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RAINFALL FREQUENCY: AN ASPECT OF CLIMATIC VARIATION

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Abstract--Analyses which have been made in the past have shown no significant trend in annual values of rainfall during the period of rainfall records in the southwestern United States. In the present study, frequency of daily rains of various sizes are analyzed for four long-record stations in New Mexico. It is shown that the frequency of rains smaller than 0.50 inch in a day progressively increased from 1850 to about 1930. Opposite trends in different size classes tended to partially compensate one another in such a way that trends do not appear in the annual rainfall totals. Frequency of rains of various sizes comprising wet years and dry are compared. Some effects of changes in rainfall frequency on vegetation and erosion are discussed.

During the period since the last retreat of the glaciers of Wisconsin time, climatic variations have caused important changes in the regimen of rivers, particularly in western United States. Over a large area, both ephemeral and perennial streams have, by alternate aggradation and degradation, built a series of terraces made up of relatively fine-grained material. Because changes in climate operate on streams through the medium of induced changes in rainfall and through concomitant changes in vegetal cover, it is a problem of considerable interest to workers in the field of sedimentation to attempt to particularize the nature of these climatic variations and their effects on the flow of streams.

Since the advent of heavy grazing on the semi-arid lands of western United States, an epicycle of erosion has begun. It is clear that overuse of these lands by stock has been a major factor in initiating this erosion. But in view of the geologic evidence that climatic variations in the postglacial but prehistoric period had similarly caused successive periods of erosion alternating with sedimentation, some geologists have argued that the modern erosion is a result of a slight shift of climate, and that grazing acted as a trigger-pull, timing a change about to take place.

In considering the question of the relative importance of overgrazing versus climatic change in causing the modern epicycle of erosion in the southwestern United States (hereafter called the Southwest), two of the key points at issue are: (1) Is there in the Southwest any evidence of important climatic variations in the past century which might have some bearing on the cause or timing of the epicycle of erosion? (2) In what direction must the climate change be in order to initiate erosion? That is, will a change toward a more arid regime initiate erosion or will it cause alluviation? The present study deals with these two points.

There is voluminous evidence of significant climatic variations in the past century in large areas over the world [as examples, see LYSGAARD, 1949; AHLMANN, 1948]. However, it has been recognized by THORNTHWAITE, SHARPE, and DOSCH [1942] and other authors that the annual values of precipitation and temperature for the Southwest do not show significant trends. On the basis of the lack of progressive variation, it has been argued by them that climatic change cannot be considered an important contributing factor in the present epicycle of erosion.

Climatic variations have been studied by use of data on a wide variety of phenomena. Not only have records of various meteorologic elements been analyzed, but indirect evidence of great value has been derived from archeology, dendrochronology, pollen analysis, and other fields. In the use of precipitation data for studies of climatic variation there has been a tendency to restrict analyses to the consideration of average values, primarily mean annual values. Mean annual values of precipitation are useful in reducing voluminous observations to a form simple enough for easy handling, but it should be remembered that annual values of precipitation may obscure short-period features in the rainfall pattern which in themselves might have great significance.

Climatic variations are made up of various combinations of wet and dry years. Wet and dry years must differ not only in total annual precipitation but also in the frequency of daily rains of various sizes, and changes in rainfall frequency may have as important effects on vegetation as changes in annual totals.

In the present study the longest precipitation records in New Mexico were analyzed to determine whether there is evidence of secular trends in the frequency of daily rains of different sizes. Wet years are compared with dry years with respect to rainfall frequency and frequencies are compared between stations of different average annual precipitation.

Trends in annual number of rains--The number of cases of rains of different magnitudes was tabulated from the records of daily rains published by the U. S. Weather Bureau in Climatological Data and Monthly Weather Review for years subsequent to 1895. For the period 1849-1895 the daily rainfall data are not published and were tabulated from the original records kept by the Surgeon General and Army Signal Corps; available in the Archives of the United States, Washington, D. C. For the first portion of the present analysis, the breakdown by sizes of rains consisted of three categories, 0.01-0.49 inch, 0.50-0.99 inch, and $\geq$1.00 inch in a day. Traces of rain were not considered. In cases of very old records the number of traces was used as an indication of whether or not the observer was actually reading the gage in months when the number of cases of measurable rain seemed unusually low. The observers of the Surgeon General's Office and of the Army Signal Corps were generally more assiduous in writing useful explanatory notes than were the observers of more recent years.

In New Mexico, the records shown in Table 1 were considered sufficiently long to be useful in investigating trends in frequencies.

