CHAPTER 4

MEASUREMENT OF THE DEMAND FOR WATER

Water system managers tend to view the existing rate structure as given for the future as well as the present and to see their role as the provision of "all the water people want" at present prices.[1] Thus, observed variations in demand over time in the same city will generally be attributable to changes in non-price variables such as per capita income and the water-use characteristics of local industry. Differences between cities in the same year, however, will reflect differences in the level of water rates. Our interest is in the time-series variation for each city, and so we concentrate on non-price variables in examining variations in demand.

For example, the level of average per capita daily demand for water will vary between towns with the composition of demand. In particular, cities where a high proportion of total demand comes from industrial and commercial users will have higher per capita demand rates than cities where the major use of water is domestic. In our survey towns, the upper third of towns in terms of percentage of industrial demand (average industrial demand 60 percent of total) consumed an average of 178 gallons per day (gpd) per person between 1962 and 1966. In contrast, the lower third (average industrial demand 10 percent of total) consumed an average of 89 gpd per person during the same period.

In addition, the variation in use between different industries is very large in terms of gpd per employee or per dollar of value added. For example, in Fitchburg, water use per capita increased dramatically from about 1940

[1] This view is supported by the data on managers' attitudes reported below in Chapter 8 and by such examples of extreme historical rate constancy as that of New York City reported in Jack Hirshleifer, James C. DeHaven, and Jerome W. Milliman in *Water Supply: Economics, Technology, and Policy* (Chicago: University of Chicago Press, 1960), p. 263.

on with the growth of the plastics industry and the demise of the textile industry even though population and total employment showed little change.

The growth of demand is, of course, the product of a number of different influences. In particular places, shifts in the composition of the industrial sector can, as just reported, cause significant corresponding shifts in demand. The rate of growth of population will be reflected to some extent in the rate of growth of demand. In general, a high rate of population growth will accentuate the rate of growth of demand which results from a set of influences common to virtually all urban and suburban areas. Particularly important among these latter factors has been the widespread adoption by households of water-using appliances and devices such as home laundries, air-conditioning equipment, dishwashers, and garbage disposals.[2] Another major factor has been suburbanization, with the attendant growth in the acreage of lawn and garden space. The demand for water to irrigate these planted areas has affected virtually all municipal water systems.[3]

The net impact of these several influences will, of course, differ from community to community. But in Massachusetts a common rule of thumb cited by engineers suggests that the long-term average annual increase in per capita daily water use in the past was on the order of 1 to 1.5 gallons per year. For 25 communities from our detailed survey, however, the average annual increase in per capita daily consumption between the years 1950 and 1962 was 3.4 gallons.

MEASUREMENT: RECORDED CONSUMPTION

The measurements of municipal water use, or consumption, used throughout this study are those made by the individual cities and towns in the sample. The figures used for the calculation of demand (i.e., average per capita daily consumption, P), are based on the total water system outputs of the communities studied, as opposed to the amount of water passing through customers' meters. These records are of differing origin, some

[2] See John C. Geyer, Jerome B. Wolff, and F. P. Linaweaver, Jr., "Final and Summary Report on Phase One of the Residential Water Use Research Project," Department of Sanitary Engineering and Water Resources, The Johns Hopkins University, Baltimore, Oct. 1963.

[3] F. P. Linaweaver, Jr., John C. Geyer, and Jerome B. Wolff, "Final and Summary Report on the Residential Water Use Research Project," Department of Environmental Engineering Science, The Johns Hopkins University, Baltimore, June 1966. Linaweaver, et al. reach the conclusion that "for practical use in design, water distribution systems serving metered residential areas with gross densities of about seven homes per acre or less should be designed to supply irrigation water in an amount equivalent to evapotranspiration from a crop of grass covering the entire area served."

being meter readings from source outflows, others estimates based on pump use. Similarly, their quality varies with the accuracy of the equipment involved and the care with which readings were made and recorded. In addition, of course, there will generally be a discrepancy between system output as measured at the source and the total quantity delivered to customer meters. This wastage was determined for 23 of our study cities and, expressed as a percentage of output, averaged about 17 percent over this subsample.[4]

RELATIONSHIP BETWEEN RECORDED CONSUMPTION AND DEMAND

A more fundamental observation for our efforts to measure historic demand is the fact that the recorded consumption for any given year in a particular town, even if accurately measured, need not reflect the average level of demand at the existing price. Leaving aside the imposition of restrictions due to low supplies, any number of other major and minor disturbances could cause differences between the average level of demand and the actual level of consumption. For example, distribution difficulties could lead to the imposition of restrictions on peak period uses such as lawn-sprinkling; strikes on the one hand or overtime work on the other could shift the water use for one or more significant industrial firms.

