CHAPTER 6

CLIMATIC VARIATION: MEASUREMENT AND PERCEPTION

Since "climate" is really a multidimensional concept, involving temperature, precipitation, solar radiation, and other factors, variation in the climate may take any of a large number of forms. All of these are more or less remotely relevant to drought. For example, it is clear that variations in the number of cloudless days per summer and in average summer temperatures will affect both the demand for water deliveries—especially through increased lawn irrigation—and the available supply in a surface storage system—through surface evaporation. It is, however, the variation in precipitation that is most closely associated with drought. For example, the recent drought period was characterized by cooler-than-average temperatures over the Northeast.[1] We will confine our discussion of climatic variation to that observed in precipitation and related series.

We chose to use precipitation rather than streamflow records as our basic climatic measures for several reasons. First, precipitation records are more extensive in areal and temporal coverage, and extended series could be developed for each of the systems studied in detail.[2] In addition, precipitation records, while subject to the vagaries of change in station location, are not as easily affected as streamflow by the permanent changes (only partly understood) that accompany urbanization.[3] Finally, we felt it

[1] See Jerome Namias, "Nature and Possible Causes of the Northeastern United States Drought during 1962–65," *Monthly Weather Review*, XCIV (1966), 543–54.

[2] Streamflow records were not, in general, available for this purpose. Some Massachusetts streams have very long records, but others were not even being recorded during the 1908–11 period of design drought.

[3] For a discussion of the hydrologic changes attributable to urbanization, see John Savini and J. C. Kammerer, *Urban Growth and the Water Regimen*, Water Supply Paper 1591a (Washington: U.S. Government Printing Office, 1961); and Luna Leopold, *Hydrology for Urban Land Planning*, Circular 554 (Washington: U.S. Geological Survey, 1968). A review of the runoff process and an explanation of its complexity are given in *Handbook of Applied Hydrology*, Ven Te Chow, ed. (New York: McGraw-Hill, 1964), 14/4–14/5.

significant that precipitation records were the measures of climate preferred by our respondent managers, 27 percent of whom employed rainfall measurements or rainfall plus measures of the behavior of the water storage system to define drought. In contrast, none of the superintendents interviewed utilized streamflow in this way. (See Table 8 and our later discussion of managers' perception of climate.)

LONG-TERM ANNUAL PRECIPITATION SERIES: DESCRIPTION

The specific precipitation records which we used in developing measures of climatic variation were those for stations at Fall River, Fitchburg, Pittsfield, and Worcester. These sites were chosen in connection with other studies of engineering reports and additions to system capacity.[4] The stations used in the analysis are shown in Figure 10, and a summary of sources,

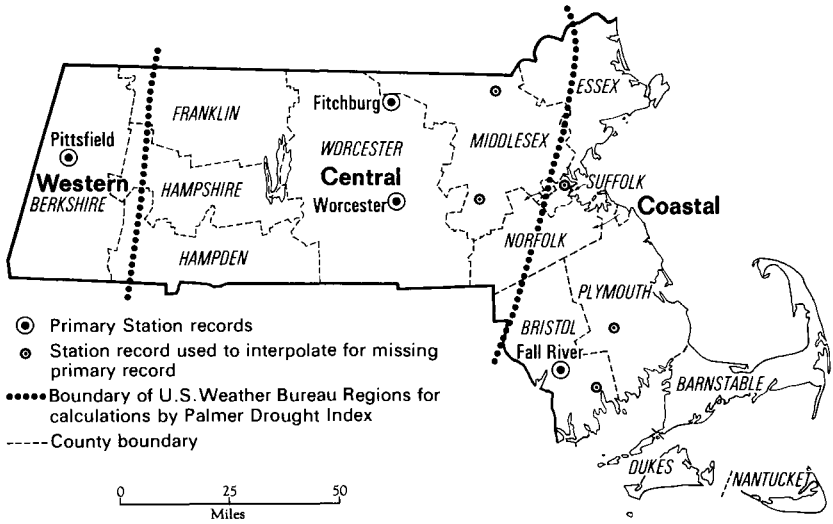

Figure 10. Stations used in rainfall analysis.

