5-1969

A Study of Precipitation Characteristics for Utah

Tsing-Yuan Chang

Recommended Citation

Chang, Tsing-Yuan, "A Study of Precipitation Characteristics for Utah" (1969). *All Graduate Theses and Dissertations*. 2931.
https://digitalcommons.usu.edu/etd/2931

A STUDY OF PRECIPITATION CHARACTERISTICS FOR UTAH

by

Tsing-Yuan Chang

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil Engineering

UTAH STATE UNIBERSITY
Logan, Utah

1969

ACKNOWLEDGMENT

Sincere appreciation is expressed to Professor Joel E. Fletcher, Chairman of my graduate committee, and Professor Cleve H. Milligan who was Chairman of my committee before his leave of absence, and Professor T. W. Daniel and Eugene E. Farmer who assisted in the preparation of this thesis and offered appropriate suggestions which helped in its completion.

Tsing-Yuan Chang

TABLE OF CONTENTS

Page

INTRODUCTION 1

DEFINITIONS 4

  Precipitation forms 4

    Drizzle 4
    Rain 4
    Glaze 5
    Sleet 5
    Snow 5
    Snow pellets 5
    Small hail 5
    Hail 6

  Types of precipitation 6

    Cyclonic precipitation 6
    Convective precipitation 7
    Orographic precipitation 8

REVIEW OF LITERATURE 9

PROCEDURES 11

  Precipitation in Utah 11
  Data and adjustment 13

EXPERIMENTAL 15

  Elevation and precipitation 15
  Distribution of precipitation amounts and frequency of occurrence 22
  Seasonal distribution of precipitation 32
  Long-time precipitation trends 36

RESULTS AND DISCUSSION 38

TABLE OF CONTENTS (Continued)

Page

CONCLUSIONS 44

Relationship of precipitation to elevation 44
The frequency of dry years in Utah 44
Seasonal distribution of precipitation in Utah 45
Long-time precipitation trends 46

LITERATURE CITED 49

APPENDIX 51

LIST OF TABLES

Table Page

1. Relationship of precipitation to elevation near Ephraim, Utah 52

2. Relationship of precipitation to elevation near Beaver, Utah 53

3. Relationship of precipitation to elevation near Cedar City, Utah 54

4. Relationship of precipitation to elevation near Salt Lake City, Utah 55

5. Relationship of precipitation to elevation near Farmington, Utah 56

6. Relationship of precipitation to elevation near Logan, Utah 57

7. Annual precipitation at some Utah stations 58

8. Percentages of the annual precipitation falling each month at six Utah stations 61

9. Precipitation vs per cent of total years in each size class 62

LIST OF FIGURES

Figure Page

1. Relation of annual precipitation to elevation for 36 Utah stations 16

2. Seasonal distribution of precipitation at different elevations in the Wasatch Front Area 17

3. Seasonal distribution of precipitation at different elevations in Southern Utah 18

4. Relationship of Salt Lake City annual precipitation to Brighton annual precipitation 20

5. Relationship between March precipitation at Salt Lake City Airport and Brighton 21

6. Frequency distribution of annual precipitation amounts for Northern Utah stations 23

7. Frequency distribution of annual precipitation amounts Southern Utah stations 24

8. Mass distribution of annual precipitation amounts at Southern Utah stations 25

8A. Mass distribution of annual precipitation amounts at Northern Utah stations 25

9. Return periods of annual precipitation amounts at Logan 26

10. Return periods of annual precipitation amounts at Ogden 27

11. Return periods of annual precipitation amounts at Salt Lake City 28

12. Return periods of annual precipitation amounts at Brighton . . . 29

13. Return periods of annual precipitation amounts at Cedar City . . 30

LIST OF FIGURES (Continued)

Figure Page

14. Reutrn periods of annual precipitation amounts at Beaver . . . 31

15. Frequency of consecutive occurrence of wet and dry years for Northern Utah stations 33

16. Frequency of consecutive occurrence of wet and dry years for Southern Utah stations 34

17. Seasonal distribution of precipitation at Northern and Southern Utah stations 35

18. 5-point means of annual precipitation for Beaver, Logan and Salt Lake City 37

LIST OF APPENDIX FIGURES

Figure Page

1. Relationship of precipitation to elevation near Ephraim 65

2. Relationship of precipitation to elevation in vicinity of Beaver . . 66

3. Relationship of precipitation to evelation near Cedar City 67

4. Relationship of precipitation to elevation near Salt Lake City . . 68

5. Relationship of precipitation to elevation near Farmington 69

6. Relationship of precipitation to elevation near Logan 70

ABSTRACT

A Study of Precipitation Characteristics for Utah

by

Tsing-Yuan Chang, Master of Science

Utah State University, 1969

Major Professor: Joel E. Fletcher
Department: Civil Engineering

Data on monthly precipitation for three areas of Southern Utah--Beaver, Cedar City and Ephraim--and three areas of Northern Utah--Salt Lake City, Ogden and Logan--where a series of measuring stations were arranged as traverses from the valleys to the mountain tops; were assembled and analyzed.

The relationships between elevation and precipitation amounts were shown. The Southern Utah stations were drier at the same elevations than the Northern Utah stations and the differences became greater as the elevations increased. There was a close correlation between the high elevation and low elevation stations in the same traverse even with the above divergence.

A higher percentage of the annual precipitation fell during the winter months at the Northern Utah stations than at the Southern Utah stations. These differences were also greater at the high elevations.

There appears to be an elevation of maximum precipitation between 9000 and 10, 000 feet. The annual precipitation decreases both above and below these elevations.

A higher percentage of the years in Southern Utah are near the mean showing more uniformity than the stations in Northern Utah. These difference in not reflected in the numbers of consecutive dry years except when the consecutive years extend beyond 8 wherein the Northern Utah stations have had as many as 14 consecutive years of subnormal precipitation. The Northern Utah stations show the same trend in consecutive wet years, with the Logan record showing as many as 14 consecutive years with above normal precipitation.

The Beaver precipitation record showed a continually decreasing 5-year mean, while Salt Lake City and Logan records showed the opposite trend.

(80 pages)

INTRODUCTION

Precipitation may be defined by the hydrologist as those hydrometeors which reach the earth. The forms of precipitation of most general interest to hydrologists are: rain, sleet, hail, snow, groupel, dew, fog, ice fog, rime, etc.

Historically it was observed that only about one-fourth of the precipitation falling on the continental land masses could be accounted for as stream-flow to the seas, or groundwater flow. Hence, it was generally believed that continental evaporation was the chief source of water for precipitation.

According to Sulakvelidze, Bibiloshvili and Lapcheva (1965), the formation of clouds and precipitation is involved with a remarkable diversity of micro-scale and macro-scale processes. No wonder, then, that obersvers were led to conclusions which now seem untenable. The first measurements of the amounts of water in the air of the earth (Bernard, 1942) revealed that if all the water in the air of the earth were suddenly completely precipitated, it would only amount to a depth of about one inch of water over the surface of the earth. How then can storms of 20 inches in 24 hours occur?

Moisture in the air can occur as (1) water vapor, (2) liquid droplets, (3) solid particles. All three of these forms are free to move if the particles are small enough as though they were a gas subject to the laws of thermodynamics.

Bergeson (1933) proposed that the growth of cloud particles could be due to

1. electric forces between drops induced by the earth's electric field,

2. a difference in the capillary and hygroscopic forces on the surface of drops of comparable sizes.

3. a difference in the temperatures of cloud elements either from radiation or a difference in origin,

4. turbulence leading to collesions of drops and coalescence, and

5. the existence of hydrodrynamic attraction forces between drops having similar descent velocities.

All of these forces contribute in some measure to precipitation but none could lead to precipitation.

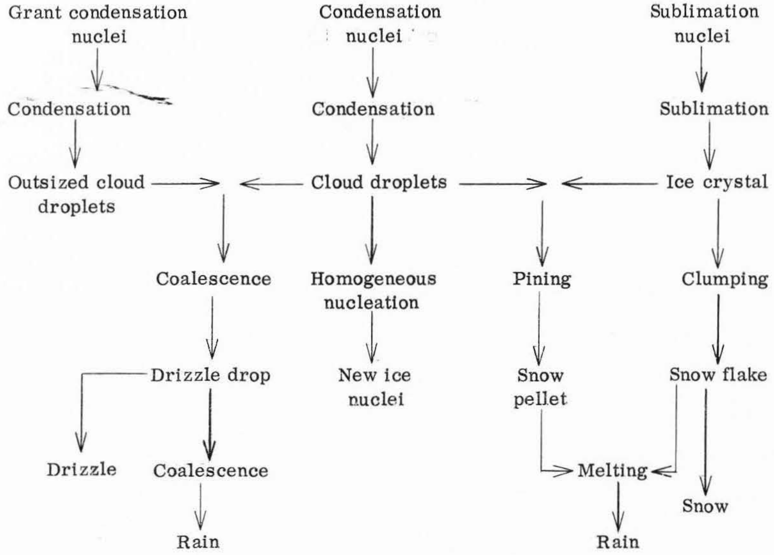
Berguson considered the cloud to be an isolated system from which precipitation only fell when ice crystals from surrounding areas fell through it. This view was well accepted until in 1943-46 Langmuir (1948) observed that showers in tropical regions fell from clouds too warm for ice to exist.

These views have developed until the present time when essentially two processes are postulated known as the warm and cold rain processes.

In Utah, it is though that combinations of these processes take place. The warm rain process being represented by storms of the connective type and the cold process represented by the orographic frontal storms. Both processes in Utah are thought to be limited by the supply of moisture aloft.

The supply of moisture aloft is principally from tongues of moisture from the warm tropical seas, augmented by evaporation from lakes and land areas.

The current theories as specified by Braham (1960) are as follows:



DEFINITIONS

Precipitation forms

Atmospheric vapor may condense on condensation nuclei to form water droplets or, if supercooled, on sublimation nuclei to form ice crystals.

Any product of condensation of atmospheric water vapor, whether formed in the free air or at the earth's surface, is a hydrometeor. Only these hydrometeors referring to falling moisture are defined below. Among those hydrometeors not included are damp haze, fog, ice fog, drifting snow, blowing snow, frost, and rime.

Drizzle. Uniform precipitation consisting of water droplets less than 0. 02 inches in diameter is called drizzle. It usually falls from stratiform clouds, and its intensity is generally less than 0. 04 inches/hour.

Rain. Rain consists of water drops generally larger than 0. 02 inches in diameter. It is usually reported in three intensities, light for rates of fall from a trace to 0. 10, moderate from 0. 11 to 0. 30, and heavy over 0. 30 inches/ hour. A drop falling through still air rapidly reaches a maximum downward velocity, the terminal velocity, where the resistance of the air balance the weight of drop. Terminal velocities increase with drop size up to about 0. 22 inches and then decreases because of increasing air resistance due to flattening of the drops. For the large diameters, the deformation is sufficient to break up the drops before they can attain the terminal velocity which would be expected for their dimensions. Upward velocities exceding the terminal velocities of the largest drops are not unusual in vigorous connective systems, so that drops of any size up to maximum may be found in some clouds. The intensity of the upward movement of air thus determines the average size of drops in clouds and, consequently, in the falling precipitation. Since the velocity of the ascending current is generally not uniform everywhere under a cloud layer, there is no definite lower limit to the size of the falling drops.

Glaze. The ice coating formed when rain or drizzle freexes as it comes in contact with cold objects at the ground is called glaze. It can occur only when the air temperature is near 32 F.

Sleet. When raindrops are frozen while falling through air below 32 F, transparent globular grains of ice known as sleet, or ice pellets, are formed. The pellets are ordinarily between 0. 04 and 0. 16 inches in diameter.

Snow. Precipitation in the form of ice crystals is snow. Single ice crystals can reach the ground, but usually a number of them coalesce and fall as snowflakes. The density of freshly fallen snow varies greatly; 5 to 20 inches of snow is generally required to equal 1 inch of water. The average density is assumed to be about 0. 1.

Snow pellets. Snow pellets are white, opaque, round, or occasionally conical grains of snowlike structure 0. 02 to 0. 20 inches in diamter. They are crisp and easily compressible and rebound when falling on hard ground.

Small hail. Translucent, round, or sometimes conical grains of frozen water, about 0. 08 to 0. 20 inches in diameter, are called small hail. Each grain consists of a snow pellets nucleus covered by a thin layer of ice, which gives it a glazed appearance. Small hail is not crisp or easily compressible and when falling on hard ground does not ordinarily rebound or burst. It often occurs with rain and almost aleays when the temperature is above freezing. It should not be confused with true hail, which has a different size and structure and usually occurs with thunderstorms.

Hail. Precipitation in the form of balls or irregular lumps of ice over 0.2 inches in diameter is called hail. Hailstones are generally composed of alternating clear ice and opaque snowlike layers as a result of repeated ascents and descents within the cloud during their formation. Thus by the time the hailstones reach the ground they have acquired an onionlike structure. Hail occurs almost exclusively in violent or prolonged thunderstorms and never with below-freezing temperature at the ground It is a late spring or summer rather than a winter phenomenon.

Types of precipitation

On the basis of causes of uplift, precipitation may be divided into three types, namely, cyclonic, orographic, and convective. This classification is based upon the meteorological phenomena which cause and accompany the precipitation. The fundamental factors in all types of storms are the accumulation of moisture-laden air, and the lifting of it to higher altitudes for cooling with resulting condensation of the vapor, and subsequent precipitation.

