9.50	10.00	2.84	14.56	3.14	14.25
	A	8.65	8.57	2.27	11.37	3.14	11.40
	M	5.89	4.01	1.33	7.21	2.62	6.71
	J	6.41	4.09	1.51	7.91	3.14	7.60
	O	6.41	1.62	1.89	8.30	3.14	9.50
	N	2.35	6.35	2.52	6.61	3.14	12.66
VIII	D	10.42	10.20	2.52	12.94	12.73	12.09
	A	15.59	15.30	2.06	17.61	17.31	9.90
	M	12.31	4.01	1.33	13.64	5.34	6.40
	J	4.12	3.72	1.26	5.38	4.98	6.05
	O	5.06	4.66	1.62	6.68	6.60	7.77
	N	6.62	6.47	2.27	8.89	8.74	10.88
IX	D	10.44	10.21	2.84	13.27	13.05	13.88
	A	8.69	8.51	2.27	10.96	10.78	11.10
	M	5.08	4.75	1.26	6.34	6.01	6.17
	J	5.52	5.20	1.42	6.94	6.62	6.94
	O	6.09	5.77	1.62	7.93	7.61	7.93
	N	7.93	7.61	2.27	11.10	10.77	11.10
X	D	14.60	14.35	2.44	14.60	14.35	10.57
	A	6.81	2002.01	2.03	6.81	B6.81	8.81
	M	5.11	5.11	1.52	6.06	5.11	6.61
	J	1004.38	1000.62	1.43	6.13	4.81	6.22

in a season for which there is a grazing shortfall. Private range, Forest Service (FS), and state-owned AUM's all have the same nutritional value to livestock as AUM's from BLM land grazing so the shadow values of these forage feeds are not given. Aftermath has the same nutritional value as private pasture as imposed in the model and, similarly, the shadow price is not given. Only the shadow prices for BLM and private pasture are then given in the table for cow/calf and sheep activities. The general pattern of grazing feed resource scarcity is reflected by the shadow prices derived from the optimal solution to the model for the base year simulation. In general, forage was scarce in the winter and early spring months, and the price a producer could pay for the grazing resource increased for these months. As feed became more and more available in the spring and summer months, the shadow price declined. The actual price shown in Table 3.14 is the fee cost for the use of the public lands forage. All other costs of using the public lands were excluded.

Nielson (1982) has shown that when all costs of management, improvements, losses, etc. are included with the fee cost, the total cost to use public land grazing is approximately $11.34 per AUM. This value is much closer to the shadow prices for the feed in each livestock production use. For the utilization of private pasture, it appears from looking at the shadow prices relative to the fees paid that there was some under-utilization and some over-utilization of available AUM's, depending on the season and region. Of course, instantaneous adjustments cannot be made as forage value changes. In some cases, the higher shadow prices relative to the private pasture fee can be explained by the fact that all hay produced as imposed in the model was alfalfa hay. While 90 percent of the total hay harvested in Utah in 1979 was alfalfa, most of the other hay produced in the state, as well as much of the poorer quality alfalfa, is used in the cow/calf and sheep activities. Since this hay is of inferior quality, it brings a lower price in the market. The price used in the model was for alfalfa hay and represented a higher price alternative resource than what ranchers may actually pay. In some regions and seasons the higher price for this substitute feed resource made the shadow price of the grazing feeds higher than what actually may be the case in some regions and seasons.

Livestock production by region is presented in Table 3.15. The actual patterns of livestock production was described quite well by these results from the base year simulation of the linear programming model. The two rather significant exceptions to this were the high beef backgrounder levels and low dairy backgrounder levels in Utah. The model solution indicated that fed beef, turkeys, hogs, dairy backgrounders, eggs, and milk were not as profitable to the livestock economy as produced in Utah as they were when produced in other regions. This information corroborates the findings of other studies of comparative advantage in Utah relative to other producing areas (Bailey, 1980 and Perry, 1982).

The pattern of comparative advantage can be seen by reviewing the pattern of reduced cost values which are derived from the optimal solution to the model. The reduced cost value is similar in meaning to that of the shadow price discussed above, but it is associated with activities which have bounds or production constraints represented in the model. The value represents a change in the objective function when a production bound in a region is changed one unit, resulting in an inverse change in production in the region which is in the base solution

TABLE 3.15

Livestock Production Levels Derived From The Base Year Solution To The Economic Model And Actual Production Levels By Region[a]

Region		Sheep	Cow/Calf	Beef Backgrounder	Dairy Calves	Dairy Milk Backgrounder	Fed Beef	Pork	Broiler	Turkey	Egg	Milk
I	Optimal	4,918	27,190	2,448	3,545	10,565	12,585	813	-0-	-0-	63	110,450
	Actual	4,918	27,190	—	3,660	—	14,200	1,311	-0-	-0-	72	114,009
II	Optimal	4,522	44,883	61,018	3,337	530	37,954	552	-0-	-0-	315	103,940
	Actual	4,522	42,519	—	3,374	—	42,857	885	-0-	-0-	360	105,123
III	Optimal	3,658	32,953	2,469	14,792	-0-	51,076	3,162	-0-	8,504	28,914	460,800
	Actual	3,658	31,217	—	15,253	—	57,602	5,091	-0-	6,213	32,799	475,182
IV	Optimal	5,637	41,147	25,012	3,682	3,968	34,542	2,355	-0-	48,360	501	114,690
	Actual	5,637	39,980	—	3,797	—	38,992	3,792	-0-	62,433	576	118,284
V	Optimal	6,151	25,663	-0-	2,355	-0-	760	201	-0-	-0-	27	75,654
	Actual	6,151	25,663	—	2,428	—	853	324	-0-	-0-	30	75,654
VI	Optimal	3,716	30,926	4,246	1,575	-0-	4,106	873	-0-	-0-	93	49,050
	Actual	3,716	30,926	—	1,623	—	4,628	1,404	-0-	-0-	105	50,565
VII	Optimal	534	25,805	23,540	286	-0-	2,773	276	-0-	-0-	66	8,910
	Actual	531	24,443	—	295	—	3,131	444	-0-	-0-	75	9,186
VIII	Optimal	182,820	2,199,123	2,308,956	532,332	762,019	2,991,566	190,740	653,700	303,500	879,971	19,080,008
	Actual	182,820	2,166,500	—	536,074	—	3,239,937	230,295	678,099	104,643	898,149	
IX	Optimal	421,780	16,444,128	21,501,190	888,395	673,216	21,409,297	11,942,383	1,081,500	903,200	899,100	25,167,000
	Actual	421,780	16,444,128	—	959,030	—	19,399,627	12,514,335	1,197,642	1,134,484	990,342	
X	Optimal	75,293	7,318,500	2,261,437	2,870,593	2,870,593	4,963,279	10,451,000	13,784,489	1,694,452	3,958,399	78,431,504
	Actual	75,293	7,318,500	—	2,791,478	—	6,469,777	9,836,154	13,600,986	1,348,335	3,838,341	

[a] one unit represents 1000 lbs. of Liveweight Sheep, Fed Beef, Pork, Broilers, and Turkey; 1000 dozen Eggs; 1000 lbs. of Milk; numbers of Beef Calves, Dairy Calves and Backgrounders.

or a solution which is not at a production constraint value. It tells us the activity or activities which would be the next most profitable activities to come into a base solution. It represented, in the model here constructed, the amount a given region would have to change its revenue received for a particular activity to be equally profitable with the same activity being produced in the region which was shown to be in the base solution of the model. By reviewing these costs, one can see which regions produced certain activities with comparative advantage, i.e., with a cost advantage, a price advantage, or both. These reduced cost values are given in Table 3.16 for the major "finished" livestock products such as fed beef, pork, broilers, turkeys, eggs, and milk.

TABLE 3.16

Reduced Costs Of Livestock Production
Derived From The Base Year Solution

Region	Fed Beef	Pork	Broiler	Turkey	Egg	Milk
I	75.34	66.67	---	---	41.10	23.33
II	86.00	82.00	---	---	43.76	32.07
III	61.44	64.59	---	8.54	40.70	20.44
IV	82.76	77.60	---	2.86	44.15	28.94
V	64.68	69.85	---	---	41.53	24.28
VI	73.00	82.97	---	---	54.05	29.92
VII	73.45	88.29	---	---	57.97	25.66
VIII	68.30	16.40	20.24	58.63	-0-	8.07
IX	-0-	-0-	30.18	19.37	46.28	4.69
X	11.69	8.11	-0-	-0-	-0-	-0-

[a] units are in 1979 dollars per livestock product.

If we look at the milk activity in the table, it shows that Region X had the comparative advantage in producing milk, i.e., the reduced cost element was zero. Regions VIII and IX were not far behind. The value of 20.44 in Region III of Utah, the major milk producing region of Utah, suggested that revenue to milk product producers in this region would have to increase $20.44 per livestock unit (in this case 1000 lbs), in order for it to be equally profitable with the milk product activity in Region X. It is somewhat surprising to find the rather significant discrepancies in comparative advantage between Region III and the Midwest and Eastern Regions. There are some possible explanations. Revenues for dairy calves were not easily obtainable. As a result, revenues for beef calves were used. This results in an overestimate of the value of dairy calves in the dairy industry. Since the Western Regions produce more milk per cow than do the regions in the Midwest and East, they consequently produce fewer calves per thousand pounds of milk (since calf production is tied to milk production in the model). Hence profitability of milk production in these regions could have been overestimated relative to the Western Regions such as Utah and areas in California or even Washington.

Turkey production in Utah was shown to be close to being equally competitive with Region X. The turkey activity in Utah is able to purchase and transport feed in from the Midwest at a relatively low cost, given the distance between these regions, and the producing regions in Utah are relatively free of disease. Notice that two regions, Regions VIII and X, were equally competitive in producing eggs. Sheep, cow/calf, and backgrounder activities were in the base solution for all regions and therefore, a reduced cost value was not computed and not included in Table 3.16.

Another important description of the Utah agricultural economy is the pattern of imports, since many feeds are imported to support the livestock industry. Table 3.17 shows the import levels derived from the trade activities of the base year simulation for the imports into the Utah regions. Barley and corn were the major feeds imported from outside Utah (from Regions VIII and IX), and Regions I and III were the major importing regions in the State., since the bulk of the feeding and milk production is located in these regions. Over 77 percent of the grain corn consumed by livestock in Region I was imported and some 85 percent of the grain corn consumed in Region III was imported, all of which comes in from Region IX. All of the sorghum product feeds were imported to support mainly the turkey and egg industries of the State.

TABLE 3.17

Utah Feed Imports Derived From The Base Year Simulation

		Utah Importing Region						
Exporting Region	Commodity	I	II	III	IV	V	VI	VII
VIII	Barley	350		470				
	Hay	304						
IX	Barley			210			106	85
	Corn	29,460	778	121,955	25,541	10,583	3,946	
	Sorghum	113		60,198	47,502			

An orchard and vegetable crop industry exists mainly in Region III. Actual 1979 production of all these crops combined into a speciality crop category (which was used in the model) was 182,120 tons at a weighted price of $173.93 per ton of produce. The base year optimal solution showed only 180,142 tons were optimally demanded and the shadow price was $170.23 per ton. Alfalfa seed is a significant crop in Regions I, II and III and some 2,380 tons of seed were produced in the base year at a value of $2,080 per ton. The base year simulation derived a demand for alfalfa seed of 2,402 tons and a shadow price at $2,086 per ton.

3.6.2 1934 Drought Simulation

Information from Chapter 2 on the hydrology of the reservoir systems studied, combined with information on water availability by hydrologic sub-basin unit was used to develop drought condition changes in the model for altering water availability. These changes were allocated to the climatological regions used as the regional delineation for the study. Precipitation changes for the climatological regions were obtained from the historical record of the State Climatologist. Precipitation records for the drought years are given in Chapter 1. Then the range condition changes were calculated using equation (3.4) and the estimated parameters given in Table 1.5. Equations (3.6) and (3.7) were used to project, respectively, dryland wheat and other dryland crop production changes, given the changes in evapotranspiration and precipitation changes for the drought conditions reflective of the 1931-34 drought period. The price-quantity relationships imposed on the model in the form of elasticities for each of the crops involved as inputs to the livestock sectors were altered as the model derived new production levels for the crop. Reductions in quantities will increase prices, the degree of increase depending on the value of the elasticity. This increases the cost of feeds used in the livestock sectors of each region. Alternate trade routes may be chosen by the model and these, in turn, change the transportation cost structure of the model. Using the above information as alterations of the constraint system and objective function parameters of the model, a new optimal solution was generated by the maximization of returns to fixed factors of production, subject now to the new constraints and parameter values of the model which were reflective of drought conditions.

Table 3.18 lists the changes in surface water availability for the 1934 drought simulation. Ground water availability information for the 1931-34 period is not complete from state engineer's records. Therefore, information on pumping that took place during the 1977 drought was used to set an upper

TABLE 3.18

Changes In Surface Water Availability Under 1934 Drought Conditions As A Percent Of The Base Year By Region

Region	Water Availability (Percent Of Base Year)
I	51
II	56
III	54
IV	40
V	46
VI	46
VII	46

limit on the amount of water which could be used from groundwater sources for each of the climatological divisions (Utah Consortium for Energy Research and Education, 1981). During the 1977 drought there was a considerable increase in reliance on ground water for irrigation in Regions II and III in Utah. However, the use of this period for an upper limit groundwater use may have underestimated the ground water available during a drought such as the 1931-34 extended drought period.

Precipitation changes were imposed in the model, since crop and range forage production levels are functions of both water available for irrigation and precipitation. The precipitation changes as percents of the base year are given in Table 3.19.

TABLE 3.19

Changes In Precipitation Under 1934 Drought Conditions Expressed As Percent Of The Base Year By Region

Region	1934 Precipitation Conditions (Percent of Base Year)
I	79
II	79
III	60
IV	66
V	47
VI	49
VII	62

Range condition changes, which are directly related to forage AUM availability, are given in Table 3.20 by region for the 1934 drought conditions.

TABLE 3.20

Changes In Range Forage Availability Under 1934 Drought Conditions As Expressed As Percents Of The Base Year By Region

Region	Range Forage Availability (Percent of Base Year)
I	70
II	96
III	37
IV	57
V	54
VI	70
VII	62

Using the above information and obtaining a new optimal solution, given the 1934 conditions represented in the model, information was generated on the estimated losses sustained in the various regions delineated in the study, but most particularly for the Utah regions of interest. These estimated losses were calculated from the changes in net profit by sector in comparing the net profit and cost elements of the optimal solutions of the 1934 simulation with those of the base year. These estimated losses are presented in Table 3.21 and are divided between Northern and Southern Utah losses, since the losses generated were generally from different activities and break out based on this north-south delineation. Northern Utah is comprised of Regions I, III, and V, or Northwest, North Central and Northern Mountains climatological regions.

TABLE 3.21

Simulated Losses For 1934 Drought Conditions By Region

Region			Estimated Loss (Millions of 1979 Dollars)
	Northern Utah Regions		
I	Northwest	Crop	7.2
		Livestock	2.5
		TOTAL	9.7
II	North Central	Crop	(1.2)[a]
		Livestock	13.5
		TOTAL	12.3
V	N. Mountains	Crop	5.0
		Livestock	1.8
		TOTAL	6.8
	TOTAL NORTHERN UTAH		28.8
	Southern Utah		
II	Southwest	Crop	1.25
		Livestock	2.1
		TOTAL	3.35
IV	South Central	Crop	2.0
		Livestock	5.25
		TOTAL	7.25
VI	Uinta Basin	Crop	1.1
		Livestock	4.1
		TOTAL	5.2
VII	Southeast	Crop	3.4
		Livestock	0.005
		TOTAL	3.405
	TOTAL SOUTHERN UTAH		15.885
	TOTAL LOSS FOR UTAH		44.655

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[a] Numbers within parentheses are gains and not losses

Southern Utah is made up of Regions II (Southwest), IV (South Central), VI (Uinta Basin), and VII (Southeast).

As seen from Table 3.21, the simulated losses in agriculture as a result of the 1934 extended drought were great. These losses were decreases in returns to fixed inputs in the agricultural sector in Utah. Therefore, the losses came from increased costs as well as decreased revenue in some cases. A loss of $44.655 million is significant, given that total net farm income in the agriculture sector in Utah for the base year was $76.5 million. The greatest cost increases were attributed to the increased feed costs. Liquidation of livestock during the drought conditions also increased the costs. The shifts in costs incurred under 1934 drought conditions relative to the cost position in the base year are given in Table 3.22.

TABLE 3.22

Net Cost Change In Production Of Crops And Livestock By Region (Millions Of 1979 Dollars)

	Cost Item					
Region	Crop Production	Feed Transport	Feed	Nonfeed	Livestock Liquidation	Livestock Transport
I	-3.6	+0.4	+1.9	-0.7	+0.2	+0.1
II	-0.3	-0.097	+3.6	-1.9	+0.2	-0.2
III	-0.3	-0.6	+13.7	-0.2	+0.2	+0.1
IV	-0.8	+0.1	+5.4	-1.8	+0.3	+0.5
V	-2.6	+0.5	-0.1	-0.6	+1.2	-0.1
VI	-0.3	+0.9	+2.3	-0.9	+1.3	0
VII	-1.5	+0.28	+0.2	-1.6	+0.9	+0.1
Rest of U.S.	+148.5	+4.6	+7.4	-41.0	+13.0	+16.0

Net cost changes for each of the regions in Utah and for the other three regions of the U. S. combined are listed by cost item as delineated in the economic model. Under the drought conditions, feed production was shifted primarily into Regions VIII and IX, and to some degree into Region X. Particularly barley, wheat, and hay were shifted to these regions. Corn production was generally reduced in all regions, as was corn silage. As the shortages showed up in the market place, prices were increased, hence, the very large increase in feed costs that were generated in the regions outside of Utah. Crop production costs were increased in these regions also, but they were reduced in all regions in Utah because of the reductions in acreage harvested and the yield reductions. Dryland crop production dropped some 26 percent while acreage in wheat in Utah was only 73 percent of the acreage of the base year. Because of the livestock liquidations that occurred in particularly the Utah regions and in Regions VIII and IX, the nonfeed costs of livestock production were reduced. Some of the details of the impacts of the 1934 drought conditions are given in some discussion and tables presented below.

Feed production as derived from the simulation of the 1934 drought condition impacts is given in Table 3.23. The production of particularly hay and corn silage were reduced considerably in the Utah regions. Hay production in Region V, the Northern Mountains region, was only a little over 40 percent of that actually produced in that same region during the base year. Hay production was also reduced in Regions VIII, IX, and X. Corn silage production in Region IX and X actually increased, since feeding was shifted to these regions under the drought conditions. Recall that no water availability effects are assumed to take place in the region east of the Mississippi River, so considerable shifting of livestock activity

TABLE 3.23

Feed Production Derived From The Simulation Of The 1934 Drought Conditions

								Private Pasture		Private Range	
Region	Corn	Oats	Barley	Wheat	Sorghum	Hay	Corn S.	Cattle	Sheep	Cattle	Sheep
I	-0-	1,361	40,304	4,002	---	79,243	8,650	29,715	4,432	74,270	25,398
II	2,421	1,261	52,952	1,751	---	160,972	11,874	79,520	41,767	104,928	15,881
III	21,800	2,032	56,060	22,784	---	157,461	34,118			21,528	15,463
IV	-0-	-0-	37,677	291	---	139,554	9.339	-0-	-0-	21,808	16,489
V	-0-	-0-	9,471	203	---	38,956	-0-	38,012	799	43,427	47,370
VI	3,270	-0-	5,667	127	---	69,471	8,503	21,769	1,740	31,052	19,455
VII	1,236,112	172,951	663,187	478,200	66,427	7,830,870	2,149,050	11,396,616	1,141,920	8,517,960	1,858,156
IX	63,068,045	3,977,582	898,450	2,293,817	15,218,861	31,247,685	3,346,563	84,183,659	3,034,065	122,052,000	5,957,382
X	106,618,446	766,535	641,550	372,418	888,723	20,734,010	31,296,698	-0-	-0-	129,800,000	2,106,811

from other regions to this region occurred. Barley production in the North Central region, Region III, was considerably reduced.

The great impact of the drought conditions would apparently be felt in the grazing activity in livestock production. Table 3.23 shows very significant reductions in AUM available from private pasture and private range sources in the Utah regions, and this activity was increased in the non-Utah regions, particularly for sheep grazing in Region VIII, the Western U.S. region. This reflects the comparative advantage position that other regions have in producing livestock over that of most areas in Utah. Bailey's (1980) analysis has shown that Utah competes relatively well with Nevada and some parts of the Southwest in range livestock production but would not compete cost-wise with Idaho, Oregon and California grazing activities.

It is interesting to review what happened to the shadow prices for these feeds. These shadow prices were all increased significantly as shown in Table 3.24. They were even increased for those feeds which maintained production levels near the base year production levels, such as wheat and sorghum. Wheat used for feed and food purposes changed very little during the drought as Commodity Credit Corporation stocks were called out into the market. However, prices were now higher for wheat used as a feed grain, while wheat was maintained for food uses. All corn storage was also called, but corn production in Region IX was significantly reduced.

The allocations of grazing and non-grazing feed to the cow/calf and sheep industries by region under the 1934 drought conditions are given in Tables 3.25 and 3.26. Again, reductions

TABLE 3.24

Shadow Prices For The Non-Grazing Feeds As Derived From The Economic Model Simulation Of 1934 Drought Condition

Region	Corn	Oats	Barley	Wheat	Sorghum	Hay	Corn S.
I	198.25	171.42	187.95	198.47		72.16	31.71
II	206.64	178.68	200.62	206.88		70.55	33.91
III	196.69	170.07	189.50	196.92		73.04	29.23
IV	205.00	177.27	196.41	205.25		75.36	36.08
V	199.24	172.27	191.32	199.47		76.54	___
VI	206.49	178.54	194.90	206.73		77.75	35.04
VII	209.72	179.34	192.39	207.65		84.29	43.83
VIII	205.81	177.56	181.28	205.59	203.08	70.38	32.23
IX	166.10	145.89	173.44	168.78	161.34	68.88	33.50
X	174.77	155.34	208.69	179.61	181.76	63.78	24.57

in feed available were apparent. There was also a shift in the grazing feed use pattern in most regions in Utah and in Region VIII. More grazing by cow/calf and sheep operations was shifted to the Bureau of Land Management lands for winter grazing. Hay would have to be fed for an extended time relative to the base year feeding period.

TABLE 3.25

Allocation Of Feed To The Cow/Calf Activity By Season And Region Under The 1934 Drought Conditions As Derived By The Economic Model

Cow/Calf

Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protien
I	D	—	16,465	902	-0-	—	-0-	56,043	1,674	-0-	-0-
	A	454	4,532	709	7,217	—	-0-	13,644	418	-0-	-0-
	M	426	4,933	1,502	14,434	—	12,984	11,975	418	-0-	-0-
	J	5,811	14,504	3,978	52,619	—	16,732	43,242	1,674	-0-	-0-
	O	1,042	1,229	-0-	-0-	5,053	-0-	9,015	418	-0-	-0-
	N	141	3,926	-0-	-0-	5,053	-0-	6,596	418	-0-	-0-
II	D	—	51,086	3,555	-0-		-0-	71,137	2,544	-0-	-0-
	A	-0-	12,198	2,368	10,493		9,859	5,232	636	-0-	-0-
	M	2,176	15,029	-0-	20,486		20,486	1,796	636	-0-	-0-
	J	46,532	26,129	17,760	73,449		49,175	33,464	2,544	-0-	-0-
	O	4,578	5,538	-0-	-0-	5,158	-0-	7,432	636	-0-	-0-
	N	831	11,316	-0-	-0-	5,158	-0-	10,095	636	-0-	-0-
III	D	—	271	97	-0-		-0-	56,043	2,036	-0-	-0-
	A	-0-	74	97	-0-		-0-	13,644	507	-0-	-0-
	M	-0-	106	193	4,316		11,035	11,975	620	-0-	-0-
	J	16,467	357	578	17,266		33,106	43,242	2,384	-0-	-0-
	O	800	32	-0-	-0-	2,670	-0-	9,015	507	-0-	-0-
	N	-0-	65	-0-	-0-	2,671	-0-	6,596	507	-0-	-0-
IV	D	—	18,245	-0-	-0-		-0-	66,382	2,322	-0-	-0-
	A	217	4,968	1,069	-0-		-0-	13,965	580	-0-	-0-
	M	1,068	6,169	-0-	-0-		-0-	18,216	580	-0-	-0-
	J	78,374	15,706	8,398	21,808		-0-	13,647	2,322	-0-	-0-
	O	4,987	2,442	-0-	-0-	4,294	-0-	7,626	580	-0-	-0-
	N	14	4,778	-0-	-0-	4,294	-0-	4,432	580	-0-	-0-
V	D	—	514	117	-0-		-0-	9,038	-0-	-0-	-0-
	A	-0-	249	234	4,343		-0-	6,216	-0-	-0-	-0-
	M	-0-	1,524	468	8,698		9,476	3,326	-0-	-0-	-0-
	J	29,786	6,749	-0-	30,386		28,534	18,401	-0-	-0-	-0-
	O	96	684	1,522	-0-	2,357	-0-	4,118	-0-	-0-	-0-
	N	-0-	269	-0-	-0-	2,357	-0-	4,493	-0-	-0-	-0-
VI	D	—	8,114	550	-0-		-0-	43,700	2,362	-0-	-0-
	A	-0-	2,439	550	-0-		-0-	10,419	454	-0-	-0-
	M	195	2,861	1,099	6,210		20,972	3,513	614	-0-	-0-
	J	22,422	8,156	3,297	24,842		796	35,547	1,814	-0-	-0-
	O	1,356	1,671	-0-	-0-	5,207	-0-	5,431	454	-0-	-0-
	N	-0-	2,363	-0-	-0-	5,207	-0-	708	454	-0-	-0-
VII	D	—	41,038	2,070	-0-		-0-	21,922	1,344	-0-	-0-
	A	—	11,644	1,725	-0-		-0-	4,330	336	-0-	-0-
	M	-0-	12,127	-0-	5,584		-0-	5,369	336	-0-	-0-
	J	25,574	11,563	13,453	22,347		-0-	18,644	1,867	-0-	-0-
	O	3,499	3,434	-0-	-0-	3,755	-0-	2,818	336	-0-	-0-
	N	-0-	9,120	-0-	-0-	3,755	-0-	-0-	-0-	-0-	-0-
VIII	D	—	402,294	-0-	918,027		-0-	3,215,325	136,900	-0-	-0-
	A	—	241,024	-0-	612,018		438,042	439,346	34,232	-0-	-0-
	M	64,642	353,425	-0-	1,224,036		876,084	266,823	34,232	-0-	-0-
	J	1,598,755	1,106,213	-0-	2,992,880		8,453,400	-0-	165,455	-0-	-0-
	O	95,980	155,136	-0-	2,643,442	240,020	432,382	-0-	34,232	-0-	-0-
	N	-0-	199,874	-0-	127,557	240,020	1,196,709	887,500	34,232	-0-	-0-

TABLE 3.25

Continued

Cow/Calf											
Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protein
IX	D	—	535,935	-0-	18,912,600		-0-	21,495,034	983,100	-0-	-0-
	A	—	144,235	-0-	12,608,400		4,149,600	1,000,009	312,700	-0-	-0-
	M	148,709	292,725	-0-	16,629,989		8,299,200	-0-	-0-	-0-	-0-
	J	2,151,899	1,117,039	-0-	26,088,886		70,654,586	-0-	868,143	-0-	-0-
	O	121,083	206,862	-0-	23,824,070	-0-	1,080,274	-0-	312,700	-0-	-0-
	N	-0-	186,430	-0-	23,998,054	-0-	-0-	-0-	312,700	-0-	-0-
X	D	6,890	-0-	-0-	20,970,000	—	-0-	5,130,787	670,000	-0-	-0-
	A	1,723	-0-	-0-	12,671,490	—	-0-		168,400	-0-	-0-
	M	10,635	-0-	-0-	13,803,180	—	-0-		168,400	-0-	-0-
	J	37,895	-0-	-0-	55,280,952	—	-0-		670,000	-0-	-0-
	O	10,635	-0-	-0-	14,728,783	-0-	-0-		168,400	-0-	-0-
	N	1,722	-0-	-0-	12,339,593	-0-	-0-		168,400	-0-	-0-

TABLE 3.26

Allocation Of Feed To The Sheep Activity By Season And Region Under The 1934 Drought Conditions As Derived By The Economic Model

		Sheep									
Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protein
I	D	—	30,662	-0-	-0-	—	-0-	8,013	531	-0-	-0-
	A	—	6,965	-0-	2,540	—	-0-	3,087	132	-0-	-0-
	M	54	1,174	-0-	5,079	—	4,432	648	132	-0-	-0-
	J	1,679	-0-	-0-	17,779	—	-0-	11,492	875	-0-	-0-
	O	8	259	-0-	-0-	3,086	-0-	550	132	-0-	-0-
	N	-0-	3,711	-0-	-0-	3,086	-0-	189	132	-0-	-0-
II	D	—	29,466	-0-	-0-		-0-	1,934	616	-0-	-0-
	A	-0-	6,807	-0-	800		4,657	948	154	-0-	-0-
	M	-0-	2,303	-0-	-0-		8,097	-0-	154	-0-	-0-
	J	9,816	1,746	-0-	15,082		29,014	-0-	616	-0-	-0-
	O	-0-	2,388	-0-	-0-	1,062	-0-	274	154	-0-	-0-
	N	-0-	4,840	-0-	-0-	1,062	-0-	266	154	-0-	-0-
III	D	—	499	-0-	-0-		-0-	8,237	436	-0-	-0-
	A	-0-	111	-0-	-0-		-0-	2,950	109	-0-	-0-
	M	-0-	25	-0-	3,092		1,040	1,504	109	-0-	-0-
	J	7,555	31	-0-	12,371		3,120	8,138	651	-0-	-0-
	O	539	7	-0-	-0-	964	-0-	868	109	-0-	-0-
	N	18	61	-0-	-0-	964	-0-	310	109	-0-	-0-
IV	D	—	5,870	-0-	-0-		-0-	6,904	685	-0-	-0-
	A	-0-	2,052	1,220	-0-		-0-	1,507	171	-0-	-0-
	M	-0-	735	-0-	-0-		-0-	4,288	171	-0-	-0-
	J	35,125	1,040	-0-	16,489		-0-	-0-	1,006	-0-	-0-
	O	134	763	-0-	-0-	3,190	-0-	426	171	-0-	-0-
	N	-0-	1,463	-0-	-0-	3,190	-0-	235	171	-0-	-0-
V	D	—	1,072	-0-	-0-		-0-	4,612	-0-	-0-	-0-
	A	-0-	484	-0-	616		-0-	2,081	-0-	-0-	-0-
	M	-0-	335	-0-	9,474		799	906	-0-	-0-	-0-

TABLE 3.26

Continued

Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protein
	J	29,786	627	-0-	36,600		-0-	-0-	-0-	-0-	-0-
	O	96	126	-0-	679	-0-	-0-	1,523	-0-	-0-	-0-
	N	-0-	232	-0-	-0-	-0-	-0-	1,498	-0-	-0-	-0-
VI	D	—	22,386	-0-	-0-		-0-	1,988	535	-0-	-0-
	A	—	5,726	-0-	-0-		-0-	1,116	134	-0-	-0-
	M	-0-	159	-0-	3,891		1,740	980	134	-0-	-0-
	J	7,798	18	-0-	15,564		-0-	797	535	-0-	-0-
	O	-0-	3	-0-	-0-	335	-0-	1,103	134	-0-	-0-
	N	—	1,794	-0-	-0-	335	-0-	424	134	-0-	-0-
VII	D	—	7,286	-0-	-0-	—	-0-	283	76	-0-	-0-
	A	—	1,610	-0-	-0-	—	-0-	159	19	-0-	-0-
	M	-0-	510	-0-	334	—	-0-	133	19	-0-	-0-
	J	11,388	33	-0-	1,002	—	-0-	-0-	76	-0-	-0-
	O	45	99	-0-	329	-0-	-0-	9	19	-0-	-0-
	N	-0-	866	-0-	-0-	-0-	-0-	46	19	-0-	-0-
VIII	D	—	89,388	-0-	222,392		27,420	401,519	22,155	-0-	-0-
	A	—	22,049	-0-	148,261		54,841	113,398	5,539	-0-	-0-
	M	4,757	30,123	-0-	296,523		1,059,659	47,446	5,539	-0-	-0-
	J	214,857	88,255	-0-	1,044,415	—	-0-	-0-	33,921	-0-	-0-
	O	12,464	14,758	-0-	146,064	41,131	-0-	-0-	5,539	-0-	-0-
	N	-0-	14,773	-0-	-0-	41,131	160,026	-0-	5,539	-0-	-0-
IX	D	—	124,499	-0-	868,407		-0-	826,127	59,654	-0-	-0-
	A	—	27,716	-0-	578,938		144,737	157,212	14,921	-0-	-0-
	M	10,213	45,441	-0-	878,042		289,466	-0-	-0-	-0-	-0-
	J	235,949	147,953	-0-	2,725,182		2,563,153	-0-	-0-	-0-	-0-
	O	12,084	30,701	-0-	434,373	-0-	36,710	-0-	-0-	-0-	-0-
	N	-0-	28,701	-0-	472,439	-0-	-0-	-0-	-0-	-0-	8,115
X	D	361	-0-	-0-	443,711	—	-0-	59,216	9,151	-0-	-0-
	A	90	-0-	-0-	219,194	—	-0-	-0-	2,288	-0-	-0-
	M	540	-0-	-0-	222,180	—	-0-	-0-	-0-	-0-	-0-
	J	1,983	-0-	-0-	1,030,849	—	-0-	-0-	-0-	-0-	-0-
	O	541	-0-	-0-	93,027	-0-	-0-	-0-	-0-	-0-	-0-
	N	90	-0-	-0-	97,850	-0-	-0-	-0-	2,288	-0-	-0-

The derived shadow prices for the BLM and private pasture which were converted to cow/calf and sheep production are given in Table 3.27. In general, the shadow prices for these grazing feeds increased most during months where there was formerly an abundant supply of forage, i.e., in the spring and summer months. With some exceptions, the shadow prices derived for the BLM forage were equal to or exceeded those of the private pasture. So the drought impacted the main forage used for weight gain activity, and the forage which is valued the most was that which is generally used for brood animal maintenance. Livestock operations in general appeared to go into a holding operation, attempting to maintain what herd that can be held for expectations of better weather and economic conditions.

Livestock production under the drought conditions as simulated by the economic model is given in Table 3.28. The most noticeable change seen in livestock production was the near total pull-out from beef backgrounding activities in Utah. Only in Region II, the Southwest Utah region, was the beef backgrounding activity profitable at all, and even in this region the level of production was little more than a third that of the base year. Dairy backgrounding was also hurt by the lack of feed. The cow/calf, and particularly, the small fed beef production activities of the State were maintained during the drought conditions representative of the 1934 drought severity. There were some liquidations in Region II, IV, V, VI and VII in the cow/calf activity, but Regions I and III were able to maintain their numbers. The small pork, egg and turkey enterprises in Utah were maintained during the drought conditions, as was the dairy industry, even though feed costs increased substantially.

TABLE 3.27

Shadow Prices For Selected Grazing Feeds Under Drought Conditions And Their Percentage Change From The Base Year

		Bureau of Land Management		Private Pasture	
Region	Season	Cattle	Sheep	Cattle	Sheep
I	D	28.82	28.33	28.82	28.33
	A	30.49	28.79	29.82	28.79
	M	27.21	27.92	27.22	26.75
	J	25.68	25.25	25.68	25.25
	O	24.12	23.72	28.43	23.71
	N	15.31	27.33	17.69	27.49
II	D	27.23	25.96	26.45	25.95
	A	26.90	24.34	26.91	24.69
	M	24.84	22.87	24.85	22.88
	J	25.10	23.91	25.11	23.92
	O	21.75	21.38	21.74	21.38
	N	12.21	19.57	30.97	20.52
III	D	28.82	28.33	28.83	28.33
	A	29.28	28.79	29.29	28.79
	M	27.23	26.77	27.23	26.77
	J	26.00	25.55	26.00	25.55
	O	24.12	23.72	27.65	27.21
	N	13.40	28.05	17.70	32.46
IV	D	28.91	28.02	28.49	28.01
	A	28.96	28.42	28.96	28.42
	M	26.89	26.44	28.20	26.44
	J	27.15	25.97	30.11	25.97
	O	23.79	23.40	32.20	23.40
	N	14.79	13.65	17.20	37.46
V	D	32.19	29.41	32.19	29.41
	A	32.65	31.40	32.65	31.59
	M	30.59	30.08	30.59	30.07
	J	26.64	25.60	26.63	25.60
	O	27.50	27.03	28.73	27.03
	N	15.25	29.50	20.30	29.50
VI	D	31.76	26.16	31.76	25.44
	A	32.23	24.90	32.22	26.32
	N	30.16	29.65	30.16	29.65
	J	29.18	28.68	29.17	28.68
	O	27.07	26.60	31.07	26.60
	N	20.41	31.28	23.04	35.59
VII	D	31.34	24.90	31.34	52.02
	A	31.80	22.18	321.80	24.08
	M	29.74	29.24	29.74	29.24
	J	30.00	24.58	32.44	44.31
	O	26.64	26.08	26.64	26.12
	N	12.21	23.08	15.60	24.59
VIII	D	28.71	28.23	28.11	28.23
	A	34.13	33.55	34.13	33.55
	M	32.27	31.73	32.27	31.73
	J	7.01	7.01	7.01	7.01
	O	8.31	8.31	9.01	8.31
	N	10.77	9.76	12.62	12.62

TABLE 3.27

Continued

		Bureau of Land Management		Private Pasture	
Region	Season	Cattle	Sheep	Cattle	Sheep
IX	D	36.47	35.86	36.48	35.86
	A	33.54	32.97	33.55	32.97
	M	8.21	8.21	8.21	8.21
	J	8.81	8.81	8.81	8.81
	O	9.58	9.58	10.07	10.07
	N	12.07	12.07	14.10	13.69
X	D			22.01	21.64
	A			11.27	6.81
	M			11.37	5.11
	J			11.82	4.81
	O			10.37	5.11
	N			11.27	6.81

TABLE 3.28

Livestock Production Levels Under The 1934 Drought Conditions And The Changes From The Base Year

	Livestock Production										
Region	Sheep	Cow/Calf	Beef Backgrounder	Dairy Calf	Dairy Backgrounder	Fed Beef	Pork	Broiler	Turkey	Egg	Milk
I	3,987	27,190		3,545	-0-	12,585	813	-0-	-0-	63	110,450
II	3,666	42,519	27,628	3,337	-0-	37,954	552	-0-	-0-	315	103,940
III	2,964	32,953		14,791	-0-	51,076	3,162	-0-	8,504	28,914	460,800
IV	4,569	38,980		3,681	-0-	34,542	2,355	-0-	48,360	501	114,690
V	4,983	22,986		2,354	-0-	760	201	-0-	-0-	27	73,350
VI	3,032	27,700		1,575	-0-	4,106	873	-0-	-0-	93	49,050
VII	432	21,894		286	-0-	2,773	276	-0-	-0-	66	8,910
VIII	167,700	2,166,500	2,353,093	532,366	561,936	2,991,566	190,740	653,700	303,500	879,971	19,081,226
IX	406,700	16,240,000	15,762,447	888,395	902,800	21,166,447	11,942,383	1,081,500	903,200	899,100	25,167,000
X	76,800	7,318,500	7,796,053	2,870,548	2,856,143	4,963,279	10,451,000	13,784,489	1,694,452	3,958,399	78,430,278

Sheep were reduced in all the regions in Utah and also in Regions VIII and IX. It appears that for the range livestock industry, sheep production was the least viable enterprise during economic stress, such as that induced by drought conditions. To some degree the price situation in the sheep market is more volatile than that in the feeder cattler market. Some caution should be exercised in interpreting these results, however, since the complete pricing of wool by livestock unit as a joint product was not done in the current modeling exercise.

The change in competitive position of all the regions in producing selected livestock products can be seen in Table 3.29 which lists the reduced costs for fed beef, pork, broilers, turkey, eggs and milk. Recall the reduced cost element derived which would have to be generated in each region in order to be equally competitive with the region in the base solution of the optimal solution of the model, i.e., the region with a zero reduced cost element. There was a very small, but upward, change in the reduced cost elements of milk and fed beef in the Utah regions in general. There was a significant deterioration of the competitive position of egg producers in the Utah regions, as seen by the greater reduced cost elements in this column.

Liquidations of livestock units under the drought conditions are given in Table 3.30. There were liquidations of cow/calf units in the Northern Mountains, Uinta Basin, and Southeast regions in Utah. Sheep livestock units were liquidated in every region in Utah and also in the Western U.S. and Midwest regions. For example, some 931 units of sheep were culled in Region I. This means that 9310 ewes were liquidated in that region. Generally, sheep were shown to be liquidated rather heavily in the sheep-producing regions of the Western U.S.

TABLE 3.29

Reduced Cost Derived From The 1934 Drought Simulation

Region	Fed Beef	Pork	Broiler	Turkey	Eggs	Milk
I	76.55	66.67			45.58	23.49
II	91.89	68.45			53.61	31.46
III	61.40	64.58		6.08	45.18	20.39
IV	87.10	77.60		5.32	54.20	29.14
V	64.68	69.85			49.36	23.03
VI	74.25	82.97			63.46	30.01
VII	75.79	86.94			66.91	24.75
VIII	68.89	12.84	22.54	61.09	-0-	-0-
IX	-0-	-0-	32.48	21.82	50.77	7.31
X	13.11	3.00	-0-	-0-	-0-	-0-

TABLE 3.30

Liquidations Of Livestock Units Under The 1934 Drought Simulation

Region	Cow/Calf[a]	Sheep[b]
I		931
II		856
III		694
IV		1,068
V	2,677	1,168
VI	3,226	684
VII	2,549	94
VIII		5,180
IX		2,800
X		

[a] number of brood cows.

[b] multiply the element in the sheep column by 10 for for number of ewes.

Imports into the Utah regions were increased significantly under the drought conditions imposed on the economic model. The Utah feed import picture is described in Table 3.31.

TABLE 3.31

Utah Feed Imports By Region Derived From The 1934 Drought Simulation

Exporting Region	Commodity	I	II	III	IV	V	VI	VII
VIII	Barley	610		2,205		345		
	Hay	33,907		51,426		24,407	36,344	11,851
IX	Barley			460			256	
	Corn	28,282		78,070	24,549	1,546	3,724	
	Sorghum	113	75	60,198	48,400	48	167	

Hay imports from Region VIII to several of the Utah regions were both introduced and increased compared to the base year import situation. Corn imports from Region IX were reduced somewhat relative to the base year corn imports. Barley imports were increased somewhat. The sorghum product imports remained the same, since the turkey and egg enterprises are relatively unaffected by the drought conditions. The increased hay imports also point out that most livestock operations, particularly the range livestock activities, were attempting just to maintain herds rather than to provide weight gains and profitability in Utah under these severe drought conditions. However, liquidations were necessary, as discussed previously.

It is interesting to note the water use in each of the Utah regions when the drought conditions were imposed on the model. Water utilization under the drought conditions, as imposed in terms of the percent used to that available for use, is given in Table 3.32. Utilization under the drought conditions was compared to that in the base year. The greatest increases in utilization under the drought conditions relative to the base year utilization came in Region III, IV and V. It should be recognized, however, that there were small amounts of groundwater used for supplemental irrigation purposes in Regions V, VI and VII, but supplemental water from any source was used under the drought conditions. It was only in Regions II and III that some water available for irrigation would be left unused at the end of the production year. Groundwater was generally used as a supplemental water source for irrigation in most regions except in the major irrigated areas of the

TABLE 3.32

Water Utilization Relative To Water Availability Under 1934 Drought And Base Year Conditions

	Surface Water Use (percent)		Ground Water Use (percent)	
Region	Drought	Base	Drought	Base
I	100	59	100	92
II	88	42	86	86
III	86	37	82	82
IV	100	60	100	48
V	100	52	100	53
VI	100	77	100	68
VII	100	78	100	87

Southwest Utah region (Region II) and to some extent in some areas of the South Central Utah region (Region IV). However, given current water delivery technology (1979 base), much of the supplemental water sources were called on as sources of supply to maintain irrigated agriculture during the drought conditions representative of 1934 drought severity.

Recall that the shadow price of a resource, as derived from the economic model and explained earlier, represents the value of an additional unit of that resource as demanded by users of the resource. Since water was nonbinding as a resource in the base year solution of the model, no shadow prices were derived. However, in the 1934 drought solution of the model some shadow prices were derived since water in most regions is a limiting resource. These shadow prices ranged from a low of $13.76 per acre/foot of surface water in Region V to a high of $36.00 per acre/foot for groundwater in Region I. The shadow price for groundwater in Region IV, the main ground water-using region, was $28.08 per acre/foot. These values were representative of the worth of water which was used in the irrigated agriculture sector of Utah under the water shortage conditions imposed by a drought of the 1934 intensity.

3.6.3 1977 Drought Simulation

Again, information from Chapters 1.0 and 2.0 was used to derive input to the economic model in order to impose conditions representative of the 1977 drought on the model. Various constraint systems of the model were adjusted, particularly water availability, precipitation, price-quantity relationships, and range forage availability. A new solution was then generated by solving for a new optimum to the linear programming-spatial equilibrium model described previously.

Changes in surface water availability representative of the 1977 drought conditions are given in Table 3.33. Precipitation conditions imposed in the model are given in Table 3.34.

TABLE 3.33

Changes In Surface Water Availability Under 1977 Conditions As A Percent Of The Base Year By Region

Region	Surface Water Availability (Percent of Base Year)
I	62
II	85
III	60
IV	51
V	63
VI	59
VII	27

TABLE 3.34

Changes In Precipitation Under 1977 Drought Conditions Expressed As A Percent Of The Base Year By Region

Region	1977 Precipitation Conditions (Percent of Base Year)
I	117
II	124
III	97
IV	90
V	77
VI	120
VII	111

With the exceptions of Regions III, IV and V, precipitation conditions were more favorable than those in the base year and certainly far better conditions than represented for the 1934 precipitation situation. For Region VII (Southeast Utah), the precipitation situation for 1977 was worse than the 1934 situation.

The changes in range forage availability for the 1977 conditions were estimated, using the range condition equation described earlier in this chapter and in Chapter 1. These changes are presented in Table 3.35 below.

TABLE 3.35

Changes In Range Forage Availability Under 1977 Drought Conditions As Expressed As A Percent Of The Base Year By Region

Region	Range Forage Availability (Percent of Base Year)
I	77
II	64
III	97
IV	63
V	63
VI	57
VII	47
VIII	92
IX	120

Changes in crop production in the non-Utah regions were imposed by using crop indices derived from Koo et al. (1978). The worst conditions in the recent ten years were used to represent the 1977 conditions, and the appropriate regional average index was used to adjust crop production in these regions to reflect production levels during the 1977 drought. A new solution to the model was obtained using this information, and the losses as derived by the model are listed for each region in Table 3.36. The greatest losses generated existed in Regions I and VII and these were the regions with the least amount of surface water available for irrigation purposes. The result is that crop losses showed up as being the greatest of all the regions under the 1977 drought conditions. Net revenues to the livestock sector in Region I actually increased under the drought conditions, mainly because the higher price feed for livestock was mostly accountable in Region III, where Region I sheep and cattle were fed at some point during the production season. The increased revenues rather than losses that were derived in Region III were mainly due to increased prices for specialty crops and the increases in feed prices which occurred as a result in the cutback in production. Supply was shifted back, given inelastic demand curves for the commodities; therefore, net revenue was increased. The same occured in the Uinta Basin (Region VI).

The net cost changes which were derived from the optimal solution to the economic model are listed in Table 3.37. Crop production costs generally declined in the Utah regions but were increased in the other regions, since crop production was shifted mainly to the Midwest and the Eastern U.S. regions. Feed transport costs were up in all regions because of increased imports and some different trade routes which came into the optimal solution which were slightly more expensive than those used in the base year solution. Feed costs in general were increased under the 1977 drought conditions except in Regions I and VIII. The lower feed costs in Region I were the cause of the net revenue in that region being increased under the drought conditions. The decreased grazing caused the nonfeed costs to decline in the Utah regions. There were liquidations

TABLE 3.36

Simulated Losses For The 1977 Drought Conditions By Region

Region		Estimated Loss (Millions of 1979 Dollars)
Northern Utah Regions		
Northwest I	Crop	3.9
	Livestock	(0.4)
	TOTAL	3.5
North Central III	Crop	(2.3)
	Livestock	2.5
	TOTAL	0.2
Northern Mountains	Crop	0.6
	Livestock	2.0
	TOTAL	2.6
NORTHERN UTAH TOTAL		6.3
Southern Utah Regions		
Southwest II	Crop	0.7
	Livestock	1.3
	TOTAL	2.0
South Central IV	Crop	0.8
	Livestock	0.4
	TOTAL	1.2
Uinta Basin VI	Crop	(1.2)
	Livestock	2.8
	TOTAL	1.5
Southeast VII	Crop	3.5
	Livestock	0.3
	TOTAL	3.8
SOUTHERN UTAH TOTAL		8.6
TOTAL UTAH LOSS		14.9

of sheep in all regions except Region X, which explained the increased liquidation costs.

TABLE 3.37

Net Cost Changes In Production Of Crops And Livestock By Region (Millions Of 1979 Dollars)

Region	Crop Production	Feed Transport	Feed	Non-Feed	Livestock Liquidation	Livestock Transport
I	-3.6	+0.4	+1.9	-0.7	+0.2	+0.1
II	-0.3	-0.097	+3.6	-1.9	+0.2	-0.2
III	-0.3	-0.6	+13.7	-0.2	+0.2	+0.1
IV	-0.8	+0.1	+5.4	-1.8	+0.3	+0.5
V	-2.6	+0.5	-0.1	-0.6	+1.2	-0.1
VI	-0.3	+0.9	+2.3	-0.9	+1.2	0.0
VII	-1.5	+0.28	+0.2	-1.6	+0.9	+0.1
Rest of U.S.	+148.5	+4.6	+7.33	-41.0	+13.0	+16.0

The feeds produced under the drought conditions of 1977 are given in Table 3.38. Corn production was reduced somewhat in the corn producing regions. Oats were reduced in all regions except Regions I and III. The reduction in Utah represented a decision on the part of farm producers to avoid the establishment of alfalfa during the early spring by using oats as a nurse crop. The outlook for irrigation water was bleak during the winter and spring of 1977, so new alfalfa establishment was curtailed, as is represented by the model solution. Barley production was cut drastically in Regions VII, VIII, IX and X. Wheat production held its own during these conditions, but the dry bean crop, not shown in the table, was a disaster in Southeast Utah (Region VII), where wheat and dry beans substitute for one another in the crop rotations. During

TABLE 3.38

Feed Production Under The 1977 Drought Conditions

	Corn	Oats	Barley	Wheat	Sorghum	Hay	Corn S.	Cattle	Sheep	Cattle	Sheep
I	8,681	1,361	40,766	4,006	---	128,161	16,802	64,661	16,679	81,697	27,938
II	2,421	-0-	53,221	1,751	---	319,170	10,698	53,012	27,845	69,952	10,588
III	21,800	2,032	63,116	22,712	---	287,250	12,326	115,720	10,907	56,580	40,538
IV	-0-	-0-	37,789	291	---	202,619	10,059	83,475	17,984	24,104	18,225
V	-0-	-0-	9,564	203	---	91,607	-0-	50,681	1,066	57,902	63,160
VI	3,270	-0-	5,704	127	---	104,950	17,699	104,638	8,242	25,285	15,842
VII	-0-	-0-	297	803	---	37,372	4,505	-0-	-0-	21,174	1,263
VIII	1,353,826	189,409	1,135,454	478,200	95,172	10,299,946	3,703,681	7,808,441	650,601	11,873,520	2,590,157
IX	97,259,835	4,794,553	1,642,267	2,089,000	18,648,326	37,440,956	14,261,507	47,329,402	1,747,462	174,360,000	7,487,069
X	76,481,050	766,535	396,352	426,300	888,723	32,278,992	31,296,699	-0-	-0-	129,800,000	2,053,365

the 1977 season, some 5000 acres were planted to beans in Utah and only approximately 1000 acres were harvested, with a yield of less than 200 pounds per acre compared to late year averages of around 350 to 390 pounds per acre. The model approximated this loss fairly close. Yet the yields of dry beans were simulated somewhat higher than what actually occurred.