record lengths, and relevant statistics is given in Table 6. The most striking features of this table are the high autocorrelations exhibited by three of the series; only Fall River's record fails to show first-order autocorrelation at

[4] The records were assembled with the interpolation of missing values from a regional gaging station network. See J. L. H. Paulhus and M. A. Kohler, "Interpolation of Missing Precipitation Records," *Monthly Weather Review*, LXXX (1952), 129–33. It has since been suggested to us that regression methods of interpolation might have been preferable.

the 95 percent confidence level.[5] We note also that we found no evidence of trend for any of the series and that, as we would expect, the series are highly intercorrelated, the degree of this intercorrelation varying inversely with the distance between the sites.

TABLE 6. STATISTICS OF RECORDS FOR STATIONS USED IN ANNUAL PRECIPITATION SERIES

Station	Record length	Mean annual precipitation	Standard deviation of annual precipitation	First-order autocorrelation coefficient	Evidence[a] of trend	Correlations Between Records			
						Fall River	Fitchburg	Worcester	Pittsfield
	(*years*)	(*inches*)	(*inches*)						
Fall River	96	45.0	6.66	0.119[b]	None	1.000	0.606	0.708	0.506[c]
Fitchburg	96	42.4	7.56	0.383	None	0.606	1.000	0.832	0.609[c]
Worcester	96	44.1	6.65	0.250	None	0.708	0.832	1.000	0.554[c]
Pittsfield	66	40.5	5.24	0.428	None	0.506[c]	0.609[c]	0.554[c]	1.000

Sources: U.S. Weather Bureau, *Climatology of the U.S.*, No. 10–23 (1955), 11–23 (1958), and 86–23 (Washington: U.S. Government Printing Office, 1964). U.S. Weather Bureau, *Climatological Data*, Annual Summaries, Volumes 72–77 (Washington: U.S. Government Printing Office, 1960–66). E. K. Knox and R. M. Soule, *Hydrology of Massachusetts*, Part 1, U.S. Geological Survey, Water Supply Paper 1105 (Washington: U.S. Government Printing Office, 1949).

[a] Evidence of trend was taken to exist if the regression of annual rainfall on time was significant (as measured by the *F*-test) at the 5 percent level.

[b] Not significant at the 5 percent level. Test for significance of autocorrelation coefficient based on R. H. Anderson, "Distribution of the Serial Correlation Coefficient," *Annals of Mathematical Statistics*, XIII (1942), 1–13.

[c] The correlation coefficients involving Pittsfield were computed using 68 years for which all four records are complete, 1899–1966.

TRANSFORMATION OF THE PRECIPITATION SERIES

In order to capture the persistency feature of the drought, we experimented with several moving-sum transformations of the annual data. We chose to use as our basic transformation a 4-year cumulation of deviations from the long-term mean for each series. The choice of period length was made primarily on the grounds that four years seemed to span the critical portions of the two important New England droughts of this century:

[5] This finding was not expected and runs counter to the intuition of experienced hydrologists. There is, however, evidence that while precipitation records in relatively dry climates exhibit serial independence, the degree of serial correlation will increase with increases in the humidity of the climate. See, for example, V. M. Yevdjevich, *Fluctuations of Wet and Dry Years, Part II, Analysis of Serial Correlation*, Hydrology Papers, No. 4 (Fort Collins, Colo.: Colorado State University, 1964), pp. 42–48.

1908–11 (used by engineers as the "design drought") and 1963–66.[6] In symbolic terms, the value of our transformed variable in year t is given by:

$$\Delta_t \equiv \sum_{j=t-3}^{t} (R_j - \bar{R}); \tag{6-1}$$

where R_j is the precipitation total for year j, $\bar{R}$ is the long-term mean of annual precipitation, and Δ_t is the cumulated deviation. The relevant statistics for the four series of cumulated deviations are presented in Table 7 and the series are shown graphically in Figure 11.