Cyclonic precipitation. Precipitation associated with the passage of cyclones, or low and high pressure areas, is called cyclonic precipitation. This type can be classified into nonfrontal and frontal. Nonfrontal precipitation can occur following any kind of barometric depression. The lifting of the air is caused by horizontal convergence resulting from inflow into the low-pressure area.

Frontal precipitation is the result of lifting of warm air over cold. Warm-front precipitation is formed in the warm air which moves upward over a wedge of cold air. The area of precipitation may extend two or three hundred miles ahead of the surface front, and precipitation is generally light to moderate and nearly continuous until after the passage of the warm front. Cold-front precipitation, on the other hand, is of a showery nature and is formed in the warm air forced upward by an advancing wedge of cold air. Precipitation usually occurs near the surface front but may extend 100 miles or more ahead of it.

Connective precipitation. This type of precipitation results from the upward movement of air that is warmer than its surroundings. Being of lesser density, the ascending air has a tendency to continue rising until it reaches a level where it has the temperature of its environment. The temperature contrast causing convection may result from heating of surface air, cooling aloft, or mechanical lifting over a frontal surface or mountain barrier. Connective precipitation is of showery nature, and its intensity may vary from light showers to cloud bursts, depending on the temperature and moisture conditions. The areas of the shower centers are generally smaller than 4 1/2 square miles and instantaneous intensities are high.

Orographic precipitation. The precipitation caused by lifting of air over mountain barriers is called orographic precipitation. Orographic barriers often supply the lift to set off cyclonic or convective precipitation. For this reason, precipitation is heavier on windward slopes, with rain shadows, regions of lighter precipitation, on leeward slopes. Orographic precipitation not associated with cyclonic or convective action is ordinarily low intensity.

LITERATURE REVIEW

Stansbury (1852) probably made the first major climatic observations in Utah beginning in May of 1849. He noted the occurrence of thunderstorms in May of that year.

In a series of interim reports the Environmental Science Services Administration, Jorgensen, Klein and Korte (1966), discussed the precipitation and synoptic climatology of the Intermountain areas of the west which included Utah, they related the occurrence of laws at various altitudes with the occurrence of precipitation under various conditions of orography; the specification of precipitation at selected stations by means of correlation fields and the climatological probability of precipitation for individual stations.

Brancato (1942) made a study of the thunderstorms--including those in Utah--of the United States. He concluded that thunderstorms were more frequent at the high elevations but those at low elevations produced more water.

Peck and Brown (1962) developed a method for constructing isohyitol maps in mountainous terrain. Isohyitol maps of Utah and Arizona for October to April and May to September periods were constructed.

Gifford, Ashcroft, and Magnuson (1967) developed probabilities of precipitation amounts for Western United States which included Utah. Their probabilities built on the knowledge presented by Herschfeld et al. (1955) to give a generalized picture of precipitation patterns found at low elevation stations in Utah.

The number of precipitation gages at high elevation is very small but even smaller during the winter months. Wilson (1954) using the cooperative snow investigations made an analysis of the winter precipitation in Utah. Such effects as winds and elevation were enumerated.

PROCEDURES

Precipitation data were collected and analyzed for the following purposes:

1. Relationship of precipitation to elevation for the groups of stations in Utah including Ephraim, Beaver, Cedar City, Salt Lake City, Farmington, and Logan.

Relationship of valley precipitation to mountain precipitation for Salt Lake City vs Brighton is also analyzed.

2. Frequency of wet and dry years in Utah for stations Logan, Ogden, Salt Lake City, Brighton, Cedar City, and Beaver.

3. Relationships of seasonal distribution of precipitation and October 1 to January 1 precipitation to October 1 to April 1 precipitation for stations Logan, Salt Lake City, Brighton, Cedar City, and Beaver.

4. Long-time precipitation trends for stations Logan, Salt Lake City, and Beaver.

Precipitation in Utah

Cyclonic precipitation results from the movement of centers of high and low air pressures. The unequal heating of the earth's surface causes the formation of these pressure centers. Warm air is rising in a low pressure area, resulting in precipitation, while cold air falling in a high pressure area results in cooler weather. These pressure centers follow each other across the country from West to East and determine largely the weather during the winter months. The storms usually enter the United States on the coast of Northern California, Oregon, or Washington, and move eastward, bending southward until the continental divide is crossed, and then bending northward again and going out through the St. Lawrence River Valley.

The distance these cyclonic storms paths are deflected southward largely determines the weather and amount of precipitation that falls in Utah during the winter months. The summer precipitation in Utah results principally from local storms. The warm air on hot summer afternoons upon striking the high mountain is forced to rise. As the air rises it expands and cools rapidly causing condensation and precipitation. This type of storm explains the spotted character of the intense summer storms common in Utah.

elev. - precip

Bagley, Jeppsen and Milligan (1964) estimate that approximately 80 per cent of the run-off of streams in Utah comes from areas above 7,000 feet elevation. This area comprises only about 20 per cent of the area of the state. The area above 7,000 feet is least known, and yet it holds the key to the state's most valuable resource.

In general, precipitation increases with altitude. There are a few instances, however, where it has been proved that after a certain elevation has been reached precipitation decreases with increased elevation.

elev - precip

George D. Clyde (1931) gives isohyetal lines of Cache County and states that the isohyetal lines show the least annual precipitation is to be over the lowest portion of the valley floor and greatest near the foothills. From the foothills to the top of the mountains, the precipitation increases, but the rate of increase varies widely from year to year and from locations with the precipitation per unit of elevation decreasing with the distance east of the front ranges.

Price and Evans (1937) state that precipitation on the plateau area varies widely in amount and character between vegetational zones due to difference in elevation and topography. Records of the average annual precipitation for the four zones are: Pinon-juniper, 11.70 inches; oakbrush, 17.51 inches; aspen-fir, 29.48 inches; and spruce-fir, 28.01 inches. The amount of precipitation increases rapidly from the valley floor to an elevation of approximately 9,000 feet, above which a slight decrease takes place.

Data and adjustment

The data were assembled from Weather Bureau and U. S. Forest Service sources. Missing data were estimated from regression. Eastimated points are shown in parentheses thus (18.64).

Correlations between stations were: Logan vs Ogden, 0.683, m = 66; Cedar City vs Beaver, 0.5945, m = 47; and Salt Lake City vs Brighton, 0.5684 m = 45. The mean annual and montly precipitation and elevation six traverses from the valley to the mountain tops in Utah are tabulated in Tables 1 to 6 (see Appendix) and the annual precipitation for a group of stations with annual values and their dates are given in Table 7 (see Appendix).

The percentages of the annual precipitation falling in each month are tabulated in Table 8 (see Appendix).

Table 9 (see Appendix) shows a tabulation of precipitation class and the frequency in number of years and percentage that each size class occurs for 5 Utah stations.

EXPERIMENTAL

Elevation and precipitation

The relationships between elevation and precipitation were studied by selecting traverses from the valley up the upwind face of a mountain front at three locations in Southern Utah: Ephraim, Table 1; Beaver, Table 2; and Cedar City, Table 3; and three locations in Northern Utah; Salt Lake City, Table 4; Farmington, Table 5; and Logan, Table 6.

Figure 1 shows the relationship of elevation to the annual precipitation with the stations grouped by location in Northern and Southern Utah. There is a clear separation between the two groups of stations with the Southern Utah stations being dried over the full range of elevations than the Northern Utah stations with the greatest difference at the high elevations. The stations grouped left of the curve and generally a greater distance downwind from the mountain front than those stations on the right of the curve.

Figures 2 and 3 show the seasonal distribution of precipitation at different elevations. The Northern Utah stations, Figure 2, and the Southern Utah stations, Figure 3, differ in their seasonal distributions with the northern stations, having a higher percentage of their precipitation falling during the winter months, as well as greater total precipitation. It can also be seen in Figure 3 that elevations above 10, 000 feet get less precipitation than the 9-10, 000 feet stations for most of the year.

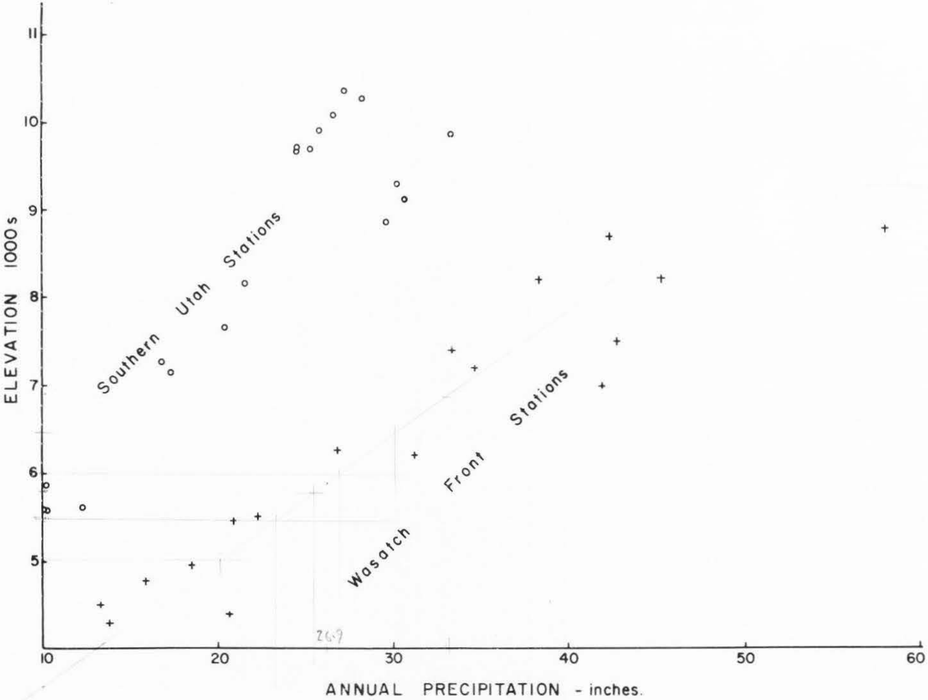


Figure I. Relation of Annual Precipitation to Elevation for 36 Utah Stations. Southern Utah Stations Data in Tables I, 2 and 3. Northern Utah Stations Data in Tables 4, 5 and 6.

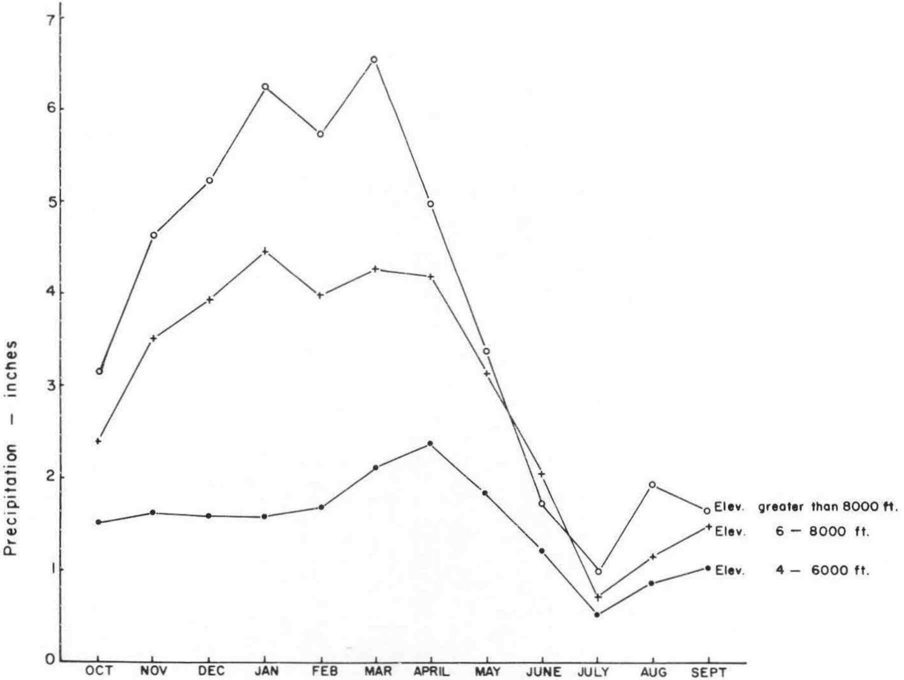


FIGURE 2. Seasonal Distribution of Precipitation at Different Elevations in The Wasatch Front Area.