Hay production simulated by the model was mixed, and that is what actually happened during the 1977 season. Precipitation actually increased as the production season progressed, and some record yields of forage occurred in some areas of Utah and the Western U.S. because of the increased moisture and the timing of the rains which came during the summer. Corn silage was reduced quite significantly in all regions except in Region X. The rather large reductions were experienced in the range and pasture forage feeds. In a sense, the 1977 drought could be classified as a range and pasture drought, since a large part of the adverse impact was on the production of range and pasture forage. Irrigated crops fared quite well because of the summer precipitation. Therefore, a large part of the impacts of this drought was felt in the livestock enterprises, particularly the range livestock activities, but the impacts were shown to be considerably less adverse than those experienced by the 1934 drought conditions.

The shadow prices for the non-grazing feeds, as derived from the economic model, are shown in Table 3.39. Most all shadow prices showed increases over the base year shadow values, but not nearly the increases that were derived for the 1934 drought conditions, since quantitity reductions were much less under the 1977 drought conditions relative to the more severe imposition of the earlier drought. The shadow prices for hay were mixed, since in some regions hay production under the 1977 drought conditions relative to the more severe imposition of the earlier drought. The shadow prices for hay are mixed since in some regions hay production under the 1977 drought conditions exceeded that of the base year. Hay shadow prices as shown in Table 3.39 ranged from $51.00 per ton to $63.15, whereas the shadow prices for the base year ranged from $52.17 per ton to $121.53 per ton. However, under the 1934 drought imposition, the shadow values for hay ranged from $63.78 to $84.29 per ton.

TABLE 3.39

Shadow Prices For The Non-Grazing Feeds Under The 1977 Drought Conditions

Region	Corn	Oats	Barley	Wheat	Sorghum	Hay	Corn S.
I	127.75	119.54	132.24	157.87	---	51.02	25.15
II	138.14	129.93	135.97	138.30	---	57.33	26.69
III	126.19	113.00		157.87	---	51.889	27.70
IV	134.51	125.91	132.58	151.69	---	54.38	29.39
V	128.74	117.09	132.51	128.89	---	53.71	---
VI	135.93	125.82	134.32	137.27	---	60.84	32.44
VII	140.74	121.69	138.39	140.90	---	63.15	39.72
VIII	136.92	126.21	115.57	145.67	140.36	36.89	27.62
IX	112.10	96.93	114.34	160.95	108.89	41.80	26.18
X	87.92	90.16	140.62	103.55	96.25	37.71	25.79

The feed utilization situations, as derived from the economic model for the cow/calf and sheep activities by season, are respectively shown in Tables 3.40 and 3.41. As was the case for the 1934 drought conditions, hay was mainly fed to beef cattle compared to the feed pattern in the base year simulation. Private range and private pasture feed were generally reserved for the May and June periods (designated as Seasons M and J, respectively in the table). This indicates that grazing feeds had their greatest value relative to other feeds during the growing season under drought conditions, and could be most profitably used during this season.

The shadow prices for BLM and private pasture forage by season given in Table 3.42 revealed some additional information concerning the use of grazing forage. Under the drought conditions, the value of public grazing for wintering sheep increased relative to public grazing used for cattle. Hay was apparently used for wintering the cattle and maintenance during the drought, whereas the desert winter range was most valuable for maintaining the sheep activity, although under the drought conditions sheep livestock units were liquidated, as is shown in Table 3.43. The BLM grazing value was lower in the region of Utah which had greater winter forage area, such as in Region II. Livestock production levels under the 1977 drought imposition are shown in Table 3.44. The significant change from the base year production levels presented earlier was again the exit of the backgrounding activity in Utah almost in its entirety, with the only exception being a reduced beef backgrounding activity in Region II. Sheep production was reduced in all regions except Region X. There were some reductions in the cow/calf activity, but the remaining livestock activities were maintained at similar levels to those of the base year.

TABLE 3.40

Allocation Of Feed To The Cow/Calf Activity By Season And Region Under The 1977 Drought Simulation

Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protein
I	D	---	-0-	992	-0-	---	-0-	45,920	1,674	-0-	-0-
	A	---	-0-	780	-0-	---	-0-	11,009	418	-0-	-0-
	M	-0-	-0-	1,652	15,877	---	14,282	3,175	418	-0-	-0-
	J	6,392	15,954	4,376	65,820	---	50,379	4,878	1,674	-0-	-0-
	O	-0-	-0-	-0-	-0-	5,559	-0-	6,244	418	-0-	-0-
	N	155	4,848	-0-	-0-	-0-	-0-	10,449	418	-0-	-0-
II	D	---	8,854	-0-	-0-	---	-0-	69,251	2,544	-0-	-0-
	A	---	8,132	1,579	6,995	---	6,573	9,375	636	-0-	-0-
	M	1,451	10,019	-0-	13,990	---	13,658	8,757	636	-0-	-0-
	J	31,021	17,420	14,210	48,967	---	32,782	35,817	2,544	-0-	-0-
	O	588	3,692	-0-	-0-	3,439	-0-	10,121	636	-0-	-0
	N	-0-	4,764	-0-	-0-	-0-	-0-	16,766	636	-0-	-0-
III	D	---	-0-	253	-0-	---	-0-	55,987	2,036	-0-	-0-
	A	---	-0-	253	-0-	---	-0-	13,589	507	-0-	-0-
	M	-0-	-0-	506	11,316	---	28,930	3,004	620	-0-	-0-
	J	43,170	936	1,518	45,264		86,791	4,130	2,384	-0-	-0-
	O	-0-	-0-	-0-	-0-	7,000	-0-	7,474	507	-0-	-0-
	N	---	-0-	-0-	-0-	---	-0-	13,501	507	-0-	-0-
IV	D	---	-0-	-0-	-0-	---	-0-	66,382	2,322	-0-	-0-
	A	240	5,411	1,181	-0-	---	-0-	13,731	580	-0-	-0-
	M	1,181	6,818	-0-	-0-	---	-0-	17,945	580	-0-	-0-
	J	86,624	3,853	4,665	24,104	---	83,475	7,810	2,322	-0-	-0-
	O	5,512	2,700	-0-	-0-	4,746	-0-	7,186	580	-0-	-0-
	N	16	5,281	-0-	-0-	-0-	-0-	15,242	580	-0-	-0-

TABLE 3.40

Continued

egion	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn S.	Barley	Protein
V	D	---	19,506	156	-0-	---	-0-	37,540	-0-	-0-	-0-
	A	499	5,511	312	-0-	---	-0-	8,618	-0-	-0-	-0-
	M	469	7,735	624	11,597	---	12,635	2,132	-0-	-0-	-0-
	J	22,941	8,999	2,030	46,305	---	38,046	11,365	-0-	-0-	-0-
	O	4,358	2,346	-0-	-0-	3,143	-0-	4,471	-0-	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	10,580	-0-	-0-	-0-
VI	D	---	6,607	447	-0-	---	-0-	49,872	2,362	-0-	-0-
	A	---	1,986	447	-0-	---	-0-	11,983	454	-0-	-0-
	M	158	2,330	895	5,057	---	17,077	7,331	614	-0-	-0-
	J	18,258	6,641	2,886	20,228	---	87,561	15,272	1,814	-0-	-0-
	O	1,104	1,361	-0-	-0-	4,240	-0-	6,977	544	-0-	-0-
	N	---	1,924	-0-	-0-	-0-	-0-	12,514	-0-	-0-	-0-
VII	D	---	76,479	-0-	-0-	---	-0-	13,911	1,344	-0-	-0-
	A	---	8,827	1,308	2,117	---	-0-	5,807	336	-0-	-0-
	M	-0-	9,193	2,615	4,233	---	-0-	7,344	336	-0-	-0-
	J	19,387	22,272	7,583	14,824	---	-0-	27,112		-0-	-0-
	O	2,652	2,603	-0-	-0-	2,846	-0-	4,530	1,867	-0-	-0-
	N	---	6,914	-0-	-0-	2,846	-0-	659	336	-0-	-0-
VIII	D	---	560,773	-0-	1,279,674	---	-0-	3,030,227	136,900	-0-	-0-
	A	---	335,973	-0-	853,116	---	610,604	258,346	34,232	-0-	-0-
	M	90,108	492,654	-0-	1,706,232	---	955,208	-0-	34,232	-0-	-0-
	J	2,228,569	1,541,995	-0-	4,741,737	---	3,918,858	-0-	165,455	-0-	-0-
	O	-0-	216,250	-0-	1,623,337	-0-	-0-	-0-	34,232	-0-	-0-
	N	---	-0-	-0-	-0-	-0-	-0-	893,206	-0-	-0-	-0-
IX	D	---	765,622	-0-	27,018,000	---	-0-	18,634,421	983,100	-0-	-0-
	A	---	206,050	-0-	18,012,000	---	1,306,604	140,797	312,700	-0-	-0-
	M	-0-	418,178	-0-	8,791,636	---	11,128,658	-0-	312,700	-0-	-0-
	J	3,074,141	1,595,770	-0-	68,199,029	---	7,277,406	-0-	983,100	-0-	-0-
	O	-0-	-0-	-0-	19,920,295	-0-	-0-	-0-	312,700	-0-	-0-
	N	---	-0-	-0-	19,920,295	-0-	-0-	-0-	312,700	-0-	-0-
X	D	6,890	-0-	-0-	20,970,000	---	-0-	5,264,188	670,000	-0-	-0-
	A	-0-	-0-	-0-	8,934,773	---	-0-	-0-	168,400	-0-	-0-
	M	-0-	-0-	-0-	8,934,773	---	-0-	-0-	168,400	-0-	-0-
	J	-0-	-0-	-0-	35,769,259	---	-0-	-0-	670,000	-0-	-0-
	O	10,635	-0-	-0-	8,924,138	-0-	-0-	-0-	168,400	-0-	-0-
	N	1,722	-0-	-0-	8,933,015	-0-	-0-	-0-	168,400	-0-	-0-

TABLE 3.41

Allocation Of Feed To The Sheep Activity By Season And Region Under The 1977 Drought Simulation

Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn	S. Barley	Protein
I	D	---	-0-	-0-	-0-	---	-0-	11,110	531	-0-	-0-
	A	---	4,814	-0-	2,794	---	-0-	1,314	132	-0-	-0-
	M	59	985	-0-	5,443	---	4,876	-0-	132	-0-	-0-
	J	20,801	-0-	-0-	19,700	---	11,803	-0-	875	-0-	-0-
	O	9	285	-0-	-0-	3,395	-0-	339	132	-0-	-0-
	N	-0-	1,174	-0-	-0-	3,395	-0-	173	132	-0-	-0-
II	D	---	19,644	-0-	-0-	---	-0-	3,275	616	-0-	-0-
	A	---	4,538	-0-	-0-	---	2,864	1,049	154	-0-	-0-
	M	-0-	1,535	-0-	2,117	---	6,211	187	154	-0-	-0-
	J	14,648	1,164	-0-	8,471	---	18,769	1,863	616	-0-	-0-
	O	-0-	1,592	-0-	-0-	708	-0-	677	154	-0-	-0-
	N	-0-	3,220	-0-	-0-	549	-0-	293	154	-0-	-0-
III	D	---	9,401	-0-	-0-	---	-0-	4,494	436	-0-	-0-
	A	---	787	-0-	4,054	---	76	1,230	109	-0-	-0-
	M	-0-	-0-	-0-	8,107	---	325	-0-	109	-0-	-0-
	J	-0-	-0-	-0-	28,377	---	10,506	-0-	651	-0-	-0-
	O	919	-0-	-0-	-0-	2,528	-0-	-0-	109	-0-	-0-
	N	---	739	-0-	-0-	2,528	-0-	168	109	-0-	-0-
IV	D	---	9,368	-0-	-0-	---	-0-	9,414	685	-0-	-0-
	A	---	2,718	5,966	-0-	---	-0-	1,507	171	-0-	-0-
	M	-0-	813	-0-	3,645	---	4,496	1,413	171	-0-	-0-
	J	30,718	1,149	-0-	14,580	---	13,488	-0-	616	-0-	-0-
	O	153	843	-0-	-0-	3,526	-0-	276	154	-0-	-0-
	N	---	1,623	-0-	-0-	3,526	-0-	219	154	-0-	-0-
V	D	---	27,065	-0-	436	---	-0-	4,612	-0-	-0-	-0-
	A	---	2,499	-0-	5,503	---	-0-	2,081	-0-	-0-	-0-
	M	-0-	753	-0-	12,632	---	1,066	-0-	-0-	-0-	-0-
	J	28,469	836	-0-	37,708	---	-0-	-0-	-0-	-0-	-0-
	O	621	185	-0-	5,138	-0-	-0-	44	-0-	-0-	-0-
	N	47	2,638	-0-	1,745	-0-	-0-	751	-0-	-0-	-0-
VI	D	---	18,268	-0-	-0-	-0-	-0-	1,988	535	-0-	-0-
	A	---	4,668	-0-	438	---	-0-	1,116	134	-0-	-0-
	M	-0-	129	-0-	3,169	---	1,417	1,3656	134	-0-	-0-
	J	22,054	95	-0-	10,997	---	6,825	-0-	535	-0-	-0-
	O	-0-	2	-0-	-0-	273	-0-	1,125	134	-0-	-0-
	N	---	1,709	-0-	937	273	-0-	308	134	-0-	-0-
VII	D	---	2,603	-0-	-0-	---	-0-	283	76	-0-	-0-
	A	---	769	-0-	-0-	---	-0-	159	19	-0-	-0-
	M	-0-	453	-0-	253	---	-0-	181	19	-0-	-0-
	J	5,025	25	-0-	345	---	-0-	-0-	76	-0-	-0-
	O	34	75	-0-	364	-0-	-0-	8	19	-0-	-0-
	N	---	409	-0-	-0-	-0-	-0-	47	19	-0-	-0-

TABLE 3.41

Continued

Region	Season	FS	BLM	State	PR	AFT	PP	Hay	Corn	S. Barley	Protein
VIII	D	---	124,602	-0-	310,001	---	-0-	358,549	22,155	-0-	-0-
	A	---	30,734	-0-	206,667	---	38,222	86,147	5,539	-0-	-0-
	M	6,631	41,990	-0-	413,336	---	59,903	-0-	5,539	-0-	-0-
	J	229,498	123,022	-0-	1,432,690	---	552,476	-0-	33,921	-0-	-0-
	O	17,374	20,572	-0-	119,139	57,333	-0-	-0-	5,539	-0-	-0-
	N	---	20,592	-0-	108,324	57,333	-0-	16,357	5,539	-0-	-0-
IX	D	---	177,856	-0-	1,240,582	---	-0-	692,973	59,654	-0-	-0-
	A	---	39,594	-0-	827,054	---	171,844	62,352	14,921	-0-	-0-
	M	14,590	64,916	-0-	723,686	---	413,522	-0-	14,921	-0-	-0-
	J	337,070	211,361	-0-	3,923,056	---	1,162,098	-0-	75,023	-0-	-0-
	O	17,263	43,854	-0-	364,957	-0-	72,088	-0-	14,921	-0-	-0-
	N	---	41,002	-0-	407,734	-0-	-0-	32,4902	14,921	-0-	-0-
X	D	361	-0-	-0-	443,711	---	-0-	-0-	2,288	-0-	-0-
	A	90	-0-	-0-	214,824	---	-0-	54,911	9,151	-0-	-0-
	M	540	-0-	-0-	214,374	---	-0-	-0-	2,288	-0-	-0-
	J	1,983	-0-	-0-	996,840	---	-0-	-0-	9,151	-0-	-0-
	O	541	-0-	-0-	87,755	-0-	-0-	-0-	2,288	-0-	-0-
	N	90	-0-	-0-	95,860	-0-	-0-	-0-	2,288	-0-	-0-

TABLE 3.42

Shadow Prices For Selected Grazing Feeds And Percentage Change Of The 1977 Values From The Base Year

		BLM		Private Pasture	
Region	Season	Cattle	Sheep	Cattle	Sheep
I	D	19.59	19.26	19.59	19.25
	A	20.47	18.70	20.02	18.86
	M	18.10	15.51	18.10	15.51
	J	18.16	16.14	18.16	16.14
	O	15.21	14.96	20.72	14.96
	N	7.62	17.90	9.73	20.01
II	D	20.35	20.01	20.35	10.01
	A	20.79	19.16	20.79	19.37
	M	18.87	18.55	18.87	18.54
	J	19.10	18.79	19.10	18.79
	O	15.98	15.71	15.98	15.71
	N	7.62	17.90	20.35	20.01
III	D	21.44	20.14	20.49	20.14
	A	20.42	14.67	20.72	19.73
	M	19.00	14.67	19.00	14.67
	J	18.47	15.82	14.47	14.67
	O	16.11	15.51	20.00	16.21
	N	6.58	15.62	10.17	19.03
IV	D	22.38	20.26	20.60	20.26
	A	21.03	20.61	21.03	20.62
	M	19.11	18.79	20.14	18.79
	J	19.35	16.74	19.35	16.74
	O	16.23	15.96	21.29	18.68
	N	8.02	15.46	26.17	16.17
V	D	22.20	20.86	22.20	20.86
	A	22.63	20.86	22.63	21.24
	M	20.71	17.67	20.71	17.67
	J	19.12	15.06	17.83	16.79
	O	17.83	16.49	17.83	16.79
	N	5.46	20.06	11.02	20.60
VI	D	23.96	21.24	23.96	20.90
	A	24.39	21.68	26.26	22.16
	M	22.47	22.09	22.47	22.09
	J	21.65	18.31	21.65	18.31
	O	19.59	19.26	19.59	20.08
	N	8.26	22.68	11.89	22.86
VII	D	25.50	17.14	25.49	16.00
	A	25.93	14.37	25.93	16.70
	M	24.00	23.60	24.00	23.60
	J	22.47	14.21	24.35	34.91
	O	21.12	15.71	21.12	36.96
	N	9.92	14.48	13.53	16.55
VIII	D	20.63	20.29	20.63	20.29
	A	25.68	25.24	25.68	25.24
	M	17.14	6.91	17.14	6.91
	J	6.52	6.52	6.52	6.52
	O	7.82	7.82	8.39	7.82
	N	10.28	10.28	11.74	11.46

TABLE 3.42

Continued

		BLM		Private Pasture	
Region	Season	Cattle	Sheep	Cattle	Sheep
IX	D	17.06	16.78	17.07	16.78
	A	14.48	10.42	14.48	10.10
	M	7.17	4.84	7.17	4.84
	J	7.77	5.44	7.77	5.44
	O	8.54	6.21	8.88	6.55
	N	10.03	8.70	12.43	9.60
X	D			15.37	15.12
	A			8.23	6.81
	M			7.75	5.11
	J			7.94	4.81
	O			7.07	5.11
	N			8.22	6.81

TABLE 3.43

Livestock Unit Liquidations Derived From The 1977 Drought Simulation

Region	Cow/Calf[a]	Sheep[b]
I		931
II		856
III		649
IV		1,068
V		1,168
VI		684
VII		99
VIII		
IX		1,934
X		221

[a] numbers of brood cows.
[b] multiply the element in the sheep column by 10 to obtain number of ewes.

TABLE 3.44

Livestock Production Levels Under The 1977 Drought Simulation

Region	Sheep	Cow/Calf	Beef Backgrounder	Dairy Calf	Dairy Backgrounder	Fed Beef	Pork	Broiler	Turkey	Egg	Milk
I	3,987	27,190	-0-	3,545	-0-	12,585	813	-0-	-0-	63	110,450
II	3,666	42,519	5,495	3,337	-0-	37,954	552	-0-	-0-	315	103,940
III	2,964	32,953	-0-	14,791	-0-	51,076	3,162	-0-	4,812	28,914	460,800
IV	4,569	38,980	-0-	3,681	-0-	34,542	2,355	-0-	48,360	501	114,690
V	4,983	25,663	-0-	2,345	-0-	760	201	-0-	-0-	27	73,350
VI	3,032	30,926	-0-	1,574	-0-	4,106	873	-0-	-0-	93	49,050
VII	432	24,443	-0-	286	-0-	2,2773	276	-0-	-0-	66	8,910
VIII	181,920	2,166,500	532,332	561,902	2,991,566	272,970	653,700	303,500	834,000	19,080,000	
IX	427,083	16,407,321	16,407,321	888,395	888,395	19,157,218	11,860,153	1,081,500	903,200	899,100	25,167,000
X	75,293	7,393,823	7,393,823	2,870,593	2,870,593	7,215,358	10,451,000	13,784,489	1,698,144	4,004,370	78,431,504

The reduced cost elements derived from the model presented in Table 3.45 reveal some rather important changes in comparative production advantage among the regions under the 1977 drought scenario relative to the base year and the 1934 drought. In fed beef production, the comparative advantage was switched to Region X, whereas under the base year simulation Region IX had the advantage, and that situation remained intact under the 1934 drought simulation. In milk production, Region X was the most competitive region in the base year, but Regions VIII and X were shown to be equally competitive under the 1934 drought conditions. Because of the extent of the 1977 drought

TABLE 3.45

Reduced Costs For Selected Livestock Product Activities From The 1977 Drought Simulation By Region

Region	Fed Beef	Pork	Broiler	Turkey	Egg	Milk
I	85.32	37.54			77.94	28.82
II	103.33	52.86			68.66	37.53
III	70.17	35.47		12.15	77.37	25.84
IV	95.87	48.47		22.82	69.04	34.42
V	73.44	40.73			73.87	29.68
VI	82.93	53.74			79.68	35.90
VII	89.68	61.53			85.34	31.65
VIII	80.42	13.46	37.60	77.13	1.61	12.47
IX	30.85	-0-	56.98	47.96	98.46	16.75
X	-0-	61	-0-	-0-	-0-	-0-

impact on reducing hay production in Region VIII, as shown earlier in Table 3.38, that region's competitive position in milk production was significantly deteriorated. All reduced costs for livestock product activities for regions not in the base solution of the model were significantly increased, indicating the deterioration which takes places as the drought imposes itself on the cost and production structure of the agricultural economy. The import situation given in Table 3.46 indicates some of the reasons for the deterioration in competitive position, at least for the regions in Utah. Hay imports were increased significantly, as were corn imports relative to base-year imports. Barley imports were increased some under the 1977 drought conditions but not nearly as much as was the case for the 1934 drought conditions.

TABLE 3.46

Imports Into Utah As Derived From The 1977 Drought Simulation

Exporting Region	Commodity	I	II	III	IV	V	VI	VII	VIII	IX	X
VIII	Barley	461		2,13							
	Hay	5,015		4,130		18,697	15,333	27,123			
IX											
X	Barley			572				211			
	Corn	32,146	5,615	127,521	69,480	10,583	7,233	4,588			
	Sorghum	113	70	60,198	48,230	32					

Water utilization under the 1977 drought conditions compared to use under the more severe 1934 drought and the base year use is given in Table 3.47.

TABLE 3.47

Water Utilization Relative To Water Availability Under Drought And Base Year Conditions

	Surface Water Use (Percent)			Ground Water Use (Percent)		
Region	1977 Drought	1934 Drought	Base Year	1977 Drought	1939 Drought	Base Year
I	73	100	59	93	100	92
II	34	88	42	86	86	86
III	64	86	37	82	82	82
IV	100	100	60	89	100	48
V	100	100	52	53	100	53
VI	100	100	77	68	100	68
VII	100	100	78	87	100	87

3.7 Summary Of Drought Impacts

The economic portion of the study of drought in Utah attempted to describe drought by simulating, via an economic model, the economic impacts of drought as it affects agriculture production and the many economic interactions which exist in that sector. The economic framework used to estimate the drought impacts was a spatial equilibrium system imbedded within a linear programming model. This framework was used in order to capture the many economic interactions which take place within the agricultural economy of Utah, and to capture the interregional trade impacts of changes in production as drought imposes itself on other regions as well as Utah.

A ten-region model was specified for the U. S. with seven regions delineated within Utah to represent the agricultural activities of the climatological regions of the State. One of those regions was further disaggregated to reflect actual production differentiation within a broader climatological region. Three other regions represented the Western U.S., Midwest, and Eastern U.S. production areas. Various crop and livestock production systems, yield-water availability relationships, feed-to-livestock conversion systems, and precipitation and water availability limits by region, and interregional trade routes and costs were included within the constraint system of the model. The objective function of the model was to maximize returns to fixed factors of production, subject to the constraint system. Solving the model for an optimum solution for given prices and costs, as well as given resource constraints, determined the optimal levels of regional production, interregional feed and livestock trade flows, and resource (water, feeds, etc.) utilization. Initially, the model was used to simulate base year production and resource use conditions. The year 1979 was chosen as the base year because of its currency in representing water delivery and storage technology in Utah and because it was desired to estimate the impacts of drought on current crop and livestock patterns and distribution. This year was also chosen because it is the most recent year for which all data were available. The resource limitations, reflective of a drought of the 1931-34 intensity, were then imposed on the model to estimate the production, trade, and resource utilization impacts of a drought of that magnitude. Then the drought of lesser intensity and possible effect was introduced into the model. This was the 1977 drought situation. These two simulations provide information on the economic definition of drought and the impacts of two drought types on Utah specifically, and other regions of the U.S. in general.

Simulated losses in net revenue to agriculture attributable to the 1934 drought conditions amounted to some $44.7 million in 1979 dollars. This was the loss derived from comparing net revenues generated by the model under the 1934 drought simulation with those generated from the base-year simulation. The losses under the drought conditions were caused mainly because of extensive reductions in non-grazing and grazing feed availability and the accompanying increases in non-grazing feed costs in all regions west of the Mississippi River in the U.S. Major Utah feed import changes were also derived from the 1934 drought simulation, as increased hay and barley imports and the costs of these imports were shown to occur in all Utah regions. Cow/calf and sheep grazing was reduced considerably and forced the liquidation of some 8,452 brood cows and 54,950 ewes and increased livestock liquidation costs by approximately $4.3 million. The competitive position of all livestock product activities in all regions in Utah was eroded by the increased cost imposed by the drought conditions. Feeding was primarily for maintaining herds to avoid liquidation.

Simulated losses in net revenue of $14.9 million under the imposed 1977 drought conditions were one-third those derived for the 1934 simulation. Increased feed and liquidation costs were again the leading causes of the erosion of net revenues due to the drought effects of reducing feed production. Imports of hay and barley into Utah regions increased relative to the import position of the base year, but they were still only 46 percent of the import levels derived for the 1934 drought simulation. The competitive position of all livestock enterprises in Utah deteriorated relative to those in other regions of the U.S. under the conditions of both drought types, but certainly more so under severe and more prolonged water shortages because of severe grazing reductions and the non-grazing feed import position facing Utah livestock producers.

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4. METEOROLOGY OF DROUGHT

4.1. Introduction

To determine the potential for drought mitigation by weather modification, a study was performed to investigate the meteorology of drought periods in Utah. The study was limited to the winter months (November through April). Non-drought periods occurring during winter months were also considered for purposes of comparison. The analysis covered a large range of atmospheric processes, from Rossby waves that influence weather over several thousand kilometers to small scale cloud parameters inferred from rawinsonde data. The seven climatological divisions in Utah that were studied are shown in Figure 4.1, along with selected cities and generalized land use.

In the following sections, the meteorological analyses will be presented and implications of the results toward wintertime drought mitigation will be discussed.

4.2 Preliminary Work

Prior to beginning the analyses of the meteorology of drought, various preliminary tasks were performed. These included forming the drought and non-drought samples and acquiring the necessary data. The tasks are described in more detail in the following sections.

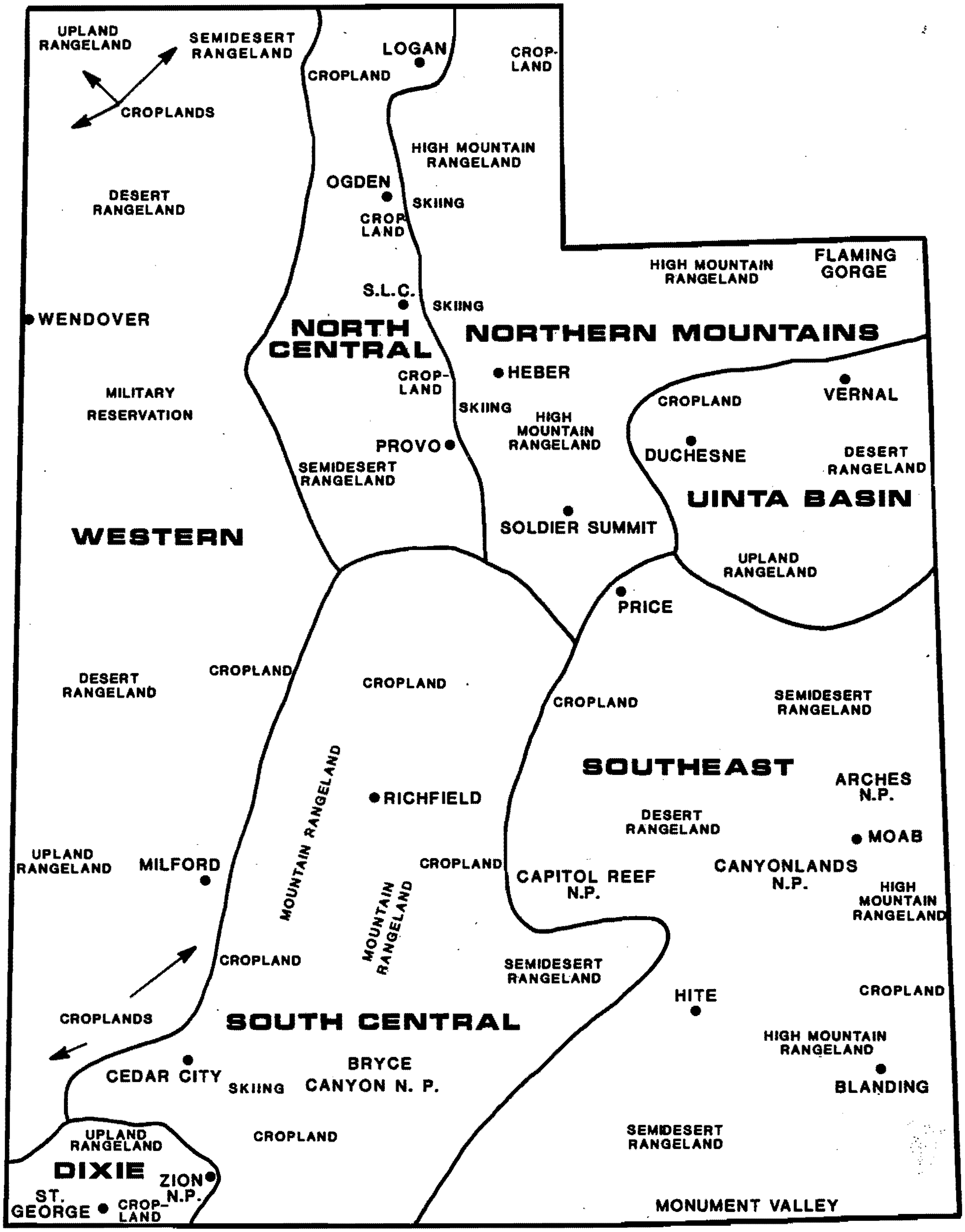


FIGURE 4.1. The Seven Climatological Divisions Of Utah. Scale 1 cm = 25 km

4.2.1 Identification Of Drought And Non-Drought Periods For 1931 to 1980

As was discussed in Section 1, the Palmer Index has been used to objectively identify drought periods. To perform the meteorological analyses, a monthly Palmer Index of less than -2 was used to form the drought sample. Indices below -2 include all moderate or worse droughts. The comparative non-drought sample was formed by selecting nine winter (November-April) periods when statewide Palmer Indices exceeded zero. The non-drought sample was selected to contain roughly the same number of months as the drought sample. There were other months of statewide non-drought that simply were not included in the sample.

Table 4.1 shows the drought and selected non-drought periods for the seven climatological divisions of Utah. By way of example, during the 1931 to 1980 period, the Western Division had 85 months of moderate or worse drought. In contrast Dixie had only 34 months of drought. The average number of drought months for all seven divisions was 57, which is about 20 percent of all winter months in the 49-year sample. The statewide non-drought periods totaled 48 months. The mean Palmer Index for the various drought months was about -3, a value that separates the moderate and severe drought categories. The corresponding mean index for the non-drought months was about +2, which separates the slightly and moderately wet categories.

4.2.2. Data Acquisition

Much of the data required to perform the analyses were available in-house at NAWC. In-house data included a listing

TABLE 4.1

Occurrence Of Moderate Or Worse Drought In Each Of Utah's Seven Climatological Divisions

X = WESTERN
O = DIXIE
□ = NORTH CENTRAL
Δ = SOUTH CENTRAL
● = NORTHERN MTNS.
■ = UINTA BASIN
▲ = SOUTHEAST
——— = NON-DROUGHT PERIOD

YEAR	NOV	DEC	JAN	FEB	MAR	APR
1931 – 32	●	●	●	●	●	●
– 33	●	●	●	●	●	□●
– 34	□●■	□●■	□Δ●■	□Δ●■	XO□Δ●■▲	XO□Δ●■▲
– 35	Δ●■	Δ●■	Δ●■	Δ●■	Δ●■	Δ●
1935 – 36	Δ●■	Δ●■	Δ■	Δ■	■	Δ■
– 37	———	———	———	———	———	———
– 38						
– 39						
– 40		□●	●	●	●	●
1940 – 41						
– 42						
– 43						■▲
– 44	———	———	———	———	———	———
– 45						
1945 – 46				■	■	■
– 47					▲	▲
– 48						
– 49		———	———	———	———	———
– 50						
1950 – 51	XOΔ▲	XOΔ▲	XOΔ■▲	XOΔ■▲	XOΔ■▲	XOΔ■▲
– 52	———	———	———	———	———	———
– 53		□	X	XO□	XO□	XO
– 54	XO□	XO□■	XO□■	XO□■	XO□■	X□■
– 55	X□▲	X□▲	X□	X□	XO□	XO□Δ
1955 – 56	X▲	X▲	X▲	XOΔ▲	XOΔ▲	XOΔ▲
– 57	XO□Δ■▲	XO□Δ■▲	X□Δ	X□Δ	X□Δ	X
– 58	X	X	X	X	X	
– 59	X□●	X□●	X□Δ●■▲	X□●	X□Δ●	X□Δ●■▲
– 60	XΔ▲	XΔ	X□Δ	XΔ	XΔ	XΔ
1960 – 61	X□Δ	X□Δ●■	X□Δ●■	X□Δ●■	X□Δ●■	X□Δ●■
– 62	———	———	———	———	———	———
– 63		X□●■	X□Δ●■	X□Δ●■	X□Δ●■	Δ■
– 64	■▲	▲	Δ●■▲	Δ●■▲	Δ●■▲	■▲
– 65			O	O		
1965 – 66	———	———	———	———		
– 67	X□	X□	X	X□	X□	▲
– 68						
– 69			———	———	———	———
– 70						
1970 – 71						
– 72					XOΔ▲	XOΔ□▲
– 73	———	———	———	———	———	———
– 74						
– 75	X●■	XΔ●■	XΔ●■	XΔ■		
1975 – 76						
– 77	XΔ■▲	XO□Δ●■▲	XO□Δ●■▲	XO□Δ●■▲	XO□Δ●■▲	XO□Δ●■▲
– 78	XΔ●■▲	XOΔ●■▲	XO	XO	X	
– 79	———	———	———	———	———	
– 80						

of North American weather types for three-day periods from 1921 to 1980, historical daily surface and 500 mb charts, and daily rain gage data for various stations in each climatological division.

Rawinsonde data for selected National Weather Service stations were acquired from the National Climatic Center. Stations and periods of record are shown in Table 4.2. This data set contains all soundings made at each station, from the inception of the rawinsonde program through December, 1979. More recent soundings were not yet available on magnetic tape.

TABLE 4.2

Rawinsonde Data Inventory

Station	Period of Record
Salt Lake City	Aug 1956 to Dec 1979
Ely	Jul 1952 to Dec 1979
Grand Junction	Jan 1948 to Dec 1979
Las Vegas (including Yucca Flats and Desert Rock)	Sep 1956 to Dec 1979

4.3 Analyses

The data were subjected to a variety of comparative drought/non-drought analyses. Included in these analyses were a comparison of North American weather types, an investigation of the characteristics of individual storms, a study of daily precipitation in each of the seven divisions, and an analysis of rawinsonde-inferred cloud and air mass parameters. Results are described in the following sections.

4.3.1 North American Weather Types

In a series of articles in Weatherwise, Elliott (1949) classified weather patterns affecting North America into various generalized three-day weather types. Classification was based on the location and movement of high and low pressure systems and both surface and mid-tropospheric data were used. About 20 types and sub-types were developed.

For this study of Utah drought, 12 North American weather types were used, the excluded types describing weather patterns peculiar to the Eastern United States. The 12 weather types are described in Table 4.3 and shown in Figure 4.2. (Note: the maps in Figure 4.2 were reproduced from Elliott's articles. Two types, EJ and EN, had not yet been developed and therefore do not appear in Figure 4.2). In very broad terms pertaining to Utah weather, the 12 types could be grouped into four more general types which broadly describe the 500 mb pattern over the Western U.S.: Trough (A-AO and D), Ridge (the various B-types), Zonal Flow (the various E-types), and Split Flow (C-F types). Precipitation in Utah tends to occur with the western trough types and with the zonal types when the jet stream is near Utah. The western ridge types generally result in dry weather in Utah. Precipitation from the split-flow type occurs when the southern jet is near the state.

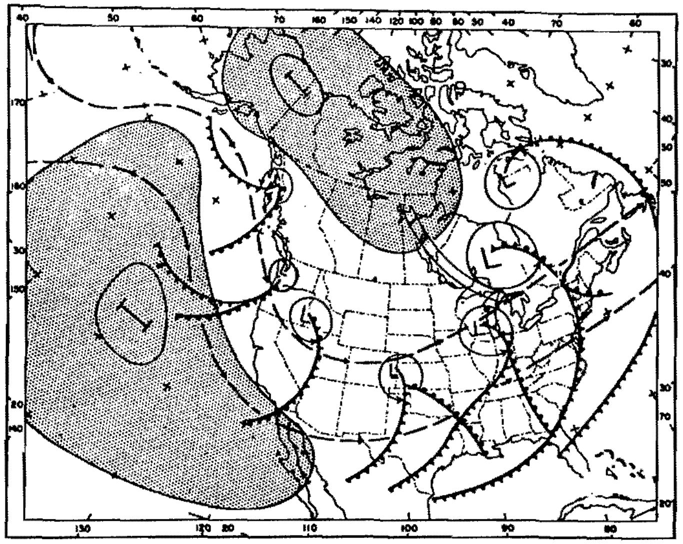
Using the sets of moderate or worse drought months and statewide non-drought months, frequency distributions of three-day weather types have been computed. Results are shown in Table 4.4. Also shown in the table is a statewide drought frequency that was obtained by weighting the frequency in each division. The drought periods were characterized by fewer A-AO, C-F, and D types than the non-drought periods. On the other hand,

TABLE 4.3

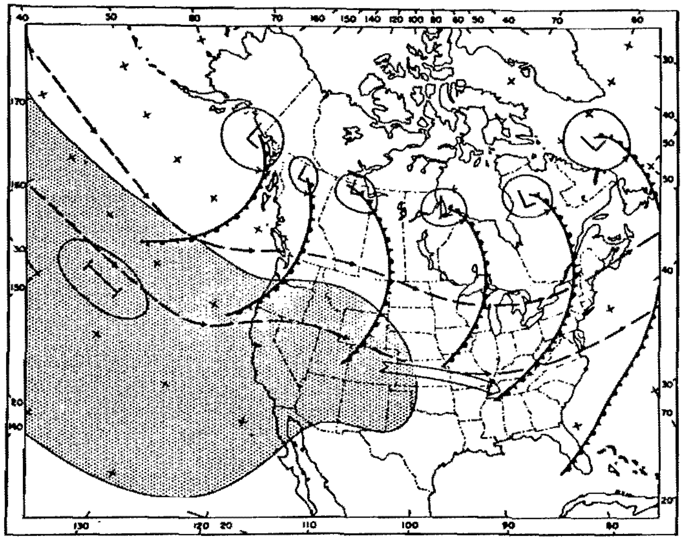
North American Weather Types

Weather Type	Prominent Weather Features	Typical Utah Weather
A-AO	Large trough over Western U.S. Strong Pacific Ridge.	Wet
B-BS	Zonal flow with jet displaced northward. Surface high pressure and weak ridge over Western U.S.	Mostly dry
BNA	Ridge of high pressure over Western U.S. and trough over Eastern U.S. Strong surface high over Great Basin.	Dry
BNB	Similar to BNA but with polar outbreak east of the Rockies.	Dry
BNC	Similar to BNB except ridge occurs along Pacific Coast and trough is displaced westward to the Great Plains. Occasionally the polar outbreak spreads west of the Rockies.	Cold, sometimes wet in north
C-F	Split flow with ridge over Pacific Northwest and trough over Southwestern U.S.	Mostly wet, especially south
D	Strong Pacific ridge. Trough off the Pacific Coast. Jet further north than with A-AO type.	Wet
EH	Zonal flow with jet much further south than normal. Very strong polar high east of Rockies. Infrequent occurrence.	Mostly dry
EJ	Zonal flow with jet from Hawaii to Central California. Infrequent occurrence.	Warm and wet
EL	Zonal flow with jet just north of Utah.	Wet
EM	Zonal flow with jet over Utah. Frequent wave development over Great Basin.	Wet
EN	Zonal flow with jet along Canadian border. Similar to B-BS but with weaker high pressure.	Wet in north

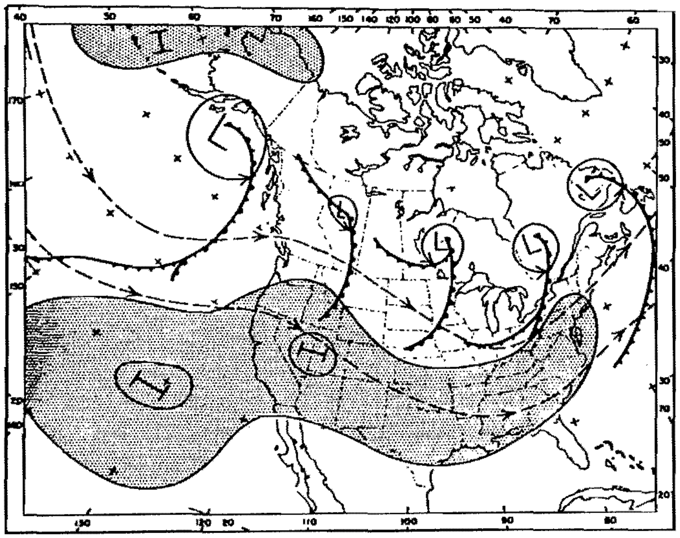
TYPE A OF NORTH AMERICAN WEATHER TYPES



TYPE B OF NORTH AMERICAN WEATHER TYPES



TYPE Bs OF NORTH AMERICAN WEATHER TYPES



TYPE CL OF NORTH AMERICAN WEATHER TYPES

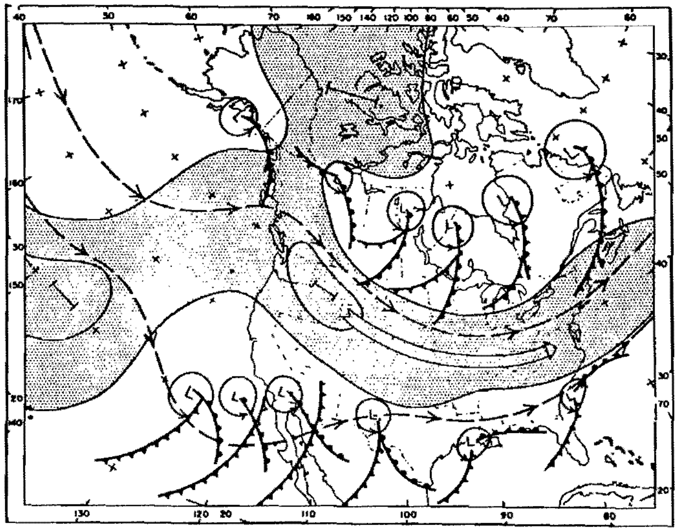
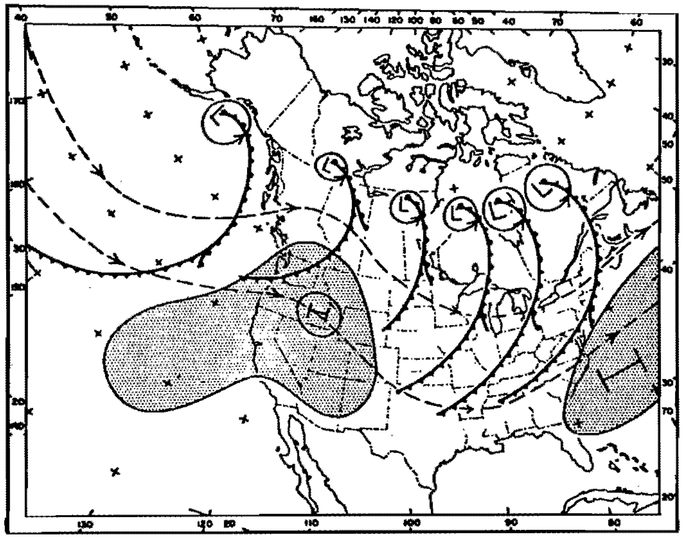
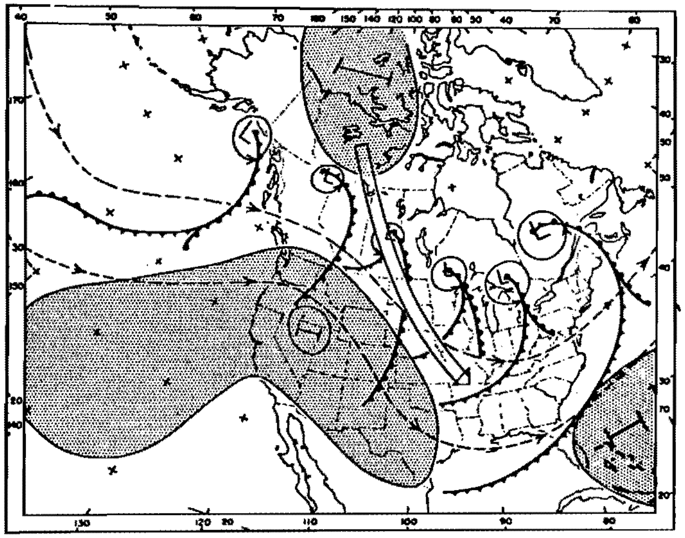


FIGURE 4.2. (a) North American Weather Types. Dashed Lines Show Mid-Tropospheric Jet Stream. Surface High Pressure Areas Are Shaded.

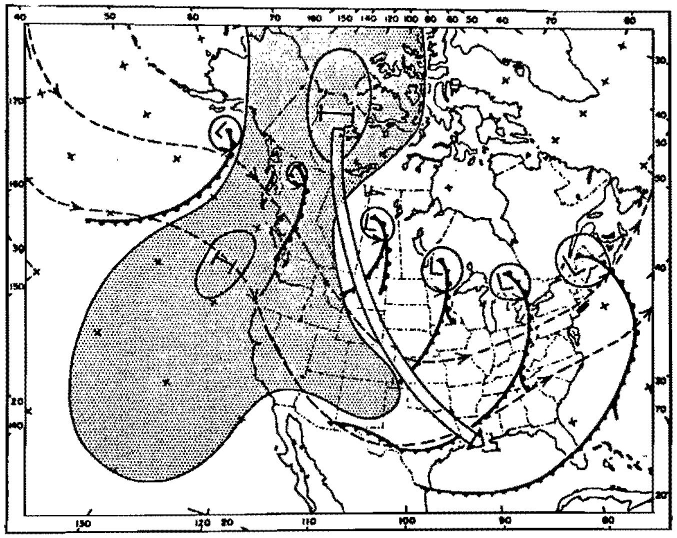
TYPE Bn-a OF NORTH AMERICAN WEATHER TYPES



TYPE Bn-b OF NORTH AMERICAN WEATHER TYPES



TYPE Bn-c OF NORTH AMERICAN WEATHER TYPES



TYPE D OF NORTH AMERICAN WEATHER TYPES

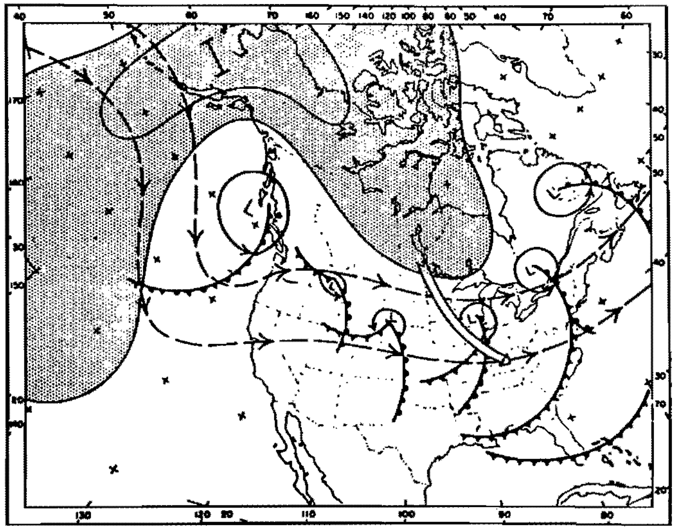
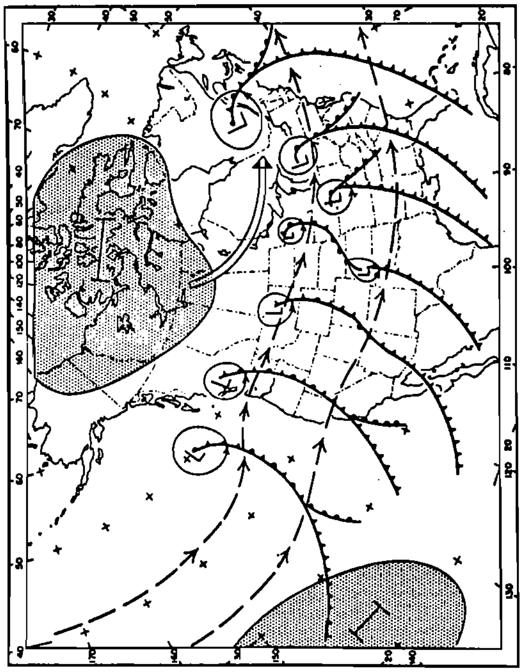
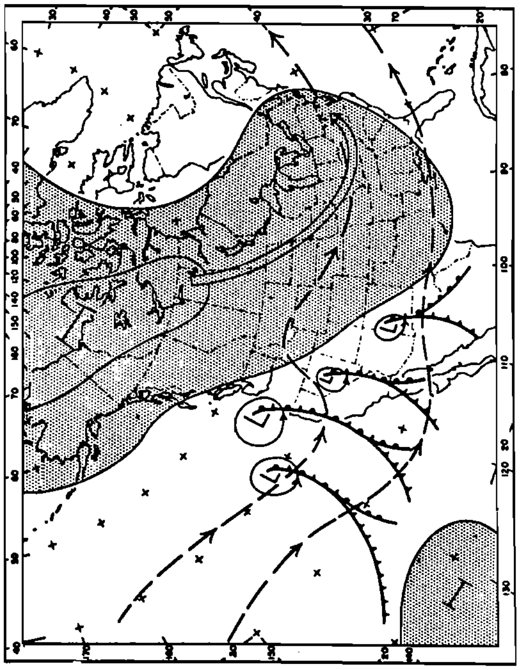


FIGURE 4.2.(b) North American Weather Types. Dashed Lines Show Mid-Tropospheric Jet Stream. Surface High Pressure Areas Are Shaded.