TABLE 7. STATISTICS FOR CUMULATED PRECIPITATION SERIES

Station	Mean	Standard deviation	First-order correlation coefficient	Correlations Between Series			
				Fall River	Fitchburg	Worcester	Pittsfield[a]
	(*inches*	(*inches*)					
Fall River	+3.40	14.37	0.778	1.000	0.523	0.755	0.519
Fitchburg	+4.55	20.31	0.855	0.523	1.000	0.867	0.512
Worcester	+2.44	16.16	0.833	0.755	0.867	1.000	0.408
Pittsfield	+1.48	14.90	0.826	0.519	0.512	0.408	1.000

[a] See note 3 to Table 6.

The series of cumulative deviations all exhibit, of course, very strong first-order autocorrelation. This has been guaranteed by the moving-sum process itself. We note also that the correlations between the series are roughly as they were before, though in general somewhat higher. The means of the series are all positive, though close to zero.

From the figure we can see that there have been four major periods of precipitation shortfall over the last 100 years in Massachusetts, with the trough years being 1883, 1911, 1943 (or 44), and 1966. The depth of these droughts varies from station to station for each event, but the recent period was clearly the most severe one at Fall River and Pittsfield. In central Massachusetts (represented by Worcester and Fitchburg), the period of the 1880's was an event of even greater intensity. In addition, it appears from the figure that the recent drought "moved" from west to east across the state. If we adopt some arbitrary level of severity for purposes of comparison—for example, a cumulated precipitation deficit of 10 inches—we find that this level was reached in 1962 at Pittsfield, in 1964 at Fitchburg,

[6] Originally, we also felt it would be desirable to maintain comparability with a study conducted by the Massachusetts Water Resources Commission which stressed the cumulated precipitation deficiency over the critical drought period. This did not turn out to be a significant advantage as our study progressed.

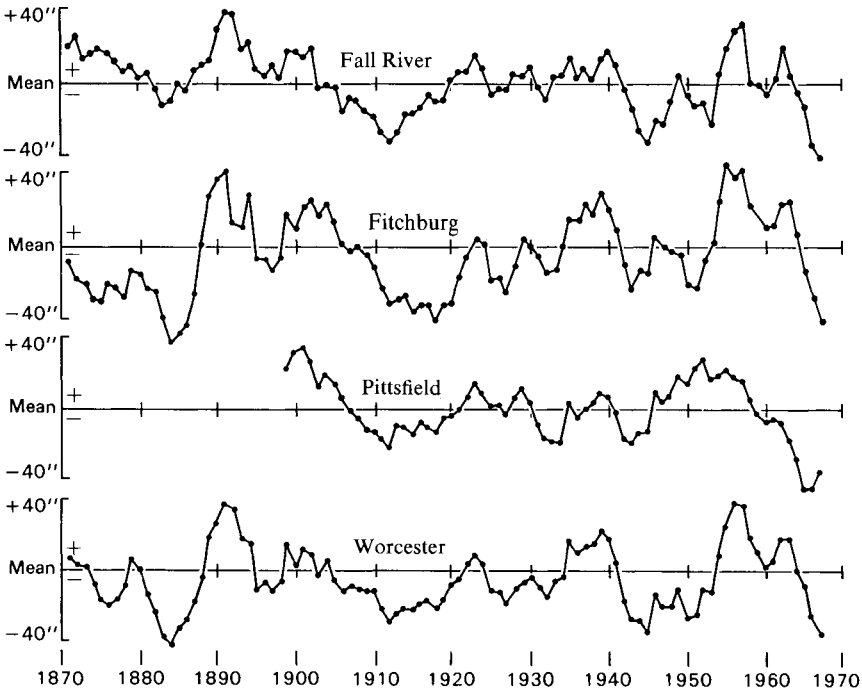

Figure 11. Four-year cumulative deviations from mean of annual precipitation in 4 Massachusetts Communities, 1867–1966.