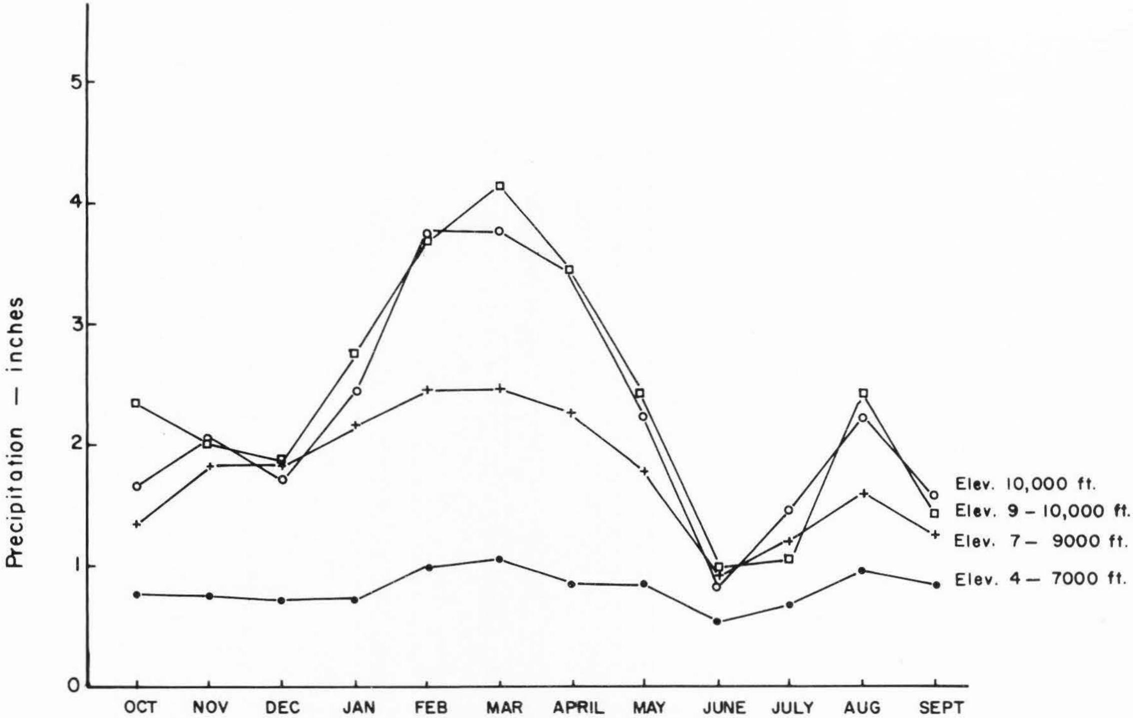


Figure 3. Seasonal Distribution of Precipitation at Different Elevations in Southern Utah.

These relationships are shown in more detail in Appendix Figures 1-6 which compares May to October precipitation to October to May precipitation at the same stations. The Figures cover the five valley to mountain top traverses discussed earlier.

Figure 4 shows the relationship of the annual precipitation at Salt Lake City and Brighton over the period from 1916 to 1960. Clyde (1931) pointed out that there was little correlation between high and low elevation stations during convective or summer storms. With 35 per cent reduction for the whole year a much better relation would be expected during the winter storms. Even here, however, Peck and Brown (1962) point out that with cold low aloft storms there is a comparatively greater amount of precipitation at the low elevation than with non-cold low aloft storms. Figure 5 illustrates the improved relation during winter storms in the relationship between the March Salt Lake City precipitation and that at Brighton where the reduction is increased more than 10 per cent to 46 per cent. It would be anticipated that if the storms could be stratified to just include non-cold-low aloft storms that the relationship would improve to levels practical for forecasting.

The relation between the mean annual precipitation at each station and the extreme maximum has a rank correlation coefficient of 1. 0. Even the simple correlation coefficient is 0. 933. The minimum is not related to the mean significantly.

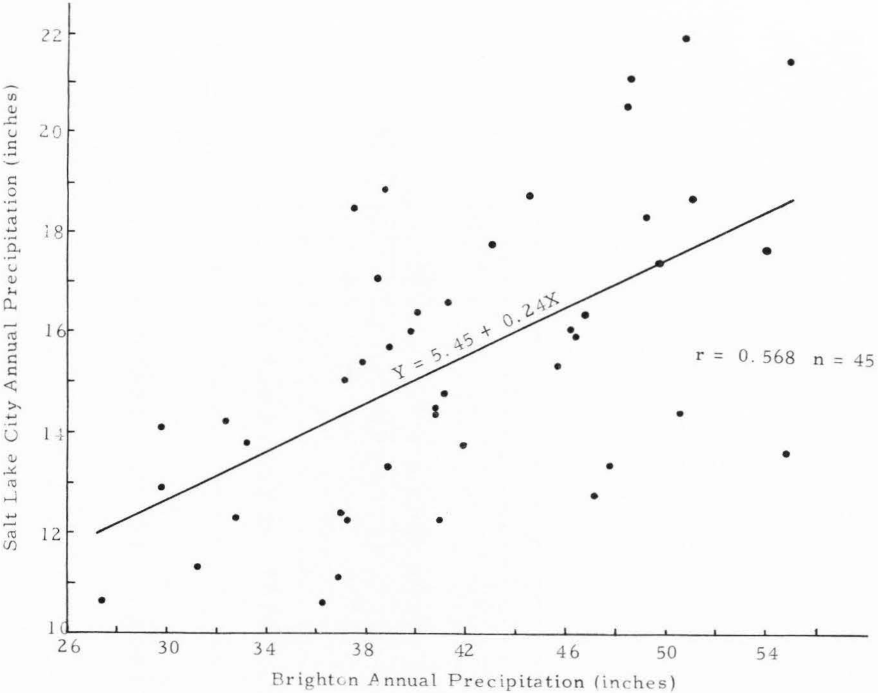


Figure 4. Relationship of Salt Lake City annual precipitation to Brighton annual precipitation.

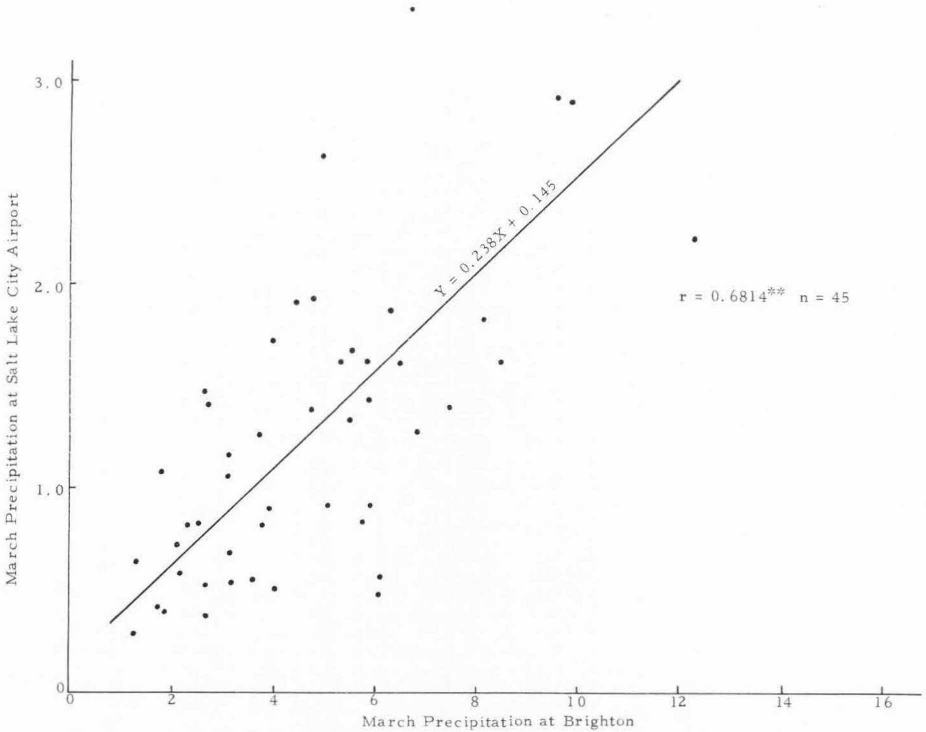


Figure 5. Relationship between March precipitation at Salt Lake City Airport and Brighton.

Distribution of precipitation amounts and frequency of occurrence

Annual precipitation for Logan, Ogden, Salt Lake City, Cedar City, and Beaver was divided into 2 inch classes and the frequency of annual precipitation in each class determined. The results are shown in Figures 6 and 7.

The modal classes were as follows: Logan, 18 to 20; Ogden, 12 to 14, 16 to 18 and 20 to 22; Salt Lake City, 14 to 16; Cedar City, 10 to 12; and Beaver, 10 to 12. The principal mode of the multimoded Ogden station was in the 12 to 14 inch class.

At the Northern Utah stations (Figure 8A) Salt Lake City had 80 per cent of the years with precipitation less than the 16-18 inch class, Logan had 71 per cent of the years drier than the 16-18 inch class and Ogden had only 60 per cent drier than the 16-18 inch class. By contrast the Southern Utah stations (Figure 8) were: Cedar City 75 per cent drier than 12-14 inch class and Beaver 73 per cent drier than the 12-14 inch class.

In Figures 9-14 the annaul precipitations for Logan, Ogden, Salt Lake City, Brighton, Cedar City and Beaver are plotted an extreme probability paper. The four Northern Utah stations have about 60 per cent of the years with below average precipitation while the two Southern Utah stations have only about 55 per cent of years below normal.

The ratios of 100/10 year annual precipitation for the Northern Utah stations are Logan,26/20, Ogden, 30.3/22.2; Salt Lake City, 25.0/19.6 and Brighton, 64/51. The same ratios for the two Southern Utah stations are Cedar

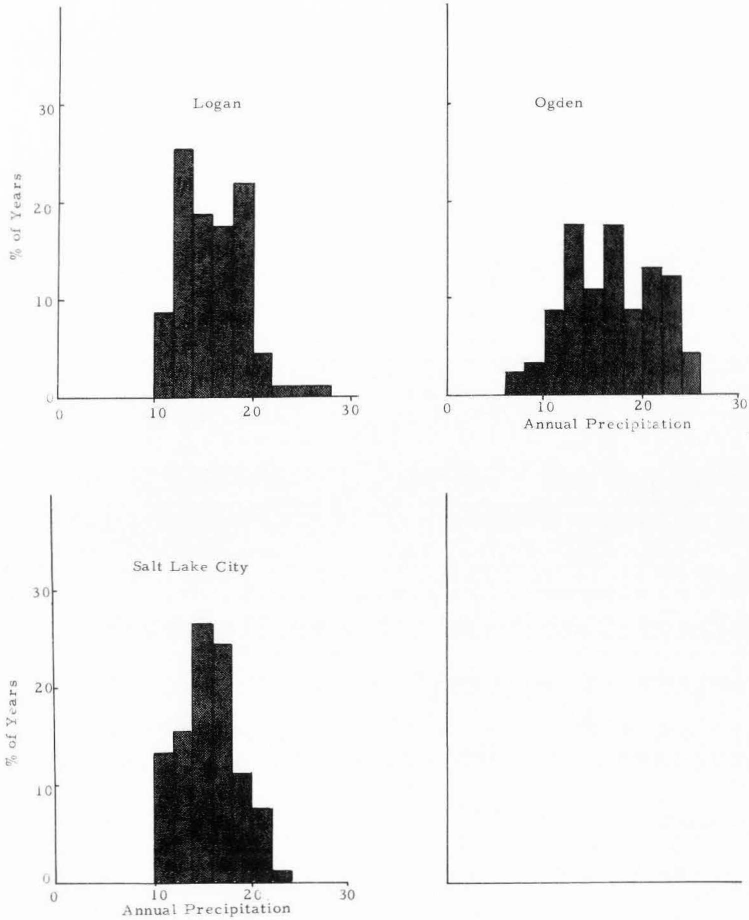


Figure 6. Frequency distribution of annual precipitation amounts Northern Utah stations.

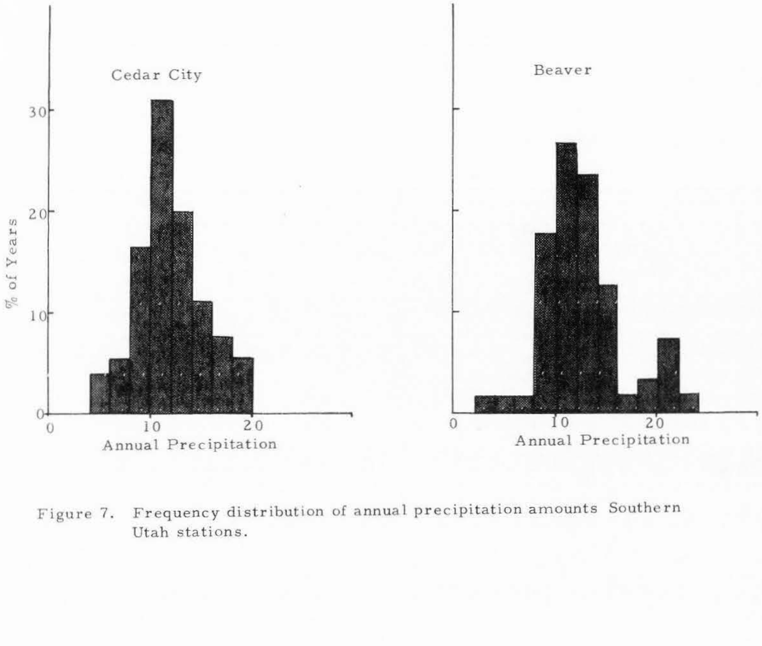


Figure 7. Frequency distribution of annual precipitation amounts Southern Utah stations.

