#132

Journal of Hydrology 15 (1972) 285–300 © *North-Holland Publishing Company*

Not to be reproduced by photoprint or microfilm without written permission from the publisher

Purchased by the U. S.
Department of Agriculture
for official use

AVAILABLE SOIL WATER: TIME-DISTRIBUTION IN A WARM SEASON RANGELAND

H. A. SCHREIBER and N. G. SUTTER*

Southwest Watershed Research Center, Southwest Branch
Soil and Water Conservation Research Division, Tucson, Ariz.

Abstract: Daily total rainfall depths served as input to a computer program that estimated infiltration and subsequent evaporation. Printed output stated when a predefined start of the growing season occurred at Tombstone, Ariz., using official precipitation records from 1897 to 1970. The output listed moisture sequences by assigning a wet or dry status to the soil.

The start of the growing season for perennial range grasses, defined as the presence of four consecutive days of wet soil, has occurred from June 8 to as late as early September, with a median start at July 14. The total number of wet days averaged 38 during the 4-month period of June to September. Every year had at least one period of drought within the growing season; drought periods occurred an average of 6 times and could exceed 12. The average maximum dry period was 18 days; the corresponding wet period was 21 days. The starting wet period averaged 13 days and the ensuing dry period was 5 days. The maximum wet period tended to occur earlier in the season than the dry.

Introduction

Range plant communities and their forage production in arid and semiarid regions are usually determined and characterized in part by the average amount of total season or annual rainfall. It is commonly thought that below-average rainfall automatically reduces forage yields without regard to when rainfall is received.

It is probable that the importance of timing of water availability will be realized as increasingly quantitative knowledge becomes available about other factors of range plant growth. Such information will be used to predict current season production and future conditions of plant growth and vigor. Timing of water availability has been shown to be helpful in optimizing agronomic crop production.

The work presented in this paper was done to develop a model that would explain the presence of water, especially its temporal soil distribution. Such

* Current address of the latter is: Lease Management Systems, 4749 E. Andrew, Tucson, Ariz. This work was done in cooperation with the Arizona Agricultural Experiment Station, Tucson, Ariz.

a model may also aid in assessing the importance of timing of soil water in determining yield of non-cultivated range plants. It must be emphasized that the input data are representative of about one square mile around the city of Tombstone for the record period. The rainfall input data should be representative of small areas of similar elevation within the geographical province; however, points over a large domain of land surface must be considered individually. Osborn and Renard (1970) stated that no key gage (or unit area) can predict a large area's summer rainfall distribution and disposition. This is because of the spatial variability of the air-mass thunderstorms characteristic of the study area. Models to better represent large area rainfall input are being developed by Osborn and Renard on the 58-mile^2 experimental watershed surrounding Tombstone.

Osborn (1968), working with 15 years of record on Walnut Gulch found that at least two random points on a one-mile^2 grid within the 58-mile^2 watershed received 0.25 inch or more from rain on 3 out of 4 days during July–August in a high rainfall year, 1955. In the same period of a low rainfall year, 1960, the frequency dropped to 1 out of 4 days. July–August averages over the entire watershed for 1955 and 1960 were, for 28 and 50 gages respectively, 11.42 and 2.73 inches.

Description of the area

The daily rainfall records of Tombstone, Ariz. date continuously from 1897, at least for summer rainfall as defined below. These records were copied from the collection of Arizona weather records held by the Institute of Atmospheric Physics, University of Ariz., Tucson. Tombstone is in the center of the Walnut Gulch Experimental Watershed, from which various modern hydrologic data have been collected since 1955. Crossing the watershed is a line separating a desert shrub community (chiefly *Larrea divaricata, Acacia vernicosa, Flourencia cernua*) from a short grass community (*Bouteloua gracilis, B. eriopoda, Hilaria mutica* and *H. belangerii*). The shrub community elevation ranges from 4000′ to 4600′ and most of the grass community extends to 5000′. Soils of the shrub community are thermic, close to skeletal with A–C horizons, while grass-community soils are usually mesic and have an argillic horizon.

The entire area was covered with grass when silver ore was discovered in 1878 in the hills adjacent to Tombstone. A series of ecologically significant incidents – intense cattle grazing, grass mowing for hay, perhaps less frequent wildfires, an alleged drought in the 1890's – conspired 50 to 90 years ago to permit the change to shrub vegetation in the lower elevations of the watershed.