Table 1--New Mexican records used in investigating trends

Station	Elevation	Mean annual rainfall	Location in State
	ft	in	
Santa Fe	7010	14.3	North central
Fort Union	6880	18.0	Northeastern
Albuquerque	5200	8.1	Central
Las Cruces (Agri. College)	3860	8.6	South central

Santa Fe records from 1849 to 1892 were taken at Fort Marcy, located on a low bench overlooking the city, close to the later gage location. The Albuquerque gage apparently has always been located on the plateau overlooking the river valley. For many years it was at the University about two miles from its present location but in a nearly identical topographic position.

The early portion of the record for Las Cruces Agricultural College is made up of data from Fort Seldon, 17 miles upstream and somewhat closer to the river, and Fort Filmore, four miles down the river and in topographic position similar to that of the College.

San Marcial appears in "Climatic Summary of the United States" as a long record but in fact is made up of a combination of Fort Conrad, Fort Craig, San Marcial, and Socorro. A study of the record led to the conclusion that it is too heterogeneous for the present purpose.

The number of cases per year for each of the three rainfall size classes as well as the annual rainfall totals are plotted as five-year moving averages in Figure 1. The lack of any trend in the annual totals is obvious, and is borne out by statistical comparison of the means of the first half versus the last half of the records.

On the other hand, the trend exhibited in the frequency of the small rains, 0.01-0.49 inch, is striking. The small rains generally increased in number from the beginning to the latter part of the record at all stations. For Albuquerque and Las Cruces, the upward trend continued at least until 1940, while Santa Fe shows a decrease from about 1933 to 1945.

The trends in rainfall frequency represent one aspect of climatic variation. In determining whether such trends in hydrologic data result from real physical changes in climatic factors, they might logically be judged by two criteria. First, the data showing the trend should, in successive time units, be mutually independent and be arranged in a non-random manner. If the individual observations partake of some natural cycle (for example, annual cycle) causing a repetitive variation of values, the observations should be grouped in time units such that the cyclic variation is eliminated.

The second criterion is that the trend should be of such magnitude that important physical effects on land or people are implied. In instances where these criteria are fulfilled, neither