and in 1965 at Fall River and Worcester. By the beginning of 1967 at Pittsfield the cumulated deviation series had turned up, while at the other sites, the turning point had not yet been reached.[7]

In order to produce a distribution of climatic events roughly typical of the state for later use in the estimation of actual shortages and in the derivation of expected loss functions, we pooled the deviation series for the

[7] Another measure of climatic severity which we may use in assessing the duration and timing of the stress of precipitation shortfall across Massachusetts is the Palmer Index. This is a measure of the moisture stress placed on plants and was developed by W. C. Palmer on the basis of earlier work by C. W. Thornthwaite. In it, "normal" weather produces a value of zero while drought conditions are indicated by negative numbers, with extremely dry conditions giving readings in the neighborhood of −4.0. Through the cooperation of the U.S. Weather Bureau, the Index values for three broad regions of the state (western, central, and coastal), were made available to us for the years 1929 through 1966. By this measure, the period of drought stressful to the natural world began in 1961 in the west, 1962 in the center of the state, and in 1963 along the coast. Its extreme value (−5.00) was reached in the west in 1965. In the same year the central region stress also appeared to reach bottom at −4.14. The index was still falling in 1966 for the coastal area. (Figures based on average of 4 summer months for each year.)

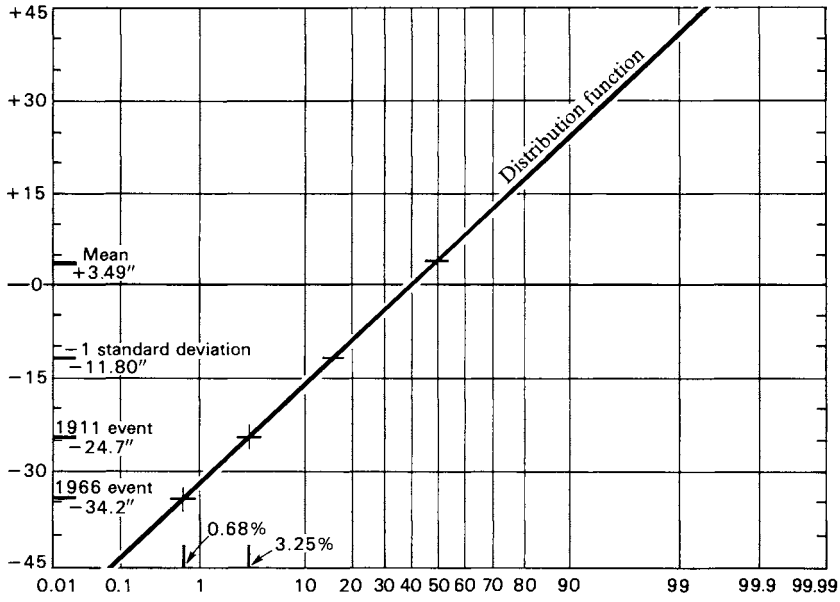

Figure 12. Pooled record distribution function for cumulative precipitation deviations.

three 96-year records (Fitchburg, Worcester, and Fall River). It may be shown that if the three deviation series are considered to be drawn from a trivariate normal distribution, the series of weighted sums of the observations is distributed as the univariate normal distribution with moments given (where each series is weighted equally) by:

$$\mu_s = \sum_{i=1}^{3} 1/3\mu_i$$

and

$$\sigma_s^2 = \sum_{i=1}^{3} 1/9\sigma_i^2 + 2 \sum_{\substack{i<j \\ i=1}}^{3} 1/9\rho_{ij}\sigma_i\sigma_j,$$

where:

μ_s = the mean of the statewide series;
μ_i = the mean of the series for the ith site;
σ_s = the variance of the statewide series;
σ_i = the standard deviation of the series for the ith site; and
ρ_{ij} = the correlation coefficient between the series for the ith and jth sites,[8] for the pooled series.