TYPE E_L OF NORTH AMERICAN WEATHER TYPES



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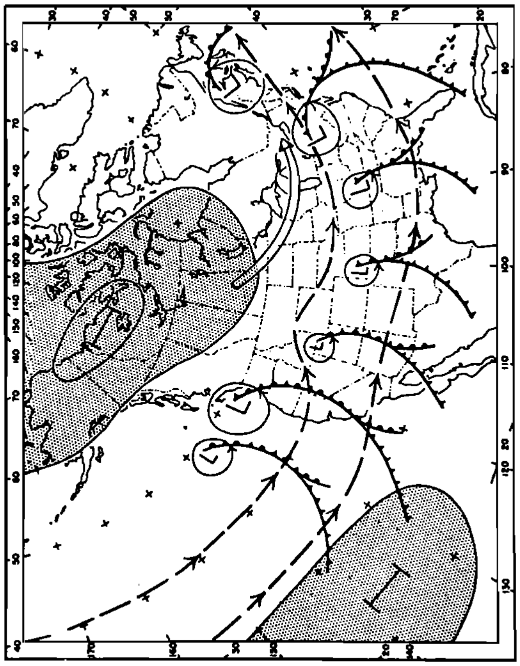

TYPE E_M OF NORTH AMERICAN WEATHER TYPES

FIGURE 4.2.(c) North American Weather Types. Dashed Lines Show Mid-Tropospheric Jet Stream. Surface High Pressure Areas Are Shaded.

TABLE 4.4

Frequency Of Occurrence Of Wintertime 3-Day North American Weather Types For Each Climatological Division

Weather Type	Moderate or Worse Drought							Weighted Statewide Drought Frequency	Statewide Non-Drought Periods
	Western	Dixie	North Central	South Central	North Mtns	Uinta Basin	Southeast		
A-AO	13.3%	14.1%	14.4%	13.7%	12.7%	12.8%	15.3%	13.6%	22.7%
B-BS	20.0	16.8	20.7	18.3	20.3	18.3	17.8	19.1	19.1
BNA	7.3	7.9	7.6	6.7	7.4	8.0	8.7	7.6	7.6
BNB	7.4	7.4	9.1	7.1	8.2	9.5	6.4	7.9	4.8
BNC	11.3	13.8	11.7	10.5	9.0	9.4	11.6	10.8	7.4
C-F	6.8	7.9	7.2	9.7	8.5	8.3	8.2	8.0	9.0
D	4.8	3.8	4.1	3.2	2.4	2.3	3.1	3.4	6.1
EH	0.9	0.3	1.1	1.4	2.4	1.9	0.0	1.2	1.5
EJ	1.4	0.3	0.6	0.6	0.0	0.0	0.9	0.6	0.0+
EL	7.5	8.5	8.3	8.4	10.0	8.9	8.4	8.5	7.6
EM	10.0	7.9	8.3	9.5	10.5	9.1	8.4	9.3	6.5
EN	8.6	10.3	6.9	10.2	7.6	10.8	10.0	9.1	7.6
Missing	0.6	0.9	0.0	0.8	0.8	0.8	1.1	0.7	0
No. of 3-day cases	850	340	540	630	620	640	450		476

the BNB and BNC types were relatively more frequent during drought, as were the E types. Even though the A-AO type was relatively less frequent during drought, it was still the second most frequent of the 12 types. During the non-drought periods, the A-AO type was the most frequent.

Table 4.5 shows the frequency of occurrence of the four general types mentioned above for the weighted drought and statewide non-drought periods. The difference between the drought and non-drought frequencies and the relative difference (the difference divided by the non-drought frequency) are also shown in the table. The western trough weather types were almost half as frequent during the drought periods as during the non-drought periods. On the other hand, the western ridge and zonal flow types occurred more frequently during drought.

TABLE 4.5

Frequency Of Occurrence Of Generalized Weather Types

General Type	Weighted Statewide Drought	Statewide Non-Drought	Difference	Relative Difference
Western Trough (A-AO, D)	17.0%	28.8%	-11.8%	-41%
Western Ridge (B-types)	45.4	38.9	+ 6.5	+17
Zonal Flow (E-types)	28.7	23.3	+ 5.4	+23
Split Flow (C-F types)	8.0	9.0	- 1.0	-11
Missing	0.9	0.0	+ 0.9	---

These results show the importance of the western trough weather types in the seasonal precipitation balance. Their relative absence contributed significantly to the occurrence of drought.

Thus, drought in Utah is not characterized by the predominance of ridges of high pressure. Tables 4.4 and 4.5 showed that western ridge types were also very frequent during the non-drought periods. Instead, Utah drought seems to be characterized by a change in the general circulation that favors the occurrence of zonal flow. In meteorological terms, this type of circulation can be described as low wave number or high index. The relative absence of the western trough types could be explained by the fact that those types tend to occur under high wave number conditions.

4.3.2. A Comparative Analysis Of Individual Storms

Using the Daily Series - Synoptic Weather Maps published by the Environmental Data Service, Department of Commerce, an analysis was performed to determine if individual storms occurring during drought had different characteristics than their non-drought counterparts. This subjective analysis considered such general parameters as frontal locations and central pressures of troughs and closed lows.

Twelve storms occurring with the A-AO weather type were selected from the sample of drought months. Those were compared with 12 non-drought A-AO type storms. A similar comparison was done with 12 drought and 12 non-drought EM-type storms. Figures 4.3 and 4.4 give examples of the weather maps used in the analysis.

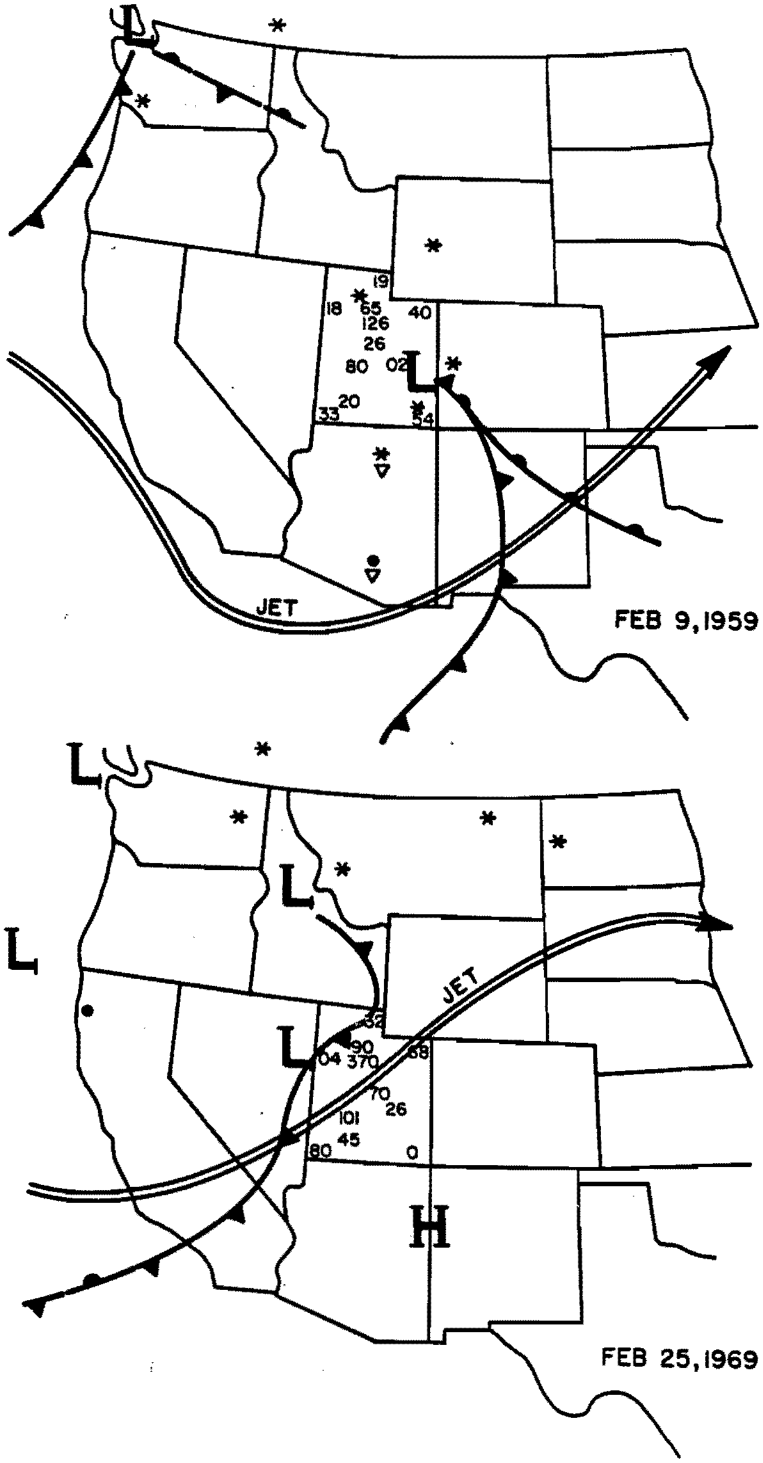

FIGURE 4.3. Example Of Drought (Above) And Non-Drought (Below) A-AO Weather Types. Storm Total Precipitation At Selected Stations Is Shown In Hundredths Of An Inch.
Symbols Are As Follows: • Rain; * Snow; ∇ Shower.

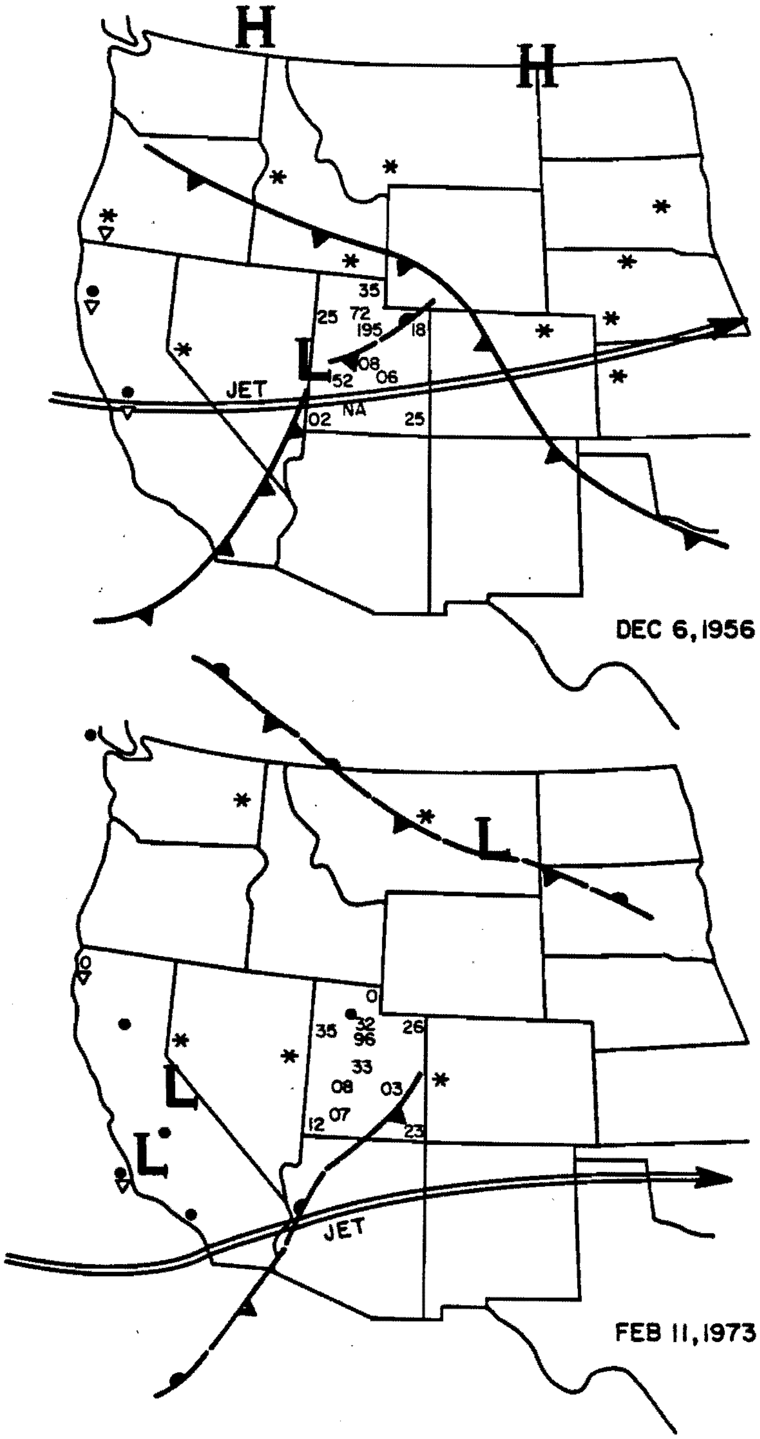

FIGURE 4.4. Example Of Drought (Above) And Non-Drought (Below) EM Weather Types. Storm Total Precipitation At Selected Stations Is Shown In Hundredths Of An Inch.
Symbols Are As Follows: • Rain; * Snow; ▽ Shower.

Results of the comparative analysis indicate little difference in storm characteristics between the drought and non-drought samples. Much greater variation was noted within the weather types. That is, the 24 A-AO and 24 EM-type storms showed considerable variation within their types but little variation according to drought occurrence.

4.3.3 Daily Wintertime Precipitation

Drought periods obviously suffer a deficit of precipitation relative to non-drought periods. The deficit could be caused by a lower frequency of wet days or smaller amounts on wet days or both. To determine which of those causes contributed more to Utah drought episodes, a study was undertaken to analyze daily precipitation at a station in each of the seven climatological divisions. The source of the precipitation data was the monthly Climatological Data for Utah, published by the Environmental Data and Information Service, National Climatic Center. Selection of a precipitation station in each division was based primarily on the consistency of the record. The stations selected are listed in Table 4.6.

Using the sets of drought and non-drought months, the frequency of days with precipitation and the mean daily amount were computed for each station. Days with a trace of precipitation were excluded.

TABLE 4.6

Precipitation Stations Used In Precipitation Analysis

Division	Station	Years of Record (up to 1980)
Western	Wendover	63
Dixie	St. George	83
North Central	Salt Lake City Airport	52
South Central	Fillmore	88
Northern Mountains	Silver Lake - Brighton	65
Uinta Basin	Vernal	70
Southeast	Blanding	72

Results of the calculations are listed in Table 4.7. For the stations west of or within the Wasatch Range (the first five in the table), the drought deficit seems to be related more to the frequency of days with precipitation than to smaller daily amounts. The two stations east of the Wasatch Range had a lower frequency of days with precipitation as well as smaller amounts.

The product of the number of winter days with precipitation and the mean daily amount is the mean winter precipitation. For example, in the Western Division, the mean winter precipitation for the drought periods is the product of 12 percent of 181 days and 2.0 mm, which is 44.2 mm. The mean winter precipitation for the drought and non-drought periods, expressed as the percent of normal winter precipitation at each station, is given in Table 4.8. The Dixie, Uinta Basin, and Southeast Divisions all have a much larger difference between the drought

TABLE 4.7

Precipitation Frequency And Mean Daily Amounts For Drought And Non-Drought Periods In Each Climatological Division

		Percent of winter days with precipitation		Mean Daily Amount	
Division	Station	Drought	Non-Drought	Drought	Non-Drought
Western	Wendover	12%	18%	2.0 mm (0.08 in)	2.0 mm (0.08 in)
Dixie	St. George	9	23	3.8 mm (0.15 in)	4.6 mm (0.18 in)
North Central	Salt Lake City	24	34	3.8 mm (0.15 in)	4.3 mm (0.17 in)
South Central	Fillmore	17	25	5.8 mm (0.23 in)	6.6 mm (0.26 in)
Northern Mtn	Brighton	43	47	7.9 mm (0.31 in)	9.7 mm (0.38 in)
Uinta Basin	Vernal	8	15	3.0 mm (0.12 in)	5.3 mm (0.21 in)
Southeast	Blanding	11	23	3.3 mm (0.13 in)	5.3 mm (0.21 in)

TABLE 4.8

Mean Percent Of Normal Winter Precipitation For Drought And Non-Drought Periods

Division	Station	Drought	Non-Drought	Normal Winter Precipitation
Western	Wendover	81%	119%	55 mm (2.17 in)
Dixie	St. George	50	152	119 mm (4.69 in)
North Central	Salt Lake City	72	113	226 mm (8.91 in)
South Central	Fillmore	77	121	232 mm (9.12 in)
Northern Mtns	Brighton	80	105	769 mm (30.27 in)
Uinta Basin	Vernal	55	157	88 mm (3.47 in)
Southeast	Blanding	48	152	146 mm (5.76 in)

and non-drought percents of normal than do the other four divisions. For example, the difference for the Northern Mountains Division is only one-fourth the difference in those three divisions. Curiously, the mean monthly Palmer Index during drought was similar in all divisions (about -3).

To further investigate precipitation differences during drought and non-drought periods, the precipitation data were grouped according to the four general weather types discussed in Section 4.3.1 (western trough, western ridge, zonal flow, split flow). The contribution of each type to the mean percent of normal winter precipitation shown in Table 4.8 was then computed. Results, given in Table 4.9, show that the relative lack of western trough types (detailed in Section 4.3.1) was a major factor in explaining the deficit in precipitation during drought. Precipitation from western trough weather types was especially lacking in the Dixie, Uinta Basin, and Southeast Divisions.

TABLE 4.9

Contribution To Mean Percent Of Normal Precipitation By General Weather Type

	Western Trough		Western Ridge		Zonal Flow		Split Flow	
Division	Drought	Non-Drought	Drought	Non-Drought	Drought	Non-Drought	Drought	Non-Drought
Western	25%	50%	21%	24%	30%	30%	5%	15%
Dixie	10	75	22	25	15	37	3	15
North Central	22	44	23	33	23	27	4	9
South Central	30	51	23	31	18	27	6	12
Northern Mtns	17	41	29	25	31	32	3	7
Uinta Basin	19	75	14	32	18	33	4	17
Southeast	12	67	16	34	15	40	5	11

In summary, this analysis has shown that precipitation deficits during drought are chiefly the result of fewer days with precipitation. When precipitation did occur during drought periods, the daily amounts were similar to those observed during non-drought periods, at least for stations west of the Wasatch Plateau. However, stations east of the plateau were doubly affected by fewer days with precipitation and by smaller daily amounts. The relative absence of western trough storm types was the main contributing factor to the drought deficit.

4.3.4 Comparative Analysis Of Rawinsonde Data

In the late 1940's and 1950's, the U.S. Weather Bureau, now the National Weather Service, initiated a program of upper air observations with balloon-carried radiosondes. Twice daily measurements of temperature, humidity, pressure, and wind have since become routine at selected locations across the country. Rawinsonde observation stations in and near Utah include Salt Lake City (SLC); Ely, Nevada (ELY); Grand Junction, Colorado (GJT); and Las Vegas, Nevada, including Yucca Flats and Desert Range (LAS). As was mentioned in Section 4.2.2, all data collected at those four stations were obtained for this study (see Table 4.2 for the periods of record).

Three types of humidity sensing systems have been used. A lithium chloride sensor was used until 1964. It was then replaced by a carbon humidity element which had a much faster response. The carbon element mounting system was modified in about 1972 to account for errors arising from solar insolation and restricted ventilation.

Since cloud base and top heights will be considered in the ensuing analysis of the rawinsonde data, the humidity data prior to 1964 have been excluded. The slow response of the lithium humidity sensor would result in inaccurate cloud heights. Pressure, temperature, and wind data from the pre-1964 rawinsondes were not excluded. The humidity errors for the 1964 to 1972 period have been accounted for in two ways. First, in his doctoral dissertation, Rhea (1978) developed a correction for the ventilation error. His correction has been incorporated in the data processing program used here. Second, the insolation error should be minimized on stormier winter days. Since this analysis is to address the potential for weather modification during drought, periods of fair weather have been excluded. Thus, the data set should include mostly cloudy days.

To identify the "stormy days" included in the data set, the Daily Series - Synoptic Weather Maps referenced in Sec. 4.3.2, were scanned. A day was considered "stormy" if some type of precipitation occurred within the state.

Table 4.10 shows general statistics for the two sets. The drought sample contains a larger number of soundings for two reasons. First, during much of the drought-stricken 1950's, four soundings were made daily. The NWS changed to two soundings each day in the late 1950's and 1960's. Second, four of the nine statewide non-drought seasons occurred before the sounding program began.

The percent frequency of soundings that indicated clouds was just slightly less during stormy drought days. The frequency of cloudy soundings decreased from north to south. All clouds were included in this statistic, from fog to cirrus. Remember

TABLE 4.10

Selected Rawinsonde-Derived Statistics For Drought And Non-Drought Periods (Stormy Winter Days Only)

Parameter	SLC Drought	SLC Non Drought	ELY Drought	ELY Non Drought	GJT Drought	GJT Non Drought	LAS Drought	LAS Non Drought
No. of soundings	1576	650	1815	627	2004	904	1018	372
Percent with clouds	82	85	70	75	74	81	41	47
Percent with clouds based below 3 km	42	44	32	35	25	36	13	18
Mean base height• (km)	2.3	2.2	2.5	2.5	2.3	2.3	2.4	2.3
Mean cloud base mixing ratio• (g/Kg)	3.4	3.4	3.5	3.2	3.8	3.6	4.2	4.0
Mean top height•* (km)	5.7	5.7	5.1	5.1	5.5	5.5	4.6	4.8
Mean top temperature•* (°C)	-25	-25	-21	-23	-24	-24	-17	-20
Percent of soundings with low-level inversion	31	33	28	27	42	43	37	31
Mean low-level inversion depth (mb)	27	24	23	25	26	38	25	23
Mean freezing level (m)	1840	1820	2480	2250	2430	2140	2170	1980
Mean 500 mb height (m)	5550	5520	5560	5530	5570	5550	5600	5560

• : Statistics are for clouds based below 3 km. Soundings prior to 1964 were excluded due to humidity errors.

* : Cloud top based on saturation relative to ice.

that even though these "stormy" days during drought and non-drought periods had similar frequencies of clouds, the earlier analyses have indicated fewer stormy days during drought.

Considering low-based clouds (based below 3 km MSL), which are more likely to precipitate and should be more treatable by ground-based seeding techniques, the drought samples at Salt Lake City and Ely had similar frequencies to the non-drought samples. However, at Grand Junction and Las Vegas, the drought samples had fewer occurrences of low-based clouds. For example, at Grand Junction, the frequency of all clouds was nine percent less during drought (74 vs 81 percent); whereas the frequency of low-based clouds was 31 percent less (25 vs 36 percent). This relative lack of low-based clouds could help explain the large deficits in wintertime precipitation during drought in the Dixie, Uinta Basin, and Southeast Divisions (see Section 4.3.3). Grand Junction is near the latter two divisions, while Las Vegas is generally upwind of the Dixie Division.

When low-based clouds did occur during drought, their base heights, top heights, and top temperatures averaged about the same as their non-drought counterparts. Cloud base mixing ratios (an indicator of the amount of water available at cloud base) were slightly higher in the drought sample. Since base heights were similar, the greater mixing ratios reflect a slightly warmer air mass during drought.

In terms of low-level inversions, which could trap seeding agents released at ground level, the two samples had similar frequencies, with Grand Junction having the highest frequency of inversions. Interestingly, inversions there tended to be deeper during the non-drought period. The other three stations showed little difference in inversion depth.

Freezing levels at the stations tended to average about 10 percent higher during drought. Also higher were mean 500 mb heights, generally by about 30 m. On a typical "stormy" 500 mb chart, an increase in height of 30 m corresponds to a southward shift of the iso-contours of about 125 km (75 miles). Thus, the increase in height during drought was consistent between stations but was relatively small in magnitude.

Wind frequency distributions and mean wind speeds by quadrants for the 850, 700, and 500 mb levels are given in Tables 4.11a - 4.11c. At the 850 mb level (about 1500 m MSL), there were few consistent differences between the drought and non-drought periods. Apparently at those small heights above ground, the strength of the diurnal flow patterns (southeasterly and northwesterly at Grand Junction, for example) overcomes any possible differences due to drought occurrence.

At 700 mb (about 3000 m MSL), consistent differences do appear. At all four stations, northwesterly winds were more frequent during drought and were also 10 to 15 percent stronger. Southeasterly and southwesterly winds were relatively less frequent during drought. Speeds associated with those two direction categories were not especially different during drought.

The increase in frequency and speed of the northwesterly winds at 700 mb during drought was also observed at 500 mb (about 5500 m MSL). Additionally, southeasterly and southwesterly winds were relatively less frequent during drought. Considering all directions, wind speeds during drought averaged over 10 percent greater at Salt Lake City and Ely. The average speeds at Grand Junction and Las Vegas were also greater but considerably less than 10 percent.

TABLE 4.11a

Frequency And Mean Speed Of 850 mb Winds By Quadrants (Stormy Winter Days)

		SLC		ELY		GJT		LAS	
Quadrant	Para-meter	Drought	Non Drought	Drought	Non Drought	Drought	Non Drought	Drought	Non Drought
NE	Freq. Speed	8.5% 3.7 m/s	9.2% 3.2 m/s	NA (Sur. Press. < 850 mb)		12.8% 2.0 m/s	16.3% 2.0 m/s	16.3% 5.8 m/s	13.8% 5.0 m/s
SE	Freq. Speed	32.3% 6.7	32.7% 6.5	NA		38.2% 3.2	40.1% 2.8	13.1% 5.2	18.5% 5.9
SW	Freq. Speed	22.4% 6.2	24.8% 5.8	NA		9.3% 1.8	6.1% 1.9	38.6% 6.8	34.2% 6.6
NW	Freq. Speed	35.8% 4.9	32.4% 4.4	NA		37.0% 2.6	32.3% 2.9	30.4% 5.7	32.9% 5.4
All	Speed	5.6 m/s	5.3 m/s	NA		2.6 m/s	2.5 m/s	5.9 m/s	5.8 m/s

TABLE 4.11b

Frequency And Mean Speed Of 700 mb Winds By Quadrants (Stormy Winter Days)

		SLC		ELY		GJT		LAS	
Quadrant	Para-meter	Drought	Non Drought	Drought	Non Drought	Drought	Non Drought	Drought	Non Drought
NE	Freq. Speed	5.5% 6.7 m/s	5.2% 5.3 m/s	9.6% 9.1 m/s	9.9% 7.4 m/s	5.6% 6.4 m/s	6.6% 5.7 m/s	10.8% 11.2 m/s	9.7% 10.6 m/s
SE	Freq. Speed	5.3% 8.0	9.5% 7.8	5.1% 7.8	7.7% 7.1	5.2% 7.0	8.1% 7.5	3.4% 8.3	5.1% 10.7
SW	Freq. Speed	48.0% 10.4	50.1% 9.9	39.4% 10.5	43.5% 9.9	65.3% 10.2	66.0% 10.0	41.8% 11.8	43.4% 11.8
NW	Freq. Speed	41.2% 9.8	35.2% 8.5	45.9% 9.2	38.9% 8.1	24.0% 8.6	19.4% 7.7	44.0% 10.7	41.8% 9.2
All	Speed	9.8 m/s	9.0 m/s	9.6 m/s	8.8 m/s	9.5 m/s	9.1 m/s	11.1 m/s	10.5 m/s

TABLE 4.11c

Frequency And Mean Speed Of 500 mb Winds By Quadrants (Stormy Winter Days)

Quadrant	Para-meter	SLC		ELY		GJT		LAS	
		Drought	Non Drought	Drought	Non Drought	Drought	Non Drought	Drought	Non Drought
NE	Freq	5.0%	4.7%	6.7%	8.7%	2.7%	4.3%	6.0%	6.4%
	Speed	12.2 m/s	10.7 m/s	14.4 m/s	12.3 m/s	13.1 m/s	10.4 m/s	16.6 m/s	13.0 m/s
SE	Freq	3.0%	6.3%	2.9%	4.5%	2.6%	4.1%	1.6%	2.8%
	Speed	12.0	8.7	11.4	7.6	10.7	11.5	14.7	13.9
SW	Freq	52.4%	57.1%	43.6%	48.2%	55.5%	60.6%	37.2%	44.5%
	Speed	19.5	17.5	19.0	18.3	19.3	19.3	21.6	21.3
NW	Freq	39.6%	31.8%	46.8%	38.6%	39.2%	31.0%	55.2%	46.3%
	Speed	19.9	18.2	20.4	18.5	18.1	17.5	20.3	18.6
All	Speed	19.1 m/s	16.9 m/s	19.1 m/s	17.3 m/s	18.4 m/s	18.1 m/s	20.5 m/s	19.4 m/s

Summarizing this analysis of rawinsonde-inferred air mass and cloud statistics on "stormy" days, the drought and non-drought periods showed small differences in such parameters as frequency of soundings with clouds, cloud-base heights, cloud-top heights and temperatures, and frequency and depth of low-level inversions. The heights of the freezing level and the 500-mb level averaged slightly higher during stormy drought days, as did mean base mixing ratios, reflecting the slightly warmer conditions during drought. Winds at 700 and 500 mb occurred relatively more frequently from the west through north during the drought periods, and those northwesterly winds were stronger during drought.

At the two leeside rawinsonde stations, Grand Junction and Las Vegas (actually to the lee of the Sierra Nevada), the frequency of low-based clouds was less during drought. This relative lack of low clouds could contribute to the large deficit in seasonal precipitation during drought in the climatological divisions near those stations. The stronger wind speeds aloft during drought could also contribute to the precipitation deficit by enhancing lee-side evaporation, thereby amplifying the natural rain shadow effect.

4.3.5 Implications Concerning Weather Modification During Drought

These studies of meteorological conditions during drought have shown that, over much of the state, drought is characterized more by a reduction in the number of precipitation events than by differences in the events. Indeed, the storms that occurred during drought periods tended to have very similar characteristics to storms occurring during non-drought periods. Some differences were noted to the lee of the Wasatch Plateau.

There, the frequency of occurrence of low-based clouds was somewhat less during drought.

In conclusion, the storms that did occur during drought should have been no more or no less seedable than those that occurred during non-drought periods.

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5. DESIGN OF STANDBY CLOUD SEEDING PROGRAMS IN UTAH

In this section, a standby wintertime cloud seeding program will be developed for each of Utah's seven climatological divisions. Since drought frequently occurs in adjacent divisions, standby seeding programs covering several divisions will also be considered. The designs will be based on previous experience, numerical modeling guidance, and practical considerations. Program costs will be estimated so that the economic benefits from the program can be determined.

Since implementation of these standby seeding programs could occur at any time in the future, the current seeding program in much of Southern Utah has been ignored. That is, a standby program will be developed for the area covered by the current program. The design given here will, however, rely heavily on the design used on the Southern Utah seeding program (Thompson et al., 1978).

5.1 Preliminary Consideration

Prior to discussing the design for each division, several preliminary topics will be addressed. Those include state and federal cloud seeding regulations, seeding agents and modes, a description of the numerical model used for seeding guidance, data required in the conduct of the seeding programs, evaluation of seeding results, early recognition of drought, and a suggested range of seeding-related increments in precipitation.

5.1.1 State And Federal Regulations

The Utah Cloud Seeding Act of 1973 stipulates that cloud seeding programs must be conducted by persons licensed by the Division of Water Resources (DWR). A permit must also be obtained for each program. Prior to granting a permit, the state must have proof of publication that a Notice of Intent has been published weekly for three weeks by a newspaper in the affected area. In certain extreme cases, the DWR can waive the requirements. For example, the permitting procedure was waived in the 1977 drought to allow rapid extension of the Southern Utah seeding program into Northern Utah. The state also requires copies of all daily operational logs and any reports, publications, pamphlets, and evaluations pertinent to the seeding program.

Federal cloud seeding regulations are administered by the National Oceanic and Atmospheric Administration (NOAA). The regulations deal primarily with reporting requirements. Licensing and permitting are not regulated by NOAA.

5.1.2 Seeding Agents

A variety of chemical agents have been used in research and operational cloud seeding programs. The agents fit into two broad categories, those that enhance the conversion of cloud liquid water to ice and those that enhance the growth of cloud liquid water droplets. Ice-forming agents include silver iodide, dry ice, and organic chemicals such as metaldehyde. Liquid droplet growth-enhancing (hygroscopic) agents include common salt, urea, and ammonium nitrate.

Practically all operational wintertime cloud seeding programs have used silver iodide. The ice-forming silver iodide nuclei are formed by combustion followed by rapid quenching. This process generally produces around 10^{13} to 10^{14} effective ice-forming nuclei per gram at -10°C. The number of nuclei increases with colder temperature and vice versa. In the ensuing design, the use of silver iodide has been assumed.

5.1.3 Seeding Modes

Seeding agents are normally released in one of two modes, ground-based seeding or aerial seeding. Seeding material released at the ground is mixed into clouds either by convection or orographic uplift caused by airflow over mountainous terrain. Aerial seeding results in more direct injection of seeding agents into a cloud.

Advantages of ground-based seeding include relatively low costs, continuous operation for extended periods, and the ability to affect a large area continuously through a network of ground-based seeding units. Disadavantages include the inability to seed when low-level inversions or light winds occur and the uncertainty in the targeting of specific areas.

A manually controlled ground-based seeding device is shown in Figure 5.1. The silver iodide-acetone mixture is held in the lower half of the device. Propane from the tank on the left pressurizes the silver iodide tank. Flow out of the tank is regulated by a flow control valve. The propane is ignited manually and the silver iodide-acetone solution is injected into the propane flame. The wind screen is in the upper half of the device to project the flame.

FIGURE 5.1. An Example Of A Ground-Based Cloud Seeding Device

FIGURE 5.2. A Piper Aztec Aircraft Equipped for Aerial Cloud Seeding

Aerial seeding has the advantages of very accurate targeting, flexible seeding rates and agents, and the ability to seed when inversions or light winds prohibit the use of ground-based seeding. Disadvantages include relatively high costs, non-continuous seeding over a relatively limited area (eased by multiple aircraft), flight in potentially hazardous turbulence or icing conditions, and minimum altitude restrictions that could rule out flying at the optimum altitude required to maximize seeding effects (generally the -5 to -10°C level).

An aircraft equipped for aerial seeding is shown in Fig. 5.2. The wing-tip tanks contain a pressurized silver iodide, acetone mixture. An electrical switch in the cabin releases the mixture, which is then ignited by a sparking device. The aircraft also is equipped with a belly-mounted pyrotechnic rack. Silver iodide flares are ejected from the rack. When ejected, the flare is ignited and burns while falling several thousand feet before being completely consumed.

Although not mandatory, aerial seeding under Instrument Flight Rules (IFR) conditions is facilitated by flying along FAA-designated Victor Airways, where radar and radio contact with FAA is assured. A map showing Victor airways and minimum altitudes in Utah is given in Figure 5.3. Noteworthy is the high density of airways in Northern Utah and the lack of airways in the southeast part of the state. IFR flight in the absence of Victor airways is strictly regulated by FAA. However, it is possible if certain procedures are followed.

In the designs given in Section 5.2, both ground-based and aerial seeding have been considered. Advantages and disadvantages have been weighed to arrive at the mode recommended to provide the best results.

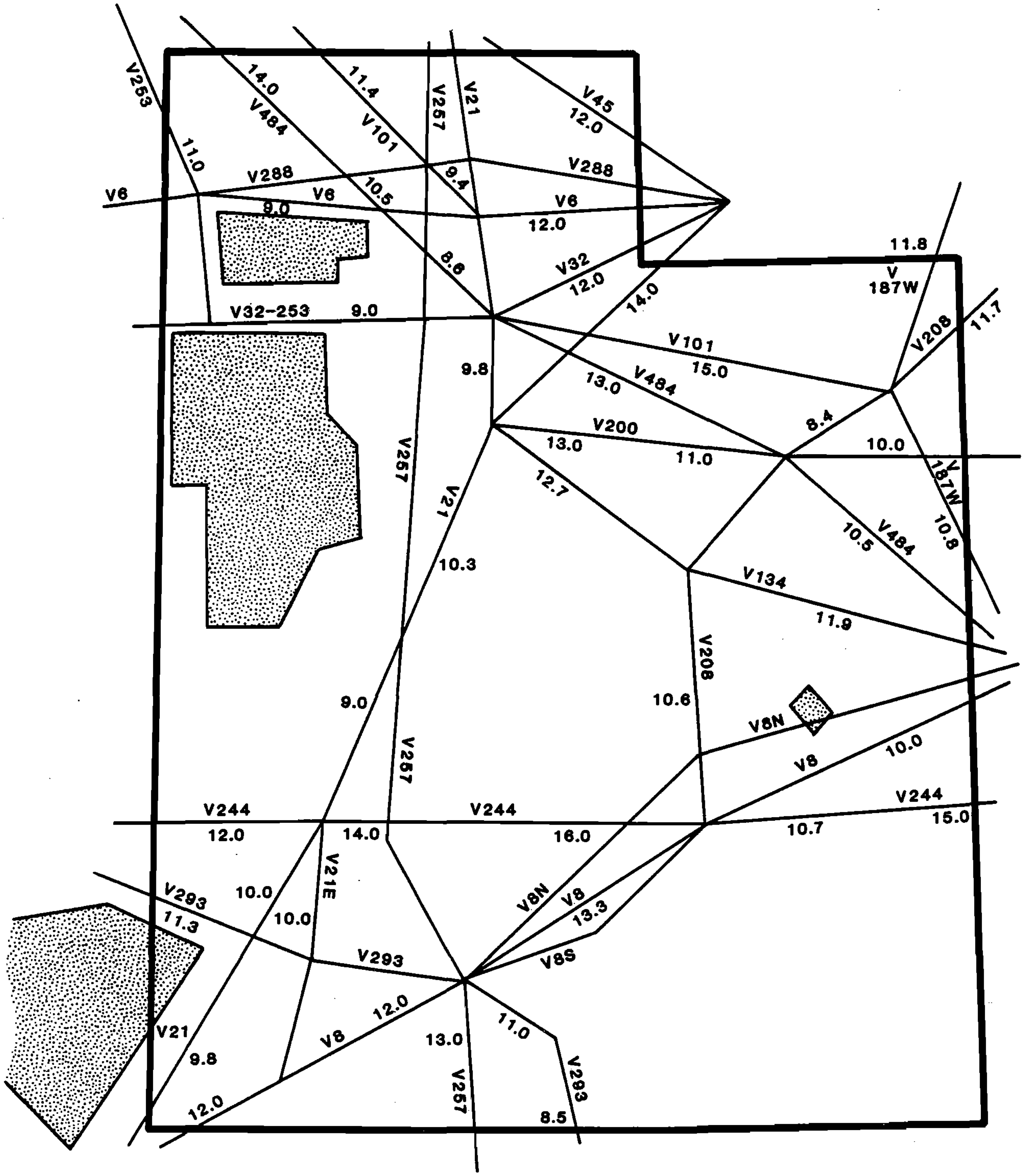


FIGURE 5.3. Victor Airways In Utah. Minimum Enroute Altitudes In 1000's Of Feet Are Shown. Areas Prohibited To Non-Military Aircraft Are Speckled.

5.1.4 Data Requirements

Research seeding programs over the past two decades have identified certain cloud conditions conducive to positive seeding effects. These include cloud tops warmer than a certain threshold, the presence of supercooled liquid cloud water above a certain threshold, and in-cloud wind speeds within certain limits (to prevent the seeding agent from being blown away from the intended target). Criteria currently in use on the seeding programs in Southern Utah include cloud top temperature warmer than -30°C, cloud base mixing ratio greater than 3 g/kg, and cloud depth and 700 mb wind speed within a specified limit that varies with the dimensions of the mountain range being targeted (Thompson et al, 1978).

To monitor those conditions, the operator of a cloud seeding project requires a variety of weather data. Rawinsonde data, either from project-specific or National Weather Service (NWS) soundings, provide indications of cloud top temperatures, water contents, and winds. Satellites provide near-continuous indications of cloud heights over a large area. Hourly weather reports from NWS and Federal Aviation Administration (FAA) stations provide current weather within and upwind of a seeding area. All those data types would also be useful in assessing hazardous situations during which seeding should be suspended (flooding, avalanche danger, severe storms, etc.). These weather data are available from leased teletype and facsimile machines interfaced to NWS data lines.

For the standby seeding programs, two teletype machines (NWS Service A and C), one satellite facsimile machine and one facsimile machine for weather charts are recommended.

Additionally, arrangements should be made for general weather observations from persons within the program area.

5.1.5 Evaluation Of Seeding Effects

The design of a seeding program should consider some type of evaluation of seeding effects. Indeed, unevaluated programs tend to be short-lived. A variety of evaluation techniques have been used, including randomization and target-control comparisons. Randomization requires that no seeding occur on a random selection of days when the proper seeding conditions do in fact exist. A comparison is then made of measurements taken on seeded and not-seeded days. Such measurements could include precipitation gage data, radar data, or cloud physics data. Randomization generally has not been used on operational (non-research) seeding programs, since the program sponsor is not willing to forego seeding opportunities. An alternative is to make a target-control evaluation. An area near the target, but not close enough to be affected by seeding, is selected as a control. Historical non-seeded data, (for example, mean seasonal precipitation), are analyzed to develop a regression equation between the target and control areas. The regression equation is then used to predict precipitation in the seeded target as a function of precipitation in the control area. The difference in observed and predicted target precipitation is the seeding effect. This technique has been used to evaluate the current seeding program in Southern Utah (Thompson and Griffith, 1981).

Since selection of a control area is a function of which areas in the state are being seeded, no specific evaluation details have been given in Section 5.2. However, a target-control procedure is recommended. Selecting target and control area data sources prior to initiation of the seeding program would strengthen the statistical testing. The program costs given in Section 5.2 include one man-month for evaluations.

5.1.6 Early Recognition Of Drought

When a seeding program should begin it involves a number of issues, including past precipitation, reservoir and stream levels, and the desires of the population within the affected area. One parameter that could aid in the decision-making process for winter seeding operations is a late summer monthly Palmer Index. If the index for September, for example, was suitably correlated with the mean winter Palmer Index, then the September index could be used to alert decision-makers of impending drought.

Along those lines, the September and the average September-October Palmer Index for each climatological division were correlated with the mean winter (November to April) Palmer Index. The correlation coefficients for the September index and the mean winter index ranged from +0.62 for Dixie to +0.84 for the Western Division. The average September-October index resulted in slightly higher correlation coefficients. Another way to express the relationship is given in Table 5.1. If September was dry (moderate or worse drought), the relationship was not too good. For example, in the Southeast Division, only 20 percent of the winters that followed a dry September were also dry. However, in all divisions, when September or September and October were near normal or wetter than normal, the probability was low that the ensuing winter would be dry.

A contributing factor to the reasonably good correlations is the conservative nature of the Palmer Index equation.

Ninety percent of the previous month's index is used in computing the present month's value. As a result, a substantial change in precipitation, evapotranspiration, runoff, etc. is required to produce large changes in the index. Since the large scale atmospheric circulation tends to change slowly, the Palmer Index changes slowly and monthly values over a short period tend to be similar.

Thus, a late summer index is not necessarily a good indicator of impending winter drought. If the late summer was wet, then the winter should not be dry. However, a dry late summer does not always precede dry winters.

TABLE 5.1

Conditional Probability Of Winter Palmer Index Averaging Less Than -2 (Moderate Or Worse Drought) According To September (September-October) Palmer Index. Period Of Record Was 1931-80

	September Palmer Index			
Division	Moderate or Worse Drought (≤-2)	Mild Drought (-1.9 to -1.0)	Near Normal (-0.9 to +1.0)	Slightly Wet or Greater (+1.0)
Western	93% (100%)	0% (43%	13% (0%)	0% (0%)
Dixie	38 (40)	25 (31)	0 (0)	0 (0)
North Central	44 (50)	33 (40)	21 (12)	0 (0)
South Central	67 (67)	44 (44)	14 (15)	0 (0)
Northern Mountains	64 (64)	0 (20)	19 (18)	0 (0)
Uinta Basin	36 (60)	45 (31)	8 (0)	0 (0)
Southeast	20 (22)	40 (25)	0 (0)	0 (0)

5.1.7 A Description Of The Numerical Seeding Guidance Model

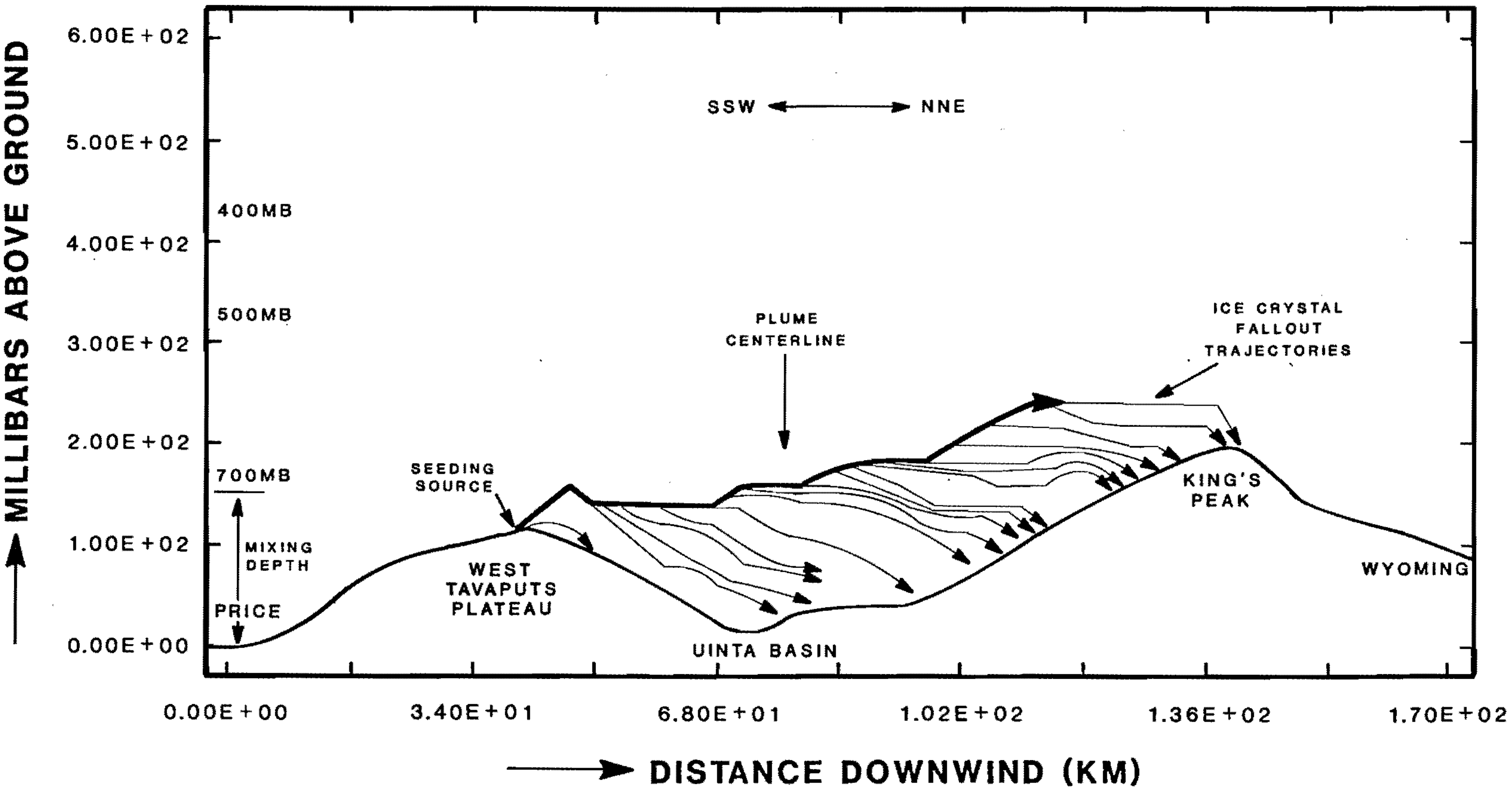
The model used to simulate seeding effects in various parts of the state was developed at NAWC by Robert Elliott for the Bureau of Reclamation-sponsored Sierra Cooperative Pilot Project. The model has been described in detail in Elliott et al, (1981).

In simple terms, the model simulates airflow over a barrier and contains modules to compute artificial and natural nucleation of cloud water and the subsequent ice crystal fallout. Both ground-based and aerial seeding can be simulated. Convection is handled by the use of a pre-determined mixing depth and a mean convective updraft within the mixing layer.

Data required by the model include a terrain profile (generally values averaged over a width of 20 km normal to the wind and spaced in 10 km downwind steps), a profile representing a streamline in middle levels of the atmosphere, an upwind rawinsonde sounding, and cloud water profiles vertically above each terrain step.

The model provides a variety of displays of computed results. In this study, the principal display was a downwind distance VS height above ground plot that shows how far downwind and how high above ground a seeding plume drifts and where the artificially-nucleated ice crystals fall to the ground as snow or rain. This display also shows the seeding-related increment in precipitation at each fallout step downwind. An example of this display is shown in Figure 5.4. The seeding increment (called Footprint Precip in the figure) is the increase over what would have occurred without seeding. Typical wintertime

FIGURE 5.4. An Example Of Results From The Numerical Seeding Guidance Model. (Note: The Computer-Plotted Diagram Was Drafted For This Publication).



```
SEEDING MODE AND CLOUD TYPE:  AGI GROUND POINT SOURCE-0   SOUNDING TYPE: G780111  PT. SOURCE STRENGTH (G/S):  0.004
CRYSTAL HABIT:  TEMP DEPENDENT  D.L. DEPTH (MB):  0
HORIZ. AND VERT. DISPERSION (MB/S):  2  0
ICE MULT.:  1 FOR 10^-4,  2 FOR 10^-3,  3 FOR NONE,   3
P-G TYPE 1 FOR B, 2 FOR C, 3 FOR D, 4 FOR E:  2
TIME STEPS TO AND T1 (SEC), XO, YO (KM), ZO (MB):  600  600  40   0  117

VERTICAL PLOT OF PLUME AND FALLOUT


TEMP (DEG C)
- 9.8 -11.6 -11.0 -10.9 -10.5 -10.9 -11.0 -12.4 -12.5 -12.8 -13.2 -13.5 -13.8 -14.2 -15.4 -16.6 -17.8 -19.0
PLUME CL X(KM), Z(MB), Y(KM)
 43.7  47.4  51.0  54.6  59.2  63.8  68.1  72.1  76.2  80.4  84.7  89.0  93.2  97.5 102.1 106.7 111.4 116.3
127.0 152.5 145.3 145.5 142.0 147.7 148.5 163.6 166.1 169.9 173.7 177.6 182.3 187.0 201.4 216.1 231.1 246.5
- 1.2 -2.4 -3.6 -4.7 -5.9 -7.1 -8.3 -9.5 -10.7 -11.9 -13.0 -14.2 -15.4 -16.6 -17.8 -19.0 -20.2 -21.3
FOOTPRINT PRECIP (MM HR^-1)
  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.13  0.16  0.07  0.00  0.01  0.01  0.01  0.04
FOOTPRINT X(KM), Y(KM)
  51     0     0    80    82    98     0     0     0     0    108    113    118    131    133    138    140    141
   4     0     0    16    17    23     0     0     0     0     25     25     26     32     32     33     33     33
```

precipitation rates are in the 0.5 to 1 mm/hr range. The ratio of Footprint Precip and these wintertime rates is a seeding increment. However, it should not be compared with the increments suggested below in Section 5.1.8. The modeled increment applies only to the particular conditions used as input for the model.

5.1.8 Suggested Seeding Increments

Prior to the design work, other drought study participants requested an estimate of seeding increments. Two values have been provided, a conservative estimate (M1) and a liberal estimate (M2). The two estimates also differ in length of seeding programs. The conservative estimate is based on a seeding program from November 1 to March 31, while the liberal estimate is associated with seeding from November 1 to May 31. The increments listed in Table 5.2 were based on the evaluation of the current seeding program in Utah (Thompson and Griffith, 1981) and on past experience in areas not affected by that program. The liberal estimate also includes advances in the state of the art of weather modification that could occur over the next few years.