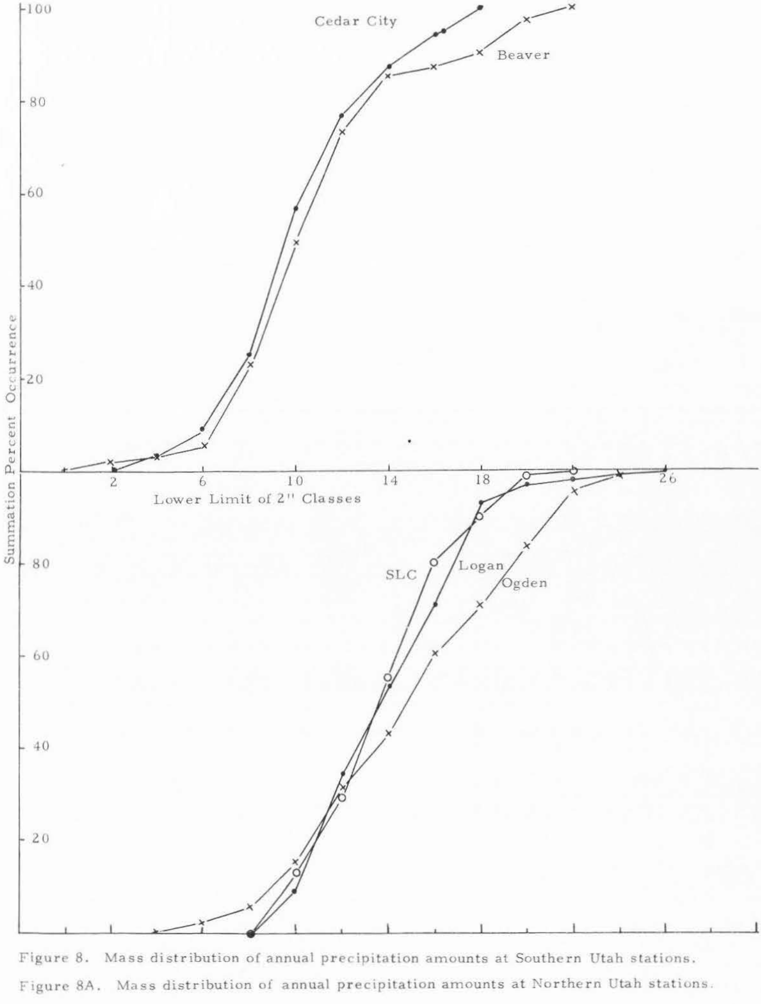


Figure 8. Mass distribution of annual precipitation amounts at Southern Utah stations.

Figure 8A. Mass distribution of annual precipitation amounts at Northern Utah stations.

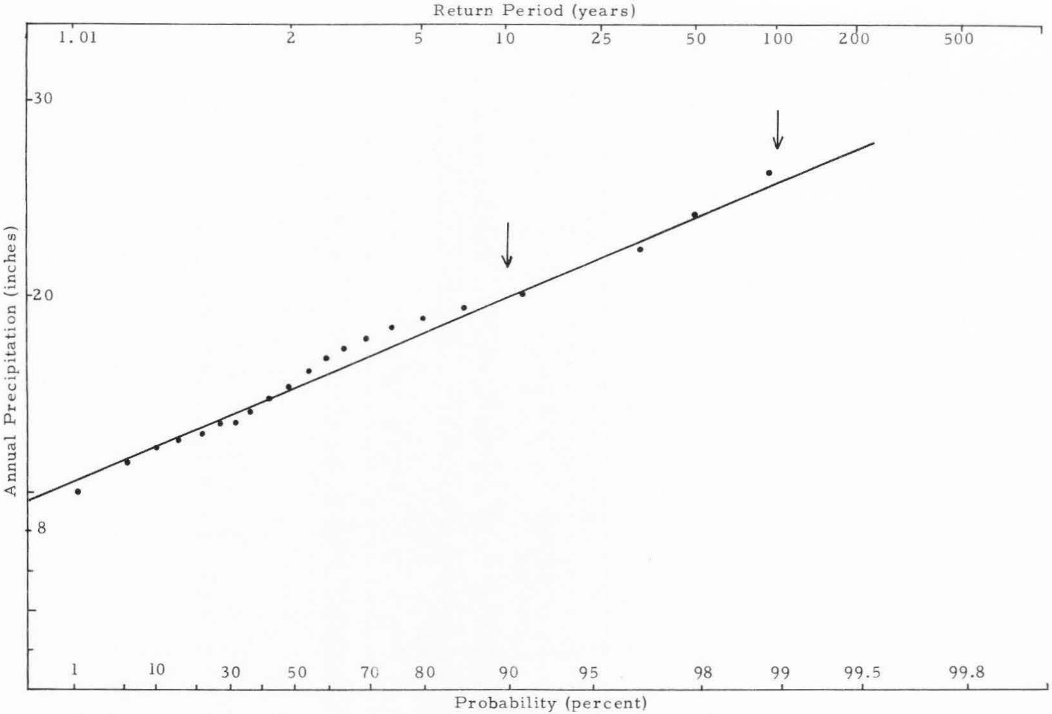


Figure 9. Return periods of annual precipitation amounts at Logan.

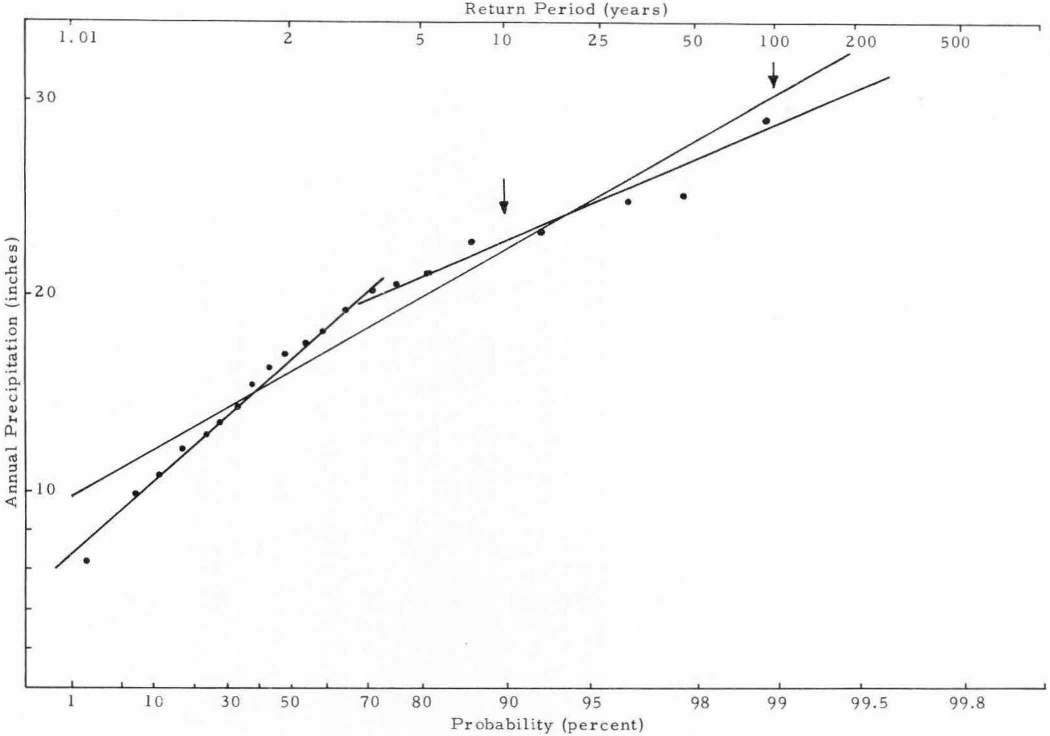


Figure 10. Return periods of annual precipitation amounts at Ogden.

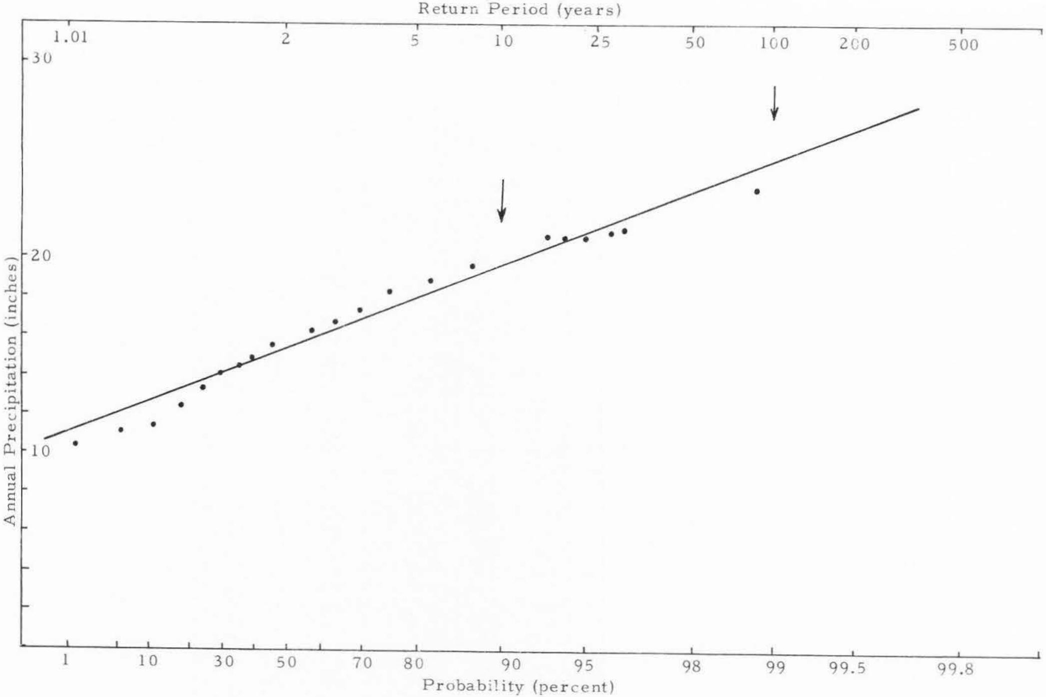


Figure 11. Return periods of annual precipitation amounts at Salt Lake City.

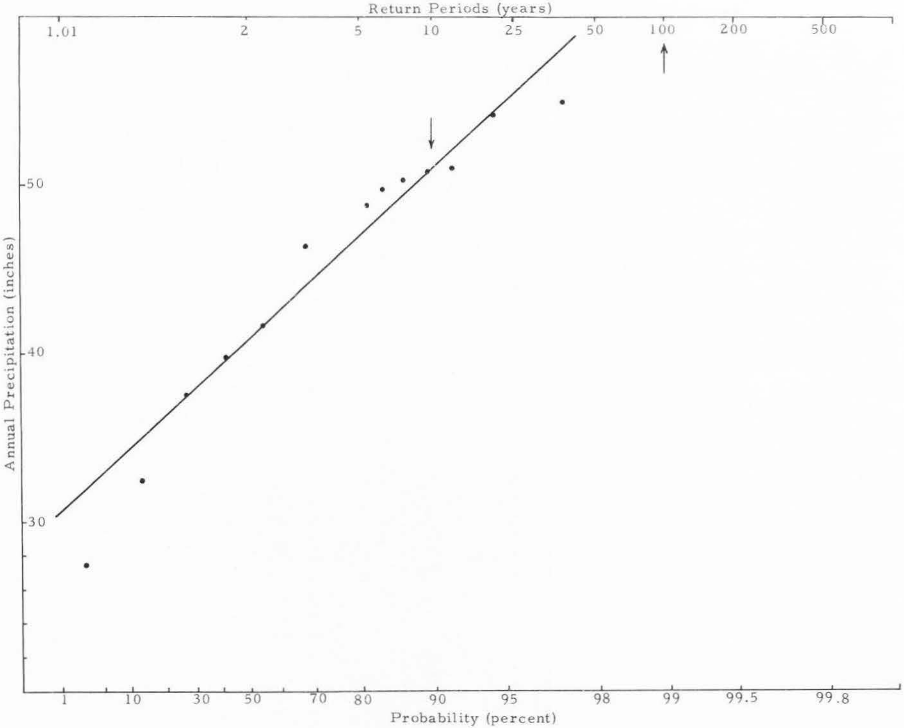


Figure 12. Return periods of annual precipitation amounts at Brighton.

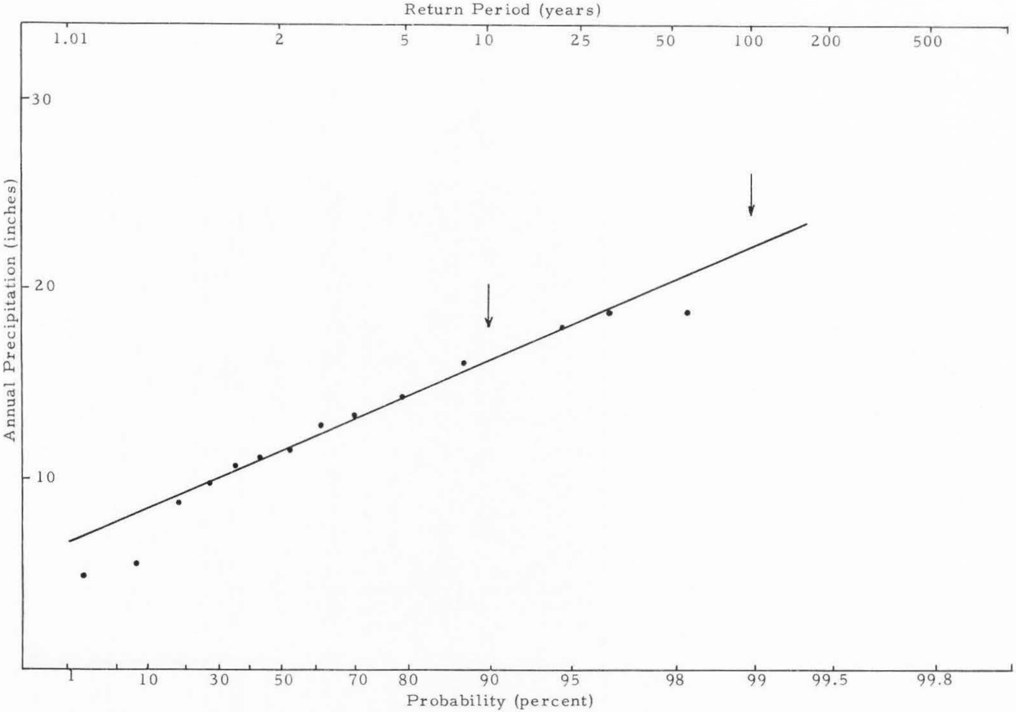


Figure 13. Return periods of annual precipitation amounts at Cedar City.