[8] See, for example, Alexander M. Mood and Franklin A. Graybill, *Introduction to the Theory of Statistics* (New York: McGraw-Hill, 1963), p. 211. This approach to the

These moments as calculated from the three individual-site series are:

$\mu_s = 3.49$ inches
$\sigma_s = 15.29$ inches

On the basis of the moments for the pooled series, we may draw the graph of the cumulative distribution function for 4-year precipitation deviations (Figure 12). On it, we also show the recurrence frequencies for the 1908–11 and 1963–66 droughts. These frequencies are based on the severity of the 4-year cumulative deviations (averaged for the three stations) as of the last year of the generally accepted drought period (1911 and 1966).[9] As shown on the graph, the cumulated precipitation deficiency as of 1911 was an event which could be expected to occur over the long run in about 3.25 percent of the years. The 1966 event, on this same basis, would occur on the average in only 0.68 percent of the years.

This pooled series will be used in Chapter 7, in combination with system inadequacy data, in predicting shortages for a sample of cities for which actual shortage estimates are available.[10] This exercise forms the basis of our assessment of the physical impact of drought.

"pooling" of our records seems adequate for our purposes here, though it is not the most efficient use of the data. The question of an efficient method for pooling non-independent series to estimate recurrence frequencies of extreme events is currently being investigated by the U.S. Geological Survey. For independent series, a pooling method is described in W. J. Conover and M. A. Benson, "Long-Term Flood Frequencies Based on Extremes of Short-Term Records," *Geological Survey Research 1962*, Professional Paper 450-E (Washington: U.S. Government Printing Office, 1962), 159–60.

[9] By a similar set of calculations, we may compute the moments of a probability distribution reflecting all four of our records over their 68 common years. These are:

$$\mu_s = .95'' \text{ and } \sigma_s = 13.23''$$

Using this distribution the recurrence frequencies are:

For 1908–11—3.45 percent
For 1963–66—0.47 percent

[10] As will become clear in the next chapter, one of our interests in working with our indices of climatic variation is to measure the severity of the climatic stress on a water supply system relative to that stress encountered during the design-drought period 1908–11. At one point it seemed desirable to broaden our inquiry to include streamflows and to estimate the relation between rainfall and streamflows for the areas of Massachusetts with which we were working. This led us to compare streamflow and precipitation records in simple regressions. The results of these regressions were not sufficiently good, nor were their subsequent applications in our drought-impact description sufficiently valuable to us, to justify the considerable tedious detail in which reporting them would involve us. Suffice it to say that working with annual precipitation and streamflow figures leaves one with considerable unexplained variation in the latter which we hypothesize is due largely to the differential runoffs from precipitation of the same amount occurring in different seasons. Thus a large storm in March while the ground is still

MANAGERS' PERCEPTION OF CLIMATIC VARIATION

The analysis of climatic variation so far presented in this chapter represents one set of perceptions as to the recurrence of extreme events. The perceptions of the system managers themselves are also important, for a complete understanding of the role of drought in water supply systems requires estimates of duration, recurrence, and intensity as held by the operators of the system as well as the estimates of the actual recurrence. Fortunately there is relatively little divergence between the two sets of estimates, although managers appeared somewhat more pessimistic than we were. However, those differences might occur simply because of the different terms of reference employed in our analysis and in the respondent answers to our questions.

First, we used in the original interview schedule the term "drought" to describe past and current situations of water shortage which are the joint product of climatic variation and system inadequacy. Thus, estimates of the recurrence of "drought" were colored for all managers by estimates of their supply capacity.

Secondly, managers face many of the same problems that we faced in studying drought frequency. What is the best measure of climatic events? What is the appropriate duration unit? Are climatic events independent events? Is there periodicity or persistence in climatic events that contributes to drought?