Walnut Gulch has many elements characteristic of the Sonoran Border Region which extends from beyond the Colorado River on the west, to the Mogollon Rim on the north, to almost the Rio Grande River in the east and includes part of the region in and contiguous to the Chihuahuan and Sonoran Deserts in Mexico.

Climate in the Arizona portion of this region is discussed by Green and Sellers (1964). The conditions they describe as causing summer rains are, perhaps, as dependable as those of any other western region, with the result that a severe lack of summer rain usually does not persist into sequential years. The variation in other-than-summer precipitation is 2 to 4 times greater than the variation in summer rainfall.

Computer model

A model translating rainfall into infiltration was made in the form of a computer program. The infiltrated water was allocated through evaporation to predict wet and dry periods according to one of two assumptions about plant growth. One is that if a plant is placed under a stress for water even in part of a given day, physiologic interruptions and adjustments result. If this day occurs in the midst of a given process or processes, there are reactions in the plant that would not have occurred if stress had not been applied. The alternate assumption is that any water present, even a fraction of the daily requirements, makes that day wet; native range plants, even when growing and elaborated as cultivated plants, have inherent facilities for making full use of any water and throwing off drought effects for at least the rest of a day. These different hypotheses give two very different pictures of soil-water distribution in time.

These two assumptions require two different options of the model, the "fully" wet option for the first, and the "partially" wet option for the second. The options differ in the definition of a wet day. The first option defines a day as being wet only if the soil storage reservoir has enough water to supply the entire day. If the reservoir cannot meet this requirement, the entire day is called dry in the first option. The rationale for this is that runoff and the storms generating runoff occur at Walnut Gulch late in the day (Diskin, 1970); hence, these storms do not provide water for that day's evaporation requirements. If the model's bookkeeping shows that the assumed constant ET requirement during a day can be only partly satisfied, that day will be termed wet only in the partially wet option. This admittedly implies abrupt "on-off" water relationships between soil and plant, but provides a convenient accounting of a very complex process.

The model essentially determines sequences of wet and dry days, given

daily rainfall information for one or more years. Since the most obvious plant growth beneficial to the cattle industry occurs during June through September, these months are defined as the growing season. Information for all other months is ignored.

It was necessary to determine when in these four months a growing season commenced as a function of the presence of water. A light rain, providing soil water for one or two days, does not break plant dormancy. A week with available soil water promotes growth to a point that irreversible changes in tissue differentiation have occurred which succeeding drought can damage. A 4-day period of available water was selected as a compromise to define a start.

Three other generalizing assumptions are made by the program. First, an equation for infiltration as a function of rainfall was needed. The following equation was derived by observations of runoff from experimental 6 × 12 ft plots, Schreiber and Kincaid (1967).

$$\text{Infil} = \text{Minimum} \begin{cases} \text{Rain} \\ \text{or} \\ 0.152 + 0.44 \times \text{Rain} \end{cases} \tag{1}$$

where Infil is the amount of infiltration, and Rain is the amount of precipitation. The lower minimum term is the assumed infiltration for depths of rain exceeding 0.275 inch. Thus, all precipitation is assumed to infiltrate up to 0.275 inch while some is allowed to run off above that amount. Hopefully, the above equation gives an unbiased characterization of input to storage for all types of warm season storms. Implicit in the relationship is the understanding that a daily total depth of rain results from a single storm. This assumption of a single storm per day was tested in a cursory fashion with modern data from Walnut Gulch recording rain gages. Records of three gages, were examined for 1955, 1961, and 1966. Number of days with rain ranged from 25 to 39 for these gage-years, averaging 30+ days. From 0 to 7 days per year per gage (av. = 2.55) had double events, the total of which were high enough to cause probable underestimation of infiltration amounting to a part of a day's increase in storage. This cause of inaccuracy is probably less than the imprecision inherent in the basic infiltration equation.

The second assumption concerned the maximum available water retention for the root-containing soil layer. A value of 1.5 inches was used. Thus all infiltration exceeding 1.5 inches is discarded. This assumption is predicated on the existence of a uniform, gravelly sandy loam, able to hold one inch of water per ft and containing roots to an 18-inch depth. Perennial grasses have been observed to leave available water beyond that depth at season's end. Results using the program indicate that penetration beyond 18 inches

would have occurred in 14 of the 73 years, but only once in any specific year.