These considerations suggest that the recorded values for consumption (say, average per capita per day) should be "smoothed," and the resulting trend lines considered as representing the path of demand over time. This approach will be more or less well grounded depending on the extent to which there really are a fairly large number of independent random disturbances acting to make observed consumption different from demand (again abstracting from the pure measurement problems).

Our particular approach to this matter of smoothing the recorded consumption data is to assume, first, that the major influences on the growth of per capita demand can be represented simply by time itself. But, while this might be acceptable as a first approximation, additional reflection suggests that it ignores at least two factors affecting the level of demand which may not be correlated with time. Because we are ultimately interested in projection of demand for individual years and not simply in the identification of trends, it is necessary for us to take account of such additional influences.

The most important such factor surely is weather, particularly through its effect on lawn-sprinkling. A priori we would also expect the pace of

[4] This compares with the average percentage of unaccounted for water in United States waterworks of 15 percent, cited in Gordon M. Fair, John C. Geyer, and Daniel A. Okun, *Water and Waste Water Engineering* (New York: Wiley, 1966), I, 5–15.

economic activity, especially as reflected in the industrial sector, to play a significant part in modifications of water demand from the trend level. (This will be true to the extent that the correlation between economic activity and time is not so close as to obscure the independent impact of the former.)

Accordingly, our method is to estimate the parameters in the regression equation:

$$P_t = a + b_1 t + b_2 W_t + b_3 E_t + e_t \tag{4-1}$$

for each of the 47 communities for which we have sufficient data. In the equation:

P_t = the observed consumption in year t in gallons per day per capita.

t = time, running from year 0 (1950) to year 12 (1962), giving 13 observations. (For several towns, one or more observations on P_t were missing.)

W_t = a weather index for year t. It equals the sum of the Palmer Drought Index[5] over the 4 summer months of year t. This index is available for the western, central, and coastal regions of the state; not for any finer division.

E_t = an index of industrial employment in the particular community in year t. 1950 level of employment = 100.[6,7]

e_t = an error term, assumed to have the usual convenient properties.

We use only the years through 1962 in our analysis, because, by 1963, the drought had begun all over the state, and our major purpose is to project demand levels into the drought period when for many systems they could be expected to be greater than actual deliveries. (See the discussion of the time pattern of the onset of drought across the state in Chapter 6.)

[5] The derivation of the Palmer Drought Index is shown in Chapter 6.

[6] This index of the pace of economic activity was chosen because of its availability on a town-by-town basis through the publications of the Massachusetts Department of Labor and Industries, Division of Statistics, particularly their *Employment Newsletter*. It would, of course, have been preferable to have an index of production such as value-added in constant dollars. Such an index could have been developed for some of our towns for some of the years of interest, but not for every year in any town. This was the result of the combination of spatial and temporal gaps in the coverage of the *Census of Manufactures*, published occasionally by the same Massachusetts agency.

[7] Unfortunately, we did not have sufficient information to use either demand composition by sector or industrial sector makeup as explanatory variables.

TABLE 5. SUMMARY OF RESULTS OF REGRESSION ANALYSIS

Equation estimated:

$$P_t = a_t + b_1 t + b_2 W_t + b_3 E_t + e_t$$

1. Of 47 trials *33* resulted in significant relationships (as measured by the F-ratio test) at the 0.05 level.

   Median r^2 for 33 significant relations *0.834*

2. Estimated b_1 significant at 0.05 level by t-test in *25* cases. (Range of b_1 values: -3.12 to 10.82; mean = 3.58)
3. Estimated b_2 values significant at 0.05 level by t-test in 9 cases. (Range of b_2 values: -6.88 to -0.24; mean = -0.76)
4. Estimated b_3 significant at 0.05 level by t-test in *7* cases.

   (Range of b_3 values: -1.19 to 1.90; mean = 0.55)

Note: If we apply a significance test to the *numbers of successes* in each "trial" listed above, we find that the first two results could have occurred by chance only with probability less than 0.0010; the last result is significant at the 1 percent level.

Our results are summarized in Table 5.[8] We note from this table that both time and weather behaved rather well as explanatory variables, while the employment index behaved badly. This is primarily the result of the multicollinearity between time and employment in our data. Since we are interested primarily in projection of P into the four drought years, however, we need not be particularly concerned over this. It is reasonable to expect that the relation between time and employment which has interfered with our results above will continue over the short projection period and hence that our projection will not suffer.

[8] A similar analysis of the determinants of per capita demand was made for four towns (Fall River, Fitchburg, Pittsfield, and Worcester) for the period 1929–62. Again, time, the summer Palmer Index value, and an employment index were used as explanatory variables. The results achieved do not differ in any significant way from those discussed above. Generally high r-squares were obtained (median = 0.92), and time was the strongest explanatory variable. The coefficients for employment and weather were each significant in only one town, though P was strongly related to employment in three towns. (Collinearity of time and employment was again a problem, even though the distinctive employment pattern of the depression years was reflected in the values used.)