These questions were not clearly seen as issues at the time we planned the study. Thus, many of them either were not posed at all or were inadequately posed to the sample of respondent managers. It was, however, clear from the answers to our questions that managerial personnel use an operational definition of drought rather than a climatological one. Indication of drought occurrence was derived primarily from measurement data referring to the behavior of community storage systems. This suggests that our definition of drought as a water shortage imposing social costs corresponds with empirical evidence on managerial behavior. As shown in Table 8, fully 58 percent of the superintendents rely solely on system measurements such as reservoir or groundwater levels to indicate drought, while 79 percent use system measures alone or in combination with rainfall data.

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frozen will probably have a substantially larger impact on streamflow than a similar storm in August.

For some related work also aiming at using precipitation records to make statements about probabilities of low flows see: F. A. Huff and S. A. Changnan, Jr.,"Relation Between Precipitation Deficiency and Low Streamflow," *Journal of Geophysical Research*, LXIX (1964), 605–13.

TABLE 8. TYPES OF DATA USED BY SYSTEM MANAGERS TO INDICATE THAT THE DROUGHT WAS AFFECTING THEIR WATER SUPPLY

	Number of managers	Percentage of total
A. System measures alone		
1. Reservoir level only	16	33.3
2. Groundwater level only	4	8.3
3. Reservoir and groundwater level	8	16.7
Subtotal for A	28	58.3
B. System measures in combination with rainfall data		
1. Rainfall and reservoir level	10	20.8
2. Rainfall and groundwater level	0	0
Subtotal for B	10	20.8
Subtotal for A + B	38	79.1
C. Rainfall data alone	2	4.2
D. Other data		
1. Rainfall and "other" data	1	2.1
2. Safe-yield or water-use data	6	12.5
3. External advice	1	2.1
Subtotal for D	8	16.7
Grand Total	48	100.0

Perception of the Beginning of the Drought

On the average, the water managers who responded to our questions about timing saw the drought as beginning approximately 1½ years after the date suggested by the Palmer Index for their region. This lag time represents, no doubt, the year or more of grace provided by most municipal storage systems.[11] Indeed, this lag may be seen as evidence of the usefulness of our definition of drought; for purely meteorological drought, as defined by the Palmer Index, may or may not have an impact on a particular system, depending on the relative inadequacy of that system. The meteorological conditions required to push the Palmer Index just over the edge into the drought range are still far more favorable than those corresponding to safe-yield flows. Hence even systems with demand much greater than safe yield will not feel a pinch in the first year of a "Palmer" drought.

The lag time in perception varied significantly, however, among the water managers. Of the 27 respondents, eight (30 percent) felt that the

[11] For further evidence on this drawdown-of-storage phenomenon, see the results of testing the model as reported in Chapter 7.

drought began in the same year as indicated by the Palmer Index; eleven (44 percent) perceived the beginning with at least a 2-year lag; four (15 percent) with a 3-year lag (Table 9). There was a tendency for this lag to be shorter for managers whose systems were affected later by meteorological drought. Thus, in 1961, the communities of two of our respondents were affected by "drought" according to the Palmer Index, but it was not until two years later that the water managers in these communities felt that their systems were affected. This lag averaged 1.2 years for managers whose communities were affected in 1962 and only 6 months for those affected in 1963.

TABLE 9. MANAGERS' PERCEPTION OF BEGINNING OF DROUGHT

Manager's region	Actual beginning (Palmer Index)	Manager Perceived Drought as Beginning						
		Earlier	Same year	1-year lag	2-year lag	3-year lag	4-year lag	Total
Western	1961	0	0	0	0	2	0	2
Central	1962	0	4	5	4	2		15
Coastal	1963	0	4	3	3			10
Total		0	8	8	7	4	0	27
Percentage of total[a]		0	30	30	26	15	0	

[a] Percentages do not add to 100.0 because of rounding.