In the third assumption, the evapotranspiration equation used was

$$\text{Use} = -0.0005 \times \text{Day} + 0.172 \tag{2}$$

where Day is the number of the day in the season beginning with June 1 as day 1, and Use is the number of inches of water use per day by the

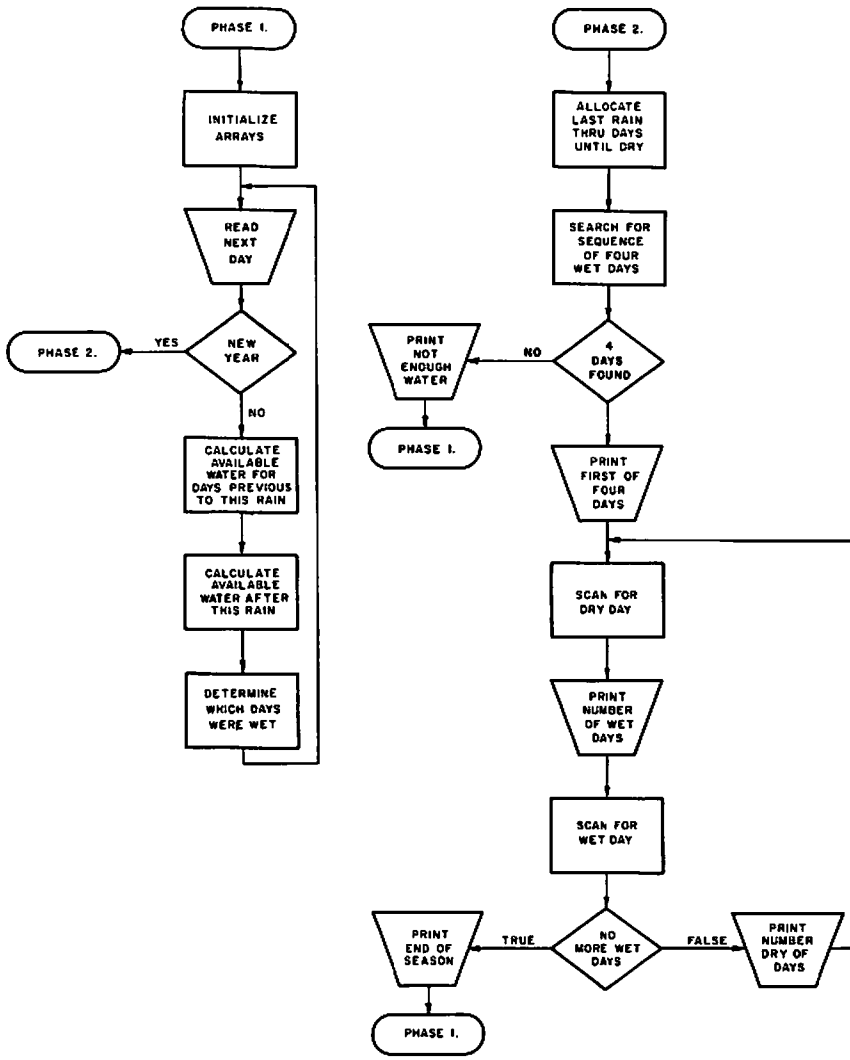

Fig. 1. Logic flow of program spells.

vegetation. This equation was derived from the Blaney-Criddle relationship as given in Chow (1964). Two periods of soil water measurement on a range site in the watershed showed 0.15 inch daily water use in July. From this a seasonal consumptive use coefficient, K, of 0.58 inch was derived and mean monthly points were calculated through September. A daily linear relationship was derived from the monthly points for the computer program.

The logic flow of the computer program is shown in Fig. 1. The program is written to allow modification of any of the assumptions.

The program output by either option is a year by year accounting of the sequences of wet and dry days, as the state of day is defined earlier. In addition the program lists the amount of available water for each day.