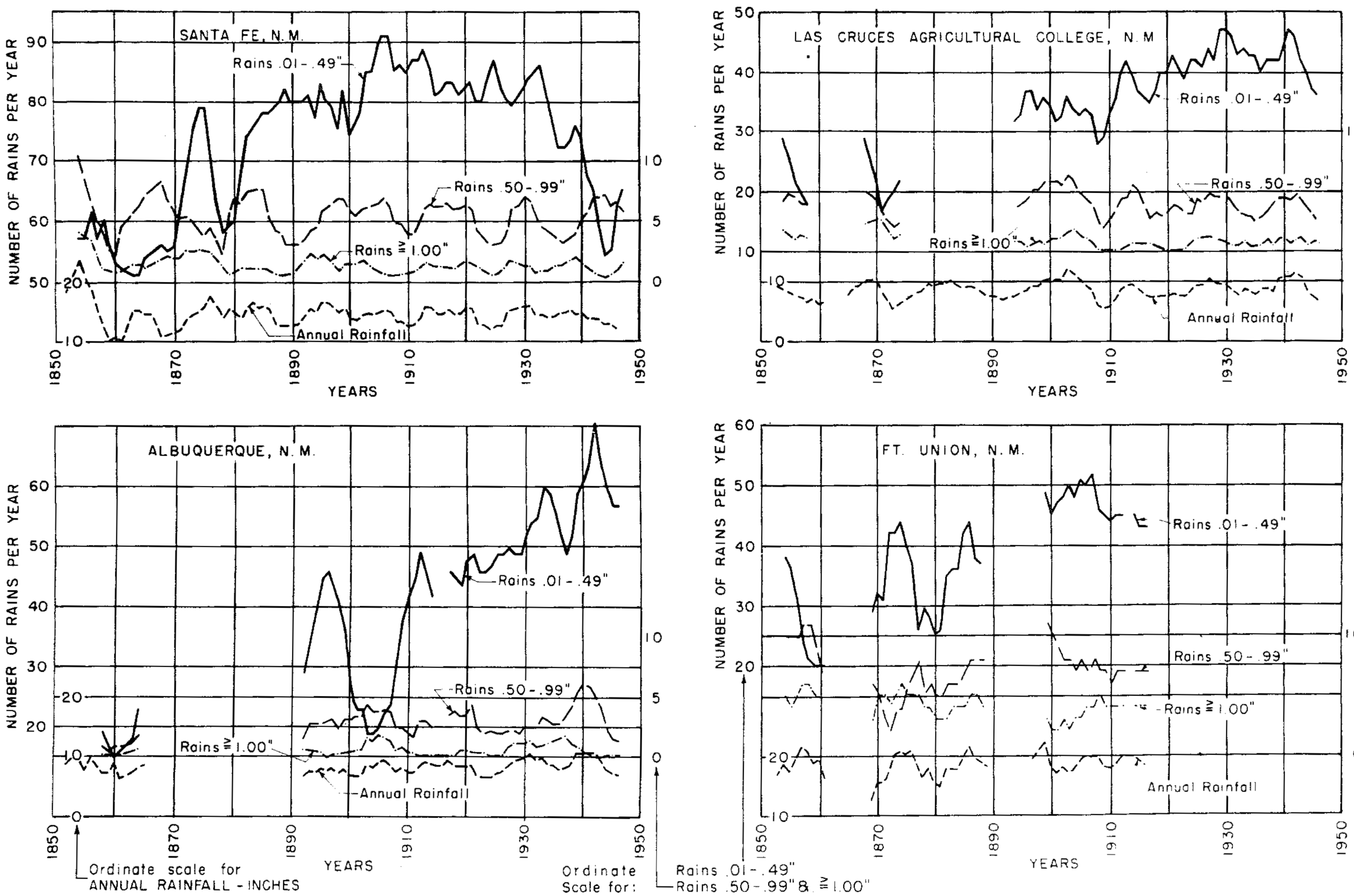

Fig. 1--Frequency of rains of various amounts in a day at four long-record stations in New Mexico, five-year moving averages (five-year moving averages of annual rainfall are presented for comparison)

permanent changes nor cyclic variations in climatic factors are necessarily implied. Such trends are generally not useful for prognostication, but the establishment of their reality is a step in understanding the types of variations to which climatic factors are subject.

With regard to the first criterion, it is of interest to examine the Santa Fe record between 1850 and 1939. This period of record was studied by THORNTHWAITE, SHARPE, and DOSCH [1942]. In view of the absence of progressive change in the annual rainfall totals, they concluded that "the more or less random interactions of air masses ... determine present climatic variations" in the Southwest. We will split the record into two parts, 1849-1895 and 1896-1939, approximately the division used by Thornthwaite. The average number per year of rains of 0.01-0.49 inch in the first part of the record was 66 and in the later part 81, with a standard deviation of 3.0. The difference between these means is statistically significant well beyond the one per cent level.

In the same periods, the average number of rains per year in excess of 1.00 inch was 1.7 and 1.1 respectively, with a standard deviation of 0.3. The difference is significant at the five per cent level.

The number of rains of intermediate size, 0.50-0.99 inch, was not significantly different between the two periods.

For another test of the trend, a simple form of sequential analysis can be applied. An upward trend in the sequence of values will provide a tendency for long runs of numbers less than the median followed by long runs greater than the median [HOEL, 1947, p. 177]. Thus, a pronounced trend will be characterized by long runs, whereas a weak trend will have a large number of short runs.

Consider the Santa Fe record for which nearly complete data are available from 1853-1949. The median number of rains per year in the category 0.01-0.49 inch is 76. In this period the sequence is broken by missing years in 1862, 1866, 1867, 1882, and 1883. Assuming the magnitudes of frequencies for the missing years in the most adverse manner, that is, to provide the maximum number of runs, there would be 38 runs. The probability is 0.01 that such a small number of runs would occur in a random sample.

The frequency of rains of 0.01-0.49 inch at Albuquerque (1889-1948) was subjected to a similar test of the number of runs. The missing years, 1891, 1915, and 1916 are similarly interpolated in the most adverse manner. The probability is 0.05 that such a small number of runs would occur in a random sample. In the Las Cruces record (1886-1948), the probability is more than 0.05 and therefore the number of runs could occur in a random sample. The Fort Union record is too broken to provide a satisfactory test.

Because the annual rainfall totals do not show the trend apparent in rainfall frequencies, there is implied a compensation by which the increase in number of small rains is balanced by a concurrent decrease in number of large rains, a fact already demonstrated in the statistical test of the mean frequencies for Santa Fe.

It appears, therefore, that the rainfall-frequency data for the few available long records in New Mexico show trends which are real and are not merely the result of random variations. Thus the first criterion mentioned earlier is fulfilled.