TABLE 5.2

Suggested Seeding Increments

Division	Conservative (M1)	Liberal (M2)
Western	5%	15%
Dixie	10	20
North Central	10	20
South Central	10	20
Northern Mountains	10	20
Uinta Basin	0	10
Southeast	5	15

As the design for each division is developed, the increment that seems most likely achievable will be given.

5.2 Standby Seeding Programs For Each Climatological Division

In the following sub-sections, a design for standby cloud seeding programs in each climatological division will be presented. The designs were based on previous experience in a division, practical considerations, and modeling guidance.

Eight different areas, shown in Fig. 5.5, were modeled. The arrows show the downwind trajectory (generally 180 km), while the dots show the modeled seeding locations.

No modeling was done for the North Central and Dixie Divisions. It was felt that the design used in the current seeding program in Southern Utah could be used in those divisions. Modeling was done for the South Central Division to compare modeled results with the results of the Southern Utah program. Since the Uinta Mountains have proven difficult to seed in previous programs, three different modeling approaches were tried there.

As the modeling studies were being made, it was observed that results were very sensitive to the pre-specified cloud liquid water contents. To provide for some intercomparison between divisions, a maximum water content of 0.5 g/m^3 was used. Liquid water contents varied according to location relative to terrain but never exceeded that value. Modeling results are given in each sub-section.

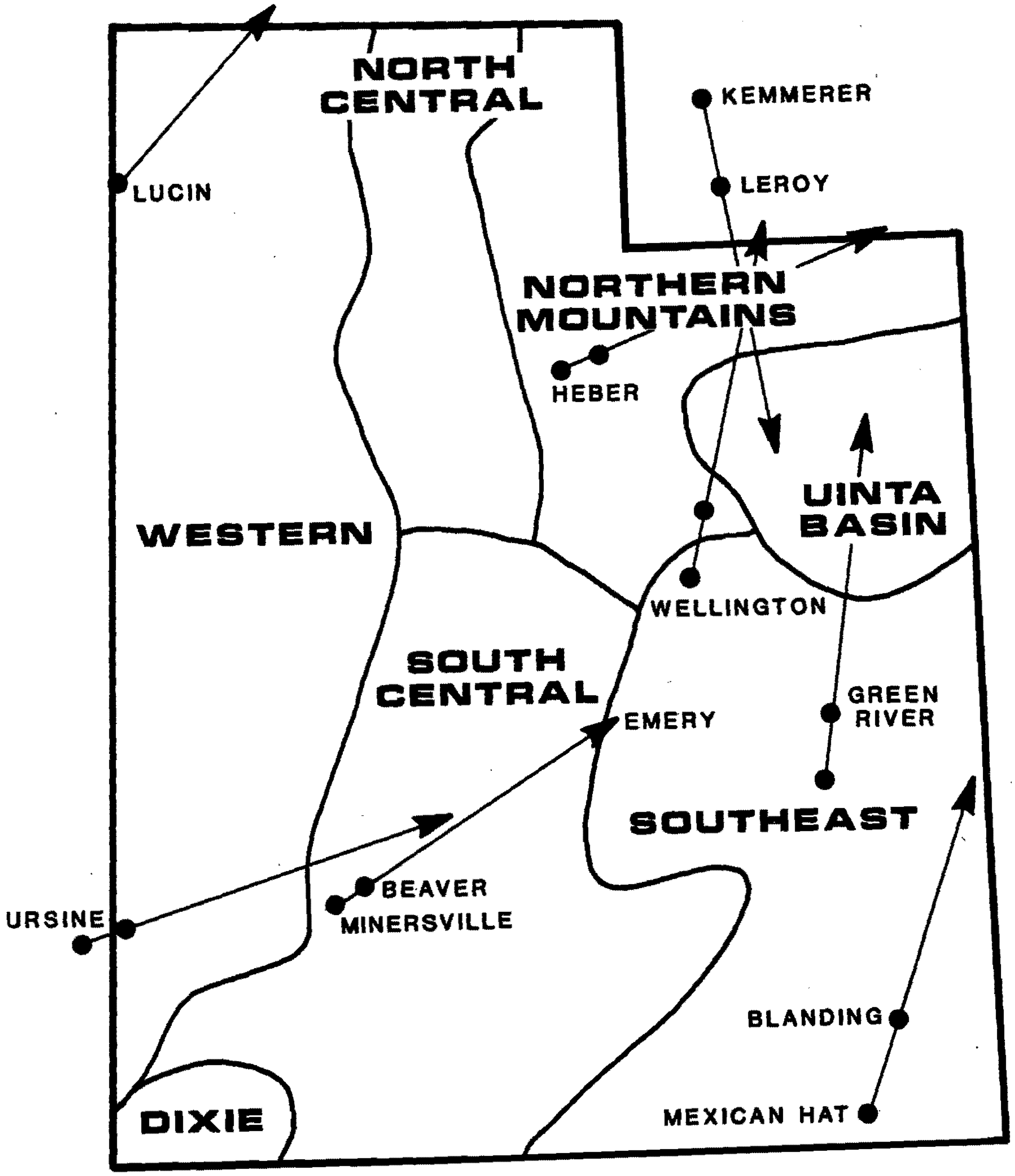


FIGURE 5.5. Location Of Numerical Model Studies. Seeding Sites Indicated By ●

5.2.1 Western Division (Northern Part)

The Western Division of Utah is over 300 miles long, with different characteristics at the two ends. For that reason, the division was split into northern and southern parts and a design was developed for each. A design was not considered for the very dry, military-dominated central part of the division.

For the northern part, the area north and east of Lucin was considered. This area includes upland rangeland (the Raft River Mountains and Grouse Creek Mountains), semidesert rangeland, and some irrigated cropland. The population is very sparse.

Modeling results are given in Table 5.3. For ground-based seeding near Lucin, the seeding plume in the absence of convection failed to rise to colder temperatures (where more artificial nuclei can freeze liquid cloud drops) until it was over the crest of the Raft River Mountains. Results from ground-based seeding improved somewhat with convection. However,blowover of seeding effects into Idaho also occurred. Moving the seeding unit nearer the Raft River Mountains actually worsened seeding effects since vertical plume dispersion was limited by the shorter time period in reaching the mountain. These modeling results are representative of the problems in ground-based seeding of a small, narrow mountain range like the Raft River Mountains. Orographic uplift of the seeding plume is limited, and seeding effects occur to the lee of the crest, where leeside evaporation decreases the effects.

Seeding effects improved considerably with simulated aerial seeding. Releasing the artificial nuclei within the

TABLE 5.3

Summary Of Numerical Modeling Runs For (North) Western Division.
Upwind Sounding Was Ely, 78021112

Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
Lucin, UT	Ground (5000 ft MSL)	SW	No	-14°C	0 $\frac{mm}{hr}$	NA	Maximum plume lift over Raft River Mountains. Blowover of very limited effects into Idaho
Lucin, UT	Ground	SW	Yes	-19°C	0.1	Raft River Mountains	Blowover of seeding effects into Idaho
30 km NE of Lucin (Grouse Creek Mtns)	Ground (7500 ft MSL)	SW	No	-12°C	0	NA	Insufficient vertical dispersion
Over Lucin (Victor Airway 6 or 288)	9000 ft MSL (minimum altitude)	SW	No	-26°C	0.8	Raft River Mountains	Smaller increments from NE of Lucin to Raft River Mtns. Also blowover of effects into Idaho.

cloud at the proper temperature allowed seeding effects to occur nearer the seeding location. In this case, seeding increments of about 0.2 mm/hr occurred to the east of the Grouse Creek Mountains, while the maximum effect occurred in the Raft River Mountains. In spite of the upwind displacement of seeding effects relative to ground-based seeding, blowover of effects into Idaho also occurred.

It should be remembered in viewing these and subsequent modeling runs that results apply only for the meteorological conditions used in the model. Different winds or temperatures could result in different values and locations of the increment. However, the rawinsonde data used for input were considered representative.

In terms of logistics, the sparse population of the region argues against ground-based seeding. Aerial seeding can be done on several of the Victor Airways upwind of the seeding area, and minimum altitude requirements are not restrictive.

Based on these considerations, an aerial standby seeding program is recommended. The base of operations could be Salt Lake City, which has excellent instrument landing facilities. Flight time from Salt Lake City to the seeding area should be 45 minutes to an hour. Personnel should include a meteorologist and a full-time pilot. Some cost savings could be realized by using an on-call pilot. However, considering the one hour flight to the seeding area and the one to two hour lag required for pilot notification and preparation, seeding opportunities could be missed. Since no weather observations are made near the program area, a part-time weather observer living in the area, say Park Valley, should be used.

The aircraft should be a turbocharged, de-iced twin, such as the Piper Aztec. Seeding equipment would consist of continuous burning wing-tip silver iodide dispensers, as well as vertical-fall silver iodide pyrotechnic racks. Possible flight tracks are shown in Figure 5.6.

Since rawinsonde soundings are made twice daily at Salt Lake City, no project-specific rawinsondes are recommended. The Salt Lake City sounding data could be supplemented by aircraft soundings. Other data requirements are listed in Section 5.1.4.

Cost estimates for the design were prepared for both M1 and M2 type operations (November to March for M1 and November to May for M2). Costs are summarized in Table 5.4. Note: the loaded total includes a general and administrative fee (15%) and profit (10%). Based on the modeling studies, the expected seeding increment is 15 percent (M2).

TABLE 5.4

Cost Estimates For Standby Seeding Operations In The Western Division (Northern Part)

	Cost Estimate (1000's of Dollars)	
Expense	M1	M2
Labor	$ 46	$ 65
Aircraft	40	50
Ground Seeding Network	0	0
Seeding Reimbursables	28	41
Rawinsonde	0	0
Office Data, Living Allowance	14	20
Travel	0+	1
Reports	1	1
Sub-Total	$129	$178
Loaded Total	$163	$225

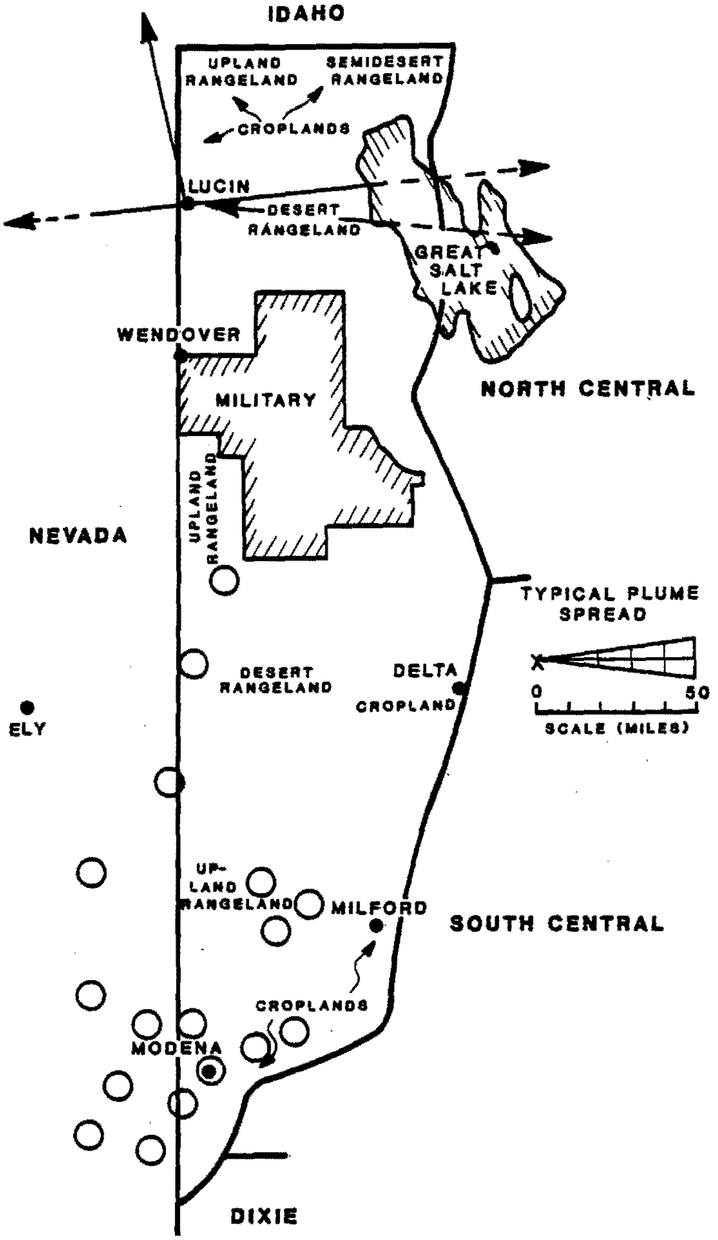


FIGURE 5.6. Suggested Design For Cloud Seeding Operations In Western Division. Ground-Based Seeding Units Are Indicated By O. Aircraft Flight Tracks Shown By Arrows.

5.2.2 Western Division (Southern Part)

The southern part of the Western Division extends south and west of Delta. Much of this area is desert rangeland. However, the Indian Creek Range and Wah Wah Mountains provide upland rangeland in the southwest. There are irrigated croplands near Delta, Milford, and Modena. As in the northern part of the division, population density is very low.

The modeling location, shown earlier in Figure 5.2, is from Ursine, Nevada to the Tushar Mountains east of Milford. This location allows for simulation of possible orographic effects from the Indian Peak Range and for simulation of seeding effects over the flatter terrain southwest of Milford.

Modeling results are given in Table 5.5. Ground-based seeding from Ursine had no effect under stable conditions. Plume dispersion in the vertical was insufficient. Seeding effects improved considerably with convection and occurred primarily over the flat terrain southwest of Milford. With lighter winds than those used in the model (10 to 15 m/s in the lower levels), the effects would be shifted upwind. Good increases also occurred with simulated aerial seeding along Victor Air- ways 293. However, the effects were located along the far eastern side of the division. Aerial operations further southwest in order to shift effects upwind would not be possible due to a large restricted area in Southern Nevada.

These results suggest that a network of ground-based seeding units be used for standby seeding operations. Seeding should only be performed under convective conditions. Possible seeding sites are shown in Figure 5.6. The base of operations could be Cedar City. Recommended personnel include a meteorologist

TABLE 5.5

Summary Of Numerical Modeling Runs For (South) Western Division. Upwind Sounding Was Ely, 78022800

Seeding Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
Ursine, NV	Ground (6000 ft MSL)	WSW	No	-4°C	$0 \frac{\text{mm}}{\text{hr}}$	NA	Insufficient plume rise
Ursine, NV	Ground	WSW	Yes	-23°C	0.4	N of Lund	Large area of increase from near Lund to south of Milford
30 km downwind of Ursine (Victor Airway 293)	11,300 Ft MSL (minimum altitude)	WSW	No	-29°C	0.6	SW of Milford	Increases primarily in far eastern side of division

and a part-time technician to assist in installing and removing the 15 to 20 ground seeding units. Rawinsonde data from Ely and Las Vegas should suffice.

Cost estimates for M1 and M2-type designs are listed in Table 5.6. Based on the modeling studies, a modified M1 design, with operations during the more convective March through May period, is recommended. The expected seeding increment is five percent.

TABLE 5.6

Cost Estimates For Standby Seeding Operations In The Western Division (Southern Part)

	Cost Estimate (1000's of Dollars)	
Expense	M1	M2
Labor	$ 25	$ 49
Aircraft	0	0
Ground seeding network	4	4
Seeding Reimbursables	4	10
Rawinsonde	0	0
Office, Data, Living Allowance	8	20
Travel	1	2
Reports	1	1
Sub-Total	$ 43	$ 86
Loaded Total	$ 55	$109

5.2.3 Dixie Division

Smallest of the seven climatological divisions, Dixie nevertheless has diverse features. The Pine Valley Mountains occupy the northern part of the division. Desert rangeland covers the western regions, while semidesert rangeland and some cropland can be found around St. George. Zion National

Park is located to the east. Population centers include St. George, Hurricane, and La Verkin.

No modeling runs were done for the Dixie Division. The current Southern Utah Seeding program includes the division, and the evaluation of effects is favorable (Thompson and Griffith, 1981).

The recommended standby seeding includes a network of six to ten ground-based seeding units (see Figure 5.7). Personnel requirements consist of a meteorologist. No technician should be necessary. The base of operations should be St. George. No project-specific rawinsondes are suggested.

Cost estimates for M1 and M2-type designs are shown in Table 5.7. The current evaluation indicates an M2 seeding increment (20 percent).

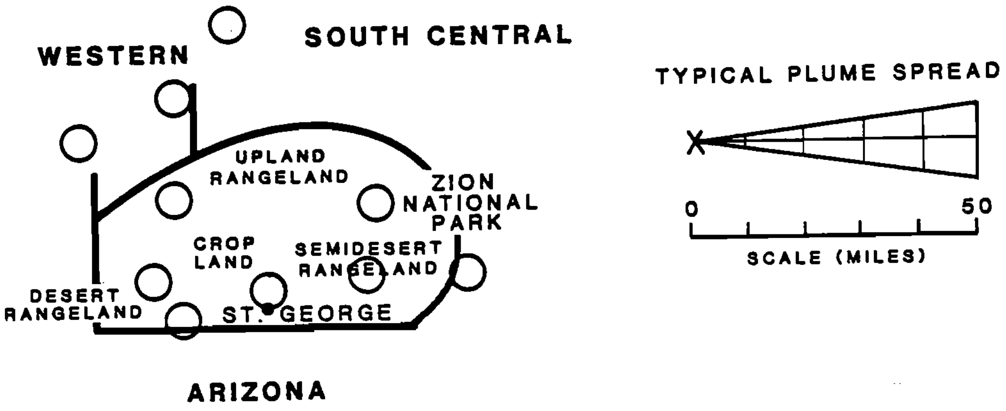


FIGURE 5.7. Suggested Design For Standby Cloud Seeding Operations In Dixie Division. Ground-Based Seeding Units Are Indicated By O.

TABLE 5.7

Cost Estimates For Standby Seeding Operations In The Dixie Division

Expense	Cost Estimate (1000's of Dollars) M1	M2
Labor	$ 35	$ 48
Aircraft	0	0
Ground Seeding Network	2	2
Seeding Reimbursables	6	9
Rawinsondes	0	0
Office, Data Living Allowance	14	20
Travel	1	1
Reports	1	1
Sub-Total	$ 60	$ 81
Loaded Total	$ 76	$102

5.2.4 North Central Division

The North Central Division contains much of the state's population. Land use away from the cities includes considerable croplands, mountain rangeland (the Oquirrh and Stansbury Mountains), and semidesert rangeland between the two mountains.

As with Dixie, no modeling was done for the North Central Division. The Oquirrh and Stansbury Mountains are currently included in the on-going Southern Utah seeding program. The design for the remainder of the division was based on the design used in that program. Much of the water used in the North Central Division comes from runoff from the Wasatch Range just east of the division. The design should therefore include that area as well.

The suggested network of about 35 ground-based seeding units is shown in Figure 5.8. Many of the units in the eastern part of the division would be used for increasing snowpack in the Wasatch Plateau. However, if the results of the Southern Utah program apply in the north as well, increases should also occur in the valley locations.

Personnel requirements include a meteorologist (based in Salt Lake City) and a part-time technician to assist in network installation, maintenance, and removal.

Cost estimates for M1 and M2-type designs are given in Table 5.8. The expected seeding increment is 20 percent (M2).

TABLE 5.8

Cost Estimates For Standby Seeding Operations In The North Central Division

	Cost Estimate (1000's of Dollars)	
Expense	M1	M2
Labor	$ 37	$ 50
Aircraft	0	0
Ground seeding network	5	5
Seeding reimbursables	19	27
Rawinsondes	0	0
Office, Data, Living Allowance	14	20
Travel	2	4
Reports	1	1
Sub-Total	$ 78	$107
Loaded Total	$100	$135

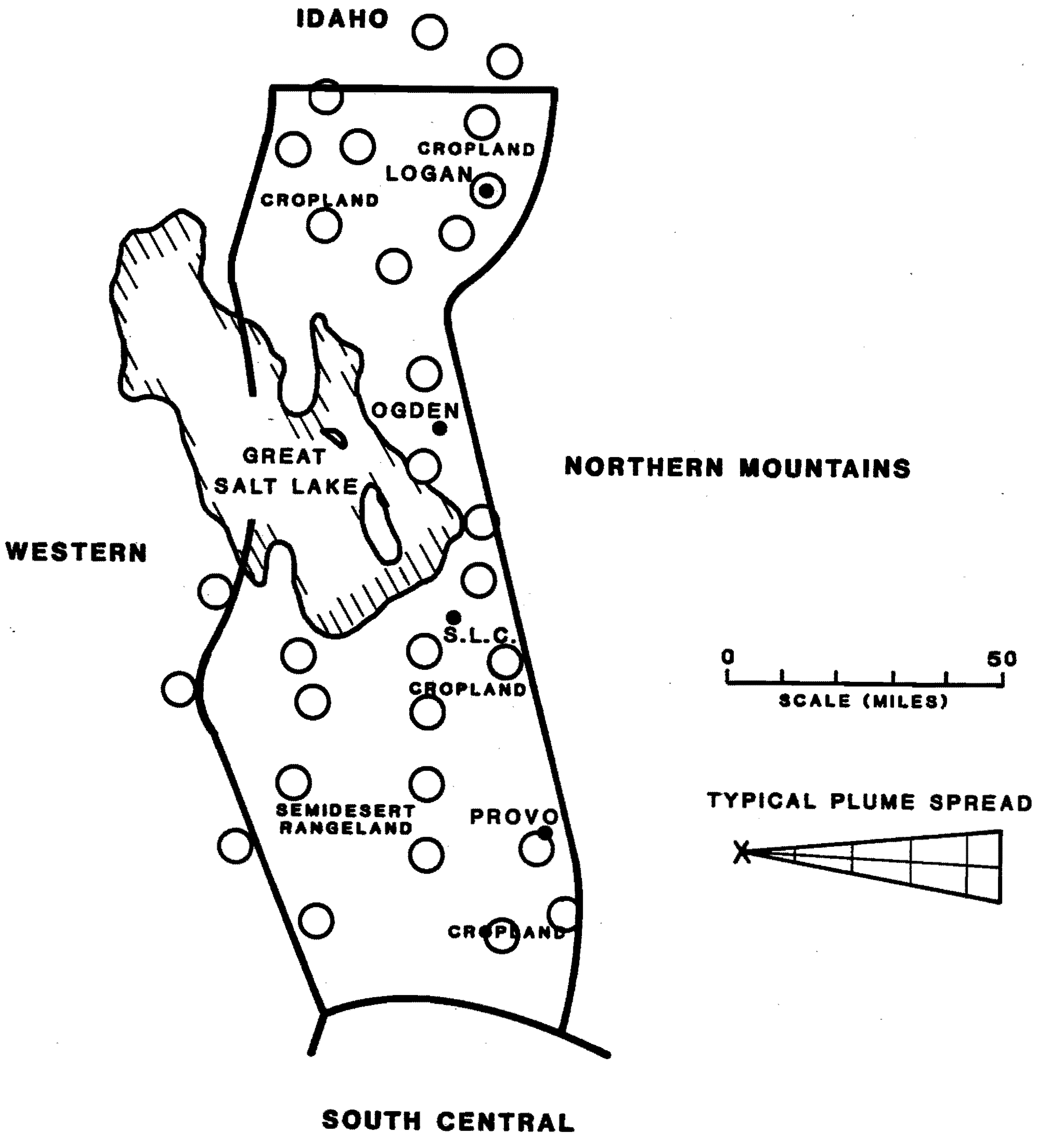


FIGURE 5.8. Suggested Design For Standby Cloud Seeding Operations In North Central Division. Ground-Based Seeding Units Are Indicated By O.

5.2.5 South Central Division

The large South Central Division contains a variety of land use types. The Wasatch Plateau extends north-south through the central part of the division. Runoff supports croplands on the upwind side of the plateau. Semidesert rangeland occurs to the lee of the plateau. Population is much less dense than in the North Central Division. However, there are many more farming communities than in the Western Division.

The area selected for modeling studies was from near Minersville to Emery (refer to Figure 5.5). The current Southern Utah seeding program includes a remotely-controlled ground-based seeding unit in the Black Mountains south of Minersville and a manually controlled seeding unit located near Beaver.

Modeling results are shown in Table 5.9. For stable conditions, seeding with the remotely-controlled unit near Minersville produced only a small effect on Monroe Peak (northeast of Marysvale). No seeding effect was predicted when the seeding site was removed to Beaver. With convection, the seeding increments increased, especially when the site near Minersville was used.

A special modeling run was made to simulate the more convective springtime storms. In this case, the cloud liquid water contents were doubled (maximum of 1 g/m^3). Seeding from the remote control site near Minersville resulted in good increases in the Tushar Mountains. Aerial seeding along Victor Airway 21E near Minersville resulted in a large area of seeding increases in and east of the Tushar Mountains.

TABLE 5.9

Summary Of Numerical Modeling Runs For South Central Division. Upwind Sounding Was Beaver, Composite

Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
near Minersville	Ground (8000 ft MSL)	SW	No	-17°C	0.1 mm/hr	Monroe Peak	Very small increment on Tushar Mountains
near Minersville	Ground	SW	Yes	-21	0.3	Fish Lake Mountains	Smaller increments on Monroe Peak and Tushar Mountains
Beaver	Ground (6500 ft MSL)	SW	Yes	-12	0	N/A	Plume lifted up Tushar Mnts and then blown downwind
Beaver	Ground	SW	Yes	-21	0.1	Monroe Peak	Blowover into Castle Valley
near Minersville	Ground	SW	Yes	-21	0.7	Tushar Mtns	Cloud liquid water increased to simulate more convective spring storms
near Minersville (Victor Airway 21E)	11,000 ft MSL	SW	No	-31	0.7	Fish Lake Mountains	Smaller effects on Tushar Mountains

These modeling results and the favorable results obtained in the on-going Southern Utah program argue for a design using a network of about 50 ground-based seeding units. Suggested seeding locations are shown in Figure 5.9. Four remotely-controlled, high elevation seeding units are included. The modeling studies suggest that the manually controlled sites in the central valley (from Manti to Panguitch) should only be used with light winds aloft. Otherwise, seeding effects would occur to the lee of the Wasatch Plateau. Similarly, the western-most seeding sites should be used to affect the front ranges of the Wasatch Plateau.

Personnel requirements include a meteorologist and a part time technician. In addition to assisting in installation and removal of the seeding network, the technician would also perform rawinsonde soundings from the operation base in Cedar City.

Cost estimates for M1 and M2 type designs are given in Table 5.10. Compared to the cost estimates for the North Central Division, these estimates are higher primarily because of the four remotely controlled seeding units, which are considerably more expensive than manual seeding units and also more difficult to service due to their remote, high altitude locations. The anticipated seeding increment is 20 percent (M2).

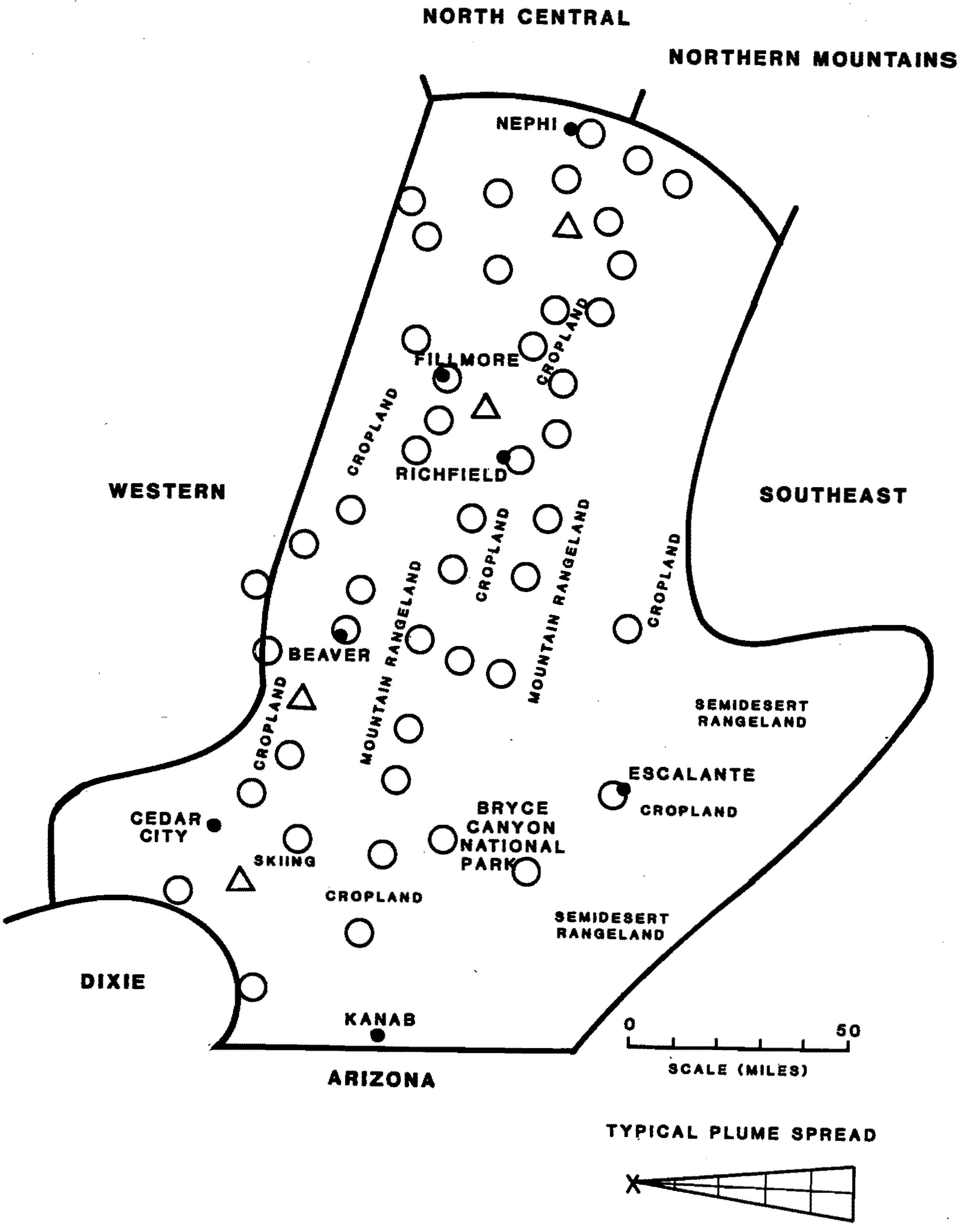


FIGURE 5.9. Suggested Design For Standby Seeding Operations In South Central Division. Ground-Based Seeding Units Are Indicated By O (Manual Control) or (Remote Control)

TABLE 5.10

Cost Estimates For Standby Seeding Operations In South Central Division

Expense	Cost Estimate (1000's of Dollars)	
	M1	M2
Labor	$ 41	$ 54
Aircraft	0	0
Ground seeding network	56	56
Seeding reimbursables	32	45
Rawinsondes	10	14
Office, Data, Living Allowance	14	25
Travel	3	4
Reports	1	1
Sub-Total	$157	$199
Loaded Total	$199	$252

5.2.6 Northern Mountain Divisions

The Northern Mountains Division includes both the Wasatch Range and the Uinta Mountains. Accordingly, most of the division consists of high mountain rangeland. However, there are areas of croplands in the high valleys, especially around Heber, Morgan, and Randolph.

Modeling studies concentrated on the Uinta Mountains. As was shown in Figure 5.5, three different wind flow patterns were investigated. Modeling results are summarized in Table 5.11.

For southwesterly flow, ground-based seeding near Heber was simulated. Under stable conditions, results were hindered by model time limitations (light low-level winds resulted in limited downwind dispersion). Extrapolating the last plume position further downwind suggests that the seeding plume

TABLE 5.11

Summary Of Numerical Modeling Runs For Northern Mountains Division. Upwind Sounding Was Salt Lake City, 78122812 Or Salt Lake City, 76120512

Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
Heber	Ground (5600 ft MSL)	SW	No	NA	NA	NA	Model limitation. Light winds near ground were nearly parallel to barrier, resulting in limited horizontal dispersion
Heber	Ground	SW	Yes	-30°C	$0.2\ \frac{mm}{hr}$	Uinta Mtns west of King's Peak	Small increment from near Heber to Uinta crest
20 km NE of Heber	Ground (7400 ft MSL)	SW	Yes	-28°C	0.0+	King's Peak	Blowover of effects into Wyoming
10 km NE of Heber (Victor Airway 484)	13000 ft MSL (minimum altitude)	SW	No	-30°C	0.5	Uinta Mtns west of King's Peak	High minimum altitude could preclude seeding colder storms
Southwest of Kemmerer, WY	Ground (6500 ft MSL)	NW	No	-21°C	0.2	King's Peak	Small increments in north slope foothills
Leroy, WY (40 km SE of previous location)	Ground (7500 ft MSL)	NW	No	-24°C	0.0+	Mountain Home, lower south slope foothills	Effects are displaced downwind and lessened relative to previous run

TABLE 5.11

Continued

Seeding Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
Southwest of Kemmerer, WY	Ground	NW	Yes	-26°C	0.4 $\frac{mm}{hr}$	Lower north slope foothills (in Wyoming)	Similar increments in higher elevations of north slope
Leroy, WY	Ground	NW	Yes	-24°C	0.0+	Mountain Home	Very small effects in Uinta Mountains
Fort Bridger VORTAC (Victor Airway 6)	10,000 ft (minimum altitude)	NW	No	-27°C	0.6	King's Peak	Good increments along north slope
West Tavaputs Plateau (40 km of NNE of Wellington)	Ground (9500 ft MSL)	SSW	No	-10°C	0.0+	South slope of Uinta Mtns Mountains	Increments from lower foothills to near King's Peak. Remote-control required.
West Tavaputs Plateau	Ground	SSW	Yes	-19°C	0.2	South slope of Uinta Mountains	Increments from lower foothills to King's Peak.

might ascend high enough to produce a seeding increment. With convection, the plume was carried aloft into stronger winds, and the maximum seeding increment occurred slightly west of King's Peak, with smaller increments predicted southwest of there to near Heber. Moving the seeding source 20 km downwind of Heber, where the elevation would be 1800 ft higher, had a negative effect on the maximum seeding increment, which decreased to almost zero from the 0.2 mm/hr increment from seeding near Heber. In addition, blowover of effects into Wyoming was also noted. Aerial seeding along Victor Airway 484 near Heber resulted in good seeding increments in the Uinta Mountains. However, the high minimum altitude requirements in this region could prevent seeding when the temperature at the seeding level was too cold. In the case used in the model, the temperature at seeding level was -15°C. Seeding at temperatures much colder than that would probably result in smaller seeding increments.

Another simulation was made for northwesterly flow over the Uinta Mountains. Seeding from near Kemmerer, Wyoming under stable flow resulted in a good increment at King's Peak. The width of the Uinta Mountains and the relatively large distance upwind to the seeding site probably explain the good results under stable conditions. When the seeding site was moved 40 km downwind (near Leroy, Wyoming), the seeding increment was decreased substantially compared to the previous run and blowover of marginal seeding increments to the Uinta Basin occurred. With convection, seeding from near Kemmerer produced a good increment in the north-facing slopes of the Uinta Mountains. Again, moving the seeding site to near Leroy decreased the increment. Considering the results under convective conditions in "real world" terms would probably change the value and location of the seeding increment, since "real world" convective updrafts and downdrafts occur in discrete locations rather than the averaged conditions in the model. That is, seeding near Kemmerer might not be as successful as the model indicates. An actual convective element near the seeding site could entrain the seeding material and result in seeding effects much nearer Kemmerer than modeled. Aerial seeding on Victor Airway 6 halfway between Kemmerer and Leroy resulted in a very good seeding effect along the north-facing slopes of the Uinta Mountains.

The third simulation for the Uinta Mountains was seeding atop the West Tavaputs Plateau with south-southwesterly flow. This modeling study was actually a variation of seeding studies for the Uinta Basin (see Section 5.2.7) and was shown in Fig. 5.4. The seeding location would require a remotely-controlled seeding unit. Seeding under stable flow resulted in only a slight increment in the Uinta Mountains. However, seeding in a more convective environment gave a good seeding increment to the south-facing slopes of the Uinta Mountains.

No modeling studies were conducted for the Wasatch Range. It was felt that the seeding design used for the portions of the Wasatch Plateau in the South Central Division could be transferred northward to the Northern Mountains Division.

The suggested design for standby seeding operations in this division involves a network of 35 ground-based seeding units, most of which would be located in the high valleys of the Wasatch Range (see Figure 5.10). Other seeding units would be located in Southwestern Wyoming to affect the Uinta Mountains under northwesterly flow. Two remotely controlled seeding units in the West Tavaputs Plateau are also recommended. The units located within the Wasatch Range would be used for

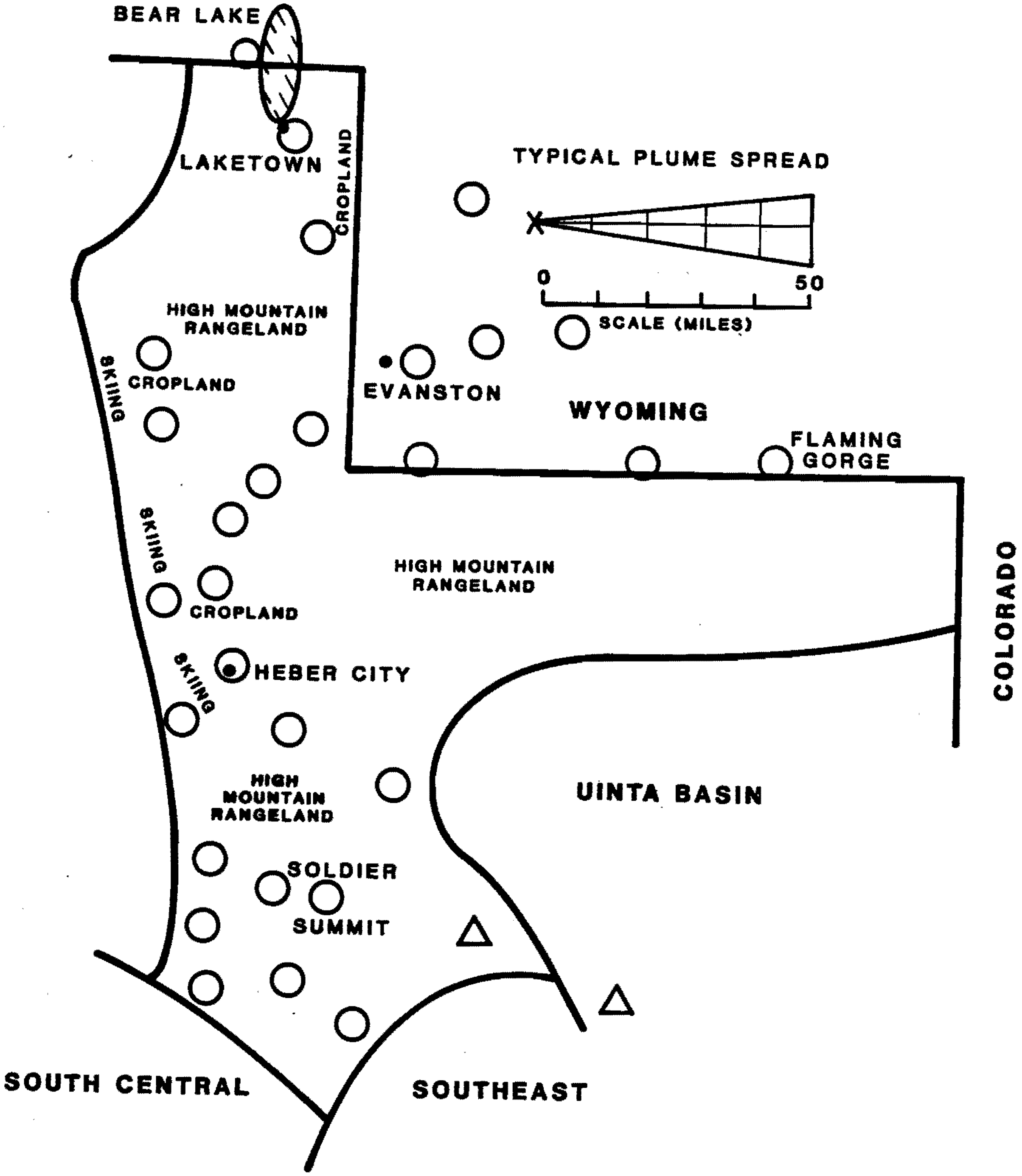


FIGURE 5.10. Suggested Design For Standby Cloud Seeding Operations In Northern Mountains Division. Ground-Based Seeding Units Are Indicated By 0 (Manual Control) And (Remote Control).

localized effects with light winds or for affecting the Uinta Mountains under stronger flow. Seeding effects in the Wasatch Plateau would actually be achieved with the network of seeding units used for the North Central Division (discussed in Section 5.2.4). This interconnection of divisions shows the problems in considering a design for only one division. Designs for combined divisions will be addressed in Section 5.4.

Recommended personnel include a meteorologist and a part-time technician to assist in network installation, maintenance, and removal. The operations base could be Salt Lake City. No project-specific rawinsondes should be required.

Cost estimates for M1 and M2-type designs are listed in Table 5.12. The expected seeding increment is 20 percent (M2).

TABLE 5.12

Cost Estimates For Standby Seeding Operations In The Northern Mountains Division

	Cost Estimate (1000's of Dollars)	
Expense	M1	M2
Labor	$ 37	$ 50
Aircraft	0	0
Ground seeding network	34	34
Seeding reimbursables	16	22
Rawinsondes	0	0
Office, Data, Living Allowance	14	20
Travel	3	4
Reports	1	1
Sub-Total	$105	$131
Loaded Total	$133	$166

5.2.7 Uinta Basin Division

The Uinta Basin is located in the northeastern part of the state and is formed by the Uinta Mountains to the north and the Tavaputs Plateau to the south. Cropland can be found in the north part of the division, while upland rangelands cover much of the south part. Most of the population is located in the Duchesne-Vernal area.

Previous studies (Thompson et al., 1978) have shown that trapping inversions occur frequently in the lower elevations of the basin. Therefore, seeding simulations within the basin were restricted to the Tavaputs Plateau. Both the West and East Tavaputs Plateau were considered (see Figure 5.5).

Results of the modeling simulations are listed in Table 5.13. For the West Tavaputs Plateau, seeding from Wellington under stable conditions had no effect, since vertical dispersion of the seeding plume was limited. Convection resulted in relatively small increments in the plateau and a smaller increment downwind near Duchesne. As was discussed in the previous section, seeding atop the West Tavaputs Plateau produced increases in the Uinta Mountains. Aerial seeding on Victor Airway 134 resulted in good increases in the plateau, with smaller effects downwind into the Uinta Mountains.

Very similar results were obtained from the modeling studies for the East Tavaputs Plateau. Seeding effects occurred only with convection when ground-based seeding was considered. Aerial seeding south of Green River on Victor Airway 8 produced better results.

TABLE 5.13

Summary Of Numerical Modeling Runs For Uinta Basin Division. Upwind Sounding Was GJT, 78011100

Seeding Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
Wellington	Ground (5500 ft MSL)	SSW	No	-11°C	0 $\frac{mm}{hr}$	NA	Limited vertical dispersion
Wellington	Ground	SSW	Yes	-21°C	0.1	West Tavaputs Plateau	Very small increment near Duchesne
Over Wellington (Victor Airway 484)	11,900 ft MSL (minimum altitude)	SSW	No	-28°C	0.4	West Tavaputs Plateau	Smaller increment on Uinta Mountains
East of Green River, Utah	Ground (4,500 ft MSL)	SSW	No	-7°C	0	NA	Limited vertical dispersion
East of Green River, Utah,	Ground	SSW	Yes	-14°C	0.2	East Tavaputs Plateau	Considerable blowover of diluted plume toward Vernal
40 km south of Green River (Victor Airway 8)	10,000 ft MSL	SSW	No	-17°C	0.5	East Tavaputs Plateau	Broad ice crystal fallout zone

In spite of the better effects from aerial seeding, the economic factors argue for a network of ground-based seeding units. The suggested network is shown in Figure 5.11. Note that all seeding units are located in the Southeast Division in order to target the Tavaputs Plateau. As a result of the small area affected, personnel requirements include only a meteorologist. No technician should be needed. The base of operations could be Price.

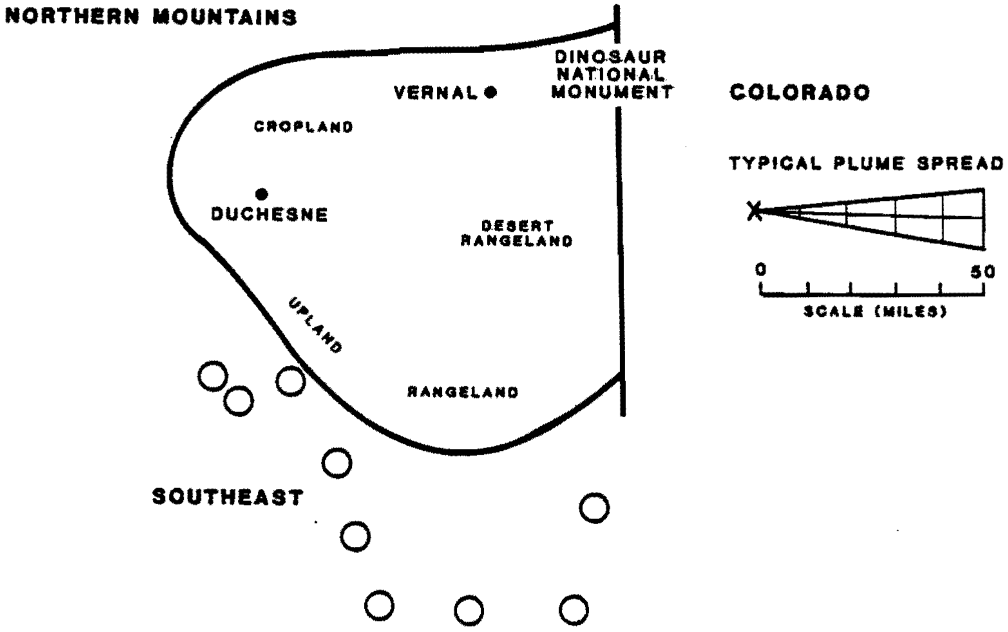


FIGURE 5.11. Suggested Design For Standby Cloud Seeding Operations In The Uinta Basin Division. Ground-Based Seeding Units Are Indicated By O.

Cost estimates for an M2-type design are given in Table 5.14. Since the conservative M1 seeding increment is zero, no cost estimates were provided for that type of design. The M2 increment is 10 percent.

TABLE 5.14

Cost Estimates For Standby Seeding Operations In The Uinta Basin Division

Expense	Cost Estimate (1000's of Dollars) M1	Cost Estimate (1000's of Dollars) M2
Labor	$ 0*	$ 48
Aircraft	0	0
Ground seeding network	0	0
Seeding reimbursables	0	7
Rawinsondes	0	0
Office, Data, Living Allowance	0	0
Travel	0	1
Reports	0	1
Sub-Total	$ 0	$ 79
Loaded Total	$ 0	$100

*: No design for M1 due to zero increment

5.2.8 Southeast Division

The arid Southeast Division consists mostly of semidesert and desert rangeland. However, the La Sal and Abajo Mountains near Moab and Blanding, respectively, provide high mountain rangelands. Three national parks, one national monument, and a national recreation area are located within the division.

The on-going seeding program in Southern Utah includes a network of ground-based seeding units located to affect the La Sal and Abajo Mountains. Project-specific rawinsondes are taken at Blanding.

As was shown in Figure 5.5, the simulated seeding location was from Mexican Hat to the Abajo Mountains to the La Sal

Mountains. Modeling results are shown in Table 5.15. Seeding from Mexican Hat or near Blanding produced a good effect in the Abajo Mountains with or without convection. The seeding increment was larger when the Mexican Hat seeding location was used. In this case, the greater distance upwind provided more time for vertical plume dispersion. Aerial seeding over Mexican Hat resulted in a large increment in the Abajo Mountains. (Unless unrealistically strong low level winds were used, seeding effects further downwind in the La Sal Mountains could not be simulated.)

The suggested design for standby seeding operations includes an aircraft in addition to a network of ground-based seeding units. The ground-based seeding network would be used in the windier, more convective storms. Aerial seeding would be used during more stable conditions and when northwesterly flow occurs. Figure 5.12 shows the elements of this design.

Project personnel include a meteorologist, a part-time technician, and an on-call pilot. The technician would assist in seeding network installation, maintenance, and removal and would also perform project-specific rawinsonde soundings. The recommended base of operations is either Blanding or Moab. Both have suitable airport facilities.

Cost estimates for M1 and M2-type designs are shown in Table 5.16. The anticipated seeding increment is 15 percent (M2).

TABLE 5.15

Summary Of Numerical Modeling Runs For Southeast Division. Upwind Sound Was GJT, 78021600

Seeding Location	Seeding Altitude	Wind Flow	Convection	Minimum Plume Temperature	Maximum Increment	Location of Maximum Increment	Remarks
Mexican Hat	Ground (4500 ft MSL)	SSW	No	-24°C	0.2 mm/hr	Abajo Mtns	
15 km SW of Blanding	Ground (5500 ft MSL)	SSW	No	-20	0.1	South slope of Abajo Mtns	Smaller effects near La Sal Junction
Mexican Hat	Ground	SSW	Yes	-27	0.4	Southwest of Blanding	Smaller effects in Abajo Mountains
15 km SW of Blanding	Ground	SSW	Yes	-22	0.2	South slope of Abajo Mtns	
Over Mexican Hat (no Victor Airway, 245° Radial from Cortez)	7500 ft MSL	SSW	No	-32	0.6	Abajo Mtns	

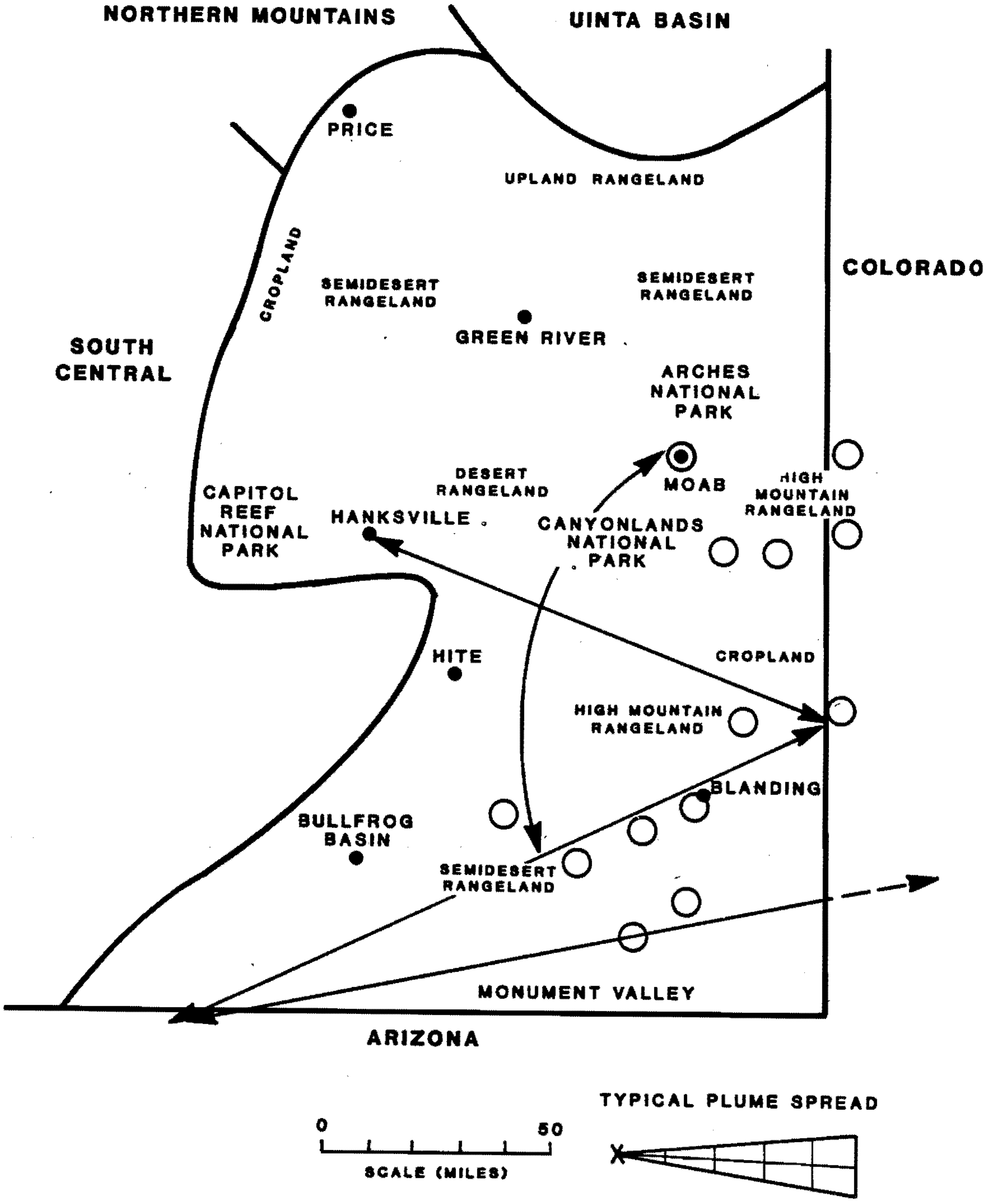


FIGURE 5.12. Suggested Design For Standby Cloud Seeding Operations In The Southeast Division. Ground-Based Seeding Units Are Indicated By O. Possible Aircraft Flight Tracks Are Shown By Arrows.