Results

Figure 2 shows (A) the cumulative frequency of years with start of season on or before a given date (the ascending curve), (B) the conventional or unconditional probability of wet soil through the season based on the 73-

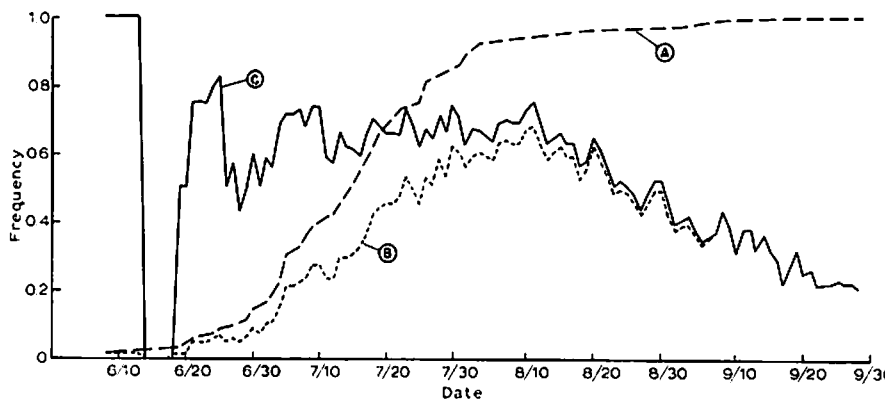

Fig. 2. Summation curve of seasonal starts (A) and probability of wetness on 73 year record basis (B) or the conditional probability of wet soil, given that by the fully wet option the season has started (C).

year record, and (C) the conditional probability of wet soil through the season – given that the season had started. Mathematically, curve (C) is the total number of wet days per day of the season, divided by the number of years when the season had begun on or before that day. The median day for starting available water was July 14.

Curve C in Fig. 2 shows that from July 4 or 5 to about August 10 there is essentially no difference in the frequency of available water. Before June 25 the small number of starts (6) might not reflect a valid picture of early conditions. Or, the latter suggests that for the period of record the chances of drought are good following extremely early starts.

Beginning about August 10 and continuing to September 20, a transition is reflected in curves B and C by a decreasing probability during which the summer air-mass storms stop, perhaps to be replaced by the frontal-convective storms characteristic in the autumn.

With 20% of the record years having started by the 35th day, the frequency line (C) shows that from July 5 to about August 10 chances of having available water are approximately 2 out of 3. In late August the chances are 1 out of 2, and by late September the chances have dropped to 1 out of 5.

Figure 3 in part shows the model's observed total number of fully wet days per year for the years of record. These points are shown as ●'s. There is a slight shift during 1936 to 1942 wherein the dry years are drier than

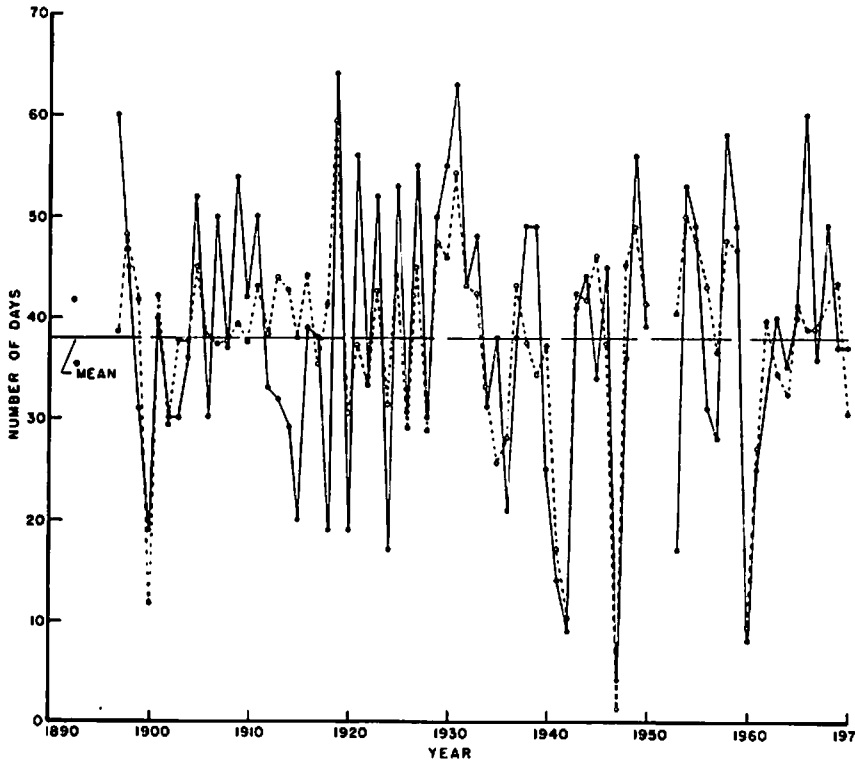

Fig. 3. Total number of wet days (●) and predicted total number of wet days (○).