Trends in seasonal rainfall frequencies--Figure 2 shows the march of number of small rains (0.01-0.49 inch) at Santa Fe, New Mexico, broken down into its summer and non-summer components. Both seasons show the trend in rainfall frequency though it is somewhat more pronounced in the non-summer data. The summer rainfall is derived primarily from moisture brought in at high levels from the Gulf of Mexico under the influence of the anticyclonic circulation of the upper-air counterpart of the Bermuda anticyclone. Winter rain is primarily caused by the passage of fronts or upper troughs precipitating moisture derived from Pacific sources. The specific weather features of the lowest troposphere are quite different in the two seasons, yet both seasons partake of a similar trend.

Within this overall similarity in trend, the rainfall frequencies of the two seasons may be in or out of phase for periods of a few years. Note that the summer rainfall frequency was high and winter frequency low in the period 1853-1863 and vice versa in 1864-1871. A similar out-of-phase relation exists in the period 1895-1905. In-phase relation is apparent in 1870-1880 and approximately so in 1937-1947.

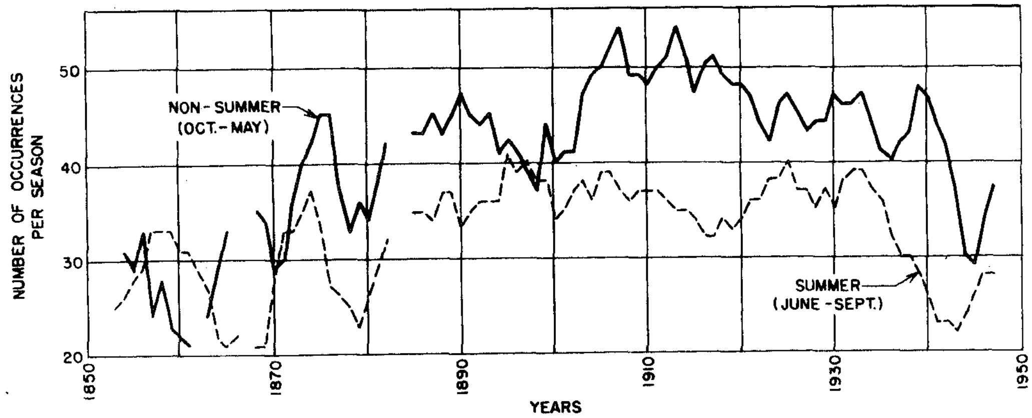

Fig. 2--Seasonal frequency of rainfalls of 0.01-0.49 inch in a day, five-year moving averages, Santa Fe, New Mexico

It is suggested, therefore, that the short-period variations tend to be random and are different in nature from the longer period secular trends which are probably governed by the large features of the general circulation. The secular trends are doubtless related to the same factors which have caused the climatic variations now well authenticated for many areas in the northern hemisphere.

Rainfall frequency in relation to erosion history--It is logical to assume that rainfall frequency has a substantial effect on the erosion process. Small rains, that is, rains of small amount in a day, do not contribute greatly to erosion because they generally produce only small surface discharges, if any. The smallest rains tend only to wet the soil and thus are utilized by plants or evaporated from the soil surface. Large rains tend to penetrate to a deeper layer of soil and thus contribute also to plant growth, but a much larger percentage of the water from a large rain runs off. Erosion, both sheet and gully, is caused primarily by the large rains.

The seasonal occurrence of rains of various magnitude provides some indication of the effects of frequency on plant growth. Table 2 shows that the four summer months contain more than half of the cases of rains of all sizes, and an even larger share of the heavy rains. Note that the mean intensity of the small sizes of rains is greater in summer than winter.

Thus, a decrease of the small rains of summer which provide the main moisture for grasses, particularly annual grasses, would weaken that portion of the protective vegetation. Both shrubs and perennial grasses depend greatly on late winter moisture infiltrating deeply in the soil. A decrease in small rains in winter would also adversely affect the vegetal cover.

In summary, it seems clear that during the early portion of the past hundred years, New Mexico experienced a relatively low frequency of small rains both in summer and winter. At least in some areas, the early period of record shows a relatively high frequency of large rains. Such a circumstance must have been conducive to a weak vegetal cover and relatively great incidence of erosion. That the modern epicycle of erosion began in the Southwest about 1885 is well established

Table 2--Frequency of rains of various sizes and their contribution to the annual total, Las Cruces, New Mexico, 1892-1939

Rainfall size classes	Summer, June-Sep.		Non-summer, Oct.-May	
	Number per year	Per cent of total annual rain	Number per year	Per cent of total annual rain
in				
0.01-0.09	10.4	6	10.0	4
0.10-0.49	9.3	29	8.2	16
0.50-0.99	2.6	23	1.4	8
$\geq$ 1.00	0.5	12	0.2	2
All sizes	22.8	70	19.8	30

[BRYAN, 1925, 1928]. We see, then, that not only was grazing tending to promote erosion at that time, but meteorologic conditions were more conducive to erosion than during the period of the present generation. Thus there is established concrete evidence of a climatic factor operating at the time of initiation of southwestern erosion which no doubt helped to promote the initiation of that erosion.