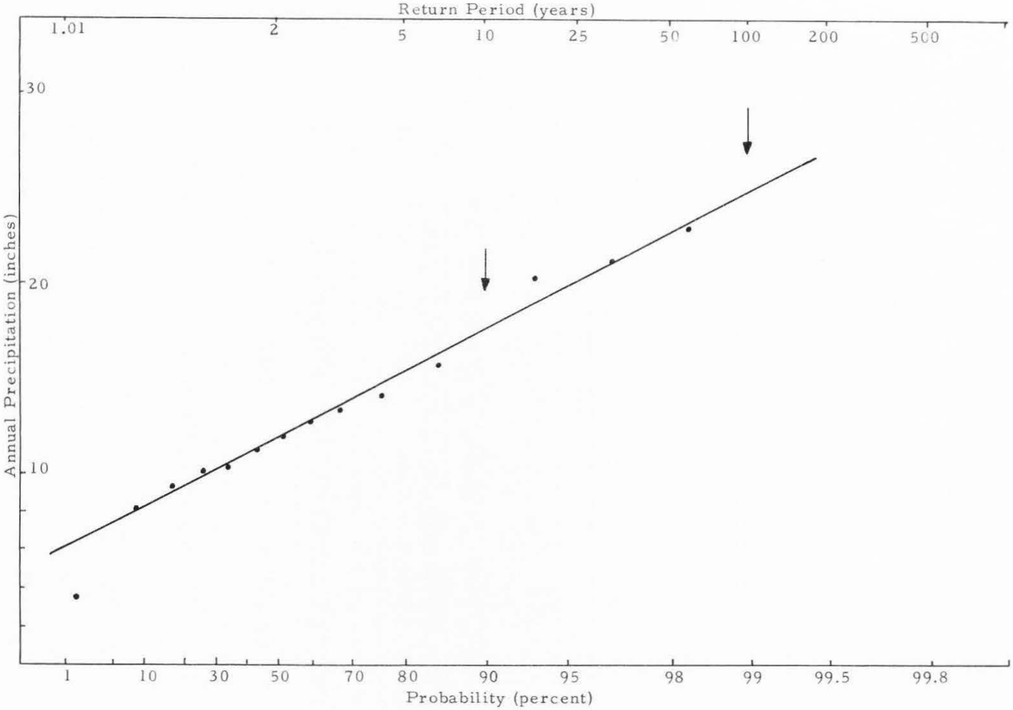


Figure 14. Return periods of annual precipitation amounts at Beaver.

City, 22.2/16.2; and Beaver, 24.8/17.6. These ratios are quite constant ranging from 1.26 to 1.41 which suggests that perhaps all of the stations come from a hydrologically homogeneous region.

From the standpoint of irrigation design it is desirable to know the frequency that dry years follow dry years and wet years follow wet years. These relations are shown in Figure 15 for three Northern Utah stations and in Figure 17 for two Southern Utah stations.

It appears that at Ogden about 25 per cent of the time, nine or more years of drought occur consecutively and 80 per cent of the time three or more years occur consecutively at both Logan and Ogden.

At the Southern Utah stations, Cedar City has 37 per cent of the time with 11 or more consecutive years of drought and 80 per cent of the time at both Cedar City and Beaver have 2 or more consecutive years of drought.

Seasonal distribution of precipitation

Figure 16 shows the seasonal distribution of precipitation at six stations, four from Northern and two from Southern Utah, plotted as percentages of annual precipitation occurring in each month. The effects of convective precipitation can be seen in the months of July, August and September. This effect is most pronounced at the two Southern Utah stations and least at the high elevation station of Brighton.

Peaks in precipitation are noticeable in the late winter months at Logan, Ogden and Salt Lake City while decreases occur after March at Brighton, Cedar City and Beaver.

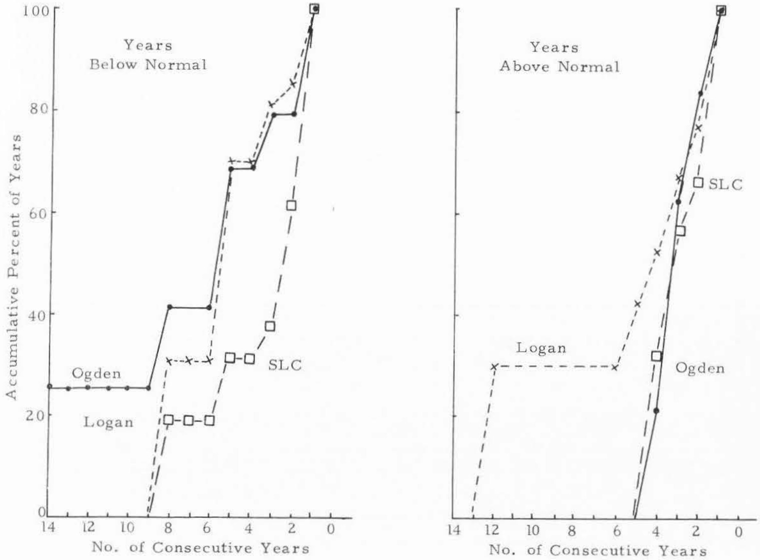


Figure 15. The frequency of consecutive occurrence of wet and dry years for Northern Utah stations.

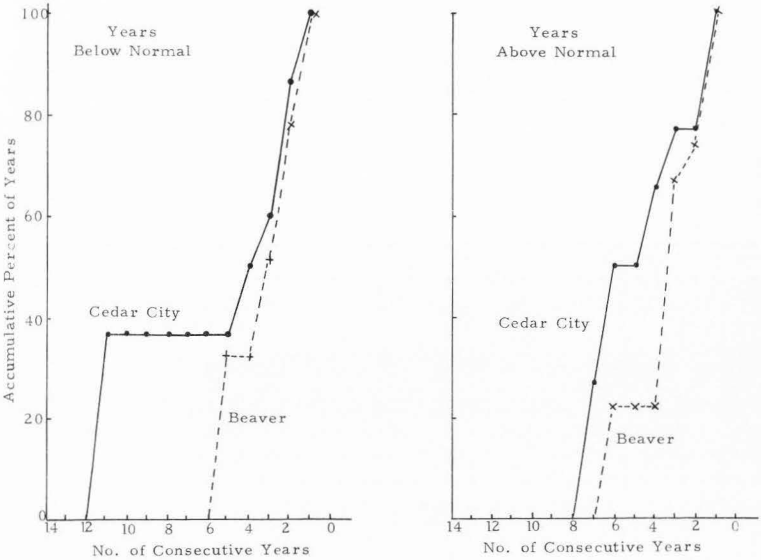


Figure 16. The frequency of consecutive occurrence of wet and dry years for Southern Utah stations.

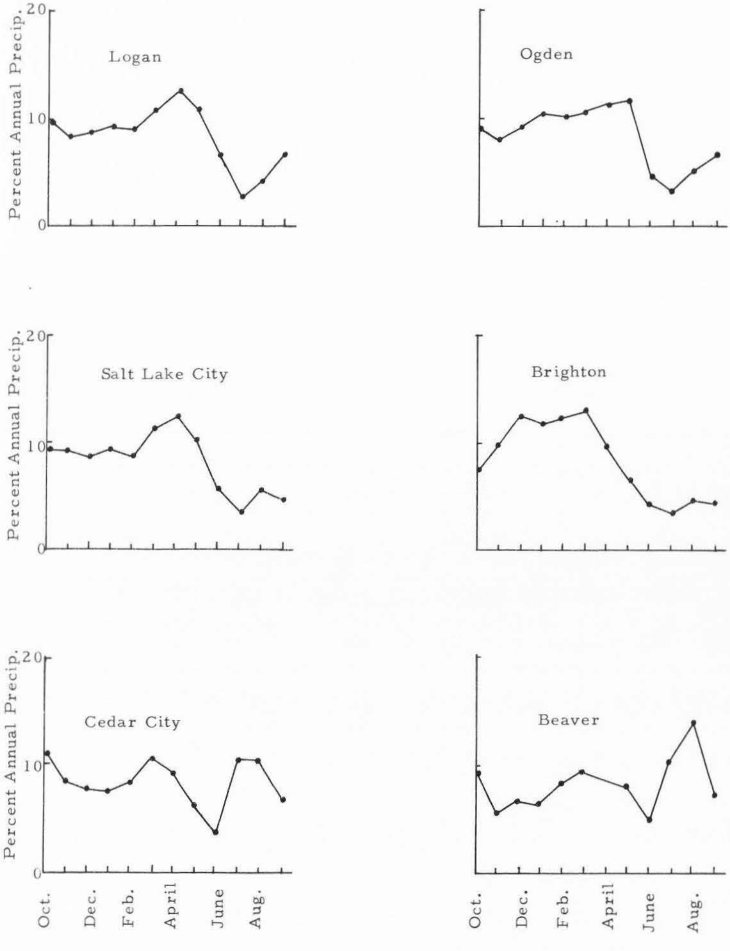


Figure 17. Seasonal distribution of precipitation at Northern and Southern Utah stations. All stations are plotted as percentage of the annual precipitation.

Long time precipitation trends

The long time precipitation trend at Beaver, Logan and Salt Lake City are shown in Figure 18, wherein 5-point means of annual precipitation are plotted against time. It is noticeable that some of the peaks and hollows are offset in time as the stations are considered from north to south.

It is also observable that there is a slight increase in mean precipitation with time in the two northern stations while the reverse appears at the southern station.

Figure 18. 5-point means of annual precipitation for Beaver, Logan and Salt Lake City.

RESULTS AND DISCUSSION

The results of the analysis of the relationship of precipitation to elevation show that the maximum annual precipitation occurred at lower mountain stations, and the minimum at stations in the valley or in the bottom of a valley. For instance, in the Beaver group, the minimum annual precipitation occurred at Beaver, a valley station with elevation of 5,860 feet and maximum at Kimberly Mine, a lower mountain station with elevation of 9,100 feet. It should be noted that the annual precipitation at Big Flat, a high mountain station with an elevation of 10,120 feet was lower than at Kimberly Mine.

In the Cedar City group, the minimum annual precipitation occurred at Cedar City Power House with an elevation of 5,680 feet. Only 67 feet higher than the lowest station (Cedar City) and the maximum at Castle Valley with an elevation of 9,200 feet. The annual precipitation at Cedar Breaks with elevation of 10,360 feet was lower than at Castle Valley.

From observation of other groups of stations Salt Lake City, Farmington, and Logan, it can be concluded that the same condition stated above--the minimum annual precipitation occurred at valley stations and the maximum occurred at the 8-10,000 feet stations.

In the Ephraim group the minimum annual precipitation occurred at Ephraim City with an elevation of 5,580 feet (only 37 feet higher than the lowest station, Sorenson's Field, the second highest annual precipitation occurred at

Headquarters-G. B. Research Center with an elevation of 8,850 feet. The annual precipitations at Left Fork Ephraim Creek # 1 (elevation 9,700 feet), Left Fork Ephraim Creed # 2 (elevation 9,700 feet), Alpine Cattle Pasture (elevation 10,120 feet) were lower than that of Headquarters-G. B. Research Center. The only exception is that the annual precipitation at Meadows (average of 2 stations, with elevation of 9,860 feet) was higher than that of Headquarters-G. B. Research Center. It can be concluded that the minimum annual precipitation occurred at valley stations and that the maximum at lower mountain stations. It is evident that the annual precipitation seems to increase quite uniformly with the elevation from the valley floor to the lower mountains of about 9,000 feet. After passing this elevation the annual precipitation decreases.

The above fact plays an important role in the construction of isohyetal maps by which engineers can study the general precipitation distribution characteristic of the area and still more serve the fundamental data for water supply studies and streamflow forecasting, etc.

The mean monthly precipitation at lower stations is quite uniform, and there may exist quite fixed relationships between the mean monthly precipitation among the valley stations.

On the contrary, for stations of higher elevations, non-uniform mean monthly precipitation occurs and there may be no fixed relationship of mean monthly precipitation between valley and mountain precipitation. The mountain precipitation is extremely "spotty" in character, especially in the summer.

Although the spots of mean monthly precipitations are scattered for mountain stations, it is not difficult to draw mean straight lines to show the relation of precipitation to elevation.

It can be noted that the maximum mean monthly precipitation occurred at the lower mountain stations and the minimum at stations in the valley.