before 1940, and exceptionally wet and dry years occur less frequently. Compared to pre-1940, the av. total wet days has not changed significantly, however. The mean and standard deviation of pre-1941 wet day sums are 39.28 and 12.55, respectively. The corresponding figures for 1941 and on are 36.0 and 14.72. Taking 25 wet days as a floor, two consecutive dry years have occurred only in 1941–1942 and 1960–1961. Assuming 50 wet days as an exceptional year, there have been long periods when such wet years do not occur – 1898–1904, 1912–1919, 1932–1948, and 1959–1965.

Simple correlations suggested that the seasonal starting day and the lengths of the first wet and dry periods might be used to predict the total number of wet days. These early-occurring parameters would enable prediction of the future season. For this purpose Eq. (3) was obtained:

$$\Psi = 58.8 - 0.503X_1 + 0.409X_2 - 0.424X_3 \pm SE \qquad (3)$$

where Ψ = total number of wet days
X_1 = starting day of the season (days from May 31)
X_2 = length of the first wet period (days)
X_3 = length of the first dry period following X_2 (days)
SE = standard error (9.6 days).

Both starting day and first wet period length were highly significantly contributory factors with about 50% of the variance in total wet days explainable. First dry period length barely entered the equation at the 0.05 level, increasing the explainable variance to only 53%. Parenthetically, other parameters, listed in the correlations section later, increased the explainable variance significantly. However, such information is after the fact and would not help in forecasting the future.

The number of total wet days predicted from Eq. (3) were entered in Fig. 3 as ○'s. A visual comparison of these points with those actually calculated by the computer model discloses that there is a disappointing centralizing tendency or a uniform scattering from the mean of the predicted numbers, at least for years prior to the 1930's. The extent of the peaks in all years with more than 50 wet days is always missed, and prior to 1930, extremely dry years were missed. The miscalled years were 1962, 1956, 1953, and 5 of the years 1913–1918.

In another method using Eq. (3) to describe predicted and observed rainfall, directions of departure of predicted wet days from the mean were examined and placed in a contingency table (Table 1). Good years were defined as having 38 or more wet days per season, and bad years as those having less than 38 wet days. Two-thirds [(27+22)/73], of the record years behaved as predicted by this reasoning. A year with 38 wet days or more would be a

TABLE 1

Observed vs. Predicted total wet years, Good ≥ 38 days, Bad < 38 days

Predicted	Observed		
	Good	Bad	Total
Good	27	16	43
Bad	8	22	30
Total	35	38	73

good year, when some normal number of stock would have adequate grass. Twenty-seven of 35 such years were properly called. Similarly, 22 of 38 bad years were also properly called. In such years, forage will be reduced and grazing should be eliminated. The other 8 observed good years, improperly called bad, perhaps would not be wasted. The unanticipated gain in forage could be used after the growing season or the land completely deferred for that year, minimizing wasted capital. Of course, the 16 "good" years that turned bad would be financially disappointing. If forage production really correlates with total seasonal wet days in a "success-failure" sense, as indicated by the foregoing use of Eq. (3), its use would indicate 4 correct choices in 5 decisions.

The discussion developed in the following paragraphs is based on the data shown in Table 2, a listing of averages and standard deviations of various parameters, describing the season's distribution of available water and arranged by the starting period of available water. Tests of significance beyond standard deviation were not performed, because of the small number of data present in some periods.

The table shows that the average number of fully wet days per period was usually above 38 for starts from June to the end of July. Years starting in the first five days of July had a fairly uniform number of wet days, one year more than 50 days, 3 with 30 or fewer. Years starting during the rest of July were closer to average and relatively uniform regarding total number of fully wet days. Beginning with the 13th period, or almost August 1, the 12 remaining years in the record had almost all below-average numbers of wet days. From total number of wet days and a tendency for the longest wet period to occur in late July, it might be concluded that water must be available in July to achieve at least an average wet season.