TABLE 5.16

Cost Estimates For Standby Seeding Operations In The Southeast Division

	Cost Estimate (1000's of Dollars)	
Expense	M1	M2
Labor	$ 40	$ 54
Aircraft	40	50
Ground seeding network	3	3
Seeding reimbursables	26	39
Rawinsondes	9	13
Office, Data, Living Allowance	14	20
Travel	2	3
Reports	1	1
Sub-Total	$135	$183
Loaded Total	$171	$231

5.3 Standby Seeding Programs In Combined Divisions

The standby seeding programs developed in the preceding section considered seeding within each of the seven climatological divisions of Utah. However, seeding programs designed to affect a region composed of several divisions would not only be more logical but also more cost-effective. For example, much of the water used in the North Central Division is runoff from the Northern Mountains Division. Thus, drought mitigation in the North Central Division should involve seeding in the Northern Mountains Division as well.

Based on these types of considerations, three regions of the state would seem suitable for a combined seeding program design. The regions include the northern part of the state (north part of the Western Division), North Central Division, and Northern Mountains Division), the southwestern part of the state (southpart of the Western Division), Dixie Division, and South Central Division) and the southeastern part of the state (Southeast Division and Uinta Basin Division).

Designs for those three regions will be developed below. No additional numerical modeling studies were performed for these combined designs.

5.3.1 Northern Region

The suggested design for the Northern Region consists of a network of ground-based seeding units to affect the North Central and Northern Mountains Divisions and an aircraft for seeding the far northwestern part of the region. Personnel requirements include two meteorologists, a pilot, and a part-time technician. No project-specific rawinsondes are recommended. The NWS soundings at Salt Lake City could be supplemented by aerial soundings if necessary.

Unless there are no seeding opportunities in the northwestern part of the region, use of the aircraft in other parts of the region is not recommended. Previous experience has shown that using an aircraft over too large an area greatly reduces the efficiency of aerial seeding.

Cost estimates for M1 and M2-type designs for the Northern Region are given in Table 5.17. These cost estimates show the considerable savings that can be realized by combining the seeding programs of adjacent divisions. The total costs of M2-type operations in each of the Western (north part), North Central, and Northern Mountain Divisions was $526,000, which is $125,000 more than the corresponding cost estimate for combined operations.

TABLE 5.17

Cost Estimates For Standby Seeding In The Northern Region

Expense	Cost Estimate (1000's of Dollars) M1	M2
Labor	$ 81	$107
Aircraft	40	50
Ground seeding network	37	37
Seeding reimbursables	66	95
Rawinsondes	0	0
Office, Data, Living Allowance	18	25
Travel	2	3
Reports	3	3
Sub-Total	$247	$320
Loaded Total	$312	$405

5.3.2 Southwestern Region

A network of 70 ground-based seeding units is the major constituent of the design for the Southwestern Region. Additionally, four remotely-controlled seeding units in the southern Wasatch Plateau are recommended. Personnel requirements include two meteorologists based in Cedar City and a full-time technician. Project-specific rawinsondes at Cedar City are also recommended.

In the M1-type design for the southern part of the Western Division (see Section 5.3.2.), a special operating season of March through May was suggested. For the combined M1 design, deploying the seeding units in that part of the region in November is recommended, since they can also be used to seed the Pine Valley Mountains and far southern Wasatch Plateau under northwesterly flow.

Cost estimates for M1 and M2-type designs for the Southwestern Region are given in Table 5.18. As with the Northern Region, savings resulting with the combined program are considerable. For the M2-type design, the cost reduction is $137,000 ($463,000 vs $326,000).

TABLE 5.18

Cost Estimate For Standby Seeding In The Southwestern Region

	Cost Estimate (1000's of Dollars)	
Expense	M1	M2
Labor	$ 72	$ 95
Aircraft	0	0
Ground seeding network	59	59
Seeding reimbursables	42	59
Rawinsondes	10	14
Office, Data, Living Allowance	18	25
Travel	2	3
Reports	3	3
Sub-Total	$206	$258
Loaded Total	$261	$326

5.3.3 Southeastern Region

The design for the Southeastern Region is very similar to the design for the Southeastern Division. It differs by incorporating a network of ten ground-based seeding units from Price to east of Green River to affect the Tavaputs Plateau. Seeding north of there to affect the remainder of the Uinta

Basin Division was not considered for two reasons. First, inversions seem to be a frequent problem within the Uinta Basin. Second, much of the water used in the basin is runoff from the Uinta Mountains, which would be seeded in the Northern Region combined program.

The suggested design for this region involves a network of ground-based seeding units to affect the La Sal and Abajo Mountains and the Tavaputs Plateau and an aircraft for seeding when use of the ground-based network would be inappropriate.

Personnel include a meteorologist, a part-time technician, and an on-call pilot. The base of operations should be either Blanding or Moab. Rawinsonde soundings from the base are recommended.

Cost estimates for M1 and M2 designs are listed in Table 5.12. Note that the estimate for M1 operations is identical to the estimate for the Southeast Division alone (Table 5.16), the reason being that the estimated M1 increment for the Uinta Basin was zero.

TABLE 5.19

Cost Estimate For Standby Seeding In The Southeastern Region

Expense	Cost Estimate (1000's of Dollars) M1	Cost Estimate (1000's of Dollars) M2
Labor	$ 40	$ 55
Aircraft	40	50
Ground seeding network	3	4
Seeding reimbursables	27	48
Rawinsondes	9	13
Office, Data, Living Allowance	14	20
Travel	2	3
Reports	1	3
Sub-Total	$136	$196
Loaded Total	$171	$248

5.4 Summary Of Standby Seeding Design

In this section, designs for standby cloud seeding programs have been developed. Programs for individual climatological divisions and for combined divisions were considered. Silver iodide, released either from ground-based seeding devices or from aircraft, was the seeding agent recommended for all programs. Development of the designs relied on previous experience, numerical modeling guidance, and logistical considerations.

Elements of the suggested design for individual divisions are listed in Table 5.20. Each seeding program would be directed by a meteorologist, who in most cases would be assisted by a technician. Aerial seeding was recommended in the northern part of the Western Division and in the Southeast Division.

TABLE 5.20

Summary Of Design For Stand-By Seeding Operations In Each Climatological Division

						Estimated Costs (1000's of dollars)	
						M1	M2
Division	Personnel	Ground-based Seeders	Aircraft	Rawinsondes	Suggested Base	Conservative	Liberal
Western (north)	M, P	0	1	0	SLC	$163	$225
Western (south)	M, T	20	0	0	CDC	55*	109**
Dixie	M	10	0	0	SGU	76	102
North Central	M, T	30	0	0	SLC	100	135
South Central	M, T	54	0	1	CDC	199	252
Northern Mountains	M, T	37	0	0	SLC	133	166
Uinta Basin (Tavaputs)	M	10	0	0	PRI	NA	100
Southeast	M, T, (P)	15	1	1	BLD	171	231

Legend:

Personnel - M = meteorologist, T = technician, P = pilot, (P) = on-call pilot
Base - SLC = Salt Lake City, CDC = Cedar City, SGU = St. George, PRI = Price, BLD = Blanding
M1 - Conservative seeding increment, operations from November 1 to March 31
M2 - Liberal seeding increment, operations from November 1 to May 31
* - Modified operating season, March 1 to May 31
** - Conservative increment, liberal operating period

In all other divisions, a network of ground-based seeding devices was recommended.

Combining the seeding programs of adjacent divisions would result in large cost reductions since personnel and facilities could be shared. Combined seeding programs were developed for three regions of the state. These include the North, which consists of the northern part of the Western Division, the North Central Division, and the Northern Mountains Division; the Southwest, consisting of the southern part of the Western Division, the Dixie Division, and the South Central Division; and the Southeast, which includes the Tavaputs Plateau of the Uinta Basin Division and the Southeast Division. Seeding programs for those three regions are summarized in Table 5.21.

TABLE 5.21

Summary Of Design For Stand-By Seeding Operations In Combined Climatological Divisions

						Estimated Costs (1000's of dollars)	
						M1	M2
Region of Utah	Personnel	Ground-based Seeders	Aircraft	Rawinsondes	Suggested Base	Conservative	Liberal
North	2M, T, P	50	1	0	SLC	$312	$405
Southwest	2M, T	74	0	1	CDC	261	326
Southeast	M, T, (P)	25	1	1	BLD	171	248

Legend:

Personnel - M = meteorologist, T = technician, P = pilot, (P) = on-call pilot
Base - SLC = Salt Lake City, CDC = Cedar City, SGU = St. George, PRI = Price, BLD = Blanding
M1 - Conservative seeding increment, operations from November 1 to March 31
M2 - Liberal seeding increment, operations from November 1 to May 31

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6. THE ECONOMICS OF CLOUD SEEDING AND ALTERNATIVE DROUGHT RELIEF PROGRAMS

6.1 The Economics Of Cloud Seeding Technology

Cloud seeding is a supply-increasing technology and therefore needs to be evaluated in terms of the benefits of supply augmentation over supply without the technology. Cloud seeding is also used to modify the extremes of weather conditions, particularly to suppress hail damage or to modify drought conditions, the latter function being the important use as far as this current study is concerned. In both cases the supply function, in our case at hand, for crops and livestock commodities is shifted by successful application of the technology. In one sense, weather modification through cloud seeding can be applied to existing production conditions, such as reported by Buller et al. (1981) for wheat, corn, and soybean production in Kansas. It can also be applied to reduce the damage from drought conditions, as is reported here in this study. The key economic issue is the measurement of benefits from supply augmentation of existing production conditions relative to measuring the benefits of the modification of a hazard for certain locations and economic activities, such as agricultural production. In Chapter 3 we were concerned with the definition of economic damage due to the drought hazard. It was at that point that an estimation of the value of economic activity was made, taking into account the physical effects of drought and the value of economic activity if no drought had taken place. Damages were defined as the direct cost attributable to drought conditions, not including costs incurred by, say, inappropriate responses to drought. If, for example, after a drought occurs, an entrepreneur chooses an activity which is less valuable than the optimal (costminimizing or profit-maximizing) activity for his or her resource base and market, that loss should not be charged off as drought damage. The inclusion of such losses are ruled out by the use of the optimization procedure to estimate the impacts of drought. The approach used is a "with drought-without drought" analysis of the damage costs of drought rather than a "before drought-after drought" analysis. The latter is an incorrect approach because it includes not only the effects of the drought itself, but the effects of anything else that might have happened in the intervening period, as well as the effects caused by the passage of time. We have shown how to calculate the market evaluation of damage from two types of drought episodes. These are imposed at a time when the economic and technological conditions of production are completely described and the physical effects of the drought are known. However, such calculations are not necessary, nor are they sufficient to make optimal investment decisions about the modification of the drought hazard. Furthermore, as pointed out some time ago by Brown et al. (1972), to understand the benefits of any hazard control measure does not require a knowledge of expected damages before or after the hazard control measure. However, the concept can aid in establishing lower and upper bounds to the benefits of control of hazards, such as drought conditions, and thus be of some use in making decisions about drought modification. Certain public policies concerning drought, such as relief policies, are based on the magnitude of drought damages and are triggered by the realization of damages at different levels. We later discuss some of the resource misallocation effects of such policies which are based on damage magnitudes.

In order to determine benefits associated with the modification of drought impact, we have to have associate hazard cost and damage reduction to the benefits of hazard reduction. Formal conceptual treatises on this issue have been presented by Lind (1967), Freund and Tolley (1964), Brown (1972) and Brown et al. (1972). The conclusions of these derivations are only summarized here.

The hazard cost of any economic activity is the expected present value of the infinite stream of damages imposed by some hazard which, in the case at hand, is the damage resulting from a history of drought episodes imposed on any particular economic activity. The hazard cost is actually the difference between the expected present value of an economic activity's income stream without damage due to drought (or any other hazard), and the expected present value of the activity as affected by the probability of damage. The expected present value of the activity is a decreasing function of the probability of damage. The purpose of drought modification as an ongoing program is simply to reduce the probability of drought occurrence. Such modification alters the hazard cost and leads to damage reduction. This can be defined as the difference between the hazard cost of an activity at some original hazard occurrence probability, and the hazard cost associated with a new and reduced probability of damage occurrence.

Damage reduction is defined for a given activity. Damage reduction is undefined if entrepreneurs change activities as a result of hazard protection, such as drought modification. Damage reduction cannot be taken as the benefits of hazard modification if the activities change. If, for example, Activity #1 is less vulnerable to the impacts of drought, then it is a more attractive activity when drought episodes occur frequently. If Activity #2 is more vulnerable to the effects of drought, then it is a more profitable alternative than Activity #1 when drought occurs less frequently. If the probability of drought for a certain intensity is, for example, 0.60 before some modification is implemented, entrepreneurs in the location susceptible to the drought hazard would engage in Activity #1 and face the hazard cost associated with that probability. If the modification project is implemented and the probability of the drought is reduced to 0.20, then entrepreneurs would now operate Activity #2, since it has higher expected present value and the hazard cost faced is now reduced. Therefore, the benefits of the drought modification program have to be measured in such a way as to account for the switching of activities as the probability of the hazard occurrence is altered. Benefits of the modification program are not identical to the damage reduction. This distinction between damage reduction and project benefits can be made clear by an actual example from Utah agricultural operations. Milk production in Utah could potentially incur great costs from drought conditions because of the dependence on alfalfa hay for feed, whereas turkey production depends on a fairly reliable sorghum product as a feed, which is imported from the Midwest and is, therefore, less vulnerable to drought conditions. Nonetheless, the returns from milk production are greater and less volatile than those from turkey production in the State, and it is worthwhile to risk an occasional large cost. This is a case of the hazard cost increasing with a decrease in drought probabilities. Yet, if the expected present value of the dairy industry with a given probability of drought occurrence is greater than the expected present value of turkey production facing the same probability of drought, then the benefits of drought modification are positive. The hazard cost from the modification can be reduced, increased, or be left unchanged, but the absolute value of the damages tells us nothing about the benefits of the modification program. Damage reduction can only give us upper and lower bounds on the benefits of the program if we know the optimal activities before and after the implementation of modification, along with the hazard cost for each activity as a function of the probability of drought occurrence.

The optimization model used accounts for the major interactions of agricultural activities in the regions of the conterminous U.S. which impact Utah agriculture. Therefore, activity switching is accounted for in each optimal solution to the model, rendering it not only useful in estimating drought costs but also appropriate in deriving the benefits of drought modification, as is done in this chapter. Simulations have already been made of the 1934 and 1977 drought conditions as imposed on current crop, livestock, and water delivery and storage activities. This provides the "without project" base, upon which to impose drought modification effects of the cloud seeding technology for the State of Utah as outlined in Chapter 5.

6.2 The Benefits Of Modifying The 1934 And 1977 Drought Types By Cloud Seeding

6.2.1 Benefits Of Modification By The Best-Practice Technology

A cloud seeding design for each climatological region in Utah was previously developed and reported in Chapter 5. The design for each region specified the percent increase in precipitation that is most likely to be achieved, and we term that particular design and associated percentage increment in precipitation as the "best-practice technology" for each region. A very conservative increment in precipitation due to the cloud seeding has been termed the M1 increment as a short symbolism for the conservative level of weather modification. A more liberal or optimistic level of modification was also estimated and has been labeled the M2 increment. As indicated earlier in Chapter 5, the two seeding increments differ in the length of the seeding program as well as the degree of moisture increment which can be obtained at any given period of time during the seeding program. The suggested seeding increments for both the M1 and M2 levels are listed for each region in Table 6.1 along with the suggested best-practice increments for each region. Recall the Dixie climatological region was also included in the estimates with the M1 increment being 10.0 percent and the M2 increment at 20.0 percent. In the estimate of benefits of modification, we take an estimate of the precipitation increments (for example,

TABLE 6.1

Suggested Cloud Seeding Increments And Best Practice Seeding Program For Each Climatological Region Of Utah

Region	Conservative Increment (M1)	Liberal Increment (M2)	Best Practice Technology (M1 or M2)
	Percent	Percent	
Northwest (I)	5.0	15.0	M2
North Central (III)	10.0	20.0	M2
Northern Mountains (V)	10.0	20.0	M2
Southwest (II)	5.0	15.0	M1
South Central (IV)	10.0	20.0	M2
Uinta Basin (VI)	0.0	10.0	M2
Southeast (VII)	5.0	15.0	M2

the M1 and M2 values for the western region which was divided into northern and southern sub-divisions). These divisions we have delineated as, respectively, the Northwest and Southwest Regions.

By using the above percentage change in precipitation conditions for the best practice modification technology applied to each region, changes in water availability and, in turn, production conditions were derived from the hydrological analysis of Chapter 2 and the new solution to the economic model with new parameters reflective of the modification imposed on the constraint system of the model. The incremental changes in the availability of surface water in each region are listed in Table 6.2, and the incremental changes in range forage production, which will in turn change the availability of animal unit months (AUMs), are given in Table 6.3.

These and other alterations were imposed on the economic model to obtain an estimate of net revenue for each region of interest under conditions of modification of both the 1934 and the 1977 drought imposition on the model. A comparison of the revenues derived from the model under the modified conditions with those under the drought imposition, i.e. the difference between the two revenue levels, provided estimates of the benefits of the best-practice seeding technology. These estimated benefits, as derived from the modeling procedure, are given in Table 6.4 for the Utah regions and for modification of both drought types. It is seen that by far the greatest benefit was realized in Southern Utah Regions, particularly in the Southeast Region where the modification, if implemented, would help to maintain the dry bean enterprise as well as the cow/calf operations which exist in that region. The losses which were reflected in Regions III and II were due to price

TABLE 6.2

Incremental Changes In Surface Water Availability Due To The Estimated Best-Practice Cloud Seeding

	Percent	Change
Region	From 1934 Drought Conditions	From 1977 Drought Conditions
Northwest (I)	12.0	16.0
North Central (III)	11.0	17.0
Northern Mountains (V)	15.0	17.0
Southwest (II)	4.0	2.0
South Central (IV)	30.0	21.0
Uinta Basin (VI)	no change	10.0
Southeast (VII)	29.0	26.0

TABLE 6.3

Incremental Changes In Range Forage Availability Due To The Best-Practice Cloud Seeding

	Percent	Change
Region	From 1934 Drought Conditions	From 1977 Drought Conditions
Northwest (I)	3.0	6.0
North Central (III)	12.0	3.0
Northern Mountains (V)	4.0	7.0
Southwest (II)	no change	2.0
South Central (IV)	5.0	7.0
Uinta Basin (VI)	no change	5.0
Southeast (VII)	3.0	12.0

TABLE 6.4

Estimated Benefits Of The Best-Practice Cloud Seeding Program For Regions In Utah

Region	Benefits (Millions of 1979 Dollars) Above 1934 Drought Conditions	Above 1977 Drought Conditions
Northwest (I)	2.2	1.1
North Central (III)	(0.5)[a]	1.2
Northern Mountains (V)	2.0	0.5
Southwest (II)	1.0	(0.4)[a]
South Central (IV)	1.0	0.2
Uinta Basin (VI)	1.7	1.0
Southeast (VII)	5.2	2.1
TOTAL UTAH BENEFITS	12.6	5.7

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[a] Numbers in parenthesis indicate a loss.

changes which occurred in specialty crops (alfalfa hay and alfalfa seed) as increased quantities of these commodities were produced under the modification scenario as derived from the economic model. In general, Utah producers gained from a state policy of cloud seeding relative to other producers in other regions, as production was increased by the cloud seeding influence on water availability and, in turn, an increase in the supply of agricultural commodities in the state. However, there were some crops whose production does dominate the market during certain seasons of the year, and, hence, price was affected by production changes, in the case of modification, in a downward direction. That is, supply was shifted (increased) under inelastic demand conditions and therefore revenues decreased as indicated in the two regions which suffered losses from the modification program. In general, all livestock activities benefited greatly from the seeding program primarily because range forage in all regions was increased, which reduced imports of hay and barley.

6.2.2 Benefit - Cost Comparisons

Total benefits of cloud seeding in a static setting to modify the effects of a drought of the 1934 intensity as imposed on current agricultural production conditions in the state are estimated at $12.6 million; that is, if the best practice modification program is assumed to be undertaken. The costs for such a program, if set up on a region-by-region basis for all of the climatological regions of the state, as derived in Chapter 5., is currently estimated at $1.3 million. The static benefit/cost ratio is then 9.69 for the state program. To modify the drought conditions of the 1977 intensity using best practice seeding procedures requires the same estimated cost of $1.3 million, but the benefit of the modification is much less at $5.7 million, giving a static benefit/cost ratio of 4.38. The more relevant comparison, however, is a benefit/cost comparison on a regional basis. Static benefit/cost ratios have been computed for each region for modifying both the 1934 and 1977 drought conditions and are given in Table 6.5.

It was indicated in Chapter 5 that costs could possibly be reduced by implementing the cloud seeding program on a broader regional basis than the climatological divisions of the State. If the program is implemented as a Northern Utah, Southwestern Utah and Southeastern Utah Program, the modification costs for these broader regions would be estimated at, respectively, $405,000, $326,000 and $248,000. With these savings, the benefit/cost ratio for the State would be 12.6 for modifying the impacts of the 1934 drought conditions and 5.7 for modifying the 1977 drought conditions. The estimated static benefit/cost ratios for the Northern Utah, Southwest Utah, and Southeast Utah Regions would be, respectively, 9.1, 6.1, and 27.8 for modifying the impacts of a drought of the 1934 intensity. To modify the impacts of a drought of the 1977 severity, the benefit/cost ratios are 6.9 and 12.5 for, respectively, the Northern Utah and Southeastern Utah Regions, but seeding incurs a loss in the Southwestern Utah Region.

TABLE 6.5

Estimated Static Benefit/Cost Ratios For Cloud Seeding To Modify The Impacts Of Droughts Of The 1934 And 1977 Intensities

	Benefit/Cost Ratios	
Region	To Modify 1934 Drought	To Modify 1977 Drought
Northwest (I)	9.8	4.9
North Central (III)	loss	8.9
Northern Mountains (V)	12.0	3.0
Southwest (II)	18.2	loss
South Central (IV)	4.0	0.8
Uinta Basin (VI)	17.0	10.0
Southeast (VII)	22.5	9.1

6.2.3 The Benefits Of The Conservative Cloud Seeding Program

For comparative purposes, alterations in the economic model to reflect changes resulting from the more conservative cloud seeding program (M1) outlined in Chapter 5 were made and a new model solution was obtained for modification of both the 1934 and 1977 drought conditions. The estimated benefits derived from the new solutions are given in Table 6.6.

Benefits derived from the M1 level of drought modification were, of course, considerably lower than those derived for modification using the best-practice cloud seeding program. The small benefits listed for the Uinta Basin Region (Region VI)

TABLE 6.6

Estimated Benefits For The Conservative (M1) Cloud Seeding Program For The Regions Of Utah

	Estimated Benefits (Millions of 1979 Dollars)	
Region	Above 1934 Drought Conditions	Above 1977 Drought Conditions
Northwest (I)	1.3	0.7
North Central (III)	(0.1)[a]	0.6
Northern Mountains (V)	1.1	0.2
Southwest (II)	0.2	(0.1)
South Central (IV)	0.5	0.2
Uinta Basin (VI)[b]	0.01	0.07
Southeast (VII)	1.2	0.9

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[a] Numbers in parenthesis indicate a loss.

[b] No cloud seeding is proposed for the Uinta Basin under the M1 seeding program. Values indicate increases arising from decreased import and livestock enterprise input costs.

reflected increases in net revenues in that region despite the fact that no cloud seeding is assumed to be implemented in that area under the M1 seeding program. The increased revenues arise from the fact that import costs decreased and some decreases in input costs for the livestock sectors in that region declined with increased production in other regions in Utah due to cloud seeding in these other regions.

Some benefit/cost comparisons can be made using these estimates of the benefits from a smaller increment in precipitation conditions. The estimated cost for such a program is $897,000. The total benefit for the State of Utah is $4.2 million for modifying the 1934 drought type and $2.6 million for modifying the 1977 drought conditions. Therefore, the static benefit/cost ratios are respectively, 4.7 and 2.9. The regional benefit/cost ratios are, 6.5, 1.5, 2.5, 8.3, and 6.0 for, respectively, Regions I, II, IV, V, and VII for modifications of the 1934 drought conditions. There is a loss calculated for Region III, and no investment is assumed in Region VI but that region does receive a positive external benefit from the seeding program in the state. For modifying the 1977 drought impacts, the static benefit/cost ratios for Regions I, III, IV, V and VII are, respectively, 3.5, 6.0, 1.0, 1.7 and 4.5.

Reductions in cost can again be experienced by combining the regions into broader regions for administering the seeding program. This saves some $153,000 compared to the region-by-region program based on the climatological divisions of the state. The benefit/cost ratios at the state level then become 5.7 and 3.5 for modifying, respectively, the 1934 and 1977 drought conditions as imposed on current production and distribution conditions. The broader region benefit/cost ratios with the savings in cost are estimated at 7.4, 2.7, and 6.1 for respectively, the northern, southwestern, and southeastern parts of Utah for altering the 1934 drought type, and are 4.9, 0./4, and 4.9, respectively, for the same broader regions for modifying the 1977 drought.

In general, it does not currently appear feasible to cloud seed in the southwestern part of Utah if only the conservative level change in moisture conditions can be achieved and drought conditions are of similar intensity to that of the 1977 severity. There are some questions about the implementation of a conservative increment operation of cloud seeding along the Wasatch Front (Region III) because of the price changes that are induced by the program, particularly prices of specialty crops such as fruit crops, and to a certain extent alfalfa hay at certain times of the year. It should be remembered, however, that benefits to agriculture are the only gains which are evaluated here. Benefits to urban or industrial activities may be even larger, but, of course, there are costs to add also.

6.3 Evaluation Of Alternatives To Cloud Seeding

There are several alternatives to cloud seeding which have been implemented during periods of drought. Most of these alternatives are aimed at recovering damages after drought conditions have deteriorated a particular economic activity or after some deterioration in capital investment has taken place. Many of the policies to recover from losses are tied to some critical level of loss or damage. These programs can be categorized into a general class of relief policies, and their effects on the investment policies of private firms or individuals are much the same for all variations and types of policies. There is another policy which is important to consider in a discussion of alternative policies to implement in the face of hazards, such as drought conditions. It is not so much a policy implemented by some oversight agency as it is the performance of exchange in the face of shortages of inputs and finished products, and that is the performance of input and output markets to appropriately allocate resources in the face of the drought risk. The existence or lack of existence of certain institutions and assignments of property rights influences the performance of the markets for goods and services, and hence the allocation of resources. In the market economies of the Western world, it is generally the price in the market which adjusts to the supply and demand conditions to allocate resources and products to competing users. In centrally planned economies, prices are generally administered to remain constant, though demand and supply conditions may vary from time to time. Under such conditions, the rationing is done by queues. Shortages precipitate queues in these types of economies, whereas shortages, i.e., backward shifts in supply for given demands, cause prices to adjust to clear the market in market economies. Frictionless adjustments in price yield optimum welfare in an economic sense, i.e., social welfare is increased by swift adjustment. If adjustments take time or are never completely made in the market, then welfare losses occur. It is on these two broad classes of alternatives that we concentrate our qualitative evaluation in the next two sections.

6.3.1 Relief Policies

Monetary grants, loan funds, replacement of capital, expense sharing, tax breaks, etc. can all be considered as some form of a relief policy to modify the impacts of drought. During the recent drought of 1976-77, several forms of these policies were proposed at both the state and national policy-making level. Several states adopted legislation which enabled a contingency fund to be eventually built up either to loan funds at a favorable interest rate relative to the market rate or to tie monetary grants to certain claims or actions on the part of individuals, firms, or communities who suffered from drought damage. This is also a prime example of a relief policy.

The main objection to relief policies in general is that they have a misallocative effect on markets and the investment process under certain conditions. Intertemporally (over time), and in the absence of any drought hazard, an investor will prefer a specific activity which is vulnerable to drought conditions over another activity which is less vulnerable if the present value of the returns from the first activity is greater than that of the less vulnerable activity. If the two activities are identical in every aspect except that the less vulnerable activity is more durable because there has been a greater investment to provide durability, then intertemporally as the discount rate (social rate of time preference) increases so does the investment in the more vulnerable activity. That is the social order of preference for investment activities, since a higher present value of returns is derived from the activity with the lower initial cost. That preference does not change with the implementation of a relief policy to aid private investors who face damages from natural hazards. Thus, resources are channeled into the more vulnerable activity and the process is not changed, and in some cases is even accelerated by relief policies. There is no incentive provided for shifting to more durable investment alternatives in the face of expected damages to occur from the particular hazard. In fact, the relief policy in the case of identical activities, with the exception of the initial cost difference associated with durability, constitutes a direct disincentive to invest in durability.

Relief payments or loans can come in various forms, but are usually given in some relation or proportion to initial investment costs or replacement costs of certain damaged activities. Some are variable proportion relief policies, and some are in the form of a fixed percentage of the initial investment or replacement costs. In general, fixed percentage relief policies have a smaller misallocative affect than the variable relief policies. Under relief programs, the private investor may find it convenient to invest in the more vulnerable activity even if the cost of doing so is substantially higher than the social break-even point. However, the private break-even point under the disincentives of a fixed percentage relief is at a point which is less, in terms of level of investment, than the private break-even point under the disincentives of a variable relief policy. All of these conclusions require rather complex mathematical proofs which are not outlined here, but most can be found in Brown (1970), Brown et al. (1972), and Lind (1973).

Our discussion thus far has assumed that risk preferences do not need to be accounted for. However, the firm which is subject to the occurrence of drought faces, in a sense, a stochastic tax on capital by nature so that the level of profits becomes a random variable. Assuming that the firm's objective is to then maximize the expected utility of profits, then a risk-averse entrepreneur in an area vulnerable to drought will consider the risk of the drought as a cost of capital in addition to the drought damages to capital, the capital being items such as live capital (brood cows or ewes in the case of livestock firms) or range forage land, etc. The risk-averse firm, in this case, produces less output and employs less capital relative to labor in the production process than in the case where risk preference is not considered or in the case of risk neutrality. Relief programs administered in proportion to the investment cost or replacement of capital will alter the perceived price of capital, i.e., lower the price of capital and cause increases in the employment of capital relative to labor by the risk-averse firm, and thereby increase output and the expected damages from a drought hazard. Again, the misallocative effect of relief programs is present. For the risk-averse firm, the alternative of purchasing some form of insurance also operates to increase the costs from a drought hazard by reducing the perceived cost of capital. Insurance for risk-preferers raises the perceived cost of capital by eliminating the desired risk of loss, hence reduces the expected damages from drought hazard, or any other natural hazard. Risk-preferers, however, are unwilling to purchase insurance voluntarily.

6.3.2 The Water Market During Drought

As indicated previously, water (as a productive and very important resource in the arid West) can be appropriately allocated to its most valued use if markets for water are operating in such a way as to maximize the mobility of the resource. We briefly discuss the operation of markets under current water law, which governs the allocation of water in the Western U.S. and Utah in particular, in order to make some qualitative statements about the use of markets as an allocative mechanism during periods of drought to modify the impacts of drought conditions.

In the Western U.S., the states have generally adopted some form of the appropriation doctrine to govern the use of water within their borders. Accordingly, they set up state laws to govern water use and transfer among users. The strict interpretation of the appropriation doctrine is to maintain established or senior rights to water upon perfecting the right under beneficial use criteria established by state law, or as state law empowers authority in a state engineer or other agency. For simplicity of explanation, we can assume two water users who use water from a particular source, with User A being the upstream user and B being the downstream user. Both users derive benefits from their respective diversions and these benefits increase as the diversions increase up to a certain critical level of diversion at which marginal (incremental) benefits fall to zero. Weights may or may not be attached to the benefits of either user as generated from the use of their diversions. Such weights, if associated with benefits, could reflect a public policy to favor certain uses over others, such as the protection of agricultural uses, or they could reflect the effect that differing seniorities of water rights can have on water allocation. Economic efficiency requires the discovery of a particular pattern of water allocation between the users that will maximize the net quantifiable benefits resulting from the water use. That is, the diversions of A and B are chosen so as to maximize the sum of the weighted benefits subject to the constraints that the upstream user, A, cannot, of course, divert more water than is provided by the source, and that the downstream user, B, cannot divert more than the capacity of the source less user A's consumptive use fraction applied to A's diversion (water not consumed by A from the source). To the extent that the capacity of the water source is greater than user B's diversion point where marginal benefits fall to zero plus user A's consumptive use, there is no allocation problem.

The usual case, and the one which poses problems during drought conditions is one where the sharing of the capacity of the water source is involved. Generally, the upstream user, A, diverts part of the flow while the downstream user, B, uses the nondiverted portion plus the return flow of A. Efficiency in the allocation requires the (weighted) marginal benefits of A's diversion to be equated with the (weighted) marginal benefits of B. Both A's and B's benefits are evaluated from the total system viewpoint in this case, and are evaluated assuming the unlikely event that all of A's diversions are consumptive and the weights of the benefits are equal. Otherwise, efficient allocation requires A's (weighted) marginal benefits to be equated with the opportunity cost of the last unit of water diverted by A, i.e., the marginal rate at which B is losing benefits because of the consumptive uses out of the last unit diverted by A.

Assume that the two parties have filed for their rights up to the diversion point where marginal benefits of the diversion fall to zero given the two users water demands and land upon which the water is used. If Part A is the senior, the strict form of the appropriative rights rules that the weight of B's use is zero, and A is allowed to divert any quantity up to the point where the marginal benefits of diversion fall to zero. If B is senior, the opposite is true. So in the short run, appropriative water rights clearly violate the conditions of economic efficiency outlined earlier.

Efficient allocation over time requires that the efficiency equation (condition) hold at all points in time. The volume of divertable water fluctuates over time and can become very scarce during conditions of drought, but the efficiency condition would require a reduction in water use, in this case, by both water users. As the severity of water shortage intensifies, reductions in use by both users continue in the weighted proportions necessary to the efficiency equation, at least until one use (depending of course on the weights of the two uses) is reduced to zero. Again, however, a strict priority system associated with the appropriation doctrine would not permit this adjustment to be made over time, since the senior user would get his or her full decree before the other user got any water. It is true that the profit motive may stimulate short run exchanges of water and thus maintain the efficiency conditions. User B, for example, would be willing to pay User A at most the marginal benefits to be gained from using an additional fraction (the consumptive use fraction) of a unit of water. If the marginal benefits to A are below this amount, the A should be willing to rent the water, and bargaining between the two parties results.

The problem with the bargaining arises when there are more than two parties involved in diversion. Any market transaction between two users would ignore the return flow effects on the other users. The impact of transactions on return flows presents a case of true externalities, including the possibilities of the diminished quantities and qualities of return flows. Thus, under the appropriate system, private motivated exchanges of water during periods of water shortage tend to promote efficiency, but there may be some element of externalities (in this case damage to third parties) which would call for intervention in the market to cause the externalities to be internalized or included in the private decision.

Certainly private transfers would work to promote optimum allocation of water during periods of severe shortage and can work within the outlines of the appropriative system. Gardner and Fullerton (1968) long ago reported on the transfer efficiency associated with water allocation in the Lower Sevier River system in Utah. Relaxation of the constraint permitting only intra-irrigation company transfers of water in the post-1948 years resulted in higher value productivity of water in the area (increased by about four times) and promoted efficiency in water use and storage facilities. Currently, in that area a water banking system exists, and farmers know that water can be rented. During this period of water shortage, cropping patterns are shifted to take advantage of the system, both to grow crops and to rent water. There is an interesting case in Colorado where ownership rules under the appropriative system have been made more flexible in order to promote exchange (Howe et al., 1982). The Colorado-Big Thompson project filed for junior storage rights on the Upper Colorado River during the 1930's. The Bureau of Reclamation, who developed the project, then sold water by contract to the Northern Colorado Water Conservancy District, which distributes to its members. The members hold title to the water under the regulations of the district, free of the regulations of state law. Owners of the allotments are able to sell them to any party within the district boundaries, subject to approval of the district board of directors. This is a way of promoting exchange and is a possibility for handling the third party problems (externalities) discussed previously. The permission of exchange would provide a basis for water brokers to come forward to provide allocation service between jurisdictions in times of water shortage or when new uses for the water arise.

6.4 Summary And Some Suggestions For Future Investigation

6.4.1 Summary Of The Economic Evaluation

By using an economic modeling procedure described earlier and incorporating the hydrological and other physical effects of two drought episodes as imposed on current production, water delivery, and water storage conditions, and then imposing incremental changes associated with two cloud seeding designs to modify the drought impacts, some important economic information has been generated about the effects of drought and the benefits of modifying those effects through cloud seeding. Supply-augmenting technologies such as weather modification may have adverse or favorable impacts on the revenues of agricultural producers, depending on the character of the supply and particularly the demand conditions associated with the products which are produced. Most agricultural products are price-inelastic in demand in the total market for the products, meaning that supply shifts on the specific demand curve result in greater price effects than quantity-demanded effects. When supply is augmented, then under such conditions, revenues will be decreased unless smaller regions relative to the total market are being considered and their share of the products produced in the smaller region does not dominate the total market. Technically, that means that the region's share has to be less in absolute value than the price elasticity of demand for the specific commodity.

It was found, in general, that this is the case for Utah agricultural products relative to the total markets, and revenues are increased with increased production in Utah, induced by a state policy to seed clouds to modify drought conditions. There are some exceptions, particularly in the case of orchard, vegetable, and seed crops for particular seasons since the model was developed on a seasonal bases.

The benefits for employing the best-practice cloud seeding program, as derived from the economic modeling, amounted to some $12.6 million for modification of drought conditions of the 1934 drought severity. Some $5.7 million in benefits were derived for modification of the less severe 1977 drought condition. These are benefits at the state level. The benefit/ cost ratios for modifying the impacts of the 1934 and 1977 type droughts were, respectively, 9.7 and 4.4 for a cloud seeding program on a region-by-region basis in Utah, with the region based on the climatological divisions of the state. Considerable cost savings can be generated by administering the seeding program on a broader regional basis, thus increasing the benefit/ cost ratios to 12.6 and 5.7 for modification of the same two drought types. Regional benefit/cost ratios without the cost savings attributable to operating the program on a broader base ranged from 3.3 to 22.5 for modifying the impacts of a 1934 type drought, and ranged from 0.7 to 10.0 for modifying the less severe 1977 drought conditions. Some losses were derived in the North Central Region for modification of the 1934 drought because of resulting price reductions for specialty crops and alfalfa hay in certain seasons, and in the Southwest Region because of price reductions in both alfalfa hay and alfalfa seed, as well as some livestock operations going from a liquidation position to a loss position.

The benefits generated under a more conservative increment in precipitation from cloud seeding were considerably lower than under the best-practice or most likely to succeed seeding program. In general, if the best practice design cannot be achieved, then it appears that seeding would be infeasible in the southwestern portions of Utah, and there is some question about seeding the Wasatch Front area (Region III), since declines in specialty crop and alfalfa hay prices during certain seasons were induced by the seeding effect on increasing production of these crops. So the evaluation does suggest that precipitation increments which are closer to the best-practice design would be the desirable program to implement in Utah. The evaluation also shows that the greater benefits are to be realized in Southern Utah. This is the area of Utah where the livestock industry, particularly the range livestock enterprises, are concentrated, and a large party of the benefit of cloud seeding is attributable to livestock-feed cost reduction by increased range forage, decreased feed imports, and decreased hay and barley prices. The dairy and fed beef enterprises, which are primarily located in the Northern Regions of Utah, change their operations very slightly during drought and the modification of its effects. The competitive position of all of these enterprises does deteriorate relative to the same enterprises in other western and midwestern states as the drought episodes are imposed, but the dairy and fed beef enterprises, as well as the turkey enterprise, appear to remain considerably more viable during the drought conditions. Large numbers of livestock unit liquidations occur in the cow/calf and sheep enterprises which are the mainstay industries in most parts of the State. Sheep operations appear to be more vulnerable to drought hazards than the cow/calf operations. There is not a great deal of change in the fed beef enterprise, but fed beef production in Utah is very small compared to fed beef operations in other states.

The results generated by this investigation compare favorably with those of other studies on weather modification. Studies of seeding results in North Dakota, Montana, South Dakota, Oklahoma, and Illinois are consistent with this one in that it was found that increased rainfall has, in general, a positive effect on crop production and farm income in the states involved. These studies were referenced earlier. The Kansas study by Buller et al. (1981) was, however, the first to consider the problem of declining revenues where production from a state could dominate the total market. But even in this case, benefits were derived for some crops as revenues increased due to weather modification. The experiment, in this case, was not to evaluate the impacts of modifying drought, as was the case in the present investigation, but rather to evaluate the benefits of augmenting rainfall on existing conditions in Kansas. This was to actually augment the existing "normal" supply of agricultural commodities. In the Kansas study, it was found that farm income was increased approximately some $66 million even though the commodities produced have an inelastic demand. Most of the increase in this case was from increased corn and soybean production, with some small increases in wheat income in Western Kansas. Moisture increments in Central and Eastern Kansas hamper planting and harvesting operations and were, therefore, not feasible to produce in these areas. Wheat production in Kansas make up a large share of the total market for wheat, particularly wheat produced in the central and eastern portions of the state, and revenues of producers in these areas experienced price declines from increases in production. The costs of the Kansas program amounted to $1.4 million, making the static benefit/cost ratio very favorable.

6.4.2 Suggestions For Future Investigations

This study considered only the evaluation of modifying drought conditions. It would appear to be important to evaluate the economic effects of augmenting the existing or "normal" agricultural commodity supply in Utah. The economic model could be used to justify that, but additional work is needed in developing hydrological data, assuming some increment in precipitation would have to be completed, so as to be incorporated into the model constraint system. In fact, it would seem desirable to model the increment due to cloud seeding in a mathematical expectation or expected value framework. Again, the model as developed could efficiently use such information in generating optimum solutions for base conditions and augmented conditions, but probabilities for various weather or precipitation events would have to be generated from estimated distribution functions in order to compute the expected values of various weather-revenue events. These weather events should represent a historical period of weather which includes drought, normal conditions, water surplus periods, etc. in order to reflect the distribution of weather. In a sense, we have captured some parts of the spectrum of the weather distribution in modeling the effects of the 1934 and 1977 drought conditions. We know the physical impacts of these particular events and have represented them as physical constraints incorporated into an economic model. We then maximize an economic objective subject to the physical constraints of obtaining the economic objective. We allow for enterprise changes which take place as movement from one physical event to another is made, i.e., different activities are allowed to become optimal under varying conditions, which appropriately accounts for the underlying economic changes and benefits or losses associated with physical change as it induces economic change. However, additional work in estimating probability distributions reflecting the spectrum of events would need to be completed. That could be done using observations on the Palmer Index or some other weather event measure.

Once the probabilities of events are generated, an investigation of modification strategies in a Bayesian Decision Theoretic Framework could be made. Conditional probability projections could be made about drought event, for example, projections of the Palmer Index Value, and this could be incorporated into a decision rule to decide on the value of the stand-by cloud seeding program on a year-by-year basis. We have generated some valuable information on stand-by strategy in this study which is useful for state policy makers. Some conditional probability projections of drought conditions measured by the Palmer Index were presented in Chapter 5, and the benefits of modifying two types of drought were generated in this section. Whenever an index average for the winter months which is similar to that average of the 1977 drought episode is projected, it appears economically feasible to seed clouds if the seeding can be projected to bring about similar precipitation increments to those estimated for the best-practice seeding design projected in this study.

Cloud seeding to increase precipitation is a supply-increasing technology which is currently regulated by a state agency. The success of the program is measured by the increase in revenues which are generated by the increased water availability in the case of the agricultural sector. That achievement depends largely on market forces such as the share of the state's production in the total market when inelastic demand conditions exist in the market. Producers in other states who produce the same commodities or their substitutes will be influenced by the seeding policy through the price effect. Producers in other states who use the commodities whose supply has been augmented may be influenced by the policy because of import changes and perhaps declining prices of imports of commodities whose supply has been increased. In the case of Utah, that effect would appear to work in reverse since Utah livestock producers extensively use feed imports from other states to maintain livestock enterprises such as turkey, milk, and fed livestock enterprises. It would appear legitimate to ask the questions, at what production location is it most optimal to implement a cloud seeding program to augment the supply of certain commodities of interest, and what are the impacts of such augmentation programs? The economic model developed is a very efficient system which can be used to answer these questions and others of similar nature, since it is a detailed model of the agricultural economies of several regions, the whole of which comprise the conterminous U.S. However, additional detail of enterprises of other regions would have to be incorporated in order to make an evaluation of the augmentation programs of other regions. the interregional trade specifications of the model which are necessary in an evaluation of this kind are intact and already incorporated in the model as is. The model could be used to model the feasibility of cloud seeding programs which are existent in the Southwest Drought Modification Program, for example, or to evaluate the effects of modification in the Southwest versus any other production location.

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7. OTHER APPLICATIONS OF METHODS DEVELOPED IN THE STUDY

Some applications of the methods and techniques developed in the study are currently being made by the research team or others to solve other problems, or to provide information on various problems and issues. These applications are briefly described in this chapter.

7.1 Application Of The Range Condition Palmer Index Relationship

7.1.1 Range Condition Projections

The range condition - Palmer Index Relation developed in Chapters 1 and 3 is now being used to provide projections of range conditions. Palmer Index Values have been substituted into equation (3.4) described earlier, and using the estimated coefficients of (3.4) for the various climatological divisions found in Table 1.35 in Chapter 1, predicted range condition values have been obtained and shared with range managers of the Bureau of Land Management within Utah.

The projection power of the relationship has been quite satisfactory, since the projections have been very consistent with survey range condition values for the 1982 range forage production year, to this point. Projection of values outside of the general range of values used for estimating the equation have also been successful. This particular year has been a very favorable year for range forage yields, and the model, as used, has been a successful tool in projecting the higher range condition values associated with the higher yields for this year. Moreover, range-condition projections have been made for other regions outside of Utah, such as for range conditions in Oregon and Montana. Again, the projections are consistent with the survey range condition values. The parameter set estimated for other regions gives small squared errors of the sample range condition values using appropriate sample Palmer Index Values.

7.1.2 Projection Of The Yield Of Other Crops

Use is currently being made of the general relationship which is represented by the range condition - Palmer Index equation (3.4) and described in Chapters 1 and 3. The logistic function from which it derives is being used to estimate range forage yield in relation to range pest damage and control in a study of strategies to improve rangeland productivity in the Four Corner States regional area (Glover, 1982). The relationship is used in combination with a range pest population equation, a pest damage relationship, and an economic optimization model to develop range improvement strategies.

Other generalizations of this relationship are being developed for use in projecting alfalfa forage and seed yield in Utah. This work has just commenced during the summer of 1982, so the results of the application to these crops are still unknown.

7.2 Uses Of The Linear Programming - Spatial Equilibrium Model

The economic model described in Chapter 3 is being used to evaluate the impacts of public land grazing cut-back policies which have either been implemented in various public land resource planning units in Utah, or those which have been proposed. In this application, the grazing unit availability, as a resource, is reduced, and the model, in a simpler form than used in this current study, is used to simulate changes in net revenues due to the grazing restrictions. The model, in a more detailed interregional trade route form, is also being used to estimate the impacts of various feed grain production and price policy schemes on the viability of livestock production in the Intermountain West, including Utah.

7.3 Uses Of The Runoff Model

The Salt River Project in Arizona is participating in the Southwest Drought Project, and personnel of the project are reviewing the potential of precipitation augmentation in Central Arizona. This review includes estimating the increase in runoff that can be expected from alternative weather modification programs. Mr. Larry Beddome, Hydrologist, Salt River Project, plans to utilize the procedures for runoff estimation developed by the Utah hydrologists and described in Chapter 2.

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APPENDIX A

A. ESTIMATION OF DATA

A.1 Additional Data Analysis

The hydrologic analysis of these drought periods required estimates of pan evaporation. The pan evaporation information was used in making estimates of the water budget of important reservoirs. In some cases the reservoirs had not even been constructed at the time of the 1933-34 drought, and a total budget for a then non-existent reservoir had to be constructed.

Several methods of estimating evapotranspiration and pan evaporation have been reported in the literature, but most of these were developed in more humid parts of the world. Dugas (1980) reviewed several of these and found that, with the limited amount of climatological information available at standard climate stations, the Blaney-Criddle (1962) approach was considerably better than the others.

A.1.1 Estimating Pan Evaporation

In an attempt to improve on the method of estimating pan evaporation used by Dugas, a modification of Dalton's equation was tested. This method was developed as a portion of a study to predict range production and development of selected range plant and insect species, sponsored by the Four Corners Commission and the Bureau of Land Management. However, the methodology is also well suited for the needs of this study and is therefore included in this report. The modified equation is shown below:

$$EPan = (es - RH(es))\ (A + B(u) + C(SO)) \qquad (1)$$

Where:

EPan = calculated pan evaporation
es = saturation vapor pressure at the average temperature for the day
RH = relative humidity as calculated from the equation ($RH = 1.03 - 0.0468DR$)
DR = daily range in temperature: ($Tx - Tn$)
SO = estimated daily solar radiation obtained from equations shown in next section
U = estimated daily wind movement
A,B,C = regression constants for each month, see Table 3.1.1.1

TABLE A.1

Constants For Multiple Regression Equations Used To Calculate Pan Evaporation Using The Modified Dalton Equation

Month	A	B	C	R^2
January	.5955	.001951	.002276	.2328
February	1.3125	.002329	.003115	.4135
March	1.9866	.003732	.003502	.4580
April	1.8743	.003652	.002191	.6955
May	2.2806	.004374	.002538	.8026
June	1.1742	.003245	.0009034	.7004
July	.9543	.002880	.0007183	.7792
August	.9097	.003259	.0008065	.7961
September	.8575	.003597	.0008822	.8303
October	.7378	.004356	.0009935	.7213
November	1.5427	.004310	.005185	.4068
December	.4253	.004561	.001103	.4631

The constants for the months of November through March were calculated from estimated evaporation amounts. The estimates were made by assuming that the annual totals calculated from the map published in Tech Paper 37 (1959) followed a curve shaped similar to the temperature curve for the station. The fact that only estimated values were available during these months helps to account for the low R^2 values. Also, there is a great deal more variability in evaporation during the winter months. Since the winter evaporation is generally only 20 percent or less of the annual total, the reduced accuracy of estimates during the winter period is not so critical.