The association of arid climate with erosion--The second question to be discussed is the direction in which a climate must change in order to initiate a period of degradation of alluvial valleys. The field evidence strongly favors the association of aridity with periods of erosion. Sand dunes have been found associated with stratigraphic evidence of degradation in many localities which have been studied. These associations have not been confined to a single area but, on the contrary, have been found from the Hopi Country of Arizona to the western border of the High Plains of Texas, and north as far as Wyoming.

The occurrence of caliche is typical in the upper strata of alluvial formations which were eroded subsequent to or during the accumulation of the caliche. The occurrence of strong calcification in the B horizon of a fossil soil is interpreted as direct evidence of a relatively arid climate [BRYAN, 1948]. It is possible, of course, that the period of formation of the caliche in the fossil soil was neither contemporaneous with nor associated with the subsequent erosion of the formation, but in the typical case there is no evidence to dispute the association of the erosion of the alluvium with the semi-arid climate which produced its caliche subsoil.

Tremendous herbivorous animals such as the mammoth could hardly have lived in any area where the vegetation was sparse. Since these animals became extinct during a period of great erosion at the end of Deposition 1 of the Southwestern Alluvial Chronology [BRYAN and McCANN, 1943], we have further inference that aridity was associated with erosion.

It is the purpose of this section to investigate the nature of wet and dry years with respect to rainfall frequency and to draw from the results, inferences regarding the effects of relative wetness on the erosion process.

Frequency characteristics of stations of different annual precipitation--Las Cruces and Santa Fe, New Mexico, were chosen to represent in a rough way a low-elevation dry area in New Mexico and a higher relatively moist one. Santa Fe has a mean annual precipitation more than 1.5 times that of Las Cruces. It is desirable to determine what sizes of daily rainfalls provide Santa Fe with a higher annual mean than that of Las Cruces.

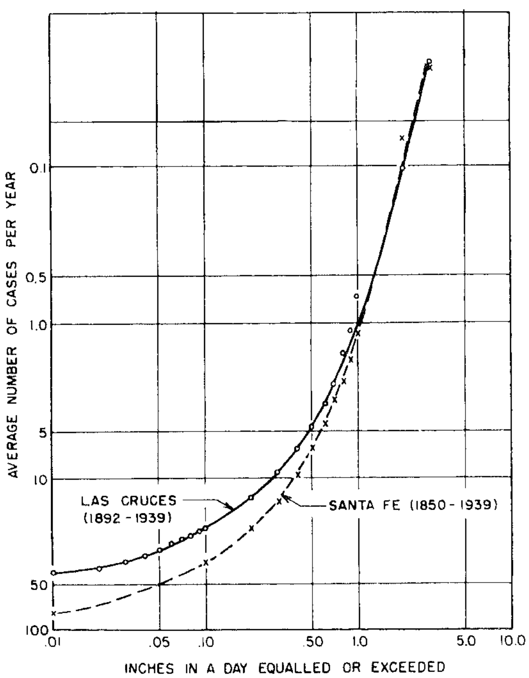

Fig. 3--Cumulative frequency curve of daily rains of various sizes, Las Cruces and Santa Fe, New Mexico

The numbers of days having various rainfall amounts were counted or tallied at the two stations. The class intervals were 0.01 inch between 0.01 and 0.09, 0.1 inch between 0.10 and 0.99 inch, and one inch for rains equal to one inch or more. The number of cases in each class interval was divided by the number of years of record to obtain the average annual frequency of rains of a given size. In Figure 3, accumulated frequency of rains is plotted against size classes of daily amount of rainfall.

Several important relations are apparent from this graph. Las Cruces gets only 60 per cent of the mean annual rainfall of Santa Fe, yet the frequency with which the two stations receive large rains (greater than one inch in a day) is about the same. The difference in the total annual rainfall is made up by the larger number of small rains experienced by Santa Fe.

In New Mexico the mean annual rainfall of a given station is higher than that of another station because of a larger number of rains, and more especially of small rains. A corollary to this fact is that at a given station, a large percentage of its total annual fall is contributed by the small rains, as will now be demonstrated.