A cycle is defined as a change in state to wet and through the ensuing

TABLE 2

Means and standard deviations of available water by 5-day periods into the season

Starting			Fully wet option, average						Partial wet option, average		
Period	Days from May 31	No. of years	Σ wet day	No. of cycles	Max. no. consecutive wet days*	Max. no. consecutive dry days*	Length first period Wet	Length first period Dry	No. cycles	Σ wet day	Starting day
1	1–5	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	6–10	1	52.00	8.00	11.00 – 4	29.00 – 1	6.00	29.00	10.00	64.00	8.00
3	11–15	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	June										
4	16–20	1	56.00	9.00	28.00 – 2	13.00 – 4	7.00	7.00	6.00	67.00	18.00
5	21–25	4	46.50	6.25	24.50 – 2	24.25 – 1	8.00	14.50	8.25	61.25	20.50
			(12.44)	(1.48)	(10.59)	(2.86	(3.54)	(9.71)	(1.48)	(10.42)	(3.20)
6	26–30	4	48.75	8.00	15.00 – 6	22.25 – 7	5.75	4.75	8.00	60.00	28.75
			(5.02)	(1.58)	(4.30)	(6.06)	(2.05)	(3.03)	(1.87)	(6.44)	(1.09)
	July										
7	31–35	11	41.45	7.18	19.73 – 4	24.54 – 7	10.90	4.73	7.54	53.09	31.64
			(9.90)	(2.04)	(11.76)	(8.28)	(12.52)	(3.77)	(2.23)	(9.43)	(4.52)
8	36–40	6	35.67	6.17	17.50 – 4	23.67 – 6	6.83	2.67	6.67	47.00	34.83
			(14.49)	(1.21)	(8.44)	(8.32)	(2.73)	(1.49)	(1.80)	(11.72)	(6.69)
9	41–45	9	40.44	7.22	18.00 – 6	18.44 – 8	11.67	4.22	7.00	54.56	38.00
			(8.51)	(2.39)	(7.33)	(9.18)	(7.82)	(3.85)	(2.67)	(7.73)	(9.61)
10	46–50	14	40.50	4.85	24.36 – 2	17.50 – 4	17.64	6.00	4.36	50.43	44.57
			(10.83)	(1.85)	(10.98)	(7.02)	(11.91)	(3.55)	(1.99)	(9.05)	(5.38)
11	51–55	4	39.50	4.75	25.25 – 1	15.25 – 2	22.25	2.75	5.25	51.25	47.00
			(4.72)	(0.43)	(10.26)	(1.48)	(14.08)	(1.09)	(1.64)	(7.89)	(5.05)
12	56–60	7	37.71	3.86	26.43 – 1	13.14 – 4	24.71	5.71	5.86	48.86	47.00
			(16.52)	(1.81)	(20.72)	(9.00)	(21.94)	(4.77)	(1.64)	(17.95)	(9.91)

Table 2 (continued)

Period	Starting Days from May 31	No. of years	Fully wet option, average: Σ wet day	No. of cycles	Max. no. consecutive wet days*	Max. no. consecutive dry days*	Length first period: Wet	Length first period: Dry	Partial wet option, average: No. cycles	Σ wet day	Starting day
	August										
13	61–65	5	30.60	3.80	19.00 – 2	17.80 – 3	10.60	3.80	5.80	44.80	46.60
			(6.56)	(1.47)	(8.10)	(7.44)	(7.83)	(2.32)	(2.64)	(2.99)	(4.36)
14	66–70	1	30.00	6.00	14.00 – 1	9.00 – 6	14.00	3.00	10.00	51.00	41.00
15	71–75	1	25.00	2.00	23.00 – 1	15.00 – 2	23.00	8.00	18.00	67.00	20.00
16	76–80	1	14.00	6.00	4.00 – 1	9.00 – 5	4.00	7.00	11.00	38.00	52.00
17	81–85	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	86–90	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	91–95	1	19.00	4.00	9.00 – 4	5.00 – 2	4.00	3.00	9.00	45.00	41.00
20	96–100	2	8.50	2.50	5.50 – 1	10.00 – 2	5.50	3.00	10.50	34.00	54.50
			(0.50)	(0.50)	(1.50)	(1.00)	(1.50)	(1.00)	(1.50)	(5.00)	(1.50)
21	101–105	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	106–110	1	4.00	1.00	4.00	9.00	4.00	9.00	7.00	29.00	50.00

( ) – standard deviation.