Estimating Solar Energy. Virtually no solar radiation data are available for Utah. There are only two stations within the boundaries of the state with an appreciable history. The regression equations developed to estimate the solar radiation were calculated using daily values from Salt Lake City for several years. These data were regressed against daily values of the daily temperature range for the corresponding periods. The general regression equations is of the form:

$$SO = A + B(DR) \qquad (2)$$

The constants A and B for each month of the year have been tabulated in Table A.2. The correlations between the daily solar radiation measurements at the Salt Lake Airport and the daily range in temperature are quite good during the summer season, with R^2 values ranging generally between .52 and .81. The fog and low clouds which so frequently occur during the winter season in the valley, decrease the winter predictive accuracy considerably. However, as was indicated previously, there is little if any plant growth during these winter months and in general the relationships worked surprisingly well when used in the EPan equations.

Comparing the sums of predicted daily values over the evaporation season with measured values at several stations for different years showed very good results. The predicted totals were all within 10% or less of the measured accumulations. These results are considerably better than the results obtained by using other equations to calculate the pan evaporation.

TABLE A.2

Regression Constants For Calculating Solar Radiation From Daily Range In Temperature At the Salt Lake Airport

Month	A	B	R^2
January	107.82	7.344	.504
February	96.72	16.502	.401
March	245.05	13.127	.171
April	199.90	22.149	.437
May	247.51	24.557	.517
June	174.53	30.407	.716
July	99.02	33.571	.581
August	153.14	26.4312	.815
September	120.23	22.1706	.691
October	103.90	16.4196	.780
November	130.38	7.1406	.116
December	2.166	16.848	.61

<u>Estimating Winds For Evaporation Calculation.</u> A vital part of the modified Dalton equation for calculating pan evaporation is the wind movement during the desired period - either daily or monthly. The method used to estimate the

wind movement in our drought study research is related to the method of estimating temperatures that has been used by the National Climatic Center for many years. The assumptions are made that the pressure gradients which produce the wind cover wide areas of the state at any one time and that the topographic influences do not change appreciably over extended periods of time for any given site.

Estimating The Normal Wind Movement. A ratio and proportion technique which relates the normal annual wind movement to the monthly wind movement has been used to estimate the wind movement at any particular time. This method is similar to the method that was used generally by the National Weather Service climatologists to estimate general missing temperature and precipitation values.

A map of the normal average daily wind movement during the evaporation season was first developed for the State of Utah (Fig. A.1). A second map showing the percent of the normal annual wind movement which occurs during the evaporation season was then plotted (Fig. A.2). A first estimate of normal annual wind movement can then be obtained for any site by reading the estimated seasonal wind movement from Figure A.1 and dividing this value by the percent of annual wind movement at the site as determined from Figure A.2.

To obtain an estimate of normal monthly average daily wind movement, maps showing the percent of the average annual daily wind movement occurring during each month of the year were prepared (Figures A.3 through A.14). Monthly percentages for any desired site can then be estimated from each map. The estimated annual wind movement is then multiplied by the appropriate monthly percentage to obtain an estimate of the normal average daily wind movement for each month of the year.

Estimating Wind Movement For A Particular Month. Since variations in the synoptic patterns and the associated pressure gradient are the major cause of most of the variations in wind speed between different months, it can be assumed that the percent of annual wind movement during any particular month should be about the same over a fairly wide area of the state. It is recognized, of course, that different synoptic patterns will produce different fields of wind speed with differing topographic characteristics, but as a first approach to an estimate where no information was available the assumption worked quite well.

To obtain an estimate of the average daily wind speed for any desired month, the percent of annual winds occurring at the most representative available site for the desired period were calculated. The average annual daily wind for the desired site was obtained by using the same ratio and proportion technique.

$$Ua/Una = Ub/Uba \qquad (3)$$

where

Ua = desired average daily wind speed at Station A for the desired year.

Una = Normal average daily windspeed for Station A determined as discussed under the section on estimating normal wind movement.

UB = Measured average annual daily wind speed at Station B for same year.

UBa = Measured normal average annual daily wind speed at Station B.

The estimated average annual daily wind speed at the desired station was then multiplied by the appropriate month's percentages to determine the average daily wind speed for each desired month.

While these estimated monthly values were only approximations, the values obtained at least appear to be representative of the area in question. These winds were then used to calculate an estimate of the evaporation at the site for the desired month.

Estimating Relative Humidity. Relative humidity is another required meteorological variable for the evaporation equation. Several years ago, Richardson made a study of the relationship between the minimum relative humidity and the average daily range in temperature for some 500 first-order stations in the U.S. The assumptions were made that the minimum relative humidity occurred at the same time as the maximum temperature of the day and the maximum relative humidity occurred at the same time as the minimum temperature. The resulting regression equation (Equation 4)

$$RH = 1.03 - 0.0468\ DR \qquad (4)$$

showed an R^2 relationship of .878. Since the daily temperature ranges occasionally predicted relative humidity values outside the possible range of occurrence, certain limiting conditions were imposed. The limits imposed were: If $RH > 100\%$ $RH = 100\%$ and if $RH < 5\%$ $RH = 5\%$.

Model Calibration. To validate the evaporation models, the equations were used to estimate the daily evaporation for randomly selected years at Milford and Bear River Bird

Refuge. While estimated daily values often departed appreciably from the corresponding measured values, the seasonal accumulations were all within 10% and most years within 5%.

When measured wind movement is not available, the accuracy will depend to a large extent upon the reliability of the wind estimates. However, it was decided that this method of estimating evaporation was the best available for comparing the various drought periods in areas where no data were available.

A.1.2 Development Of Normal Evaporation Tables

Since normal values of the pan evaporation were needed in estimating the evaporation for selected drought periods, a set of normal values of selected meteorological variables for the years 1951-1980 were calculated using the method just described. A tabulation of these estimates for all of the stations for which normal temperature values were available is given in Table A.3. This table includes monthly temperatures (TX), normal monthly minimum temperature (TN), normal monthly precipitation (PP), estimated normal monthly wind movement (UU), estimated normal daily solar radiation for each month (RH), estimated normal saturation vapor pressure for each month (ES) and estimated normal pan evaporation for each month (EP).

A.1.3 Application Of Evaporation Equations

Using the methods described in Section 3.1, pan evaporation estimates for the drought periods 1933-1934 and 1976-1977 were calculated for the selected reservoirs used by the hydrology and economics groups. These estimates were used in evaluating management strategies as discussed in other sections of this report.

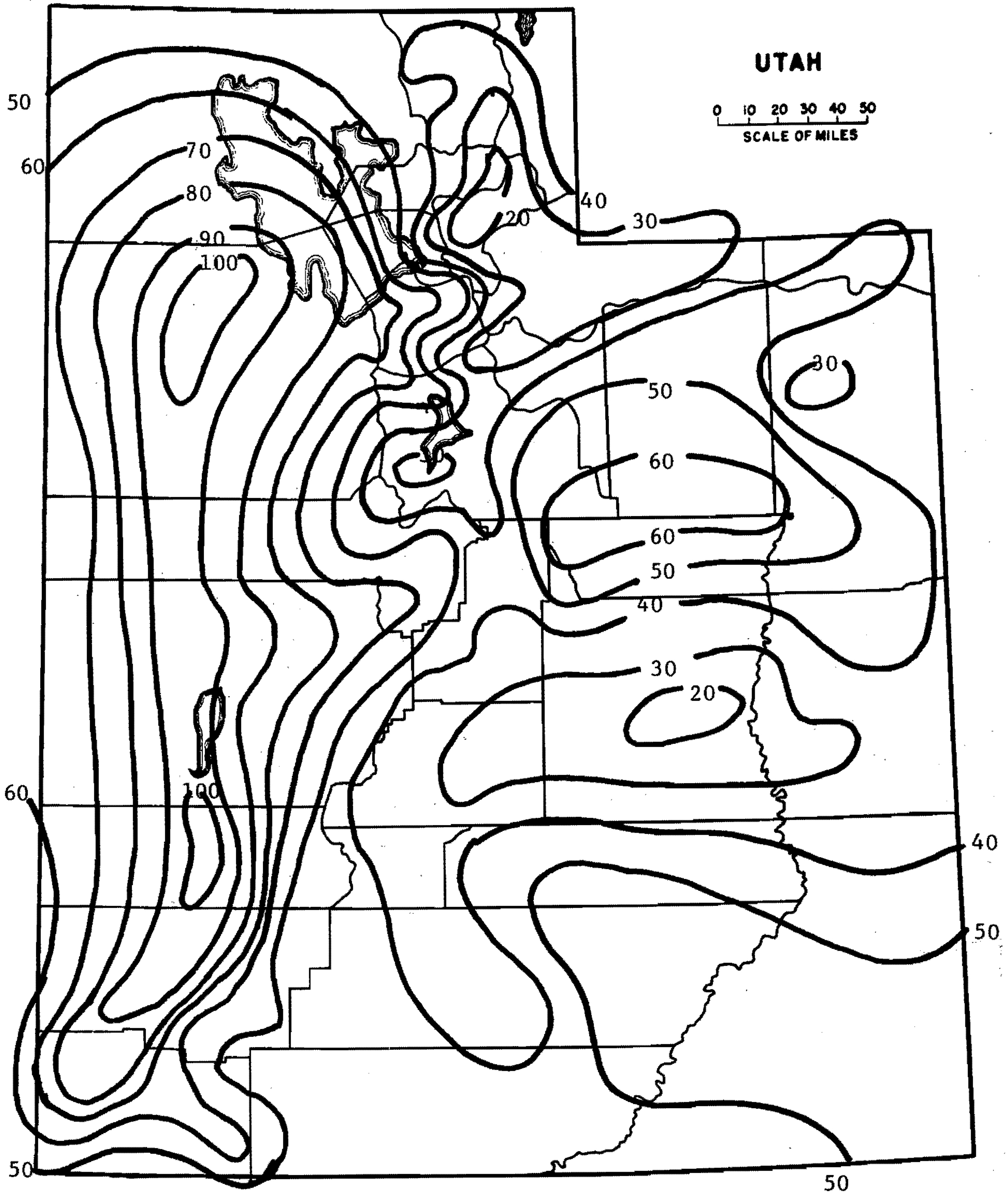

FIGURE A.1. Normal Average Daily Wind Movement During The Evaporation Season

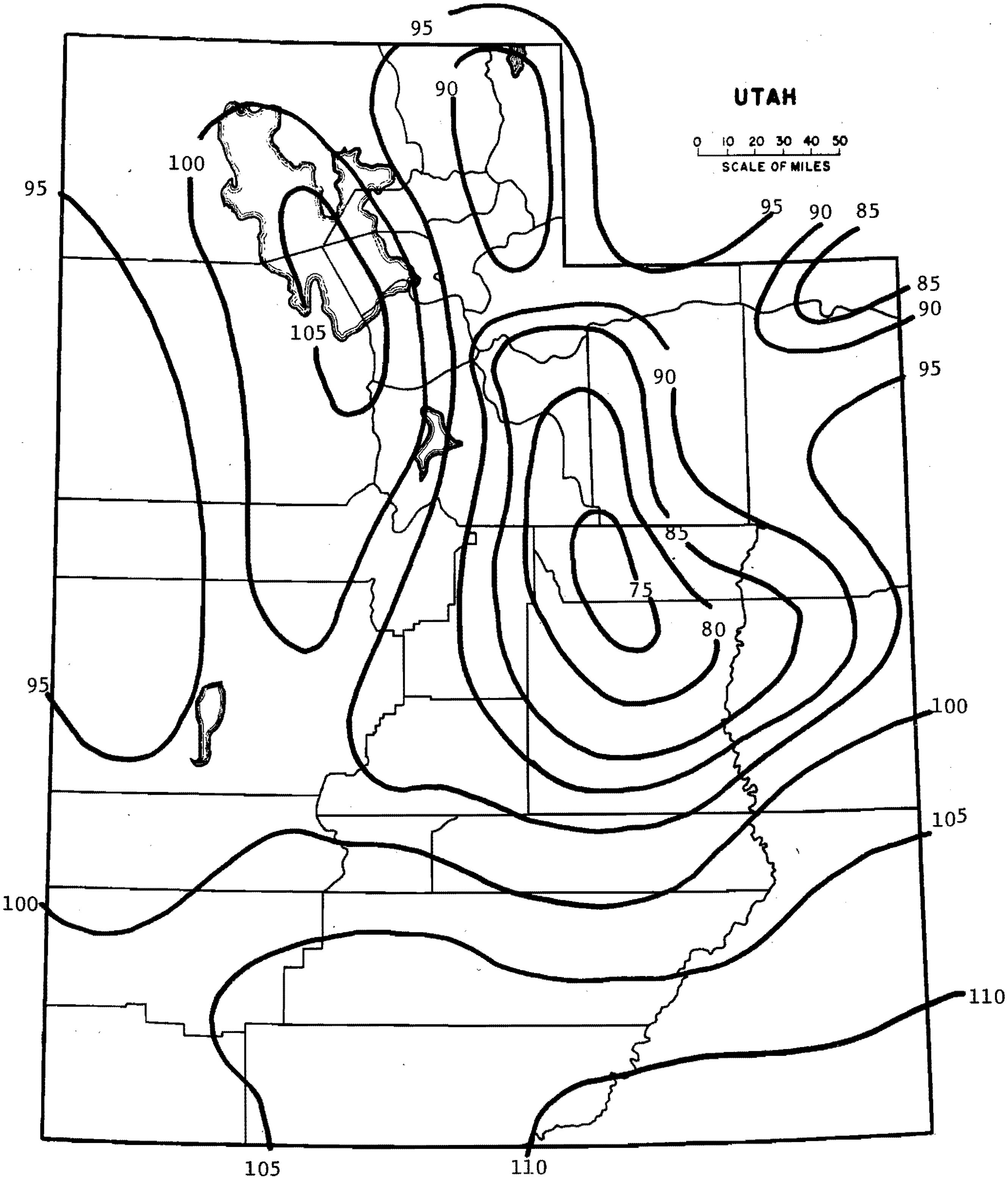

FIGURE A.2. Seasonal Percent Of Annual Wind Movement Occurring During The Evaporation Season

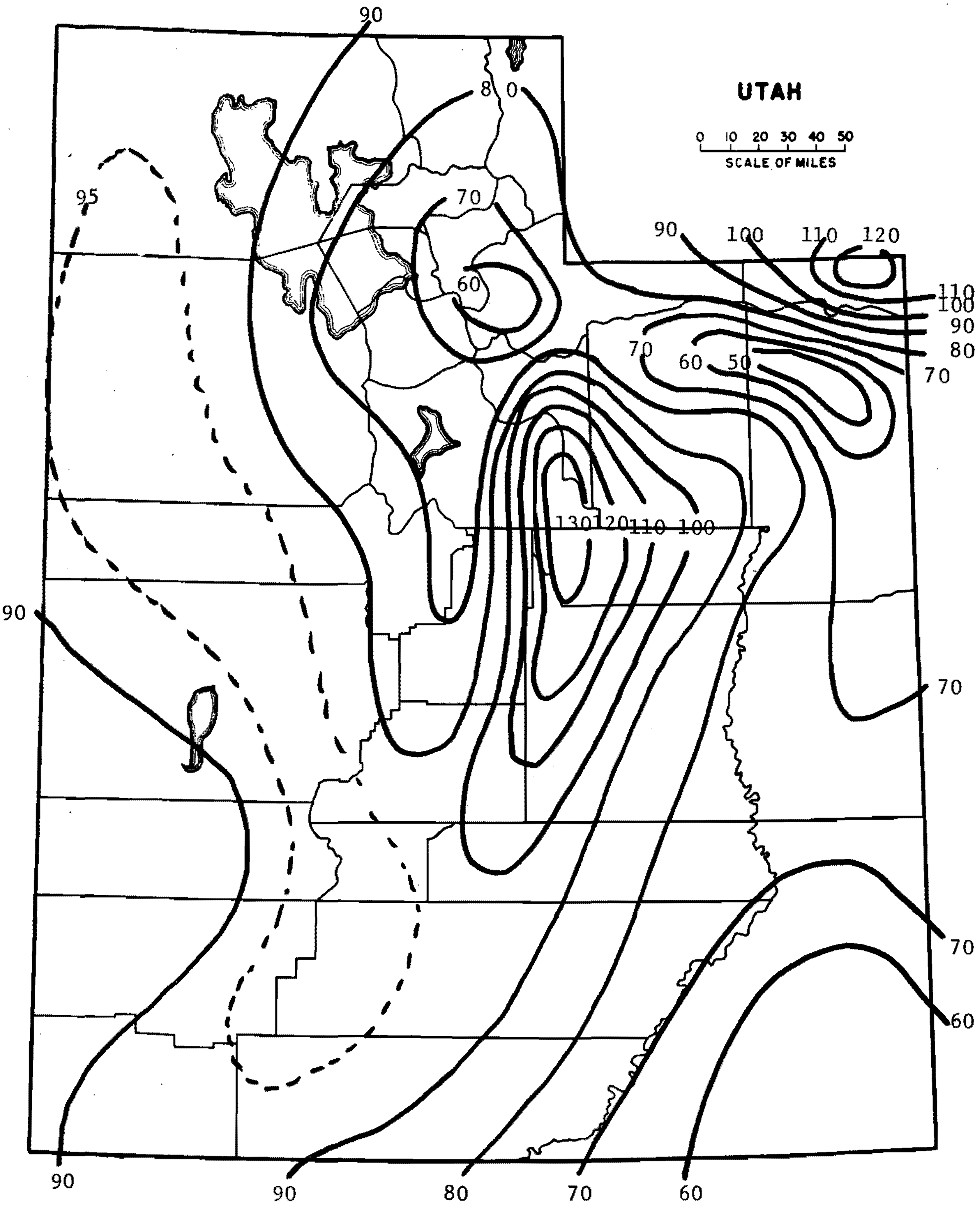

FIGURE A.3. Percent Of Annual Wind Movement During January

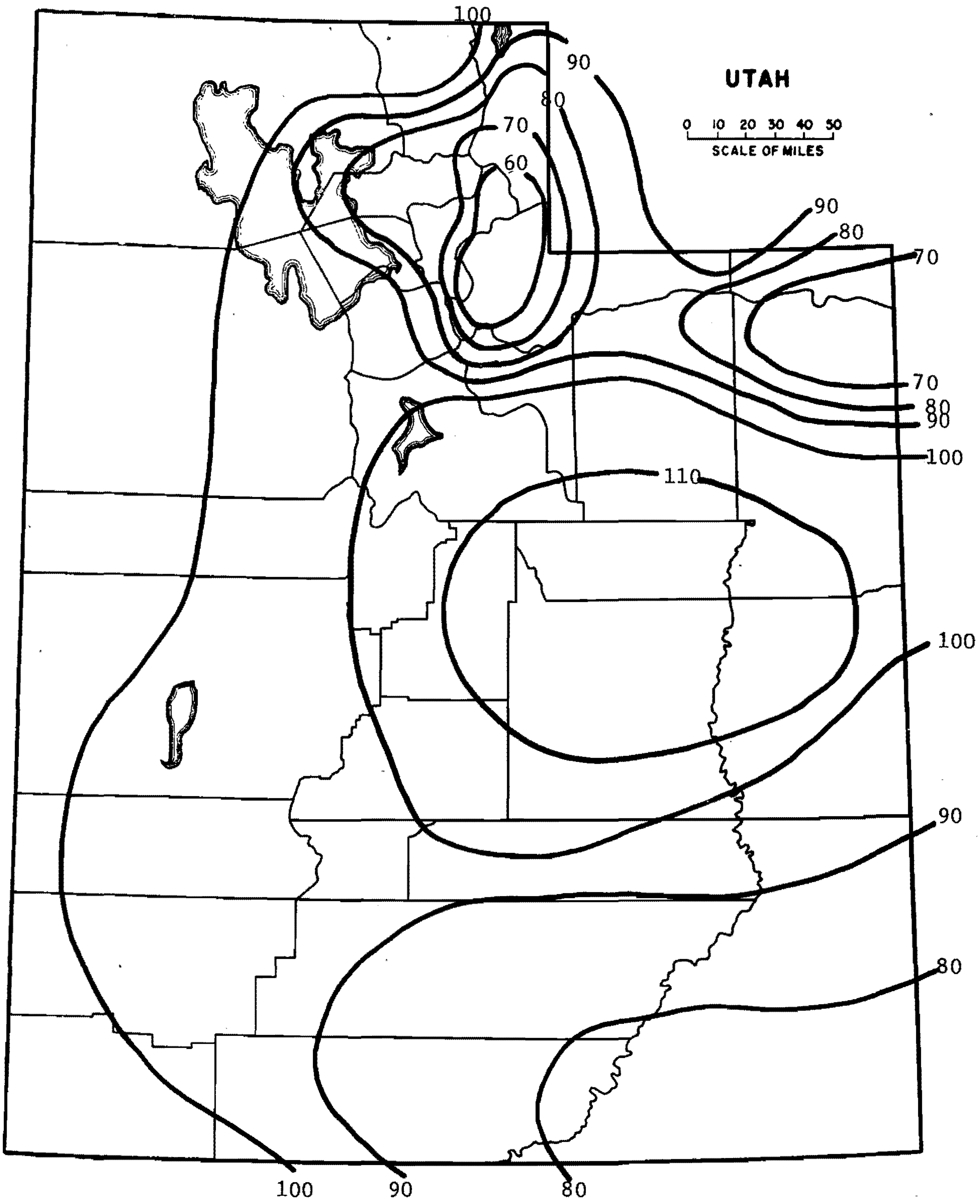

FIGURE A.4. Percent Of Annual Wind Movement During February

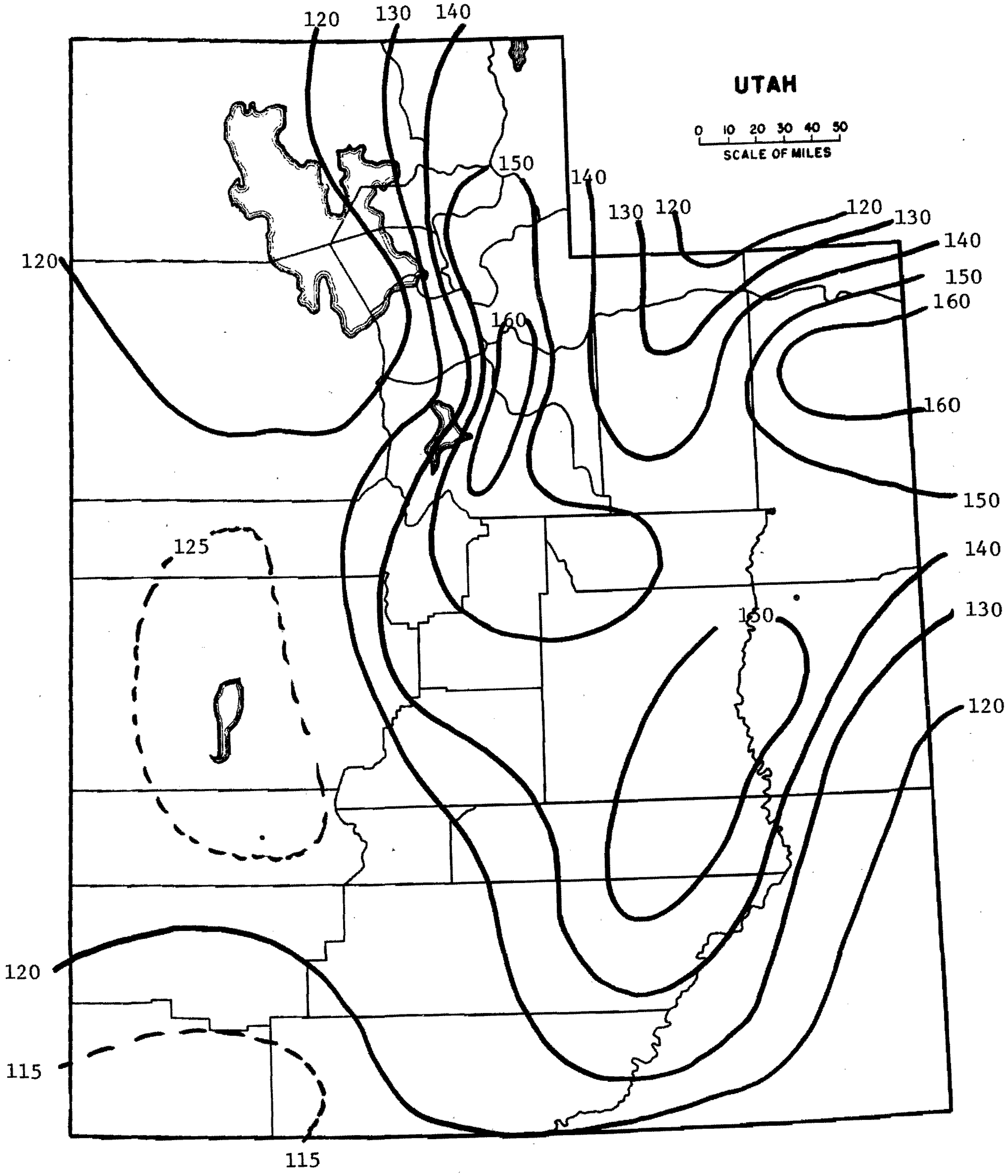

FIGURE A.5. Percent Of Annual Wind Movement During March

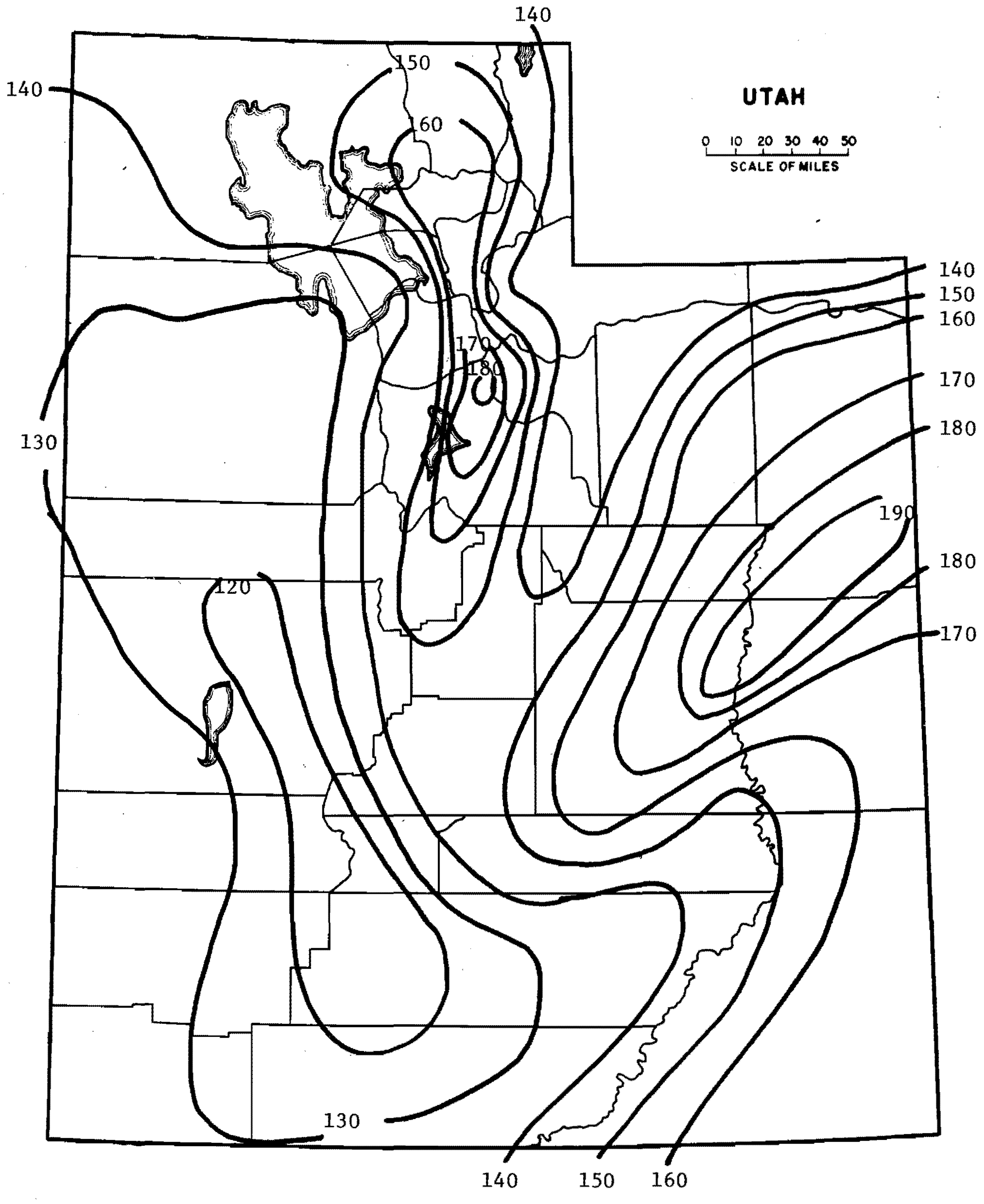

FIGURE A.6. Percent Of Annual Wind Movement During April

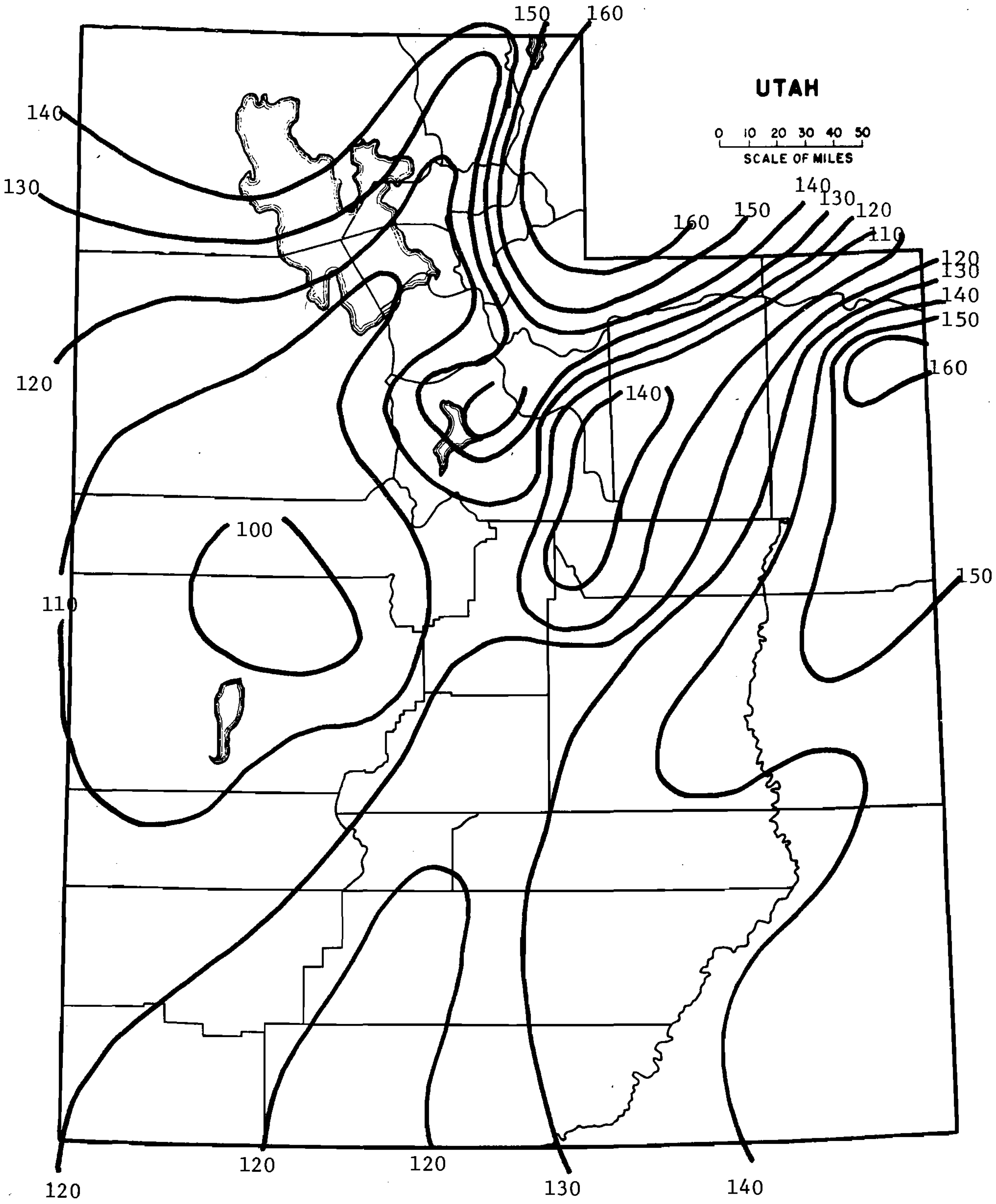

FIGURE A.7. Percent Of Annual Wind Movement During May

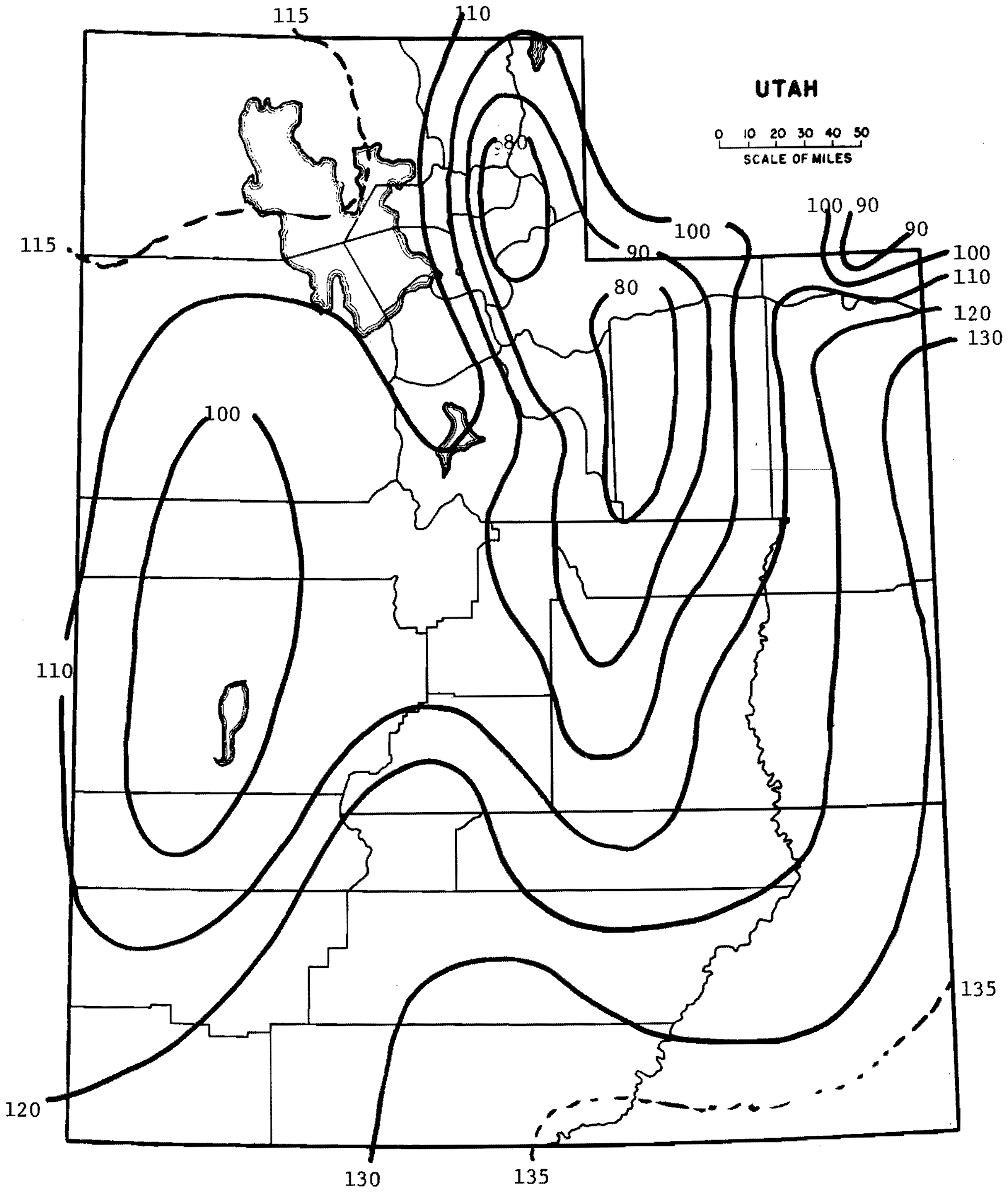

FIGURE A.8. Percent Of Annual Wind Movement During June

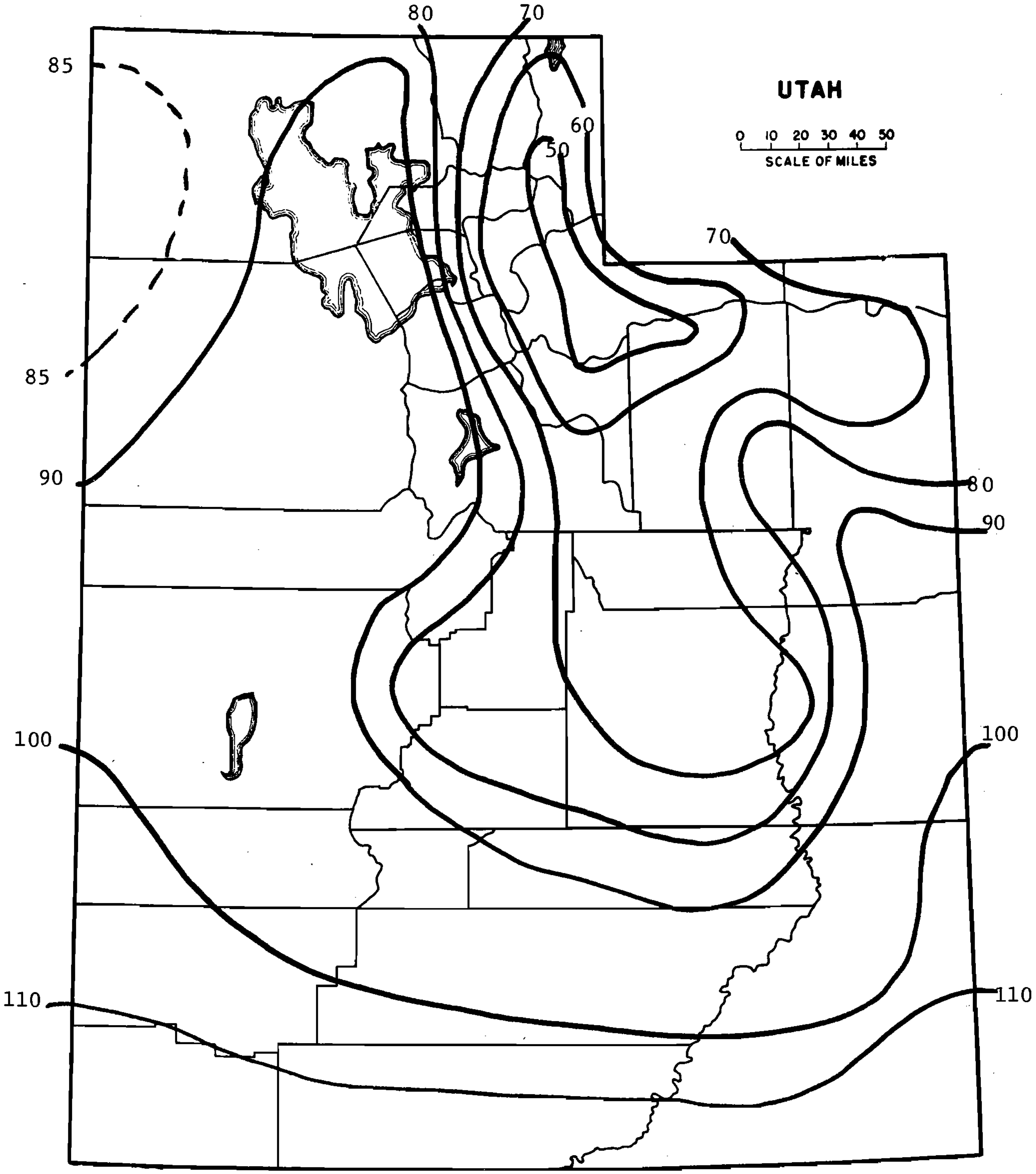

FIGURE A.9. Percent Of Annual Wind Movement During July

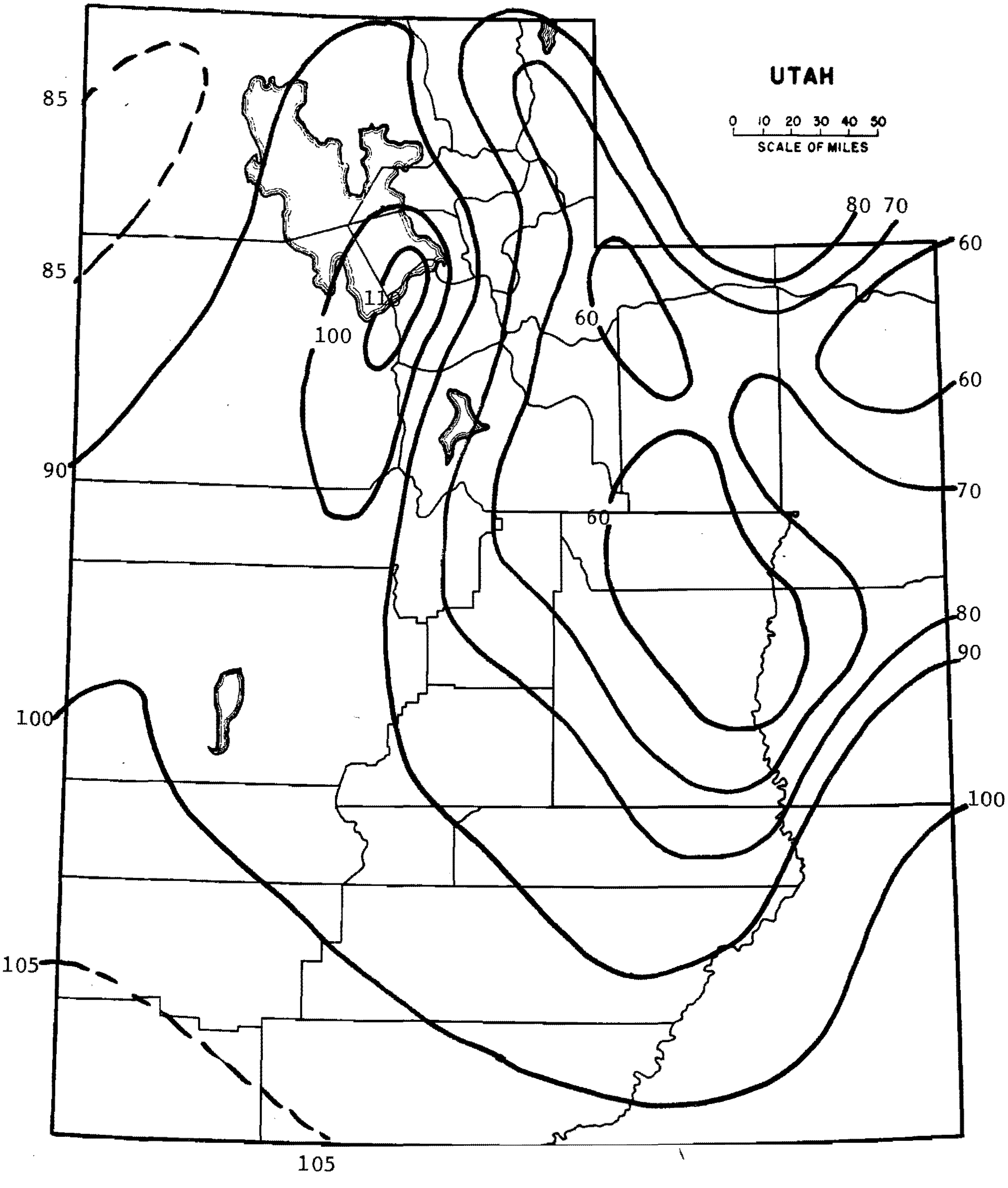

FIGURE A.10. Percent Of Annual Wind Movement During August

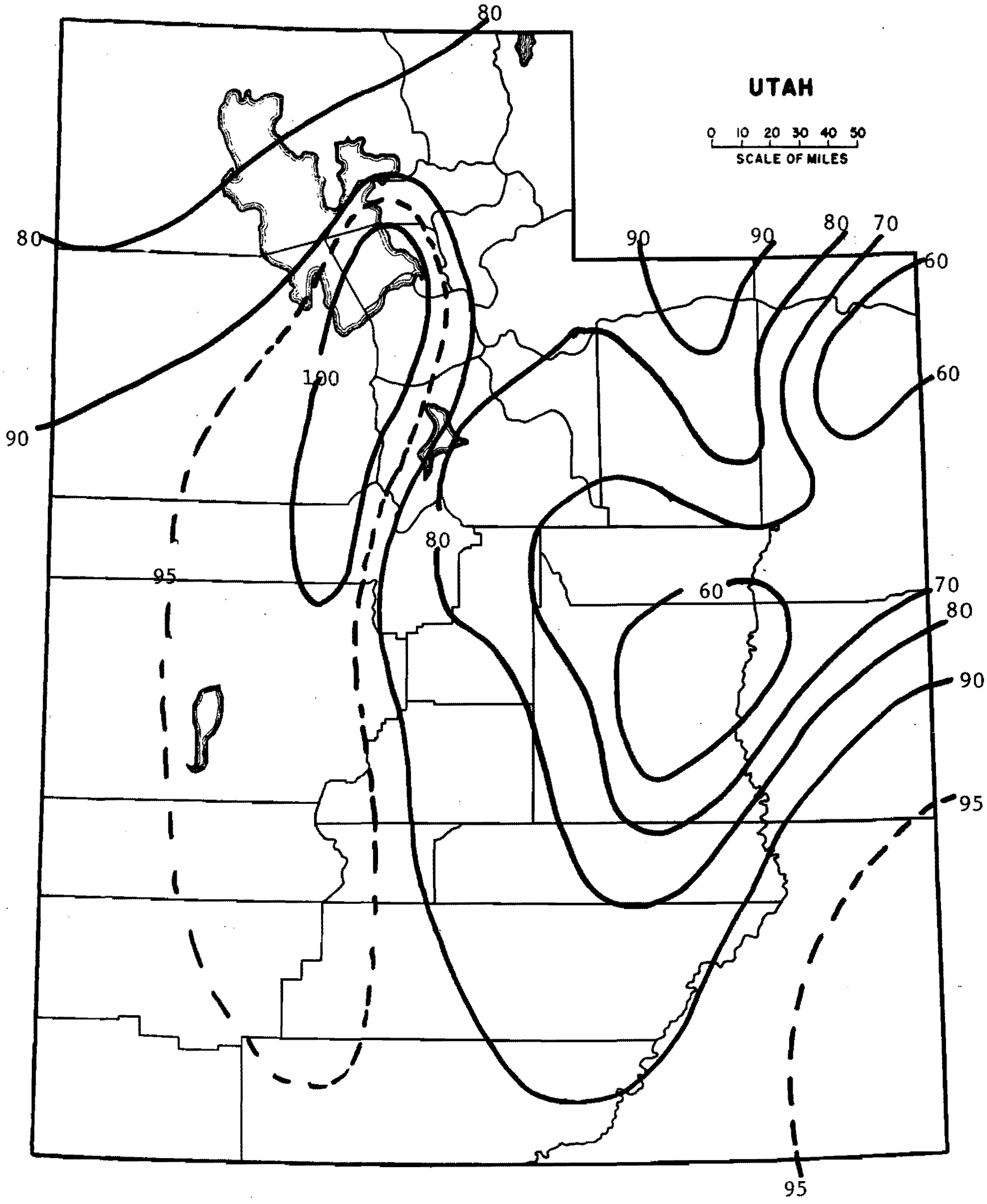

FIGURE A.11. Percent Of Annual Wind Movement During September

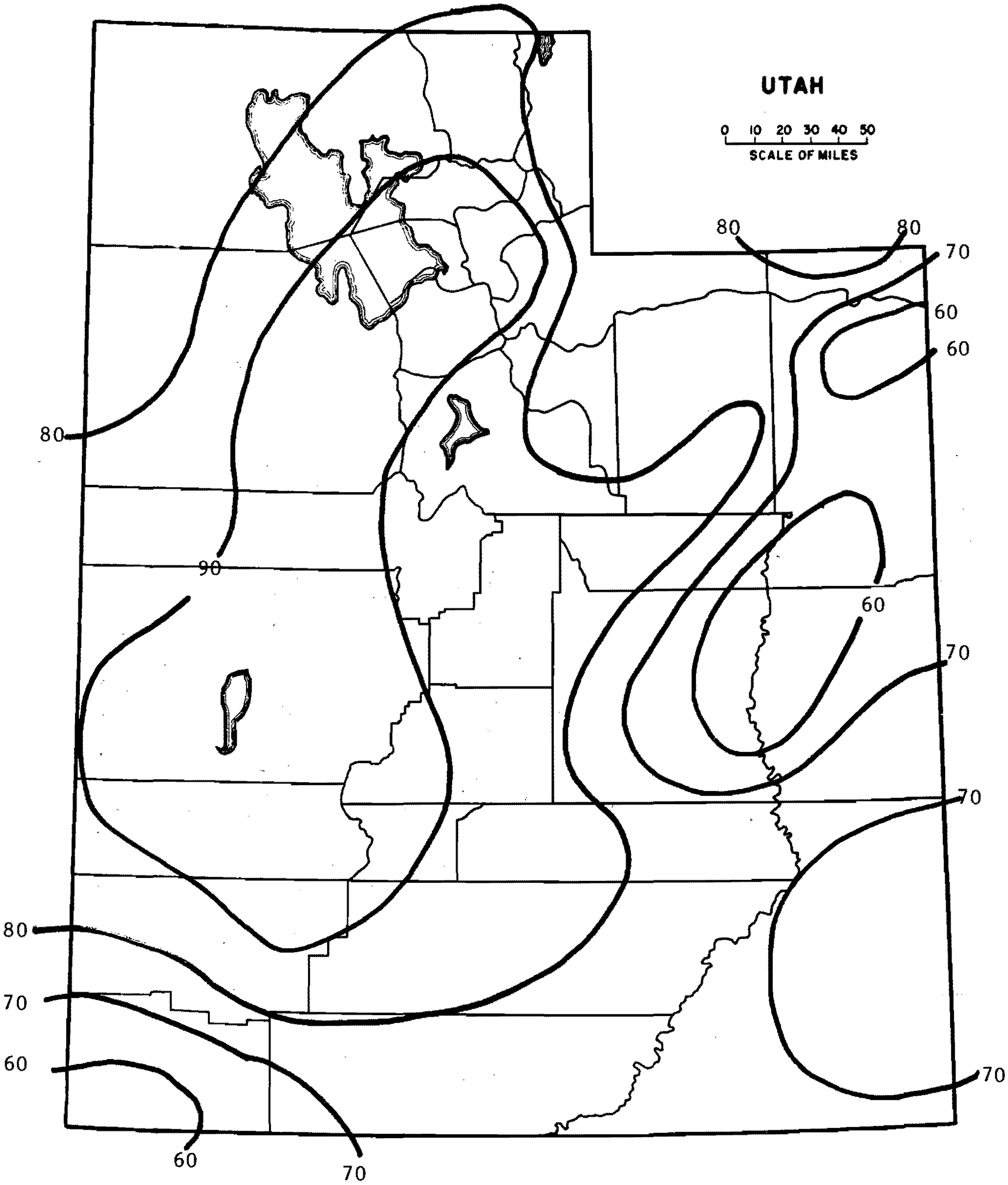

FIGURE A.12. Percent Of Annual Wind Movement During October

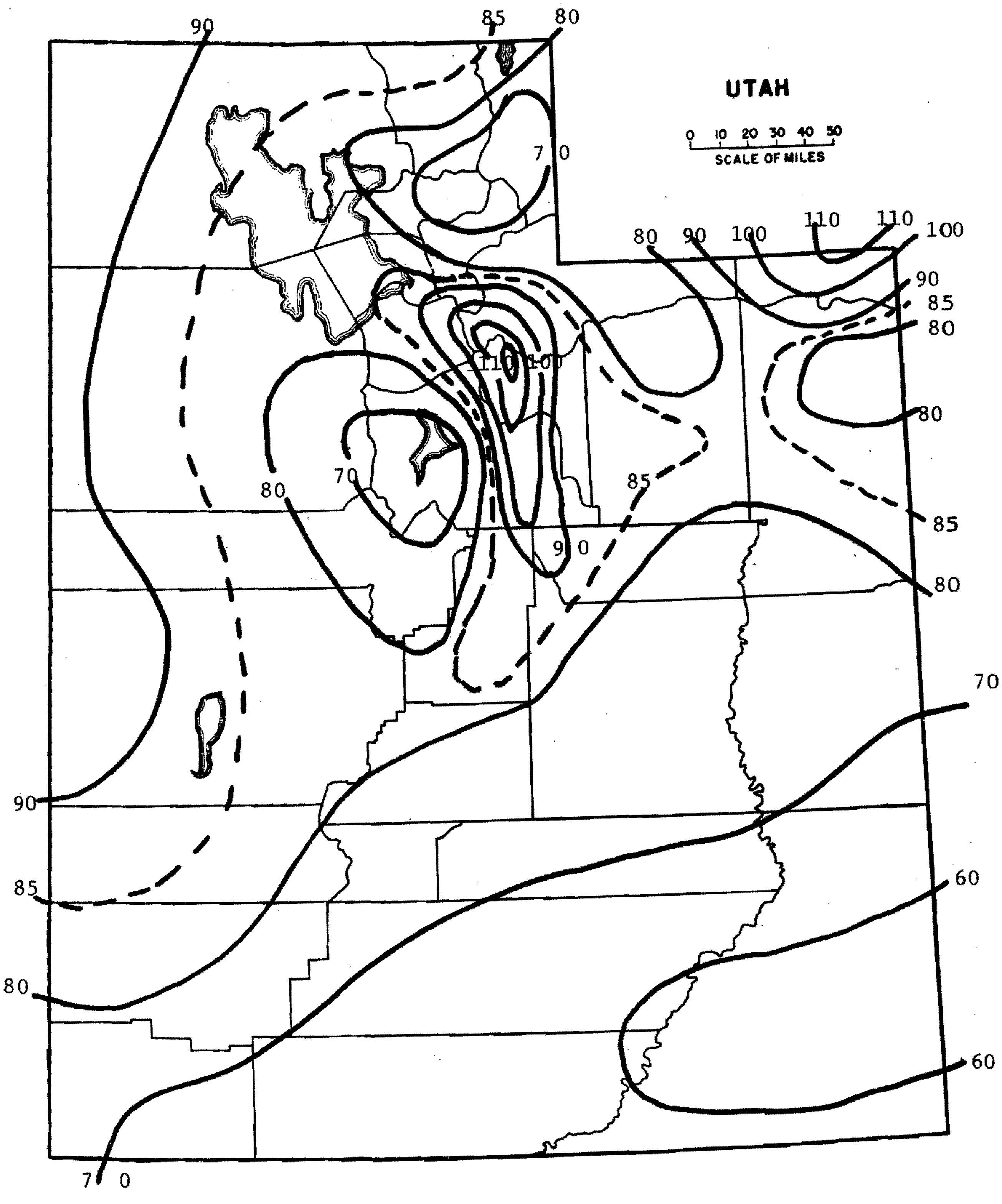

FIGURE A.13. Percent Of Annual Wind Movement During November

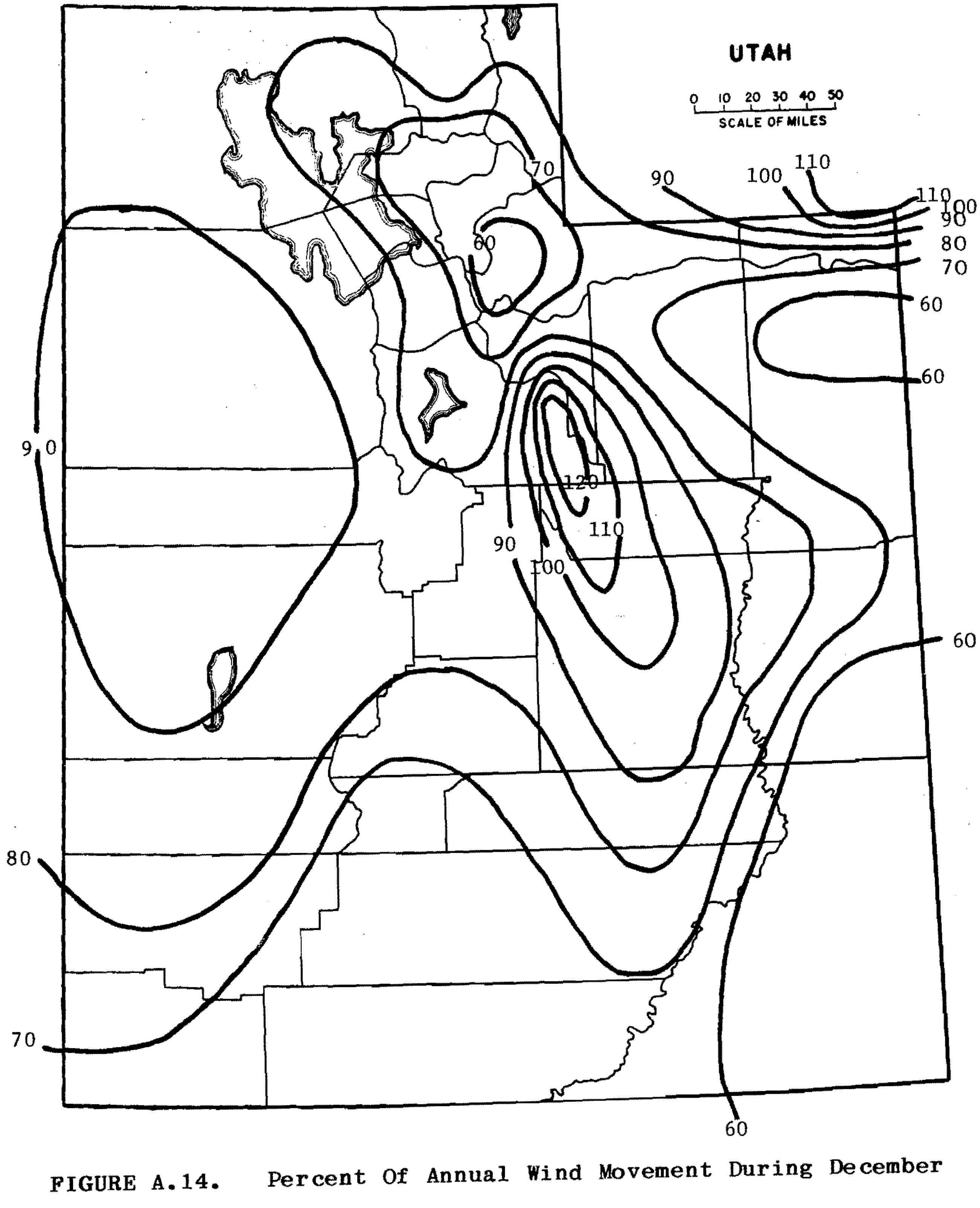

FIGURE A.14. Percent Of Annual Wind Movement During December

TABLE A.3

Monthly Meteorological Values Used For Pan Evaporation

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ALPINE#	61	111 47	40 27	4920