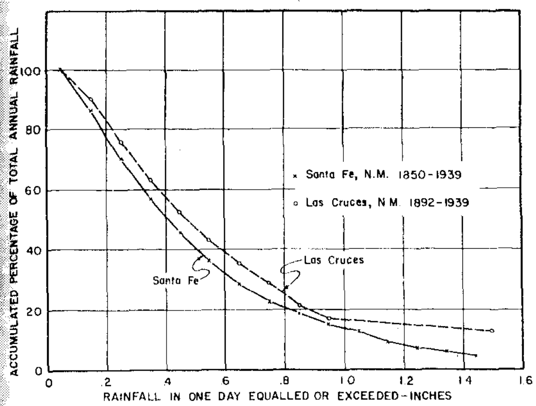

Fig. 4--Contribution of daily rainfalls of various sizes to annual total rainfall

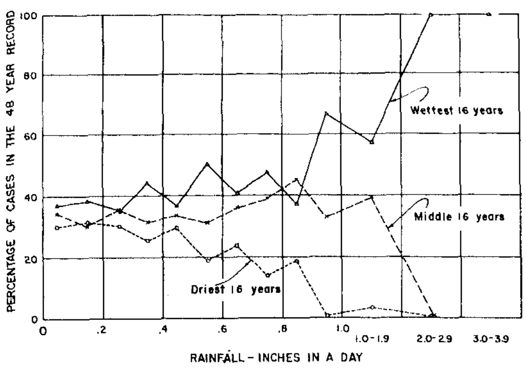

Fig. 5--Percentage of cases of daily rains of various sizes contributed by the driest, wettest, and near-normal years, Las Cruces, New Mexico, 1892-1939

Using the data in the frequency histograms of daily rainfall at the two stations, the mean value of each class interval of rainfall was multiplied by the respective number of cases. The resulting numbers provide an approximation of the total contribution of the daily rains of various sizes. Dividing the total for each size class by the total rainfall for the station and then accumulating, we obtain the accumulated percentage contribution of each size class to the total. These percentages are plotted against the daily rainfall size classes in Figure 4 which shows that because the number of cases increases exponentially with decreasing values of daily rainfall, the smaller rains contribute a large percentage of the total annual fall.

Rains smaller than 0.42 inch in a day contribute 50 pct of the annual total at Santa Fe. Rains smaller than 0.48 inch contribute 50 pct of the Las Cruces total. Note that rains in excess of 1.5 inches in a day make up 13 pct of the Las Cruces annual total, but only five per cent of the Santa Fe annual rainfall.

Frequency of daily rainfall amounts in wet and dry years--Now that we have some idea of the frequency relationships at stations of different annual precipitation, let us determine how wet years and dry years at a given station contribute to the mean annual precipitation. For this purpose the 48 yearly rainfall totals for Las Cruces in the period 1892-1939 were arranged in order of magnitude. The array was then divided into three equal groups or tritiles. Thus the frequency of each size class of daily rainfall for the wettest tritile can be compared with that of the middle and driest tritiles. The number of occurrences in each size class were counted for each of the tritiles separately.

For a given size class, the frequency in percentage of the total number of cases in the 48-year record was computed for each third part and plotted in Figure 5. The figure shows that the dry years contain (1) the smallest total number of rainfall days, (2) none of the days of highest daily rainfalls, and (3) a progressively decreasing share of cases as one goes from low to high rainfall categories.

The middle tritile contained nearly the same percentage of the total cases in all size classes except that it contained none of the daily rains greater than two inches. All the latter were included in the wet or upper tritile.

In the case of the Las Cruces record, the average annual rainfall for the 16 wettest years (upper third) was 11.6 inches, for the middle third 8.4 inches, and for the driest third 5.6 inches, so the wettest third of the years had a mean annual rainfall about twice that of the driest third.

Now it is obvious that the concentration of the heavy rains in the wet third increased the annual totals of the respective years in which they occurred, and therefore helped determine which years would fall in the upper or wet third. The extent to which the heavy rains contributed to the total rainfall of each third is summarized in Table 3.

Table 3--Contribution of rains less than and greater than one inch in a day, to the total annual rainfall, Las Cruces, New Mexico, 1892-1939

Tritile	Annual rainfall		Percentage of annual rainfall	
	In rains larger than one inch	In rains smaller than one inch	In rains larger than one inch	In rains smaller than one inch
	in	in		
Driest	0.1	5.5	2	98
Middle	0.9	7.5	11	89
Wettest	2.2	9.4	19	81

The tabulation shows that although wet years are characterized by increased contributions from rains of all sizes the make-up is markedly different. The percentage contribution of heavy rains to the annual total is decidedly greater in wet years than in dry.

Meteorologically this relation means that a greater frequency of weather conditions from which rain is liable to fall differentiates wet years from dry ones. As a result of increased frequency of such synoptic conditions, all sizes of rainfalls are increased in number.