* = number following "–" is consensus cycle during which attribute occurred.

dry condition. Presence of available water at the season's end was not counted as a cycle.

The number of cycles could reflect and influence changes induced in the physiology of active plants being stressed for water. Abnormally high cycling could cause cumulative difficulties in recovering from stresses and make the plant unable to make normal use of a given amount of water. The number of cycles with fully wet days exhibit no trends for starts from June 8 to July 15, ranging from 4 to 12 and averaging about 7. In seasons that started after July 15, the cycles generally decreased to below 4. An overall view of the relationship between cycles and wet days tends to show there is an increase in wet days with an increase in cycles. Even though significant, the relationship is partly coincidental. An important realization from the cycling, however, is that even in years with highest total wet days, there usually are breaks in water availability.

Also tabulated was the longest wet period and the cycle in which it appeared. When the season began in July, a relatively constant maximum wet period length was obtained, increasing as the month progressed. The coefficient of variability is much greater for this parameter than for total wet days. A poor relationship existed between maximum length and total wet days, although weekly average pairings show that about half of the wet days per year are provided in this single, maximum wet period.

The cycle in which the longest wet period occurs is quite variable. For years when water was available in June or early July, this maximum wet period occurred in the middle of the season or late, but not the first cycle. For years when the wet season started in mid or late July, the longest wet period was often the first of the season. Almost uniformly, when the first cycle was the wettest, these years were below average in total wet days. This information on cycles indicates that late July is the most probable time for rain over all years and starting days.

A similar examination was made of maximum dry period length and when it appeared. This decreased rather steadily as the season progressed – ranging from 21–24 days in early July to 13–17 days by the first week in August. An unusual aspect of the maximum dry period was the much more uniform coefficient of variability than that for the maximum wet period. More often than not, the maximum dry period in the early-season years occurred in the first or last cycle. Three years out of six starting in June had the longest dry period immediately after the first wet period, perhaps indicating a failure to sustain the atmospheric conditions producing the complex precipitation system from early starts.

The maximum dry period lengths are of interest for describing the length of time perennial plants are subjected to a water stress. If the driest period is

near the end of the growing season, as is usual, it is merely an index of foreshortening of a season, wet or dry. Midseason dry periods of 25 or 30 days are not unusual and suggest that all perennial plants have adjusted to this stress.

When the partially wet option defined earlier in the paper was used in the computer program, changes occurred in most parameters. The starting day was affected because the fourth day in a string was called wet even if a drought began some time in that last day. Using the partially wet option, almost all the years of record showed seasonal starts in the first half of July. Along with this uniform seasonal start of rain, the total number of wet days was remarkably constant, compared to the fully wet option. It can be concluded that every year has a relatively invariate number of rainy days.

This then gives rise to the question: what decides whether a year is good or bad if the total days of rain is relatively constant? The answer must lie in the early season rainfall distribution and its effects on plant growth. Rainfall depths providing at least four continuous days of wet soil must enable the dormant perennial plants to organize as functioning entities, capable of using subsequently available water for additional tissue production or for carbohydrate storage for future growth. Early season storms yielding this much water correlate with a stronger seasonal depth.

Substantiation of these conclusions comes from an observer stationed for parts of his lifetime within the rain gage area used in this study. As a part of this study, the senior author had conversations with retired rancher Ernest Escapule, Sr. His remembrances appear to correlate very well with the patterns predicted by the fully wet option. In 1942, for instance, there were only 8 wet days by that option, while the partially wet day option gave 45 wet days. Mr. Escapule remembers the year as providing disastrously little grass for grazing. When the model indicated a large number of wet days by the wet option, as in 1938–39, he recalls that there was abundant grass for grazing in the summers. He remembers the 1920's as being extremely cyclic, as brought out in Fig. 3. From these historic remembrances, it would appear that the fully wet option is reflecting what actually happened regarding past grazing conditions or yields.