Furthermore, the mean monthly precipitation increases a little uniformly with elevation from the valley floor to the mountains of about 9,000 feet. After passing these elevations the mean monthly precipitation drops and then recovers to increase insignificantly with elevation. For example, in the Beaver group the minimum monthly precipitation occurred at Beaver with elevation of 5,860 feet. The precipitation increased as elevation increases. After passing Beaver Canyon Power House with an elevation of 7,275 feet the precipitation increased to the maximum at Kimberly Mine with an elevation of 9,100 feet, and then the precipitation decreased though the elevation increased to 10,120 feet at Big Flat. The same condition can be seen in the Farmington group.

In the Ephraim group the mean monthly precipitation increases from Ephraim City (elevation, 5,580 feet) to a maximum at Headquarters-G. B. Research Center (elevation, 8,850 feet). Then the precipitation decreases at Left Fork Ephraim Creek # 1 and Left Fork Ephraim Creek # 2 (elevation, both 9,700 feet). After that the precipitation recovers to increase insignificantly. At Meadows (elevation, 9,860 feet) and Alpine Cattle Pasture (elevation, 9,900 feet) the precipitation increases after the mean monthly precipitation exceeds the corresponding Sorenson's Field (ordinate Valley station) precipitation of about 1 inch.

The higher the elevation, the greater the ratio of mountain or foothill precipitation to valley precipitation within elevation of about 9,000 feet. This fact is useful in constructing isohyetal maps of the area within elevation of about 9,000 feet. The higher the elevation, the greater the rate of increase of precipitation with respect to valley precipitation.

The ratio of Salt Lake City mean annual precipitation to Brighton mean precipitation is expressed by a straight line.

Mountain precipitation is greater than valley precipitation.

The 45 year mean annual precipitation at Salt Lake City is 15.450 inches, while that for Brighton is 41.442 inches. This means that the mountain precipitation is 2.682 times the valley precipitation or valley precipitation is only 27 per cent of the mountain precipitation. The difference of elevation for the two stations is 4,440 feet (8,700 feet-4,260 feet), the corresponding difference of mean annual precipitation is 25,992 inches. If the precipitation increases uniformly from the valley floor to the mountain, precipitation increases 5,854 inches per 1,000 feet rise in elevation between Salt Lake City and Brighton.

The seasonal precipitation (May 1 to October 1 and October 1 to May 1) increase as total annual precipitation increases.

The annual precipitation corresponding to the maximum per cent of total years is about 17 inches in Northern Utah and decreases to 11 inches in Southern Utah, while the corresponding maximum per cent of total years is about 26 per cent (about one-quarter of total years) for all around Utah except Ogden.

The climate of Utah is divided into a distinct wet and a distinct dry season. Precipitation is light during June, July and August and heavier during the remaining months of the year. Approximately 56 per cent of the annual precipitation at Logan occurs during the period October to March, inclusive, with Salt Lake City receiving approximately 57 per cent, and Beaver approximately 46 per cent for the same period. Cyclonic storms are the source of most of the precipitation from October to June, inclusive. The July-September, inclusive, precipitation is approximately 14 per cent for Logan and Salt Lake City, while it is approximately 32 per cent for Beaver of the annual precipitation.

The ratio of October 1 to January 1 precipitation to October 1 to April 1 precipitation is 0.48 for Logan, Salt Lake City and Beaver.

The relationships may be summarized as:

	Logan	Salt Lake City	Beaver
$\frac{\text{October-March}}{\text{Annual}}$ precipitation (%)	56	57	46
$\frac{\text{July-September}}{\text{Annual}}$ precipitation (%)	14	14	32
$\frac{\text{October 1-January 1}}{\text{October 1-April 1}}$ precipitation (%)	48	48	48

It may be seen that the seasonal precipitation distribution characteristics for Logan and Salt Lake City are the same, while at Beaver, the ratio of October to March precipitation to annual precipitation is lower and the ratio of July to September precipitation to annual precipitation is higher than those of the two other stations, but the ratio of October 1 to January 1 precipitation to October 1 to April 1 precipitation is the same as that at Logan and Salt Lake City.

The seasonal precipitation distribution characteristics stated above is quite important for hydrologic studies and can be helpful in seasonal precipitation forecasting for engineers.

The long-time precipitation slightly decreases year by year in Logan, Salt Lake City and Beaver. This important fact should call attention of engineers in planning a long time water resource utilities in Utah in the field of agricultural, industrial and municipal use, etc.

Logan, annual precipitation decreasing 0.015 inches per year.

Salt Lake City, annual precipitation decreasing 0.009 inches per year.

Beaver, annual precipitation decreasing 0.009 inches per year.

CONCLUSIONS

Relationship of precipitation to elevation

1. Minimum precipitation occurs at valley stations and the maximum occurs at foothill stations.

Precipitation seems to increase quite uniformly with elevation from the valley floor to about 9,000 feet. After this elevation, precipitation drops, and then recovers to increase insignificantly with elevation.

2. Monthly precipitation at lower elevations is quite uniform and a fixed relationship exists for monthly precipitation among the valley stations.

3. Monthly precipitation at higher elevation is not uniform and no fixed relationship exists between valley and mountain precipitation, especially in summer.

4. The higher the elevation, the greater the ratio of mountain or foothill precipitation to valley precipitation within elevations below 9,000 feet, and above elevations of about 9,000 feet, the smaller the rate of increase of precipitation with respect to valley precipitation.

The frequency of dry years in Utah

The annual precipitation corresponding to the maximum per cent of total years is about 17 inches in Northern Utah and decreases to 11 inches in Southern Utah, while the corresponding maximum per cent of total years is about 26 per cent (about one-quarter of the total years) for all around Utah, except Ogden.

Seasonal distribution of precipitation in Utah

1. The climate of Utah is divided into a distinct wet and a distinct dry season. Precipitation is light during June, July and August and heavier during the remaining months of the year. The month of June, a critical period for plant growth, receives the least precipitation in Southern Utah and in July in Northern Utah.

2. Approximately 56 per cent of the annual precipitation at Logan and Salt Lake City occurs during the period October to March, inclusive and a large part of it falls as snow. The higher the altitude the longer the snowfall period, and the greater the proportion of annual precipitation occurring as snow. Snowfall constitutes about 45 per cent of the total amount precipitation in the valley floor and increases with elevation to about 80 per cent in the high mountains. Water content of snow cover, in relation to depth, increases with the advance of the snowfall season. At the beginning the ratio is 1.5 which increases to 1:3 during April and May when melting occurs in the spring. Water content of the snow cover in relation to annual precipitation ranges from about 30 per cent to 65 per cent according to elevation. The date of snow disappearance is delayed on an average of approximately 15.5 days per 1,000 feet rise in elevation.

The July-September precipitation is approximately 14 per cent of the annual for Logan and Salt Lake City. By comparing the two seasonal precipitations stated above for Logan and Salt Lake City, it can be concluded that most of the water in Northern Utah comes from snowfall. On the contrary, in Beaver, the precipitation occurring in October-March decreases to 46 per cent, while that occurring during July-September increases to 32 per cent. It can be seen that a proportion of the water resource of Southern Utah depends upon summer precipitation.

3. The ratio of October 1 to January 1 precipitation to October 1 to April 1 precipitation is 0.48 for all of Utah. This means that precipitation occurring during January-March is 2 per cent greater than that occurring during October-December throughout Utah.

Long-time precipitation trends

The long-time precipitation trends in Utah slightly decrease year by year, decreasing 0.015 inches in Logan, 0.009 inches in Salt Lake City, and 0.0096 inches in Beaver, respective each year.

The long-time precipitation decreases in Utah should attract the attention of engineers planning long-time water resources development of Utah.

At the end of this paper, the writer emphasizes the importance of installing more weather stations in the high mountains of Utah.

The major sources of waters flowing in the streams in this arid region is the high mountains adjacent to the valleys. For many years precipitation records have been kept at valley stations. Due to the inaccessibility of the high watersheds in the winter. The scarcity of permanent inhabitants, and to the difficulty of measuring precipitation which falls as snow, few records of precipitation are available in the high mountains.

There is a general lack of reliable data on precipitation and other meteorological data on high watersheds in spite of the fact that these areas are the source of water supply for irrigation, domestic, and power purposes. More complete data on mountain watersheds would permit a more complete utilization of water resources. The writer is going to give in the following the reasons for installing sufficient numbers of weather stations in high mountains of Utah.

a. Local storms furnish most of the summer precipitation in Utah. It is evident that (1) there is no fixed relationship between the valley and mountain precipitation and (2) that the mountain summer precipitation is extremely spotted in character as these storms occur irregularly and are extremely spotted in intensity and total amount. Consequently, a large number of mo untain precipitation stations are necessary to obtain an average record of summer precipitation.

b. Existing records indicate that there is only a poor correlation between valley and mountain winter precipitation in Utah. This means that winter precipitation occurring in the valley is poor index of the winter precipitation on the high watershed without storm stratification.

c. Valley precipitation is a poor index of the probable water supplies and at times may be misleading.

d. Winter precipitation on high mountain watersheds is measured by snow surveys. It is quite uniform over wide areas. Thus the winter precipitation as measured by annual snow surveys apparently is a good index of the water supply to be expected from such watersheds.

e. It has been estimated that approximately 80 per cent of the run-off in Utah comes from areas above 7,000 feet elevation, and thus holds the key to the state's most valuable resources.

f. Since approximately 80 per cent of the run-off in Utah comes from high watersheds, the precipitation character in mountains is indispensable to streamflow forecasting.

LITERATURE CITED

Alter, J. C. 1919. "Precipitation in Utah." U. S. Monthly Weather Rev. 47:633-636.

Bagley, J. M., Roland W. Jeppson and Cleve H. Milligan. 1964. Water
7515 Yields in Utah. Utah Agric. Expt. Sta. Spec. Rpt. 18. 65 pp.

Bergeron, T. 1933. On the Physics of Clouds. Mem. Meterogy Assoc. Int. Union Geod-Geophys. Lisbon 1933. pp. 156-175.

Bernard, Merrill. 1942. Precipitation in Hydrology. New York: Dover Inc.

Braham, Roscoe R. Jr. "Physical Properties of Clouds." J. Irrig. and Drainage Div. ASCE 86(1R1):111-119.

Brancato, George N. "The Meteorological Behavior and Characteristics of Thunderstorms." Hydro Met. Sec. USWB 1942. 14 pp.

Clyde, George D. 1931. "Relationship Between Precipitation in Valleys and on Adjoining Mountains in Northern Utah." Monthly Weather Rev. March. pp. 113-117.

Fok, Y. S. 1959. "Streamflow Forecasting for Blacksmith Fork River, Utah." Unpublished Master's thesis, Department of Civil and Irrigation Engineering, Utah State University, Logan, Utah, 1959.

Foster, Edgar E. Rainfall and Runoff. New York: The Macmillan Company.

Gifford, R. O., G. L. Ashcroft, and M. D. Magnuson. 1967. Probability of Selected Precipitation Amounts in the Western Regions of the United States. Agricultural Experiment Station, University of Nevada, Reno, Nevada. No pagination.

Herschfeld, D. 1955. Rainfall Intensity-Duration-Frequency Curves. USDC Westher Bur. Tech. Paper No. 25. 53 pp.

Holzman, B. 1937. Sources of Moisture for Precipitation in the United States, U. S. Department Agric. Tech. Bull. 589, 1937.

Jorgensen, D. L., Wm. H. Klein and A. F. Korte. 1966. A Synoptic Climatology of Precipitation from Upper air Circulation for Intermountain Areas of the West. Tech. Note 45-TDL-4. ESSA Weather Bur. 21 pp.

Langmuir, Irving. 1948. "The Production of Rain by a Chain Reaction in Cumulus Clouds at Temperatures Above Freezing." J. Meteor. 5.

Linsly, R. K., Max A. Kohler and Joseph L. H. Paulhus. 1949. Applied Hydrology. New York: McGraw-Hill Company.

Nir, Nahman and T. Y. Chang. 1960. "Correlation of Yields vs Water Applied and vs Consumptive Use, 1950-1956." Unpublished Report, Utah State University, Project No. 306.

Peck, Eugene L. and Merle J. Brown. 1962. "An Approach to the Development of Isohyetal Maps for Mountainous Areas." J. Geophys. Res. 67:681-694.

Price, Raymond and Robert B. Evans. 1937. "Climate of the West Front of the Wasatch Plateau in Central Utah." Monthly Weather Review. 65(8):291-301.

Snedcor, George W. 1961. Statistical Methods, Fifth Edition. Ames, Iowa: The Iowa State University Press.

Stansbury, H. 1852. Explorations and Survey of the Valley of the Great Salt Lake. Philadelphia, Pennsylvania: Lippincott, Grambo and Company.

Sulakuelidze, G., N. Bibiloshvili, and V. Lapcheva. 1965. Formation of Precipitation and Modification of Hall Processes. Trans. from Russia. Pub. NSF. 207 pp.