Thus, the managers seem to have been influenced by a "bandwagon" effect. As more communities officially or unofficially recognized the problem, it became easier for other managers to do so also. Indeed, it may very well be that drought was "perceived" because public concern demanded it, rather than because of actual system inadequacy relative to climatic events. This suggestion is supported by such evidence as could be constructed relating time of perception to conditions of shortage or surplus existing at that time.[12] These data are available for 13 communities. In three of these, drought was perceived as a problem when our calculations show an available surplus of water. In the other 10, the range of shortages at time of perception was from 1 to 19 percent.

Perception of the End of the Drought

As for the end of the drought, those managers who were willing to take a stand were about evenly divided between those who thought the drought

[12] Shortage was defined in Chapter 5 as the percentage difference between projected demand and actual deliveries from the normal water system.

had ended and those who believed it had not. (Note that these interviews were conducted in the summer of 1966.) The results on this point are summarized in Table 10. The ambivalence apparent in the responses to the question about the end of the drought may simply represent an expected division of people into groups of optimists, pessimists, and "skeptics," or it may be an indication of lack of dependence on expert advice. At the time of these interviews, no public statements had been made by such agencies as the U.S. Geological Survey, the Massachusetts Water Resources Commission, and the U.S. Weather Bureau either indicating the termination of the drought or its continuation past the summer of 1966. In the absence of expert assessments of the likely course of the future, the managers apparently relied on intuition and the behavior of their own water systems. Such inductive reasoning regarding natural events has been noted in the past.[13]

TABLE 10. MANAGERS' PERCEPTION OF END OF DROUGHT
(QUESTION: HAD DROUGHT ENDED BY THE SUMMER OF 1966?)

	Yes	No	Can't tell	External sources say yes-no	Not ascertained	Total
Number of managers answering	20	17	8	2	1	48

Perception of the end of the drought appears to be unrelated to the emergency status of the community, its location in the state, the severity or progress of the drought as measured by the Palmer Index, or the type of storage system used by the community.

By combining interview information on when the managers believed the drought began and whether or not they thought it had ended, it is possible to determine how long at least some of the managers believed the drought was. Doing this, we find that 10 of the 12 respondents for whom we could define the duration period saw the drought as a 3- or 4-year event (Table 11). This is considerably shorter than the 4- to 6-year period indicated by the Palmer Index. Once again we turn to the main source of the managers' perceptions, system performance, for a likely explanation of this discrepancy between the perceived world and the "objectively" measured world. It is not difficult to imagine that whereas the first year of drought is discounted by the drawdown of storage, the last year (or more) may be

[13] See Ian Burton and Robert Kates, "The Perception of Natural Hazards in Resource Management," *Natural Resources Journal*, III (1964), 434.

TABLE 11. DROUGHT DURATION PERCEIVED BY MANAGERS BELIEVING DROUGHT HAD ENDED BY SUMMER OF 1966
(QUESTION: HAS THE DROUGHT ENDED?)

Duration when answer was yes	Section			
	Western	Central	Coastal	Total
(*years*)				
1	0	0	0	0
2	0	1	0	1
3	1	3	1	5
4	0	2	3[a]	5
5	0	1[a]	0	1
6	0[a]	0	0	0
Total ascertained	1	7	4	12
Total not ascertained[b]	1	4	3	8
Total believing drought over in 1966	2	11	7	20
(% of total interviews)	50	44	37	
Total interviews	4	25	19	48

[a] Duration as measured by the Palmer Drought Index.
[b] Managers who believed drought was over but who gave no answer on year of its beginning.

similarly discounted because of successful adjustments to reduce supply through water restrictions or other demand-reducing measures.

Another interesting feature of Table 11 is the variation across the state in the percentage of managers definitely feeling the drought was over in 1966. From 50 percent in the west, this figure shrinks to 37 percent along the coast. In this, our climatic statistics support the perception of the managers, for we find the drought moderating in the western part of the state in 1966, but peaking along the coast in that same year. (See Figure 11 and footnote 7 in this chapter.)

Perception of Severity and Recurrence Frequency. Other perceptual questions related to the comparative severity and recurrence interval of droughts. The drought of the sixties was by far the worst drought within the memory of the system managers. Table 12 shows that only 4 managers cited drought events which they believed to have been more serious.