CORRELATION COEFFICIENTS

The data of all years were left ungrouped and the interrelationships examined by simple correlations. In this manner no time-dependent trends appear, but more analytical power is lent to any possible whole-season effects. Almost half the possible pairings of factors tested in Table 2 were significlantly related as shown in Table 3

TABLE 3

Simple correlations of ungrouped data, $n = 73$ years

	12	11	10	09	08	07	06	05	04	03	02	01
1. Starting day	*−0.435*	0.080	*0.639*	−0.247	0.095	*−0.343*	*−0.452*	*−0.416*	−0.169	*−0.582*	*−0.600*	
2. Σ Fully wet days	*0.870*	*−0.381*	*−0.342*	*−0.007*	*0.317*	0.015	−0.124	*0.291*	*0.637*	0.137		
3. No. cycles	0.183	*0.373*	*−0.386*	0.055	*−0.465*	*0.779*	0.071	*0.475*	*−0.267*			
4. Max. wet period, days	*0.555*	*−0.411*	−0.075	−0.093	*0.661*	−0.232	−0.173	−0.182				
5. Which cycle 4 appears in	*0.299*	0.171	*−0.300*	−0.131	*−0.419*	*0.461*	0.146					
6. Max. dry p., days	*−0.297*	−0.132	−0.265	0.129	−0.166	0.097						
7. Cycle in which 6 appears in	0.039	0.240	−0.129	*−0.365*	*−0.418*							
8. Length 1st wet period	*0.292*	*−0.364*	0.034	−0.014								
9. Length 1st dry period	0.021	0.192	*0.400*									
10. Partial wet, start day	*−0.512*	*−0.384*										
11. Partial wet, cycles	−0.002											
12. Partial wet, Σ total days												

Italicized figures are significant: 5% = 0.232, 1% = 0.302.

As the starting day advanced into the season, the number of fully or partially wet days, the number of cycles, and the maximum dry period length decreased. With later starts, the maximum dry period occurred earlier. Simple explanations are that the chances of receiving rain decreased as starts became later, or there is not a corresponding increase in the chance of a rain late in a late season to counteract an early deficiency.

As the length of the first fully wet period increased, the total fully wet days, and the maximum wet period length increased. Also, the number of cycles decreased, both the maximum-length dry and wet periods appeared earlier, and the number of partially wet cycles decreased. The length of the first wet period was neither related to the starting day, nor to the length of the first or maximum dry period.

As the length of the first fully dry period increased, only the time of appearance of maximum dry period and the partially wet starting day were affected, decreasing and increasing, respectively.

Conclusion

A computer model was made to calculate periods of time within the warm growing season when water was available for plant growth. Input data were the daily rainfall depths recorded over 73 years beginning in 1893. The growing season was defined as starting when rainfall provided sufficient soil water to satisfy evapotranspiration for four consecutive days.

Commencing with these four days, the number of wet days and their distribution from June 1 to September 30 for each year was determined. Starts were normally distributed from June 8 to September 21, with a median start by July 14. Within the growing season there was an average of 38 wet days and a range of from 4 to 64. A prediction equation for the qualitative determination of the number of wet days per year above or below 38 correctly predicted 49 of the 73 years.

Every year had at least one period when water was lacking and plants were stressed. The average number of stress periods was 6, but as many as 12 were observed. The average length of maximum dry period was 18 days, and the average maximum wet period was 21 days. The former seemed not to have any particular time of appearance, but the maximum wet period was most likely to occur in late July. There was no best likelihood of wetness before August 10 – simply a plateau, when considering probability of wetness on the basis of only those years having started.

Bibliography

CHOW, VEN TE, et al., Handbook of applied hydrology. (McGraw-Hill, New York, 1964) 11–27

DISKIN, M. H. and L. J. LANE, A stochastic model for runoff events for a semiarid watershed in southeastern Arizona. Proc. ARS-SCS Watershed Modeling Workshop, Tucson, Ariz. (March 1970)

GREEN, CHRISTINE R. and WILLIAM D. SELLERS, Arizona Climate. (University of Arizona Press, Tucson, 1964)

OSBORN, H. B., Persistence of summer rainy and drought periods on a semiarid rangeland watershed. Bull. Int. Ass. Sci. Hydrol. 13 (1968) 14–19

OSBORN, H. B. and K. G. RENARD, Thunderstorm runoff on the Walnut Gulch experimental watershed, Arizona. Int. Ass. Sci. Hydrol., Symposium of Wellington, 92 (1970) 455–464

SCHREIBER, H. A. and D. R. KINCAID, Regression models for predicting on-site runoff from short-duration convective storms. Water Resources Res. 3 (2) (1967) 389–395