# PART II

# CLIMATIC VARIATION, THE LEVEL OF SHORTAGE, AND THE NATURE OF SHORT-RUN ADJUSTMENTS

## CHAPTER 5

# PROJECTION OF DEMAND AND MEASUREMENT OF SHORTAGE

The heart of the impact of drought on a water system is the creation of a discrepancy between the demand for water at the existing prices and weather and the available supply. The losses which arise from a "drought" are the results of decisions as to how to deal with this discrepancy; that is, particularly, decisions to ration the limited supply through restrictions or to augment the normal sources with "emergency supplies." In order that our study might provide us with the information we desired for planning applications, we needed to be able to relate observed shortages to both the measured severity of the drought and the chosen adjustment levels of the systems involved. But just what are "observed shortages" in terms of the measures we have been discussing?

### THE DEFINITION OF SHORTAGE

One straightforward and reasonable way of obtaining a measure of system shortages during the several years of the recent drought is to project into this period our estimates of per capita daily demand based on the regression equations of Chapter 4, and values of the weather and employment indices appropriate to each community and year. Multiplication of these projections by 365 and by population produces an estimate of total annual demand which may be compared with observed system output.[1]

If projected demand is found to be greater than observed consumption for a particular city and year, it is reasonable to say that that city suffered a water shortage in that year. We may, in addition, transform the absolute

[1] See Chapter 4 for a brief comment on the difference between system output and deliveries to customers.

amount of shortage into a percentage figure by dividing it by the projected demand level.

In order to express this definition symbolically, we use the following notation:

$P_{it}$ = projected per capita daily demand for water from system $i$ in year $t$ for given price, and for known weather and employment conditions (from our regression analysis of the last section).
$C_{it}$ = observed total annual consumption of water from system $i$ in year $t$.
$N_{it}$ = population served by system $i$ in year $t$.
$S_{it}$ = water shortage (as a percentage of projected demand) suffered by system $i$ in year $t$.

Then in per capita per day terms we have:

$$S_{it} = \frac{P_{it} - \dfrac{C_{it}}{N_{it} \cdot 365}}{P_{it}} \times 100. \qquad (5\text{-}1)$$

If we let $D_{it} \equiv P_{it} \cdot N_{it'} \cdot 365$ (total, annual projected demand), we have in total annual terms:

$$S_{it} = \frac{D_{it} - C_{it}}{D_{it}} \times 100. \qquad (5\text{-}2)$$

It will not always be correct, however, to use actual consumption alone in our measurement of shortage. As noted earlier, in many instances a community threatened with potential shortage will choose to reduce or eliminate the gap by obtaining emergency supplies, for example, by pumping from a nearby recreational lake into the reservoir system. But, though no consumer may actually lack water, there is still clearly an opportunity cost involved for the community, and indeed for the society as a whole. Thus, if we wish to connect the severity of drought (in shortage terms) with its costs, we will certainly wish to measure the original gap and to include the costs of emergency supplies along with the other losses.

These considerations lead us to define another quantity, Normal System Supply ($V_{it}$) as the actual consumption ($C_{it}$) less the amount of emergency supplies ($E_{it}$) obtained by system $i$ in year $t$.[2] Thus, symbolically, we have,

[2] Some measurement problems arose here in addition to the expected one of doubtful record quality. Some systems which obtained emergency supplies used these not only to meet current demands but also to attempt to refill lowered reservoirs. Whenever we had information that this had been done, we attempted to make appropriate corrections for it.

$$V_{it} \equiv C_{it} - E_{it}.\text{[3]} \qquad (5\text{-}3)$$

Shortage, then, is correctly and completely defined as the percentage difference between potential demand and normal system supply; thus, in per capita per day terms:

$$S_{it} = \frac{P_{it} - \dfrac{V_{it}}{N_{it} \cdot 365}}{P_{it}} \times 100 = \frac{P_{it} - \left[\dfrac{C_{it} - E_{it}}{N_{it} \cdot 365}\right]}{P_{it}} \times 100; \qquad (5\text{-}4)$$

and, in total annual terms:

$$S_{it} = \frac{D_{it} - V_{it}}{D_{it}} \times 100 = \frac{D_{it} - (C_{it} - E_{it})}{D_{it}} \times 100. \qquad (5\text{-}5)$$

## THE MEASUREMENT OF SHORTAGE

The actual sample of cities for which shortage measurements for the drought years were available was established in the following way. For 33 systems, we had significant regression relations as discussed in Chapter 4. For 5 of these, however, data were not available on actual consumption in one or more of the drought years. The latter five systems were omitted from the sample because we wished to use the same set of systems in each drought year in testing hypotheses about the relation between climatic severity, level of adjustment, and observed shortage. Thus, we began with a set of demand projections for each of 28 systems for the years 1963 through 1966.

As noted in Chapter 4, there are certain difficulties with our projection equations, and it seemed desirable to test them in some way. To do this, we compared our projections of average per capita daily consumption with observed consumption for each of nine cities in the four years 1963–66. These nine cities had neither imposed restrictions nor obtained emergency supplies during the drought, and hence we had reason to hope that any discrepancy between predicted and observed consumption would not, at least, be due to problems of supply. A more complete discussion of the

[3] In principle, normal system yield should be defined to exclude net drawdown of overyear storage. In our original work, we viewed a 4-year drought period as a single demand period and hence were able to assume relatively full reservoirs at the beginning of 1963 and at the end of 1966, leaving no net drawdown. Some of the difficulty we find in considering each year separately is undoubtedly traceable to the fact that, particularly in the early drought years, shortages never appear because of net drawdowns. It seems, however, that this means of dealing with the drought proved inadequate as the dry spell stretched into 1964 and reservoir levels fell. Thus, 1965 and 1966 are probably relatively free of the problem since the refilling of reservoirs in 1966 was almost entirely confined to the fall, after the high consumption period had passed.

test and its results is contained in Appendix A. We confine ourselves to noting here that:

For 5 of the 9 cities, our average prediction error over the 4-year period was less than 10 percent; for 7 it was less than 15 percent.

In no year was the average prediction error across the towns greater than 1.2 percent.

Of the total of 36 errors calculated (9 cities over 4 years), 18 were less than 10 percent and 29 were less than 15 percent.

While there is no apparent bias in our predictions when applied to the group of towns, there is a tendency consistently to over- or underestimate for a particular city over the period. Thus, for only one city does the sign of the prediction error change over the period.

We are now prepared to measure the shortages suffered by various Massachusetts cities during the drought. Two major tasks remain in our effort to extract useful planning information from this study: first, these shortages must be related to chosen levels of adjustment and severity of climatic events; and second, losses must be attached to various levels of shortage suffered. As our next step in the direction of completing these tasks, we consider in Chapter 6 the measurement and perception of climatic variation.