Two different methods were used in eliciting frequency of recurrence estimates.[14] In response to these questions, managers' modal estimate of

[14] Note that the questions asked in this area did not properly distinguish between "droughts" of one or more years, nor were they entirely explicit on the severity of the event, the recurrence interval of which was to be estimated.

TABLE 12. MANAGERS' PERCEPTION OF RELATIVE SEVERITY OF PAST DROUGHTS

	No.	Percent
Past droughts were:		
All less severe than 1963–66	36	75.0
As severe as 1963–66	4	8.3
More severe than 1963–66	4	8.3
No answer, not ascertained	4	8.3
	48	99.9

the recurrence frequency of a drought similar to the one being experienced was once in 25 years. If we ignore for the moment problems raised by differing perceptions of the *length* of the drought event being discussed, we may compare this estimate with our earlier recurrence estimates based on rainfall data. There we estimated that the recent drought was roughly the 150-year event (in terms of 4-year cumulated precipitation deviations); the 1908–11 drought appeared to be about a 30-year event. Thus, the managers' modal perception is very pessimistic relative to the "objective" estimates of the frequencies of the two most serious droughts of the century.

TABLE 13. MANAGERS' ESTIMATES OF RECURRENCE FREQUENCY OF DROUGHT OF EARLY 1960'S

Managers expected drought to recur:	Number	Percent
Once in 5 years	1	2.1
Once in 10 years	9	18.8
Once in 20 years	5	10.4
Once in 25 years	10	20.8
Once in 50 years	5	10.4
Once in 100 years	4	8.3
Once in 500 years	0	
Once in 1,000 years	0	
No answer, not ascertained	14	29.2
	48	100.0

Certainly, the expectation that at some future date there will be another drought as serious as the recent one (as shown in Table 14) represents a willingness of managerial personnel to accept the challenge provided by uncertain nature.

A major divergence between our technical estimates and those of the managers centers on their perception of periodicity, a belief that drought comes in cycles. Only 8 of 43 managers rejected the cyclical notion of

TABLE 14. MANAGERS' PERCEPTION OF RECURRENCE OF DROUGHT

Managers:	Number of Managers	Percent
Believe there will be drought like 1963–66 in the future.	33	68.8
Do not believe there will be drought this bad again.	4	8.3
Do not know or cannot tell whether there will be droughts like this.	11	22.9
	48	100.0

drought occurrence, although 19 of those who accepted a cyclical view were reluctant to cite some specific duration of the cycle. (It seems reasonable to characterize the views of these 19 as quasi-random, since if the duration of the cycle were unknown after 100 years of recording weather variations, they might be expected to act as though it were unknowable.) If one considers, however, how deeply imbedded in scientific thinking is the grail-like search for cycles,[15] then perhaps this managerial opinion is less an irrational conclusion and more a deep reflection of the desire for an ordered universe shared by professional and nonprofessionals alike.

[15] The literature pertaining to cycles in climatological data is extensive, and as Mitchell has pointed out, "If one takes the trouble to amass the prodigious literature on the subject of cycles in climate and to try to collate all the conclusions thereof, he becomes utterly perplexed rather than enlightened." He goes on to say that "with one possible exception (a cycle of 80 to 90 years related to solar activity), if . . . cycles exist at all they must be so small in amplitude and/or so variable in period that their *practical* significance for long-range prediction is vanishingly small." J. Murray Mitchell, Jr., "A Critical Appraisal of Periodicities in Climate," in *Proceedings of a Conference*, May 3–6, 1964 sponsored by the Center for Agriculture and Economic Development (Ames: Iowa State University, 1964), pp. 189–227. Another recent review of the cycle hunt is provided in John T. Carr, "Predicting Droughts," *Symposium on Consideration of Droughts in Water Planning*, Texas Water Commission Bulletin 6512 (Austin: Texas Water Commission, 1965), pp. 7–24.