Wilson, W. T. 1954. "Analysis of Winter Precipitation in the Cooperative Snow Investigations." Monthly Weather Rev. 82:183-199

APPENDIX

Table.1. Relationship of precipitation to elevation near Ephraim, Utah

Station (gage)	Elevation (feet)	Mean monthly precipitation (inches)												Annual
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
Sorenson's Field	5,543	0.88	0.75	0,91	0,81	1.01	1.14	0,99	0.98	0.67	0.66	0.68	0.74	10.22
Ephraim City	5,580	1.02	0.69	0.87	0.75	0.93	1.13	0.87	0.97	2.78	0.72	0.77	0.62	10.12
Rasmusson Field	5,600	0.84	0.89	1.10	0.80	1.68	1.38	1.56	0.78	0.76	0.27	0.68	1.52	12.26
Major Flat	7,150	0.86	1.59	1.81	1.66	2.16	1,64	2.03	1.81	0.84	0.73	1.03	1.07	17.23
Oaks	7,655	1.53	1.80	1.87	1.86	2.11	2.54	2.16	1.88	1.06	1.19	1.24	1.09	20.33
Headquarters-- G.B. Research Center	8,850	1.98	2.55	2.80	3.04	3.50	3.98	3.42	2.48	1.31	1.54	1.68	1.39	29.67
Left Fk. Eph. Cr. # 1	9,700	3.01	1.31	1.24	3.01	3.51	3.56	2.58	2.52	0.74	0.72	1.77	0.54	24.51
Left Fk. Eph. Cr. # 2	9,700	2.65	1.48	1.68	2.34	3.42	3.92	2.69	2.60	0.79	0.80	1.62	0.54	24.53
Meadows (Ave. of stas.)	9,860	2.25	3.06	3.00	3.39	4.03	4.58	3.88	2.71	1.82	1.48	1.70	1.45	33.35
Alpine Cattle Pasture	9,900	2.32	1.65	1.58	2.20	3.63	4.37	3.85	2.40	0.96	0.79	1.55	0.49	25.79
Left Fk. Eph. Cr. # 3	10,120	1.64	2.22	1.66	1.83	4.95	4.55	3.65	2.30	0.45	0.69	1.01	1.64	26.59

Table 2. Relationship of precipitation to elevation near Beaver, Utah

Station (gage)	Elevation (feet)	Mean monthly precipitation (inches)												Annual
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
Beaver	5,860	0.67	0.65	0.38	0.92	1.14	0.78	0.90	0.96	0.43	0.76	1.47	0.98	10.04
Beaver Canyon Power House	7,275	1.03	1.22	0.94	1.87	2.12	1.68	2.00	1.37	0.55	1.10	1.81	1.10	16.79
Kimberly Mine	9,100	1.99	2.16	1.61	2.73	4.20	4.70	4.49	2.46	0.79	1.05	2.61	1.87	30.66
Big Flat	10,290	1.74	1.97	1.40	2.53	3.80	3.82	3.75	2.47	0.84	1.32	2.96	1.52	28.12

Table 3. Relationship of precipitation to elevation near Cedar City, Utah

Station (gage)	Elevation (feet)	Mean monthly precipitation (inches)												Annual
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
Cedar City	5,613	0.66	0.80	0.51	0.55	0.72	0.94	0.87	0.76	0.39	0.97	1.21	0.68	9.06
Cedar City Power House	5,680	0.60	0.77	0.49	0.58	0.53	1.00	0.76	0.71	0.34	0.83	1.06	0.58	8.25
Cedar City Coll. Br.	8,135	1.42	1.94	1.71	2.27	2.19	2.44	1.76	1.45	0.89	1.49	2.24	1.72	21.52
Webster Flat	9,200	2.10	2.47	2.11	3.48	3.95	3.74	3.65	2.17	1.01	1.31	2.56	1.79	30.34
Castle Valley	9,700	1.92	1.86	1.82	2.04	3.15	3.72	2.91	2.03	0.74	1.04	2.46	1.57	25.26
Cedar Breaks	10,360	1.65	2.09	2.09	2.94	2.62	2.98	3.02	1.92	1.15	2.42	2.82	1.58	27.28

Table 4. Relationships of precipitation to elevation near Salt Lake City, Utah

Station (gage)	Ele-vation (feet)	Mean monthly precipitation (inches)												Annual
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	
Salt Lake City	4,260	0.85	1.15	1.13	1.31	1.24	1.65	2.16	1.26	0.82	0.73	0.93	0.54	13.77
Red Butte # 1	4,910	1.47	1.74	1.60	1.73	1.71	2.31	2.65	1.92	1.22	0.47	0.22	0.84	18.48
Red Butte # 2	5,425	1.68	1.94	1.79	1.88	1.91	2.54	2.87	2.29	1.33	0.59	0.92	1.09	20.83
Mountain Dell Dam	5,500	1.93	2.08	2.24	2.00	2.31	2.63	2.63	2.23	1.39	0.57	1.06	1.14	22.21
Red Butte # 4	6,200	2.43	2.97	3.19	3.50	3.11	4.05	4.12	3.09	1.75	0.75	1.16	1.18	31.30
Red Butte # 6	7,200	2.79	3.80	3.89	4.14	3.24	4.10	4.70	3.60	1.92	0.81	1.04	1.23	34.76
Silver Lake (Brighton)	8,700	2.92	4.66	5.11	5.10	4.87	5.90	4.13	2.87	2.04	1.12	1.91	1.78	42.41
Alta	8,760	4.78	6.53	7.54	8.00	7.15	8.53	6.01	3.59	0.97	1.10	3.23	0.84	58.27

Table 5. Relationship of precipitation to elevation near Farmington, Utah

Station (gage)	Elevation (feet)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
		Mean monthly precipitation (inches)												
Farmington Warehouse	4,334	1.64	1.99	2.04	2.16	1.84	2.32	2.80	2.09	1.59	0.35	1.04	0.81	20.67
Farmington Rice	7,000	3.16	4.37	4.86	4.86	4.42	5.18	5.08	3.81	2.73	0.71	1.45	1.37	42.00
Farmington Flats	7,500	2.50	4.26	4.82	6.18	4.49	5.43	5.28	3.87	2.59	0.59	1.24	1.66	42.91
Farmington Parrish Plots	8,200	2.20	3.38	3.90	5.48	4.12	5.21	5.56	3.67	2.06	0.53	1.07	1.21	38.39

Table 6. Relationship of precipitation to elevation near Logan, Utah

Station (gage)	Elevation (feet)	Mean monthly precipitation (inches)												
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
Logan	4,504	1.80	0.75	0.80	0.64	0.99	1.51	1.42	1.52	1.12	0.60	0.37	1.69	13.21
Logan (USU)	4,775	1.14	1.61	1.52	1.44	1.72	1.71	1.98	1.55	1.02	0.31	0.77	1.05	15.82
Tony Grove Ranger Sta.	6,250	1.50	2.58	3.45	3.60	3.66	2.85	2.64	1.91	1.53	0.72	0.92	1.58	26.94
Klondike Narrows	7,400	1.99	3.53	3.30	4.34	5.05	4.03	3.33	2.47	1.66	0.69	1.06	1.88	3.33
Tony Grove Lake	8,200	2.64	3.92	4.34	6.37	6.77	6.50	4.21	3.43	1.83	1.10	1.57	2.74	45.42

Table 7. Annual precipitation at some Utah stations

Year	Logan	Ogden	Salt Lake City	Brighton	Cedar City	Beaver
1870	(10.38)	7.21				
1871	(12.53)	10.99				
1872	(10.00)	6.54				
1873	(15.62)	16.42				
1874	(13.28)	12.30				
1875	(18.05)	20.69	23.67			
1876	(14.70)	14.80	21.28			
1877	(14.22)	13.95	16.35			
1878	(14.88)	15.11	19.75			
1879	(13.31)	12.35	13.11			
1880	(12.11)	10.24	10.94			
1881	(12.29)	10.56	16.88			
1882	(12.51)	10.96	15.98			
1883	(12.53)	10.98	14.24			
1884	(17.37)	19.49	17.52			
1885	(17.32)	19.40	19.69			
1886	(13.45)	12.60	18.89			
1887	(11.48)	9.14	11.66			
1888	(13.12)	12.03	13.62			
1889	(15.90)	16.91	18.46			
1890	(16.31)	17.63	10.33			6.06
1891	(19.43)	23.11	15.93			10.10
1892	12.90	15.86	14.08			
1893	14.51	16.03	17.35			
1894	14.36	13.71	15.27			
1895	13.51	12.09	11.95			
1896	16.15	14.35	18.42			
1897	17.45	16.65	16.74			
1898	13.18	13.64	16.09			
1899	12.57	13.53	17.57			
1900	15.06	12.53	11.53	8.44		
1901	14.47	13.80	16.08			
1902	13.33	12.79	11.41			
1903	13.97	9.91	14.62			
1904	13.52	15.97	16.31			

Table 7. Continued

Year	Logan	Ogden	Salt Lake City	Brighton	Cedar City	Beaver
1905	12.51	17.00	14.23			12.21
1906	26.40	22.86	21.28		14.70	15.87
1907	21.96	19.23	19.22		16.16	(19.56)
1908	18.77	20.44	20.85		13.73	15.04
1909	22.31	24.81	19.68		(15.24)	18.01
1910	11.74	(9.59)	11.25		11.77	15.93
1911	19.07	18.69	15.13		13.68	14.05
1912	18.90	18.56	19.19		12.98	11.43
1913	17.82	20.89	16.69		10.10	14.53
1914	19.59	(23.39)	16.10		10.63	(10.26)
1915	15.17	17.31	14.49		14.04	13.43
1916	18.77	20.24	16.06	46.28	18.19	(22.97)
1917	18.44	14.14	14.17	29.62	11.91	(12.41)
1918	16.91	13.02	16.11	46.04	11.60	10.57
1919	15.70	17.52	13.42	38.89	11.07	11.15
1920	19.24	21.24	21.56	50.84	18.73	21.20
1921	18.33	20.41	14.45	50.57	17.46	20.20
1922	15.16	17.97	21.69	54.97	15.66	12.45
1923	16.91	22.75	18.96	38.72	13.63	9.38
1924	12.42	17.72	13.86	33.12	13.65	11.31
1925	16.32	22.15	17.17	38.51	16.71	13.37
1926	15.97	20.54	15.61	37.80	9.17	10.16
1927	18.38	20.29	20.69	48.42	16.22	12.49
1928	10.81	11.66	12.10	32.82	11.54	9.34
1929	15.97	20.29	14.47	40.80	12.85	9.56
1930	20.33	24.12	15.73	38.95	13.36	12.58
1931	12.32	12.22	11.40	31.12	12.80	8.06
1932	16.42	15.92	14.88	41.04	15.40	10.89
1933	11.93	13.56	11.11	36.82	8.82	10.65
1934	11.79	16.37	14.29	32.32	7.62	9.20
1935	13.47	16.59	12.96	29.74	10.95	8.40
1936	18.31	23.03	17.75	54.09	13.60	20.78
1937	20.41	20.37	14.54	40.78	11.04	14.15
1938	17.76	23.23	16.41	46.75	14.38	12.70
1939	12.42	(10.79)	10.68	27.31	10.30	8.86

Table 7. Continued

Year	Logan	Ogden	Salt Lake City	Brighton	Cedar City	Beaver
1940	17.05	22.36	18.58	37.58	9.42	12.54
1941	19.62	29.07	21.24	48.63	18.76	20.48
1942	17.97	20.24	16.12	39.89	10.01	9.18
1943	18.12	15.64	12.81	47.16	10.73	(10.42)
1944	18.88	20.95	18.87	44.55	10.73	11.18
1945	24.47	22.54	18.82	51.05	11.13	12.51
1946	20.48	17.06	16.51	40.08	13.65	13.88
1947	18.77	20.60	17.86	43.02	10.93	12.97
1948	17.30	18,02	15.43	45.64	9.31	10.25
1949	19.77	25.18	16.70	41.34	12.57	(13.52)
1950	19.88	17.60	13.49	47.75	6.66	(3.58)
1951	18,92	22.51	17.50	49.80	9.57	14.06
1952	12.82	18.24	15.14	37.13	8.30	11.99
1953	14.00	18.07	12.32	36.97	8.32	11.80
1954	12.46	13.31	12.43	38.69	8.15	10.46
1955	20.17	19.46	13.63	41.83	6.88	10.28
1956	11.68	15.37	12.39	31.68	5.71	5.82
1957	17.80	23.31	18.44	45.25	11.53	16.03
1958	13.58	15.14	10.72	42.71	9.97	8.69
1959	16.38	17.14	13.82	41.95	4.95	6.35
1960	14.18	16.56	12.37	33.76	10.18	9.18
Range	10.00- 26.40	6.54- 29.07	10.33- 23.67	27.31- 54.97	4.95- 18.76	3.58- 22.97
Mean	16.575	18.097	15.803	41.173	11.810	12.242

Table 8. Percentages of the annual precipitation falling in each month at six Utah stations

Month	Logan	Ogden	Salt Lake City	Brighton	Cedar City	Beaver
Oct.	9.60	9.08	9.35	7.31	11.18	9.54
Nov.	8.36	8.02	9.25	9.86	8.14	5.42
Dec.	8.84	9.34	8.73	12.44	7.82	6.86
Jan.	9.16	10.33	9.39	11.93	7.45	6.46
Feb.	9.07	10.06	8.82	12.28	8.30	8.15
Mar.	10.81	10.80	11.42	13.01	10.52	9.40
Apr.	12.40	11.02	12.58	9.85	9.04	8.74
May	10.82	11.69	10.28	6.54	6.13	8.19
June	6.92	4.97	5.92	4.11	3.86	5.00
July	2.99	3.31	3.75	3.56	10.44	10.87
Aug.	4.16	5.12	5.63	4.67	10.29	14.10
Sept.	6.87	6.40	4.86	4.34	6.90	7.28