Seasonal rainfall--We shall now examine the number of occurrences of rains of different sizes by season, again using Las Cruces as an example. Table 4 shows the average number of cases of various sizes of daily rains per season, summer (June-September) separated from non-summer (October-May), and keeping the division by thirds based on annual totals. It is immediately apparent that all the cases of rains greater than two inches in a day occurred in the summers of wet years. The summers of wet years constitute a total of 64 months of record. These experienced more rains greater than one inch, a total of 25, than the remaining 512 months of the record which experienced 15.

Table 4--Number of cases per season of daily rains of various sizes, Las Cruces, New Mexico, 1892-1939, subdivided by tritiles of annual rain, and by season

Rainfall size classes	Summer, June-Sep.			Non-summer, Oct.-May		
	Dry	Middle	Wet	Dry	Middle	Wet
in						
<0.09	8.4	11.9	12.0	9.8	9.9	10.1
0.10-0.49	8.7	10.9	10.5	7.0	8.2	9.4
0.50-0.99	1.3	2.9	3.6	0.7	1.4	2.1
1.0 -1.9	0.6	0.38	0.81	0	0.31	0.19
2.0 -2.9	0	0	0.25	0	0	0
3.0 -3.9	0	0	0.06	0	0	0

Relation of rain frequency to annual rainfall--The effect of doubling the annual rainfall will now be investigated. The annual totals for the 48 years of record (1892-1939) at Las Cruces were again arranged in order of magnitude and divided into 12 parts, each containing four years. No division into seasons was made. For each of the four-year periods, the average numbers of cases of daily rains were plotted against the respective size categories. The sum of the products of number of cases times the weighted average of the respective sizes should equal the annual rainfall total for the given part. The curves drawn through the points were adjusted until this equality existed. From the family of curves so constructed, the data for Figure 6 were compiled, in which the relation of annual rainfall to the frequency of rains of various sizes is shown. In the family of curves of Figure 6, any abscissa value is equal to the sum of the products of number of cases times weighted mean rainfall in the various size classes.

It is now possible to compute the effect of a doubling of the annual rainfall. Since the mean annual rainfall at Las Cruces is 8.5 inches, let us note the effect of a hypothetical change of annual rainfall from a value of six inches to a value of 12 inches.

Inspection of Figure 6 indicates that for a fixed relation between the frequencies of different class intervals of rainfall, a doubled annual rain would be composed of less than twice the number

Table 5--Average frequency per year of rains of various sizes in four segments of the record, 1850-1948

Station	Period	Size classes of daily rains, inches			Mean annual rain for period
		0.01-0.49	0.50-0.99	>1.00	in
Santa Fe	1850-1880	59.7	5.7	1.96	14.6
	1881-1910	80.8	5.5	1.07	14.4
	1911-1930	82.8	5.3	1.20	14.3
	1931-1948	71.5	5.1	1.05	12.9
Las Cruces	1850-1880[a]	23.8	3.8	1.65	7.9
	1881-1910[a]	31.7	4.7	1.17	8.8
	1911-1930	41.1	3.9	0.50	8.4
	1931-1948	42.0	3.3	0.67	8.6
Albuquerque	1859-1880[a]	21.2	1.3	0.40	8.0
	1881-1910[a]	30.5	2.9	0.71	7.7
	1911-1930	47.0	2.6	0.56	8.5
	1931-1948	58.3	3.4	0.67	9.0

[a]Record broken, as explained in connection with Figure 1.

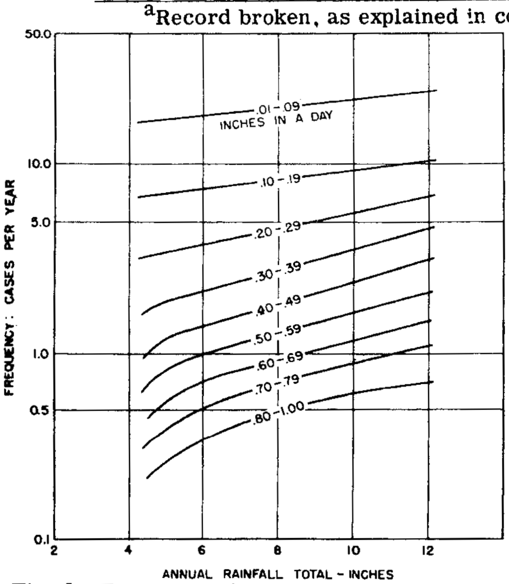

Fig. 6--Frequency of various sizes of rains in relation to annual rainfall total, Las Cruces, New Mexico, 1892-1939

of small rains and more than twice the number of moderate rains. The number of rains in the highest category studied, 0.80-1.00 inch, was exactly doubled. This can also be seen in the varying slope of the family of curves. The data are insufficient, however, to establish definitely whether these characteristics are significant.