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.50	43.40	50.80	60.00	70.00	80.20	89.00	87.40	78.30	66.00	49.70	39.70	62.75
TN	17.00	20.30	26.00	33.10	39.60	46.50	54.10	57.90	43.70	34.60	25.90	18.40	34.76
PP	1.68	1.45	1.51	1.96	1.48	1.00	.51	.92	.91	1.30	1.27	1.56	15.55
UU	29.3	39.9	53.0	61.2	54.7	47.3	36.7	35.9	36.7	34.3	32.6	31.0	41.05
SO	196	308	426	531	662	744	750	586	546	390	225	202	464
RH	.54	.50	.46	.40	.31	.23	.20	.34	.20	.29	.48	.55	.38
ES	.15	.18	.23	.32	.43	.57	.78	.81	.54	.36	.23	.16	.40
EP	.32	1.05	2.47	5.21	7.99	9.07	10.77	9.28	6.46	4.06	1.85	.77	59.30

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ALTON	86	109 20	37 15	4620

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.40	43.70	47.60	57.00	66.90	77.30	83.80	81.30	74.50	64.30	50.70	42.80	60.86
TN	14.90	17.20	20.30	26.70	34.10	41.80	49.70	48.20	41.20	32.80	22.70	16.50	30.51
PP	2.04	1.68	1.57	1.13	.93	.51	1.49	1.77	1.32	1.12	1.39	1.61	16.56
UU	45.7	44.3	57.3	58.7	60.2	61.6	52.5	49.1	46.2	37.6	32.7	32.3	48.18
SO	212	340	444	573	695	774	735	639	530	391	241	248	485
RH	.44	.41	.39	.32	.25	.18	.22	.24	.24	.28	.37	.42	.31
ES	.15	.16	.19	.27	.37	.52	.66	.62	.48	.35	.22	.16	.35
EP	.30	.97	2.19	4.53	6.71	8.52	9.69	8.18	6.25	4.24	1.86	.89	54.31

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BEAR RIVER BIRD REFUGE	50	112 1	41 2	420

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.70	41.80	50.40	61.20	72.30	81.90	92.00	89.30	79.90	66.10	48.50	37.40	63.04
TN	14.90	19.50	28.30	36.90	46.30	53.50	59.70	56.90	47.70	38.00	28.20	19.80	37.48
PP	1.16	.98	.89	1.40	1.31	1.16	.35	.64	.87	1.05	1.03	.96	11.80
UU	41.5	42.6	64.7	76.2	68.9	57.3	47.0	48.2	41.1	41.6	40.6	38.9	50.72
SO	193	301	406	499	602	654	701	629	517	360	211	167	437
RH	.56	.52	.53	.47	.43	.36	.26	.26	.27	.37	.58	.65	.44
ES	.13	.17	.24	.35	.50	.68	.89	.81	.60	.39	.23	.16	.43
EP	.28	1.08	2.51	5.60	9.62	10.52	12.51	10.32	7.53	4.21	1.83	.74	66.74

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BEAVER	519	112 38	38 17	5920

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	42.80	46.10	52.10	60.60	71.10	81.90	88.60	85.90	78.90	67.50	52.90	44.20	64.38
TN	13.90	17.90	21.90	28.30	35.80	43.30	50.70	48.60	40.10	29.90	20.60	14.60	30.47
PP	.84	.91	.90	1.12	1.07	.57	1.10	1.36	1.00	.80	.72	.74	11.13
UU	46.6	47.0	60.8	58.8	58.8	59.3	47.0	48.0	47.0	45.1	37.7	34.8	49.24
SO	226	355	465	597	729	827	806	701	598	447	259	279	524
RH	.35	.37	.32	.26	.19	.10	.12	.13	.09	.13	.26	.33	.22
ES	.15	.18	.22	.29	.40	.57	.73	.66	.52	.35	.22	.16	.37
EP	.25	1.00	2.47	5.00	6.98	9.60	10.95	8.84	7.06	4.69	1.92	.94	59.69

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BLACK ROCK	730	112 57	38 43	4895

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.60	48.00	55.70	65.40	75.30	85.50	93.00	90.00	81.90	69.70	53.60	43.20	66.91
TN	13.50	18.80	23.40	29.90	37.70	44.70	53.20	51.70	41.80	31.00	21.40	14.90	31.83
PP	.61	.53	1.01	.97	.84	.53	.83	.74	.63	.69	.72	.50	8.60
UU	73.8	76.3	102.6	102.6	90.3	83.7	79.6	80.4	78.8	75.5	70.6	70.6	82.07
SO	222	364	481	637	760	864	841	716	614	457	258	267	540
RH	.37	.34	.26	.18	.13	.05	.07	.11	.06	.10	.27	.37	.19
ES	.15	.19	.25	.33	.47	.62	.81	.76	.56	.36	.23	.16	.41
EP	.26	1.20	3.32	7.02	10.08	12.06	13.83	12.40	9.46	6.32	2.66	1.39	80.00

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BLANDING	738	109 28	37 37	6036

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.40	44.50	51.50	61.30	72.30	83.70	89.50	86.20	78.80	66.20	50.60	40.70	63.64
TN	16.20	21.50	26.30	32.90	41.40	50.00	57.50	55.30	47.30	37.30	26.20	18.30	35.85
PP	1.34	.95	.80	.67	.59	.37	1.04	1.41	.89	1.46	.89	1.29	11.70
UU	26.9	36.6	54.3	75.9	68.1	60.7	50.9	49.5	44.9	31.5	26.9	26.4	46.05
SO	198	308	429	549	669	744	696	607	508	368	227	212	460
RH	.53	.50	.45	.36	.30	.23	.27	.30	.28	.35	.47	.52	.38
ES	.14	.19	.24	.32	.47	.66	.84	.76	.57	.39	.23	.16	.41
EP	.30	1.08	2.52	5.33	9.23	11.09	11.92	9.63	7.25	4.42	1.82	.77	65.37

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BLUFF	788	109 33	37 17	4315

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	42.50	51.80	60.70	70.50	79.90	90.50	95.90	92.80	85.60	72.70	56.70	44.40	70.33
TN	16.60	22.80	28.30	35.70	44.20	51.70	59.90	58.10	47.70	35.60	25.00	17.20	36.90
PP	.78	.64	.55	.40	.37	.19	.76	.77	.60	1.15	.61	.79	7.61
UU	27.5	39.1	58.8	82.0	73.5	67.5	59.9	51.0	47.5	35.0	29.5	28.5	49.98
SO	213	363	481	628	735	830	770	663	587	442	256	257	519
RH	.43	.35	.26	.20	.17	.09	.17	.20	.12	.14	.28	.40	.23
ES	.16	.22	.30	.40	.56	.76	.96	.87	.66	.42	.26	.17	.48
EP	.32	.99	3.05	6.89	11.00	13.64	14.71	12.24	9.15	5.63	2.02	.89	80.53

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BRIGHAM CITY#	928	112 02	41 31	4285

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.40	42.50	51.10	61.40	73.10	82.90	92.90	89.80	81.20	66.30	49.30	38.10	63.75
TN	18.70	23.40	28.40	36.60	45.70	53.50	60.80	58.00	48.80	38.60	28.90	21.00	38.53
PP	2.31	1.67	1.94	2.21	1.92	1.48	.42	.91	1.32	1.56	1.80	1.90	19.44
UU	41.5	42.8	64.7	76.5	68.9	57.3	47.0	48.2	41.1	41.6	40.6	38.9	50.76
SO	180	272	411	505	621	671	698	620	519	357	211	162	436
RH	.64	.61	.51	.46	.39	.34	.27	.28	.26	.38	.57	.66	.45
ES	.15	.19	.25	.35	.50	.68	.93	.84	.62	.39	.2[illegible]	.16	.44
EP	.31	1.16	2.64	5.66	9.79	10.74	12.98	10.58	7.83	4.17	1.90	.75	68.51

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BRYCE CANYON FAA	1002	112 09	37 42	7585

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.50	38.60	43.30	52.40	62.80	73.80	80.10	77.00	70.60	59.70	45.20	37.40	56.37
TN	5.00	8.50	14.40	22.00	29.50	36.10	44.10	43.10	35.00	26.10	15.40	6.90	23.84
PP	.84	1.04	.98	.74	.89	.53	1.09	1.77	1.27	1.04	.96	.96	12.11
UU	45.3	42.0	58.5	58.1	57.6	61.4	48.1	46.7	44.8	39.2	31.6	30.7	47.00
SO	232	373	456	574	702	811	770	651	559	410	249	288	506
RH	.31	.32	.35	.31	.24	.12	.17	.22	.18	.23	.33	.31	.26
ES	.10	.12	.16	.22	.31	.43	.56	.52	.40	.28	.16	.11	.28
EP	.15	.61	1.73	3.75	5.52	7.14	8.28	6.76	5.28	3.48	1.40	.61	44.70

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
BRYCE CANYON NP	1008	112 10	37 39	7915

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.10	38.90	43.60	52.90	63.30	74.40	80.50	77.20	70.80	59.90	45.30	38.00	56.74
TN	8.40	11.00	15.60	22.70	30.10	37.80	45.40	43.90	35.90	26.90	17.00	10.10	25.40
PP	1.25	1.35	1.37	.96	1.02	.58	1.22	2.15	1.52	1.22	1.18	1.16	14.98
UU	40.8	25.1	52.7	52.3	51.8	55.3	43.4	42.5	40.4	34.9	28.5	27.6	41.27
SO	221	353	449	572	700	793	754	642	550	405	243	263	495
RH	.38	.38	.37	.32	.24	.15	.19	.24	.20	.24	.37	.38	.29
ES	.11	.13	.16	.23	.32	.45	.57	.54	.40	.28	.17	.12	.29
EP	.20	.70	1.61	3.80	5.55	7.14	8.26	6.76	5.09	3.32	1.42	.63	44.49

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
CALLAO#	1144	113 43	39 54	4320

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.60	45.30	53.40	62.00	72.20	80.80	89.50	87.40	79.10	66.90	51.90	40.30	64.03
TN	14.60	19.80	25.40	33.50	41.90	49.80	58.00	54.50	44.00	34.00	23.10	16.00	34.55
PP	.31	.34	.35	.43	.67	.72	.41	.53	.37	.45	.31	.25	5.14
UU	75.6	81.4	97.1	97.1	81.4	72.8	72.0	70.5	73.6	68.9	68.1	72.0	77.54
SO	210	330	449	551	661	698	687	636	553	404	245	230	471
RH	.45	.44	.37	.36	.32	.30	.28	.25	.19	.25	.35	.47	.34
ES	.14	.19	.24	.33	.47	.62	.84	.76	.56	.36	.23	.15	.41
EP	.29	1.35	3.29	6.54	10.15	10.49	12.48	11.15	8.41	5.52	2.52	1.19	73.36

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
CAPITOL REEF NP	1171	111 16	38 17	5500

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.60	47.70	56.20	66.00	76.00	86.70	92.30	88.90	81.60	69.00	53.20	42.20	66.70
TN	17.50	24.00	29.80	37.50	46.30	55.10	62.50	60.40	52.70	42.90	30.00	20.30	39.92
PP	.28	.23	.38	.48	.68	.40	.92	1.07	.74	.81	.59	.28	6.86
UU	49.5	47.9	71.4	75.0	66.8	58.1	45.9	44.4	41.8	42.3	36.2	37.7	51.42
SO	202	314	438	551	653	708	655	572	476	342	222	207	445
RH	.50	.49	.42	.36	.33	.28	.33	.36	.35	.42	.50	.53	.41
ES	.16	.21	.28	.39	.54	.76	.93	.87	.66	.45	.27	.17	.47
EP	.33	1.36	3.17	6.88	10.59	12.26	12.56	10.25	7.68	4.64	2.28	.90	72.89

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
CASTLEDALE#	1214	111 01	39 13	5660

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.30	42.80	51.80	63.10	73.10	83.40	90.30	87.30	79.50	67.60	50.20	39.80	63.77
TN	8.80	14.90	22.60	32.10	39.00	47.00	53.90	51.40	42.60	32.60	21.00	12.00	31.49
PP	.53	.52	.44	.48	.74	.48	.66	.97	.72	.71	.55	.52	7.32
UU	53.6	50.1	66.0	67.3	54.1	39.0	30.1	30.1	30.1	35.4	35.9	44.3	44.67
SO	220	353	458	581	713	789	778	680	575	423	246	262	507
RH	.39	.38	.34	.30	.22	.16	.16	.17	.14	.19	.34	.38	.26
ES	.12	.16	.22	.33	.45	.62	.78	.71	.54	.36	.21	.14	.39
EP	.21	.93	2.54	5.93	8.34	9.92	10.40	8.36	6.32	4.04	1.74	.78	59.50

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
CEDAR CITY FAA	1267	113 06	37 42	5620

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	42.10	46.60	52.40	61.20	71.60	83.30	90.10	87.30	79.90	67.80	52.70	43.90	64.91
TN	17.00	21.80	25.90	32.70	40.90	49.30	57.90	56.30	47.10	36.30	25.40	18.30	35.74
PP	.64	.80	1.06	.98	.82	.45	1.10	1.17	.90	.78	.91	.65	10.26
UU	43.8	46.6	56.2	61.4	58.1	57.6	50.5	49.0	44.7	38.6	36.7	33.8	48.08
SO	210	324	438	551	666	749	700	608	524	391	239	242	470
RH	.45	.46	.41	.36	.30	.22	.27	.30	.25	.28	.39	.44	.34
ES	.16	.19	.24	.32	.45	.64	.84	.78	.60	.39	.24	.17	.42
EP	.33	1.20	2.69	5.38	8.28	10.26	11.78	9.96	7.65	4.67	2.03	.98	65.21

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
COALVILLE#	1588	111 24	40 55	5550

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.80	42.40	49.00	59.00	69.60	75.10	85.70	84.20	77.30	66.70	50.90	39.20	61.41
TN	10.90	14.20	19.90	27.40	33.00	39.40	45.40	43.50	35.40	27.10	19.50	13.00	27.39
PP	1.28	1.10	1.35	1.83	1.58	1.12	.83	.95	1.03	1.27	1.35	1.35	15.04
UU	17.5	17.2	46.3	41.9	45.4	23.8	16.0	23.2	24.7	29.1	25.2	17.2	27.29
SO	218	355	457	589	747	778	851	751	636	465	255	247	529
RH	.40	.37	.35	.28	.15	.17	.06	.05	.05	.07	.29	.42	.22
ES	.12	.15	.19	.28	.37	.47	.64	.60	.45	.32	.20	.14	.33
EP	.23	.65	1.78	4.50	5.58	7.13	7.70	6.24	4.85	3.55	1.50	.65	44.35

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
CORINNE#	1731	112 07	41 3	4230

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.20	41.50	50.40	61.40	72.50	81.70	92.10	89.20	79.60	66.00	48.80	37.50	62.99
TN	15.50	20.50	56.30	34.00	41.00	49.70	56.70	54.50	44.80	39.80	2.50	18.70	36.17
PP	1.78	1.52	1.36	1.77	1.66	1.42	.48	.80	1.04	1.18	1.39	1.50	15.90
UU	41.5	42.8	64.7	76.2	68.9	57.3	47.0	48.2	41.1	41.6	40.6	38.9	50.73
SO	188	289	202	221	232	238	241	243	244	244	245	245	236
RH	.59	.56	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.93
ES	.13	.17	.40	.07	.02	37.50	72.50	1.78	-.00	.00	.00	.00	9.38
EP	.28	1.08	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.36

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
COTTONWOOD WEIR	1759	111 47	40 37	4950

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.70	46.20	52.70	61.60	72.60	83.20	92.90	90.30	80.70	67.90	51.30	41.50	65.13
TN	21.90	26.00	30.80	38.60	47.60	56.50	66.10	63.80	54.90	43.40	31.40	23.10	42.01
PP	1.98	1.96	2.61	3.03	2.24	1.20	.74	1.25	1.46	1.80	1.92	2.26	22.45
UU	40.6	50.8	79.0	87.4	68.8	62.6	44.6	50.8	53.6	53.6	49.6	41.7	56.92
SO	185	282	405	483	589	626	599	542	438	327	209	174	405
RH	.61	.58	.53	.50	.45	.41	.41	.41	.43	.47	.59	.62	.50
ES	.17	.21	.27	.36	.52	.73	1.02	.93	.68	.45	.26	.18	.48
EP	.36	1.32	2.92	5.91	10.25	10.82	13.25	10.39	7.62	4.79	2.19	.96	70.78

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
COVE FORT	1792	112 35	38 36	5980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.80	44.90	50.20	59.50	70.10	82.00	90.50	87.70	79.60	67.00	52.10	43.40	64.07
TN	13.00	17.00	21.80	28.40	36.60	44.40	54.00	52.00	42.80	31.90	21.20	14.90	31.50
PP	.97	1.35	1.54	1.54	1.20	.65	1.00	1.12	.95	.98	1.03	1.07	13.40
UU	49.4	48.9	64.9	59.2	59.2	58.2	47.9	48.9	50.0	47.4	41.7	41.2	51.41
SO	225	353	452	583	705	810	780	677	574	424	253	269	509
RH	.35	.38	.36	.29	.23	.13	.15	.17	.15	.19	.30	.36	.26
ES	.14	.17	.21	.29	.40	.57	.78	.73	.54	.35	.22	.16	.38
EP	.24	.99	2.43	5.07	7.19	9.58	11.54	9.74	7.24	4.65	2.00	.99	61.67

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
DEER CREEK DAM	2057	111 32	40 24	5270

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	33.20	37.90	45.80	56.60	67.80	77.80	87.50	84.80	76.20	64.60	47.60	37.30	59.76
TN	7.70	9.80	18.10	27.20	34.60	40.70	46.60	45.10	36.40	27.90	20.20	12.70	27.25
PP	3.09	2.43	2.02	1.78	1.49	1.06	.64	1.03	1.09	1.60	2.03	2.55	20.81
UU	33.5	42.5	69.3	80.5	62.6	45.6	32.6	34.4	37.1	37.1	39.8	31.3	45.52
SO	212	354	447	562	700	801	862	736	610	439	239	232	516
RH	.44	.37	.38	.34	.24	.14	.05	.07	.07	.15	.39	.46	.26
ES	.10	.12	.18	.27	.37	.50	.66	.62	.45	.31	.19	.13	.33
EP	.20	.62	2.00	4.73	7.52	8.43	9.08	7.49	5.54	3.79	1.65	.76	51.82

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
DESERET	2101	112 39	39 17	4585

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.60	46.10	54.50	64.00	74.50	85.10	93.60	90.10	80.80	67.90	51.20	40.20	65.55
TN	13.10	19.30	23.90	30.90	39.70	47.10	55.30	52.90	42.40	31.90	21.80	14.40	32.72
PP	.59	.52	.75	.80	.82	.43	.45	.63	.49	.67	.63	.55	7.33
UU	63.1	61.8	83.9	79.3	63.7	66.3	59.8	60.5	63.7	60.5	54.0	57.9	64.54
SO	212	342	468	607	722	816	813	699	593	432	247	244	516
RH	.44	.41	.31	.24	.20	.11	.11	.14	.10	.17	.34	.43	.25
ES	.14	.19	.24	.32	.47	.64	.84	.78	.56	.36	.22	.14	.41
EP	.27	1.22	2.94	6.22	9.18	10.90	13.01	11.34	8.23	5.45	2.27	1.01	72.04

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
DESERT EXPERIMENT STN	2116	113 45	38 36	5252

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.00	47.10	53.70	62.50	73.00	84.40	92.50	89.40	80.80	68.10	52.30	43.10	65.66
TN	11.80	18.30	23.30	30.30	38.80	47.00	55.10	53.30	43.40	32.30	21.10	13.50	32.35
PP	.30	.31	.55	.60	.62	.42	.78	.84	.56	.50	.35	.29	6.12
UU	62.0	72.2	91.1	97.7	79.5	73.6	73.6	74.4	67.8	67.1	64.9	63.5	73.95
SO	227	361	467	596	714	806	797	683	581	430	254	279	516
RH	.34	.35	.31	.27	.21	.13	.13	.16	.13	.17	.29	.33	.24
ES	.14	.19	.24	.31	.45	.64	.84	.76	.56	.36	.22	.15	.40
EP	.22	1.13	3.14	6.15	9.78	11.71	13.42	11.74	8.87	5.59	2.39	1.28	75.41

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
DUGWAY	2257	112 56	40 11	4340

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.30	45.20	52.40	62.00	73.20	84.20	94.40	91.20	80.80	66.80	50.20	38.90	64.80
TN	17.20	23.70	27.90	35.70	44.60	53.50	62.50	60.00	48.70	36.80	26.10	18.70	37.95
PP	.51	.59	.63	.76	.83	.59	.44	.47	.48	.55	.52	.54	6.91
UU	77.5	81.6	113.4	102.0	85.7	80.8	76.7	78.3	78.3	74.3	67.7	75.1	82.62
SO	194	294	424	524	638	693	694	611	516	378	226	191	449
RH	.55	.54	.47	.42	.36	.30	.27	.29	.27	.32	.48	.58	.40
ES	.15	.19	.25	.35	.50	.71	.96	.89	.62	.39	.23	.16	.45
EP	.32	1.44	3.30	6.90	10.98	12.18	14.84	13.03	9.25	5.72	2.48	1.07	81.50

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ECHO	2285	111 26	40 58	5500

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.50	40.40	47.10	57.10	68.40	78.70	88.80	86.40	77.80	65.60	48.00	37.90	60.98
TN	10.60	13.60	20.60	28.80	35.90	41.70	48.20	46.40	37.40	29.00	20.50	13.10	28.82
PP	1.15	.94	1.20	1.58	1.54	1.17	.71	.92	.93	1.30	1.13	1.23	13.80
UU	15.5	14.8	39.7	36.7	38.7	19.9	13.5	20.4	21.7	23.7	19.9	14.8	23.27
SO	209	342	438	548	691	800	856	740	618	438	239	234	513
RH	.46	.41	.41	.37	.26	.14	.05	.06	.05	.15	.39	.46	.27
ES	.12	.14	.19	.28	.39	.52	.71	.64	.48	.32	.19	.14	.34
EP	.24	.67	1.80	4.30	6.12	7.69	8.26	6.61	5.29	3.37	1.44	.59	46.37

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ELBERTA	2418	111 57	39 57	4690

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.20	44.20	53.10	62.80	73.50	83.90	92.00	89.00	80.20	67.10	51.00	39.70	64.56
TN	17.00	21.80	26.60	33.50	41.50	49.60	58.10	56.10	46.80	35.90	26.30	18.60	35.98
PP	.90	.80	.93	1.06	.98	.73	.65	1.04	.68	.85	.90	.94	10.46
UU	25.4	31.5	45.1	46.4	36.5	33.1	28.7	26.6	26.6	26.9	20.4	24.7	30.99
SO	194	302	438	560	684	754	731	636	532	389	228	200	471
RH	.55	.52	.41	.34	.27	.21	.22	.25	.23	.29	.46	.55	.36
ES	.15	.19	.25	.33	.48	.66	.87	.81	.60	.39	.24	.16	.43
EP	.32	1.08	2.55	5.35	8.14	9.57	10.96	9.26	6.62	3.97	1.82	.65	60.29

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PINE VIEW DAM	6869	111 50	41 15	4940

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	31.00	36.50	44.60	56.30	67.80	77.50	87.70	85.10	75.70	63.00	44.80	33.70	58.64
TN	8.40	11.10	19.50	30.00	37.60	43.80	50.80	48.90	40.60	31.20	22.10	12.70	29.73
PP	3.83	3.11	3.06	3.05	2.68	1.72	.71	1.09	1.46	2.11	2.76	3.21	28.79
UU	30.7	32.0	61.3	29.8	51.1	43.1	29.4	37.9	37.9	39.6	29.0	29.0	37.57
SO	200	330	428	524	660	744	787	685	553	394	220	199	477
RH	.52	.44	.45	.42	.32	.23	.14	.16	.19	.28	.51	.56	.35
ES	.10	.12	.18	.28	.40	.54	.71	.66	.48	.32	.19	.12	.34
EP	.22	.69	1.86	4.59	6.27	8.31	9.63	7.79	5.93	3.70	1.56	.55	51.08

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PLEASANT GROVE#	6919	111 44	40 22	4668

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.20	45.40	52.60	62.10	73.00	82.40	91.00	88.00	79.60	67.30	50.90	40.60	64.34
TN	19.10	23.10	27.80	34.80	42.50	50.00	57.90	55.70	46.50	36.80	27.50	20.80	36.87
PP	1.72	1.51	1.68	1.92	1.45	.90	.83	.81	.93	1.33	1.25	1.49	15.82
UU	31.8	43.8	55.5	65.3	61.3	48.8	37.7	37.7	40.0	37.3	35.5	33.7	44.03
SO	190	301	426	536	664	722	716	627	528	382	223	187	459
RH	.58	.52	.46	.39	.31	.26	.24	.26	.24	.31	.49	.59	.39
ES	.16	.19	.25	.33	.48	.64	.84	.78	.57	.39	.24	.17	.42
EP	.33	1.17	2.73	5.49	9.09	10.20	11.42	9.42	6.89	4.41	1.96	.84	63.95

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PROVO BYU#	4015	111 39	40 15	4570

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.00	46.00	54.70	64.30	73.30	84.60	92.80	90.30	81.00	68.40	53.30	41.80	65.88
TN	19.10	22.60	29.40	36.70	44.90	50.30	58.30	56.20	52.30	38.60	29.10	22.30	38.32
PP	1.40	1.32	1.29	1.30	1.17	.79	.68	.96	.66	1.35	1.25	1.33	13.50
UU	23.7	33.7	49.3	57.2	48.3	33.6	26.4	25.9	24.5	26.5	18.3	25.0	32.70
SO	193	311	430	540	635	754	742	654	474	376	226	185	460
RH	.56	.49	.45	.39	.36	.21	.21	.22	.36	.33	.47	.60	.39
ES	.16	.19	.27	.37	.50	.66	.89	.81	.66	.42	.26	.18	.45
EP	.35	1.10	2.78	6.00	9.04	10.16	11.34	9.22	6.79	4.09	1.95	.69	63.51

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
RICHFIELD KSVC	7260	112 05	38 46	5270

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.90	46.90	54.40	63.00	72.70	82.90	89.90	87.50	80.30	69.30	53.50	43.70	65.50
TN	14.10	18.90	23.30	29.50	37.20	44.00	51.60	50.00	40.40	30.50	21.50	15.10	31.34
PP	.63	.62	.63	.71	.73	.41	.81	.69	.80	.64	.59	.56	7.82
UU	37.2	40.0	53.3	56.6	48.9	48.5	35.6	36.0	37.2	36.8	32.3	30.3	41.06
SO	221	353	472	612	732	832	813	704	612	458	257	270	528
RH	.38	.37	.29	.23	.18	.09	.11	.13	.07	.09	.27	.36	.21
ES	.15	.19	.24	.31	.43	.57	.76	.71	.52	.36	.23	.16	.38
EP	.27	.93	2.51	5.20	7.37	9.11	10.68	8.76	6.48	4.50	1.83	.86	58.53

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PANGUITCH#	6601	112 27	37 49	6720

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.50	43.80	50.10	59.90	69.40	76.40	85.20	82.30	76.50	67.00	51.40	41.80	62.03
TN	7.80	12.40	17.70	23.80	31.20	37.90	45.80	44.10	35.40	26.20	16.70	8.70	25.64
PP	.54	.65	.66	.60	.80	.58	1.46	1.56	1.10	.68	.74	.52	9.89
UU	41.1	39.3	39.3	50.2	52.7	53.1	42.5	42.9	41.0	37.2	29.8	28.7	41.48
SO	241	385	481	644	769	825	834	714	626	476	268	312	548
RH	.25	.29	.26	.16	.11	.10	.08	.11	.05	.05	.20	.24	.16
ES	.12	.15	.19	.27	.36	.47	.64	.57	.45	.32	.19	.13	.32
EP	.13	.63	2.00	4.04	5.46	7.52	9.26	7.49	5.86	4.20	1.46	.66	48.73

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PAROWAN	6686	112 50	37 51	5930

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	42.50	46.60	52.10	60.40	70.60	81.50	87.70	85.10	78.60	68.00	53.10	44.40	64.22
TN	15.80	20.20	24.80	31.70	39.90	48.00	55.60	53.70	45.20	34.90	24.20	17.40	34.28
PP	.87	1.07	1.29	1.24	.92	.48	1.22	1.38	.88	.88	1.02	.91	12.16
UU	45.2	45.2	57.1	59.0	58.1	58.1	48.6	48.6	45.7	42.8	36.2	32.8	48.12
SO	217	339	444	553	666	740	698	614	532	406	245	255	476
RH	.41	.42	.39	.36	.30	.23	.27	.29	.23	.24	.35	.40	.32
ES	.16	.19	.23	.31	.43	.62	.78	.71	.56	.37	.24	.17	.40
EP	.29	1.11	2.57	5.21	7.89	9.85	11.02	8.95	7.18	4.67	2.11	.99	61.84

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PARK VALLEY	6558	113 20	41 48	5400

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.10	39.80	46.60	55.70	66.30	76.00	86.90	84.20	75.50	62.50	46.30	36.70	59.30
TN	12.70	19.60	24.50	31.20	39.70	45.80	55.80	53.60	45.20	34.80	24.10	17.20	33.68
PP	1.01	.79	.73	.82	1.44	1.18	.92	1.00	.57	.71	.79	.74	10.70
UU	48.7	54.1	63.9	74.7	75.7	61.3	43.8	43.8	38.6	38.6	46.3	43.8	52.77
SO	199	282	406	501	610	685	679	602	493	357	218	185	435
RH	.52	.58	.53	.47	.41	.32	.29	.31	.32	.38	.53	.60	.44
ES	.12	.16	.21	.28	.40	.54	.76	.71	.52	.35	.20	.14	.37
EP	.26	1.06	2.36	4.48	7.76	8.79	10.65	8.60	6.16	3.66	1.66	.78	56.22

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PARTOUN	6708	113 53	39 39	4750

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.00	47.30	54.70	63.80	74.50	85.40	94.90	92.00	82.80	69.00	52.80	42.00	66.68
TN	13.20	18.80	23.70	31.50	39.90	48.00	55.40	53.40	43.00	32.70	22.30	14.30	33.02
PP	.32	.42	.48	.69	.82	.71	.58	.45	.44	.52	.42	.34	6.19
UU	65.0	71.2	85.7	89.1	74.6	73.9	63.6	64.3	64.3	58.7	63.6	62.9	69.74
SO	221	356	471	597	720	806	836	720	610	435	251	261	524
RH	.38	.36	.30	.26	.20	.13	.08	.10	.07	.16	.31	.38	.23
ES	.14	.19	.24	.33	.47	.66	.87	.81	.57	.37	.23	.15	.42
EP	.25	1.16	3.11	6.49	9.69	11.86	14.06	12.13	8.84	5.69	2.32	1.23	76.84

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
OAK CITY	6357	112 20	39 23	5070

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.50	46.40	53.60	62.60	73.80	85.10	94.10	91.40	82.80	70.10	52.30	42.20	66.24
TN	18.80	23.80	28.50	35.50	44.60	53.60	62.60	60.00	50.60	39.40	27.60	20.20	38.77
PP	1.15	1.12	1.38	1.37	1.24	.63	.44	.85	.79	.95	1.13	1.10	12.15
UU	55.8	58.2	79.8	82.8	61.8	61.8	54.0	54.6	57.6	54.6	48.0	52.2	60.10
SO	196	304	428	533	646	707	687	614	517	384	228	208	454
RH	.54	.52	.45	.40	.34	.28	.28	.29	.27	.30	.46	.53	.39
ES	.16	.20	.26	.35	.50	.71	.96	.89	.66	.43	.25	.17	.46
EP	.35	1.37	3.07	6.24	10.19	11.18	13.58	11.62	8.71	5.65	2.37	1.04	75.37

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
OGDEN PIONEER	6404	111 57	41 15	4350

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.60	43.40	50.70	60.40	71.50	81.60	91.60	88.60	79.00	66.20	49.80	39.30	63.31
TN	19.50	23.80	29.40	37.60	46.40	54.30	62.40	59.90	50.50	39.90	29.10	21.70	39.54
PP	2.36	1.90	2.05	2.52	2.14	1.58	.65	.98	1.20	1.58	1.73	1.89	20.58
UU	55.3	57.5	101.0	118.0	87.0	80.3	58.2	67.8	67.1	67.1	53.1	50.1	71.87
SO	182	276	400	480	590	636	644	575	471	344	213	167	415
RH	.63	.59	.55	.51	.45	.39	.34	.36	.36	.42	.56	.65	.49
ES	.16	.19	.25	.35	.50	.68	.93	.84	.62	.40	.24	.17	.44
EP	.33	1.29	2.76	6.07	11.05	10.99	13.62	10.63	8.08	4.98	2.26	.91	72.97

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
OGDEN SUGAR	6414	112 02	41 14	4280

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.20	42.90	50.90	61.10	72.20	82.20	92.20	89.30	79.70	67.00	50.20	39.50	63.70
TN	18.30	22.90	28.80	36.50	44.80	52.30	59.50	57.20	47.60	37.80	28.20	21.10	37.92
PP	1.52	1.27	1.41	2.06	1.71	1.43	.50	.72	1.10	1.27	1.36	1.30	15.65
UU	38.8	40.3	67.3	79.1	60.7	56.6	42.8	49.0	48.5	46.4	39.8	35.2	50.37
SO	185	280	406	503	621	680	709	624	516	370	218	174	441
RH	.61	.58	.53	.46	.39	.33	.25	.27	.27	.34	.53	.62	.43
ES	.15	.19	.25	.35	.50	.66	.89	.81	.60	.39	.24	.16	.43
EP	.32	1.16	2.58	5.69	9.90	10.13	12.54	10.02	7.56	4.58	2.05	.79	67.30

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ORDERVILLE	6534	112 38	37 16	5440

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	45.90	50.50	55.00	64.00	73.80	84.50	90.80	88.20	81.40	71.20	57.10	48.40	67.57
TN	15.40	19.80	23.30	30.10	38.70	46.50	53.60	52.30	44.80	34.20	23.90	17.00	33.30
PP	1.98	1.63	1.47	.94	.74	.56	.93	1.43	1.10	1.10	1.23	1.44	14.55
UU	41.9	43.3	53.2	56.8	56.4	57.7	51.0	46.9	42.4	32.9	30.7	30.7	45.33
SO	232	378	476	617	726	816	793	680	571	441	262	296	524
RH	.31	.30	.28	.22	.19	.11	.14	.17	.15	.14	.24	.29	.21
ES	.17	.20	.24	.32	.45	.64	.78	.73	.57	.40	.26	.19	.41
EP	.25	.92	2.55	5.39	7.71	10.50	11.56	9.95	7.65	5.18	1.90	.99	64.52

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MYTON#	5969	110	40 12	5080

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	29.60	37.50	50.80	0.00	700*7	0.00	0.00	90.50	8.70	79.00	.60	4.70	83.51
TN	1.40	8.40	19.90	29.90	39.30	47.10	53.60	51.30	42.60	31.30	18.60	6.70	29.18
PP	.42	.31	.51	.57	.68	.68	.48	.75	.60	.72	.44	.53	6.69
UU	50.6	65.0	84.2	97.0	72.6	51.9	51.3	45.8	49.4	47.6	49.4	39.9	58.73
SO	223	364	470	-167	-3	86	137	165	180	189	194	197	170
RH	.37	.35	.30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.83
ES	.09	.12	.20	.08	.03	.09	700*7	-1.33	-.00	.00	.00	.00	58.33
EP	.15	.64	2.56	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	3.35

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
NEPHI	6135	111 50	39 43	5133

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.30	44.90	51.80	61.30	72.30	83.80	93.60	90.70	81.60	69.20	52.60	42.30	65.37
TN	17.40	21.90	26.90	34.00	42.10	50.10	58.30	56.20	47.10	36.40	26.50	19.00	36.33
PP	1.30	1.27	1.46	1.48	1.22	.76	.63	.95	.88	1.07	1.22	1.26	13.50
UU	43.0	56.0	82.3	86.1	61.3	55.4	47.9	43.0	43.0	46.3	37.7	44.2	53.85
SO	201	308	427	536	660	744	757	660	545	403	234	220	475
RH	.51	.50	.46	.39	.32	.23	.19	.21	.21	.25	.42	.50	.35
ES	.16	.19	.24	.33	.47	.66	.89	.81	.60	.40	.25	.17	.43
EP	.33	1.18	2.81	6.09	9.67	10.75	12.81	10.64	7.53	4.90	2.26	.95	69.91

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
NEW HARMONY#	618	113 18	37 29	5290

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	44.80	49.30	54.20	63.10	72.40	82.60	88.70	85.90	79.70	69.30	55.60	47.10	66.06
TN	19.90	24.00	27.30	33.80	41.80	50.50	58.50	57.10	49.30	39.30	28.10	20.80	37.53
PP	2.15	2.26	2.18	1.20	.93	.52	1.07	1.60	1.24	1.15	1.59	1.64	17.53
UU	49.1	53.1	61.1	69.0	64.3	64.3	58.4	56.3	49.6	38.0	39.0	37.2	53.28
SO	209	329	441	560	665	717	662	576	495	378	239	248	460
RH	.46	.45	.40	.34	.31	.27	.32	.35	.31	.32	.39	.42	.36
ES	.18	.22	.26	.33	.47	.66	.84	.78	.62	.42	.27	.19	.44
EP	.36	1.37	3.03	5.74	8.93	10.67	11.76	9.96	7.92	5.06	2.27	1.16	68.24

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
NORTH LOGAN#	0	111 49	41 46	4700

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	32.70	38.10	46.20	57.10	68.40	77.30	87.00	85.00	75.20	63.10	45.70	34.90	59.23
TN	13.60	17.20	24.00	32.70	41.20	46.80	54.20	51.80	42.60	33.30	21.40	16.50	32.94
PP	1.90	1.64	1.86	2.22	1.74	1.61	.48	.97	1.08	1.43	1.59	1.86	18.38
UU	29.5	34.9	48.1	60.3	57.4	43.4	37.6	36.9	35.6	27.9	30.2	29.6	39.28
SO	186	288	407	500	619	690	711	641	522	376	227	174	445
RH	.61	.56	.53	.47	.40	.31	.25	.24	.26	.33	.47	.62	.42
ES	.12	.15	.20	.30	.43	.56	.76	.68	.50	.33	.19	.14	.36
EP	.25	.89	2.06	4.53	7.88	8.47	10.01	8.31	5.91	3.61	1.51	.59	54.03

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MONTICELLO	5805	109 18	37 52	6820

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.70	40.40	47.10	57.50	67.60	78.50	84.50	81.30	74.30	63.00	47.90	38.50	59.69
TN	14.20	17.60	22.60	29.60	37.70	45.40	52.80	50.90	43.40	34.10	23.30	15.80	32.28
PP	1.34	.97	.96	.86	1.00	.48	1.67	1.89	1.16	1.62	1.08	1.38	14.41
UU	27.4	39.1	54.4	75.8	67.0	60.9	47.0	47.4	45.1	30.7	27.4	26.0	45.68
SO	196	306	424	543	655	734	690	600	501	368	228	215	455
RH	.54	.51	.47	.38	.33	.24	.28	.31	.30	.35	.46	.51	.39
ES	.13	.16	.20	.29	.40	.56	.71	.64	.50	.35	.21	.14	.36
EP	.28	.91	2.18	4.73	7.97	9.19	10.02	7.88	6.15	3.97	1.67	.68	55.63

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MORGAN	5826	111 41	41 02	5070

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.30	40.70	48.40	59.00	70.40	80.80	89.50	86.90	78.10	66.30	48.00	38.10	61.79
TN	11.60	15.50	22.10	29.60	36.60	42.30	48.90	47.00	38.20	29.60	21.10	13.70	29.68
PP	1.91	1.73	1.76	2.19	1.76	1.30	.52	.97	1.04	1.50	1.64	1.75	18.07
UU	14.5	17.1	32.6	47.1	34.3	16.0	12.7	18.4	18.4	19.9	15.8	13.2	21.67
SO	205	328	437	562	709	825	856	739	612	439	237	231	515
RH	.49	.45	.42	.34	.22	.10	.05	.07	.07	.15	.40	.47	.27
ES	.12	.15	.20	.29	.42	.56	.71	.66	.48	.33	.20	.14	.35
EP	.24	.75	1.90	4.34	6.90	8.08	8.02	6.80	5.19	3.37	1.45	.54	47.60

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MORONI	5837	111 35	39 32	5525

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.50	42.30	50.80	60.70	71.50	81.90	89.60	86.70	79.40	67.30	50.00	38.70	62.95
TN	11.10	15.60	21.80	28.20	35.90	42.40	49.60	48.10	39.20	30.60	20.80	12.50	29.65
PP	.95	.86	.79	.73	.74	.46	.54	.84	.85	.77	.78	.95	9.26
UU	37.8	51.4	72.2	71.3	52.9	47.2	36.8	34.0	35.9	40.1	39.6	40.6	46.65
SO	211	341	457	600	733	842	845	720	615	439	246	247	525
RH	.44	.41	.35	.26	.18	.08	.06	.10	.06	.15	.34	.42	.24
ES	.12	.16	.21	.29	.42	.56	.73	.66	.50	.35	.20	.14	.36
EP	.24	.88	2.47	5.26	7.78	9.01	10.29	8.29	6.16	4.20	1.75	.81	57.14

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MT. DELL DAM	5892	111 43	40 45	5420

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.50	43.00	48.80	58.20	69.10	78.70	88.30	86.00	77.30	64.90	48.70	39.60	61.76
TN	13.50	16.40	21.60	29.70	37.40	43.50	50.80	49.50	41.10	32.70	23.10	15.60	31.24
PP	2.22	2.15	2.35	2.77	2.16	1.40	.85	1.10	1.46	1.94	1.90	2.40	22.70
UU	21.1	27.2	43.1	46.5	35.8	32.7	22.3	28.8	29.7	29.7	28.2	22.0	30.59
SO	210	341	443	551	680	769	798	689	566	398	232	227	492
RH	.45	.41	.40	.36	.28	.19	.13	.15	.16	.27	.44	.48	.31
ES	.14	.16	.20	.29	.40	.54	.73	.68	.50	.35	.21	.15	.36
EP	.27	.81	2.04	4.53	6.81	7.78	9.41	7.65	5.79	3.73	1.67	.74	51.23

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MEXICAN HAT	5582	109 52	37 09	4120

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	43.40	52.90	61.20	71.10	81.60	93.00	98.40	95.20	87.60	74.40	57.80	45.30	71.82
TN	18.90	24.80	30.10	38.40	48.10	57.20	65.20	63.10	52.80	40.10	28.70	20.00	40.62
PP	.50	.43	.38	.31	.35	.19	.66	.65	.54	.96	.51	.61	6.09
UU	23.6	33.4	50.2	70.0	63.0	57.8	51.2	43.5	40.6	29.9	25.2	24.3	42.73
SO	208	354	472	602	705	779	718	624	549	417	246	239	493
RH	.47	.37	.29	.25	.23	.17	.24	.27	.20	.21	.35	.45	.29
ES	.17	.24	.31	.43	.62	.87	1.09	.99	.73	.47	.28	.19	.53
EP	.35	1.10	3.11	7.15	11.71	14.51	15.55	12.85	9.34	5.69	2.16	.89	84.41

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MILFORD	5654	113 01	38 26	5028

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.40	45.30	52.70	62.20	73.10	84.80	92.90	89.90	81.20	67.80	51.50	41.50	65.19
TN	13.40	18.80	23.60	30.40	38.60	46.80	55.60	54.20	43.90	32.60	22.00	14.80	32.89
PP	.69	.74	.99	.96	.73	.42	.61	.71	.69	.73	.69	.63	8.59
UU	90.2	93.8	126.3	130.1	113.5	101.3	97.5	10.0	97.4	91.3	84.5	81.5	93.12
SO	214	340	457	591	718	816	795	677	580	425	247	252	509
RH	.43	.41	.35	.28	.21	.11	.13	.17	.13	.19	.34	.41	.26
ES	.14	.18	.23	.31	.45	.64	.84	.78	.57	.36	.22	.15	.41
EP	.26	1.37	3.40	7.00	11.32	13.63	15.20	13.64	5.71	6.71	2.85	1.46	82.57

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MOAB 4NW	5733	109 36	38 36	3965

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.80	50.90	60.80	71.20	81.90	92.70	99.40	96.10	88.00	74.90	57.40	44.50	71.63
TN	18.60	25.00	33.10	41.60	50.20	57.60	64.80	62.80	52.90	41.10	29.60	21.20	41.54
PP	.57	.52	.67	.91	.68	.37	.52	.83	.66	.94	.66	.67	8.00
UU	24.5	33.6	44.1	54.3	48.7	42.7	34.5	33.6	31.9	27.0	24.5	20.6	35.00
SO	202	334	447	564	680	767	744	642	553	412	241	220	484
RH	.50	.43	.38	.33	.28	.19	.20	.24	.19	.22	.38	.50	.32
ES	.16	.23	.32	.45	.64	.87	1.09	.99	.73	.48	.29	.19	.54
EP	.34	1.20	3.37	7.16	11.30	13.44	14.62	11.79	8.74	5.42	2.19	.86	80.43