Table 9. Precipitation vs per cent of total years in each size class

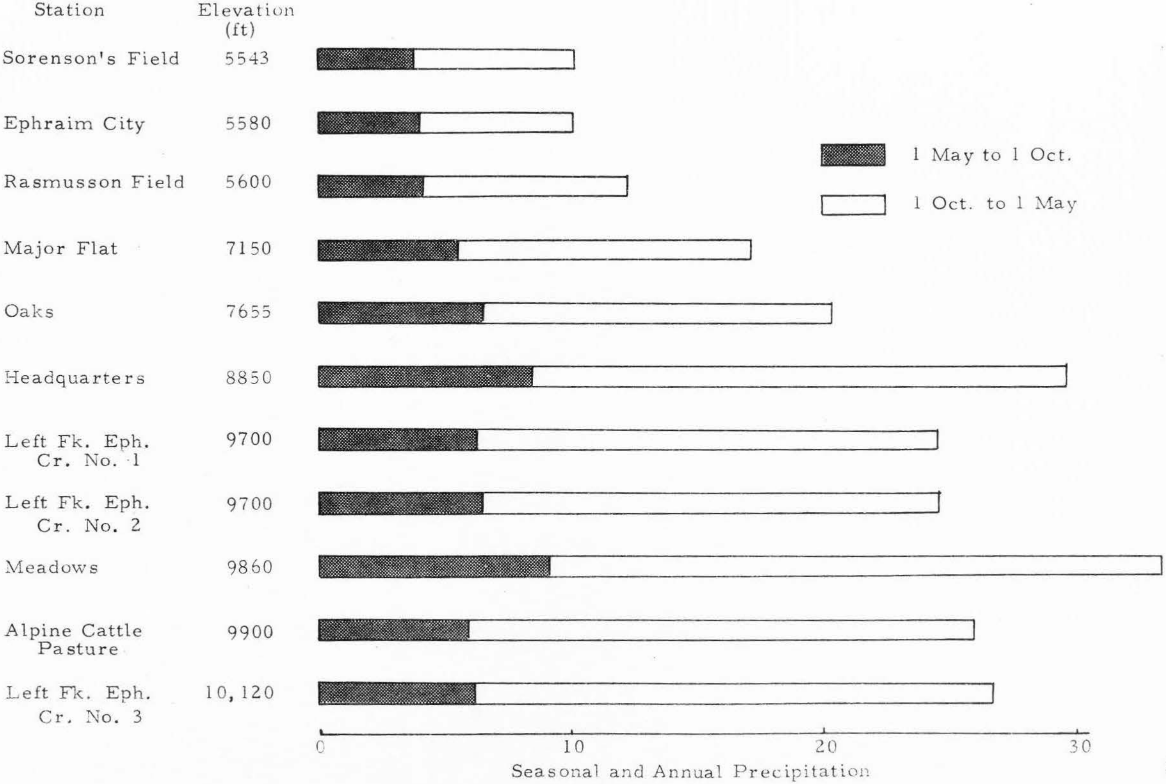
Precipitation	No. of years	Per cent of total years
LOGAN		
0-2		
2-4		
4-6		
6-8		
8-10		0
10-12	8	8.8
12-14	23	34.1
14-16	17	52.8
16-18	16	70.4
18-20	20	92.4
20-22	4	96.8
22-24	1	97.9
24-26	1	99.0
26-28	1	100.0
28-30		
Total	91	100.0
OGDEN		
0-2		
2-4		
4-6		0
6-8	2	2.6
8-10	3	5.5
10-12	8	14.3
12-14	16	31.9
14-16	10	42.9
16-18	16	60.5
18-20	9	70.4
20-22	12	83.6
22-24	11	95.6
24-26	3	98.9
26-28		
28-30	1	100.00
Total	91	100.00

Table 9. Continued

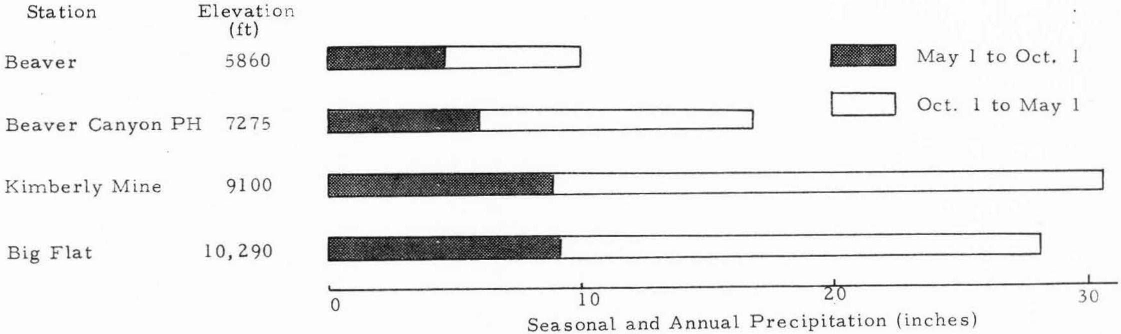
Precipitation	No. of years	Per cent of total years
SALT LAKE CITY		
0-2		
2-4		
4-6		
6-8		
8-10		0
10-12	12	13.3
12-14	14	28.9
14-16	24	55.6
16-18	22	80.0
18-20	10	91.1
20-22	7	98.9
22-24	1	100.0
24-26		
26-28		
28-30		
Total	90	100.0
CEDAR CITY		
0-2		
2-4		
4-6	2	3.6
6-8	3	9.1
8-10	9	25.5
10-12	17	56.4
12-14	11	76.4
14-16	6	87.3
16-18	4	94.6
18-20	3	100.0
20-22		
22-24		
24-26		
26-28		
28-30		
Total	55	100.00

Table 9. Continued

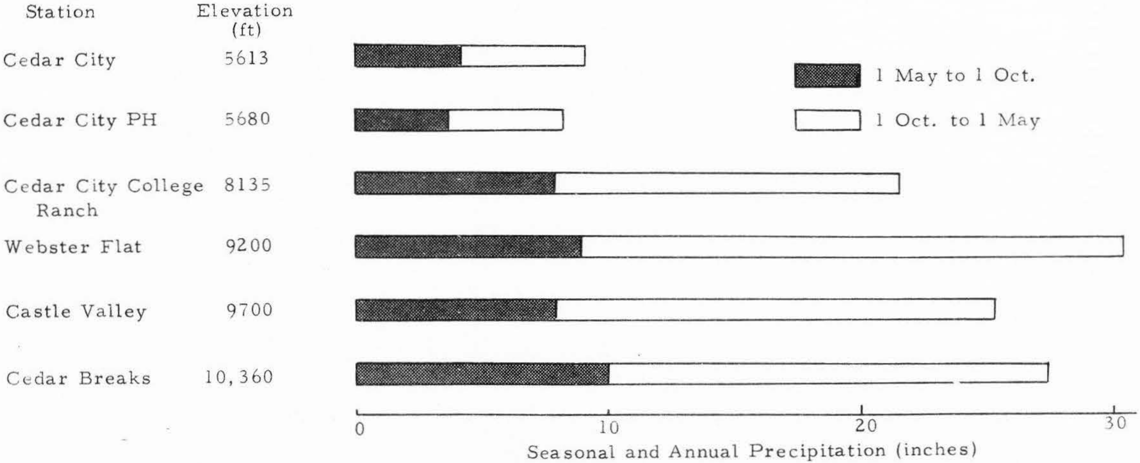
Precipitation	No. of years	Per cent of total years
BEAVER		
0-2		0
2-4	1	1.8
4-6	1	3.5
6-8	1	5.3
8-10	10	23.1
10-12	15	49.9
12-14	13	73.1
14-16	7	85.6
16-18	1	87.4
18-20	2	90.0
20-22	4	97.1
22-24	1	100.0
24-26		
26-28		
28-30		
Total	56	100.00



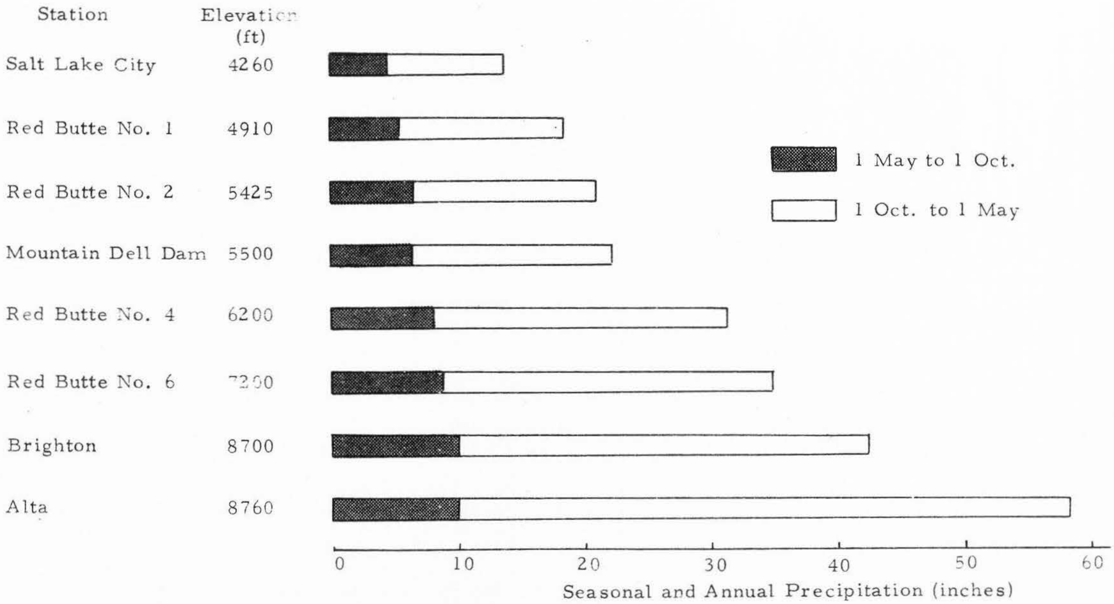
Appendix Figure 1. Relationship of precipitation to elevation near Ephraim, Utah.



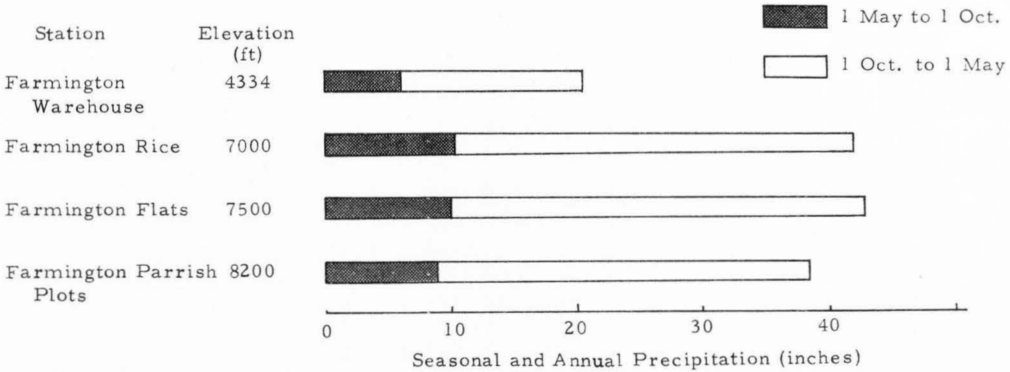
Appendix Figure 2. Relationship of precipitation to elevation in vicinity of Beaver, Utah.



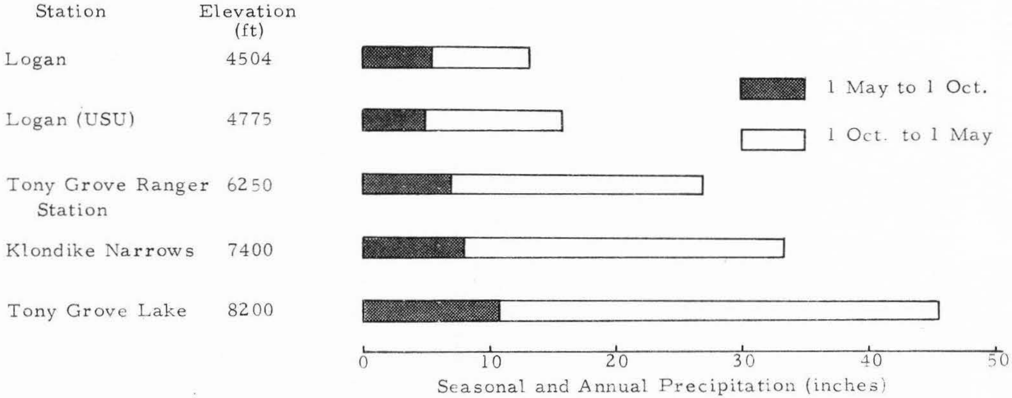
Appendix Figure 3. Relationship of precipitation to elevation near Cedar City, Utah.



Appendix Figure 4. Relationship of precipitation to elevation near Salt Lake City, Utah.



Appendix Figure 5. Relationship of precipitation to elevation near Farmington, Utah.



Appendix Figure 6. Relationship of precipitation to elevation near Logan, Utah.