On the other hand, the trend in rainfall frequencies shown in the graphs of Figure 1 indicates that during the period of record, the relation between frequencies changed. The records for the period 1850-1948 for Santa Fe, Las Cruces, and Albuquerque were arbitrarily divided into four periods broken at 1880, 1910, and 1930. The average numbers of rains in the size categories by periods are shown in Table 5.

It can be seen that in this sequence of years the relation between numbers of different sizes of rainfall shifted. The important thing to note is that in the later parts of the hundred-year record the frequency distribution at Las Cruces became more like that of Santa Fe even without a change in the annual totals. For example, if the frequencies at Las Cruces in the period 1931-1948 (42.0, 3.3, 0.67) are multiplied by the ratio of the annual rain at Santa Fe to Las Cruces for the period (12.9/8.6 = 1.50), they become 63.0, 5.0, 1.00, approximating the figures for Santa Fe for the same period. In the period 1850-1880, however, a similar adjustment (14.6/7.9 = 1.13) makes the frequencies 26.9, 4.3, 1.87, much lower than for Santa Fe in the low rainfall category but nearly equal in the high category.

It can be concluded, therefore, that during periods when there is no differential trend in rainfall frequencies, an increase in annual rainfall implies a disproportionate increase in frequency of rains of moderate size, 0.40-0.70 inch in a day, relative to the increase in frequency of the lightest and heaviest rains. It can be presumed that the largest rains are those most effective in erosion. What size of rains are most effective in promoting vegetation is not known in detail. To the extent that the rains of moderate size are the most important for promoting vegetatinn, Las Cruces data indicate that an increase in annual rainfall at the station tends to promote vegetation more than erosion.

On the other hand, in view of the fact that, during the period of record of the stations studied, the changes in annual rainfall totals have had no trend while the relation of frequencies of different sizes of rains has changed markedly, it seems logical to assume that the latter effect is more important in the erosion process than are the secular changes in annual rainfall totals.

Discussion of the results--It has been shown that secular variations in the frequency of rainfall occur in the precipitation records at the few long-record stations in New Mexico. Statistical analysis shows that these variations are not due to chance. The fact that all the available long records show similar trends indicates that the trends are probably regional in their geographical effect and points to shifts in the general circulation as the probable cause.

The rainfall record provides no indication of the magnitude or even the nature of changes in the general circulation required to produce the observed trends in rainfall frequency, but the analysis of the few stations reported here shows that trends in frequency affected both winter and summer precipitation. It is possible that a slight shift in the average position of zones of convergence related to high-level pressure troughs might influence the average amount of precipitation falling during each potentially rain-producing synoptic situation. In this manner the frequency of each size-class of rainfall might be altered.

The importance of the observed trends in rainfall frequency lies less in an improved understanding of the relation of the general circulation to climatic variation than in the introduction of another manner in which climatic variations affect the physiographic forces operating on the Earth's surface. It has long been known that records of many rivers in the United States show breaks or inconsistencies in the relation of total precipitation to total runoff. In many cases these breaks are due to local factors such as change in exposure of the rain gage. When the breaks in the rainfall-runoff relations are not random or due to local causes, it is possible that they result from changes in the frequency of rains of various sizes.

Many rivers in the semi-arid portion of western United States exhibit a series of terraces developed during alternating periods of aggradation and degradation in the post-glacial period. Changes in the rainfall-runoff relations, as the cause of variations in runoff regimen, would in many respects provide a more logical explanation of the observed river terraces than a hypothesis based only on changes in average annual precipitation.

Total sediment movement past a given point on a river is generally correlated with total stream runoff. General observations of many western rivers indicate that periods of flood or of relatively high water discharge are periods during which sediment previously deposited in the valleys of trunk streams tends to be scoured out and moved downstream. Periods of high discharge, in other words, tend toward degradation of the river channel. Accumulation or aggradation of the river bed seems to take place during periods of low flow.

Low and high flows both occur during any period of years, and the net tendency of a river bed to aggrade or degrade must depend on the relative number of flows of different sizes. Thus it seems that the change of river action from alluviation to degradation is less a function of annual precipitation than of the frequencies of various sizes of rains which presumably are closely correlated with the frequency of various sizes of flow in streams.

These relations delineate what is possibly an important way in which climatic variations operate to produce physiographic changes in rivers, particularly in semi-arid areas.

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