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MODENA	5752	113 55	37 48	5460

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	42.70	48.10	54.60	63.70	73.70	84.90	91.90	88.70	81.80	70.00	54.10	44.80	66.58
TN	14.50	19.90	22.70	28.60	36.50	44.70	52.90	51.70	42.80	32.00	22.20	15.80	32.03
PP	.69	.73	.80	.68	.70	.40	1.14	1.21	.80	.87	.73	.49	9.24
UU	52.0	60.3	70.3	81.0	68.6	66.2	63.8	62.6	54.4	44.9	48.5	46.1	59.89
SO	223	355	478	632	755	854	826	696	601	451	257	274	534
RH	.37	.37	.27	.19	.14	.06	.09	.14	.09	.11	.27	.35	.20
ES	.16	.19	.24	.31	.43	.62	.78	.73	.56	.37	.23	.16	.40
EP	.27	1.13	2.88	5.62	8.32	10.89	12.19	10.85	8.39	5.39	2.01	1.14	69.08

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
LOA	5148	111 39	38 24	7080

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.40	43.10	48.30	57.00	67.00	77.00	82.50	79.50	73.30	63.40	49.10	40.80	60.03
TN	7.80	12.40	17.50	24.60	32.90	39.70	47.10	45.20	36.60	26.70	16.30	9.00	26.32
PP	.39	.27	.34	.42	.69	.39	1.10	1.21	.87	.63	.42	.34	7.07
UU	40.6	41.0	54.5	58.6	52.1	49.2	37.3	36.5	35.3	35.7	29.9	28.3	41.58
SO	237	378	470	599	713	805	759	657	572	439	261	300	516
RH	.28	.30	.30	.26	.22	.13	.18	.21	.15	.15	.25	.28	.23
ES	.12	.15	.19	.26	.36	.48	.62	.56	.43	.30	.19	.13	.31
EP	.16	.67	2.00	4.33	6.37	7.73	8.59	6.81	5.34	3.58	1.45	.67	47.70

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
LOGAN 5 SW#	5194	111 54	41 40	4490

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	33.50	38.90	47.00	58.00	69.50	78.50	88.80	86.30	76.90	64.60	47.10	35.90	60.42
TN	11.50	13.70	20.40	32.10	38.70	45.60	51.70	49.60	39.30	30.70	18.70	12.60	30.38
PP	1.82	1.41	1.56	1.81	1.34	1.35	.37	.95	1.00	1.35	1.50	1.45	15.91
UU	52.6	54.8	68.6	77.9	56.5	47.6	46.4	49.2	46.8	44.2	56.2	58.7	54.96
SO	198	328	439	519	668	730	791	692	583	413	243	220	485
RH	.53	.45	.41	.43	.30	.25	.14	.15	.13	.22	.36	.50	.32
ES	.12	.14	.19	.30	.42	.56	.73	.68	.48	.33	.19	.12	.36
EP	.25	.87	2.33	5.04	8.36	8.74	10.24	9.07	6.57	4.28	1.69	.85	58.30

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
LOGAN USU	5186	111 49	41 45	4785

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	33.10	38.00	46.00	56.80	68.00	77.10	87.20	85.10	75.30	62.70	45.70	35.30	59.19
TN	16.30	20.00	26.30	35.20	43.80	50.90	58.70	57.10	48.20	38.50	27.60	19.10	36.81
PP	1.68	1.57	1.75	2.06	1.71	1.53	.45	.96	1.06	1.43	1.53	1.63	17.36
UU	55.7	66.4	91.6	101.4	84.4	68.7	50.8	52.3	53.6	53.0	55.6	54.9	65.70
SO	176	262	389	466	578	617	631	564	454	325	202	154	402
RH	.67	.63	.59	.54	.47	.42	.36	.37	.40	.47	.63	.68	.52
ES	.13	.16	.21	.31	.45	.60	.81	.76	.56	.37	.22	.14	.39
EP	.26	1.01	2.34	5.07	9.19	9.19	11.20	9.10	6.46	3.95	1.75	.72	60.23

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
MANTI	5402	111 38	39 15	5740

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.40	42.40	50.70	59.90	70.00	80.00	87.40	85.00	77.00	65.50	49.40	39.10	61.98
TN	14.70	18.80	24.10	31.40	39.10	46.50	53.80	52.00	43.60	34.30	23.90	16.40	33.22
PP	1.13	1.20	1.28	1.40	1.16	.69	.67	.89	1.08	.99	1.05	.99	12.53
UU	37.3	48.0	65.7	65.7	53.3	47.1	33.3	38.6	36.4	38.2	38.2	37.7	44.96
SO	200	313	439	551	669	740	726	638	532	389	232	215	470
RH	.51	.49	.41	.36	.30	.23	.23	.24	.23	.29	.44	.51	.36
ES	.14	.17	.22	.31	.43	.57	.76	.71	.52	.36	.22	.15	.38
EP	.29	1.04	2.51	5.39	8.16	8.99	10.28	8.34	6.26	4.03	1.86	.82	57.97

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
KOOSHAREM#	4764	111 53	38 31	6930

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.90	41.90	47.20	56.40	67.10	78.30	85.00	82.30	75.70	64.80	49.50	41.00	60.68
TN	9.10	13.20	18.30	24.40	31.90	39.20	46.60	44.80	36.70	26.70	17.60	10.60	26.59
PP	.64	.58	.56	.63	.88	.60	1.11	1.34	.95	.74	.50	.56	9.09
UU	33.6	35.7	47.3	50.9	45.1	44.1	32.5	32.1	31.8	32.1	27.4	24.9	36.46
SO	229	360	456	594	728	835	815	704	601	451	257	287	526
RH	.33	.36	.35	.27	.19	.09	.10	.13	.09	.11	.27	.31	.22
ES	.12	.15	.19	.25	.36	.50	.64	.60	.45	.31	.19	.14	.32
EP	.19	.73	1.97	4.03	5.95	7.74	8.78	7.21	5.43	3.65	1.48	.68	47.83

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
LAKETOWN	4856	111 19	41 49	5980

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	32.90	35.70	41.00	53.10	64.80	73.90	83.40	80.90	72.50	60.10	44.10	35.20	56.47
TN	10.60	10.70	16.40	26.10	34.20	40.30	46.70	44.90	37.10	28.70	20.90	14.20	27.57
PP	1.09	.88	.89	1.11	1.13	1.15	.53	.81	.84	.94	1.01	1.16	11.54
UU	28.8	32.0	50.6	51.6	53.8	33.8	20.6	25.6	29.5	28.1	28.1	29.2	34.31
SO	199	326	424	532	665	742	784	682	556	390	222	199	477
RH	.52	.45	.46	.40	.31	.23	.15	.17	.18	.29	.50	.56	.35
ES	.11	.12	.16	.25	.36	.47	.62	.57	.43	.29	.19	.13	.31
EP	.24	.66	1.62	3.96	6.33	7.29	7.95	6.34	4.86	3.04	1.43	.60	44.31

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
LAVERKIN	4968	113 16	37 12	3200

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	52.10	58.40	63.90	72.20	81.90	91.90	97.60	94.90	88.70	77.60	62.80	53.50	74.62
TN	24.60	29.70	34.20	40.00	47.20	55.10	63.20	61.80	54.00	42.70	31.60	25.10	42.43
PP	1.36	1.28	1.54	.78	.54	.30	.73	.86	.76	.69	.89	.86	10.59
UU	41.1	46.5	50.5	58.1	54.5	55.0	51.0	47.8	41.1	27.3	30.8	30.4	44.51
SO	220	360	462	596	721	796	741	639	548	422	254	268	502
RH	.39	.36	.33	.27	.20	.15	.21	.24	.20	.20	.29	.36	.27
ES	.23	.29	.35	.45	.62	.84	1.02	.96	.76	.52	.32	.24	.55
EP	.41	1.49	3.91	7.43	10.76	13.56	14.56	12.60	9.92	6.41	2.34	1.26	84.64

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
LEVAN	5065	111 52	39 33	5315

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.50	44.00	51.90	61.30	71.90	82.80	91.30	88.60	80.40	67.90	51.40	40.30	64.19
TN	14.00	19.20	24.50	31.70	39.90	47.60	55.80	53.80	44.80	34.70	24.30	16.30	33.88
PP	1.31	1.32	1.52	1.66	1.33	.76	.68	.91	1.05	1.09	1.24	1.37	14.24
UU	51.7	66.4	96.3	98.9	71.5	65.7	54.2	51.0	51.0	55.5	47.2	54.2	63.63
SO	208	324	445	564	684	769	761	664	559	407	238	227	488
RH	.47	.46	.39	.33	.27	.19	.18	.20	.18	.24	.40	.48	.31
ES	.14	.18	.23	.32	.45	.62	.84	.76	.57	.37	.23	.15	.40
EP	.28	1.16	2.91	6.37	9.89	10.68	12.71	10.36	7.78	4.89	2.26	.95	70.23

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
JENSON	4342	109 21	40 22	4760

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	29.20	37.70	50.80	63.40	74.80	84.50	92.40	89.20	80.50	67.00	48.20	33.60	62.61
TN	1.50	7.80	19.80	29.50	38.80	45.50	52.00	48.90	39.50	28.90	18.30	6.40	28.07
PP	.51	.52	.61	.64	.75	.69	.43	.67	.71	.89	.53	.60	7.55
UU	21.7	26.6	61.3	62.8	56.9	47.1	25.4	21.3	21.3	21.7	29.2	22.1	34.78
SO	221	371	471	617	739	833	853	745	625	451	249	257	536
RH	.38	.33	.30	.22	.17	.09	.05	.06	.05	.11	.33	.40	.21
ES	.08	.12	.20	.31	.47	.62	.78	.71	.52	.33	.19	.10	.37
EP	.14	.46	1.93	5.40	8.17	10.20	10.98	8.11	5.64	3.51	1.31	.53	56.39

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
KAMAS#	4467	111 17	40 39	6490

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	35.70	40.10	44.50	53.90	65.30	75.60	85.30	82.60	74.40	62.80	46.80	38.80	58.82
TN	11.60	14.90	20.40	26.60	34.80	40.80	48.00	44.60	38.00	29.90	20.10	13.50	28.60
PP	1.80	1.88	1.53	1.79	1.56	1.15	.96	1.04	1.15	1.43	1.65	1.72	17.66
UU	19.2	18.8	50.6	47.1	43.7	27.0	16.3	21.7	26.1	26.1	34.5	18.5	29.13
SO	206	328	421	536	664	762	795	711	569	404	236	239	489
RH	.48	.45	.48	.39	.31	.20	.13	.11	.16	.25	.41	.45	.32
ES	.12	.15	.18	.25	.36	.48	.66	.60	.45	.31	.19	.14	.32
EP	.25	.78	1.70	3.98	6.18	7.27	8.19	6.35	4.92	3.25	1.43	.75	45.06

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
KANAB	4518	112 32	37 03	4985

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	47.80	53.50	58.60	67.40	76.80	87.50	93.10	90.20	84.00	73.60	59.10	50.00	70.13
TN	22.50	26.00	29.40	35.60	43.20	51.00	58.70	57.20	50.30	40.60	30.30	23.60	39.03
PP	1.75	1.25	1.41	.82	.68	.38	.87	1.37	.79	.90	1.11	1.24	12.57
UU	38.2	42.5	50.2	56.2	53.6	54.9	48.5	45.5	39.5	30.0	28.7	28.7	43.04
SO	211	349	458	591	706	791	741	638	535	405	245	249	493
RH	.45	.39	.34	.28	.23	.15	.21	.25	.23	.24	.35	.42	.29
ES	.20	.25	.29	.39	.52	.71	.89	.84	.66	.47	.30	.22	.48
EP	.40	1.33	3.16	6.41	9.08	11.37	12.67	10.86	8.42	5.52	2.33	1.11	72.65

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
KANOSH#	457	112 26	38 48	5020

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.30	46.70	53.60	62.50	72.70	84.10	92.70	88.80	82.10	68.50	52.50	42.50	65.58
TN	18.20	24.30	28.80	35.70	42.80	54.10	63.40	61.70	52.50	41.20	28.50	21.20	39.37
PP	1.21	1.36	1.62	1.62	1.34	.64	.74	.80	.80	1.01	1.19	1.17	13.50
UU	49.7	49.7	65.6	64.4	58.2	56.7	47.6	48.2	50.2	48.2	42.9	41.2	51.88
SO	198	302	426	530	655	681	645	551	485	353	226	202	438
RH	.53	.52	.46	.41	.33	.32	.34	.40	.33	.39	.48	.55	.42
ES	.16	.21	.26	.35	.48	.71	.96	.87	.66	.43	.26	.18	.46
EP	.33	1.38	2.93	5.89	9.06	10.73	12.78	10.02	7.97	4.92	2.32	1.00	69.35

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
HANKSVILLE	3611	110 43	38 22	4308

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.80	48.60	58.40	68.70	80.00	91.40	98.00	94.40	85.60	71.80	54.00	42.10	69.40
TN	11.40	19.50	27.30	36.10	45.90	54.20	61.90	59.70	49.10	37.00	23.90	14.30	36.69
PP	.30	.22	.35	.42	.49	.23	.44	.83	.60	.63	.43	.30	5.24
UU	27.9	32.8	49.8	50.2	44.6	35.7	27.2	25.9	23.6	24.9	23.3	29.2	32.92
SO	224	364	472	601	713	803	772	663	570	421	250	262	510
RH	.36	.35	.29	.26	.22	.14	.16	.20	.15	.20	.32	.38	.25
ES	.14	.19	.28	.39	.57	.81	1.02	.93	.66	.42	.24	.15	.48
EP	.23	.87	2.77	6.39	9.66	12.46	13.30	10.64	7.52	4.37	1.71	.70	70.63

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
HEBER	3809	111 25	40 31	5580

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	34.70	39.70	47.30	57.60	68.80	77.80	87.00	84.70	76.80	65.70	48.30	37.60	60.50
TN	8.80	12.80	20.50	28.00	34.90	40.90	47.70	46.00	37.60	28.90	20.10	12.00	28.18
PP	2.09	1.52	1.27	1.32	1.18	.93	.65	.92	.92	1.29	1.50	1.73	15.32
UU	21.7	21.4	52.6	52.6	41.3	27.5	18.7	22.0	25.7	25.1	33.7	20.5	30.23
SO	213	343	440	564	710	798	832	721	603	440	242	242	512
RH	.43	.40	.41	.33	.22	.14	.08	.10	.08	.15	.37	.44	.26
ES	.11	.14	.19	.28	.39	.50	.66	.62	.47	.32	.19	.13	.33
EP	.22	.67	1.88	4.60	6.62	7.53	8.21	6.71	5.17	3.52	1.46	.71	47.28

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
HIAWATHA	3896	111 01	39 29	7220

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	32.40	37.00	43.90	54.20	64.60	75.50	83.30	79.30	71.60	59.70	43.30	34.70	56.63
TN	13.70	17.60	22.10	30.30	39.20	49.10	56.10	54.20	46.40	36.40	23.80	16.10	33.75
PP	1.05	1.03	1.04	1.01	1.19	.95	1.07	1.72	1.26	1.12	.89	1.18	13.51
UU	85.5	75.0	100.0	95.4	67.8	57.2	41.5	42.1	143.4	154.0	55.9	72.4	82.52
SO	184	275	404	494	594	620	606	522	431	316	208	176	403
RH	.62	.60	.54	.48	.44	.42	.40	.45	.45	.50	.60	.62	.51
ES	.12	.14	.19	.27	.39	.56	.73	.66	.50	.33	.19	.13	.35
EP	.25	1.05	2.29	4.79	7.96	8.10	9.38	7.03	5.20	5.46	2.67	.75	54.92

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
IBAPAH#	4174	113 59	40 02	5280

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	42.30	46.40	53.00	60.80	71.20	81.50	92.10	86.70	81.00	68.20	52.30	42.30	64.82
TN	9.70	16.00	19.80	26.40	33.20	39.00	46.00	44.40	34.30	25.20	17.60	10.00	26.80
PP	.49	.55	.80	.93	1.24	1.12	.58	.65	.51	.65	.46	.42	8.40
UU	66.0	72.6	86.4	89.1	76.0	76.7	69.1	62.2	63.9	56.3	63.2	62.2	70.31
SO	241	375	487	623	766	892	959	774	695	496	268	304	573
RH	.26	.31	.24	.21	.12	.05	.05	.05	.05	.05	.20	.26	.15
ES	.14	.17	.21	.29	.39	.52	.71	.64	.48	.32	.20	.14	.35
EP	.15	.98	2.74	5.62	7.71	9.06	10.13	9.59	6.42	4.96	1.93	1.17	60.46

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
GARFIELD	3097	112 12	40 43	4310

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.70	41.90	49.40	58.90	70.10	80.70	91.00	88.10	77.50	64.00	48.60	38.70	62.13
TN	22.30	26.90	32.60	41.00	50.60	60.00	68.90	66.10	55.80	43.80	32.60	24.80	43.78
PP	1.21	1.18	1.64	2.30	1.71	1.22	.66	.76	1.13	1.38	1.36	1.30	15.85
UU	57.9	73.9	89.9	100.6	83.8	86.9	83.1	86.1	80.8	73.2	64.0	62.5	78.56
SO	167	234	368	420	514	524	511	476	388	288	194	132	351
RH	.73	.71	.67	.64	.60	.56	.53	.53	.54	.58	.69	.74	.63
ES	.16	.19	.26	.36	.52	.73	1.02	.93	.66	.42	.26	.18	.47
EP	.30	1.12	2.58	5.02	9.18	9.31	12.51	10.72	7.55	4.39	2.05	.82	65.55

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
GARLAND	3122	112 10	41 44	4340

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	33.20	39.00	47.40	58.30	69.60	79.30	89.60	87.00	77.30	64.60	47.60	36.10	60.75
TN	14.30	19.00	25.50	33.70	42.30	49.90	57.30	55.30	45.60	35.40	25.30	17.10	35.06
PP	1.56	1.35	1.26	1.55	1.62	1.55	.54	.98	.95	1.17	1.22	1.17	14.92
UU	43.4	51.5	64.1	77.3	71.2	56.6	45.5	46.0	40.4	41.9	42.9	39.9	51.73
SO	185	280	405	503	620	671	701	619	511	370	219	180	439
RH	.61	.58	.53	.46	.39	.34	.26	.28	.28	.34	.52	.61	.44
ES	.12	.16	.21	.31	.45	.62	.81	.76	.54	.36	.21	.14	.39
EP	.26	.99	2.32	5.03	8.81	9.76	11.35	9.46	6.64	4.00	1.78	.73	61.13

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
GARRISON#	3138	114 02	38 56	5275

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.80	47.40	54.90	63.60	73.70	84.70	93.10	89.90	80.70	68.10	53.00	43.40	66.19
TN	15.60	21.10	25.30	31.70	40.20	48.30	56.80	55.70	45.10	34.70	24.20	16.70	34.62
PP	.46	.43	.82	.77	.81	.48	.53	.69	.53	.70	.59	.49	7.30
UU	55.0	60.6	76.6	79.1	68.0	66.7	61.8	61.8	58.7	55.6	53.8	53.8	62.62
SO	215	338	461	592	705	789	776	655	559	409	245	252	500
RH	.42	.42	.33	.27	.23	.16	.16	.21	.18	.23	.35	.41	.28
ES	.16	.19	.25	.33	.47	.66	.87	.81	.57	.37	.24	.16	.42
EP	.30	1.23	3.06	6.23	9.28	11.40	13.29	11.50	8.33	5.20	2.36	1.18	73.36

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
GREEN RIVER AVIATION	3418	110 10	39 00	4070

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.80	47.70	58.10	68.60	79.00	89.90	96.40	93.30	84.90	71.20	53.90	40.90	68.39
TN	9.30	17.50	26.10	34.80	44.20	51.40	59.50	57.00	45.80	34.50	22.60	12.80	34.62
PP	.40	.37	.46	.45	.61	.34	.38	.79	.61	.78	.46	.39	6.04
UU	19.8	29.8	39.7	51.2	37.1	28.9	17.9	15.0	13.6	13.2	19.8	23.2	25.77
SO	220	374	478	616	722	825	787	686	602	439	255	265	522
RH	.39	.32	.27	.22	.20	.10	.14	.16	.09	.15	.29	.37	.23
ES	.12	.19	.27	.39	.56	.76	.96	.87	.62	.40	.23	.14	.46
EP	.21	.70	2.54	6.04	9.26	11.20	11.99	9.36	6.42	3.83	1.36	.62	63.54

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
FARMINGTON USU	2726	111 54	41 01	4340

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.70	44.90	52.40	61.90	72.80	82.60	92.10	89.60	80.00	67.20	50.80	40.00	64.42
TN	19.30	23.60	28.80	36.00	44.10	51.60	59.30	57.20	47.80	37.90	28.10	21.20	37.91
PP	2.11	1.89	2.03	2.94	2.22	1.36	.58	1.08	1.11	1.52	1.71	1.77	20.32
UU	20.7	23.3	41.4	44.3	34.9	31.9	22.2	28.9	29.2	27.2	23.6	20.1	28.98
SO	187	292	417	519	639	698	711	629	517	371	220	178	448
RH	.60	.55	.49	.43	.36	.30	.25	.26	.27	.34	.51	.61	.41
ES	.16	.19	.26	.35	.48	.66	.89	.81	.60	.40	.24	.17	.43
EP	.33	1.11	2.48	5.28	8.19	9.15	11.08	8.82	6.62	4.07	1.79	.69	59.63

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
FERRON	2798	111 08	39 05	5930

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	34.90	41.40	49.30	59.50	69.90	80.20	87.30	84.30	77.00	65.90	49.50	38.10	61.44
TN	10.60	16.60	23.50	32.60	41.90	51.00	57.90	55.00	46.20	35.40	22.70	13.70	33.93
PP	.66	.60	.55	.47	.78	.51	.85	1.17	.78	.70	.58	.51	8.16
UU	44.4	41.1	52.1	55.3	45.9	34.2	25.1	30.6	26.6	29.1	29.1	33.1	37.22
SO	207	324	433	531	630	668	647	583	500	382	237	231	448
RH	.47	.46	.43	.40	.37	.34	.34	.34	.30	.31	.41	.47	.39
ES	.12	.16	.21	.31	.45	.64	.81	.73	.56	.37	.21	.14	.39
EP	.24	.97	2.31	5.00	8.03	9.04	9.76	7.80	6.12	3.78	1.66	.68	55.39

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
FILLMORE	2828	112 19	38 57	5160

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.90	46.50	53.70	62.50	72.80	83.90	92.10	89.50	81.30	68.60	52.10	41.90	65.48
TN	17.30	22.50	27.10	34.30	42.60	50.90	59.60	57.60	48.70	37.40	26.40	18.80	36.93
PP	1.45	1.52	1.79	1.75	1.26	.68	.63	.78	.93	1.07	1.31	1.34	14.51
UU	49.9	52.0	69.0	70.6	57.9	57.3	46.7	48.9	51.0	49.4	43.5	43.5	53.31
SO	204	317	439	547	660	732	705	622	522	389	232	218	466
RH	.49	.48	.41	.37	.32	.24	.26	.27	.26	.29	.43	.50	.36
ES	.16	.20	.25	.33	.48	.66	.89	.84	.62	.40	.24	.16	.44
EP	.33	1.31	2.90	5.86	9.33	10.49	12.54	10.58	7.89	5.07	2.21	.97	69.48

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
FORT DUCHESNE	2996	109 52	40 17	4990

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	28.30	36.50	49.50	62.00	73.20	83.30	91.30	87.90	78.90	65.50	46.80	32.70	61.33
TN	1.10	7.40	19.70	29.10	38.30	45.30	51.70	49.50	39.80	29.70	18.50	6.20	28.03
PP	.44	.34	.50	.60	.62	.69	.52	.73	.61	.78	.47	.52	6.82
UU	20.7	30.8	54.2	56.4	45.9	36.2	27.0	25.1	25.6	22.0	29.5	21.5	32.91
SO	219	364	462	605	724	816	838	717	602	430	243	250	523
RH	.40	.35	.33	.25	.20	.11	.07	.10	.09	.17	.37	.41	.24
ES	.08	.11	.20	.31	.45	.60	.78	.71	.50	.33	.19	.10	.36
EP	.15	.47	2.04	5.23	7.72	9.25	10.28	8.23	5.70	3.61	1.35	.51	54.53

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PINE VIEW DAM	6869	111 50	41 15	4940

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	31.00	36.50	44.60	56.30	67.80	77.50	87.70	85.10	75.70	63.00	44.80	33.70	58.64
TN	8.40	11.10	19.50	30.00	37.60	43.80	50.80	48.90	40.60	31.20	22.10	12.70	29.73
PP	3.83	3.11	3.06	3.05	2.68	1.72	.71	1.09	1.46	2.11	2.76	3.21	28.79
UU	30.7	32.0	61.3	29.8	51.1	43.1	29.4	37.9	37.9	39.6	29.0	29.0	37.57
SO	200	330	428	524	660	744	787	685	553	394	220	199	477
RH	.52	.44	.45	.42	.32	.23	.14	.16	.19	.28	.51	.56	.35
ES	.10	.12	.18	.28	.40	.54	.71	.66	.48	.32	.19	.12	.34
EP	.22	.69	1.86	4.59	6.27	8.31	9.63	7.79	5.93	3.70	1.56	.55	51.08

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PLEASANT GROVE#	6919	111 44	40 22	4668

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.20	45.40	52.60	62.10	73.00	82.40	91.00	88.00	79.60	67.30	50.90	40.60	64.34
TN	19.10	23.10	27.80	34.80	42.50	50.00	57.90	55.70	46.50	36.80	27.50	20.80	36.87
PP	1.72	1.51	1.68	1.92	1.45	.90	.83	.81	.93	1.33	1.25	1.49	15.82
UU	31.8	43.8	55.5	65.3	61.3	48.8	37.7	37.7	40.0	37.3	35.5	33.7	44.03
SO	190	301	426	536	664	722	716	627	528	382	223	187	459
RH	.58	.52	.46	.39	.31	.26	.24	.26	.24	.31	.49	.59	.39
ES	.16	.19	.25	.33	.48	.64	.84	.78	.57	.39	.24	.17	.42
EP	.33	1.17	2.73	5.49	9.09	10.20	11.42	9.42	6.89	4.41	1.96	.84	63.95

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
PROVO BYU#	4015	111 39	40 15	4570

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.00	46.00	54.70	64.30	73.30	84.60	92.80	90.30	81.00	68.40	53.30	41.80	65.88
TN	19.10	22.60	29.40	36.70	44.90	50.30	58.30	56.20	52.30	38.60	29.10	22.30	38.32
PP	1.40	1.32	1.29	1.30	1.17	.79	.68	.96	.66	1.35	1.25	1.33	13.50
UU	23.7	33.7	49.3	57.2	48.3	33.6	26.4	25.9	24.5	26.5	18.3	25.0	32.70
SO	193	311	430	540	635	754	742	654	474	376	226	185	460
RH	.56	.49	.45	.39	.36	.21	.21	.22	.36	.33	.47	.60	.39
ES	.16	.19	.27	.37	.50	.66	.89	.81	.66	.42	.26	.18	.45
EP	.35	1.10	2.78	6.00	9.04	10.16	11.34	9.22	6.79	4.09	1.95	.69	63.51

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
RICHFIELD KSVC	7260	112 05	38 46	5270

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.90	46.90	54.40	63.00	72.70	82.90	89.90	87.50	80.30	69.30	53.50	43.70	65.50
TN	14.10	18.90	23.30	29.50	37.20	44.00	51.60	50.00	40.40	30.50	21.50	15.10	31.34
PP	.63	.62	.63	.71	.73	.41	.81	.69	.80	.64	.59	.56	7.82
UU	37.2	40.0	53.3	56.6	48.9	48.5	35.6	36.0	37.2	36.8	32.3	30.3	41.06
SO	221	353	472	612	732	832	813	704	612	458	257	270	528
RH	.38	.37	.29	.23	.18	.09	.11	.13	.07	.09	.27	.36	.21
ES	.15	.19	.24	.31	.43	.57	.76	.71	.52	.36	.23	.16	.38
EP	.27	.98	2.51	5.20	7.37	9.11	10.68	8.76	6.48	4.50	1.83	.86	58.53

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
RICHMOND	7271	111 49	41 54	4680

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	33.30	38.80	47.40	58.80	69.80	79.50	90.20	87.80	77.90	64.50	47.00	35.50	60.88
TN	14.30	17.80	23.50	31.40	39.20	45.90	52.70	51.50	42.80	33.50	24.60	16.70	32.83
PP	1.78	1.48	1.73	2.15	1.96	1.51	.55	1.00	1.11	1.52	1.44	1.52	17.75
UU	37.0	44.3	59.8	64.5	58.9	46.9	33.1	35.3	34.4	35.3	37.0	36.6	43.59
SO	185	289	419	537	665	742	798	686	553	387	219	178	472
RH	.61	.56	.48	.39	.31	.23	.13	.16	.19	.30	.52	.61	.37
ES	.12	.15	.20	.30	.43	.57	.76	.73	.52	.35	.21	.14	.37
EP	.26	.93	2.23	4.99	8.12	9.24	10.56	8.87	6.24	3.81	1.69	.65	57.57

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
RIVERDALE POWER HOUSE	7318	112 00	41 10	4400

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.00	42.50	50.30	60.10	71.10	81.00	91.10	87.90	78.50	65.40	49.10	38.40	62.70
TN	19.40	23.90	29.30	36.80	44.70	52.30	60.30	58.30	49.30	39.50	29.00	21.30	38.67
PP	1.87	1.56	1.84	2.47	2.03	1.42	.64	.97	1.20	1.49	1.55	1.50	18.54
UU	35.6	36.0	61.4	71.6	54.1	50.8	37.4	44.8	44.8	42.5	36.5	31.9	45.62
SO	180	267	398	487	608	659	673	588	480	340	210	162	421
RH	.65	.62	.56	.50	.42	.36	.30	.33	.34	.43	.58	.66	.48
ES	.15	.19	.25	.33	.48	.66	.89	.81	.60	.39	.24	.16	.43
EP	.31	1.12	2.46	5.20	9.17	9.62	11.88	9.33	6.97	4.07	1.90	.72	62.75

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ROOSEVELT	7395	109 59	40 18	5104

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	29.80	38.10	51.40	63.10	74.40	84.10	91.70	88.40	79.70	66.50	47.90	33.80	62.41
TN	4.70	11.00	22.20	31.60	40.70	48.20	55.10	52.80	43.40	32.80	20.80	9.20	31.04
PP	.54	.42	.56	.63	.63	.71	.40	.73	.66	.83	.50	.60	7.21
UU	34.8	43.5	65.3	70.9	53.5	45.7	34.8	31.3	35.2	33.9	35.7	27.4	42.67
SO	210	345	458	588	707	781	782	676	567	411	238	232	500
RH	.45	.40	.34	.28	.23	.17	.15	.18	.16	.23	.40	.46	.29
ES	.09	.13	.22	.32	.48	.64	.81	.76	.56	.36	.19	.11	.39
EP	.18	.70	2.43	5.71	9.19	10.21	11.18	9.23	6.57	4.16	1.60	.62	61.78

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SAINT GEORGE	7516	113 34	37 07	2760

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	53.60	60.90	67.10	75.90	85.60	95.90	101*9	99.40	93.20	81.40	65.10	54.70	77.89
TN	26.90	31.50	36.60	43.70	52.20	60.50	67.90	66.30	56.80	45.10	33.90	27.10	45.71
PP	1.04	.90	.98	.47	.49	.21	.62	.65	.52	.56	.75	.72	7.91
UU	38.3	45.0	47.8	56.9	51.3	52.3	49.5	45.8	38.6	25.1	29.3	28.4	42.36
SO	217	366	467	596	703	773	733	639	569	435	254	261	501
RH	.41	.34	.31	.27	.23	.18	.22	.24	.16	.16	.29	.39	.27
ES	.25	.31	.39	.52	.71	.96	1.20	1.13	.87	.57	.36	.26	.63
EP	.46	1.50	4.28	8.46	12.49	15.08	16.82	14.70	11.41	7.10	2.55	1.32	96.18

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SALINA	7557	111 52	38 57	5190

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	40.90	46.50	54.60	64.20	74.60	85.20	93.00	90.30	82.10	69.90	53.20	42.70	66.43
TN	14.20	19.10	24.10	30.70	38.80	46.30	54.40	51.80	42.30	31.60	22.30	15.00	32.55
PP	.90	.86	.92	1.09	.96	.50	.65	.80	.90	.80	.81	.76	9.95
UU	34.2	39.7	55.2	56.0	47.5	42.8	30.3	33.1	34.2	34.2	31.9	30.7	39.15
SO	217	348	467	612	736	832	819	718	610	453	253	261	527
RH	.41	.39	.31	.23	.17	.09	.10	.10	.07	.11	.30	.38	.22
ES	.15	.19	.24	.32	.47	.64	.84	.76	.56	.37	.23	.16	.41
EP	.28	.98	2.52	5.45	7.85	10.03	11.45	9.04	6.80	4.51	1.81	.85	61.57

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SALT LAKE CITY AP	7598	111 57	40 27	4222

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.40	43.70	51.50	61.10	72.40	83.30	93.20	90.00	80.00	66.70	50.20	38.90	64.03
TN	19.70	24.40	29.90	37.20	45.20	53.30	61.80	59.70	50.00	39.30	29.20	21.60	39.28
PP	1.35	1.33	1.72	2.21	1.47	.97	.72	.92	.89	1.14	1.22	1.37	15.31
UU	82.1	87.5	99.2	101.3	100.3	99.2	100.3	102.4	97.1	90.7	83.2	80.0	93.61
SO	180	274	403	494	619	681	685	598	490	354	214	164	430
RH	.64	.60	.54	.48	.40	.32	.29	.32	.32	.39	.56	.65	.46
ES	.16	.19	.26	.35	.50	.68	.96	.87	.62	.40	.25	.16	.45
EP	.32	1.42	3.29	6.23	10.78	12.28	15.84	13.87	9.93	6.15	2.71	1.10	83.91

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SANTAQUIN	7686	111 47	39 58	5120

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	39.30	44.30	51.20	60.80	71.80	82.40	90.90	88.00	79.00	66.20	50.20	40.40	63.71
TN	16.70	21.00	26.30	33.90	42.90	51.40	59.70	57.30	47.80	37.40	26.20	18.70	36.61
PP	1.69	1.70	2.11	2.11	1.58	.97	.80	1.12	1.04	1.56	1.67	1.67	18.02
UU	29.4	38.7	57.7	60.6	44.6	39.4	36.8	29.4	29.4	31.6	24.9	29.0	37.62
SO	200	310	427	531	642	698	681	604	505	367	226	205	450
RH	.52	.50	.46	.40	.35	.30	.29	.30	.29	.35	.48	.54	.40
ES	.15	.19	.24	.32	.47	.66	.87	.81	.57	.39	.23	.16	.42
EP	.32	1.09	2.55	5.31	8.57	9.59	11.00	9.47	6.33	3.89	1.81	.73	60.66

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SCIPIO	7714	112 06	39 15	5306

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.90	44.20	52.20	61.60	72.00	81.60	89.60	87.20	79.40	67.40	51.30	40.50	63.83
TN	11.10	17.30	22.60	29.20	37.30	44.50	53.50	51.50	40.80	29.90	20.50	13.00	30.93
PP	1.27	1.24	1.40	1.25	1.10	.64	.70	.97	.88	.95	1.04	1.07	12.51
UU	45.7	51.3	71.6	73.7	55.4	52.3	40.6	44.7	45.2	45.7	40.6	42.7	50.79
SO	221	343	461	599	721	801	772	677	596	446	253	260	513
RH	.38	.40	.33	.26	.20	.14	.16	.17	.10	.13	.30	.39	.25
ES	.13	.17	.22	.30	.43	.57	.78	.71	.52	.35	.21	.14	.38
EP	.23	1.00	2.55	5.45	8.28	9.37	11.16	8.97	6.88	4.61	1.90	.88	61.27

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SCOFIELD DAM	7724	111 07	39 47	7630

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	28.00	32.20	37.90	47.90	59.80	70.10	78.00	75.20	67.60	56.50	40.10	31.00	52.03
TN	-.10	2.80	11.10	21.40	30.70	37.60	44.20	42.70	34.70	26.20	15.60	3.90	22.57
PP	2.00	1.64	1.33	1.09	1.07	.92	1.02	1.39	1.04	1.14	1.12	1.49	15.25
UU	148.5	130.7	171.6	153.5	80.0	67.8	52.4	50.1	54.3	71.5	103.3	139.9	101.97
SO	222	366	440	526	645	724	729	630	525	380	228	256	473
RH	.37	.34	.41	.41	.35	.26	.22	.26	.25	.32	.47	.40	.34
ES	.08	.09	.13	.20	.30	.42	.54	.50	.37	.26	.15	.09	.26
EP	.13	.89	2.23	4.81	7.95	7.24	8.06	6.57	4.83	3.24	1.61	1.02	48.59

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SILVER LAKE BRIGHTON	7846	111 35	40 36	8740

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	30.60	33.50	36.50	43.90	53.60	64.00	72.70	70.30	62.80	52.00	38.70	32.60	49.27
TN	7.30	8.50	11.30	19.30	28.30	36.10	43.70	42.00	34.50	26.10	15.10	9.00	23.43
PP	5.56	4.96	5.26	4.44	2.83	1.76	1.28	1.90	1.96	2.94	4.30	5.02	42.21
UU	21.6	23.5	47.0	56.0	40.1	31.3	20.9	25.7	28.2	28.2	31.6	21.0	31.26
SO	203	326	429	503	593	646	640	569	469	340	224	223	430
RH	.50	.45	.45	.46	.45	.38	.35	.37	.37	.43	.49	.49	.43
ES	.10	.11	.12	.18	.26	.36	.48	.45	.35	.24	.14	.11	.24
EP	.20	.57	1.22	2.74	4.50	4.85	5.69	4.56	3.53	2.19	1.10	.55	31.70

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SNAKE CREEK PH	7909	111 30	40 33	5950

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	33.90	38.40	45.20	56.10	67.40	76.90	85.00	82.20	74.10	63.00	45.90	36.00	58.68
TN	10.00	12.50	19.00	26.80	33.80	39.50	45.60	44.50	36.80	28.70	19.40	12.20	27.40
PP	3.32	2.65	2.19	1.88	1.45	1.05	.69	1.19	1.07	1.65	2.21	2.82	22.17
UU	23.5	23.5	52.9	61.6	43.9	30.2	21.4	26.1	29.1	29.1	35.2	21.8	33.19
SO	205	334	436	560	706	806	834	707	580	417	236	225	504
RH	.48	.43	.42	.34	.23	.13	.08	.12	.13	.21	.41	.48	.29
ES	.11	.13	.18	.26	.37	.48	.62	.57	.43	.31	.19	.12	.31
EP	.23	.68	1.76	4.25	6.76	7.39	7.78	6.40	4.94	3.41	1.47	.67	45.76

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SNOWVILLE#	7931	112 43	41 58	4560

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	34.20	40.20	46.90	58.50	69.30	79.50	90.50	87.80	77.70	65.10	47.80	36.90	61.20
TN	9.90	15.90	20.30	27.70	35.70	42.30	49.40	47.50	39.40	28.00	20.10	12.50	29.06
PP	1.11	.88	.86	1.14	1.48	1.26	.54	.84	.70	.70	1.00	.94	11.45
UU	45.1	50.9	57.7	70.3	72.3	55.8	40.7	47.0	36.4	37.8	42.2	39.8	49.67
SO	207	319	439	579	706	803	866	745	592	442	240	231	514
RH	.47	.47	.41	.30	.23	.14	.05	.06	.11	.14	.38	.47	.27
ES	.11	.15	.19	.28	.40	.54	.73	.68	.50	.32	.19	.13	.35
EP	.23	.94	2.27	4.74	7.65	9.50	10.65	8.85	6.74	3.93	1.66	.78	57.93

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
SPANISH FORK PH	8119	111 36	40 05	4720

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.10	43.80	52.20	62.10	73.40	84.00	92.90	89.70	80.50	67.40	50.30	39.50	64.49
TN	20.00	24.10	29.00	36.20	44.80	52.00	59.60	57.50	49.20	40.10	29.60	21.70	38.65
PP	1.78	1.68	2.05	2.11	1.66	1.07	.74	1.06	1.20	1.52	1.71	1.82	18.40
UU	28.0	37.9	57.0	63.3	46.0	37.9	32.0	27.6	28.7	30.5	25.4	28.7	36.92
SO	182	277	414	519	638	715	720	626	506	353	213	169	444
RH	.63	.59	.50	.43	.36	.27	.24	.27	.29	.39	.56	.64	.43
ES	.16	.19	.26	.35	.50	.68	.89	.84	.62	.42	.25	.17	.44
EP	.33	1.15	2.69	5.62	9.31	10.13	11.50	9.71	6.71	4.02	1.85	.68	63.68

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
THOMPSON#	8705	109 43	38 58	5150

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	37.70	46.10	55.20	65.60	75.80	86.70	93.10	90.10	81.80	70.60	52.30	40.90	66.33
TN	15.80	22.40	29.00	37.70	47.40	57.10	64.70	62.10	83.10	42.20	29.10	18.60	42.43
PP	.82	.53	.74	.70	.87	.45	.61	1.08	.79	.95	.62	.53	8.69
UU	32.4	48.9	66.2	71.6	64.9	52.9	35.6	31.1	34.7	26.7	32.4	31.6	44.08
SO	197	314	436	543	635	675	629	564	104	111	115	117	370
RH	.53	.49	.42	.38	.36	.33	.36	.37	1.00	1.00	1.00	1.00	.60
ES	.14	.19	.27	.39	.56	.78	.99	.89	1.09	.15	.04	.56	.50
EP	.30	1.15	3.06	6.69	10.74	12.14	12.76	9.84	1.00	1.00	1.00	1.00	56.68

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
TREMONTON#	8817	112 10	41 43	4310

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	34.50	39.80	50.00	60.60	69.30	78.30	90.40	90.10	81.40	67.40	49.60	37.20	62.38
TN	15.60	20.60	27.50	36.20	42.20	51.20	60.00	56.60	46.30	37.20	27.20	18.50	36.59
PP	1.67	2.05	1.31	1.35	1.61	1.41	1.07	.97	1.01	1.28	1.41	1.82	16.96
UU	41.5	42.8	64.7	76.2	68.9	57.3	47.0	48.2	41.1	41.6	40.6	38.9	50.73
SO	185	273	409	500	617	632	666	645	553	379	219	177	438
RH	.61	.60	.52	.47	.40	.40	.31	.23	.19	.32	.52	.62	.43
ES	.13	.16	.24	.33	.45	.62	.87	.81	.60	.39	.23	.15	.41
EP	.27	1.02	2.53	5.40	8.75	9.19	11.83	10.46	7.85	4.42	1.92	.74	64.38

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
TRENTON#	8882	111 56	41 55	4460

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	34.30	40.70	48.70	58.50	69.80	80.40	89.80	87.30	78.30	64.00	44.00	34.90	60.89
TN	11.30	14.80	21.60	31.10	38.40	44.40	49.90	47.90	40.10	30.70	23.10	14.50	30.65
PP	1.74	1.41	1.54	1.83	1.78	1.55	.55	.96	1.02	1.31	1.34	1.40	16.43
UU	40.3	47.8	65.4	70.2	66.4	52.1	37.0	41.7	37.0	38.4	40.8	39.8	48.08
SO	202	334	443	537	676	783	843	732	591	408	213	193	496
RH	.50	.43	.40	.39	.29	.17	.07	.08	.11	.24	.56	.57	.32
ES	.12	.15	.20	.30	.42	.56	.73	.68	.50	.32	.19	.13	.36
EP	.25	.88	2.33	5.10	8.04	9.47	10.59	8.60	6.48	3.76	1.55	.69	57.73

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
TIMPANOGOES CAVE	8733	111 42	40 27	5640

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	34.30	40.70	48.70	58.50	69.80	80.40	89.80	87.30	78.30	64.00	44.00	34.90	60.89
TN	20.20	22.90	26.80	33.90	42.10	49.40	57.60	55.70	48.00	39.20	28.60	21.80	37.18
PP	2.74	2.35	2.45	2.77	2.33	1.54	1.02	1.42	1.30	1.95	1.87	2.31	24.05
UU	28.1	35.4	53.1	64.7	51.6	42.7	31.2	32.7	34.7	33.9	32.7	28.1	39.08
SO	165	260	405	503	625	698	700	617	493	330	191	125	426
RH	.74	.64	.53	.46	.38	.30	.27	.28	.32	.46	.70	.76	.49
ES	.14	.18	.23	.31	.45	.62	.84	.78	.57	.39	.21	.15	.41
EP	.26	1.03	2.31	4.83	8.37	9.24	10.96	8.96	6.38	3.65	1.31	.48	57.77

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
TOOELE	8771	112 18	40 32	5070

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	38.50	43.10	49.70	58.90	69.00	78.90	87.90	84.90	75.70	63.10	48.40	39.30	61.45
TN	20.40	24.60	29.40	37.10	46.40	55.10	63.60	61.10	52.00	40.50	29.20	22.00	40.12
PP	1.22	1.32	1.94	2.38	1.58	1.06	.75	.86	.92	1.36	1.43	1.42	16.24
UU	52.4	63.1	78.4	88.3	74.4	73.0	66.4	73.7	69.7	63.1	51.8	57.1	67.62
SO	182	266	393	468	556	577	552	503	412	310	207	164	383
RH	.63	.62	.58	.54	.52	.48	.47	.48	.49	.52	.60	.65	.55
ES	.16	.19	.25	.33	.48	.66	.89	.81	.60	.39	.24	.17	.43
EP	.33	1.25	2.75	5.27	9.10	9.15	11.20	9.33	6.95	4.26	2.09	.89	62.58

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
TROPIC	8847	112 05	37 38	6280

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	41.00	45.70	51.50	60.30	69.70	79.70	85.60	82.40	75.60	66.30	51.90	43.60	62.77
TN	14.20	18.90	22.60	28.90	36.40	44.60	51.90	49.50	41.90	33.60	23.30	16.00	31.82
PP	1.23	1.06	.95	.70	.77	.45	1.14	1.84	1.11	1.11	.96	.98	12.30
UU	35.8	33.5	46.7	44.5	47.5	49.4	39.2	37.7	35.4	30.5	25.6	24.9	37.56
SO	217	342	456	586	702	767	728	636	535	402	244	261	490
RH	.41	.41	.35	.29	.24	.19	.23	.25	.23	.25	.36	.39	.30
ES	.15	.18	.22	.30	.40	.56	.71	.64	.50	.36	.23	.16	.37
EP	.28	.99	2.27	4.85	6.60	8.56	9.73	7.80	6.03	4.11	1.80	.80	53.80

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
UTAH LAKE LEHI	8973	111 54	40 22	4497

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.70	42.10	50.30	60.30	71.60	81.50	90.00	87.10	77.90	65.20	48.50	38.40	62.47
TN	15.70	20.80	26.30	33.30	41.00	48.10	55.20	53.50	44.20	34.40	25.40	18.20	34.68
PP	.95	.76	1.09	1.25	.98	.71	.61	.88	.74	.92	.89	.88	10.66
UU	49.5	67.5	86.6	101.5	92.6	79.8	62.6	61.1	62.4	57.9	54.5	52.7	69.06
SO	194	292	420	532	665	739	748	647	535	385	222	191	464
RH	.56	.55	.48	.40	.31	.23	.20	.23	.23	.30	.50	.58	.38
ES	.14	.17	.23	.32	.45	.62	.81	.73	.54	.36	.22	.15	.39
EP	.29	1.13	2.83	5.93	9.97	11.42	13.02	10.37	7.52	4.88	2.10	.91	70.37

TABLE A.3

Continued

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
VERNAL	9111	109 31	40 27	5280

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	29.00	37.10	49.40	62.00	72.90	82.80	90.30	87.20	78.10	64.20	45.80	32.30	60.93
TN	4.60	10.20	20.60	29.30	38.30	45.90	52.10	49.70	40.50	30.60	19.60	8.90	29.19
PP	.50	.40	.57	.69	.78	.73	.41	.67	.62	.82	.56	.63	7.38
UU	13.5	32.8	57.6	76.0	68.0	44.2	22.9	20.2	20.3	17.9	26.5	20.6	35.04
SO	207	343	455	602	720	798	811	704	583	410	234	221	507
RH	.47	.40	.35	.25	.20	.14	.11	.13	.13	.23	.42	.49	.28
ES	.09	.12	.20	.31	.45	.60	.76	.68	.50	.32	.19	.11	.36
EP	.18	.57	2.09	5.32	8.70	10.30	10.42	7.71	5.44	3.22	1.31	.51	55.78

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
WENDOVER	9381	114 02	40 44	4237

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	36.50	43.50	51.50	61.30	71.90	82.00	92.10	89.00	78.40	63.30	47.10	37.00	62.80
TN	19.70	25.20	31.30	39.20	49.80	58.60	67.50	64.40	53.70	41.10	29.00	20.80	41.69
PP	.31	.36	.42	.44	.79	.63	.25	.38	.22	.44	.38	.29	4.91
UU	70.5	77.9	89.8	97.2	90.5	83.8	63.1	63.8	62.3	57.1	68.3	66.8	74.26
SO	176	264	392	472	549	570	558	514	424	306	202	154	382
RH	.67	.63	.58	.53	.53	.49	.46	.46	.46	.53	.63	.68	.55
ES	.15	.19	.26	.36	.54	.73	1.02	.93	.64	.39	.23	.16	.47
EP	.30	1.33	3.03	5.95	10.28	10.59	13.51	10.79	7.35	4.01	1.86	.88	69.89

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
WOODRUFF	9595	111 09	41 32	6315

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	28.70	32.70	39.90	52.20	63.60	72.00	81.50	79.40	71.60	60.20	42.40	31.80	54.67
TN	2.70	5.10	13.90	23.80	31.30	38.80	43.70	41.20	32.00	22.80	13.90	5.60	22.90
PP	.51	.48	.59	.88	.89	1.12	.72	.74	.79	.82	.62	.58	8.74
UU	27.3	24.9	51.1	49.7	58.8	32.2	20.3	23.8	29.4	27.3	24.2	27.7	33.06
SO	214	350	435	549	688	735	804	714	608	445	243	247	503
RH	.43	.39	.43	.36	.26	.24	.12	.11	.07	.13	.36	.42	.28
ES	.09	.10	.14	.23	.32	.43	.57	.52	.39	.27	.15	.10	.28
EP	.16	.48	1.42	3.73	5.53	6.90	7.36	5.71	4.38	3.04	1.14	.46	40.31

STATION	STATION #	LONGITUDE	LATITUDE	ELEVATION
ZION NP	9717	112 59	37 13	4050

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL MEANS OR TOTALS
TX	51.20	57.30	62.60	71.90	82.20	93.50	99.70	96.70	90.00	78.50	62.30	52.90	74.90
TN	28.90	32.70	35.90	42.80	51.70	61.10	68.60	66.90	60.10	49.60	37.40	30.10	47.15
PP	1.76	1.71	1.78	1.12	.80	.60	.98	1.59	.88	.90	1.20	1.26	14.58
UU	52.4	56.3	64.7	72.1	68.7	70.4	64.7	60.2	52.4	37.7	38.8	37.7	56.34
SO	199	322	440	558	664	722	679	591	489	368	229	216	456
RH	.52	.46	.41	.35	.31	.26	.29	.33	.33	.35	.46	.51	.38
ES	.25	.30	.35	.47	.66	.93	1.16	1.09	.87	.60	.36	.27	.61
EP	.52	1.93	4.18	8.10	12.89	15.30	17.03	14.64	11.27	7.19	3.04	1.47	97.54